JAERI-Research
99-005

ESTIMATION OF DIFFERENT SPECIES OF Eu(III), Th(IV), U(VI) AND Am(III) EXTRACTED INTO NITROBENZENE BY N, N'-DIMETHYL-N, N'-DIHEXYL-3-THIOPENTANEDIAMIDE AND THENOYLTRIFLUOROACETONE

January 1999

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編集兼発行　　日本原子力研究所

Estimation of Different Species of Eu(III), Th(IV), U(VI) and Am(III) Extracted into Nitrobenzene by N, N'-dimethyl-N, N'-dihexyl-3-thiopentanediamide and Thenoyltrifluoroacetone

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(Received January 6, 1999)

The extracted species of Eu(III), Th(IV), U(VI), and Am(III) in nitrobenzene formed by the synergistic extraction with N, N'-dimethyl-N, N'-dihexyl-3-thiopentanediamide (DMDHTPDA: A) and thenoyltrifluoroacetone (TTA) were determined by the slope analysis of log D-log [concentration of extractant] plots. Three kinds of the synergistic extraction species of actinide cations were formed. The fractional concentration of the species depends on the ratio of the concentration of extractants, [TTA]/[DMDHTPDA], as illustrated in respective diagrams. The highest separation factor of Eu and Am was 7.2 for the species $M(A)_3(X)_3$, where X is ClO_4, and it was found that the separation factor decreases with the number of TTA molecules associated with the extraction species.

Keywords: Actinide, Synergistic Extraction, Diamide, Thenoyltrifluoroacetone, Extraction Species

N, N'-ジメチル-N, N'-ジヘキシル-3-チオペンタンジアミドとテノイルトリフルオロアセトンによるニトロベンゼン中へのEu(Ⅲ), Th(Ⅳ), U(Ⅵ)とAm(Ⅲ) 抽出における複数錯体種の推定

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（1999年1月6日受理）

N, N'-ジメチル-N, N'-ジヘキシル-3-チオペンタンジアミド（DMDHTPDA）とテノイルトリフルオロアセトン（TTA）協同抽出によるニトロベンゼン中へのEu(Ⅲ), Th(Ⅳ), U(Ⅵ)とAm(Ⅲ) の抽出錯体種をlog Dと抽出剤濃度との関係より求めた。それぞれアクチノイド陽イオンの3つの協同抽出錯体を見い出した。抽出種の存在割合は2つの抽出剤濃度の比に依存し、そのフラクション図を作成した。EuとAmの最も高い分離比、7.2、がDMDHTPDA単独の抽出剤を用いたときに得られ、その値は抽出種にTTAが関与する数とともに減少した。

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1. Introduction

Solvent extraction of lanthanide and actinide elements using neutral donors has been studied extensively[1-3]. Diamides belong to one class of the neutral donors. The advantages of use of diamides for the extraction of actinide are their strong complexation with actinides of +3, +4 and +6 valences and their extraction from acidic solution[4-6]. Diamides are incinerable enabling their ecological destruction after use[6,7]. In the previous papers, it has been shown that diamides are relatively easily synthesized as compared to the organophosphoric compounds[4,8,9]. Although the synergistic extraction by the neutral diamide donors and anionic extractants is considered to be effective for actinide ions with higher coordination numbers, information is not fully supplied. It is a general concept that the good separation between lanthanide (III) and actinide (III) cations is obtained by the solvent extraction using soft donor extractant. However, very few results are given on the separation factors of Eu/Am by diamide including the soft donor.

It was reported that the synergistic extractions of Eu^{3+} and Am^{3+} with N,N'-dimethyl-N,N'-dihexyl-3-oxapentanediamide (DMDHOPDA) and thenoyltrifluoroacetone (TTA) into toluene consist of 4 extraction reactions. The extraction species were determined to be $M(A)_3(X)_3$, $M(A)_3(TTA)(X)_2$, $M(A)_2(TTA)_2(X)$, and $M(A)(TTA)_3$ ($M=Eu^{3+}$ or Am^{3+}, A=DMDHOPDA, $X^-= ClO_4^-$ or CH_2ClCOO^-) [10,11].

