ANALYTICAL APPLICATIONS OF LIQUID ION EXCHANGERS

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CONTENTS

ABSTRACT

Various applications of liquid ion exchangers in inorganic analysis have been reviewed. A compilation of the data for the separation and determination of various elements using both liquid caion and anion exchangers is given in tabular form. The review covers the literature of the last 10 years.

INTRODUCTION

The application of liquid ion exchangers for analytical work is ever increasing. From the low pace of research after its introduction in 1948 by Smith and Page /1/, it has gained momentum and reached a stage of separate identity in the field of solvent extraction, as extensive work has been reported in the various fields of application. Very little work was done with this analytical technique, except in the field of transuranic elements, until the 1960s, despite its obvious possible advantages. The reason for the lack of

attention was partly due to the lack of knowledge of the fundamental principles of the technique and partly because of the few experimental constraints like the tendency to form emulsion between the aqueous and organic phases, the need for stripping the organic extract to complete the analysis, etc. The popularity of solvent extraction employing the readily available chelating agents and the introduction of synthetic resin exchangers also share the responsibility. However, at a later stage a number of equilibrium distribution studies of various extraction systems were carried out which served to shed more light on the intimate details of extraction processes such as the nature of the extracted species, extraction equilibria, mechanism of extraction, etc. These studies were useful not only in providing a sound basis for developing and understanding extraction procedures but also in obtaining equilibrium data for the aqueous solution chemistry of metal ions. A wide knowledge of the technique enabled scientists to avoid the difficulty of emulsion formation between the aqueous and organic phase. The increasing use of the organic phase directly for estimation, without back-extraction, increased the attractiveness of liquid ion exchangers and its incorporation as a separation stage in inorganic analysis. The introduction of the technique of selective elution with various stripping agents opened up a new field of easy separation of closely associated elements. Thus it was realized that liquid ion exchange has much to offer the analyst by providing both the speed of separation associated with solvent extraction and the selectivity offered by ion exchange under appropriate conditions for the separation of elements from other associated elements and also for the recovery and purification of metals.

Besides the use of liquid ion exchangers in analytical separations, they can also be used as a probe for studying metallic and other complexes formed in the aqueous media. The most important condition for this type of study is that an unchanging organic phase is used to determine the conditions for the constant activity of an extractable species in a series of changing aqueous phases. Alternatively, an organic phase of varying composition can be used provided it is reasonable to assume that any variations in the organic phase activity coefficients of the pertinent species will be in constant ratio.

Liquid ion exchangers find potential applications in nuclear fuel reprocessing, in processes used for the recovery and purification of metals, such as recovery of fissile and fissionable materials from irradiated fuel elements. They are also being used increasingly in hydrometallurgical and other industrial processes. The superior extracting ability of the liquid ion exchangers can be utilised for the effective removal of toxic metal ions from

industrial effluents which finds application in waste treatment technologies. Extensive study on aspects such as the nature of the organic phase and mechanism of the extraction has proved very helpful in designing optimal conditions for using these extraction systems in varied technical processes.

Chromatographic separations of a number of cations by means of paper treated with liquid ion exchanger have opened up a new field for the separation of very closely associated metals like rare earths. The practice of reverse-phase partition chromatography is becoming very popular. The use of liquid ion exchangers in gas chromatography is also very promising.

The introduction of ion-selective electrodes containing liquid ion exchanger or incorporating membranes prepared from exchangers introduced into inert supports such as polyvinyl chloride or Bakelite has opened up new fields of application.

Thus the technique of liquid ion exchange continues to attract high interest because of its varied field of application, from large scale separation and purification to preparation of carrier-free trace levels of isotopes, from designing and testing new extraction methods to physicochemical examination of important systems to determine the underlying extraction mechanism and to evaluate the role of molecular structural and experimental parameters that will help in the improvement of existing systems.

Several reviews have appeared periodically on the various aspects of liquid ion exchange. Coleman, Blake and Brown /2/ gave a list of liquid ion exchange materials, both anion and cation exchangers. Kunin and Winger /3/ have reported the properties and uses of liquid ion exchangers. The classification of liquid anion exchangers is based on primary, secondary and tertiary aliphatic amines having high molecular weight (above 240), which are insoluble in water but soluble in various organic solvents. The extraction conditions vary with the type of amine used. This differential behaviour in extraction on account of differences in amine structure has led to wide variations in the separation conditions. The various aspects of the amine extractions are dealt with in earlier reviews /4,5,13,15/. A few general conclusions are drawn on the basis of the various reported methods of extracion of metals with amines and quarternary ammonium compounds. It was seen that extraction of metal complexes by amine extraction systems depends mainly on the extent of association or aggregation of both the extractant and the metal complex and also on the concentration of the amine. In most cases quaternary ammonium compounds are better extractants than primary, secondary and tertiary amines. The extraction efficiency increases with increasing basicity of the amines. Compared to extraction of double- or multicharged anion extraction, that of single-charged anion is

more efficient. In these extraction systems aqueous reactions predominate, so that the extraction follows an inverse order with respect to hydration. The use of butyl phosphoric acid as a liquid cation exchanger was described in 1949. Other systems which can act as liquid cation exchangers are high molecular weight phosphoric, carboxylic, fluoro carboxylic, sulphonic acids, etc., like mono-(2-ethyl hexyl) phosphoric and phosphinic acid, di-(2-ethyl hexyl) phosphoric acid, mono and di-octyl phenyl phosphoric acid, versatic acids, naphthenic acid, SRS-100, perfluorooctanoic acid, dinonyl naphthalein sulphonic acid, LIX-64 N (a mixture of oximes), etc. Of these, di-(2-ethyl hexyl) phosphoric acid (HDEHP) has shown the highest contribution. However, the use of other liquid cation exchangers is also increasing considerably, especially in the field of nuclear reprocessing. Liquid cation exchangers are also extensively used for distribution studies to comprehend the nature of the extracting species, mechanism of extraction, etc. The field has yet to be explored further.

The application of liquid ion exchangers for analytical work was reviewed by several authors /6-15/. Metals in the form of ionic complexes are extracted by controlling the acidity, concentration of the exchanger, choice of the diluent and the method of stripping and estimation. Variation in the nature of diluent has led to new methods of selective extractions /16/. Most of the early work on liquid ion exchange extractions were from mineral acid media. But later other complexing agents like carboxylic acids, dicarboxylic acids, thiocyanate, thiourea and even chelating agents which form coloured ionic species started receiving attention in this field. The efficiency of separation increased as well, as in most cases direct determination in the organic phase was possible. Radiometric determination using tracers was generally employed for separations of heavy metals and also for metals involved in nuclear technology.

This technique is a useful operational method in the field of hydrometallurgy /17,18/. especially the extractions with high molecular weight amines and quarternary ammonium compounds which are the liquid anion exchangers. The extraction of Cu, Zn, Co and Cd from sulphide minerals can reduce the concentration of SO_2 and other pollutants of the field of metallurgy. Liquid anion exchangers are also extensively used as extractants in nuclear fuel process chemistry in view of their reported stability towards radiation.

Liquid ion exchangers, especially the anion exchangers, have great potential as extractants for the removal of toxic metal ions like Zn, Cd, Hg, As, Sb, Pb, etc. from industrial wastes /19-24/. Numerous amine compounds with low aqueous solubility have been screened and evaluated as extractants.

These extractants also find wide application in the estimation of traces of elements in geological specimens, soils, sediments and natural waters /25/.

Liquid cation exchangers find application in the extraction from molten nitrate salt, which is getting more and more attention in the field of separation that can be performed at rather low temperature. Initially, only neutral extractants which extract by solvation were able to be employed in this technique, with a very few exceptions when chelating or cation exchange reagents were used. The reason is that the H^+ liberated during cation exchange for extraction disturbs the partition system. However, these extractants are found to be very efficient in terms of increased selectivities in metal extraction as well as for the investigation of different types of interactions during extraction. The problem of liberation of H^+ was solved by using a metal-ligand cation exchanger salt as an extractant rather than using the high molecular weight acid for extraction /271/. An extraction of a similar type was reported by Mitsugashira *et al.* /276/, where they used Cu(II)-bis (2-ethyl hexyl) phosphate as an extractant for Ra^{2+}, Th^{4+}, PaO_2^+, UO_2^{2+} and NpO_2^+ between eutectic mixtures of $LiNO_3$ - NH_4NO_3 and $LiNO_3$ - $NaNO_3$-KNO_3.

The use of liquid ion exchangers in ion selective electrodes is also progressing. Certain anion selective electrodes were prepared /26/ by coating a platinum wire with a mixture of polyvinyl chloride and the ion-association complex formed between Aliquat 336 and the anion to be determined. Cations like Fe(III) have also been determined /27/ using an ion selective electrode of Aliquat 336 combined with polyvinyl chloride.

This review deals with the application of liquid ion exchangers for analytical separations and recovery. In many of the cases the extracted elements are eluted from the organic phase with suitable eluents which enables their selective separation from closely associated elementss; this also finds wide scope for the recovery of costly chemicals. In the direct extraction spectrophotometric determination methods either a coloured complex is extracted with a liquid ion exchanger or colour is developed in the organic phase with some reagents. Radiometric determination using tracers is also carried out in many cases in which either the estimation of the organic phase or the estimation of the aqueous phase after stripping is possible. Estimation of the aqueous phase after stripping is also effected by methods like titrimetry, atomic absorption spectroscopy, emission spectrography, etc. The various applications of the developed methods are also covered.

The analytical application of liquid ion exchangers for extraction chromatography has been surveyed in a separate review /288/ by the same authors.

