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(54) **PROCESS FOR THE PREPARATION OF MACROCYCLIC POLYAZACARBOXYLATE LIGANDS AND CHELATES**

VERFAHREN ZUR HERSTELLUNG VON MAKROCYCLISCHEN
POLYAZACARBOXYLATLIGANDEN UND CHELATEN

PROCESSUS DE PRÉPARATION DE LIGANDS ET CHÉLATES POLYAZACARBOXYLATES
MACROCYCLIQUES

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- **SOLFRID BUØEN ET AL: "Twelve-ring Azacrowns with 2-Alkoxyethyl Side-Arms.", ACTA CHEMICA SCANDINAVICA, vol. 40b, 1 January 1986 (1986-01-01), pages 278-282, XP055086567, ISSN: 0904-213X, DOI: 10.3891/acta.chem.scand.40b-0278**
- **DATABASE EPODOC [Online] EUROPEAN PATENT OFFICE, THE HAGUE, NL; XP002715914, Database accession no. CZ-20050653-A & CZ 297 577 B6 (AZACYCLES S R O [CZ]) 10 January 2007 (2007-01-10)**
- **HANSEN G R ET AL: "UNIQUE SYNTHESIS OF 1,4,7,10-TETRAAZACYCLODODECANE", JOURNAL OF HETEROCYCLIC CHEMISTRY, vol. 5, no. 2, 1 April 1968 (1968-04-01), page 305, XP000570380, WILEY-BLACKWELL PUBLISHING, INC, US ISSN: 0022-152X, DOI: 10.1002/JHET.5570050232 cited in the application**

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Description

FIELD OF THE DISCLOSURE

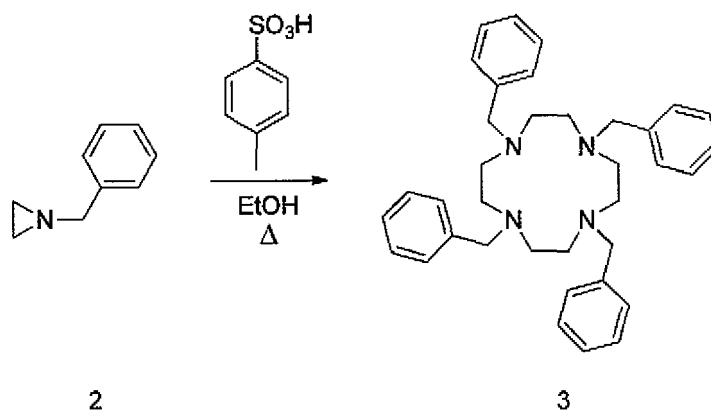
[0001] The present disclosure relates generally to a process for the synthesis of 1,4,7,10-tetraazacyclododecane ligands, chelates, and derivatives thereof. In particular, the present disclosure is directed to a process for the synthesis of 1,4,7,10-tetraaza-1,4,7,10-tetrakis(carboxymethyl)cyclododecane (DOTA) ligands, corresponding DOTA-metal chelates, and various derivatives thereof.

BACKGROUND

[0002] Polyaminocarboxylate ligands, and the chelates derived therefrom, have been widely used in medical diagnosis and therapy, such as for example in the field of Magnetic Resonance Imaging (MRI). Macrocyclic chelating agents, such as DOTA macrocyclic chelating agents, form particularly stable chelates with contrast-generating paramagnetic metal ions, and thus are suitable carriers for these metal ions. The gadolinium-DOTA chelate (Dotarem®) is one commercially available MRI agent. Radionuclide chelates, such as ¹⁷⁷Lu-DOTA and ⁹⁰Y-DOTA, conjugated to bioactive peptides have also been used as radioscintigraphic imaging and radiotherapeutic agents.

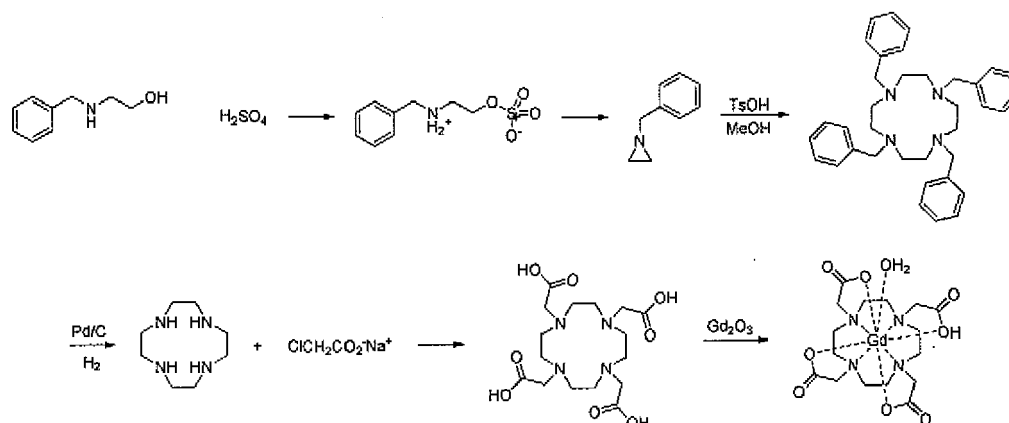
[0003] Lack of efficient and cost effective processes for the synthesis of polyazamacrocyclic ligands has been an obstacle toward widespread use of these types of ligands and associated chelates. Several synthetic routes for the preparation of DOTA are known. For instance, EP 232751 A (by Tweedle) and EP 292689 A (by Tweedle) disclose DOTA preparation by diamine:diamine or triamine:monoamine cyclic condensation.

[0004] A key intermediate in these procedures is 1,4,7,10-tetraazacyclododecane. Hansen, et al. (Hansen and Burg. Journal of Heterocyclic Chemistry 1968, 305) disclose that 1,4,7,10-tetra(benzyl)-1,4,7,10-tetraazacyclododecane can be produced by cyclo-tetramerization of N-benzylaziridine according to the following reaction scheme:



Notably, however, Hansen discloses that the cyclo-tetramerization process shown above is unique to the N-benzylaziridine substrate, as only high molecular weight polymers, and not macrocycles, were generated when aziridine, N-methylaziridine, N-phenylaziridine and N-(β-hydroxymethyl) aziridine substrates were used.

[0005] Building upon Hansen, WO9628420A2[1] (WO '420 by Messerle) and US 5,744,616 (US '616, by Petrov) disclose a process for the preparation of DOTA and Dotarem® from N-benzylaziridine substrate according to the below reaction scheme, where WO '420 discloses isolation of each intermediate before proceeding to the subsequent process step and US '616 discloses carrying each intermediate forward in solution.

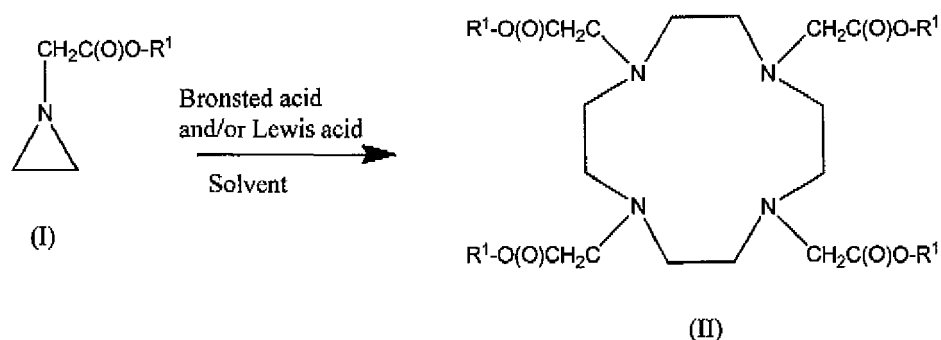


However, WO '420 and US '616 disclose tetra-benzyl cyclized intermediate yields of about 28% and about 58%, respectively.

[0006] A need therefore exists for improved and simplified processes for the preparation of macrocyclic polyazacarboxylate ligands, and more specifically 1,4,7,10-tetraazacyclododecane derivatives, such as DOTA, DOTA-chelates, and derivatives thereof, in high yield and purity.

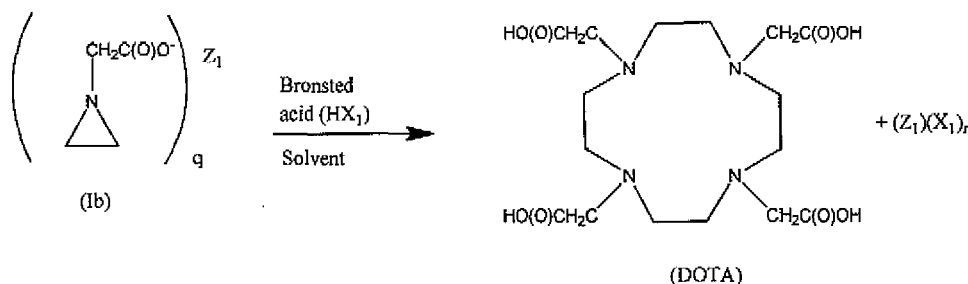
SUMMARY OF THE DISCLOSURE

[0007] Briefly, therefore, the present disclosure is directed to a process for the preparation of a macrocyclic tetramer compound of Formula (II). The process comprises forming a reaction mixture comprising a stoichiometric amount of (a) an aziridine of Formula (I), (b) a Brønsted acid, a Lewis acid, or a combination of a Brønsted acid and a Lewis acid, and (c) a solvent. The contents of the reaction mixture are reacted to form the compound of Formula (II) by cyclotetramerization of the aziridine of Formula (I), according to the following reaction:



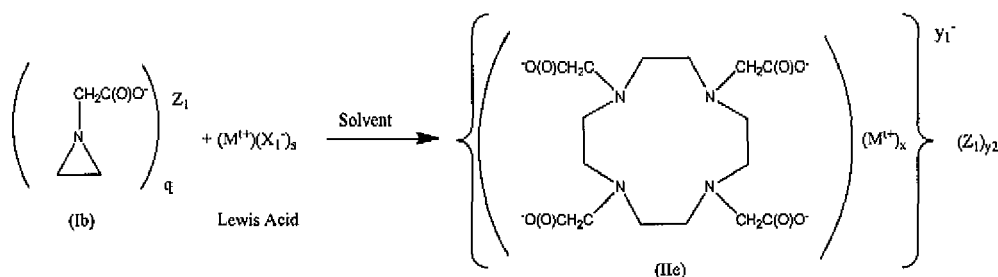
wherein each R^1 is independently selected from the group consisting of C_{1-10} hydrocarbyl.

[0008] The present disclosure is also directed to a process for the preparation of 1,4,7,10-tetraaza-1,4,7,10-tetrakis(carboxymethyl)cyclododecane (DOTA). The process comprises forming a reaction mixture comprising (a) a stoichiometric amount of an aziridine of Formula (Ib), (b) a Brønsted acid, and (c) a solvent. The contents of the reaction mixture are reacted to form DOTA by cyclotetramerization of the aziridine of Formula (Ib), according to the following reaction:



wherein Z_1 is an alkali metal having a +1 charge or an alkaline earth metal having a +2 charge and wherein q and r are 1 when Z_1 is an alkali metal and q and r are 2 when Z_1 is an alkaline earth metal.

[0009] The present disclosure is further directed to a process for the preparation of a macrocyclic tetramer compound of Formula (IIe). The process comprises forming a reaction mixture comprising (a) a stoichiometric amount of an aziridine of Formula (Ib), (b) a Lewis acid, and (c) a solvent. The contents of the reaction mixture are reacted to form a metal-1,4,7,10-tetraaza-1,4,7,10-tetrakis(carboxymethyl)cyclododecane (DOTA) chelate of Formula (IIe) by cyclotetramerization of the aziridine of Formula (Ib), according to the following reaction:



wherein $(M^{t+})(X_1^{-})_s$ is a chelatable Lewis acid metal salt formed from a cation, M , and an anion, X_1^{-} , wherein t is 1, 2 or 3 and s is selected to achieve electrical neutrality, wherein Z_1 is hydrogen, an alkali metal having a +1 charge or an alkaline earth metal having a +2 charge, wherein q is 1 when Z_1 is an alkali metal and q is 2 when Z_1 is an alkaline earth metal, and wherein t is 3 and x is 1, or t is 2 and x is 1, or t is 2 and x is 2, or t is 1 and x is 1, or t is 1 and x is 2, or t is 1 and x is 3 or t is 1 and x is 4. As disclosed in the below table, when Z_1 has a +1 charge then $y_1 = y_2 = (4 - (X^*t))$, and when Z_1 has a +2 charge then $y_1 = (4 - (X^*t))$ and $y_2 = (y_1/2)$:

		$Z_1 = +1$	$Z_2 = +2$	
t	X	y_1 and y_2	y_1	y_2
3	1	1	1	$\frac{1}{2}$
2	1	2	2	1
2	2	0	0	0
1	1	3	3	$\frac{3}{2}$
1	2	2	2	1
1	3	1	1	$\frac{1}{2}$
1	4	0	0	0

BRIEF DESCRIPTION OF THE FIGURES

[0010]

FIG. 1 is a proposed general mechanism for the reactivity of Lewis acid-activated aziridines.

FIG. 2 is a HPLC-ELSD chromatogram for DOTA-tetra(methyl ester) prepared by a process of the present disclosure, and in particular as detailed in Example 1.

FIG. 3 is a HPLC-MS chromatogram for DOTA-tetra(methyl ester) prepared by a process of the present disclosure, and in particular as detailed in Example 2.

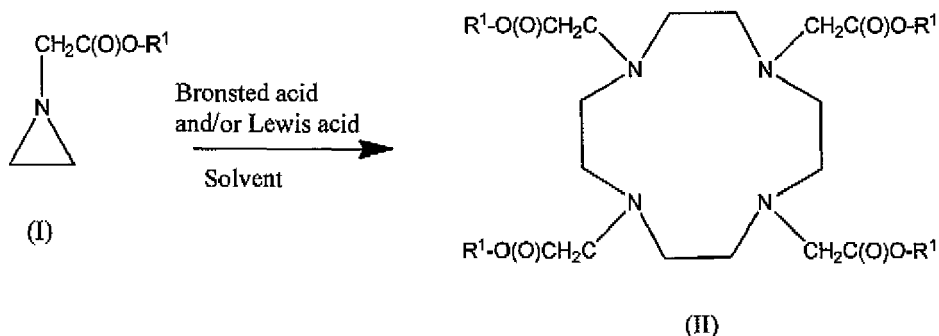
DETAILED DESCRIPTION

[0011] The present disclosure generally provides for improved and simplified processes for the preparation of macrocyclic polyazacarboxylate ligands, and more particularly 1,4,7,10-tetraazacyclododecane ligands, as well as chelates and derivatives thereof. In one exemplary embodiment, the present disclosure provides for improved and simplified processes for the preparation of DOTA, DOTA-chelates, and derivatives thereof, in high yield and purity. In accordance

with the present disclosure, it has been discovered that such ligands, particularly DOTA and DOTA-related derivatives, can be prepared from aziridine substrates in a simplified synthetic route that avoids the generation of tetra-benzyl cyclized intermediates. The various embodiments of the process of the present disclosure thereby eliminate the need for cleavage of arylmethyl groups from the ligand (e.g., DOTA or DOTA derivative), allowing for the simplified, more direct, synthesis and improved yield and purity thereof, as well as the chelates that may be formed therefrom.

[0012] In the various embodiments of the present disclosure, a substituted aziridine substrate is combined with a Brønsted acid, a Lewis acid, or a combination of a Brønsted acid and a Lewis acid, and a solvent to form a reaction mixture. A ligand (e.g., DOTA) or ligand-chelate (e.g., DOTA-chelate), or a derivative thereof, is then formed by the cyclotetramerization of aziridine.

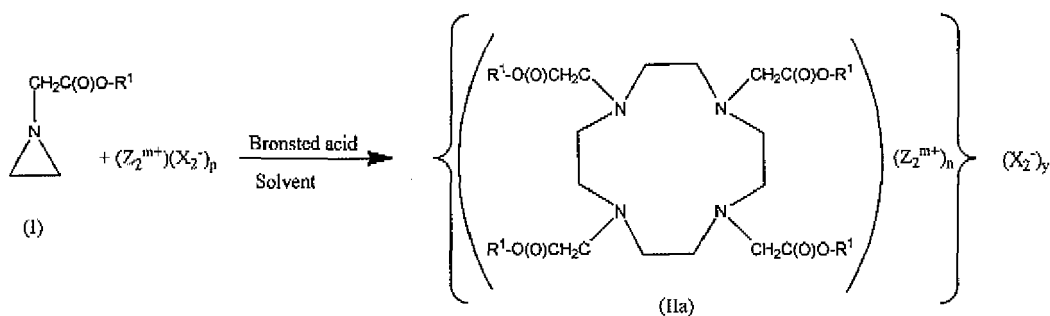
[0013] In some aspects of the present disclosure a process for the preparation of a macrocyclic tetramer compound of Formula (II) is provided. The process comprises forming a reaction mixture comprising a stoichiometric amount of (a) an aziridine of Formula (I), (b) a Brønsted acid, a Lewis acid, or a combination of a Brønsted acid and a Lewis acid, and (c) a solvent. The contents of the reaction mixture are reacted to form the compound of Formula (II) by cyclotetramerization of the aziridine of Formula (I), according to the following Reaction Scheme 1:



wherein each R^1 is independently selected from the group consisting of C_{1-10} hydrocarbyl. In some embodiments, each R^1 is independently selected from methyl, ethyl, 2-propyl and benzyl. In some other embodiments, R^1 is methyl.

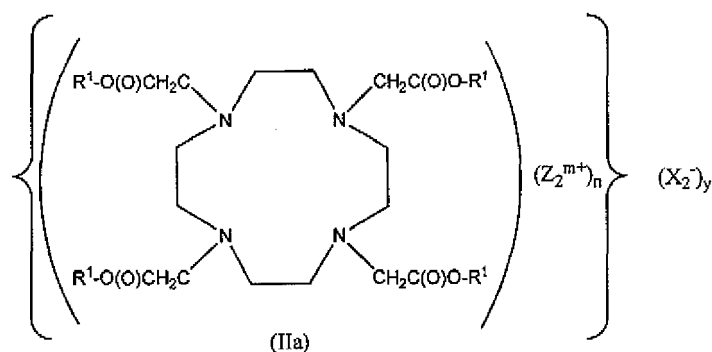
[0014] In some embodiments, the compounds of Formula (II) can be hydrolyzed or hydrogenated according to methods known the art to cleave R^1 and generate DOTA.

[0015] In some other Reaction Scheme 1 embodiments, the acid is a Brønsted acid and the reaction mixture further comprises an alkali metal salt, $(\text{Z}_2^{m+})(\text{X}_2^-)_p$, wherein Formula (IIa) is formed by cyclotetramerization of the aziridine of Formula (I) according the following Reaction Scheme 2:



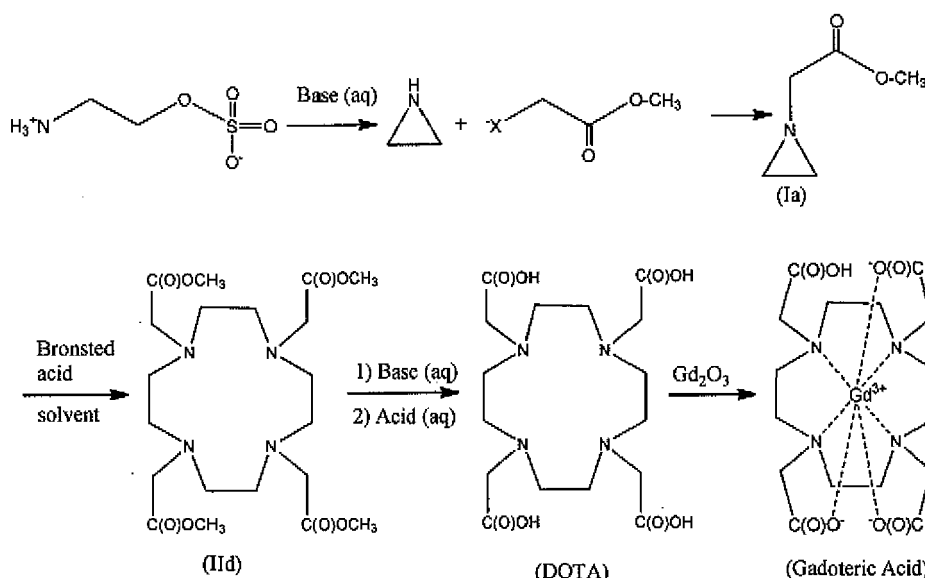
[0016] In any of these embodiments, Z_2^{m+} is a counterion selected from the group consisting of a hydrogen ion, a tertiary ammonium ion, an alkali metal ion, and an alkaline earth metal, wherein $m+$ is 1 or 2; X_2^- is selected from the group consisting of a halide, *p*-toluenesulfonate and trifluoroacetate; *p* is the number of X_2^- needed to maintain electrical neutrality with Z_2^{m+} and is selected from 1 and 2; *n* is an integer selected from 0 to 4; and *y* is the number of X_2^- needed to maintain electrical neutrality of formula (IIa). In some embodiments, Z_2 is sodium or potassium and X_2^- is chloride or bromide.

[0017] In yet other Reaction Scheme 1 embodiments, the acid is a Brønsted acid, the process further comprising contacting Formula (II) with an alkali metal salt, $(\text{Z}_2^{m+})(\text{X}_2^-)_p$, to form Formula (IIa):



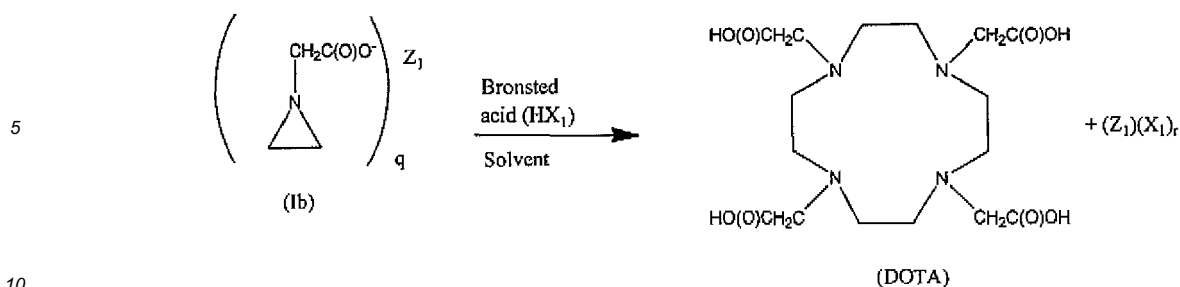
[0018] In any of these embodiments, Z_2^{m+} is a counterion selected from the group consisting of a hydrogen ion, a tertiary ammonium ion, an alkali metal ion, and an alkaline earth metal, wherein $m+$ is 1 or 2; X_2^- is selected from the group consisting of a halide, *p*-toluenesulfonate and trifluoroacetate; p is the number of X_2^- needed to maintain electrical neutrality with Z_2^{m+} and is selected from 1 and 2; n is an integer selected from 0 to 4; and y is the number of X_2^- needed to maintain electrical neutrality of formula (IIa). In some embodiments, Z_2 is sodium or potassium and X_2 is chloride or bromide.

[0019] In one Reaction Scheme 1 embodiment, gadoteric acid is prepared according to the following reaction scheme:



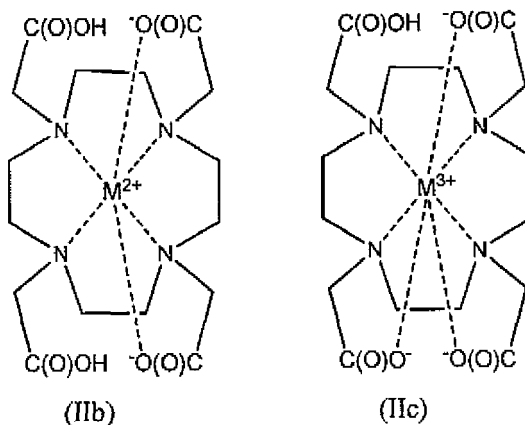
wherein the base is a metallic base such as, for instance, sodium hydroxide or potassium hydroxide; X^- is an anion such as a halide; the acid is a mineral acid such as, for instance, HCl; and the Brønsted acid and solvent are as disclosed below. In one embodiment, the base is NaOH, the acid is HCl, the solvent is methanol and the Brønsted acid is *p*-toluenesulfonic acid.