In this work, N,N'-dimethyl-N,N'-dihexyl-3-thiopentanediamide (DMDHTPDA: $CH_3(C_6H_{13})N\text{-}COCH_2\text{-}S\text{-}CH_2CO\text{-}NCH_3(C_6H_{13})$, of which the chemical structure is given elsewhere[12], was synthesized and tested for the synergistic extraction of europium ion (III), thorium ion(IV), uranyl ion(VI) and americium ion(III) from actinide elements with TTA into nitrobenzene. The extraction reactions, extraction constants, dependence of the fractional concentration of the extraction species on the concentration of extractants, and the separation of Eu and Am have been investigated.

2. Experimental

2.1 Chemicals

DMDHTPDA was synthesized from thiodiglycolic acid and N-methyl-N-hexylamine in the presence of dicyclohexylcarbodiimide[13,14]. After purification of the synthesized compound by passing through a silica gel column, it was identified by ^{1}H-NMR (varian, UNITY+400 MHz spectrometer), IR (JASCO, FT-IR 8000 spectrometer) and by elemental analysis. TTA (>98%, Wako Pure Chemical Industries, LTD) was purified by sublimation under vacuum at 50 °C. The yield of the synthesis of DMDHTPDA was 43%, and the purity was > 99%. The information on the identification was reported in a previous paper[12].

Solution of 10^{-3} M $HClO_4$ containing $^{152+154}$Eu, ^{233}U or ^{241}Am as the radioactive tracers were used throughout. The radioactive tracer of ^{234}Th was prepared as a daughter of ^{238}U by anion exchange separation column in 8M HCl media[15]. The stock solution of ^{234}Th was adjusted to 10^{-2}M $HClO_4$ solution. Chloroacetic acid (>99%, Wako Pure Chemical Industries, LTD) was used as a pH buffer at a total concentration of 0.005 M, after purification by sublimation under a vacuum. The aqueous solutions were prepared by using 0.10 M $NaClO_4$, 0.10 M $HClO_4$ and 0.10 M NaOH to the desired pH. The solvent, nitrobenzene, was of a reagent grade and used as received. All the other reagents were of analytical grade.

2.2 Extraction Procedures

Five ml of nitrobenzene containing 10^{-5}~10^{-2} M [DMDHTPDA] and/or 10^{-5}~10^{-1} M [TTA] were shaken together with 5 ml of the aqueous phase without tracer for 2 h, in order to get a preequilibrium. After preequilibrium, the organic solvent was placed in a 20 ml polyethylene vial, mixed with 5 ml of the same aqueous phase as that in preequilibrium, and spiked by 10 μl of the radioactive tracer solution. The mixture was shaken mechanically for 2 h at 25 ± 0.1°C.

The equilibrated solution was centrifuged and separated from each phase. The duplicate 1.00 ml aliquots were taken from both aqueous and organic phases, and gamma activities of $^{152+154}Eu$ and ^{234}Th were measured by NaI(Tl) scintillation counter (COBRA 5003, Packard Instrument Company) and alpha activities of ^{233}U and ^{241}Am were counted by liquid scintillation counter (Tri-Carb 1600 TR, Packard Instrument Company). The equilibrated pH of the aqueous phase was measured after the phase separation. The extraction experiments under the same conditions were repeated at least twice.