TABLE 1: SOLVENT EXTRACTION OF ELEMENTS WITH LIQUID ANION EXCHANGERS

Metal	Liquid anion exchanger	Conc. in diluent	Other details	Ref.
Ac	TOA	Benzene	Aq: $LiNO_3$ at pH 2.5 - 3.0. Separated from rare earths. Composition of the extracted species is $[(R_3NH)_2 - Ac(NO_3)_5]$	28
	Al quat 336	--	Aq: Strongly alkaline containing 2,3-dihydroxy-butane or 1,4-diamine NNN'N'-tetraacetic acid	29
^{109}Ag	Amberlite LA-2	5% in benzene	Aq: 1.8M in H_2SO_4. Determination by γ-ray spectrometry. Separated from Cd.	30
		5% in benzene	Aq: 4M in H_3PO_4 - 0.112M in HCl, or 4M in H_3PO_4 - 5mM in HBr Determination by γ-ray spectrometry. Separated from Zn.	31
Al	TOA	30mM in pentanol	Aq: pH 2-4, 7-50mM citric acid	32
		0.4M in chloroform	Aq: pH 1.8-3.5, tartaric acid	33
		0.05M in chloroform	Aq: pH 1.5-2.8, oxalic acid	33
		40mM in chloroform	Aq: pH 6.2 (adjusted with 20mM sodium tartrate and 20mM sodium hydroxide) and 2mM Alizarin S. Determination by spectrophotometry (λ_{max} = 490).	34
		0.05-0.1M in chloroform	Aq: pH 3.9 containing 0.25mM of Xylenol Orange and 5 fold excess of F^-. Determination by spectrophotometry (λ_{max} = 550 nm)	259

Al (cont.)		20-100 mM in chloroform	Aq: pH 3.1, 10mM citric acid. Stripping with 0.1M HCl. Determination by spectrophotometry (Chrome Azurol) or by complexometric titration. Separated from Y, Tb, and La. Applied for the analysis of alloys containing Al - Y and Al - Tb.	270
Am	Benzyldodecyldimethyl ammonium nitrate	0.5M in benzene	Aq: 0.3M in HNO_3 and 5M in $LiNO_3$. Determination by scintillation counter using ^{241}Am tracer. Separated from La, Ce, Pr and other fission products.	35
		--	Aq: 0.5M in HNO_3 and 6M $LiNO_3$. Determination by scintillation counter using ^{241}Am tracer. Separated from lanthanoids and yttrium.	36
	Benzyl dibutyl amine	0.5M in benzene or 0.04M in hexadecane	Aq: 0.5M in HNO_3 and up to 3.25M in $Mg(NO_3)_2$. Determination by γ-spectrometry.	37
		0.5M in benzene	Aq: 0.5M in HNO_3 and 6M in nitrate, $LiNO_3$ or $Mg(NO_3)_2$. Determination by scintillation counter using ^{231}Am tracer composition of the extracted species is $[(R_3NH^+)_2\ Am(NO_3)_5]$.	38
	Aliquat 336 + TOPO or TBP	Xylene	Aq: pH 2-8 and 1M in NH_4SCN. Determination by scintillation counter. Composition of the extracted species is $[Am(SCN)_4.3\ TOPO]^-R_4N^+$.	39

Metal	Liquid anion exchanger	Conc. in diluent	Other details	Ref.`
Am (cont.)	Aliquat 336	0.6M in cyclohexane	Aq: 2-4M in NaOH containing 4(αα-dioctylethyl) pyrocatechol and the alkylphosphonate complex-ons, ethylene diamine tetramethyl phosphonic and diethylene triamine pentamethyl phosphonic acid.	40
^{241}Am	TOA	0.44M in cyclohexane	Aq: 0.1-0.2M in HNO_3 and 7.2M in $LiNO_3$. Determination by scintillation counter.	41
As(V)	TOA	1% in toluene	Aq: 1.5M in HNO_3 and 0.1M in $(NH_4)_2MoO_4$. Determination by spectrophotometry (λ_{max} = 350 nm). Separated from P(V) and Si. Applied for the determination of As(V) in Mo based samples.	42
Au	TOA or Aliquat 336	5% in chloroform	Aq: 1.2M H_2SO_4 or 3M HCl. Determination by spectrophotometry ((λ_{max} = 325 nm). Separated from Pt.	45
	TOA	5% in chloroform	Aq: 0.1-6M in HCl or HBr. Determination by spectrophotometry. Separated from Ir, Rh, Ti, Zr, Hf, W, Nb, Cu, Co, Sb, alkali and alkaline earth metals.	44
Be	Aliquat 336	0.4M in hexane containing 5% octanol	A: pH 3 (adjusted with HCl) and 5M in KSCN. Stripping with 1M NaOH. Determination by titration. Separated from Ca, Ba, Mg, Hg	45
		– –	Aq: pH 5.0 - 6.8, oxalic acid	47
	TOA	0.3M in IBMK	Aq: pH 2.6 - 2.9 and 2M in NH_4SCN Separated from Al, Mg, Mn and Zn	46

Bk	TOA Dihexylmethyl or methyldioctyl ammonium nitrate	0.44M in cyclohexane – –	Aq: 0.1-2M in HNO_3 containing 7.2M $LiNO_3$ Aq: 4-6M in $NaNO_3$. Separated from Ce(III)	48
Cd	Amberlite LA-2	5% in benzene	Aq: 4M in H_3PO_4 and 0.128M in HBr or 4M in H_3PO_4 and 0.112M in HCl. Determination by scintillation counter using ^{115}Cd tracer. Separated from Zn.	31
		5% in benzene	Aq: 1M in HBr or 9M in H_2SO_4 and 0.05M in KI. Determination by scintillation counter (^{115}Cd tracer).	57
		5% in nitrobenzene	Aq: 2M in HCl or 1M in HBr or 1.12M in HCl - 2M in H_2SO_4 or 0.6M in HBr - 2M in H_2SO_4 or 0.64M in HBr - 7 M in H_3PO_4. Determination by scintillation counter (^{115}Cd tracer). Separated from Fe.	58
		10% in xylene	Aq: Dilute solution of HI. Stripping with 8% ethylenediamine. Determination by flameless A.A.S. Applied for the determination of Cd in silicate material.	62
	TBA	0.1M in chloroform	Aq: 1M in HBr or 0.25M in HI. Stripping with 2M HNO_3 or 0.25M aqueous ammonia. Determination by scintillation counter (^{115}Cd tracer). Separated from Zn.	49

Metal	Liquid anion exchanger	Conc. in diluent	Other details	Ref.
Cd (cont.)	TBA (cont.)	0.088M in chloroform	Aq: pH 1.5 and 0.5M in KI (adjusted with 1.5M H_2SO_4 and 6M KI) containing 10% $NaHSO_3$. Determination by spectrophotometry with dithizone. Separated from Zn.	50
	Aliquat 336	0.1M in chloroform or toluene	Aq: Acidity 0.12M and 0.2M in KSCN. Determination by scintillation counter (^{115}Cd tracer). Separated from Cr. Composition of the extracted complex is $[Cd(SCN)_4(R_3N^1N^+)_2]$	51
		0.1M in benzene	Aq: pH 2-5 and 1M in NH_4SCN	56
		5% in benzene	Aq: 0.1M in HCl or HBr. Separated from Fe(II) & Ni	271
		5% in xylene	Aq: pH 3-7 and 0.2M in KI or pH 11 and 2M in KI. Stripping with 10M aqueous ammonia or 5% ethylene diamine. Separated from Hg.	22
		5% in chloroform	Aq: pH 5.8 (adjusted with hexammine) containing 10% thiourea and 20% KI stripping with 10% KNO_3. Determination by spectrophotometry using 1(2-pyridylazo) naphthol.	54

	Alamine	0.01M in toluene	Aq: Acidity 0.014M and 2M in KSCN. Determination by scintillation counter (^{115}Cd tracer). Separated from Zn	51
		5% in xylene	Aq: 1M in HCl or HBr. Stripping with 0.1M EDTA, 1M NaOH or 2.5M NH_3. Determination by AAS. Applied for the determination of Cd in waste water.	53
	TOA	5mM in cyclohexane	Aq: 0.1M in KBr. Stripping with 0.1M H_2SO_4. Determination by spectrophotometry using dithizone. Applied for the analysis of fission products.	55
		0.1M in cyclohexane	Aq: 8-10M in HCl. Stripping with 2M H_2SO_4. Determination by spectrophotometry using dithizone. Applied for the determination of Cd in nuclear grade Zircalloy-2.	59
	Aliquat 336 or Amberlite LA-1	0.01M in chloroform 0.1M in benzene	Aq: 0.25M in HCl Stripping with 1M HNO_3. Determination by scintillation counter (^{115}Cd tracer). Separated from In	
	Alamine 336 or Aliquat 336	0.1M in benzene	Aq: 2M in HCl or LiCl. Determination by scintillation counter (^{115}Cd tracer). The ratio of the extracted complex is 1:4:2.	61

Metal	Liquid an on exchanger	Conc. in diluent	Other details	Ref.
^{109}Cd	Aliquat 336	5% in xylene	Aq: 1M in HCl. Stripping with 2M NH_3 or 5% ethylene diamine solution. Determination by scintillation counter.	63
^{115}Cd	Amberlite LA-2	5% in benzene	Aq: 0.64M in HBr. Determination by γ-ray spectrometry. Separated from ^{65}Zn and ^{60}Co	64
Ce(IV)	TOA	5% in benzene	Aq: pH 6-7 and 0.1M in succinic acid. Stripping with 6.5M H_2SO_4. Determination by EDTA titration. Separated from U, Mo, Zr, and V. The extracted species is $[(RNH^+)_2\ Ce\ (C_4H_4O_3)_3^{2-}]$	65
		0.3M in chloroform	Aq: 6M in HNO_3 containing 1 g of $KBrO_3$. Stripping with 4-6M HCl. Determination by spectrophotometry using arsenazo III. Separated from V, La, Y, Ni, Co, Mo and W.	66
Ce(III)	Aliquat 336	4% in xylene	Aq: pH 4.0, 10mM malonic acid. Stripping with 1M HCl. Determination by spectrophotometry using arsenazo III.	67
^{244}Cm	TOA	0.44M in cyclohexane	Aq: 0.1-2.0M in HNO_3 containing 7.2M $LiNO_3$	41