[0020] In some other aspects of the present disclosure, a process for the preparation of DOTA is provided. The process comprises forming a reaction mixture comprising (a) a stoichiometric amount of an aziridine of Formula (Ib), (b) a Brønsted acid, and (c) a solvent. The contents of the reaction mixture are reacted to form DOTA by cyclotetramerization of the aziridine of Formula (Ib), according to the following Reaction Scheme 3:



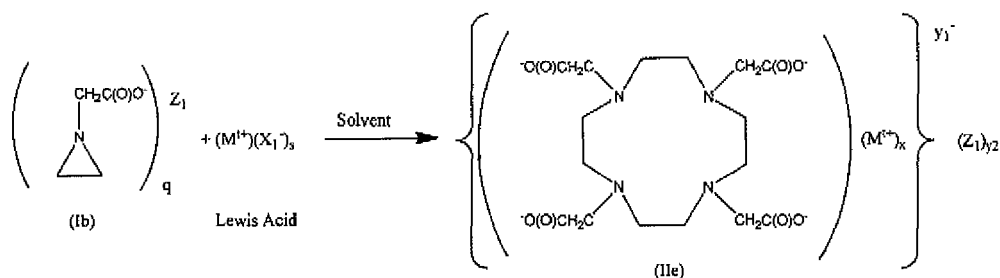
wherein Z_1 is an alkali metal having a +1 charge or an alkaline earth metal having a +2 charge and wherein q and r are 1 when Z_1 is an alkali metal and q and r are 2 when Z_1 is an alkaline earth metal. In some embodiments, Z_1 is Na^+ , K^+ , Ca^{2+} or Mg^{2+} and X_1 is Br^- , Cl^- or OSO_3^{2-} . In some embodiments, the solvent comprises water, and in other embodiments, the solvent consists essentially of water.

[0021] In some embodiments, DOTA can be treated with a metal cation, M^{n+} , wherein $n+$ is 2 or 3, provided from a metal ion source selected from the group consisting of metal oxides, metal carbonates, and weak chelates to form a metal-DOTA chelate of Formula (IIb) or Formula (IIc):



wherein the metal cation is selected from the group consisting of Gd, Eu, Tb, Dy, Sm, Lu, La, In, Ga, Re, Ru, Fe, Cu, Zn, Ni, Co, Cr, V, Ti, Sc, Zr, Nb, Mo, Rh, Pd, Ag, Cd, Sn, Hf, Ta, W, Os, Ir, Pt, Au and Y, and wherein M^{2+} coordination can occur with any two of the carboxyl moieties. In some embodiments, the metal ion source is an oxide, carbonate, weak chelate or other metal salt of Gd, Eu, Tb, Dy, Sm, Lu, La, In, Ga, Re, Ru, Fe, Cu, Zn, Ni, Co, Cr, V, Ti, Sc, Zr, Nb, Mo, Rh, Pd, Ag, Cd, Sn, Hf, Ta, W, Os, Ir, Pt, Au or Y ions. In some other embodiments, the weak chelate is an acetylacetonate chelate. In some embodiments, the metal ion source is a chelate of acetylacetonate or Gd_2O_3 and compound Formula (IIe) is gadoteric acid. Metal chelation of DOTA ligands can be accomplished by the methods well known in the art, such as described by Hancock, R., et al., Ligand Design for Selective Complexation of Metal Ions in Aqueous Solution, Chem. Rev. 1989, 89, 1875-1914; or alternatively as described in United States Patent Nos. 4,822,594 (by Gibby) and United States Patent Application Publication No. US 2009/0036674 A1 (by Moore).

[0022] In some other aspects of the present disclosure, a process for the preparation of a macrocyclic tetramer compound of Formula (hie) is provided. The process comprises forming a reaction mixture comprising (a) a stoichiometric amount of an aziridine of Formula (Ib), (b) a Lewis acid, and (c) a solvent. The reaction mixture is reacted to form a metal-DOTA chelate of Formula (Ie) by cyclotetramerization of the aziridine of Formula (Ib), according to the following Reaction Scheme 4:



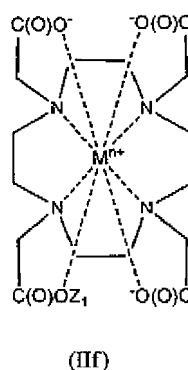
wherein $(M_t^+)(X_1^-)_s$ is a chelatable Lewis acid metal salt formed from a cation, M, and an anion, X_1^- , wherein t is 1, 2 or 3 and s is selected to achieve electrical neutrality, wherein Z_1 is hydrogen, an alkali metal having a +1 charge or an alkaline earth metal having a +2 charge, wherein q is 1 when Z_1 is an alkali metal and q is 2 when Z_1 is an alkaline earth metal, and wherein t is 3 and x is 1, or t is 2 and x is 1, or t is 2 and x is 2, or t is 1 and x is 1, or t is 1 and x is 2, or t is 1 and x is 3 or t is 1 and x is 4. As disclosed in Table A below, when Z_1 has a +1 charge then $y_1 = y_2 = (4 - (X^*t))$, and when Z_1 has a +2 charge then $y_1 = (4 - (X^*t))$ and $y_2 = (y_1/2)$:

Table A

		$Z_1 = +1$	$Z_2 = +2$	
t	X	y_1 and y_2	y_1	y_2
3	1	1	1	$1/2$
2	1	2	2	1
2	2	0	0	0
1	1	3	3	$3/2$
1	2	2	2	1
1	3	1	1	$1/2$
1	4	0	0	0

In some embodiments, the solvent comprises water, and in other embodiments, the solvent consists essentially of water.

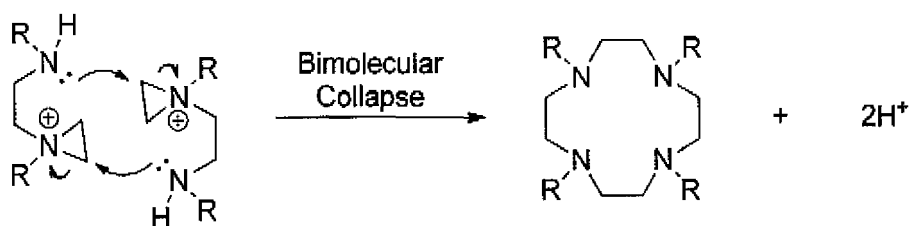
[0023] In some Reaction Scheme 4 embodiments, Formula (Ile) is of Formula (IIf):



wherein n is 3 and Z_1 is hydrogen or an alkali metal having a +1 charge. In some further embodiments, Formula (IIf) is gadoteric acid wherein M^{n+} is Gd^{3+} and Z_1 is hydrogen. In one particular embodiment, Formula (IIf) is gadoteric acid, formed for example by the cyclotetramerization of sodium 2-methylaziridinylacetate by gadolinium chloride at a pH of about -1 to about 2.

[0024] Without being bound to any particular theory, the cyclotetramerization reaction appears to be primarily driven by two factors: (i) steric effects resulting from the bulk of the R-group on the aziridine nitrogen; and, (ii) the basicity of the aziridine nitrogen. It is generally believed that activated aziridines, bearing electronegative functionalities such as carbonyl (amide) or sulfonyl (sulfonamide) groups, stabilize the resultant anion formed by nucleophilic attack on the aziridine ring. Unactivated aziridines bearing alkyl substituents typically require assistance by Lewis or Brønsted acids

for reactivity. It is further believed that treatment of protio- or alkyl-substituted aziridine with such acids results in the formation of a cationic aziridinium, which is susceptible towards attacks by nucleophiles, resulting in cyclotetramerization. However, cationic aziridinium is also susceptible to attack by unactivated aziridines, which may result in polymer formation. Both types of reactions are generally well-known in the art. (See, e.g., Pulipaka, Journal of Organic Chemistry 2008, 73, 1462; Watson, Accounts of Chemical Research 2006, 36, 194; Hashimoto, Journal of Macromolecular Science Chemistry 1984, A21 (6-7), 875; and Stephens, Journal of Chemical and Engineering Data 1969, 14, 114.) The observation of piperazine and polymer formation from 1-ethylaziridine and simple Brønsted acids has also been reported. (See, e.g., Dick, Journal of Organic Chemistry 1970, 3950.) The general mechanism for the reactivity of Lewis acid-activated aziridines has been suggested by Dick, and is outlined in FIG. 1 herein. Under this theory, it is believed that protonation of the aziridinyll nitrogen by the acid activates the ring towards nucleophilic attack by non-protonated aziridine. The subsequent aziridinium intermediate can then proceed down two paths: (i) intramolecular collapse, to make a cyclized product; or, (ii) intermolecular attack, to grow the chain. It is believed that the macrocyclic tetramer compounds of the present disclosure are predominantly formed by intramolecular collapse. It is further believed that additional tetramer could additionally be formed by the combination of two diamino moieties, thereby forming the tetramer in a more direct fashion according to the following mechanism:



Brønsted acids and Lewis acids

[0025] Suitable Brønsted and Lewis acids for the practice of the present disclosure may be selected from acids generally known in the art.

[0026] Brønsted acids may be selected from p-toluenesulfonic acid, methane sulfonic acid, triflic acid, sulfuric acid, hydrochloric acid, hydroiodic acid, hydrobromic acid, hydrofluoric acid, phosphoric acid, perchloric acid, trifluoroacetic acid, triethylammonium chloride, triethylammonium bromide, triethylammonium acetate, triethylammonium formate, tris(2-hydroxyethyl)ammonium chloride, tris(2-hydroxyethyl)ammonium bromide, tris(2-hydroxyethyl)ammonium acetate, tris(2-hydroxyethyl)ammonium formate, 4,7,13,16,21,24-hexaoxa-1,10-diazabicyclo [8.8.8]hexacosan-1-ium chloride, bromide, tris(2-hydroxyethyl)ammonium acetate, 4,7,13,16,21,24-hexaoxa-1,10-diazabicyclo[8.8.8]hexacosan-1-ium formate, bis(isopropyl)ethylammonium chloride, bis(isopropyl)ethylammonium bromide, bis(isopropyl)ethylammonium acetate, bis(isopropyl)ethylammonium formate, tris(carboxymethyl)ammonium chloride, tris(carboxymethyl)ammonium bromide, tris(carboxymethyl)ammonium acetate, tris(carboxymethyl)ammonium formate, 2-(bis(carboxymethyl)amino)-N,N-bis(carboxymethyl)ethanaminium chloride, 2-(bis(carboxymethyl)amino)-N,N-bis(carboxymethyl)ethanaminium bromide, 2-(bis(carboxymethyl)amino)-N,N-bis(carboxymethyl)ethanaminium acetate, bis 2-(bis(carboxymethyl)amino)-N,N-bis(carboxymethyl)ethanaminium formate, 2-(bis(carboxymethyl)amino)-N-(2-(bis(carboxymethyl)amino)ethyl)-N-(carboxymethyl)ethanaminium chloride, 2-(bis(carboxymethyl)amino)-N-(2-(bis(carboxymethyl)amino)ethyl)-N-(carboxymethyl)ethanaminium bromide, 2-(bis(carboxymethyl)amino)-N-(2-(bis(carboxymethyl)amino)ethyl)-N-(carboxymethyl)ethanaminium acetate, 2-(bis(carboxymethyl)amino)-N-(2-(bis(carboxymethyl)amino)ethyl)-N-(carboxymethyl)ethanaminium formate, formic acid, acetic acid, succinic acid, benzoic acid, lactic acid, citric acid, oxalic acid, nitriloacetic acid, ethylenediaminetetraacetic acid, diethylenetriaminepentacetic acid and combinations thereof. In some embodiments, the Brønsted acid is selected from sulfuric acid, hydrochloric acid, trifluoroacetic acid, p-toluene sulfonic acid, hydroiodic acid, hydrobromic acid, hydrofluoric acid, phosphoric acid and perchloric acid, methane sulfonic acid and triflic acid, and combinations thereof. In some other embodiments, the Brønsted acid is selected from hydrochloric acid, sulfuric acid, trifluoroacetic acid and p-toluene sulfonic acid, and combinations thereof.

[0027] In the various embodiments of the present disclosure, the amount of the Brønsted acid, expressed as the ratio of equivalents of the acid to equivalents of aziridine compound, is from about 0.01:1 to about 0.5:1, from about 0.03:1 to about 0.1:1, or from about 0.04:1 to about 0.08:1.

[0028] Lewis acids are generally a chelatable Lewis acid metal salt formed from a metal cation, M, and a counterion, wherein M is selected from an alkali metal, an alkaline earth metal, a rare earth metal, a transition metal and a lanthanide metal. Examples of such acids include, but are not limited to, boron tribromide, boron trichloride, boron trifluoride, boron trifluoride etherate, gadolinium tribromide, gadolinium trichloride, gadolinium trifluoride, gadolinium acetate, gadolinium formate, cupric bromide, cupric chloride, cupric fluoride, nickel bromide, nickel chloride, nickel fluoride aluminum bromide,

aluminum chloride, aluminum fluoride, ferric bromide, ferric chloride, ferric fluoride, sodium bromide, potassium bromide, potassium chloride, potassium fluoride, sodium chloride, sodium fluoride, tin(IV) chloride, and combinations thereof. In some embodiments, the acid is selected from sodium bromide, sodium chloride, sodium fluoride, sodium bromide, potassium bromide, potassium chloride, potassium fluoride, potassium bromide, gadolinium tribromide, gadolinium trichloride, gadolinium trifluoride, gadolinium acetate, gadolinium formate, and combinations thereof. In some other embodiments, the Lewis acid is selected from boron tribromide, boron trichloride, aluminum chloride, ferric chloride, tin(IV) chloride, and combinations thereof. In some embodiments the Lewis acid is suitably selected from gadolinium acetate and gadolinium chloride, or a combination thereof. In some other embodiments, is suitably selected from sodium bromide, sodium chloride, sodium iodide and combinations thereof.

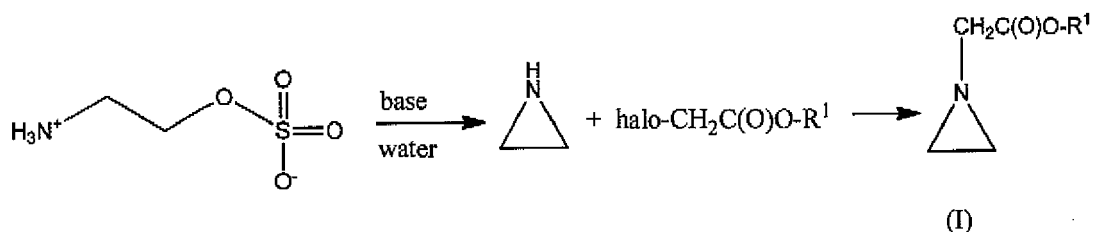
[0029] In the various embodiments of the present disclosure, the amount of the Lewis acid, expressed as the ratio of equivalents of the acid to equivalents of aziridine compound, is from about 0.05:1 to about 1.5:1, from about 0.05:1 to about 1.2:1, or from about 0.5:1 to about 1.2:1. In some embodiments, the ratio of Lewis acid to aziridine is from about 0.05:1 to about 0.5:1 or from about 0.1:1 to about 0.5:1. In some other embodiments, the ratio of Lewis acid to aziridine is from about 1.0:1 to about 1.5:1 or from about 1.0:1 to about 1.2:1.

[0030] In other alternative embodiments, the acid comprises, at least one Brønsted acid selected from the species disclosed above and at least one Lewis acid selected from the species disclosed above. In some embodiments, the Brønsted acid is selected from sulfuric acid, hydrochloric acid, trifluoroacetic acid, *p*-toluene sulfonic acid, hydroiodic acid, hydrobromic acid, hydrofluoric acid, phosphoric acid, perchloric acid, methane sulfonic acid and triflic acid, and combinations thereof, and the Lewis acid is selected from sodium bromide, sodium chloride, sodium fluoride, sodium bromide, potassium bromide, potassium chloride, potassium fluoride, potassium bromide, gadolinium bromide, gadolinium trichloride, gadolinium trifluoride, gadolinium acetate, gadolinium formate, and combinations thereof. In some other embodiments, the Brønsted acid is selected from hydrochloric acid, sulfuric acid, trifluoroacetic acid and *p*-toluene sulfonic acid, and combinations thereof, and the Lewis acid is selected from boron tribromide, boron trichloride, aluminum chloride, ferric chloride and tin(IV) chloride, and combinations thereof. In some other embodiments, the Brønsted acid is selected from hydrochloric acid, sulfuric acid, trifluoroacetic acid, *p*-toluene sulfonic acid, and combinations thereof, and the Lewis acid is selected from sodium, potassium, gadolinium salts, and combinations thereof. In yet other embodiments, the Brønsted acid is *p*-toluene sulfonic acid and the Lewis acid is selected from sodium bromide and gadolinium acetate. In still other embodiments, the Brønsted acid is suitably selected from trifluoroacetic acid, *p*-toluene sulfonic acid, sulfuric acid, hydrochloric acid, and combinations thereof, and the Lewis acid is suitably selected from gadolinium acetate and gadolinium chloride, or a combination thereof. In yet other embodiments, the Brønsted acid is suitably selected from trifluoroacetic acid, *p*-toluene sulfonic acid, sulfuric acid, hydrochloric acid, and combinations thereof, and the Lewis acid is suitably selected from sodium bromide, sodium chloride, sodium iodide and combinations thereof.

[0031] In the various embodiments of the present disclosure for the combination of at least one Brønsted acid and at least one Lewis acid, the ratio of the Brønsted acid(s) (equivalent basis) to aziridine (molar basis) is from about 0.01:1 to about 0.5:1, from about 0.03:1 to about 0.1:1, or from about 0.04:1 to about 0.08:1 and the ratio of the Lewis acid(s) to the aziridine is from about 0.05:1 to about 1.5:1, from about 0.05:1 to about 1.2:1, or from about 0.5:1 to about 1.2:1. In some of these embodiments, the ratio of Lewis acid to aziridine is from about 0.05:1 to about 0.5:1. In some other embodiments, the amount of the Lewis acid in a ratio to aziridine of from about 1.0:1 to about 1.2:1.

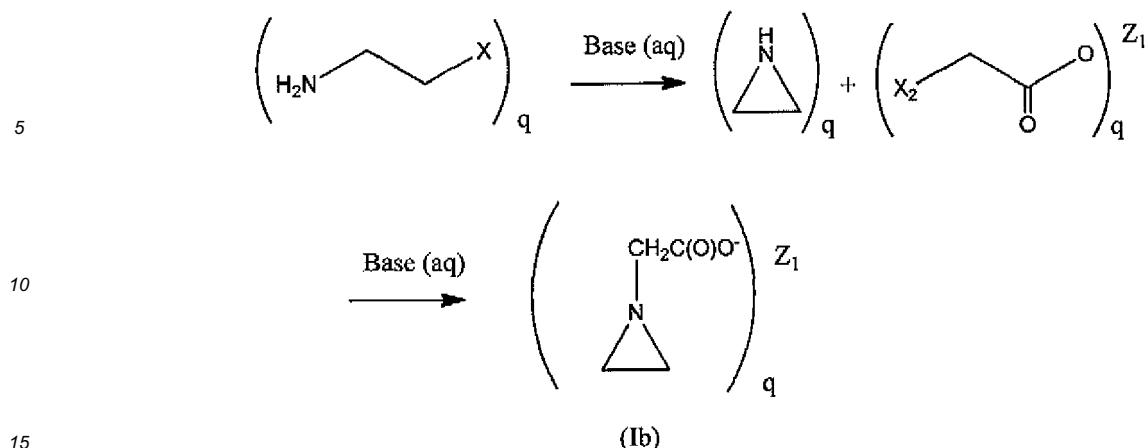
Aziridine Substrates

[0032] Aziridine substrate compounds within the scope of the present disclosure may be prepared according to methods known to those skilled in the art, such as disclosed for example by US 6,288,224 B1. For instance, aziridine Formula (I) may be prepared according to the reaction scheme below:



wherein R¹ is as defined above.

[0033] In one embodiment, aziridine of Formula (Ib) is prepared according to the reaction scheme below:



wherein X is a leaving group, X₂ is a halide, Z₁ is an alkali metal having a +1 charge or an alkaline earth metal having a +2 charge, q is 1 when Z₁ has a +1 charge, and q is 2 when Z₁ has a +2 charge. In some other embodiments, X is Cl, Br or OSO₃H, the base is NaOH or KOH and Z₁ is Na⁺, K⁺, Ca²⁺ or Mg²⁺.

Solvent

[0034] Generally speaking, the solvent may be selected from those generally known in the art for use in such a reaction. In particular, however, the solvent is suitably a polar aprotic solvent, a polar protic solvent, or a combination thereof. Polar aprotic solvents include, for example, chloroform, dichloromethane, tetrahydrofuran, ethyl acetate, acetone, dimethylformamide, dimethylacetamide, acetonitrile, 1,4-dioxane, glyme, diglyme, dimethyl sulfoxide, propylene carbonate, and combinations thereof. Polar protic solvents include, for example, methanol, ethanol, *n*-propanol, *i*-propanol, *n*-butanol, *i*-butanol, *t*-butanol, ethylene glycol, formic acid, water, acetic acid, and combinations thereof. In some other particular embodiments, the solvent is acetonitrile, dimethylacetamide, dimethylformamide, methanol or ethanol, or a combination thereof. In some particular embodiments, the solvent is an alcohol (or a mixture containing an alcohol) of the formula R'OH, wherein R' corresponds to the aziridine R¹ moiety, such as wherein both R' and R¹ are methyl. In yet other embodiments, the solvent comprises water or consists essentially of water. As used herein, a solvent "consisting essentially of water" does not exclude the presence of other solvents in amounts that do not materially affect the characteristics of the present disclosure.

Reaction Conditions

[0035] In any of the various embodiments of the present disclosure, the reaction temperature may be from about -20°C to about 150°C, from about 0°C to about 100°C, from about 10°C to about 50°C, or from about 20°C to about 30°C. In this regard it is to be noted, however, that preferred reaction temperatures may vary, for example, as a function of the solvent system, acid or base system, the equivalent ratio thereof to aziridine, and/or the aziridine concentration in the reaction system.

[0036] In any of the various embodiments of the present disclosure, the concentration of the aziridine substrate compound in the reaction mixture comprising the solvent may typically be from about 0.05 to about 1.0 moles per liter, from about 0.1 to about 0.5 moles per liter, or from about 0.1 to about 0.3 moles per liter.

Yield/Purity

[0037] Any of the various reaction products of the present disclosure can be isolated and optionally purified by means known to those skilled in the art. In some embodiments, any of Formulae (II) to (IIf), DOTA or gadoteric acid may be isolated by crystallization or precipitation from a solvent, such as by induction of super saturation therein by, for instance, evaporation, temperature reduction, pH adjustment and/or the addition of co-solvents in which the reaction product is no more than sparingly soluble. Suitable purification techniques include, for instance, precipitation, crystallization, ultrafiltration and nanofiltration. In some further embodiments, the reaction products may be isolated and/or purified by crystallization from an aqueous solvent at a pH of from about 1 to about 4. When the reaction product is gadoteric acid, the crystallization pH from aqueous solvent is preferably from about 2 to about 4. In some particular embodiments, gadoteric acid purification may be achieved by one of the following non-limiting examples: (i) adjustment to a pH of about 0.5 to about 3, followed by solvent removal, crystallization or precipitation; (ii) preparative chromatography, such as

liquid chromatography, ion exchange chromatography or size-exclusion chromatograph, with or without pH adjustment; or, (iii) nanofiltration at essentially neutral pH by meglumine addition. In some other embodiments, DOTA purification can be achieved by nanofiltration as the sodium salt thereof.

[0038] Notably, it has been discovered that the process of the present disclosure provides for high yield and/or purity of the desired macrocyclic tetramer compounds. The purity of compounds of Formulae (II)-(II_f), DOTA and gadoteric acid obtained from the process of the present disclosure is typically at least about 50%, at least about 60%, at least about 70%, at least about 80%, at least about 90%, or more, as measured by methods known to those skilled in the art such as, for example, MS chromatogram or evaporative light scattering (ELSD). Additionally, the molar yield of compounds of Formulae (II)-(II_f), DOTA and gadoteric acid obtained from the process of the present disclosure is typically at least about 40%, at least about 50%, at least about 60%, at least about 70%, at least about 80%, at least about 90%, or more, based on moles of aziridine used therein.