3. Results and Discussion

3.1 Extraction of Actinide Elements by a Single Extractant

DMDHTPDA is a weak chelator of the actinide cations, therefore the experiments were performed in nitrobenzene, which is effective solvent as extraction by diamide[16]. Eu^{3+}, Th^{4+}, UO_2^{2+} and Am^{3+} are easily extracted into nitrobenzene, as shown in Fig. 1. The slopes in the figure (Eu: 2.80, Th: 1.77, U: 1.45, Am: 2.60) suggest that the main extracted species are $Eu(A)_3(X)_3$, $Th(A)_2(X)_4$, $UO_2(A)(X)_2$ ($UO_2(A)_2(X)_2$), and $Am(A)_3(X)_3$ (A; DMDHTPDA, $X^- = ClO_4^-$ or CH_2ClCOO^-). The separation factor of Eu and Am is defined as D_{Eu}/D_{Am}, where D_{Eu} is the distribution coefficient of Eu and D_{Am} is that of Am. The average of D_{Eu}/D_{Am} is 7.2. Considering the results of DMDHOPDA alone ($D_{Eu}/D_{Am} = 8.64$)[13], the two extractants may provide rather high separation factor for Eu and Am. The results of the extraction of Eu, Th, U, and Am by TTA alone into nitrobenzene are shown in Fig. 2. The slope values suggest that the main extraction species are $Eu(TTA)_3$, $Th(TTA)_3(X)$, $UO_2(TTA)_2$, and $Am(TTA)_3$. This is in good agreement with data reported previously[10,14]. The average of D_{Eu}/D_{Am} by TTA alone is 1.7.

3.2 Synergistic Extraction of Actinide Elements by DMDHTPDA and TTA

The synergistic extraction reaction with DMDHTPDA and TTA can be described in the following equation:

$$M^{n+} + xA_{org} + yHTTA_{org} + (n-y)X^{-} \overset{K_{x,y}}{\rightleftarrows} M(A)_x(TTA)_y(X)_{(n-y)org} + yH^{+} \qquad (1)$$

where $K_{x,y}$ is the extraction constant of reaction (1). The distribution coefficient, $D_{x,y}$, are expressed using the extraction constant, $K_{x,y}$ as:

$$D_{x,y}= K_{x,y}[A]^{x}{}_{org}[TTA]^{y}{}_{org}[X^{-}]^{n-y}/ [H^{+}]^{y} \qquad (2).$$

which in logarithmic form yields:

$$\log D_{x,y} = \log K_{x,y} + x \log [A]_{org} + y \log [TTA]_{org} + (n-y) \log [X^{-}] + y\ pH \qquad (3).$$

In order to determine the number of A (x) and the number of TTA (y) in the extraction reaction (1), the dependences of log *D* on the concentration of [A] and [TTA] were investigated.

Figures 3-5 show the dependences of log *D* of Eu, Am, Th and U on log [TTA] in DMDHTPDA + TTA into nitrobenzene. There are 2 types of lines in Figs. 3 and 4, using the different condition of [DMDHTPDA] concentration. The triangle points in these figures show the results with higher [TTA]/[DMDHTPDA] conditions than those for the circle points.

The slopes of the lines in Figs. 3~5 are in the range between 0 and 2. These slopes correspond to the value, y, in the extraction reaction (1). The results suggest the presence of some M-A-TTA complexes (M: actinide cations). The log *D* values of Eu, Th, U, and Am by DMDHTPDA alone are calculated to be -0.768, -1.22, -0.95, and -1.46, at [DMDHTPDA] concentration of 0.322, 1.5, 0.297 and 0.322 mM, respectively. By observation of Figs. 3~5, the extraction species without TTA may be taken into account, even these are under the synergistic extraction.

The relationships between log *D* and log [DMDHTPDA] in the synergistic extraction by DMDHTPDA + TTA is illustrated in Figs. 6-8. Two or three lines are plotted in these figures, these lines show the extraction behaviors with the experimental conditions of lower, medium and higher [TTA]/[DMDHTPDA] ratio. Namely, [TTA]/[DMDHTPDA] ratio with 2~31 (●○) and 270~9000(▲△) for Eu and Am, 0.0033~0.033(●), 0.67~13(○), and 4.2~340 (▲) for Th, and 0.84~13(○) and 100~1010(●) for U extraction were employed as lower, medium, (and higher) ratio, respectively. The slopes of these lines suggest the number of DMDHTPDA molecules(x) associated with the extraction reaction (1). It is apparent that the value of x are from 1 to 2 for Eu, Am and Th, and from 0 to 1 for U extraction. Based on these results, the extraction species are estimated and summarized in Table 1, all of these species are due to the ion pair extraction, except for $UO_2(TTA)_2$.