Co	Aliquat	0.03M in benzene	Aq: 2M in Hcl and 0.1-10M in KSCN	68
		0.5% in benzene	Aq: 1.5M in KSCN, 1M in sodium citrate and 0.15M in Tris-H_2SO_4 buffer of pH 8. Determination by spectrophotometry using erio T. Separated from Fe, Co, Zn and Ni.	70
		5% in chloroform	Aq: Nitroso-R salt. Determination by spectrophotometry. (λ_{max} = 500 nm). Separated from Fe, Cu and Ni	71
	Alamine	0.1M in toluene	Aq: 0.1M in HCl and 0.3M in KSCN	69
		0.1M in toluene or carbon tetrachloride	Aq: 0.2M in KSCN and 0.15M in HNO_3 or 8-9M in LiCl and 0.15M HCl. Determination by scintillation counter (^{58}Co tracer).	73
	TBA	--	Aq: SCN^-. Determination by spectrophotometry. Separated from Fe(III)	273
^{60}Co	Amberlite LA-2	5% in benzene	Aq: 12-18M in H_2SO_4 and 0.64M in HBr. Stripping with 3.2M HBr.	74
		--	Aq: 0.1mM HCl. Determination by scintillation counter. Separated from ^{115}Cd and ^{65}Zn.	64

Metal	Liquid anion exchanger	Conc in diluent	Other details	Ref.
Cr(III)	TOA	5% in chloroform	Aq: 0.1M in HCl and 4.75M in KSCN. Determination by γ-counting (^{51}Cr tracer). Composition of extracted species is $[Cr(H_2O)_2(SCN)_4][R_4N^+H]$	75
	Aliquat 336	5% in chloroform	Aq: pH 3.7-4.5 (adjusted with H_2SO_4) containing 1.2-diamino-cyclohexane-NNN'N'-tetra acetic acid. Stripping with 1M KNO_3. Determination by spectrophotometry. Separated from Cu, Fe, Ni and Co.	76
		5% in benzene	Aq: pH 9, containing nitrilotriacetic acid. Composition of the extracted species is $[Cr(NTA)(OH)_2]^{2-}[R_4N^+]_2$	77
		Hexane	Aq: Excess EDTA. Determination by spectrography. Composition of the extracted species is $[CrY(H_2O)]^-[R_4N^+]$; EDTA = H_4Y	78
		5% in chloroform	Aq: 1,2-diaminocyclohexane tetraacetic acid. Determination by spectrophotometry. Composition of the complex is $[Cr(DCTA)]^-[R_4N^+]$	79
		0.1M in chloroform	Aq: 0.05M in HCl and 4.75M in KSCN. Determination by γ-ray spectrometry (^{51}Cr tracer). Composition of the extracted species is $[(Cr(SCN)_6)^{3-}(R_4N^+)_3]$. Separated from Co and Ni	69

Cr(IV)	Aliquat 336	Chloroform	Aq: 0..1-0.2M in H_2SO_4 containing diphenyl carbazide. Determination by spectrophotometry (λ_{max} = 550 nm).	80
Cu	Amberlite LA-2	4% in IBMK	Aq: pH 1-8 and 3M in NH_4SCN. Determination by AAS. Applied for the trace determination of Cu in water.	81
	Tridodecyl ethyl ammonium bromide	0.6mM in benzene	Aq: pH 7.6 (adjusted with sodium acetate phosphate buffer) containing 0.5mM of Catechol Violet. Determination by spectrophotometry (λ_{max} = 663 nm). The ratio of the extracted species is 1:2:2 (*Cu:CV:TDEA*).	82
	Capriquat	Chloroform	Aq: pH 6.8-10.5 containing Zincon. Determination by spectrophotometry. Separated from Fe(II), Ni and Sn.	83
		3% in isopropyl acetate	Aq: pH 5.0 (acetate buffer) containing 25mM $Na_2S_2O_3$. Determination by AAS. Applied for the determination of Cu in Al.	274
	Aliquat 336	0.03M in benzene	Aq: 2M in HCl and 0.1-10M in KSCN	68
	Amberlite LA-1	1:8 in heptane	Aq: pH 7 containing excess EDTA. Stripping with dil. HNO_3. Determination by AAS. Applied for the trace determination of Cu in soils and rocks	84

Metal	Liquid anion exchanger	Conc. in diluent	Other details	Ref.
Eu	Aliquat 336	--	Aq: pH 1.92 (for Cl^- medium), 2.25 (for NO_3^- medium), 2.92 (for ClO_4^- medium) containing 0.08M thenoyl trifluoro acetone. Determination by spectrophotometry. Composition of the extracted species is $[Eu(TTA)_4]^-$ $[R_4^+N]$.	85
		--	Aq: strongly alkaline containing 2,3-dihydroxy-butane and 1,4-diamine tetracetic acid	29
		0.06M in cyclohexane	Aq: 2-4M in NaOH containing 4(αα-dioctylethyl) pyrocatechol and the alkyl phosphonate com-ploxons, ethylene diamine tetramethyl phosphonic and diethylene triamine pentamethyl phosphonic acid	40
	Benzyl dibutyl amine	0.5M in benzene or 0.04M in hexadecanol	Aq: 0.5M in HNO_3 and 3.25M in $Mg(NO_3)_2$. Determination by γ-spectrometry	37
	Aliquat 336 + TOPO or TBP	xylene	Aq: pH 2.8 and 1M in NH_4SCN. Determination by scintillation counter. Composition of the extracted species is $[Eu(SCN)_4.3\ TOPO]^-$ $[R_4N^+]$	39
^{152}Eu	TOA	0.44M in cyclohexane	Aq: 0.1-0.2M HNO_3 containing 7.2M $LiNO_3$	41

Fe(III)	Aliquat 336	0.2M in dichloroethane	Aq: 4mM EDTA. Separated from several metals at high pH	86
		5% in chloroform	Aq: pH 1 (adjusted with HCl) and 30% KSCN. Determination by spectrophotometry	92
		5% in benzene	Aq: 2.8M in HCl or HBr. Separated from Ni	271
	TOA	0.1M in chloroform	Aq: pH 2-3 containing citric acid.	87
		2% in chloroform	Aq: 4M in HCl. Separated from Al, Mn, Co and Ni	90
	Tridodecylethyl ammonium bromide	0.8mM in xylene	Aq: pH 5.8-6.5 (adjusted with acetate buffered 2M HCl) and 0.5mM of Eriochrome cyamine R. Determination by spectrophotometry. (λ_{max} = 613 nm). Composition of the extracted species is $[Fe(HR)_3]^{6-}[R_4N^+]_6$.	88
		1mM in IBMK	Aq: pH 5.8 containing 0.04 mM of catechol violet. Determination by spectrophotometry (λ_{max} = 623 nm). Cu, Bi and Sn masked with 2-mercapto-ethanol and Th, Al with KF.	89
	Alamine 336	Chloroform	Aq: HCl and HN_4SCN. Determination by spectrophotometry (λ_{max} = 480 nm).	91
^{59}Fe	Aliquat 336	0.3M in xylene	Aq: 2.4M in HCl. Determination by γ-ray spectrometry. Separated from Co and ^{54}Mn. Applied for the separation of carrier free ^{59}Fe from neutron activated Co and of ^{54}Mn from neutron irradiated Fe	93

Metal	Liquid anion exchanger	Conc. in diluent	Other details	Ref.
Ga	TOA	4 mM in chloroform	Aq: pH 5.8 (adjusted with acetate buffer) and 0.5 mM of gallion. Determination by spectrophotometry. (λ_{max} = 640 nm).	94
	TLA	0.04M in toluene	Aq: pH 1-3.5 and 0.4M in KSCN. Composition of extracted species is $Ga(SCN)_3$ $(HTLA\ SCN)_2$. Separated from Al.	95
Gd	TOA or bis(2-ethylhexyl) amine or TDA	Octane or chloroform	Aq: HCl and thenoyl trifluoro acetone	96
Ge	TOA	4:1 (TOA:Ge) in kerosene	Aq: pH 0.8 containing 0.4M $(NH_4)_2SO_4$ and oxalate in the 1:4 ratio of Ge oxalate.	97
	--		Aq: Tartaric or citric acid. Ge is extracted as $[Ge(OH)L]^-$ and $[H\ Ge\ (OH_2\ (L^1)_2]$, respectively in the presence of tartaric and citric acid	98
Hf	Primene JMT	0.14M in kerosene containing 3% octanol	Aq: 0.7M H_2SO_4. Determination by scintillation counter (^{175}Hf tracer). Separated from Zr.	99
Hg	Amberlite LA-1, LA-2	0.1M in chloroform	Aq: 0.25M HCl. Determination by scintillation counter (^{203}Hg tracer). Separated from Zn and Cd	100
	TBA	0.1M in chloroform	Aq: 0.25M HBr or HI. Stripping with 0.5M aq-ammonia. Determination by scintillation counter. Separated from Zn.	49

Hg (cont.)	TBA (cont.)	0.1M in chloroform (cont.)	Aq: 0.05M HBr. Stripping with 0.5M aq-ammonia. Determination by scintillation counter. Separated from Cd.	
		0.088 M in chloroform	Aq: pH 4.0 and 0.05M in KBr. Determination by spectrophotometry using dithizone. Separated from Cd and Zn.	50
	TOA	3% in benzene	Aq: 3-4M in H_2SO_4 or 0.1-0.25M HNO_3. Stripping with 2M NaOH. Determination by EDTA titration Separated from Cd and Zn.	101
	Amberlite LA-1 or Alamine 336	Chloroform	Aq: 0.5M NH_4SCN. Stripping with 4M HNO_3. Determination by scintillation counter. Separated from Cd.	102
	Trinonyl octadecyl ammonium picrate	Toluene	Aq: dilute solution of HI. Determination by spectrophotometry. Composition of the extracted species is $[HgI_3]^-[TNODN^+]$.	103
	Aliquat 336	5% in xylene	Aq: pH 1.3-12.5 containing 0.06-4.7M of KI. Stripping with cystine. Determination by scintillation counter.	21
		0.1M in benzene or chloroform	Aq: 0.5-4M in HCl. Determination by scintillation counter.	105
		5% in benzene	Aq: 0.5M in acetic acid. Stripping with 4M NaOH. Determination by spectrophotometry. Separated from Zn, Cd, Cu, Mn and Bi.	107
	Primene JMT	0.1M in chloroform	Aq: pH 4.3 (acetate buffer). Determination by scintillation counter. Separated from Zn, Cd and Tl.	106