[0039] It is to be noted that the selection of combinations of (i) Brønsted acid and/or Lewis acid, (ii) solvent, (iii) equivalent ratios of Brønsted acids and/or Lewis acids to aziridine, (iv) aziridine species and concentration, and/or (v) reaction conditions (e.g., reaction temperature, reaction time, etc.) within the scope of the present disclosure can affect macrocyclic polyazacarboxylate yield from aziridine. Without being bound to any particular embodiment and based on experimental evidence to date, Table B below depicts some observed macrocyclic polyazacarboxylate yields from aziridine Formula (I), wherein R¹ is methyl, for various combinations of a Brønsted acid and polar protic solvent or polar aprotic solvent (wherein DMAc refers to dimethylacetamide, DMF refers to dimethylformamide, MeOH refers to methyl alcohol, ACN refers to acetonitrile, TsOH refers to *p*-toluene sulfonic acid, and TFA refers to trifluoroacetic acid).

Table B

Solvent / Acid	TFA	TsOH*H ₂ O	H ₂ SO ₄	HCl
DMAc	68% yield	92% yield	81% yield	8% yield
DMF	68% yield	74% yield	66% yield	8% yield
MeOH	62% yield	57% yield	48% yield	49% yield
ACN	64% yield	66% yield	59% yield	63% yield

In this regard it is to be further noted that, in view of the present disclosure, selection and optimization of the various combinations of Brønsted acids and/or Lewis acids, solvents, equivalent ratios of Brønsted acids and/or Lewis acids to aziridine, aziridine concentration, and/or reaction conditions for the purpose of achieving significant and commercially acceptable macrocyclic polyazacarboxylate yield and purity, is within the purview of one skilled in the art.

DEFINITIONS

[0040] The term "hydrocarbyl" as used herein describes an organic compound or radical consisting exclusively of the elements carbon and hydrogen. This moiety includes alkyl, alkenyl, alkynyl, and aryl moieties. This moiety also includes alkyl, alkenyl, alkynyl, unsaturated or partially saturated cyclic moieties, aryl and aryl moieties substituted with other aliphatic or cyclic hydrocarbon groups, such as alkaryl, alkenaryl and alkynaryl. Unless otherwise indicated, this moiety preferably contains 1 to 10 carbon atoms.

[0041] The term "aryl" or as used herein alone or as part of another group denote optionally substituted homocyclic aromatic groups, preferably monocyclic or bicyclic groups containing from 4 to 10 carbons, from 4 to 8 carbons or from 5 to 8 carbons in the ring portion, such as phenyl, biphenyl, naphthyl, substituted phenyl (e.g., alkylphenyl), substituted biphenyl or substituted naphthyl. Phenyl and alkylphenyl (e.g., benzyl) are the more preferred aryl.

[0042] The term "Lewis acid" is defined as a molecule or ion (electrophile) that can combine with another molecule or ion by forming a dative bond by accepting one or more electron pairs from that second molecule or ion.

[0043] The term "Brønsted" acid is defined as a molecule or ion that is able to lose, or "donate," a hydrogen cation (H⁺).

[0044] The term "halo" or "halogen" as used herein alone or a part of another group refers to chlorine, bromine, fluorine, and iodine.

[0045] The term "chelate" as used herein refers to a macrocycle of the disclosure complexed or coordinated with a metal.

[0046] The term "derivative" refers to a macrocyclic polyazacarboxylate compound or ligand (e.g., DOTA) having at least one chemical modification thereto, either on the macrocyclic polyazacarboxylate ring itself or at a functional group thereon.

EXAMPLES

[0047] The following non-limiting examples are provided to further illustrate the present disclosure.

Example 1: Preparation of tetramethyl 2,2',2'',2'''-(1,4,7,10-tetraazacyclododecane-1,4,7,10-tetrayl)tetraacetate (DOTA-tetra(methyl ester)) (i.e., a compound of Formula (II), wherein $-R^1 = -CH_3$).

[0048] Three solutions were prepared in vials as indicated in Table 1 below, wherein the methyl 2-aziridinylacetate solution contained (20 μ L, 184 mmol) methyl 2-aziridinylacetate in acetonitrile (ACN 1.8 mL) was treated with *p*-toluenesulfonic acid (1.48 mg, 9.21 mmol).

Table 1

Vial	1	2	3
μ L of methyl 2-aziridinylacetate solution	20	20	20
Millimoles of methyl 2-aziridinylacetate	184	184	184
Millimoles of <i>p</i> -toluenesulfonic acid	9.21	18.4	36.8
Mole fraction <i>p</i> -toluenesulfonic acid	0.05	0.1	0.2
μ L of 10mg/mL <i>p</i> -toluenesulfonic acid solution	148	295	590

[0049] The vials were stirred at ambient temperature for 16 hours (overnight). The reaction product was analyzed by HPLC-ELSD using a HILIC column and 85% acetonitrile (0.05% TFA) / 10% water (0.05% TFA). The chromatogram is shown in FIG. 2, indicating that 5 mol% and 10 mol% *p*-toluene sulfonic acid gave approximately 98% of the desired tetramer after correcting for *p*-toluene sulfonic acid. Additionally, a 20 mol% *p*-toluene sulfonic acid yielded a tetramer having a higher impurity content.

Example 2: Direct formation of DOTA tetra(methyl ester)

[0050] In a 250 mL round-bottom flask methyl 2-(aziridin-1-yl)acetate (8.69 mmol) and 4-methylbenzene sulfonic acid (0.261 mmol) were combined with 50 mL methanol to give a colorless solution. The solution was refluxed under argon overnight to yield 80% yield of DOTA tetra(methyl ester). The reacted solution was analyzed by HPLC MS. The chromatogram is shown in FIG. 3, indicating that 77.4% purity of the desired tetramer was achieved.

Example 3: Survey of Acid/Solvent Combinations for the Cyclotetramerization of Methyl 2-(aziridin-1-yl)acetate.

[0051] A series of reactions were carried out based upon a matrix of reaction conditions consisting of four different acids (trifluoroacetic acid, *p*-toluene sulfonic acid, hydrochloric acid and sulfuric acid) at three different levels (2, 5, 7 mole%), four different solvents (DMAc, DMF, ACN and MeOH) at three different concentrations of methyl 2-(aziridin-1-yl)acetate (5, 10, 20 μ L/mL, which correspond to aziridine concentrations of 0.0414, 0.0828 and 0.166 mmol/mL, respectively). The reactions were analyzed for completeness by HPLC-ELSD using a 90-80 ACN(0.05%TFA)-Water(0.05%) gradient over 15 minutes. The results were quantified by comparing to known concentrations of DOTA-tetramethyl ester, prepared by an independent method. The results are reported in Table 2 below, wherein DMAc refers to dimethylacetamide, DMF refers to dimethylformamide, MeOH refers to methyl alcohol, ACN refers to acetonitrile, TsOH refers to *p*-toluene sulfonic acid, and TFA refers to trifluoroacetic acid.

Table 2

Run	Solvent	Acid	Mole% Acid	Aziridine Conc. (mmol/mL)	% Yield
1	DMAc	TFA	2	0.0414	0
2	DMAc	TFA	2	0.0828	31
3	DMAc	TFA	2	0.166	37
4	DMAc	TFA	5	0.0414	39
5	DMAc	TFA	5	0.0828	45

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(continued)

Run	Solvent	Acid	Mole% Acid	Aziridine Conc. (mmol/mL)	% Yield
6	DMAc	TFA	5	0.166	68
7	DMAc	TFA	7	0.0414	58
8	DMAc	TFA	7	0.0828	45
9	DMAc	TFA	7	0.166	61
10	DMAc	TsOH*H ₂ O	2	0.0414	28
11	DMAc	TsOH*H ₂ O	2	0.0828	37
12	DMAc	TsOH*H ₂ O	2	0.166	46
13	DMAc	TsOH*H ₂ O	5	0.0414	59
14	DMAc	TsOH*H ₂ O	5	0.0828	76
15	DMAc	TsOH*H ₂ O	5	0.166	74
16	DMAc	TsOH*H ₂ O	7	0.0414	63
17	DMAc	TsOH*H ₂ O	7	0.0828	92
18	DMAc	TsOH*H ₂ O	7	0.166	84
19	DMAc	H ₂ SO ₄	2	0.0414	0
20	DMAc	H ₂ SO ₄	2	0.0828	40
21	DMAc	H ₂ SO ₄	2	0.166	51
22	DMAc	H ₂ SO ₄	5	0.0414	58
23	DMAc	H ₂ SO ₄	5	0.0828	76
24	DMAc	H ₂ SO ₄	5	0.166	58
25	DMAc	H ₂ SO ₄	7	0.0414	20
26	DMAc	H ₂ SO ₄	7	0.0828	81
27	DMAc	H ₂ SO ₄	7	0.166	0
28	DMAc	HCl (aq)	2	0.0414	7
29	DMAc	HCl (aq)	2	0.0828	0
30	DMAc	HCl (aq)	2	0.166	2
31	DMAc	HCl (aq)	5	0.0414	0
32	DMAc	HCl (aq)	5	0.0828	4
33	DMAc	HCl (aq)	5	0.166	2
34	DMAc	HCl (aq)	7	0.0414	8
35	DMAc	HCl (aq)	7	0.0828	4
36	DMAc	HCl (aq)	7	0.166	2
37	DMF	TFA	2	0.0414	0
38	DMF	TFA	2	0.0828	32
39	DMF	TFA	2	0.166	42
40	DMF	TFA	5	0.0414	43
41	DMF	TFA	5	0.0828	38
42	DMF	TFA	5	0.166	61
43	DMF	TFA	7	0.0414	52

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(continued)

Run	Solvent	Acid	Mole% Acid	Aziridine Conc. (mmol/mL)	% Yield
44	DMF	TFA	7	0.0828	68
45	DMF	TFA	7	0.166	68
46	DMF	TsOH*H ₂ O	2	0.0414	22
47	DMF	TsOH*H ₂ O	2	0.0828	30
48	DMF	TsOH*H ₂ O	2	0.166	43
49	DMF	TsOH*H ₂ O	5	0.0414	47
50	DMF	TsOH*H ₂ O	5	0.0828	54
51	DMF	TsOH*H ₂ O	5	0.166	67
52	DMF	TsOH*H ₂ O	7	0.0414	58
53	DMF	TsOH*H ₂ O	7	0.0828	74
54	DMF	TsOH*H ₂ O	7	0.166	74
55	DMF	H ₂ SO ₄	2	0.0414	23
56	DMF	H ₂ SO ₄	2	0.0828	37
57	DMF	H ₂ SO ₄	2	0.166	35
58	DMF	H ₂ SO ₄	5	0.0414	60
59	DMF	H ₂ SO ₄	5	0.0828	66
60	DMF	H ₂ SO ₄	5	0.166	16
61	DMF	H ₂ SO ₄	7	0.0414	59
62	DMF	H ₂ SO ₄	7	0.0828	4
63	DMF	H ₂ SO ₄	7	0.166	59
64	DMF	HCl (aq)	2	0.0414	7
65	DMF	HCl (aq)	2	0.0828	4
66	DMF	HCl (aq)	2	0.166	3
67	DMF	HCl (aq)	5	0.0414	8
68	DMF	HCl (aq)	5	0.0828	4
69	DMF	HCl (aq)	5	0.166	3
70	DMF	HCl (aq)	7	0.0414	8
71	DMF	HCl (aq)	7	0.0828	5
72	DMF	HCl (aq)	7	0.166	4
73	MeOH	TFA	2	0.0414	13
74	MeOH	TFA	2	0.0828	15
75	MeOH	TFA	2	0.166	17
76	MeOH	TFA	5	0.0414	38
77	MeOH	TFA	5	0.0828	41
78	MeOH	TFA	5	0.166	38
79	MeOH	TFA	7	0.0414	56
80	MeOH	TFA	7	0.0828	62
81	MeOH	TFA	7	0.166	57

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(continued)

Run	Solvent	Acid	Mole% Acid	Aziridine Conc. (mmol/mL)	% Yield
82	MeOH	TsOH*H ₂ O	2	0.0414	16
83	MeOH	TsOH*H ₂ O	2	0.0828	18
84	MeOH	TsOH*H ₂ O	2	0.166	19
85	MeOH	TsOH*H ₂ O	5	0.0414	31
86	MeOH	TsOH*H ₂ O	5	0.0828	40
87	MeOH	TsOH*H ₂ O	5	0.166	39
88	MeOH	TsOH*H ₂ O	7	0.0414	43
89	MeOH	TsOH*H ₂ O	7	0.0828	57
90	MeOH	TsOH*H ₂ O	7	0.166	52
91	MeOH	H ₂ SO ₄	2	0.0414	17
92	MeOH	H ₂ SO ₄	2	0.0828	23
93	MeOH	H ₂ SO ₄	2	0.166	26
94	MeOH	H ₂ SO ₄	5	0.0414	36
95	MeOH	H ₂ SO ₄	5	0.0828	42
96	MeOH	H ₂ SO ₄	5	0.166	44
97	MeOH	H ₂ SO ₄	7	0.0414	34
98	MeOH	H ₂ SO ₄	7	0.0828	48
99	MeOH	H ₂ SO ₄	7	0.166	40
100	MeOH	HCl (aq)	2	0.0414	14
101	MeOH	HCl (aq)	2	0.0828	16
102	MeOH	HCl (aq)	2	0.166	12
103	MeOH	HCl (aq)	5	0.0414	31
104	MeOH	HCl (aq)	5	0.0828	37
105	MeOH	HCl (aq)	5	0.166	28
106	MeOH	HCl (aq)	7	0.0414	43
107	MeOH	HCl (aq)	7	0.0828	49
108	MeOH	HCl (aq)	7	0.166	40
109	ACN	TFA	2	0.0414	18
110	ACN	TFA	2	0.0828	22
111	ACN	TFA	2	0.166	28
112	ACN	TFA	5	0.0414	28
113	ACN	TFA	5	0.0828	44
114	ACN	TFA	5	0.166	49
115	ACN	TFA	7	0.0414	40
116	ACN	TFA	7	0.0828	56
117	ACN	TFA	7	0.166	64
118	ACN	TsOH*H ₂ O	2	0.0414	18
119	ACN	TsOH*H ₂ O	2	0.0828	24

(continued)

Run	Solvent	Acid	Mole% Acid	Aziridine Conc. (mmol/mL)	% Yield
120	ACN	TsOH*H ₂ O	2	0.166	26
121	ACN	TsOH*H ₂ O	5	0.0414	38
122	ACN	TsOH*H ₂ O	5	0.0828	52
123	ACN	TsOH*H ₂ O	5	0.166	55
124	ACN	TsOH*H ₂ O	7	0.0414	52
125	ACN	TsOH*H ₂ O	7	0.0828	60
126	ACN	TsOH*H ₂ O	7	0.166	66
127	ACN	H ₂ SO ₄	2	0.0414	0
128	ACN	H ₂ SO ₄	2	0.0828	21
129	ACN	H ₂ SO ₄	2	0.166	2
130	ACN	H ₂ SO ₄	5	0.0414	32
131	ACN	H ₂ SO ₄	5	0.0828	50
132	ACN	H ₂ SO ₄	5	0.166	2
133	ACN	H ₂ SO ₄	7	0.0414	48
134	ACN	H ₂ SO ₄	7	0.0828	59
135	ACN	H ₂ SO ₄	7	0.166	2
156	ACN	HCl (aq)	2	0.0414	7
137	ACN	HCl (aq)	2	0.0828	4
138	ACN	HCl (aq)	2	0.166	32
139	ACN	HCl (aq)	5	0.0414	8
140	ACN	HCl (aq)	5	0.0828	32
141	ACN	HCl (aq)	5	0.166	56
142	ACN	HCl (aq)	7	0.0414	8
143	ACN	HCl (aq)	7	0.0828	6
144	ACN	HCl (aq)	7	0.166	63

The best yields of DOTA tetra(methyl ester) were achieved with DMAc and *p*-toluene sulfonic acid, with 92% and 84% in two independent runs.

Example 4: Preparation of Gd-DOTA chelate of formula (IIIa) wherein R¹ and R² are hydrogen; X¹ is -OH; and Mⁿ⁺ is Gd³⁺.

[0052] A mixture of sodium 2-aziridinylacetate (40 mmol) and gadolinium chloride or gadolinium acetate (10 mmol) in water (50 mL) may be stirred at ambient temperature for 16 hours (overnight). After the reaction, the solution may have the pH adjusted to about 7 by means of the addition of 10 mmol N-methyl glucamine (meglumine). The solvent may be removed in vacuo and the crude material may be purified by crystallization, or the reaction mixture may be purified chromatography, or the mixture may be purified by nanofiltration and the resulting solution spray dried to give the meglumine salt of gadoteric acid.

[0053] When introducing elements of the present disclosure or the embodiment(s) thereof, the articles "a", "an", "the" and "said" are intended to mean that there are one or more of the elements. The terms "comprising", "including" and "having" are intended to be inclusive and mean that there may be additional elements other than the listed elements.

[0054] In view of the above, it will be seen that the several feature or objects of the disclosure are achieved and other advantageous results attained.

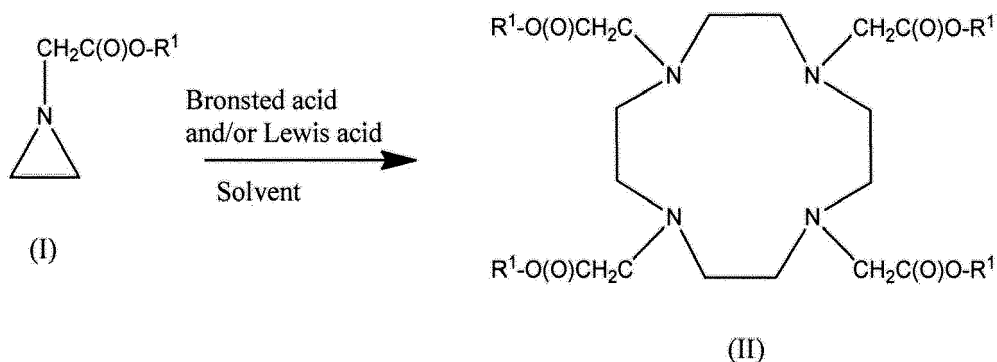
[0055] As various changes could be made in the above compositions, products, and methods (including concentrations

of reagents, process conditions, etc.), it is intended that all matter contained in the above description shall be interpreted as illustrative and not in a limiting sense.

Claims

1. A process for the preparation of a macrocyclic tetramer compound of Formula (II), the process comprising:

- (i) forming a reaction mixture comprising a stoichiometric amount of (a) an aziridine of Formula (I), (b) a Brønsted acid, a Lewis acid, or a combination of a Brønsted acid and a Lewis acid, and (c) a solvent; and
- (ii) reacting the contents of the reaction mixture to form the compound of Formula (II) by cyclotetramerization of the aziridine of Formula (I), according to the following reaction:



wherein:

each R^1 is independently selected from the group consisting of C_{1-10} hydrocarbyl.

2. The process of claim 1 wherein:

- i) each R^1 is independently selected from methyl, ethyl, 2-propyl and benzyl; and/or
- ii) the acid is a Brønsted acid selected from the group consisting of *p*-toluenesulfonic acid, methane sulfonic acid, triflic acid, sulfuric acid, hydrochloric acid, hydroiodic acid, hydrobromic acid, hydrofluoric acid, phosphoric acid, perchloric acid, trifluoroacetic acid, triethylammonium chloride, triethylammonium bromide, triethylammonium acetate, triethylammonium formate, tris(2-hydroxyethyl)ammonium chloride, tris(2-hydroxyethyl)ammonium bromide, tris(2-hydroxyethyl)ammonium acetate, tris(2-hydroxyethyl)ammonium formate, 4,7,13,16,21,24-hexaoxa-1,10-diazabicyclo[8.8.8]hexacosan-1-ium chloride, bromide, tris(2-hydroxyethyl)ammonium acetate, 4,7,13,16,21,24-hexaoxa-1,10-diazabicyclo[8.8.8]hexacosan-1-ium formate, bis(isopropyl)ethylammonium chloride, bis(isopropyl)ethylammonium bromide, bis(isopropyl)ethylammonium acetate, bis(isopropyl)ethylammonium formate, tris(carboxymethyl)ammonium chloride, tris(carboxymethyl)ammonium bromide, tris(carboxymethyl)ammonium acetate, tris(carboxymethyl)ammonium formate, 2-(bis(carboxymethyl)amino)-N,N-bis(carboxymethyl)ethanaminium chloride, 2-(bis(carboxymethyl)amino)-N,N-bis(carboxymethyl)ethanaminium bromide, 2-(bis(carboxymethyl)amino)-N,N-bis(carboxymethyl)ethanaminium acetate, bis 2-(bis(carboxymethyl)amino)-N,N-bis(carboxymethyl)ethanaminium formate, 2-(bis(carboxymethyl)amino)-N-(2-(bis(carboxymethyl)amino)ethyl)-N-(carboxymethyl)ethanaminium, 2-(bis(carboxymethyl)amino)-N-(2-(bis(carboxymethyl)amino)ethyl)-N-(carboxymethyl)ethanaminium bromide, 2-(bis(carboxymethyl)amino)-N-(2-(bis(carboxymethyl)amino)ethyl)-N-(carboxymethyl)ethanaminium acetate, 2-(bis(carboxymethyl)amino)-N-(2-(bis(carboxymethyl)amino)ethyl)-N-(carboxymethyl)ethanaminium formate, formic acid, acetic acid, succinic acid, benzoic acid, lactic acid, citric acid, oxalic acid, nitriloacetic acid, ethylenediaminetetraacetic acid, diethylenetriaminepentacetic acid and combinations thereof, for example wherein the Brønsted acid is selected from the group consisting of *p*-toluenesulfonic acid, trifluoroacetic acid, hydrochloric acid and sulfuric acid, and/or wherein the amount of the Brønsted acid, expressed as the ratio of equivalents of the acid to moles of aziridine, is from about 0.01:1 to about 0.5:1, from about 0.03:1 to about 0.1:1, or from about 0.04:1 to about 0.08:1.

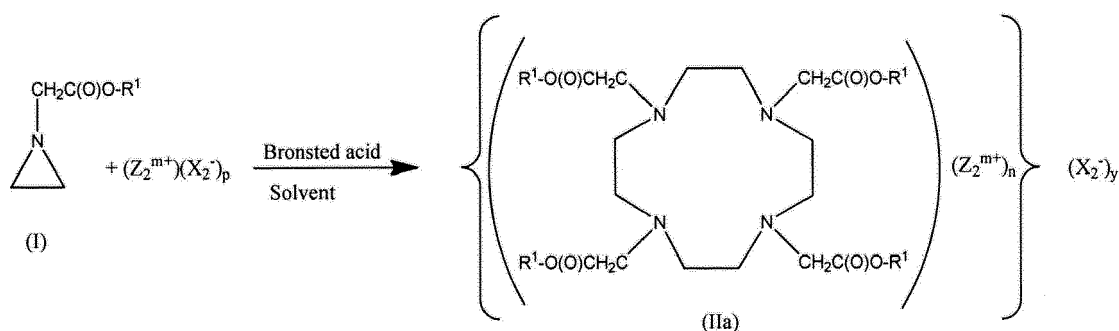
3. The process of claim 1 wherein the acid is a chelatable Lewis acid metal salt formed from a metal cation, M, and a

counterion, wherein M is selected from an alkali metal, an alkaline earth metal, a rare earth metal, a transition metal and a lanthanide metal, for example wherein the Lewis acid is selected from the group consisting of boron tribromide, boron trichloride, boron trifluoride, boron trifluoride etherate, gadolinium tribromide, gadolinium trichloride, gadolinium trifluoride, gadolinium acetate, gadolinium formate, cupric bromide, cupric chloride, cupric fluoride, nickel bromide, nickel chloride, nickel fluoride aluminum bromide, aluminum chloride, aluminum fluoride, ferric bromide, ferric chloride, ferric fluoride, sodium bromide, potassium bromide, potassium chloride, potassium fluoride, sodium chloride, sodium fluoride, tin(IV) chloride, and combinations thereof, and/or wherein:

- i) the amount of the Lewis acid, expressed as the ratio of equivalents of the acid to moles of aziridine compound, is from about 0.05:1 to about 1.5:1, from about 0.05:1 to about 1.2:1, or from about 0.5:1 to about 1.2:1;
- ii) the ratio of Lewis acid, expressed as the ratio of equivalents of the acid to moles of aziridine compound, is from about 0.05:1 to about 0.5:1 or from about 0.1:1 to about 0.5:1; and/or
- iii) the ratio Lewis acid, expressed as the ratio of equivalents of the acid to moles of aziridine compound, is from about 1.0:1 to about 1.5:1 or from about 1.0:1 to about 1.2:1.