The extraction species as summarized at the table differ from those in toluene for the same extractants, which are the neutral species as $Eu(A)(TTA)_3$, $UO_2(A)(TTA)_2$ and the ionic species, $Th(A)(TTA)_3(X)$[12]. It was reported that Eu and Am can be extracted as $M(CE)(TTA)_2^+$ of the cationic species into 1,2-dichloroethane dissolving TTA and crown ethers[17,18] (CE: crown ethers). Both nitrobenzene and 1,2-dichloroethane are solvents with moderately and highly dielectric constant, these results reflects the extraction of the cationic species.

All of the reactions for the synergistic extraction are considered as follows:

$$M^{3+} + 3A_{org} + 3X^- \overset{K_{3,0}}{\rightleftarrows} M(A)_3(X)_{3org} \tag{4}$$

$$M^{3+} + 2A_{org} + HTTA_{org} + 2X^- \overset{K_{2,1}}{\rightleftarrows} M(A)_2(TTA)(X)_{2org} + H^+ \tag{5}$$

$$M^{3+} + A_{org} + 2HTTA_{org} + X^- \overset{K_{1,2}}{\rightleftarrows} M(A)(TTA)_2(X)_{org} + 2H^+ \tag{6}$$

$$Th^{4+} + 2A_{org} + 4X^- \overset{K_{2,0}}{\rightleftarrows} Th(A)_2(X)_{4org} \tag{7}$$

$$Th^{4+} + 2A_{org} + HTTA_{org} + 3X^- \overset{K_{2,1}}{\rightleftarrows} Th(A)_2(TTA)(X)_{3org} + H^+ \tag{8}$$

$$Th^{4+} + A_{org} + 2HTTA_{org} + 2X^- \overset{K_{1,2}}{\rightleftarrows} Th(A)(TTA)_2(X)_{2org} + 2H^+ \tag{9}$$

$$UO_2^{2+} + 2A_{org} + 2X^- \overset{K_{2,0}}{\rightleftarrows} UO_2(A)_2(X)_{2org} \tag{10}$$

$$UO_2^{2+} + A_{org} + HTTA_{org} + X^- \overset{K_{1,1}}{\rightleftarrows} UO_2(A)(TTA)(X)_{org} + H^+ \tag{11}$$

$$UO_2^{2+} + 2HTTA_{org} \overset{K_{0,2}}{\rightleftarrows} UO_2(TTA)_{2org} + 2H^+ \qquad (12)$$

where M is Eu or Am. Eq. (10) is a main reaction accompanied with minor reaction of $UO_2^{2+} + A_{org} + 2X^- \rightleftarrows UO_2(A)(X)_{2org}$.

3.3 Fractional Concentration of Extraction Species of Actinide Elements

The total distribution coefficients, D, of Eu, Th, U and Am are given by the following equation:

(Eu, Am) $D_M = D_{3,0} + D_{2,1} + D_{1,2} = K_{3,0}[A]^3_{org}[X]^3 + K_{2,1}[A]^2_{org}[TTA]_{org}[X]^2/[H^+] + K_{1,2}[A]_{org}[TTA]^2_{org}[X]/[H^+]^2$ (13)

(Th) $D_{Th} = D_{2,0} + D_{2,1} + D_{1,2} = K_{2,0}[A]^2_{org}[X]^4 + K_{2,1}[A]^2_{org}[TTA]_{org}[X]^3/[H^+] + K_{1,2}[A]_{org}[TTA]^2_{org}[X]^2/[H^+]^2$ (14)

(U) $D_U = D_{2,0} + D_{1,1} + D_{0,2} = K_{2,0}[A]^2_{org}[X]^2 + K_{1,1}[A]_{org}[TTA]_{org}[X]/[H^+] + K_{0,2}[TTA]^2_{org}/[H^+]^2$ (15)

The log $K_{x,y}$ values are calculated from the experimental results in Figs. 3-8 and summarized in Table 2. The $K_{x,y}$ values were substituted into the eqs., (13), (14) and (15), and then the D_M, D_{Th}, and D_U values can be calculated. The fractional distribution coefficients, $D_{x,y}$, for each extraction species were divided by the total D value so as to know the fractional concentration of all extraction species. Here, the total D value means the sum of the distribution coefficients of all species extracted, and the $D_{x,y}$ is that of $M(A)_x(TTA)_y$ species. The fraction diagrams as a function of log [TTA] are given at Figs. 9-11. These figures support the fundamental extraction mechanisms proposed in the work and the stabilities of each extracted species.