Metal	Liquid anion exchanger	Conc in diluent	Other details	Ref.
In	Aliquat 336	10% in benzene	Aq: 0.5M in Hcl and 9M in H_2SO_4. Separated from Sn(II) and Sn(IV).	108
		4% in xylene	Aq: pH 4.0-5.0 and 0.01M in malonic acid. Stripping with 0.5M HCl. Determination by spectrophotometry with 4-(2-pyridylazo) resorcinol (PAR). Separated from Tl(I), Fe(II), Ag, As, Y, Sn and lanthanides by selective extraction and Cd, Ni, Cu, Co, Cr(III), Al and Mn by selective stripping.	109
	Alamine 336	0.5M in nitrobenzene	Aq: 8M in HCl	277
	TOA	60 mM in chloroform	Aq: pH 6.8 (acetate buffer) containing 0.5 mM of Gallion. Determination by spectrophotometry (λ_{max} = 640 nm).	94
		5% in benzene	Aq: pH 7.0, containing 0.025M sodium succinate. Stripping with 0.25M HCl. Determination by spectrophotometry (PAR). Separated from Tl.	275
	TLA	0.04M in toluene	Aq: pH 1-3.5 and 0.4M in KSCN. Separated from Al.	95
		0.02M in toluene	Aq: 0.2M in KSCN. Separated from Ga	95
Ir	TOA	0.2M in benzene	Aq: 6M in HCl. Stripping with 7M aqueous ammonia. Determination by γ-ray spectrometry (^{192}Ir tracer). Separated from Rh.	
Lanthanides	Aliquat 336	0.1M in chloroform	Aq: EDTA	111

Mg	Benzyl dimethyl tetradecyl-ammonium chloride	5 mM in chloroform	Aq: pH 10.1-11.4 containing 8-hydroxy-quinoline-5-sulphonic acid. Determination by spectrophotometry. (λ_{max} = 390 nm). Separated from five times excess of Ca. Composition of the extracted species is $[M_3^{2+} (QS^{2-} Z^+)_2 (HQS^- Z^+)]_0$ where HQS = 8-hydroxyquinoline-5-sulphonic acid and Z^+ is the cationic part of the exchanger.	112
Mo(VI)	TOA	0.05M in 2-chloro-ethyl ether	Aq: 0.5M in HE and 4-8M in NH_4F. Separated from W.	113
		Toluene	Aq: pH 0.5-2 (adjusted with H_2SO_4). Determination by spectrophotometry. Separated from Fe, V and Cr.	118
		Benzene	Aq: 0.01-0.1M in HCl. Stripping with 0.4M NaOH. Determination by spectrophotometry. Composition of the extracted species is $[MoO_2Cl_4]^{2-}[R_3NH^+]_2$.	115
	Aliquat 336	0.02M in toluene or chloroform	Aq: acidity 4M and 2-6M in Cl^-	114
		0.01M in chloroform	Aq: pH 4.6 (acetate buffer) and 0.1M in 8-hydroxyquinoline-5-sulphonate (Na) containing 1.9M hydrazine.	279
	Amberlite LA-1	0.1-1.0% in chloroform	Aq: SCN^- medium. Determination by AAS.	25
		0.1% in chloroform	Aq: 2M in HCl containing SCN^-	117
	Amberlite LA-2	0.08M in xylene	Aq: pH 3.0, 0.02M malonic acid. Stripping with 0.25M NH_3. Determination by spectrophotometry using Tiron. Applied for the estimation of Mo in steel and soil.	278

Metal	Liquid anion exchanger	Conc. in diluent	Other details	Ref.
^{99}Mo	Alamine 336	50 mM in xylene or cyclohexane	Aq: 0.01M in H_2SO_4 or 0.01M in HNO_3 containing $(NH_4)_2$ SO_4. Determination by γ-ray spectrometry. Separated from ^{99m}Tc. Applied for the determination of ^{99}Mo in reactor coolant water.	119
Mn	Aliquat 336	0.1M in toluene or chloroform	Aq: 0.05M in HNO_3 and 2M in KSCN. Determination by spectrophotometry. Composition of the extracted species is $[Mn(SCN)_4]^{2-}$ $[R_3R'N^+]_2$.	120
		0.03M in benzene	Aq: 2M in HCl and 0.1-1.0M in KSCN.	68
		Benzene	Aq: pH 2.5-7 and 0.25M in KSCN. Stripping with dilute ammoniacal solution of triethanolamine and hydroxyl ammonium chloride. Determination by EDTA titration. Separated from Ca, Mg, Al, Cu and Zn. Applied for the determination of Mn in natural ores.	121
	Amberlite LA-1	1:8 in heptane	Aq: pH 7 containing EDTA. Stripping with dil HNO_3. Determination by AAS. Applied for the determination of Mn in soils and rocks.	84
Nb	Tributyl methyl ammonium chloride	IBMK or 1,2-dichloroethane	Aq: pH 6.7-8.0 containing 3-methyl catechol, heated at 85°C for 6 min for colour development. Determination by spectrophotometry. Separated from Ti, V, Mo and W. Applied for the determination of Nb in a mixture of refractory metal ions.	122

	TOA	0.1M in xylene or dichloro-ethane	Aq: up to 1M aq. HF	123
	Trialkyl benzyl ammonium chloride (hexadecyl to octadecyl)	0.1M	Aq: pH 1.5 containing 0.4M tartaric acid. Separated from Ti.	124
	Tridodecyl ethyl ammonium bromide	1 mM in chloroform	Aq: pH 4.5 containing 0.06 mM catechol violet. Determination by spectrophotometry (λ_{max} = 553 nm). Cu, B and Sn masked with 2-mercaptoethanol.	125
	Tetraoctyl ammonium bromide	10 mM in toluene	Aq: 0.4M in oxalic acid. Stripping with (3M HCl-0.5M H_2O_2). Determination by spectrophotometry using crystal violet. Separated from W, Mo, Zn, Cu, Fe and Sn.	126
Ni	Aliquat 336	0.03M in benzene 10% in xylene 0.1M in toluene 5% containing 0.001% dithizone	Aq: 0.1-1.0M in KSCN. Aq: pH 2.5 and 1.0M in NH_4SCN. Stripping with 2M H_2SO_4 or 2.5M Na_2CO_3. Separated from Co. Aq: 0.01M in HCl and 0.3M in KSCN Aq2: pH 5.2, 10% KSCN. Determination by spectrophotometry. (λ_{max} = 503 nm).	68 127 280

Metal	Liquid anion exchanger	Conc. in diluent	Other details	Ref.
Np(IV)	Aliquat 336	10% in Solvesso-100	Aq: 3M in HNO_3. Stripping with formic or acetic acid. Determination by γ-counting.	128
		10% in Solvesso-100	Aq: 4M in HNO_3. Determination by spectrophotometry using xylenol orange (λ_{max} = 535 nm). Separated from U, Pu, Zr, F and NO_2^-.	131
	TDDA	20% in Solvesso-100	Aq: 1M in HNO_3. Determination by γ-counting.	129
	Tricapryl methylamine	30% in xylene	Aq: 7M in HCl and 4.5M in H_2SO_4. Stripping with very dilute H_2SO_4. Determination by scintillation counter. Separated from Zr, Nb, rare earths, alkali metals and transplantonium elements.	130
Np(V)	Aliquat 336 or TLA	10% in Solvesso-100	Aq: 3-4M in HNO_3. Stripping with formic or acetic acid. Determination by scintillation counter.	132
	Capriquat	--	Aq: 0.05M acetic acid-aqueous ammonia buffer and TTA. Determination by scintillation counter.	133
Np(VI)	Aliquat 336 or TLA	10% in Solvesso-100	Aq: 3M in HNO_3. Determination by scintillation counter.	132
	TOA or TDDA	10% in chloroform	Aq: 1M in acetic acid. Determination by scintillation counter.	134
Os(VIII)	TOA	5% in benzene	Aq: 5M in HCl. Stripping with 2M NaOH. Determination by spectrophotometry using thiourea. Separated from platinum group metals.	135

Pa	TOA	0.1M in xylene containing 3-5% isopentyl alcohol 0.2M in xylene containing 3-5% isoamyl alcohol	Aq: 0.5M in HCl and 1-2M in NaSCN Aq: 0.2-1.5M in SCN^-. Determination by scintillation counter. Separated from Pa(IV)	136 137
^{233}Pa	TLA	20% in benzene	Aq: 9M in H_2SO_4 and 3M in HBr. Determination by γ-ray spectrometry. Separated from Th.	138
Pb	Amberlite LA-1	3%	Aq: 0.2M in HCl and 0.3 in KI. Determination by AAS. Separated from Fe, Ni, Cd, Mn and Zn. Applied for the analysis of river water and plants from road side.	139
	Capriquat	3% in isopropyl acetate	Aq: pH 5 (adjusted with 10% citric acid - aqueous ammonia) and 0.05M in $Na_2S_2O_3$. Determination by AAS. Separated from Zn.	140
	Alamine 336 or Aliquat 336	5%	Aq: 2M in HCl. Stripping with 0.1M EDTA. Determination by AAS. Composition of the extracted species is $[PbCl_3]^-$ $[R_3N^+H]$.	141