4. The process of claim 1 or claim 2, wherein:

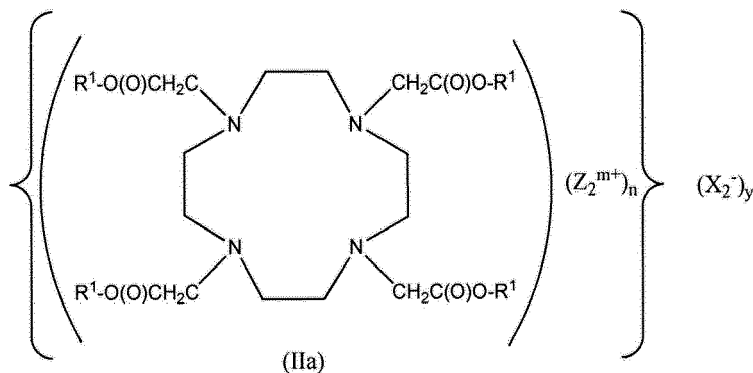
- i) the acid is a Brønsted acid and the reaction mixture further comprises an alkali metal salt, $(Z_2^{m+})(X_2^-)_p$, wherein Formula (IIa) is formed by cyclotetramerization of the aziridine of Formula (I) according the following reaction:



wherein:

- Z_2^{m+} is a counterion selected from the group consisting of a hydrogen ion, a tertiary ammonium ion, an alkali metal ion, and an alkaline earth metal, wherein $m+$ is 1 or 2;
- X_2^- is selected from the group consisting of a halide, *p*-toluenesulfonate and trifluoroacetate;
- p is the number of X_2^- needed to maintain electrical neutrality with Z_2^{m+} and is selected from 1 and 2;
- n is an integer selected from 0 to 4; and
- y is the number of X_2^- needed to maintain electrical neutrality of formula (IIa), optionally wherein Z_2 is sodium or potassium and X_2^- is chloride or bromide; or

- ii) the acid is a Brønsted acid, the process further comprising contacting Formula (II) with an alkali metal salt, $(Z_2^{m+})(X_2^-)_p$, to form Formula (IIa):



wherein:

Z_2^{m+} is a counterion selected from the group consisting of a hydrogen ion, a tertiary ammonium ion, an alkali metal ion, and an alkaline earth metal, wherein $m+$ is 1 or 2;

X_2^- is selected from the group consisting of a halide, *p*-toluenesulfonate and trifluoroacetate;

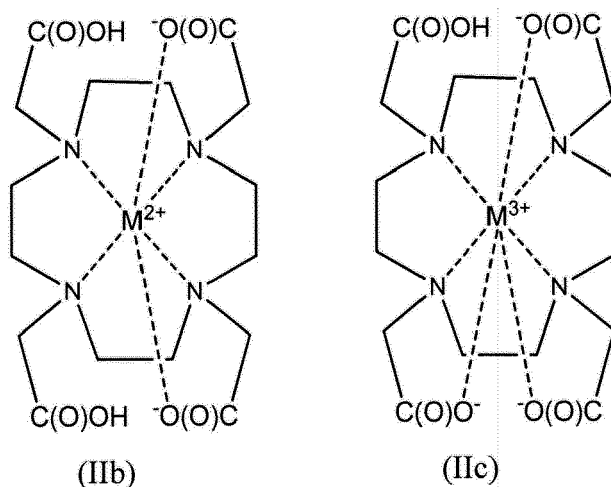
p is the number of X_2^- needed to maintain electrical neutrality with Z_2^{m+} and is selected from 1 and 2;

n is an integer selected from 0 to 4; and

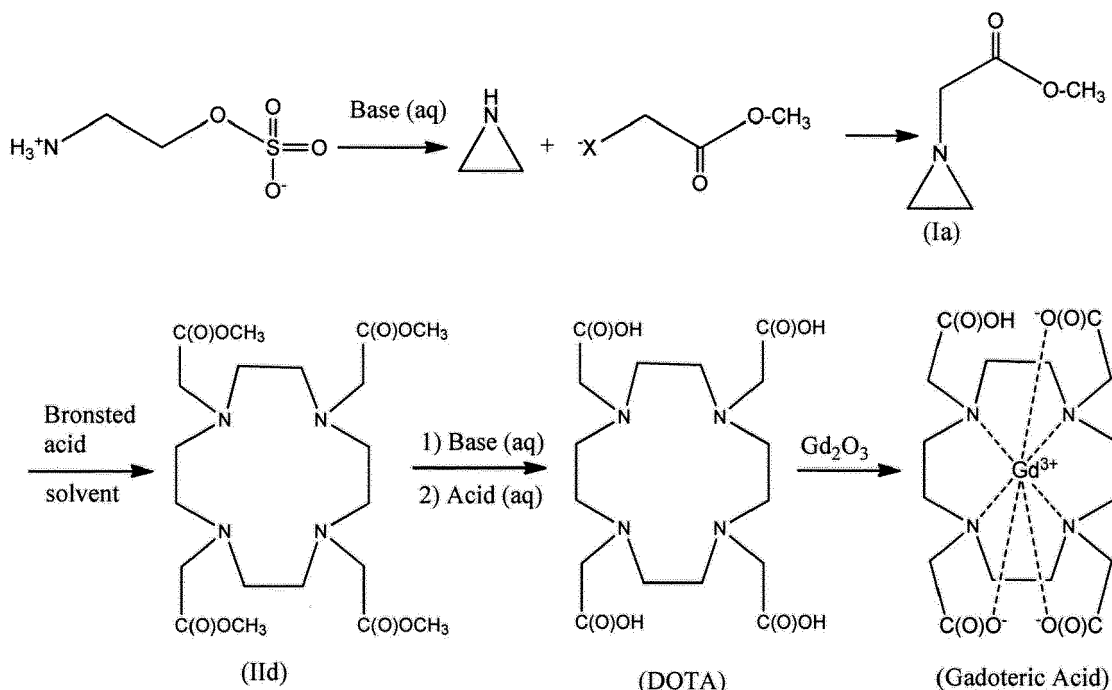
y is the number of X_2^- needed to maintain electrical neutrality of formula (IIa), optionally wherein Z_2 is sodium or potassium and X_2 is chloride or bromide.

5. The process of any one of claims 1 to 3:

i) further comprising hydrolyzing or hydrogenating Formula (II) to form 1,4,7,10-tetraaza-1,4,7,10-tetrakis(carboxymethyl)cyclododecane (DOTA), optionally further comprising treating DOTA with a metal cation, M^{n+} , wherein $n+$ is 2 or 3, provided from a metal ion source selected from the group consisting of metal oxides, metal carbonates, and weak chelates to form a metal-DOTA chelate of Formula (IIb) or Formula (IIc):



wherein the metal cation is selected from the group consisting of Gd, Eu, Tb, Dy, Sm, Lu, La, In, Ga, Re, Ru, Fe, Cu, Zn, Ni, Co, Cr, V, Ti, Sc, Zr, Nb, Mo, Rh, Pd, Ag, Cd, Sn, Hf, Ta, W, Os, Ir, Pt, Au and Y, and wherein M^{2+} coordination can occur with any two of the carboxyl moieties, for example wherein the metal ion source is a chelate of acetylacetonate or Gd_2O_3 and compound Formula (IIe) is gadoteric acid; and/or wherein ii) gadoteric acid is prepared according to the following reaction scheme:



wherein the base is a metallic base, the acid is a mineral acid and X^- is a halide; and/or wherein

iii) the solvent is selected from the group consisting of a polar aprotic solvent, a polar protic solvent, and a combination thereof wherein the solvent is a polar aprotic solvent selected from the group consisting of chloroform, dichloromethane, tetrahydrofuran, ethyl acetate, acetone, dimethylformamide, dimethylacetamide, acetonitrile, 1,4-dioxane, glyme, diglyme, dimethyl sulfoxide, propylene carbonate, and combinations thereof, and wherein the solvent is a protic solvent selected from the group consisting of methanol, ethanol, n-propanol, i-propanol, n-butanol, i-butanol, t-butanol, ethylene glycol, formic acid, water, acetic acid, and combinations thereof; and/or wherein

iv) the reaction temperature is from about -20°C to about 150°C , from about 0°C to about 100°C , from about 10°C to about 50°C , or from about 20°C to about 30°C ; and/or wherein

v) the concentration of the aziridine in the reaction mixture is from about 0.05 to about 1.0 moles per liter, from about 0.1 to about 0.5 moles per liter, or from about 0.1 to about 0.3 moles per liter; and/or wherein

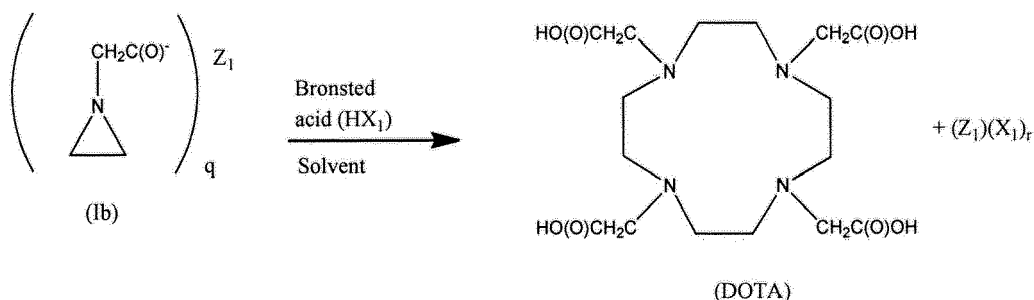
vi) further comprising purifying reaction product Formulae (II) to (IId), DOTA or gadoteric acid and isolating reaction product Formulae (II) to (IId), DOTA or gadoteric acid, optionally wherein purification is by nanofiltration and/or wherein isolation is by crystallization from aqueous solvent at a pH of from about 1 to about 4, for example wherein the reaction product is gadoteric acid and the crystallization pH is from about 2 to about 4; and/or wherein

vii) the purity of the compound Formulae (II) to (IId), DOTA or gadoteric acid is at least about 50%, at least about 60%, at least about 70%, at least about 80%, or at least about 90% as measured by MS chromatogram or evaporative light scattering (ELSD); and/or wherein

viii) the molar yield of the compound Formulae (II) to (IId), DOTA or gadoteric acid is at least about 40%, at least about 50%, at least about 60%, at least about 70%, at least about 80%, or at least about 90% based on moles of aziridine.

6. A process for the preparation of 1,4,7,10-tetraaza-1,4,7,10-tetrakis(carboxymethyl)cyclododecane (DOTA), the process comprising:

- forming a reaction mixture comprising (a) a stoichiometric amount of an aziridine of Formula (Ib), (b) a Brønsted acid, and (c) a solvent; and,
- reacting the contents of the reaction mixture to form DOTA by cyclotetramerization of the aziridine of Formula (Ib), according to the following reaction:



wherein:

15 Z₁ is an alkali metal having a +1 charge or an alkaline earth metal having a +2 charge; and
q and r are 1 when Z₁ is an alkali metal and q and r are 2 when Z₁ is an alkaline earth metal.

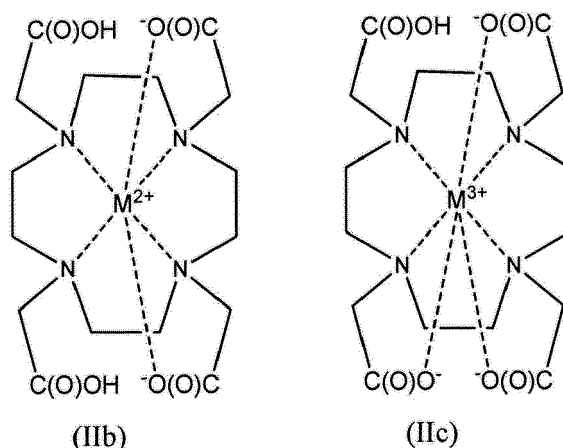
7. The process of claim 6 wherein:

20 i) the Brønsted acid is selected from the group consisting of *p*-toluenesulfonic acid, methane sulfonic acid, triflic acid, sulfuric acid, hydrochloric acid, hydroiodic acid, hydrobromic acid, hydrofluoric acid, phosphoric acid, perchloric acid, trifluoroacetic acid, triethylammonium chloride, triethylammonium bromide, triethylammonium acetate, triethylammonium formate, tris(2-hydroxyethyl)ammonium chloride, tris(2-hydroxyethyl)ammonium bromide, tris(2-hydroxyethyl)ammonium acetate, tris(2-hydroxyethyl)ammonium formate, 4,7,13,16,21,24-hexa-
25 aoxa-1,10-diazabicyclo[8.8.8]hexacosan-1-ium chloride, bromide, tris(2-hydroxyethyl)ammonium acetate, 4,7,13,16,21,24-hexa-oxa-1,10-diazabicyclo[8.8.8]hexacosan-1-ium formate, bis(isopropyl)ethylammonium chloride, bis(isopropyl)ethylammonium bromide, bis(isopropyl)ethylammonium acetate, bis(isopropyl)ethylammonium formate, tris(carboxymethyl)ammonium chloride, tris(carboxymethyl)ammonium bromide, tris(carboxymethyl)ammonium acetate, tris(carboxymethyl)ammonium formate, 2-(bis(carboxymethyl)amino)-N,N-bis(carboxymethyl)ethanaminium chloride, 2-(bis(carboxymethyl)amino)-N,N-bis(carboxymethyl)ethanaminium bromide, 2-(bis(carboxymethyl)amino)-N,N-bis(carboxymethyl)ethanaminium acetate, bis 2-(bis(carboxymethyl)amino)-N,N-bis(carboxymethyl)ethanaminium formate, 2-(bis(carboxymethyl)amino)-N-(2-(bis(carboxymethyl)amino)ethyl)-N-(carboxymethyl)ethanaminium, 2-(bis(carboxymethyl)amino)-N-(2-(bis(carboxymethyl)amino)ethyl)-N-(carboxymethyl)ethanaminium bromide, 2-(bis(carboxymethyl)amino)-N-(2-(bis(carboxymethyl)amino)ethyl)-N-(carboxymethyl)ethanaminium acetate, 2-(bis(carboxymethyl)amino)-N-(2-(bis(carboxymethyl)amino)ethyl)-N-(carboxymethyl)ethanaminium formate, formic acid, acetic acid, succinic acid, benzoic acid, lactic acid, citric acid, oxalic acid, nitriloacetic acid, ethylenediaminetetraacetic acid, diethylenetriaminepentacetic acid and combinations thereof, for example wherein the Brønsted acid is selected from the group consisting of *p*-toluenesulfonic acid, trifluoroacetic acid, hydrochloric acid and sulfuric acid; and/or wherein

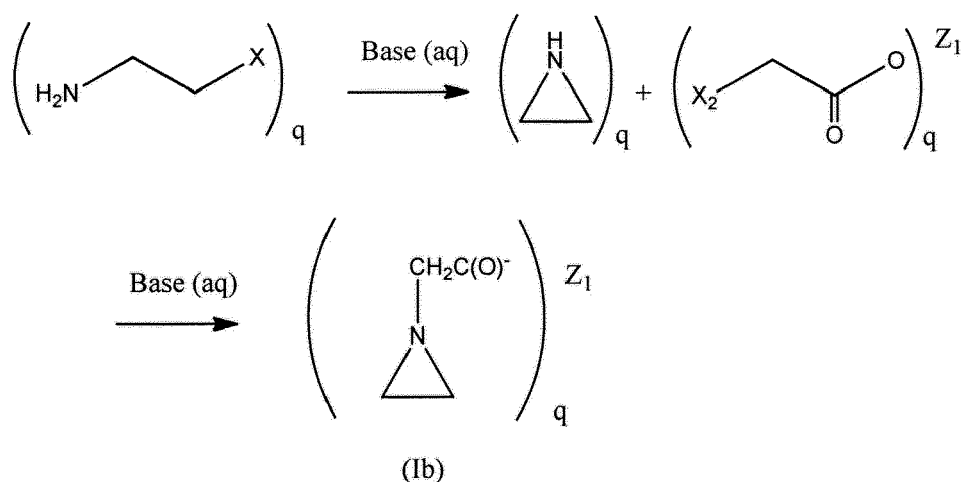
40 ii) Z₁ is Na⁺, K⁺, Ca²⁺ or Mg²⁺ and X₁ is Br⁻, Cl⁻ or OSO₃²⁻; and/or wherein

iii) the amount of the Brønsted acid, expressed as the ratio of equivalents of the acid to equivalents of aziridine, is from about 0.01:1 to about 0.5:1, from about 0.03:1 to about 0.1:1, or from about 0.04:1 to about 0.08:1; and/or

45 iv) further comprising treating DOTA with a metal cation, Mⁿ⁺, wherein n+ is 2 or 3, provided from a metal ion source selected from the group consisting of metal oxides, metal carbonates, and weak chelates to form a metal-DOTA chelate of Formula (IIb) or Formula (IIc):



wherein the metal cation is selected from the group consisting of Gd, Eu, Tb, Dy, Sm, Lu, La, In, Ga, Re, Ru, Fe, Cu, Zn, Ni, Co, Cr, V, Ti, Sc, Zr, Nb, Mo, Rh, Pd, Ag, Cd, Sn, Hf, Ta, W, Os, Ir, Pt, Au and Y, and wherein M²⁺ coordination can occur with any two of the carboxyl moieties, optionally wherein the metal ion source is a chelate of acetylacetonate or Gd₂O₃ and compound Formula (IIc) is gadoteric acid; and/or wherein v) the solvent comprises water, optionally wherein the solvent consists essentially of water; and/or wherein vi) aziridine Formula (Ib) is prepared according to the following reaction scheme:



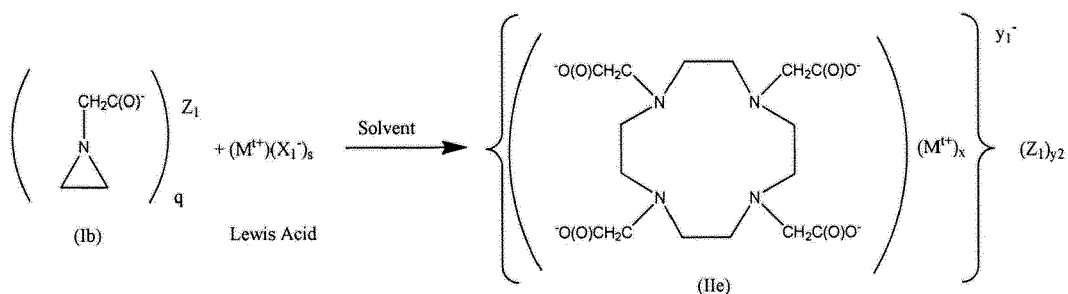
wherein X is a leaving group, X₂ is a halide, Z₁ is an alkali metal having a +1 charge or an alkaline earth metal having a +2 charge, q is 1 when Z₁ has a +1 charge, and q is 2 when Z₁ has a +2 charge, optionally wherein X is Cl, Br or OSO₃⁻, the base is NaOH or KOH and Z₁ is Na⁺, K⁺, Ca²⁺ or Mg²⁺; and/or wherein vii) the reaction temperature is from about -20°C to about 150°C, from about 0°C to about 100°C, from about 10°C to about 50°C, or from about 20°C to about 30°C; and/or wherein viii) the concentration of the aziridine in the reaction mixture is from about 0.05 to about 1.0 equivalents per liter, from about 0.1 to about 0.5 equivalents per liter, or from about 0.1 to about 0.3 equivalents per liter.

8. The process of claim 6 or claim 7 further comprising purifying reaction product Formula (IIb), Formula (IIc), DOTA or gadoteric acid and isolating reaction product Formula (IIb), Formula (IIc), DOTA or gadoteric acid, optionally wherein purification is by nanofiltration, for example wherein the gadoteric acid is nanofiltered as the meglumine salt thereof or wherein the DOTA is nanofiltered as the sodium salt thereof.
9. The process of claim 8 wherein isolation is by crystallization from aqueous solvent at a pH of from about 1 to about 4, optionally wherein the reaction product is gadoteric acid and the crystallization pH is from about 2 to about 4.
10. The process of any one of claims 6 to 9 wherein the purity of the compound Formula (IIb), Formula (IIc), DOTA or gadoteric acid is at least about 50%, at least about 60%, at least about 70%, at least about 80%, or at least about

90% as measured by MS chromatogram and/or wherein the molar yield of the compound Formula (IIb), Formula (IIC), DOTA or gadoteric acid is at least about 40%, at least about 50%, at least about 60%, at least about 70%, at least about 80%, or at least about 90% based on equivalents of aziridine.

11. A process for the preparation of a macrocyclic tetramer compound of Formula (IIe), the process comprising:

- (i) forming a reaction mixture comprising (a) a stoichiometric amount of an aziridine of Formula (Ib), (b) a Lewis acid, and (c) a solvent; and,
- (ii) reacting the contents of the reaction mixture to form a metal-1,4,7,10-tetraaza-1,4,7,10-tetrakis(carboxymethyl)cyclododecane (DOTA) chelate of Formula (IIe) by cyclotetramerization of the aziridine of Formula (Ib), according to the following reaction:



wherein:

$(M^{t+})(X_1^{-})_s$ is a chelatable Lewis acid metal salt formed from a cation, M, and an anion, X_1^{-} , wherein t is 1, 2 or 3 and s is selected to achieve electrical neutrality;

Z_1 is hydrogen, an alkali metal having a +1 charge or an alkaline earth metal having a +2 charge;

q is 1 when Z_1 is an alkali metal and q is 2 when Z_1 is an alkaline earth metal; and

t is 3 and x is 1, or t is 2 and x is 1, or t is 2 and x is 2, or t is 1 and x is 1, or t is 1 and x is 2, or t is 1 and x is 3 or t is 1 and x is 4, wherein:

(a) $y_1 = y_2 = (4 - (X^*t))$ when Z_1 has a +1 charge, and

(b) $y_1 = (4 - (X^*t))$ and $y_2 = (y_1/2)$ when Z_1 has a +2 charge according to the following table

		$Z_1 = +1$	$Z_2 = +2$	
t	X	y_1 and y_2	y_1	y_2
3	1	1	1	$\frac{1}{2}$
2	1	2	2	1
2	2	0	0	0
1	1	3	3	$\frac{3}{2}$
1	2	2	2	1
1	3	1	1	$\frac{1}{2}$
1	4	0	0	0

12. The process of claim 11 wherein:

- i) the Lewis acid is selected from the group consisting of boron tribromide, boron trichloride, boron trifluoride, boron trifluoride etherate, gadolinium tribromide, gadolinium trichloride, gadolinium trifluoride, gadolinium acetate, gadolinium formate, cupric bromide, cupric chloride, cupric fluoride, nickel bromide, nickel chloride, nickel fluoride, aluminum bromide, aluminum chloride, aluminum fluoride, ferric bromide, ferric chloride, ferric fluoride, sodium bromide, potassium bromide, potassium chloride, potassium fluoride, sodium chloride, sodium fluoride,

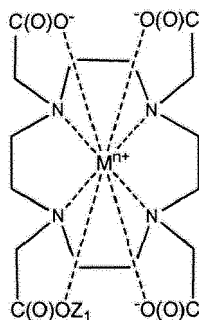
tin(IV) chloride, and combinations thereof; and/or wherein

ii) the amount of the Lewis acid, expressed as the ratio of equivalents of the acid to equivalents of aziridine compound, is from about 0.05:1 to about 1.5:1, from about 0.05:1 to about 1.2:1, or from about 0.5:1 to about 1.2:1; and/or wherein

iii) the ratio of Lewis acid, expressed as the ratio of equivalents of the acid to equivalents of aziridine compound, is from about 0.05:1 to about 0.5:1 or from about 0.1:1 to about 0.5:1; and/or wherein

iv) the ratio of Lewis acid, expressed as the ratio of equivalents of the acid to equivalents of aziridine compound, is from about 1.0:1 to about 1.5:1 or from about 1.0:1 to about 1.2:1; and/or wherein

v) Formula (Ile) is of Formula (Ilf):



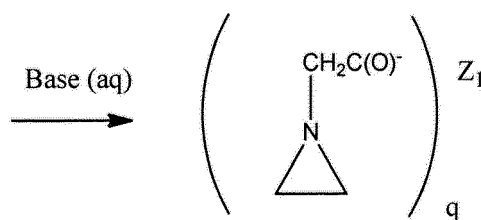
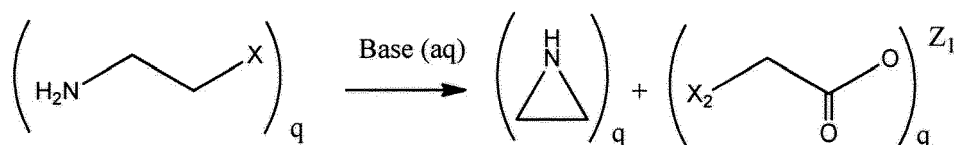
(Ilf)

wherein n is 3 and Z_1 is hydrogen or an alkali metal having a +1 charge, optionally

wherein Formula (Ilf) is gadoteric acid wherein M^{n+} is Gd^{3+} and Z_1 is hydrogen; and/or wherein

vi) the solvent comprises water, optionally wherein the solvent consists essentially of water; and/or wherein

vii) aziridine Formula (Ib) is prepared according to the following reaction scheme:



(Ib)

wherein X is a leaving group, X_2 is a halide, Z_1 is an alkali metal having a +1 charge or an alkaline earth metal having a +2 charge, q is 1 when Z_1 has a +1 charge, and q is 2 when Z_1 has a +2 charge, optionally

wherein X is Cl, Br or OSO_3^- , the base is NaOH or KOH and Z_1 is Na^+ , K^+ , Ca^{2+} or Mg^{2+} ; and/or wherein

viii) the reaction temperature is from about -20°C to about 150°C , from about 0°C to about 100°C , from about 10°C to about 50°C , or from about 20°C to about 30°C ; and/or wherein

ix) the concentration of the aziridine in the reaction mixture is from about 0.05 to about 1.0 equivalents per liter, from about 0.1 to about 0.5 equivalents per liter, or from about 0.1 to about 0.3 equivalents per liter.