3.4 Separation factors of Eu and Am

The separation factors between Eu and Am, D_{Eu}/D_{Am}, for the synergistic extraction species, $M(A)_2(TTA)(X)_2$ and $M(A)(TTA)_2(X)$ in addition to $M(A)_3(X)_3$ and $M(TTA)_3$ were calculated, and the average values of 2.5 and 1.1 were obtained, respectively. The highest separation factor in this experiment is 7.2 for the $M(A)_3(X)_3$ species. It was obvious that this value decreases with the number of TTA molecules associated with the extraction species.

4. Conclusion

We examined the experimental conditions of extraction of Eu, Am, Th and U by DMDHTPDA, TTA and DMDHTPDA + TTA into nitrobenzene. Several extraction species were estimated, from the relationship between the fractional concentrations of these species and log [TTA]. Presented diagrams give the basic information on the synergistic extraction reactions. The highest separation factor of Eu/Am, 7.2, is obtained by DMDHTPDA extractant alone, and decreases when TTA chelates with these cations.

Acknowledgements

The authors gratefully acknowledge to Dr. G. R. Choppin of Florida State University in USA and Dr. T. Adachi of Japan Atomic Energy Research Institute for the helpful discussion throughout the work and Dr. Y. Hirao of Tokyo National Research Institute of Cultural Properties for the encouragement.

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Table 1 The determined extraction species of actinide ions with DMDHTPDA and/or TTA in nitrobenzene (A; DMDHTPDA, X; ClO_4^- or Chloroacetate ion).

Element	DMDHTPDA	TTA	TTA + DMDHTPDA
Eu	$Eu(A)_3(X)_3$	$Eu(TTA)_3$	$Eu(A)_3(X)_3$, $Eu(A)_2(TTA)(X)_2$, $Eu(A)(TTA)_2(X)$
Th	$Th(A)_2(X)_4$	$Th(TTA)_3(X)$	$Th(A)_2(X)_4$, $Th(A)_2(TTA)(X)_3$, $Th(A)(TTA)_2(X)_2$
U	$UO_2(A)_2(X)_2$ ($UO_2(A)(X)_2$)	$UO_2(TTA)_2$	$UO_2(A)_2(X)_2$, $UO_2(A)(TTA)(X)$, $UO_2(TTA)_2$
Am	$Am(A)_3(X)_3$	$Am(TTA)_3$	$Am(A)_3(X)_3$, $Am(A)_2(TTA)(X)_2$, $Am(A)(TTA)_2(X)$

Table 2 The etraction constants of all extraction reactions of Eu, Th, U and Am.

	$\log K_{3,0}$	$\log K_{2,0}$	$\log K_{2,1}$	$\log K_{1,1}$	$\log K_{1,2}$	$\log K_{0,2}$
Eu	9.0 ±0.6	-	6.3 ±0.1	-	1.1 ±0.2	-
Th	-	3.8 ±0.2	7.1 ±0.1	-	5.6 ±0.3	-
U	-	4.2 ±0.2	-	3.3 ±0.1	-	4.4 ±0.3
Am	7.6 ±0.2	-	5.9 ±0.1	-	1.2 ±0.2	-