Metal	Liquid anion exchanger	Conc. in diluent	Other details	Ref.
Pd(II)	TOA	10% in carbon tetrachloride	Aq: 0.5-1M in HNO_3. Stripping with 2.5M EDTA. Determination by scintillation counter (^{103}Pd tracer). Separated from other nuclear fission products.	142
		Xylene	Aq: 6M in HCl. Determination by AAS. Separated from U.	144
		5% in chloroform	Aq: 0.1-6M in HCl or HBr. Separated from Ir, Rh, Ti, Zr, Hf, W, Nb, Cu, Co, Sb, alkali and alkaline earth metals.	44
		3-5% in benzene	Aq: 0.1M in acetic acid or 25 mM in succinate medium. Stripping with 2% NH_3. Separated from Pt, Rh, Ir, Ni, Os and Ru.	281
	Aliquat 336	5% in chloroform containing 10 ppm of dithizone	Aq: 9.6M in HCl. Determination by spectrophotometry	143
Pr	TOA or TDA or bis (2-ethyl hexyl) amine	Octane or chloroform containing TTA	Aq: HCl Determination by spectrophotometry.	96
Pt(IV)	TOA	5% in benzene	Aq: 0.1M in acetic acid or 20 mM in succinate medium. Stripping with 8M HNO_3. Separated from Pd, Rh, Ir, Ni, Os and Ru	281
		5% in chloroform	Aq: 0.1-6M in HCl or HBr	

Pu(IV)	Aliquat 336	30 in xylene 5% in xylene	Aq: 1-4M in HNO_3. Stripping with a mixture of 1M formic or acetic acid and 0.02M HNO_3. Determination by scintillation counter (^{238}Pu tracer). Aq: 4M in HNO_3. Determination by spectrophotometry using Xylenol Orange (λ_{max} = 540). Applied for the determination of Pu in uranium, fission products and cladding materials.	145 146
Pu(VI)	Aliquat 336 or TLA	10% in Solvesso-100	Aq: 3-4M in HNO_3. Stripping with formic or acetic acid. Determination by α-counting.	132
Rh	Benzyl hexadecyl-dimethyl ammonium chloride	0.195% in hexane-isoamyl alcohol mixture (9:1) 0.01-0.05M in chloroform	Aq: 1% Na_2CO_3. Stripping with 2.5% NH_4Cl solution. Separated from Mo. Aq: 1-7M in HCl. Composition of the extracted species is $[RhCl_6]^{2-}$ $[R_4N^+]_2$	147 149
	Benzyl dimethyl tetra-decyl ammonium chloride Amberlite LA-1	0.2% in kerosene-isoamyl alcohol mixture (19:1) 0.1-1% in chloroform	Aq: 20% in Na_2CO_3. Stripping with conc. H_2SO_4, HNO_3 or HCl. Separated from Mo Aq: SCN^- Determination by AAS.	148 116
	TOA	Xylene	Aq: 6M in HCl. Determination by AAS. Separated from U.	144
Ru(III)	DDA	Chloroform isoamyl alcohol	Aq: 6M in HCl	150
	TOA	Xylene	Aq: 6M in HCl Determination by AAS Separated from U.	144

Metal	Liquid anion exchanger	Conc. in diluent	Other details	Ref.
Sb	Amberlite LA-1	1% in ethyl acetate	Aq: 0.8M in HCl and 0.25M in KI. Determination by AAS. Separated from Fe(III), Cu, Pb, Cd and Zn. Applied for the determination of Sb in glass.	151
Sc	Amberlite LA-1 or LA-2	Xylene	Aq: pH 2.5-5.5 and 0.1M in malonic acid. Stripping with 0.5M HCl. Determination by spectrophotometry using Alizarin Red S (λ_{max} = 525 nm). Separated from alkali and alkaline earth metals, Tl^{+}, Tl^{3+}, Fe^{2+}, As^{3+}, Y, Sn^{4+}, Zn, Cd, Ni, Cu, Co, Cr, Al, Pb and Mn.	152
	$^{AP}19$-23 (a mixture of $^{C}19$-$^{C}23$ aliphatic primary amines	0.1M in kerosene	Aq: 0.5M in H_2SO_4. Stripping with 2M HNO_3 or HCl.	153
	TOA	5% in benzene	Aq: pH 4.5 and 0.06M in sodium succinate. Stripping with 1M HCl. Determination by spectrophotometry using arsenazo 1. Separated from Fe, Mo and U.	154
Se	Amberlite LA-1	2.5%	Aq: 9M in HCl	155
Sn(IV)	TOA	5% in benzene	Aq: 0.5M in HCl or acetic acid. Stripping with 0.5M HNO_3. Determination by spectrophotometry using Pyrocatechol Violet. Separated from Cu, Mn, Zn, Cd, Hg, Ni, Pb, Al, Bi and Mo	156
	Alamine 336	0.5M in nitrobenzene	Aq: 8M in HCl	277

Ta	TOA	0.1M in xylene or dichloro-ethane	Aq: 1M in HF	123
	Trialkylbenzyl ammonium chloride (hexadecyl to octadecyl)	0.01M	Aq: pH 1.5 and 0.4M in tartaric acid. Separated from Ti.	124
	Tetra octyl ammonium bromide	10 mM in toluene	Aq: 0.4M in oxalic acid. Stripping with 3M HCl - 0.05M H_2O_2 mixture. Determination by spectrophotometry using Crystal Violet. Separated from W, Mo, Zn, Cu, Fe^{3+} and Sn^{4+}.	126
	Amberlite LA-2	10% in benzene	Aq: 1M in HF and 0.1M in HCl. Stripping with a mixture of 1M NH_4F - 4M NH_4Cl. Determination by spectrophotometry using Malachite Green (λ_{max} = 630 nm). Separated from Fe^{3+}, Ni, Cr, Mn, B and Mo. Applied for the determination of Ta in high alloy steel.	157
Tc	TOA	10% in carbon tetrachloride	Aq: 0.5-1M in HNO_3. Stripping with 2.5M NH_3. Determination by plastic scintilator. Separated from other nuclear fission products.	142
	Alamine 336	50 mM in cyclohexane or xylene	Aq: 0.05M in HNO_3. Determination by γ-ray activity. Separated from Mo. Applied for the determination of Tc in reactor coolant water.	119

Metal	Liquid anion exchanger	Conc. in diluent	Other details	Ref.
Te	TOA	5% in xylene	Aq: 0.2M in $HClO_4$ and 0.1M in NaI. Stripping with 1M aq: NH_3. Applied for the separation of Tc from fall-out samples.	158
Th	Aliquat 336	5% in xylene	Aq: 4M in HNO_3. Determination by spectrophotometry using xylenol orange (λ_{max} = 540).	159
		5% in xylene	Aq: 4M in HNO_3. Stripping with 3M HCl. Applied for the determination of Th in reprocessing plant and in low-grade Th ores	162
		1% benzene	Aq: pH 7-8 containing 0.075-0.1M sodium succinate Stripping with 0.1M HNO_3. Separated from U(VI) and Nd.	282
	Amberlite LA-2 or TDDA	0.16M in cyclohexane	Aq: 6.6M in HNO_3. Determination by scintillation counter (^{234}Th tracer).	160
	TOA	5% in benzene	Aq: pH 6-7 and 0.1M in succinic acid. Stripping with water acidified with HNO_3. Determination by EDTA titration. Separated from U, Mo, Zr and V. The extracted species is $[Th(C_4H_4O_3)_3^{2-}(RNH^+)_2]$	65
	Amberlite LA-1	4% in xylene	Aq: pH 3 (adjusted wth 0.02M NaOH containing 0.02M malonic acid). Stripping with 1M HCl. Determination by spectrophotometry using Thoron.	162

^{230}Th	Adogen 364	30% in xylene	Aq: 2M in HNO_3. Stripping with 10M HCl. Determination by α proportional counter. Separated from Po, Pa, U, Np, Pu and Zr. Composition of the extracted species is $[Th(NO_3)_6]^{2-}[R_3NH^+]_2$	163
^{234}Th	Aliquat 336	0.16M in benzene	Aq: 2M in HNO_3 and 40% methanol. Separated from U.	164
Ti	Primary amine	Chloroform	Aq: H_2SO_4 with 20% ethanol or 30% methanol. Separated from Zr.	165
	Aliquat 336	Benzene	Aq: HCl and KSCN	166
	Aliquat 336 or TOA	5% in benzene	Aq: pH 4.5, 0.05-0.07M in sodium succinate.	283
	TOA	25 mM in chloroform	Aq: 7-8M in HCl containing 20 mM of benzohydroxamic acid or salicylohydroxamic acid. Determination by spectrophotometry (λ_{max} = 370 nm). Composition of the extracted species is $[Ti(BHA)_2Cl_4]^{2-}[R_3N^+H]_2$. Applied for the determination of Ti in aluminium containing Fe and Si.	167
		5% in benzene	Aq: pH 4.5 and 0.07M in sodium succinate. Stripping with 4M H_2SO_4. Determination by spectrophotometry using H_2O_2. Separated from Mn, Mo, U, W, Ta, V, Cr, La and Y. Composition of the extracted species is $[Ti(C_4H_4O_4)_3]^{2-}[R_3HN^+]_2$.	168

Metal	Liquid anion exchanger	Conc in diluent	Other details	Ref.
Tl(III)	Alamine 336	Chloroform	Aq: 0.1M in HCl. Stripping with 20% ammonium acetate. Determination by γ-activity measurement (^{204}Tl tracer). Separated from Cd.	52
		Benzene	Aq: 1M in HCl. Stripping with 20% ammonium acetate. Determination by γ-activity measurement (^{204}Tl tracer). Separated from In.	52
U(VI)	Aliquat 336	5% in chloroform	Aq: dil. H_2SO_4. Stripping with a mixture of 0.5 KCl and 0.5M HCl. Determination by polarography. Separated from Fe, Zn, Mn, Cu, Co, rare earth metals, Th and As. Applied for the determination of U in monazite and river sediment.	169
		0.16M in benzene	Aq: 6.5M in HNO_3.	164
		0.1% in dichloro-ethane	Aq: dil. HCl buffered at pH 6.5 with 0.1M sodium acetate and 0.1M acetic acid, containing 0.26 g azobenzene. Determination by spectrophotometry (λ_{max} = 543 nm).	174
		0.01-0.05M in xylene	Aq: 8-9 M HCl.	175
	TOA	20% in chloroform	Aq 0.25M in HNO_3 that is 1M in malonic acid. Separated from Ag, Zr, Co, Cs, Zn, Eu and Tb.	134
		0.15M in toluene	Aq: 1-2M in H_2SO_4. Determination by spectrophotometry. Composition of the extracted species is $[UO_2(SO_4)_2]^{2-}$ $[R_3NH^+]_2$	170