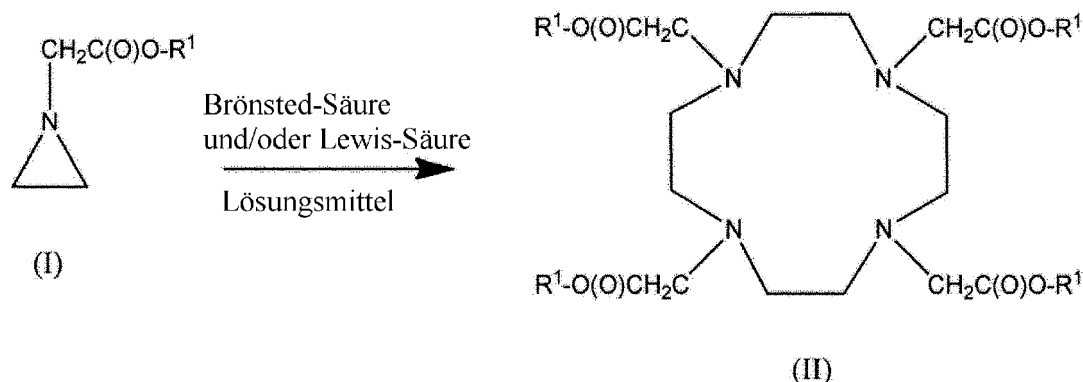
13. The process of claim 11 or claim 12 further comprising purifying and isolating reaction product Formula (Ile), Formula (Ilf) or gadoteric acid, optionally wherein purification is by nanofiltration, for example wherein the gadoteric acid is nanofiltered as the meglumine salt thereof or wherein the DOTA is nanofiltered as the sodium salt thereof.

14. The process of claim 13 wherein isolation is by crystallization from aqueous solvent at a pH of from about 1 to about 4, optionally wherein the reaction product is gadoteric acid and the crystallization pH is from about 2 to about 4.
15. The process of any one of claims 11 to 14 wherein the purity of the compound Formula (Ile), Formula (Ilf) or gadoteric acid is at least about 50%, at least about 60%, at least about 70%, at least about 80%, or at least about 90% as measured by MS chromatogram and/or wherein the molar yield of the compound Formula (Ile), Formula (Ilf) or gadoteric acid is at least about 40%, at least about 50%, at least about 60%, at least about 70%, at least about 80%, or at least about 90% based on equivalents of aziridine.

Patentansprüche

1. Verfahren zur Herstellung einer makrocyclischen Tetramerverbindung der Formel (II), wobei man:

- (i) eine Reaktionsmischung bildet, die eine stöchiometrische Menge von (a) einem Aziridin der Formel (I), (b) eine Brönsted-Säure, eine Lewis-Säure oder eine Kombination einer Brönsted-Säure und einer Lewis-Säure und (c) ein Lösungsmittel umfasst; und
- (ii) den Inhalt der Reaktionsmischung zur Reaktion bringt, was durch Cyclotetramerisierung des Aziridins der Formel (I) gemäß der folgenden Reaktion die Verbindung der Formel (II) ergibt:



wobei:

R^1 jeweils unabhängig aus der Gruppe bestehend aus C_{1-10} -Hydrocarbyl ausgewählt ist.

2. Verfahren nach Anspruch 1, wobei:

- i) R^1 jeweils unabhängig aus Methyl, Ethyl, 2-Propyl und Benzyl ausgewählt ist; und/oder
- ii) es sich bei der Säure um eine Brönsted-Säure aus der Gruppe bestehend aus *p*-Toluolsulfonsäure, Methansulfonsäure, Trifluormethansulfonsäure, Schwefelsäure, Salzsäure, Iodwasserstoffsäure, Bromwasserstoffsäure, Fluorwasserstoffsäure, Phosphorsäure, Perchlorsäure, Trifluoressigsäure, Triethylammoniumchlorid, Triethylammoniumbromid, Triethylammoniumacetat, Triethylammoniumformiat, Tris(2-hydroxyethyl)ammoniumchlorid, Tris(2-hydroxyethyl)ammoniumbromid, Tris(2-hydroxyethyl)ammoniumacetat, Tris(2-hydroxyethyl)ammoniumformiat, 4,7,13,16,21,24-Hexaoxa-1,10-diaza-bicyclo[8.8.8]hexacosan-1-iumchlorid, Bromid, Tris(2-hydroxyethyl)ammoniumacetat, 4,7,13,16,21,24-Hexaoxa-1,10-diazabicyclo[8.8.8]-hexacosan-1-iumformiat, Bis(isopropyl)ethyl-ammoniumchlorid, Bis(isopropyl)ethylammonium-bromid, Bis(isopropyl)ethylammoniumacetat, Bis-(isopropyl)ethylammoniumformiat, Tris(carboxymethyl)ammoniumchlorid, Tris(carboxymethyl)-ammoniumbromid, Tris(carboxymethyl)ammoniumacetat, Tris(carboxymethyl)ammoniumformiat, 2-(Bis-(carboxymethyl)amino)-N,N-bis(carboxymethyl)ethan-aminiumchlorid, 2-(Bis(carboxymethyl)amino)-N,N-bis(carboxymethyl)ethanaminiumbromid, 2-(Bis-(carboxymethyl)amino)-N,N-bis(carboxymethyl)ethanaminiumacetat, Bis-2-(bis(carboxymethyl)amino)-N,N-bis(carboxymethyl)ethanaminiumformiat, 2-(Bis(carboxymethyl)amino)-N-(2-(bis(carboxymethyl)amino)ethyl)-N-(carboxymethyl)ethanaminium, 2-(Bis(carboxymethyl)amino)-N-(2-(bis(carboxymethyl)amino)ethyl)-N-(carboxymethyl)ethanaminium-bromid, 2-(Bis(carboxymethyl)amino)-N-(2-(bis(carboxymethyl)amino)ethyl)-N-(carboxymethyl)-ethanaminiumacetat, 2-(Bis(carboxymethyl)amino)-N-(2-(bis(carboxymethyl)amino)ethyl)-N-(carboxymethyl)ethanaminiumformiat, Ameisen-

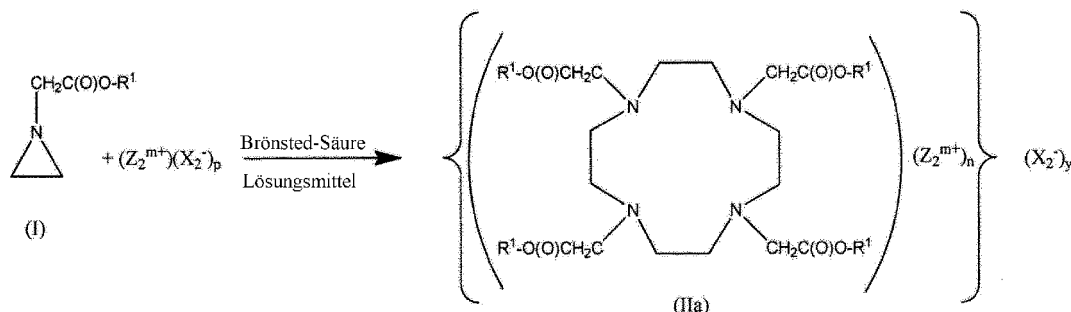
säure, Essigsäure, Bernsteinsäure, Benzoesäure, Milchsäure, Citronensäure, Oxalsäure, Nitriloessigsäure, Ethylendiamintetraessigsäure, Diethylentriaminpentaessigsäure und Kombinationen davon handelt, beispielsweise wobei die Brönsted-Säure aus der Gruppe bestehend aus *p*-Toluolsulfonsäure, Trifluoressigsäure, Salzsäure und Schwefelsäure ausgewählt wird, und/oder wobei die Menge der Brönsted-Säure, ausgedrückt als das Verhältnis von Äquivalenten der Säure zu Molen Aziridin etwa 0,01 : 1 bis etwa 0,5 : 1, etwa 0,03 : 1 bis etwa 0,1 : 1 oder etwa 0,04:1 bis etwa 0,08:1 beträgt.

3. Verfahren nach Anspruch 1, wobei es sich bei der Säure um ein chelatisierbares Lewis-Säure-Metallsalz aus einem Metallkation M und einem Gegenion handelt, wobei M aus einem Alkalimetall, einem Erdalkalimetall, einem Seltenerdmetall, einem Übergangsmetall und einem Lanthanidmetall ausgewählt ist, beispielsweise wobei die Lewis-Säure aus der Gruppe bestehend aus Bortribromid, Bortrichlorid, Bortrifluorid, Bortrifluoridetherat, Gadoliniumtribromid, Gadoliniumtrichlorid, Gadoliniumtrifluorid, Gadoliniumacetat, Gadoliniumformiat, Kupfer(II)-bromid, Kupfer(II)-chlorid, Kupfer(II)-fluorid, Nickelbromid, Nickelchlorid, Nickelfluorid, Aluminiumbromid, Aluminiumchlorid, Aluminiumfluorid, Eisen(III)-bromid, Eisen(III)-chlorid, Eisen(III)-fluorid, Natriumbromid, Kaliumbromid, Kaliumchlorid, Kaliumfluorid, Natriumchlorid, Natriumfluorid, Zinn(IV)-chlorid und Kombinationen davon ausgewählt wird, und/oder wobei:

- i) die Menge der Lewis-Säure, ausgedrückt als das Verhältnis von Äquivalenten der Säure zu Molen Aziridinverbindung, etwa 0,05:1 bis etwa 1,5:1, etwa 0,05:1 bis etwa 1,2:1 oder etwa 0,5:1 bis etwa 1,2:1 beträgt;
 ii) das Verhältnis von Lewis-Säure, ausgedrückt als das Verhältnis von Äquivalenten der Säure zu Molen Aziridinverbindung, etwa 0,05:1 bis etwa 0,5:1 oder etwa 0,1:1 bis etwa 0,5:1 beträgt; und/oder
 iii) das Verhältnis von Lewis-Säure, ausgedrückt als das Verhältnis von Äquivalenten der Säure zu Molen Aziridinverbindung, etwa 1,0:1 bis etwa 1,5:1 oder etwa 1,0:1 bis etwa 1,2:1 beträgt.

4. Verfahren nach Anspruch 1 oder Anspruch 2, wobei:

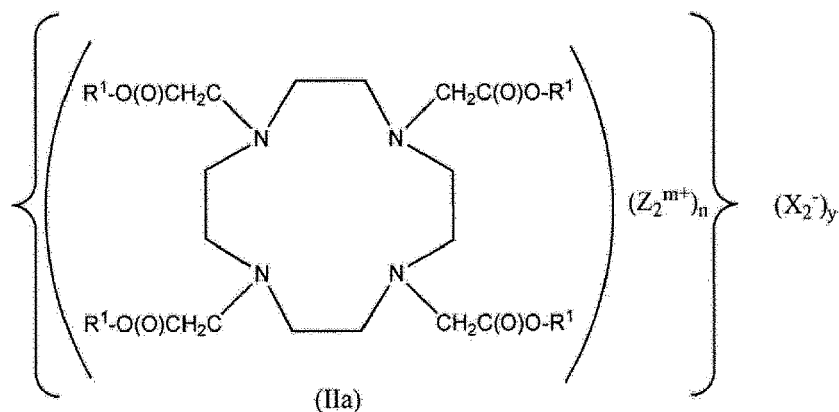
- i) es sich bei der Säure um eine Brönsted-Säure handelt und die Reaktionsmischung ferner ein Alkalimetallsalz, $(Z_2^{m+})(X_2^-)_p$, umfasst, wobei Formel (IIa) durch Cyclotetramerisierung des Aziridins der Formel (I) gemäß der folgenden Reaktion gebildet wird:



wobei:

- Z_2^{m+} für ein Gegenion aus der Gruppe bestehend aus einem Wasserstoffion, einem tertiären Ammoniumion, einem Alkalimetallion und einem Erdalkalimetall steht, wobei $m+$ für 1 oder 2 steht;
 X_2^- aus der Gruppe bestehend aus Halogenid, *p*-Toluolsulfonat und Trifluoracetat ausgewählt ist;
 p für die Zahl von X_2^- steht, die zur Aufrechterhaltung der elektrischen Neutralität mit Z_2^{m+} erforderlich ist, und aus 1 und 2 ausgewählt ist;
 n für eine ganze Zahl von 0 bis 4 steht; und
 y für die Zahl von X_2^- steht, die zur Aufrechterhaltung der elektrischen Neutralität der Formel (IIa) erforderlich ist, wobei gegebenenfalls Z_2 für Natrium oder Kalium steht und X_2^- für Chlorid oder Bromid steht; oder

- ii) es sich bei der Säure um eine Brönsted-Säure handelt und man bei dem Verfahren ferner Formel (II) mit einem Alkalimetallsalz, $(Z_2^{m+})(X_2^-)_p$, in Berührung bringt, was Formel (IIa) ergibt:



wobei:

Z_2^{m+} für ein Gegenion aus der Gruppe bestehend aus einem Wasserstoffion, einem tertiären Ammoniumion, einem Alkalimetallion und einem Erdalkalimetall steht, wobei $m+$ für 1 oder 2 steht;

X_2^- aus der Gruppe bestehend aus Halogenid, *p*-Toluolsulfonat und Trifluoracetat ausgewählt ist;

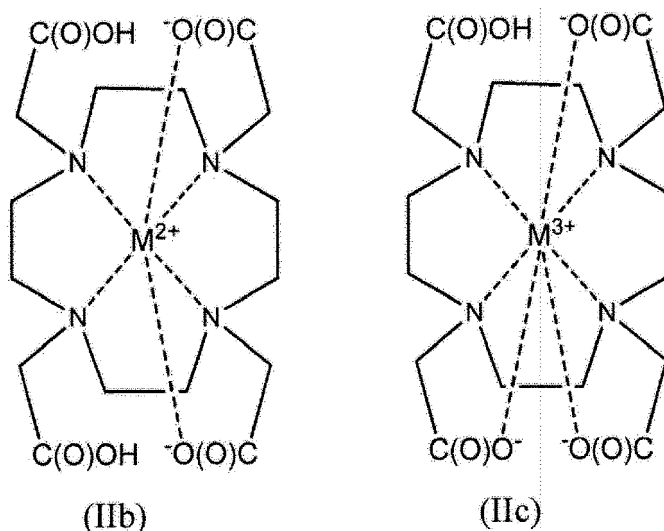
p für die Zahl von X_2^- steht, die zur Aufrechterhaltung der elektrischen Neutralität mit Z_2^{m+} erforderlich ist, und aus 1 und 2 ausgewählt ist;

n für eine ganze Zahl von 0 bis 4 steht; und

y für die Zahl von X_2^- steht, die zur Aufrechterhaltung der elektrischen Neutralität der Formel (IIa) erforderlich ist, wobei gegebenenfalls Z_2 für Natrium oder Kalium steht und X_2 für Chlorid oder Bromid steht.

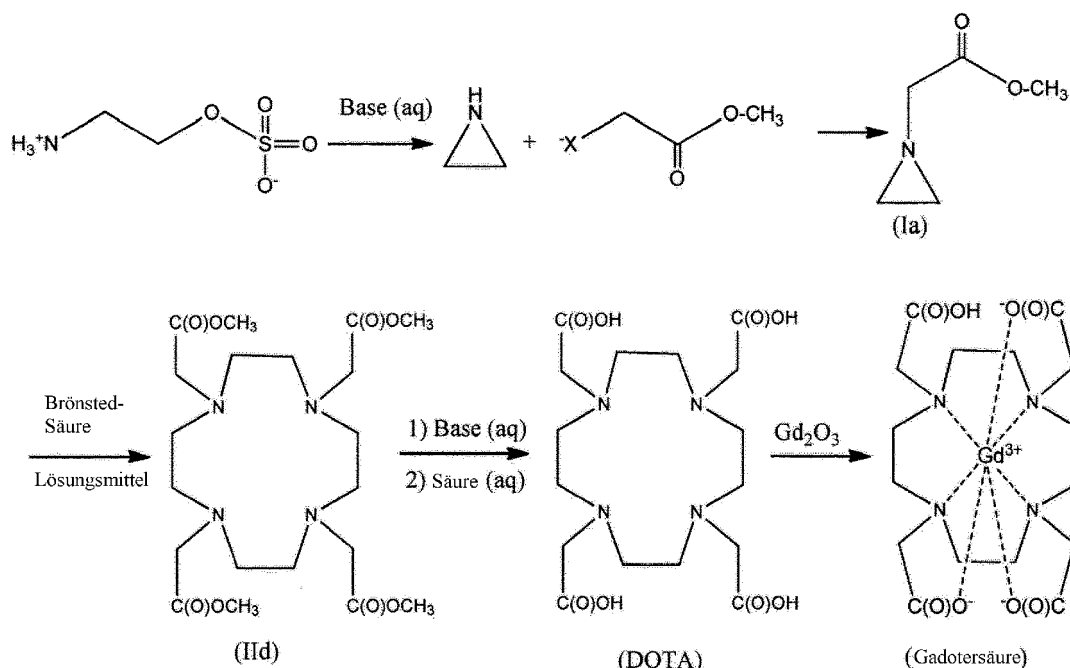
5. Verfahren nach einem der Ansprüche 1 bis 3,

i) wobei ferner Formel (II) zu 1,4,7,10-Tetraaza-1,4,7,10-tetrakis(carboxymethyl)cyclododecan (DOTA) hydrolysiert oder hydriert wird, wobei gegebenenfalls ferner DOTA mit einem Metallkation, M^{n+} , wobei $n+$ für 2 oder 3 steht, behandelt wird, welches aus einer Metallionenquelle aus der Gruppe bestehend aus Metalloxiden, Metallcarbonaten und schwachen Chelaten bereitgestellt wird, was ein Metall-DOTA-Chelat der Formel (IIb) oder (IIc) ergibt:



wobei das Metallkation aus der Gruppe bestehend aus Gd, Eu, Tb, Dy, Sm, Lu, La, In, Ga, Re, Ru, Fe, Cu, Zn, Ni, Co, Cr, V, Ti, Sc, Zr, Nb, Mo, Rh, Pd, Ag, Cd, Sn, Hf, Ta, W, Os, Ir, Pt, Au and Y ausgewählt wird und wobei die M^{2+} -Koordination mit zwei beliebigen der Carboxylgruppierungen erfolgen kann, beispielsweise wobei es sich bei der Metallionenquelle um ein Chelat von Acetylacetonat oder Gd_2O_3 handelt und es sich bei der Verbindung der Formel (IIc) um Gadotersäure handelt; und/oder wobei

ii) Gadotersäure gemäß dem folgenden Reaktionsschema hergestellt wird:



wobei sich bei der Base um eine Metallbase handelt, es sich bei der Säure um eine Mineralsäure handelt und X^- für ein Halogenid steht; und/oder wobei

iii) das Lösungsmittel aus der Gruppe bestehend aus einem polaren aprotischen Lösungsmittel, einem polaren protischen Lösungsmittel und einer Kombination davon ausgewählt wird, wobei es sich bei dem Lösungsmittel um ein polares aprotisches Lösungsmittel aus der Gruppe bestehend aus Chloroform, Dichlormethan, Tetrahydrofuran, Essigsäureethylester, Aceton, Dimethylformamid, Dimethylacetamid, Acetonitril, 1,4-Dioxan, Glyme, Diglyme, dimethylsulfoxid, Propylencarbonat und Kombinationen davon handelt und wobei es sich bei dem Lösungsmittel um ein protisches Lösungsmittel aus der Gruppe bestehend aus Methanol, Ethanol, n-Propanol, i-Propanol, n-Butanol, i-Butanol, t-Butanol, Ethylenglykol, Ameisensäure, Wasser, Essigsäure und Kombinationen davon handelt; und/oder wobei

iv) die Reaktionstemperatur etwa -20°C bis etwa 150°C , etwa 0°C bis etwa 100°C , etwa 10°C bis etwa 50°C oder etwa 20°C bis etwa 30°C beträgt; und/oder wobei

v) die Konzentration des Aziridins in der Reaktionsmischung etwa 0,05 bis etwa 1,0 mol pro Liter, etwa 0,1 bis etwa 0,5 mol pro Liter oder etwa 0,1 bis etwa 0,3 mol pro Liter beträgt; und/oder wobei

vi) ferner Reaktionsprodukt der Formeln (II) bis (IIId), DOTA oder Gadotersäure gereinigt und Reaktionsprodukt der Formeln (II) bis (IIId), DOTA oder Gadotersäure isoliert wird, gegebenenfalls wobei die Reinigung durch Nanofiltration erfolgt und/oder wobei die Isolierung durch Kristallisation aus wässrigem Lösungsmittel bei einem pH-Wert von etwa 1 bis etwa 4 erfolgt, beispielsweise wobei es sich bei dem Reaktionsprodukt um Gadotersäure handelt und der pH-Wert der Kristallisation etwa 2 bis etwa 4 beträgt; und/oder wobei

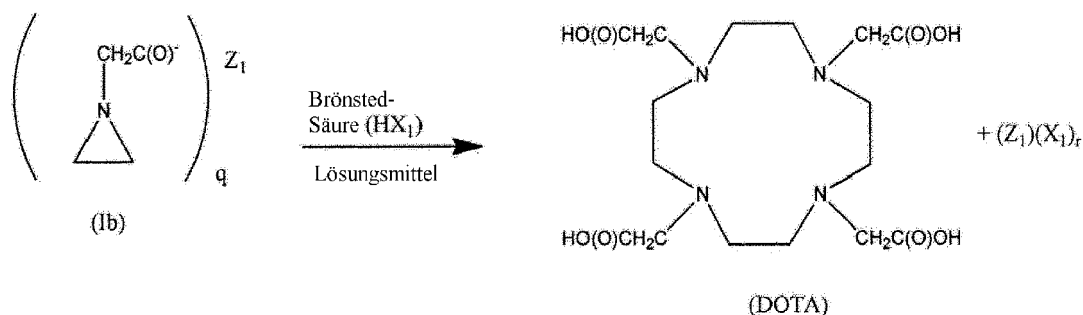
vii) die Reinheit der Verbindung der Formeln (II) bis (IIId), des DOTA oder der Gadotersäure gemäß Messung mittels MS-Chromatogramm oder evaporativer Lichtstreuung (ELSD) mindestens etwa 50%, mindestens etwa 60%, mindestens etwa 70%, mindestens etwa 80% oder mindestens etwa 90% beträgt; und/oder wobei

viii) die molare Ausbeute der Verbindung der Formeln (II) bis (IIId), des DOTA oder der Gadotersäure mindestens etwa 40%, mindestens etwa 50%, mindestens etwa 60%, mindestens etwa 70%, mindestens etwa 80% oder mindestens etwa 90%, bezogen auf Mole Aziridin, beträgt.