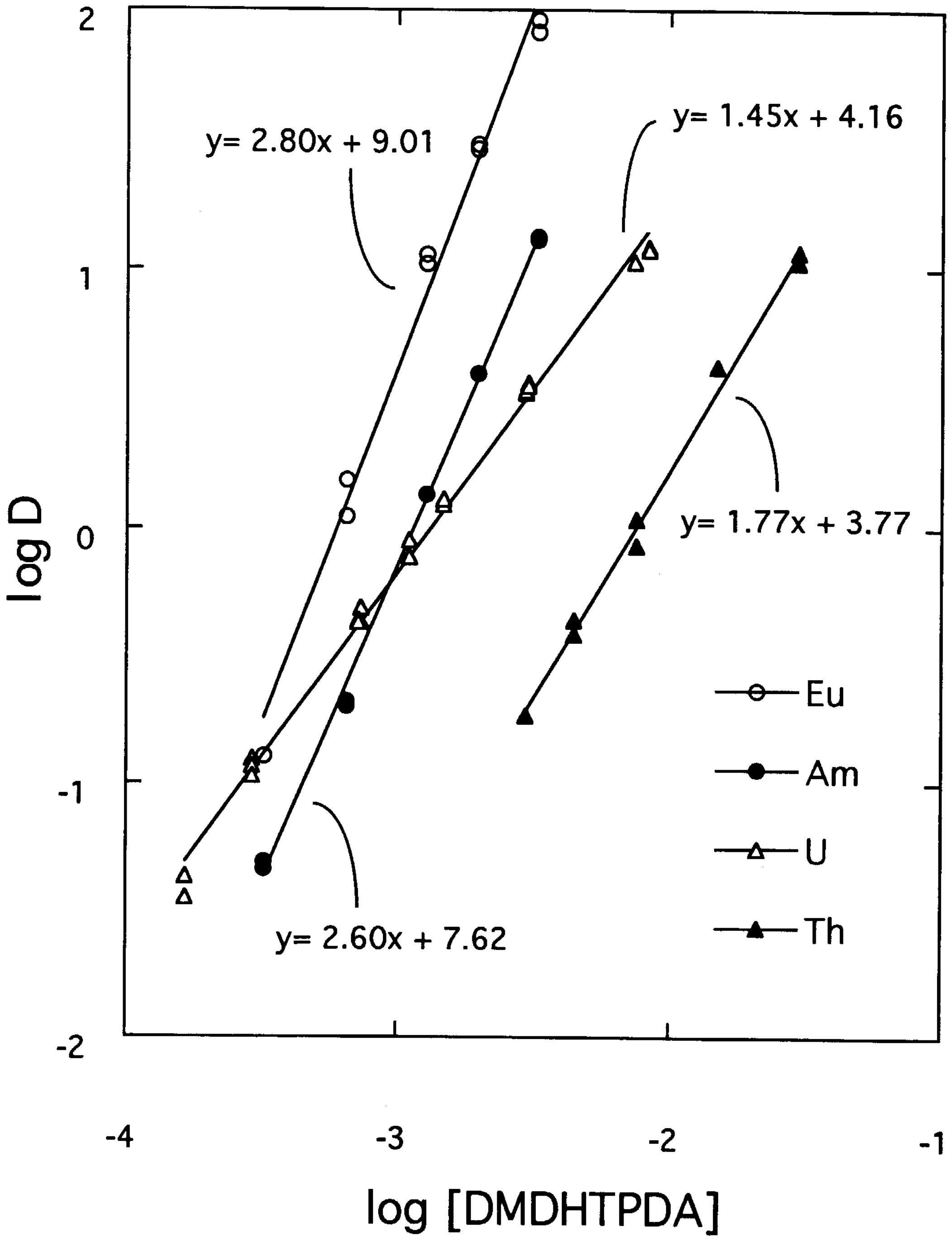

Fig. 1 Dependences of log D of Eu^{3+}, Th^{4+}, UO_2^{2+} and Am^{3+} on log [DMDHTPDA]. Organic phase: [DMDHTPDA] in nitrobenzene, Aqueous phase: for Eu, U and Am, pH=3.1; for Th, pH= 2.05 in 0.1 M [$NaClO_4$].