U(VI) (cont.)	TCA (cont.)	5% in xylene	Aq: 5M in HCl. Determination by spectrophotometry using chlorophosphonazo III. Separated from Ti, Zr, Th and rare earth metals. Applied for the determination of U in desorbing solution from the U concentration process in sea water.	173
		Kerosene	Aq: dil. H_2SO_4. Determination by a Technicon Autoanalyser system with colorimetric detection.	176
		3% in xylene	Aq: 0.05-0.2M in H_2SO_4. Stripping with 0.5M Na_2CO_3. Separated from Th. Applied for the determination of U in reprocessing plant.	162
	Aliquat 336 or TLA	10% in Solvesso-100	Aq: 6-7M in HNO_3. Stripping with formic or acetic acid. Determination by α-counting (^{233}U tracer).	132
	Amberlite LA-2 or TDDA	0.16M in cyclohexane	Aq: 6.6M in HNO_3	160
	Tridodecyl ethyl ammonium bromide	5 mM in chloroform	Aq: pH 9 (adjusted with borate buffer) containing 0.5 mM of PAR. Determination by spectrophotometry (λ_{max} = 550 nm).	171
	Alamine 336	5% in benzene or xylene	Aq: pH 1 containing H_2SO_4. Determination by spectrophotometry using arsenazo III Separated from Fe^{3+}, Mn, Cu, Ni and Co.	177

Metal	L quid anion exchanger	Conc. in diluent	Other detai s	Ref.
U(IV)	Amberlite LA-1	4% in xylene	Aq: pH 2.5-4 and 0.001M in malonic acid. Stripping with 0.01M NaOH. Determination by spectrophotometry using PAR. Separated from alkali and alkaline earth metal ions, Ti, Fe, Ag, As, Sn, Zn, Cd, Ni, Cu, Co, Cr, Al, Pb, Bi, Sb and Y.	172
		Cyclohexane	Aq: 8.5M in HNO_3. Composition of the extracted species is $[U(NO_3)_6]^{2-}$ $[R_4N^+]_2$	179
	TOA	0.1M in benzene	Aq: 0.1M in H_2SO_4. Determination by spectrophotometry.	178
^{233}U	Primene JMT	0.5M in kerosene	Aq: 12M in HNO_3 and nitrate. Composition of the extracted species is $[U(NO_3)_6(RNH_3)_2]$	180
	TLA	20% in benzene	Aq: 9M in H_2SO_4 and 0.5M in HBr. Determination by γ-ray spectrometry.	138
^{237}U	Aliquat 336	10% in toluene	Aq: 0.1-0.3M NH_4NO_3. Determination by γ-ray spectrometry. Applied for the determination of ^{237}U in fission products.	181
V(III)	TBA	2% in chloroform	Aq: 1M in H_2SO_4 containing 0.75-0.9 g $Na_2S_2O_4$.	182
V(IV)	Aliquat 336	Benzene	Aq: KSCN and HCl	166
		0.08 in benzene	Aq: 0.1M in HCl and LiCl. Composition of the extracted species is $[VOCl_3]^-$ $[R_3N^+]$	183

V(V)	TOA	Benzene	Aq: pH 4 and 0.01M in sodium succinate. Stripping with acetate buffer of pH 4.7. Determination by spectrophotometry using PAR. Separated from Nb and Ta.	184
	Tridodecyl ethyl ammonium bromide	5 mM in carbon tetrachloride	Aq: 1M in H_2SO_4 containing 0.5 mM catechol violet, pH adjusted to 5 with 2M sodium acetate. Determination by spectrophotometry (λ_{max} = 570 nm)	185
W	Benzyl dimethyl tetradecyl ammonium chloride	25 mM in chloroform	Aq: 1.7M in NH_4SCN. Stripping with 10% $SnCl_2$ in conc. HCl. Determination by scintillation counter (^{187}W tracer). Separated from Mo	186
	Amberlite LA-1	0.1-1% in chloroform	Aq: SCN^- medium. Determination by AAS.	116
Y	Tridodecyl ethyl ammonium bromide	0.6 mM in xylene	Aq: pH 5.7 (adjusted with 2M sodium acetate and 0.4M barbitone (sodium) containing Xylenol Orange. Determination by spectrophotometry. (λ_{max} = 604 nm).	187
Yb	TOA or TDA	Octane or chloroform	Aq: HCl medium	96
	Aliquat 336	--	Aq: 0-6M in H_2SO_4 and 2M in NH_4SCN Separated from Eu and Pr.	188

Metal	Liquid anion exchanger	Conc. in diluent	Other details	Ref.
Zn	Aliquat 336	5% in xylene	Aq: 1M in KBr and pH 1-2. Stripping with 1M Na_2SO_4. Determination by scintillation counter. Composition of the extracted species is $Zn\ Br_4^{2-}(R_4N^+)_2$	195
		5% in xylene	Aq: 1M in HI. Stripping with 1M Na_2SO_3. Separated from Cd.	189
		Benzene or chloroform	Aq: 0.1-4.0M in NH_4SCN. Stripping with 4M HNO_3. Determination by scintillation counter. Separated from Tl.	102
		0.046M in chloroform or carbon tetrachloride	Aq: 0.5M in SCN^-. Determination by γ-ray spectrometry.	197
		0.1M in dodecane containing 5% tridecanol	Aq: pH ≥ 10 and 0.4M in NaCN. Stripping with 12M NaOH or 4.3% aq NaClO. Determination by scintillation counter.	24
		5% in xylene	Aq: 1M in HCl. Stripping with 2M NH_3 or 5% ethylene diamine. Determination by scintillation counter.	63
	Alamine 336	0.1M in xylene	Aq: pH 0.75 containing 0.5M HCl or pH 0.2 containing 2M HBr. Stripping with 0.05M EDTA or 0.2M NaOH or 0.05M NH_3. Determination by scintillation counter (^{65}Zn tracer)	192
		Chloroform	Aq: 0.5M in NH_4SCN. Stripping with 0.1M HNO_3. Determination by scintillation counter. Separated from Cd.	102

Zn cont.	Amberlite LA-1	1:20 in nitrobenzene	Aq: ≥ 2M in HCl. Stripping with 2M HNO_3. Separated from Ce, Sr, Ba, Mn and Ni.	284
		Chloroform	Aq: 0.1M in NH_4SCN. Stripping with 0.1M HNO_3. Determination by scintillation counter (^{65}Zn tracer). Separated from Cd.	102
	Amberlite LA-2	0.1M in toluene	Aq: 2M in HCl. Stripping with water. Separated from Co.	193
		5% in benzene	Aq: 1M in HBr or 9N in H_2SO_4 and 0.05M in KI. Determination by scintillation counter.	57
		5% in benzene	Aq: 12M in H_2SO_4 and 0.64M in HBr. Stripping with water. Separated from Co.	74
	TOA	20% in chloroform	Aq: 3M in HCl. Determination by spectrophotometry using dithizone. Applied for the determination of Zn in Al and Ni.	190
	Benzyl hexadecyl dimethyl ammonium chloride	2 mM in chloroform	Aq: pH 9.7 (adjusted with 0.2M Na_2CO_3 and 0.2M $NaHCO_3$) containing 0.01% of PAR. Determination by spectrophotometry. (λ_{max} = 505 nm).	191
	Alamine 308	5% in xylene	Aq: 0.5M in HCl. Stripping with 0.2M EDTA or 0.5% ethylene diamine. Determination by AAS.	194
	Alamine 336 or Aliquat 336	0.1M in benzene	Aq: pH 2-4 and 1M in NH_4SCN. Determination by scintillation counter. Composition of the extracted species is $[Zn(SCN)_4]^{2-}$ $[R_4N^+)]_2$	196

Metal	Liquid anion exchanger	Conc. in diluent	Other details	Ref.
Zr	Aliquat 336	Benzene 0.2M in kerosene 1,2-dichloroethane	Aq: KSCN and HCl Aq: 0.8M in H_2SO_4. Stripping with 0.5-1M HNO_3. Determination by scintillation counter (^{95}Zr tracer). Separated from Hf. Aq: 6M in HCl	166 200 202
	Dodecyl amine	0.235M in benzene containing 10% 2-ethylhexanol	Aq: 0.1M H_2SO_4.	203
	Tridodecyl ethyl ammonium bromide	0.6 mM in butyl acetate	Aq: 0.1M H_2SO_4 containing 0.5 mM of catechol violet, pH 5-6 (adjusted with 2M sodium acetate). Determination by spectrophotometry. (λ_{max} = 586 nm). Composition of the extracted species is $[Zr(CV)_2]^{3-}$ $[R_4N^+]_3$	199
	Amberlite LA-1	4% in xylene	Aq: pH 3.0 and 0.01M in malonic acid. Stripping with 2M HCl. Determination by spectrophotometry using arsenazo III. Separated from Zn, Cd, Ni, Cu, Co, Al, La, Pr, Nd, Ga, Bi, Fe, U, Sc, Ce, In and Ti. Applied for the analysis of Zircon.	201

Zr cont.	Amberlite LA-1 cont.	80 mM in xylene	Aq: pH 3.5, 1 mM citric acid. Stripping with 2M HCl. Determination by spectrophotometry using arsenazo III. Applied for the analysis of Zircon.	
	TOA	5% in benzene	Aq: pH 3-7 containing 0.167 g sodium succinate. Stripping with 2M HCl. Determination by spectrophotometry using arsenazo III. Separated from Mn, Fe, Hf, V, Ta, Mo, W, U, Cr, Ti, La, Th and Y. Applied for the analysis of Zircon. Composition of the extracted species is $[Zr(C_4H_4O_4)_3]^{2-}$ $[RN^+H]_2$	168