6. Verfahren zur Herstellung von 1,4,7,10-Tetraaza-1,4,7,10-tetrakis(carboxymethyl)cyclododecan (DOTA), wobei man:

(i) eine Reaktionsmischung bildet, die (a) eine stöchiometrische Menge von einem Aziridin der Formel (Ib), (b) eine Brønsted-Säure und (c) ein Lösungsmittel umfasst; und

(ii) den Inhalt der Reaktionsmischung zur Reaktion bringt, was durch Cyclotetramerisierung des Aziridins der Formel (Ib) gemäß der folgenden Reaktion DOTA ergibt:

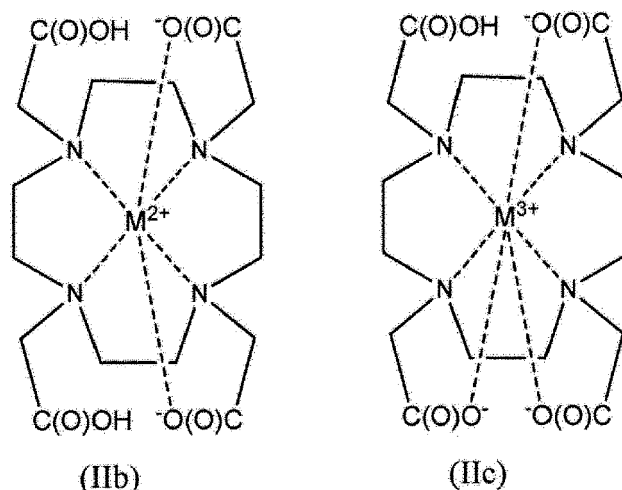


wobei:

15 Z₁ für ein Alkalimetall mit der Ladung +1 oder ein Erdalkalimetall mit der Ladung +2 steht; und q und r für 1 stehen, wenn Z₁ für ein Alkalimetall steht, und q und r für 2 stehen, wenn Z₁ für ein Erdalkalimetall steht.

7. Verfahren nach Anspruch 6, wobei:

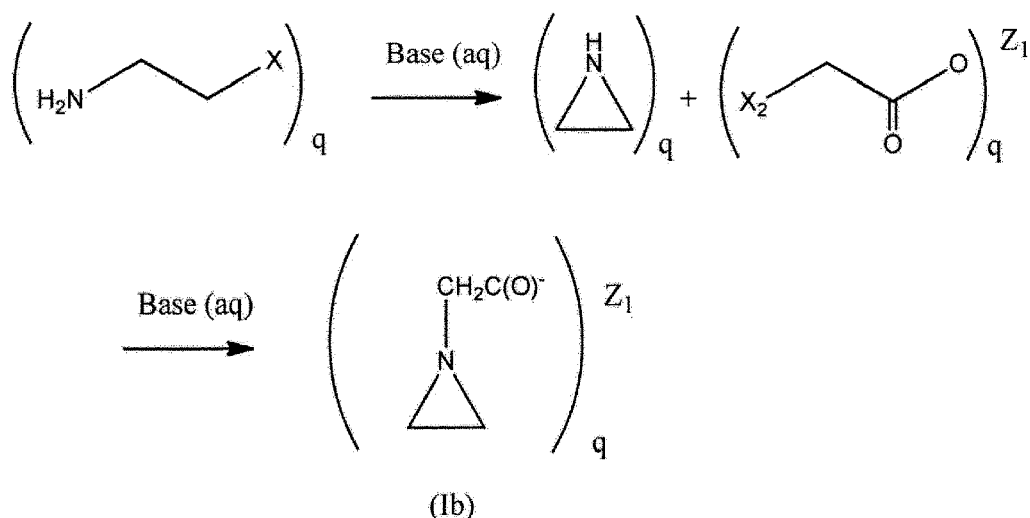
- 20 i) die Brönsted-Säure aus der Gruppe bestehend aus *p*-Toluolsulfonsäure, Methansulfonsäure, Trifluormethansulfonsäure, Schwefelsäure, Salzsäure, Iodwasserstoffsäure, Bromwasserstoffsäure, Fluorwasserstoffsäure, Phosphorsäure, Perchlorsäure, Trifluoressigsäure, Triethylammoniumchlorid, Triethylammoniumbromid, Triethylammoniumacetat, Triethylammoniumformiat, Tris(2-hydroxyethyl)-ammoniumchlorid, Tris(2-hydroxyethyl)ammonium-bromid, Tris(2-hydroxyethyl)ammoniumacetat, Tris-(2-hydroxyethyl)ammoniumformiat, 4,7,13,16,21,24-Hexaoxa-1,10-diazabicyclo[8.8.8]hexacosan-1-ium-chlorid, Bromid, Tris(2-hydroxyethyl)ammonium-acetat, 4,7,13,16,21,24-Hexaoxa-1,10-diazabicyclo-[8.8.8]hexacosan-1-iumformiat, Bis(isopropyl)-ethylammoniumchlorid, Bis(isopropyl)ethylammonium-bromid, Bis(isopropyl)ethylammoniumacetat, Bis-(isopropyl)ethylammoniumformiat, Tris(carboxymethyl)ammoniumchlorid, Tris(carboxymethyl)-ammoniumbromid, Tris(carboxymethyl)ammoniumacetat, Tris(carboxymethyl)ammoniumformiat, 2-(Bis-(carboxymethyl)amino)-N,N-bis(carboxymethyl)ethan-aminiumchlorid, 2-(Bis(carboxymethyl)amino)-N,N-bis(carboxymethyl)ethanaminiumbromid, 2-(Bis-(carboxymethyl)amino)-N,N-bis(carboxymethyl)ethanaminiumacetat, Bis-2-(bis(carboxymethyl)amino)-N,N-bis(carboxymethyl)ethanaminiumformiat, 2-(Bis-(carboxymethyl)amino)-N-(2-(bis(carboxymethyl)amino)ethyl)-N-(carboxymethyl)ethanaminium, 2-(Bis(carboxymethyl)amino)-N-(2-(bis(carboxymethyl)amino)ethyl)-N-(carboxymethyl)ethanaminium-bromid, 2-(Bis(carboxymethyl)amino)-N-(2-(bis(carboxymethyl)amino)ethyl)-N-(carboxymethyl)-ethanaminiumacetat, 2-(Bis(carboxymethyl)amino)-N-(2-(bis(carboxymethyl)amino)ethyl)-N-(carboxymethyl)ethanaminiumformiat, Ameisensäure, Essigsäure, Bernsteinsäure, Benzoesäure, Milchsäure, Citronensäure, Oxalsäure, Nitriloessigsäure, Ethylen-diamintetraessigsäure, Diethylentriaminpentaessigsäure und Kombinationen davon ausgewählt wird, beispielsweise wobei die Brönsted-Säure aus der Gruppe bestehend aus *p*-Toluolsulfonsäure, Trifluoressigsäure, Salzsäure und Schwefelsäure ausgewählt wird; und/oder wobei
- 35 ii) Z₁ für Na⁺, K⁺, Ca²⁺ oder Mg²⁺ steht und X₁ für Br⁻, Cl⁻ oder OSO₃²⁻ steht; und/oder wobei
- iii) die Menge der Brönsted-Säure, ausgedrückt als das Verhältnis von Äquivalenten der Säure zu Äquivalenten Aziridin, etwa 0,01:1 bis etwa 0,5:1, etwa 0,03:1 bis etwa 0,1:1 oder etwa 0,04:1 bis etwa 0,08:1 beträgt; und/oder
- 40 iv) wobei ferner DOTA mit einem Metallkation, Mⁿ⁺, wobei n+ für 2 oder 3 steht, behandelt wird, welches aus einer Metallionenquelle aus der Gruppe bestehend aus Metalloxiden, Metallcarbonaten und schwachen Chelaten bereitgestellt wird, was ein Metall-DOTA-Chelat der Formel (IIb) oder (IIc) ergibt:



wobei das Metallkation aus der Gruppe bestehend aus Gd, Eu, Tb, Dy, Sm, Lu, La, In, Ga, Re, Ru, Fe, Cu, Zn, Ni, Co, Cr, V, Ti, Sc, Zr, Nb, Mo, Rh, Pd, Ag, Cd, Sn, Hf, Ta, W, Os, Ir, Pt, Au and Y ausgewählt wird und wobei die M^{2+} -Koordination mit zwei beliebigen der Carboxylgruppierungen erfolgen kann, gegebenenfalls wobei es sich bei der Metallionenquelle um ein Chelat von Acetylacetonat oder Gd_2O_3 handelt und es sich bei der Verbindung der Formel (IIc) um Gadotersäure handelt; und/oder wobei

v) das Lösungsmittel Wasser umfasst, wobei das Lösungsmittel gegebenenfalls im Wesentlichen aus Wasser besteht; und/oder wobei

vi) das Aziridin der Formel (Ib) gemäß dem folgenden Reaktionsschema hergestellt wird:



wobei X für eine Abgangsgruppe steht, X_2 für ein Halogenid steht, Z_1 für ein Alkalimetall mit der Ladung +1 oder ein Erdalkalimetall mit der Ladung +2 steht, q für 1 steht, wenn Z_1 die Ladung +1 aufweist, und q für 2 steht, wenn Z_1 die Ladung +2 aufweist, gegebenenfalls wobei X für Cl, Br oder OSO_3^- steht, es sich bei der Base um NaOH oder KOH handelt und Z_1 für Na^+ , K^+ , Ca^{2+} oder Mg^{2+} steht; und/oder wobei

vii) die Reaktionstemperatur etwa $-20^\circ C$ bis etwa $150^\circ C$, etwa $0^\circ C$ bis etwa $100^\circ C$, etwa $10^\circ C$ bis etwa $50^\circ C$ oder etwa $20^\circ C$ bis etwa $30^\circ C$ beträgt; und/oder wobei

viii) die Konzentration des Aziridins in der Reaktionsmischung etwa 0,05 bis etwa 1,0 Äquivalente pro Liter, etwa 0,1 bis etwa 0,5 Äquivalente pro Liter oder etwa 0,1 bis etwa 0,3 Äquivalente pro Liter beträgt.

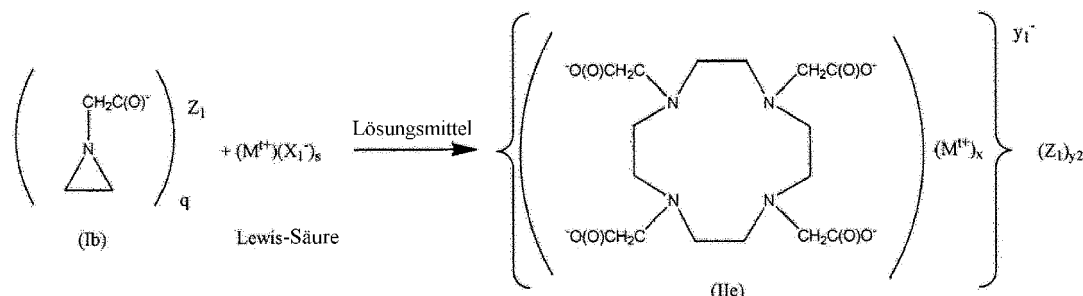
8. Verfahren nach Anspruch 6 oder Anspruch 7, wobei ferner Reaktionsprodukt der Formel (IIb), Formel (IIc), DOTA oder Gadotersäure gereinigt und Reaktionsprodukt der Formel (IIb), Formel (IIc), DOTA oder Gadotersäure isoliert wird, gegebenenfalls wobei die Reinigung durch Nanofiltration erfolgt, beispielsweise wobei die Gadotersäure als Meglumin-Salz davon nanofiltriert wird oder wobei das DOTA als Natriumsalz davon nanofiltriert wird.

9. Verfahren nach Anspruch 8, wobei die Isolierung durch Kristallisation aus wässrigem Lösungsmittel bei einem pH-Wert von etwa 1 bis etwa 4 erfolgt, gegebenenfalls wobei es sich bei dem Reaktionsprodukt um Gadotersäure handelt und der pH-Wert der Kristallisation etwa 2 bis etwa 4 beträgt.

10. Verfahren nach einem der Ansprüche 6 bis 9, wobei die Reinheit der Verbindung der Formel (IIb), Formel (IIc), des DOTA oder der Gadotersäure gemäß Messung mittels MS-Chromatogramm mindestens etwa 50%, mindestens etwa 60%, mindestens etwa 70%, mindestens etwa 80% oder mindestens etwa 90% beträgt und/oder wobei die molare Ausbeute der Verbindung der Formel (IIb), Formel (IIc), des DOTA oder der Gadotersäure mindestens etwa 40%, mindestens etwa 50%, mindestens etwa 60%, mindestens etwa 70%, mindestens etwa 80% oder mindestens etwa 90%, bezogen auf Äquivalente Aziridin, beträgt.

11. Verfahren zur Herstellung einer makrocyclischen Tetramerverbindung der Formel (IIe), wobei man:

- (i) eine Reaktionsmischung bildet, die (a) eine stöchiometrische Menge von einem Aziridin der Formel (Ib), (b) eine Lewis-Säure und (c) ein Lösungsmittel umfasst; und
(ii) den Inhalt der Reaktionsmischung zur Reaktion bringt, was durch Cyclotetramerisierung des Aziridins der Formel (Ib) gemäß der folgenden Reaktion ein Metall-1,4,7,10-Tetraaza-1,4,7,10-tetrakis(carboxymethyl)cyclododecan(DOTA)-Chelat der Formel (IIe) ergibt:



wobei:

$(M^{t+})(X_1^-)_s$ für ein chelatisierbares Lewis-Säure-Metallsalz aus einem Kation M und einem Anion X_1^- steht, wobei t für 1, 2 oder 3 steht und s so gewählt ist, dass sich elektrische Neutralität ergibt;

Z_1 für Wasserstoff, ein Alkalimetall mit der Ladung +1 oder ein Erdalkalimetall mit der Ladung +2 steht;

q für 1 steht, wenn Z_1 für ein Alkalimetall steht,

und q für 2 steht, wenn Z_1 für ein Erdalkalimetall steht; und

t für 3 steht und x für 1 steht oder t für 2 steht und x für 1 steht oder t für 2 steht und x für 2 steht oder t für 1 steht und x für 1 steht oder t für 1 steht und x für 2 steht oder t für 1 steht und x für 3 steht oder t für 1 steht und x für 4 steht,

wobei:

(a) $y_1 = y_2 = (4 - (X^*t))$, wenn Z_1 die Ladung +1 aufweist, und

(b) $y_1 = (4 - (X^*t))$ und $y_2 = (y_1/2)$, wenn Z_1 die Ladung +2 aufweist, gemäß der folgenden Tabelle:

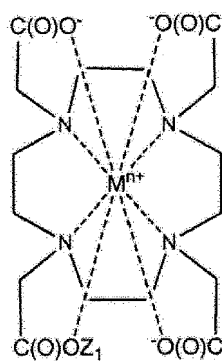
		$Z_1 = +1$	$Z_2 = +2$	
t	X	y_1 und y_2	y_1	y_2
3	1	1	1	$\frac{1}{2}$
2	1	2	2	1
2	2	0	0	0
1	1	3	3	$\frac{3}{2}$
1	2	2	2	1
1	3	1	1	$\frac{1}{2}$

(fortgesetzt)

		$Z_1 = +1$	$Z_2 = +2$	
t	X	y_1 und y_2	y_1	y_2
1	4	0	0	0

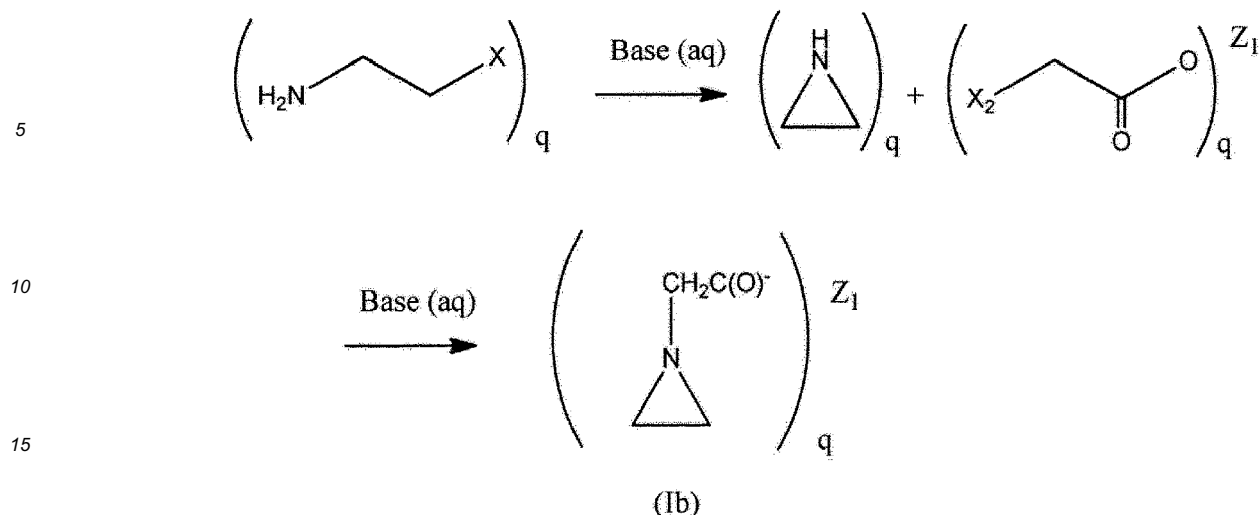
12. Verfahren nach Anspruch 11, wobei:

- i) die Lewis-Säure aus der Gruppe bestehend aus Bortribromid, Bortrichlorid, Bortrifluorid, Bortrifluoridetherat, Gadoliniumtribromid, Gadoliniumtrichlorid, Gadoliniumtrifluorid, Gadoliniumacetat, Gadoliniumformiat, Kupfer(II)-bromid, Kupfer(II)-chlorid, Kupfer(II)-fluorid, Nickelbromid, Nickelchlorid, Nickelfluorid, Aluminiumbromid, Aluminiumchlorid, Aluminiumfluorid, Eisen(III)-bromid, Eisen(III)-chlorid, Eisen(III)-fluorid, Natriumbromid, Kaliumbromid, Kaliumchlorid, Kaliumfluorid, Natriumchlorid, Natriumfluorid, Zinn(IV)-chlorid und Kombinationen davon ausgewählt wird; und/oder wobei
- ii) die Menge der Lewis-Säure, ausgedrückt als das Verhältnis von Äquivalenten der Säure zu Äquivalenten Aziridinverbindung, etwa 0,05:1 bis etwa 1,5:1, etwa 0,05:1 bis etwa 1,2:1 oder etwa 0,5:1 bis etwa 1,2:1 beträgt; und/oder wobei
- iii) das Verhältnis von Lewis-Säure, ausgedrückt als das Verhältnis von Äquivalenten der Säure zu Äquivalenten Aziridinverbindung, etwa 0,05:1 bis etwa 0,5:1 oder etwa 0,1:1 bis etwa 0,5:1 beträgt; und/oder wobei
- iv) das Verhältnis von Lewis-Säure, ausgedrückt als das Verhältnis von Äquivalenten der Säure zu Äquivalenten Aziridinverbindung, etwa 1,0:1 bis etwa 1,5:1 etwa 1,0:1 bis etwa 1,2:1 beträgt; und/oder wobei
- v) Formel (Ile) die Formel (IIf) aufweist:



(IIf)

- wobei n für 3 steht und Z_1 für Wasserstoff oder ein Alkalimetall mit der Ladung +1 steht, gegebenenfalls wobei es sich bei Formel (IIf) um Gadotersäure handelt, wobei M^{n+} für Gd^{3+} steht und Z_1 für Wasserstoff steht; und/oder wobei
- vi) das Lösungsmittel Wasser umfasst, wobei das Lösungsmittel gegebenenfalls im Wesentlichen aus Wasser besteht; und/oder wobei
- vii) das Aziridin der Formel (Ib) gemäß dem folgenden Reaktionsschema hergestellt wird:



wobei X für eine Abgangsgruppe steht, X₂ für ein Halogenid steht, Z₁ für ein Alkalimetall mit der Ladung +1 oder ein Erdalkalimetall mit der Ladung +2 steht, q für 1 steht, wenn Z₁ die Ladung +1 aufweist, und q für 2 steht, wenn Z₁ die Ladung +2 aufweist, gegebenenfalls

wobei X für Cl, Br oder OSO₃⁻ steht, es sich bei der Base um NaOH oder KOH handelt und Z₁ für Na⁺, K⁺, Ca²⁺ oder Mg²⁺ steht; und/oder wobei

viii) die Reaktionstemperatur etwa -20°C bis etwa 150°C, etwa 0°C bis etwa 100°C, etwa 10°C bis etwa 50°C oder etwa 20°C bis etwa 30°C beträgt; und/oder wobei

ix) die Konzentration des Aziridins in der Reaktionsmischung etwa 0,05 bis etwa 1,0 Äquivalenten pro Liter, etwa 0,1 bis etwa 0,5 Äquivalenten pro Liter oder etwa 0,1 bis etwa 0,3 Äquivalenten pro Liter beträgt.

13. Verfahren nach Anspruch 11 oder Anspruch 12, wobei ferner Reaktionsprodukt der Formel (Ile), Formel (Ilf) oder Gadotersäure gereinigt und isoliert wird, gegebenenfalls wobei die Reinigung durch Nanofiltration erfolgt, beispielsweise wobei die Gadotersäure als Megluminsalz davon nanofiltriert wird oder wobei das DOTA als Natriumsalz davon nanofiltriert wird.

14. Verfahren nach Anspruch 13, wobei die Isolierung durch Kristallisation aus wässrigem Lösungsmittel bei einem pH-Wert von etwa 1 bis etwa 4 erfolgt, gegebenenfalls wobei es sich bei dem Reaktionsprodukt um Gadotersäure handelt und der pH-Wert der Kristallisation etwa 2 bis etwa 4 beträgt.

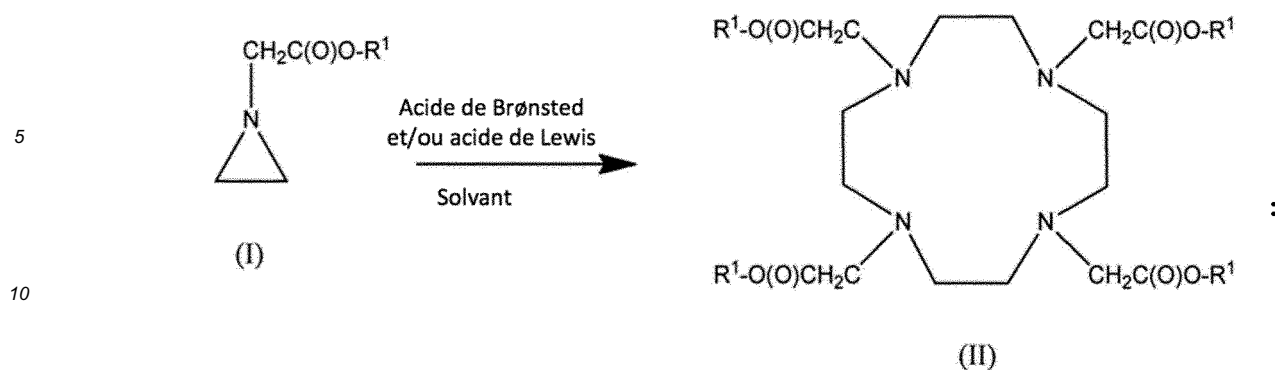
15. Verfahren nach einem der Ansprüche 11 bis 14, wobei die Reinheit der Verbindung der Formel (Ile), Formel (Ilf) oder der Gadotersäure gemäß Messung mittels MS-Chromatogramm mindestens etwa 50%, mindestens etwa 60%, mindestens etwa 70%, mindestens etwa 80% oder mindestens etwa 90% beträgt und/oder wobei die molare Ausbeute der Verbindung der Formel (Ile), Formel (Ilf) oder der Gadotersäure mindestens etwa 40%, mindestens etwa 50%, mindestens etwa 60%, mindestens etwa 70%, mindestens etwa 80% oder mindestens etwa 90%, bezogen auf Äquivalente Aziridin, beträgt.

Revendications

1. Procédé pour la préparation d'un composé tétramère macrocyclique de formule (II), le procédé comprenant :

(i) la formation d'un mélange réactionnel comprenant une quantité stoechiométrique de (a) une aziridine de formule (I), (b) un acide de Brønsted, un acide de Lewis ou une association d'un acide de Brønsted et d'un acide de Lewis et (c) un solvant ; et

(ii) la réaction du contenu du mélange réactionnel pour former le composé de formule (II) par cyclotétramérisation de l'aziridine de formule (I), selon la réaction suivante :



chaque R^1 étant indépendamment choisi dans le groupe constitué par les groupes hydrocarbyle en C_{1-10} .