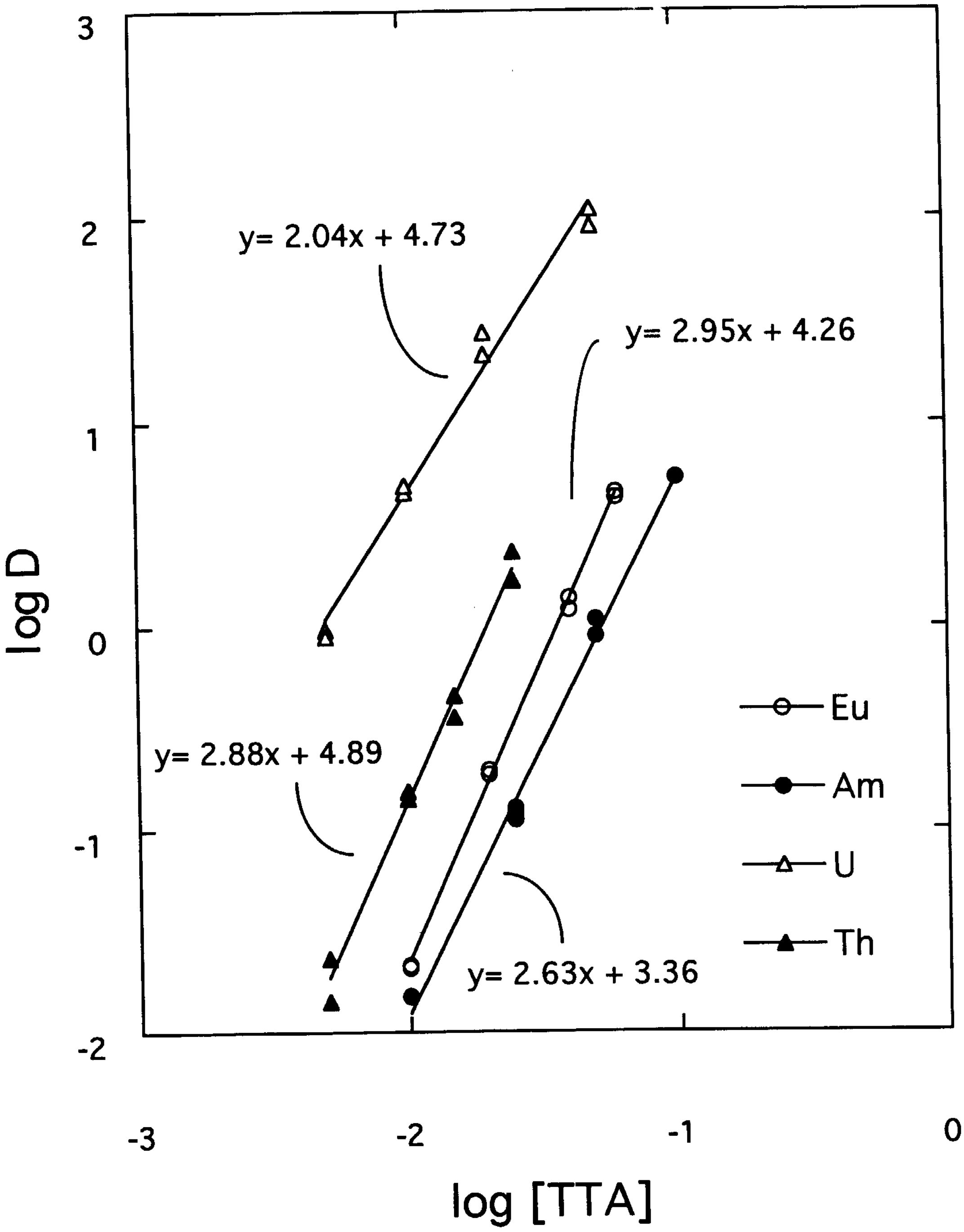

Fig. 2 Dependence of log D on log [TTA].
Organic phase: [TTA] in nitrobenzene, Aqueous phase: for Eu and Am, pH=3.6; for Th, pH= 1.5; for U, pH= 3.1 in 0.1 M [$NaClO_4$].