DDA = Dodecylamine TBA = Tribenzylamine; TDA = Tridecylamine;
TDDA = Tridodecylamine TLA = Trilaurylamine; TOA = Tri-n-octylamine
TDEA = Tridodecyl ethyl ammonium bromide

TABLE 2: SOLVENT EXTRACTION OF ELEMENTS WITH LIQUID CATION EXCHANGERS

Metal	Liquid cation exchanger	Conc. in diluent	Other details	Ref.
Ac	HDEHP	1M in benzene	Aq: pH 2.2. Stripping with 0.5M HCl. Determination by scintillation counter. Separated from Ra.	204
Al	HDEHP	--	Aq: dil. H_2SO_4. Determination of the organic phase by Ir or NMR. Distribution coefficient studies in a function of acid, metal and liquid ion exchanger concentration.	205
Am	HDEHP	Heptane	Aq: 1M in NaCl and HCl	206
		0.03-0.3M in benzene or cyclohexane containing 0.01 - 1M P_2O_5	Aq: 10M in H_3PO_4. Stripping with 30% $(NH_4)_2CO_3$ or 10% $NaHCO_3$. Determination by scintillation counter.	207
		--	Aq: 0.1M in HNO_3. Determination by neutron activation analysis.	208
		0.3M in cyclohexane containing 0.1M P_2O_5	Aq: 12M in HNO_3. Determination by γ-ray spectrometry.	209, 288
		0.003M in cyclohexane	Aq: 1-2M in HNO_3.	209
		Solvesso-100	Aq: 0.02M in HNO_3 and 2-5M in $Al(NO_3)_3$. Determination by spectrophotometry with arsenazo III ($\lambda_{max} = 652$).	287

As	Bis-(2-ethylhexyl) phosphorodithioate	0.1N in heptane	Aq: 2-4M in HCl, containing 10% KI and 5% thiourea. Stripping with 2M $(NH_4)_2SO_4$ in 5M NH_3. Determination by titrimetry. Separated from Sb.	210
Ba	SRS-100	Benzene	Aq: pH 8.75. Stripping with 3M HNO_3. Determination by complexometric titration.	211
Be	HDEHP	0.02M in hexane	Aq: pH 2 (HCl) containing 2M KSCN Determination by scintillation counter (^{7}Be tracer).	212
		0.2M in kerosene	Aq: pH 3 adjusted with 0.1M HCl. Determination by scintillation counter (^{7}Be tracer).	213
		0.1M in kerosene	Aq: pH 1-8 adjusted with 0.1M H_2SO_4. Determination by scintillation counter.	257
Bi	HDEHP	Octane	Aq: $HClO_4$. Determination by spectrophotometry using Catechol Violet (λ_{max} = 560 nm). Separated from Cu, Co, Mn, Ni, Cd, Fe^{2+} and Pb. Applied for the determination of Bi in alloys.	214
		Isobutyl methyl ketone	Aq: pH 1.0. Determination by AAS. Separated from Pb.	265
		Octane	Aq: 2M in HNO_3 containing 80% DMF. Separated from In.	215
		0.5N in octane	Aq: 8-10M in $HClO_4$. Stripping with 0.5M $HClO_4$.	216

Metal	Liquid cation exchanger	Conc. in diluent	Other details	Ref.
Bi cont.	HDEHP cont.	Benzene-light petroleum	Aq: 1-8M H_2SO_4. Stripping with 4M NaCl. Determination by spectrophotometry using thiourea. Separated from Zn, Cd, Fe^{2+}, Applied for the determination of Bi in the wet-processing of Zn ore.	217
		1.3M in chloroform	Aq: 0.2-0.5M in HNO_3. Separated from Ag, Co, Cr, Cu, Mg, Mn, N, Pb, Pt, Sb, Te and Tl.	218
		1.3M in chloroform	Aq: Cl^- medium. Stripping with a mixture of H_2SO_4 and NaCl.	221
	SRS-100	Benzene	Aq: pH 7.0 Separated from Al, Ga, In, Tl Fe Ce, Zr, Th, Mo, W, Pa, Pt, Ca, Mg, Sr and Ba	219
Bk	HDEHP	0.5M	Aq: Nitric acid - citric acid	222
Ca	Versatic 9	50% in butanol containing 5% ethanolamine	Aq: pH 7.25. Stripping with 4M HNO_3. Determination by complexometric titration.	223
	SRS-100	Benzene	Aq: pH 8 8 Stripping with 3M HNO_3. Determination by complexometric titration.	
Cf	HDEHP	0.5M	Aq: Nitric acid - citric acid	222
Cm	HDEHP	Heptane	Aq: 1M in NaCl and HCl	206
		0.5M	Aq: Nitric acid - citric acid.	222
Cu	Naphthenic acid	1M in kerosene	Aq: pH 6 85. Stripping with 0 5-2M H_2SO_4. Determination by complexometric titration	224
	LIX 64N	5-10% in kerosene	pH 1.5-2.2. Separated from Fe and Ni.	

Co	Naphthenic acid	1M in kerosene	Aq: pH 9.8. Stripping with 0.5-2M H_2SO_4. Determination by complexometric titration.	224
	LIX 64N	5-10% in kerosene	Aq: pH 1.5-2.2	224
	HDEHP	--	Aq: pH 5.5 containing $(NH_4)_2SO_4$ or Na_2SO_4	225
	HDEHP or LIX 64N	20% and 80%	Aq: pH 4, sulphate	227
	Versatic 911	-- Flash Naphtha kerosene	Aq: 4M in $(NH_4)_2SO_4$ Aq: pH 8 containing ammoniacal sulphate solution. Stripping with dil. acids.	228 225
Cd	SRS-100	Benzene	Aq: pH 8.2. Stripping with 8M H_2SO_4. Determination by complexometric titration.	211
Ce	SRS-100	50% in benzene	Aq: pH 4.3. Strippping with 4-8M H_2SO_4. Determination by titrimetry.	229
	Versatic 9	50% in benzene	Aq: pH 6.9. Separated from Sn, Pb, Pa, Pt, La, Tl, Sb, Mo, W, Zn, Cd, Hg, Co, Ni, Mn, Sr, Ba and Ag	229
	Versatic 10	0.887M in benzene	Aq: pH 5-5.5. Stripping with 2M NHO_3. Determination by complexometric titration. Separated from La, Pr, Nd, Sm, Gd, Dy, Tb, Ca, Mg, Cd, Ni, Zn and Hg	230
Eu	HDEHP	0.2M in chloroform Heptane 1M in heptane	Aq: 0.1M in HNO_3 and 0.9M in $NaNO_3$. Determination by radiometry. Aq: 1M in HCl and NaCl Aq: HCl.	231 206 232

Metal	Liquid cation exchanger	Conc in diluent	Other details	Ref.
Fe(III)	HDEHP	1M in heptane	Aq: 1M in HCl or 0.64M in HBr. Determination by radiometry (^{55}Fe tracer).	58
		0.1M in kerosene	Aq: 0.1M in H_2SO_4 or HCl. Determination by spectrophotometry.	233
	SRS-100	Benzene	Aq: pH 3.1. Stripping with 8M H_2SO_4. Determination by complexometric titration. Separated from Ca, Hg, Mg and Pa.	211
Ga	SRS-100	Benzene	Aq: pH 4.6. Separated from Tl, Fe, Al, La, Pb, Pa, Zr, Pt, Mo, W, Zn, Cd, Hg, Cu, Mn, Co, Ni, Ca, Mg, Ba and Sr.	219
	Versatic 9	1.943M in benzene	Aq: pH 3.15-4.0. Stripping with 2M HNO_3. Determination by complexometric titration. Separated from Ga, In, Tl, Bi and La.	273
Hf	DNS	36% in heptane	Aq: 2M in $HClO_4$. Determination by γ-ray spectrometry ($^{175+181}$Hf tracer).	235
	HDEHP	0.01M in chloroform	Aq: 0.1M tartaric acid and 0.1M H_2SO_4 containing 30% H_2O_2. Stripping with saturated aq. oxalic acid or dil. HF. Determination by γ-ray spectrometry ($^{175+181}$Hf tracer).	234
		0.01M in chloroform	Aq: dil. H_2SO_4. Determination by γ-ray spectrometry.	255, 258

Hg	SRS-100	Benzene	Aq: pH 9 8 Stripping with 8M H_2SO_4. Determination by complexometric titration	211
In	SRS-100	Benzene	Aq: pH 5.2. Determination by titrimetry. Separated from Tl, Al, Fe(III), La, Pb, Pa, Pt, Mo, W, Co, Ni, Cu, Mn, Zn, Cd, Hg, Ca, Mg, Sr and Ba.	219
	HDEHP	20% in benzene	Aq: 0.2M in H_2SO_4. Stripping with 1M HCl, HBr or HNO_3. Determination by γ-ray spectroscopy. Separated from Cd.	236
		Benzene-light petroleum	Aq: 1-8M H_2SO_4. Stripping with 6M HCl. Determination by spectrophotometry using thiourea.	217
La	SRS-100	Benzene	Aq: pH 8.2. Separated from Ce, Zr, Th, Fe, Ga, In, Tl, Pa, Pt, Mo, W and Hg	219
Lanthanides	HDEHP	0.04M in kerosene	Aq: pH 1.0. Determination by spectrophotometry using arsenazo III. Separated from Mg, Ca, Mn, Co, Ni, Cu, Cr, Sn, Sb, Bi, Al, Cd, Pb, Zn and Fe	237
	Naphthenic acid	0.5M in kerosene	Aq: NO_3, NH_4NO_3 as salting out agent and EDTA and NH_3 as complexing agent	104
Lu	HDEHP	Heptane	Aq: 1M in NaCl and HCl	206
Mg	SRS-100	Benzene	Aq: pH 9.2. Stripping with 8M H_2SO_4. Determination by complexometric titration.	211
	Versatic 9	50% in butanol containing 5% ethanolamine	Aq: pH 7.6. Stripping with 4M HNO_3. Determination by complexometric titration	223