2. Procédé selon la revendication 1 dans lequel :

i) chaque R^1 est indépendamment choisi parmi les groupes méthyle, éthyle, 2-propyle et benzyle ; et/ou
 ii) l'acide est un acide de Brønsted choisi dans le groupe constitué par l'acide *p*-toluènesulfonique, l'acide méthanesulfonique, l'acide triflique, l'acide sulfurique, l'acide chlorhydrique, l'acide iodhydrique, l'acide bromhydrique, l'acide fluorhydrique, l'acide phosphorique, l'acide perchlorique, l'acide trifluoroacétique, le chlorure de triéthylammonium, le bromure de triéthylammonium, l'acétate de triéthylammonium, le formiate de triéthylammonium, le chlorure de tris(2-hydroxyéthyl)ammonium, le bromure de tris(2-hydroxyéthyl)ammonium, l'acétate de tris(2-hydroxyéthyl)ammonium, le formiate de tris(2-hydroxyéthyl)ammonium, le chlorure de 4,7,13,16,21,24-hexaoxa-1,10-diazabicyclo[8.8.8]hexacosan-1-ium, le bromure, l'acétate de tris(2-hydroxyéthyl)ammonium, le formiate de 4,7,13,16,21,24-hexaoxa-1,10-diazabicyclo[8.8.8]hexacosan-1-ium, le chlorure de bis(isopropyl)éthylammonium, le bromure de bis(isopropyl)éthylammonium, l'acétate de bis(isopropyl)éthylammonium, le formiate de bis(isopropyl)éthylammonium, le chlorure de tris(carboxyméthyl)ammonium, le bromure de tris(carboxyméthyl)ammonium, l'acétate de tris(carboxyméthyl)ammonium, le formiate de tris(carboxyméthyl)ammonium, le chlorure de 2-(bis(carboxyméthyl)amino)-*N,N*-bis(carboxyméthyl)éthanaminium, le bromure de 2-(bis(carboxyméthyl)amino)-*N,N*-bis(carboxyméthyl)éthanaminium, l'acétate de 2-(bis(carboxyméthyl)amino)-*N,N*-bis(carboxyméthyl)éthanaminium, le formiate de 2-(bis(carboxyméthyl)amino)-*N,N*-bis(carboxyméthyl)éthanaminium, le 2-(bis(carboxyméthyl)amino)-*N*-(2-(bis(carboxyméthyl)amino)éthyl)-*N*-(carboxyméthyl)éthanaminium, le bromure de 2-(bis(carboxyméthyl)amino)-*N*-(2-(bis(carboxyméthyl)amino)éthyl)-*N*-(carboxyméthyl)éthanaminium, l'acétate de 2-(bis(carboxyméthyl)amino)-*N*-(2-(bis(carboxyméthyl)amino)éthyl)-*N*-(carboxyméthyl)éthanaminium, le formiate de 2-(bis(carboxyméthyl)amino)-*N*-(2-(bis(carboxyméthyl)amino)éthyl)-*N*-(carboxyméthyl)éthanaminium, l'acide formique, l'acide acétique, l'acide succinique, l'acide benzoïque, l'acide lactique, l'acide citrique, l'acide oxalique, l'acide nitriloacétique, l'acide éthylènediaminetétraacétique, l'acide diéthylènetriaminepentaacétique et les associations de ceux-ci, par exemple l'acide de Brønsted étant choisi dans le groupe constitué par l'acide *p*-toluènesulfonique, l'acide trifluoroacétique, l'acide chlorhydrique et l'acide sulfurique et/ou la quantité de l'acide de Brønsted, exprimée sous forme du rapport des équivalents de l'acide aux moles d'aziridine, étant d'environ 0,01:1 à environ 0,5:1, d'environ 0,03:1 à environ 0,1:1 ou d'environ 0,04:1 à environ 0,08:1.

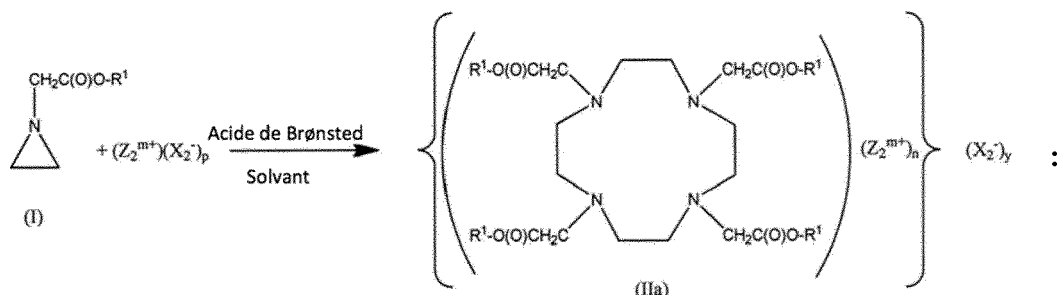
3. Procédé selon la revendication 1 dans lequel l'acide est un sel métallique d'acide de Lewis pouvant être chélaté formé à partir d'un cation métallique, M, et d'un contre-ion, M est choisi parmi un métal alcalin, un métal alcalino-terreux, un métal terre rare, un métal de transition et un métal lanthanide, par exemple l'acide de Lewis est choisi dans le groupe constitué par le tribromure de bore, le trichlorure de bore, le trifluorure de bore, l'éthérate de trifluorure de bore, le tribromure de gadolinium, le trichlorure de gadolinium, le trifluorure de gadolinium, l'acétate de gadolinium, le formiate de gadolinium, le bromure cuivrique, le chlorure cuivrique, le fluorure cuivrique, le bromure de nickel, le chlorure de nickel, le fluorure de nickel, le bromure d'aluminium, le chlorure d'aluminium, le fluorure d'aluminium, le bromure ferrique, le chlorure ferrique, le fluorure ferrique, le bromure de sodium, le bromure de potassium, le chlorure de potassium, le fluorure de potassium, le chlorure de sodium, le fluorure de sodium, le chlorure d'étain(IV) et les associations de ceux-ci et/ou :

i) la quantité de l'acide Lewis, exprimée sous forme du rapport des équivalents de l'acide aux moles de composé aziridine, étant d'environ 0,05:1 à environ 1,5:1, d'environ 0,05:1 à environ 1,2:1 ou d'environ 0,5:1 à environ 1,2:1 ;

- ii) la proportion d'acide de Lewis, exprimée sous forme du rapport des équivalents de l'acide aux moles de composé aziridine, étant d'environ 0,05:1 à environ 0,5:1 ou d'environ 0,1:1 à environ 0,5:1 ; et/ou
 iii) la proportion d'acide de Lewis, exprimée sous forme du rapport des équivalents de l'acide aux moles de composé aziridine, étant d'environ 1,0:1 à environ 1,5:1 ou d'environ 1,0:1 à environ 1,2:1.

4. Procédé selon la revendication 1 ou la revendication 2, dans lequel :

- i) l'acide est un acide de Brønsted et le mélange réactionnel comprend en outre un sel de métal alcalin, $(Z_2^{m+})(X_2^-)_p$, la formule (IIa) étant formée par cyclotétramérisation de l'aziridine de formule (I) selon la réaction suivante :



Z_2^{m+} étant un contre-ion choisi dans le groupe constitué par un ion hydrogène, un ion ammonium tertiaire, un ion de métal alcalin et un métal alcalinoterreux, $m+$ valant 1 ou 2 ;

X_2^- étant choisi dans le groupe constitué par les anions halogénure, *p*-toluènesulfonate et trifluoroacétate ; p étant le nombre de X_2^- nécessaires pour maintenir la neutralité électrique avec Z_2^{m+} et étant choisi entre 1 et 2 ;

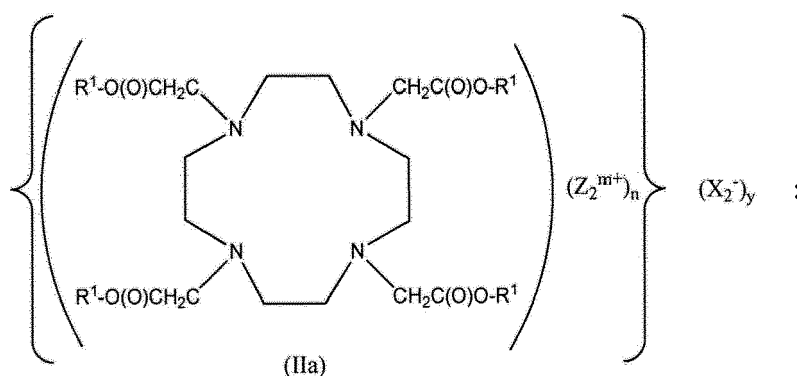
n étant un nombre entier choisi de 0 à 4 ; et

y étant le nombre de X_2^- nécessaires pour maintenir la neutralité électrique de la formule (IIa), éventuellement

Z_2 étant le sodium ou le potassium et

X_2^- étant l'anion chlorure ou bromure ; ou

- ii) l'acide est un acide de Brønsted, le procédé comprenant en outre la mise en contact de formule (II) avec un sel de métal alcalin $(Z_2^{m+})(X_2^-)_p$ pour former la formule (IIa) :



Z_2^{m+} étant un contre-ion choisi dans le groupe constitué par un ion hydrogène, un ion ammonium tertiaire, un ion de métal alcalin et un métal alcalinoterreux, $m+$ valant 1 ou 2 ;

X_2^- étant choisi dans le groupe constitué par les anions halogénure, *p*-toluènesulfonate et trifluoroacétate ; p étant le nombre de X_2^- nécessaires pour maintenir la neutralité électrique avec Z_2^{m+} et étant choisi entre 1 et 2 ;

n étant un nombre entier choisi de 0 à 4 ; et

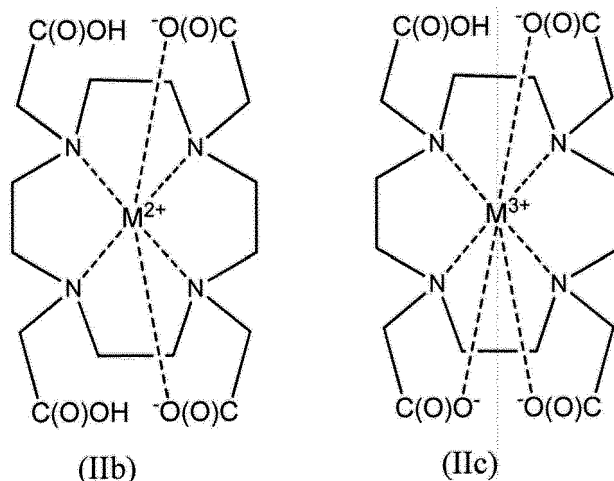
y étant le nombre de X_2^- nécessaires pour maintenir la neutralité électrique de la formule (IIa), éventuellement

Z_2 étant le sodium ou le potassium et

X_2^- étant l'anion chlorure ou bromure.

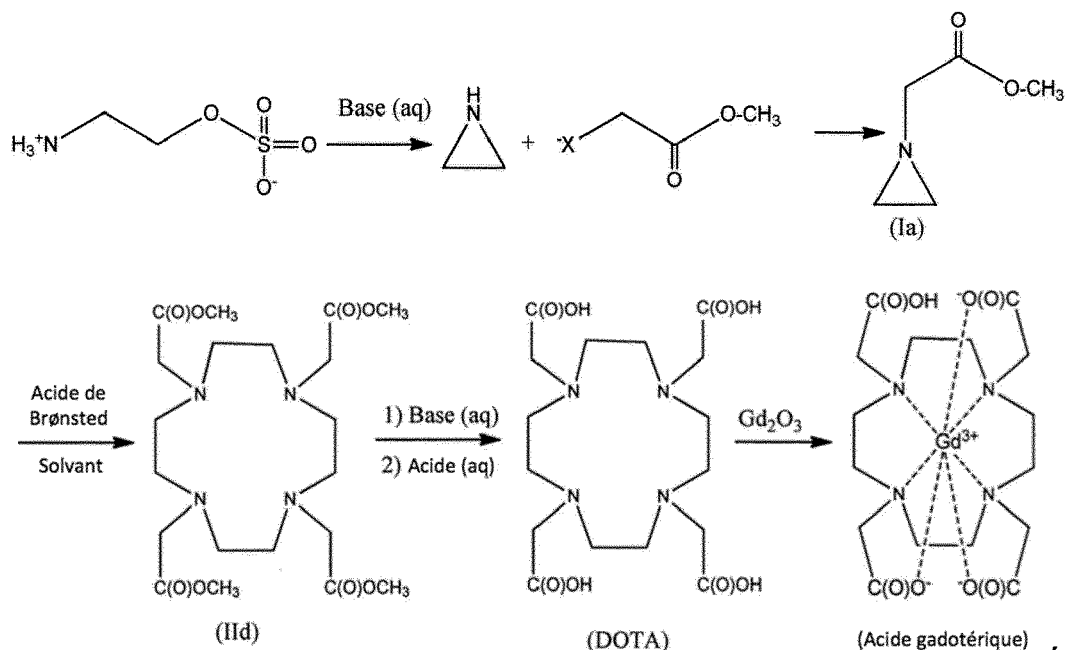
5. Procédé selon l'une quelconque des revendications 1 à 3 :

i) comprenant en outre l'hydrolyse ou l'hydrogénation de la formule (II) pour former le 1,4,7,10-tétraaza-1,4,7,10-tétrakis(carboxyméthyl)cyclododécane (DOTA), éventuellement comprenant en outre le traitement du DOTA avec un cation métallique, M^{n+} , $n+$ valant 2 ou 3, fourni à partir d'une source d'ion métallique choisie dans le groupe constitué par les oxydes métalliques, les carbonates de métaux et les chélates faibles pour former un chélate métal-DOTA de formule (IIb) ou de formule (IIc) :



le cation métallique étant choisi dans le groupe constitué par Gd, Eu, Tb, Dy, Sm, Lu, La, In, Ga, Re, Ru, Fe, Cu, Zn, Ni, Co, Cr, V, Ti, Sc, Zr, Nb, Mo, Rh, Pd, Ag, Cd, Sn, Hf, Ta, W, Os, Ir, Pt, Au et Y et la coordination de M^{2+} pouvant avoir lieu avec deux des noyaux carboxyle quelconques, par exemple la source d'ion métallique étant un chélate d'acétylacétonate ou Gd_2O_3 et le composé formule (IIc) étant l'acide gadotérique ; et/ou dans lequel

ii) de l'acide gadotérique est préparé selon le schéma réactionnel suivant :



la base étant une base métallique, l'acide étant un acide minéral et X^- étant un halogénure ; et/ou dans lequel
iii) le solvant est choisi dans le groupe constitué par un solvant polaire aprotique, un solvant polaire protique et une association de ceux-ci, le solvant étant un solvant polaire aprotique choisi dans le groupe constitué par le

chloroforme, le dichlorométhane, le tétrahydrofurane, l'acétate d'éthyle, l'acétone, le diméthylformamide, le diméthylacétamide, l'acétonitrile, le 1,4-dioxane, le glyme, le diglyme, le diméthylsulfoxyde, le carbonate de propylène et les associations de ceux-ci et le solvant étant un solvant protique choisi dans le groupe constitué par le méthanol, l'éthanol, le *n*-propanol, l'isopropanol, le *n*-butanol, l'isobutanol, le *t*-butanol, l'éthylèneglycol,

l'acide formique, l'eau, l'acide acétique et les associations de ceux-ci ; et/ou dans lequel

iv) la température de réaction est d'environ -20 °C à environ 150 °C, d'environ 0 °C à environ 100 °C, d'environ 10 °C à environ 50 °C ou d'environ 20 °C à environ 30 °C ; et/ou dans lequel

v) la concentration de l'aziridine dans le mélange réactionnel est d'environ 0,05 à environ 1,0 mole par litre, d'environ 0,1 à environ 0,5 mole par litre ou d'environ 0,1 à environ 0,3 mole par litre ; et/ou dans lequel

vi) comprenant en outre la purification de produit réactionnel formules (II) à (II_d), DOTA ou acide gadotérique et l'isolement de produit de réaction formules (II) à (II_d), DOTA ou acide gadotérique, éventuellement la purification se faisant par nanofiltration et/ou l'isolement se faisant par cristallisation dans un solvant aqueux à un pH d'environ 1 à environ 4, par exemple le produit de réaction étant l'acide gadotérique et le pH de cristallisation étant d'environ 2 à environ 4 ; et/ou dans lequel

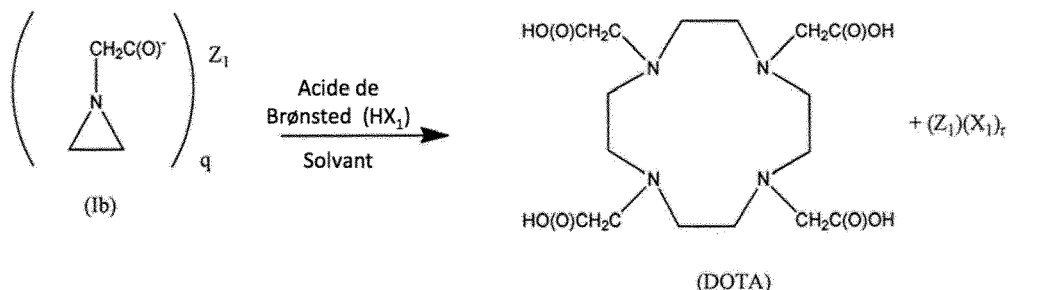
vii) la pureté du composé formules (II) à (II_d), DOTA ou acide gadotérique, telle que mesurée par spectrométrie de masse (MS)-chromatogramme ou diffusion de la lumière par évaporation (ELSD), est d'au moins environ 50 %, d'au moins environ 60 %, d'au moins environ 70 %, d'au moins environ 80 % ou d'au moins environ 90 % ; et/ou dans lequel

viii) le rendement molaire de production du composé formules (II) à (II_d), DOTA ou acide gadotérique est d'au moins environ 40 %, d'au moins environ 50 %, d'au moins environ 60 %, d'au moins environ 70 %, d'au moins environ 80 % ou d'au moins environ 90 % sur la base des moles d'aziridine.

6. Procédé pour la préparation de 1,4,7,10-tétraaza-1,4,7,10-tétrakis(carboxyméthyl)cyclododécane (DOTA), le procédé comprenant :

(i) la formation d'un mélange réactionnel comprenant (a) une quantité stoechiométrique d'une aziridine de formule (Ib), (b) un acide de Brønsted et (c) un solvant ; et

(ii) la réaction du contenu du mélange réactionnel pour former du DOTA par cyclotétramérisation de l'aziridine de formule (Ib), selon la réaction suivante :



Z_1 étant un métal alcalin ayant une charge +1 ou un métal alcalinoterreux ayant une charge +2 ; et q et r valant 1 lorsque Z_1 est un métal alcalin et q et r valant 2 lorsque Z_1 est un métal alcalinoterreux.

7. Procédé selon la revendication 6 dans lequel :

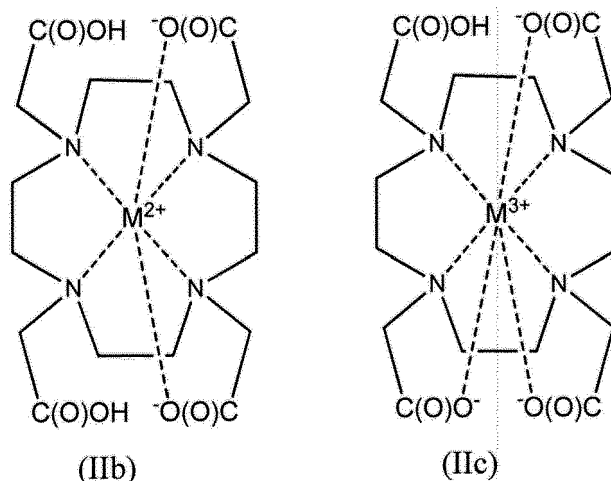
i) l'acide de Brønsted est choisi dans le groupe constitué par l'acide *p*-toluènesulfonique, l'acide méthanesulfonique, l'acide triflique, l'acide sulfurique, l'acide chlorhydrique, l'acide iodhydrique, l'acide bromhydrique, l'acide fluorhydrique, l'acide phosphorique, l'acide perchlorique, l'acide trifluoroacétique, le chlorure de triéthylammonium, le bromure de triéthylammonium, l'acétate de triéthylammonium, le formiate de triéthylammonium, le chlorure de tris(2-hydroxyéthyl)ammonium, le bromure de tris(2-hydroxyéthyl)ammonium, l'acétate de tris(2-hydroxyéthyl)ammonium, le formiate de tris(2-hydroxyéthyl)ammonium, le chlorure de 4,7,13,16,21,24-hexaoxa-1,10-diazabicyclo[8.8.8]hexacosan-1-ium, le bromure, l'acétate de tris(2-hydroxyéthyl)ammonium, le formiate de 4,7,13,16,21,24-hexaoxa-1,10-diazabicyclo[8.8.8]hexacosan-1-ium, le chlorure de bis(isopropyl)éthylammonium, le bromure de bis(isopropyl)éthylammonium, l'acétate de bis(isopropyl)éthylammonium, le formiate de bis(isopropyl)éthylammonium, le chlorure de tris(carboxyméthyl)ammonium, le bromure de tris(carboxyméthyl)ammonium, l'acétate de tris(carboxyméthyl)ammonium, le formiate de tris(carboxyméthyl)ammonium, le chlorure de 2-(bis(carboxyméthyl)amino)-*N,N*-bis(carboxyméthyl)éthylaminium, le bromure

de 2-(bis(carboxyméthyl)amino)-*N,N*-bis(carboxyméthyl)éthanaminium, l'acétate de 2-(bis(carboxyméthyl)amino)-*N,N*-bis(carboxyméthyl)éthanaminium, le formiate de bis 2-(bis(carboxyméthyl)amino)-*N,N*-bis(carboxyméthyl)éthanaminium, le 2-(bis(carboxyméthyl)amino)-*N*-(2-(bis(carboxyméthyl)amino)éthyl)-*N*-(carboxyméthyl)éthanaminium, le bromure de 2-(bis(carboxyméthyl)amino)-*N*-(2-(bis(carboxyméthyl)amino)éthyl)-*N*-(carboxyméthyl)éthanaminium, l'acétate de 2-(bis(carboxyméthyl)amino)-*N*-(2-(bis(carboxyméthyl)amino)éthyl)-*N*-(carboxyméthyl)éthanaminium, le formiate de 2-(bis(carboxyméthyl)amino)-*N*-(2-(bis(carboxyméthyl)amino)éthyl)-*N*-(carboxyméthyl)éthanaminium, l'acide formique, l'acide acétique, l'acide succinique, l'acide benzoïque, l'acide lactique, l'acide citrique, l'acide oxalique, l'acide nitriloacétique, l'acide éthylènediaminétriaacétique, l'acide diéthylènetriaminepentaacétique et les associations de ceux-ci, par exemple l'acide de Brønsted étant choisi dans le groupe constitué par l'acide *p*-toluènesulfonique, l'acide trifluoroacétique, l'acide chlorhydrique et l'acide sulfurique ; et/ou dans lequel

ii) Z_1 est Na^+ , K^+ , Ca^{2+} ou Mg^{2+} et X_1 est Br^- , Cl^- ou OSO_3^{2-} ; et/ou dans lequel

iii) la quantité de l'acide de Brønsted, exprimée sous forme du rapport des équivalents de l'acide aux équivalents d'aziridine, est d'environ 0,01:1 à environ 0,5:1, d'environ 0,03:1 à environ 0,1:1 ou d'environ 0,04:1 à environ 0,08:1 ; et/ou