Metal	Liquid cation exchanger	Conc. in diluent	Other details	Ref.
Mo	HDEHP	Benzene containing 2-ethyl-1-hexanol	Aq: pH 3-3.5 Stripping with aq. HN_3. Separated from W	238
	Polyalkyl benzene		Aq: 8M in H_2SO_4 or 3.5M in HCl or 1.5M in HNO_3.	239
		Polyalkyl benzene	Aq: pH 2.0 adjusted with HNO_3.	241
	HDEHP + DNS	50% and 0.25% in kermac 470B	Aq: pH 1.8 containing tartaric acid. Separated from W.	240
Nb	HDEHP	0.1M in chloroform	Aq: 3M in H_2SO_4.	234
Ni	Naphthenic acid	1M in kerosene	Aq: pH 9.4	224
	LIX 64N	5-10 in kerosene	Aq: pH 1.5-2.2. Stripping with 0.5-2M H_2SO_4. Determination by complexometric titration.	
	Versatic 911	Kerosene	Aq: pH 5-9 containing 0-4M $(NH_4)_2SO_4$.	242
Np(III)	HDEHP	Octane	Determination by γ-ray spectrometry	220
	DNS + TBP or TOPO	Benzene, cyclohexane or chloroform	Aq: 90.5M in $HClO_4$.	60
Pb	SRS-100	Benzene	Aq: pH 6.9. Stripping with 3M HNO_3. Determination by complexometric titration. Separated from Pa, Ca, Mg, Hg, Ce and Zr.	211
	Versatic 9	1.943M in benzene	Aq: pH 6-7.5, 0.1M acetate. Stripping with 2M HNO_3. Separated from Mg, Ca, Sr, Ba, Cu, Pb, Hg Cr and Sr.	104

Pd	SRS-100	Benzene	Aq: pH 5.45. Separated from Fe, Co, Ni, Zn, Cu, Mn, Pb, Ce, Zr, Th, Ga, In and Tl.	211
Pm	HDEHP	Heptane	Aq: 1M in NaCl and HCl.	206
^{210}Po	HDEHP	Petroleum ether	Aq: 0.05N in HCl. Stripping with 12M HCl.	243
Pu	DNS + TBP or TOPO	Benzene cyclohexane or chloroform	Aq: 0.5M in $HClO_4$.	60
RH	HDEHP	0.2M in chloroform	Aq: pH 8.0, adjusted with NaOH and HCl. Stripping with 5M HCl. Separated from Pt.	244
Sb(III), Sb(V)	HDEHP	1M in benzene	Aq: 0.1-0.2M H_2SO_4 or 0.1N HCl or 0.1M HNO_3. Determination by radiometry (^{122}Sb tracer)	245
Sb(III)	Bis-(2-ethylhexyl) phosphorodithioate (diethyl dithio phosphoric acid)	0.1M in heptane	Aq: 2-4M in HCl containing 10% KI and 5% thiourea. Stripping with 12M HCl. Determination by titration ($KBrO_3$). Separated from As	210
Sm	HDEHP	Xylene	Aq: dil. HCl.	246
Sn(II)	Bis-(20ethylhexyl) phosphorodithioate	0.5N in heptane	Aq: 1-2M in HCl. Stripping with 8M HCl. Separated from alkali and alkaline earth metals, Zr, Ti, Ga, Al, Mn, Cr, As and Fe. Applied for the determination of Sr in various ores.	247
	HDEHP	1M in heptane	Aq: dil. HBr containing mercaptoacetic acid. Separated from Ag, Al, Bi, Fe, Co, Cd, Ca, Cu, Cr, Mn, Mg, W, Ni, Pb, Zn, Fe(II) and Tl. Applied for the analysis of high purity Sn	248
Sr	SRS-100	Benzene	Aq: pH 8.8. Stripping with 3M HNO_3. Determination by titrimetry.	211

Metal	Liquid cation exchanger	Conc. in diluent	Other details	Ref.
^{182}Ta	HDEHP	0.1M in carbon-tetrachloride	Aq: 1.6M in HCl containing 0.01M oxalic acid. Stripping with 0.01M HF. Determination by γ-ray spectrometry. Separated from ^{95}Nb.	249
Th	HDEHP	0.7M in xylene	Aq: 6M in H_2SO_4. Stripping with 2.5M NH_4CO_3. Determination by scintillation counter (^{234}Th tracer). Separated from U and Ce.	250
	Versatic 10	16% in benzene	Aq: pH 4.7 (adjusted with NaOH) and 0.1M in acetic acid. Stripping with 2M HNO_3. Separated from Co, Ni, La, Mn, Ca, Sr and Ba.	251
		0.83M in benzene	Aq: pH 4-5.2, 0.1M acetic acid. Separated from rare earths.	116
	SRS-100	50% in benzene	Aq: pH 6.0.	229
	Versatic 9	50% in benzene	Aq: pH 6.0. Stripping with 4-8M H_2SO_4. Determination by titrimetry. Separated from Pa, Mo, W, Co, Ni, Ca, Mg, Sr, Ba and Hg.	229
	Bis-(2-ethylhexyl) phosphorodithioate	0.1-0.2M in butanol	Aq: 1M in $HClO_4$ and $NaClO_4$. Determination by spectrophotometry using Thoron.	266
^{227}Th	HDEHP	1M in benzene	Aq: pH 2.2. Stripping with 0.5M HCl. Determination by scintillation counter. Separated from Ac and Ra.	204
Ti	HDEHP	0.2M in benzene	Aq: 0.35M in H_2SO_4. Determination by spectrophotometry.	252

Tm	HDEHP	0.2M in heptane	Aq: 0.1M in HNO_3 and 0.9M in $NaNO_3$. Determination by radiometry.	231
		Heptane	Aq: 1.0M in NaCl and HCl	205
Tl(I)	Bis-(2-ethylhexyl) phosphorodithioate	2-ethyl hexanol	Aq: 0.2-1.0M in H_2SO_4. Stripping with 9M HNO_3. Determination by complexometric titration after oxidising to Tl(III). Applied for the separation of Tl from solution of Pb-Zn and Cd-Zn production	253
Tl(III)	SRS-100	Benzene	Aq: pH 6.2. Separated from La, Fe, Co, Ni, Cu, Pa, Pt, Mo, V, Ca, Mg, Sr and Ba.	219
	HDEHP	0.3N in heptane	Aq: 20M in H_2SO_4 and 0.5M in NaBr. Determination by spectrophotometry using Methyl Red (λ_{max} = 555 nm).	254
U(IV)	HDEHP	0.5M in kerosene containing 0.1M dibutyl butyl phosphonate	Aq: 6M in H_3PO_4. Determination by spectrophotometry and fluorimetry.	255
		50% in nitrobenzene	Aq: ≤ 1.3M in $HClO_4$.	256
		--	Aq: < 2M in HNO_3	257

Metal	Liquid cation exchanger	Conc. in diluent	Other details	Ref.
U(VI)	Bis-(2-ethylhexyl) methyl phosphate	10% in benzene	Aq: 1M in HNO_3 containing 30 mM of SCN^- and 3% solution of $Al(NO_3)_3$. Determination by spectrophotometry (λ_{max} = 514). Separated from Al, Bi, Co.	258
	Versatic 10	33% in benzene	Aq: pH 5.6-6.0 containing 0.1M acetic acid. Stripping with 2M HNO_3. Separated from alkali and alkaline earth metals, Mn, Co, Ag, Cd, Hg, Tl, Pb, Th and rare earth.	259
	HDEHP	33% in benzene 0.7M in xylene	Aq: > 6M in $HClO_4$. Aq: 2.5M in HCl and 50% in ethanol or 4.5M in HCl. Separated from Ce. Aq: 6M in H_2SO_4. Stripping with 11M HCl. Determination by scintillation counter (^{233}U Tracer). Separated from Th and Ce.	260 250
	Mono-(2-ethylhexyl) hydrogen phosphate + TOPO	0.5M in kerosene	Aq: 6M in H_3PO_4. Stripping with 12M H_3PO_4. Determination by spectrophotometry of fluorimetry.	198
V(IV)	HDEHP	40% in kerosene	Aq: pH 2-3 and 1M in NaCl or 2M in $NaClO_4$ containing NaF or citric acid or suiphosalicylic acid as masking agent. Separated from V(III).	261
V(V)	HDEHP	Butanol and benzene	Aq: pH 1.5-1.7. Determination by spectrophotometry	262

Y	DEHP	1M in kerosene	Aq: pH 8.6 and 0.011M in diethylene triamine penta acetic acid. Separated from other lanthanides.	263
		Heptane	Aq: 1M in NaCl and HCl.	206
Zn	SRS-100	Benzene	Aq: pH 7.1. Stripping with 4N H_2SO_4. Determination of complexometric titration	211
	HDEHP	0.1-1.0M in various solvents	Aq: < 3M in HNO_3 or $HClO_4$.	264
	Versatic 9	1.943M in benzene	Aq: 6.5-8, 0.1M in acetate Stripping with 2M HNO_3. Separated from Mg, Ca, Sr, Ba, Pd, Hg, G, Sn, Mo, W and Tl.	283
Zr	Versatic 9	1.943M in benzene	Aq: pH 2.9	229
	SRS-100	50% in benzene	Aq: pH 2.4. Stripping with 4-8M H_2SO_4. Determination by titrimetry. Separated from Th, Sn, Pb, Pa, Pt, Ga, In, Tl, Mo, W, Bi, Sb, Cr, La, Co, Ni, Cu, Zn, Cd, Hg, Mn, Ag, Al, Ba and Sr.	
		1M in octane	Aq: 1-4.5M in H_2SO_4. Stripping with 1M NH_4F.	258

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