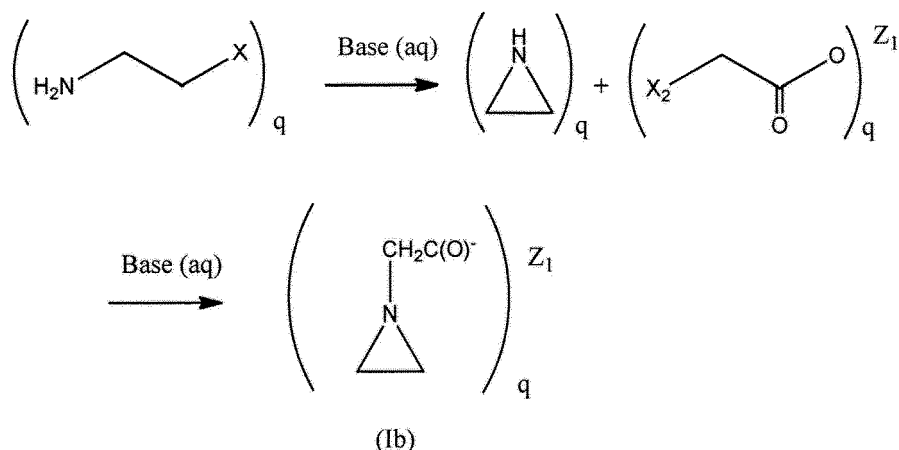
iv) comprenant en outre le traitement de DOTA avec un cation métallique, M^{n+} , n valant 2 ou 3, fourni à partir d'une source d'ion métallique choisie dans le groupe constitué par les oxydes métalliques, les carbonates de métaux et les chélates faibles pour former un chélate métal-DOTA de formule (IIb) ou de formule (IIc) :



le cation métallique étant choisi dans le groupe constitué par Gd, Eu, Tb, Dy, Sm, Lu, La, In, Ga, Re, Ru, Fe, Cu, Zn, Ni, Co, Cr, V, Ti, Sc, Zr, Nb, Mo, Rh, Pd, Ag, Cd, Sn, Hf, Ta, W, Os, Ir, Pt, Au et Y et la coordination de M^{2+} pouvant avoir lieu avec deux des fractions carboxyle quelconques, éventuellement la source d'ion métallique étant un chélate d'acétylacétonate ou Gd_2O_3 et le composé formule (IIc) étant l'acide gadotérique ; et/ou dans lequel

v) le solvant comprend de l'eau, éventuellement le solvant étant essentiellement constitué d'eau ; et/ou dans lequel

vi) l'aziridine de formule (Ib) est préparée selon le schéma réactionnel suivant :



X étant un groupe partant,

X₂ étant un halogénure,

Z₁ étant un métal alcalin ayant une charge +1 ou un métal alcalinoterreux ayant une charge +2,

q valant 1 lorsque Z₁ a une charge +1 et q valant 2 lorsque Z₁ a une charge +2, éventuellement

X étant Cl, Br ou OSO₃⁻,

la base étant NaOH ou KOH et

Z₁ étant Na⁺, K⁺, Ca²⁺ ou Mg²⁺ ; et/ou dans lequel

vii) la température de réaction est d'environ -20 °C à environ 150 °C, d'environ 0 °C à environ 100 °C, d'environ 10 °C à environ 50 °C ou d'environ 20 °C à environ 30 °C ; et/ou dans lequel

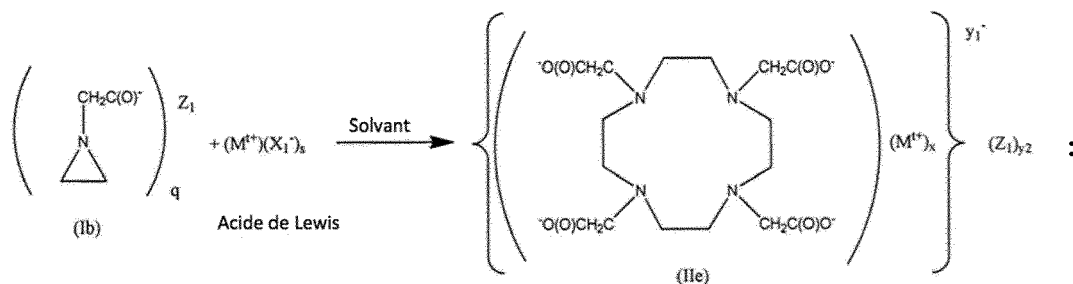
viii) la concentration de l'aziridine dans le mélange réactionnel est d'environ 0,05 à environ 1,0 équivalent par litre, d'environ 0,1 à environ 0,5 équivalent par litre ou d'environ 0,1 à environ 0,3 équivalent par litre.

8. Procédé selon la revendication 6 ou la revendication 7 comprenant en outre la purification de produit réactionnel formule (IIb), formule (IIc), DOTA ou acide gadotérique et l'isolement de produit réactionnel formule (IIb), formule (IIc), DOTA ou acide gadotérique, éventuellement la purification se faisant par nanofiltration, par exemple l'acide gadotérique étant nanofiltré sous forme du sel de méglumine de celui-ci ou le DOTA étant nanofiltré sous forme du sel de sodium de celui-ci.
9. Procédé selon la revendication 8 dans lequel l'isolement se fait par cristallisation dans un solvant aqueux à un pH d'environ 1 à environ 4, éventuellement le produit de réaction étant l'acide gadotérique et le pH de cristallisation étant d'environ 2 à environ 4.
10. Procédé selon l'une quelconque des revendications 6 à 9 dans lequel la pureté du composé formule (IIb), formule (IIc), DOTA ou acide gadotérique, telle que mesurée par MS-chromatogramme, est d'au moins environ 50 %, d'au moins environ 60 %, d'au moins environ 70 %, d'au moins environ 80 % ou d'au moins environ 90 % et/ou dans lequel le rendement molaire de production du composé formule (IIb), formule (IIc), DOTA ou acide gadotérique est d'au moins environ 40 %, d'au moins environ 50 %, d'au moins environ 60 %, d'au moins environ 70 %, d'au moins environ 80 % ou d'au moins environ 90 % sur la base des équivalents d'aziridine.
11. Procédé pour la préparation d'un composé tétramère macrocyclique de formule (IIc), le procédé comprenant :

- (i) la formation d'un mélange réactionnel comprenant (a) une quantité stoechiométrique d'une aziridine de formule (Ib), (b) un acide de Lewis et (c) un solvant ; et
- (ii) la réaction du contenu du mélange réactionnel pour former un chélate métal-1,4,7,10-tétraaza-1,4,7,10-tétrakis(carboxyméthyl)cyclododécane (DOTA) de formule (IIc) par cyclotétramérisation de l'aziridine de formule (Ib), selon la réaction suivante :

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(M^{t+}) (X₁⁻)_s étant un sel métallique d'acide de Lewis pouvant être chélaté formé à partir d'un cation, M, et d'un anion, X₁⁻, t valant 1, 2 ou 3 et s étant choisi pour obtenir la neutralité électrique ;
 Z₁ étant l'hydrogène, un métal alcalin ayant une charge +1 ou un métal alcalinoterreux ayant une charge +2 ;
 q valant 1 lorsque Z₁ est un métal alcalin et q valant 2 lorsque Z₁ est un métal alcalinoterreux ; et
 t valant 3 et x valant 1 ou t valant 2 et x valant 1 ou t valant 2 et x valant 2 ou t valant 1 et x valant 1 ou t valant 1 et x valant 2 ou t valant 1 et x valant 3 ou t valant 1 et x valant 4 :

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(a) y₁ = y₂ = (4-(X*t)) lorsque Z₁ a une charge +1 et

(b) y₁ = (4-(X*t)) et y₂ = (y₁/2) lorsque Z₁ a une charge +2 selon le tableau suivant

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		Z ₁ = +1	Z ₁ = +2	
t	X	y ₁ et y ₂	y ₁	y ₂
3	1	1	1	1/2
2	1	2	2	1
2	2	0	0	0
1	1	3	3	3/2
1	2	2	2	1
1	3	1	1	1/2
1	4	0	0	0

12. Procédé selon la revendication 11 dans lequel :

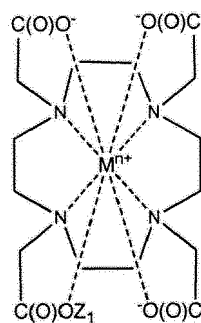
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- i) l'acide de Lewis est choisi dans le groupe constitué par le tribromure de bore, le trichlorure de bore, le trifluorure de bore, l'éthérate de trifluorure de bore, le tribromure de gadolinium, le trichlorure de gadolinium, le trifluorure de gadolinium, l'acétate de gadolinium, le formiate de gadolinium, le bromure cuivrique, le chlorure cuivrique, le fluorure cuivrique, le bromure de nickel, le chlorure de nickel, le fluorure de nickel, le bromure d'aluminium, le chlorure d'aluminium, le fluorure d'aluminium, le bromure ferrique, le chlorure ferrique, le fluorure ferrique, le bromure de sodium, le bromure de potassium, le chlorure de potassium, le fluorure de potassium, le chlorure de sodium, le fluorure de sodium, le chlorure d'étain(IV) et les associations de ceux-ci et/ou dans lequel :
- ii) la quantité de l'acide Lewis, exprimée sous forme du rapport des équivalents de l'acide aux équivalents de composé aziridine, est d'environ 0,05:1 à environ 1,5:1, d'environ 0,05:1 à environ 1,2:1 ou d'environ 0,5:1 à environ 1,2:1 ; et/ou dans lequel :
- iii) la proportion d'acide Lewis, exprimée sous forme du rapport des équivalents de l'acide aux équivalents de composé aziridine, est d'environ 0,05:1 à environ 0,5:1 ou d'environ 0,1:1 à environ 0,5:1 ; et/ou dans lequel :
- iv) la proportion d'acide Lewis, exprimée sous forme du rapport des équivalents de l'acide aux équivalents de composé aziridine, est d'environ 1,0:1 à environ 1,5:1 ou d'environ 1,0:1 à environ 1,2:1 ; et/ou dans lequel :
- v) la formule (IIc) est de formule (IIf) :



(IIIf)

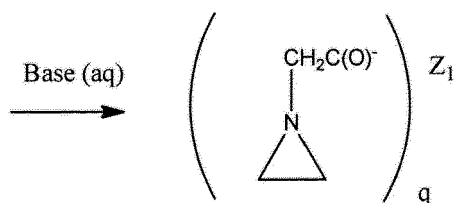
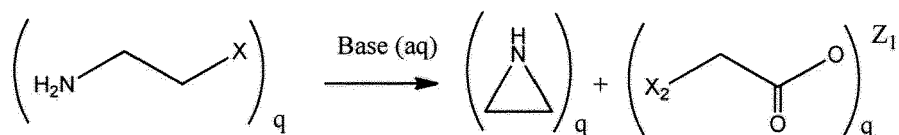
n valant 3 et

Z_1 étant l'hydrogène ou un métal alcalin ayant une charge +1, éventuellement

la formule (IIIf) étant l'acide gadotérique, M^{n+} étant Gd^{3+} et Z_1 étant l'hydrogène ; et/ou dans lequel

vi) le solvant comprend de l'eau, éventuellement le solvant étant essentiellement constitué d'eau ; et/ou dans lequel

vii) l'aziridine formule (Ib) est préparée selon le schéma réactionnel suivant :



(Ib)

X étant un groupe partant,

X_2 étant un halogénure,

Z_1 étant un métal alcalin ayant une charge +1 ou un métal alcalinoterreux ayant une charge +2,

q valant 1 lorsque Z_1 a une charge +1 et q valant 2 lorsque Z_1 a une charge +2,

éventuellement

X étant Cl, Br ou OSO_3^- ,

la base étant NaOH ou KOH et

Z_1 étant Na^+ , K^+ , Ca^{2+} ou Mg^{2+} ; et/ou dans lequel

viii) la température de réaction est d'environ $-20\text{ }^\circ\text{C}$ à environ $150\text{ }^\circ\text{C}$, d'environ $0\text{ }^\circ\text{C}$ à environ $100\text{ }^\circ\text{C}$, d'environ $10\text{ }^\circ\text{C}$ à environ $50\text{ }^\circ\text{C}$ ou d'environ $20\text{ }^\circ\text{C}$ à environ $30\text{ }^\circ\text{C}$; et/ou dans lequel

ix) la concentration de l'aziridine dans le mélange réactionnel est d'environ 0,05 à environ 1,0 équivalent par litre, d'environ 0,1 à environ 0,5 équivalent par litre ou d'environ 0,1 à environ 0,3 équivalent par litre.

13. Procédé selon la revendication 11 ou la revendication 12 comprenant en outre la purification et l'isolement du produit de réaction de formule (IIc), formule (IIIf) ou acide gadotérique, éventuellement la purification se faisant par nanofiltration, par exemple l'acide gadotérique étant nanofiltré sous forme du sel de méglumine de celui-ci ou le DOTA étant nanofiltré sous forme du sel de sodium de celui-ci.

14. Procédé selon la revendication 13 dans lequel l'isolement se fait par cristallisation dans un solvant aqueux à un pH d'environ 1 à environ 4, éventuellement le produit de réaction étant l'acide gadotérique et le pH de cristallisation étant d'environ 2 à environ 4.

5 15. Procédé selon l'une quelconque des revendications 11 à 14 dans lequel la pureté du composé de formule (IIc),
formule (IIf) ou acide gadotérique, telle que mesurée par MS-chromatogramme, est d'au moins environ 50 %, d'au
moins environ 60 %, d'au moins environ 70 %, d'au moins environ 80 % ou d'au moins environ 90 % et/ou dans
lequel le rendement molaire de production du composé de formule (IIc), formule (IIf) ou acide gadotérique est d'au
10 moins environ 40 %, d'au moins environ 50 %, d'au moins environ 60 %, d'au moins environ 70 %, d'au moins
environ 80 % ou d'au moins environ 90 % sur la base des équivalents d'aziridine.

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FIG. 1

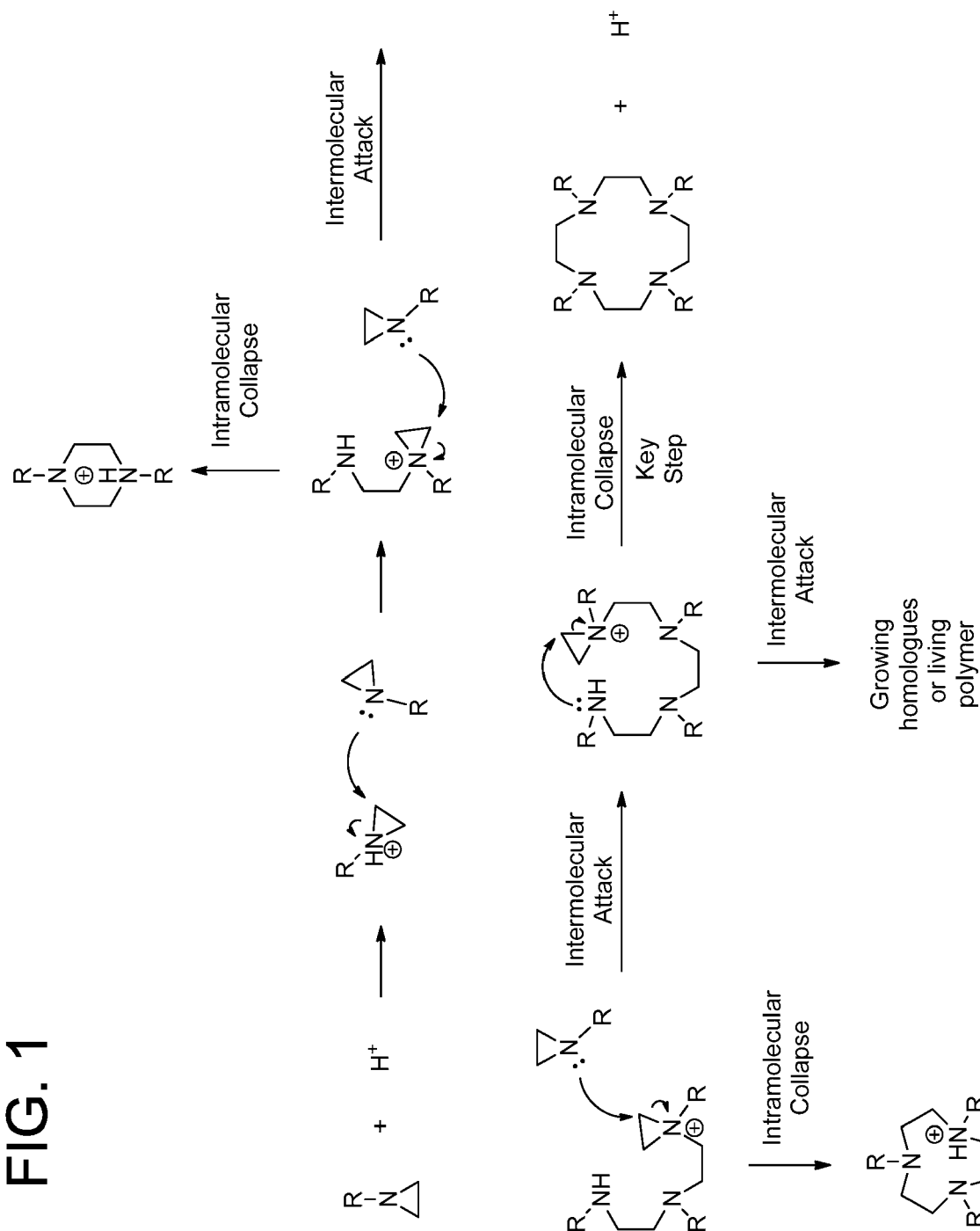


FIG. 2

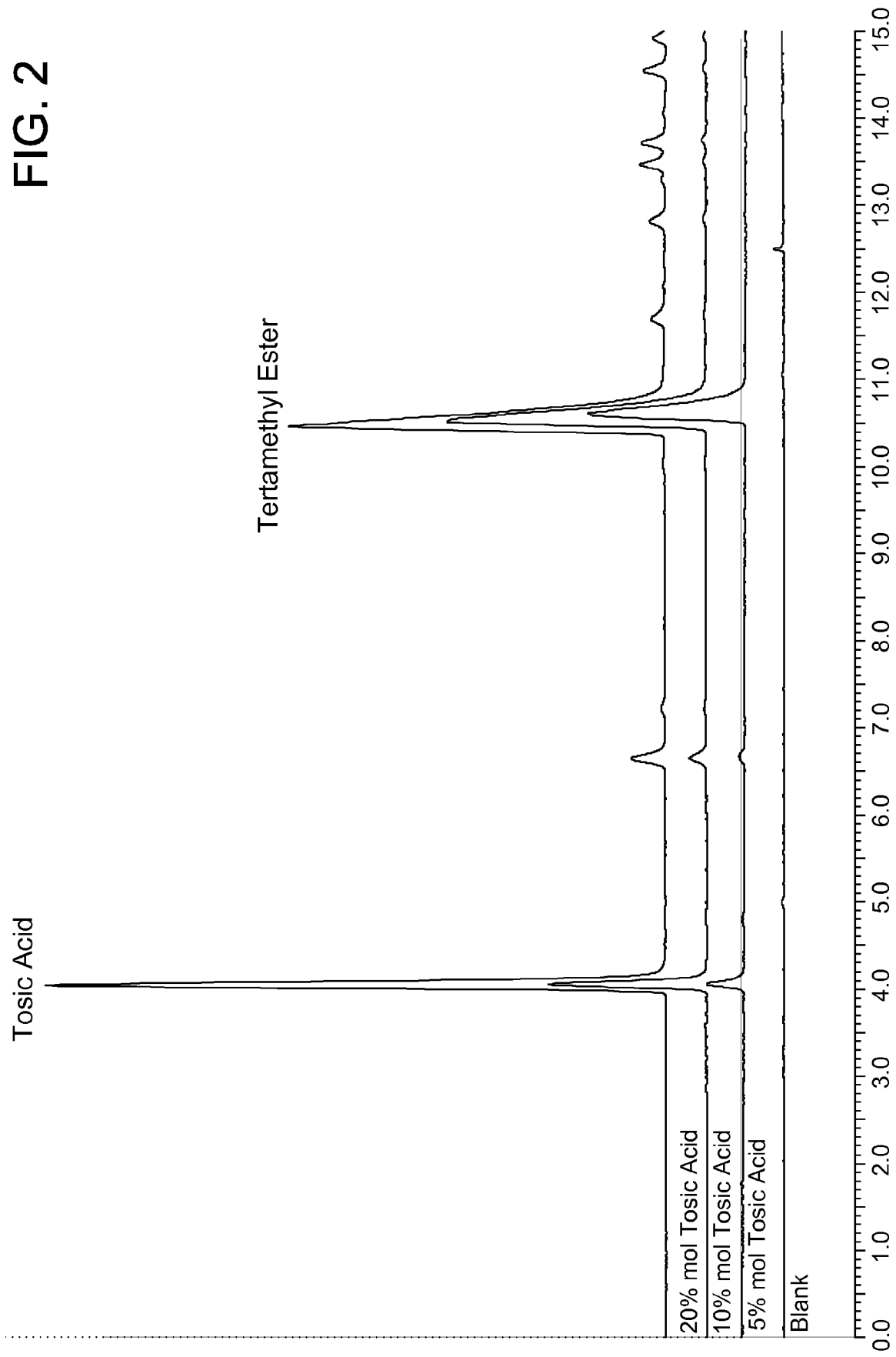
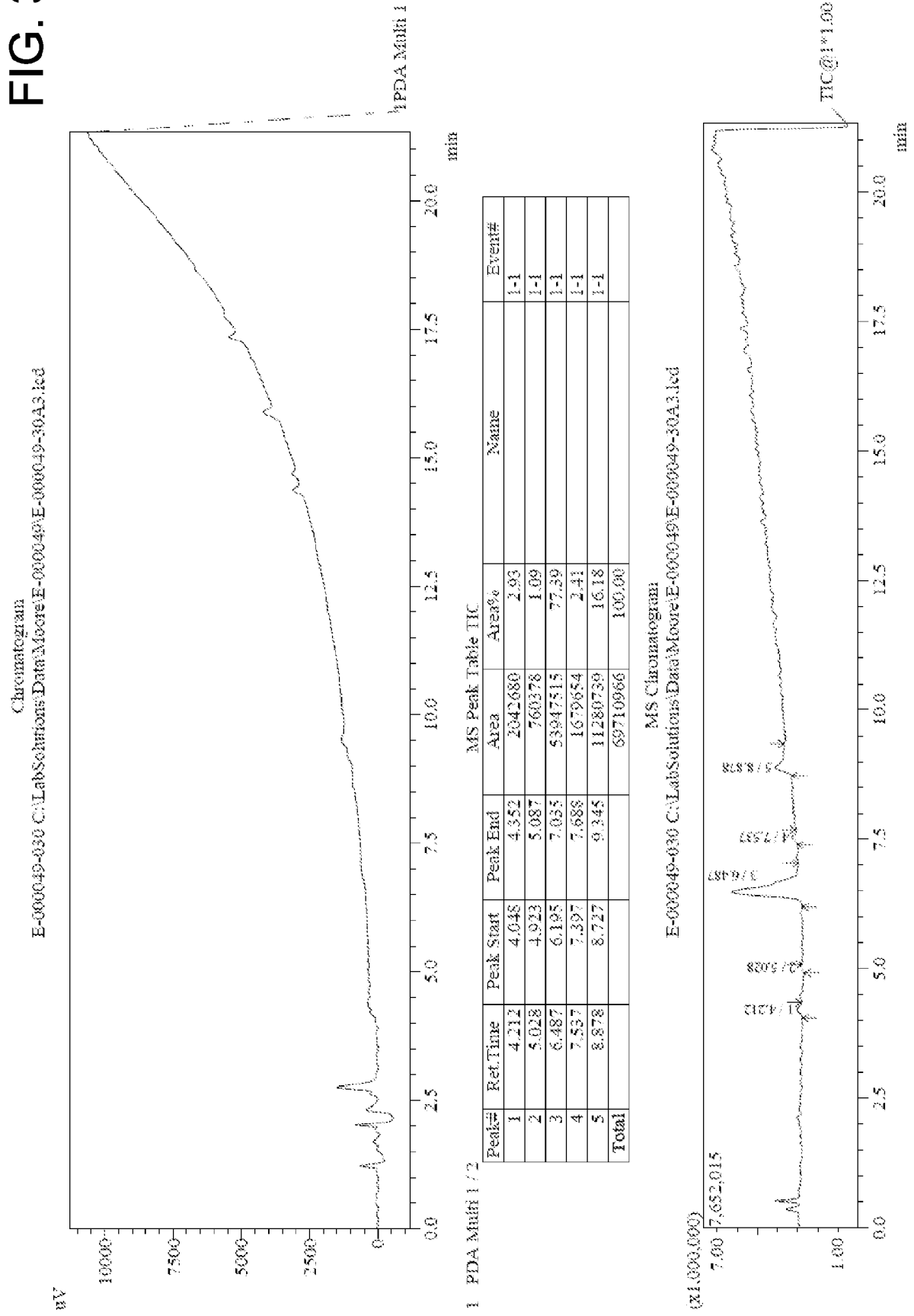


FIG. 3



REFERENCES CITED IN THE DESCRIPTION

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