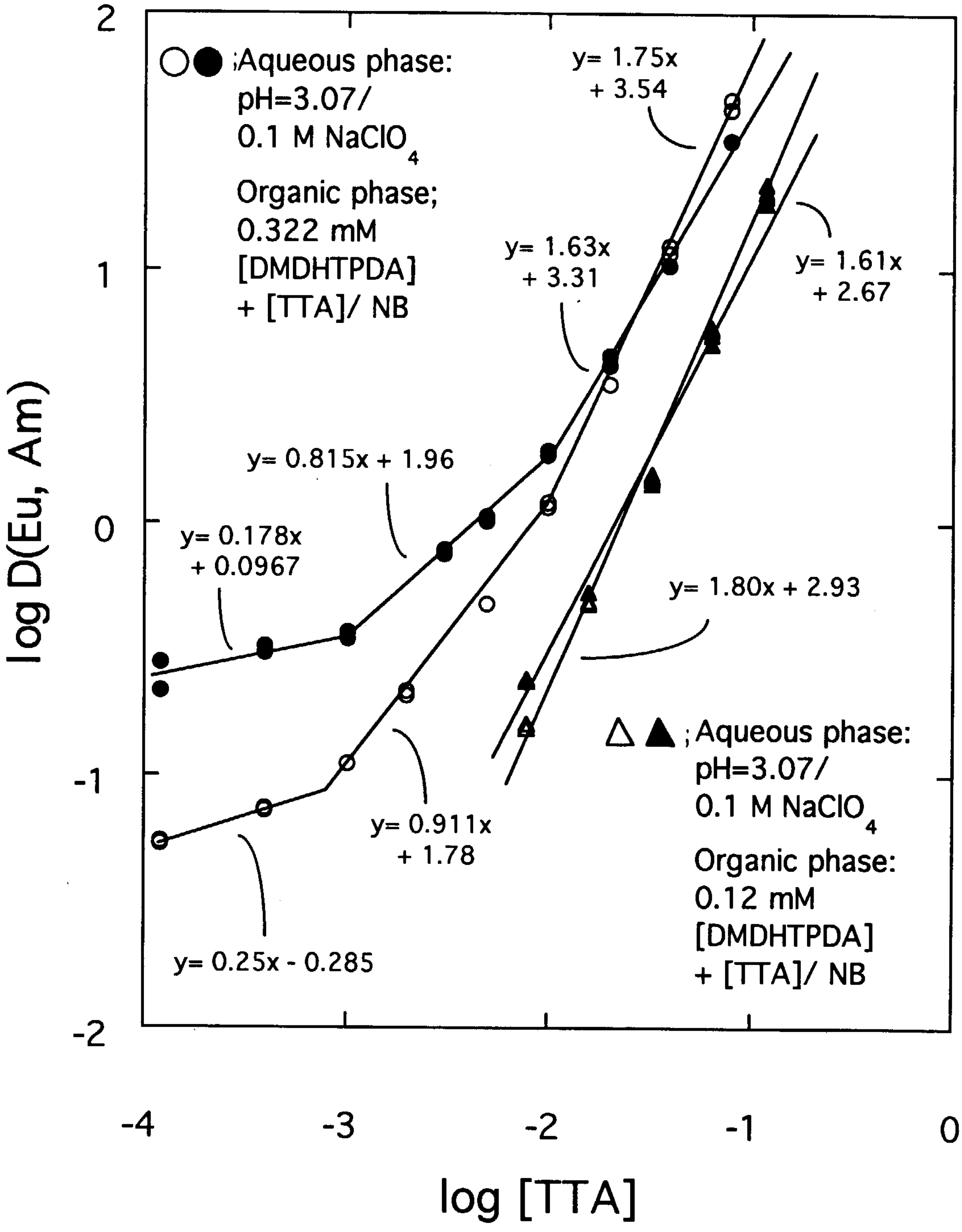

Fig. 3 Dependence of log D_{Eu} and log D_{Am} on log [TTA] in the synergistic system. Eu:(● ▲) ; Am: (○ △)

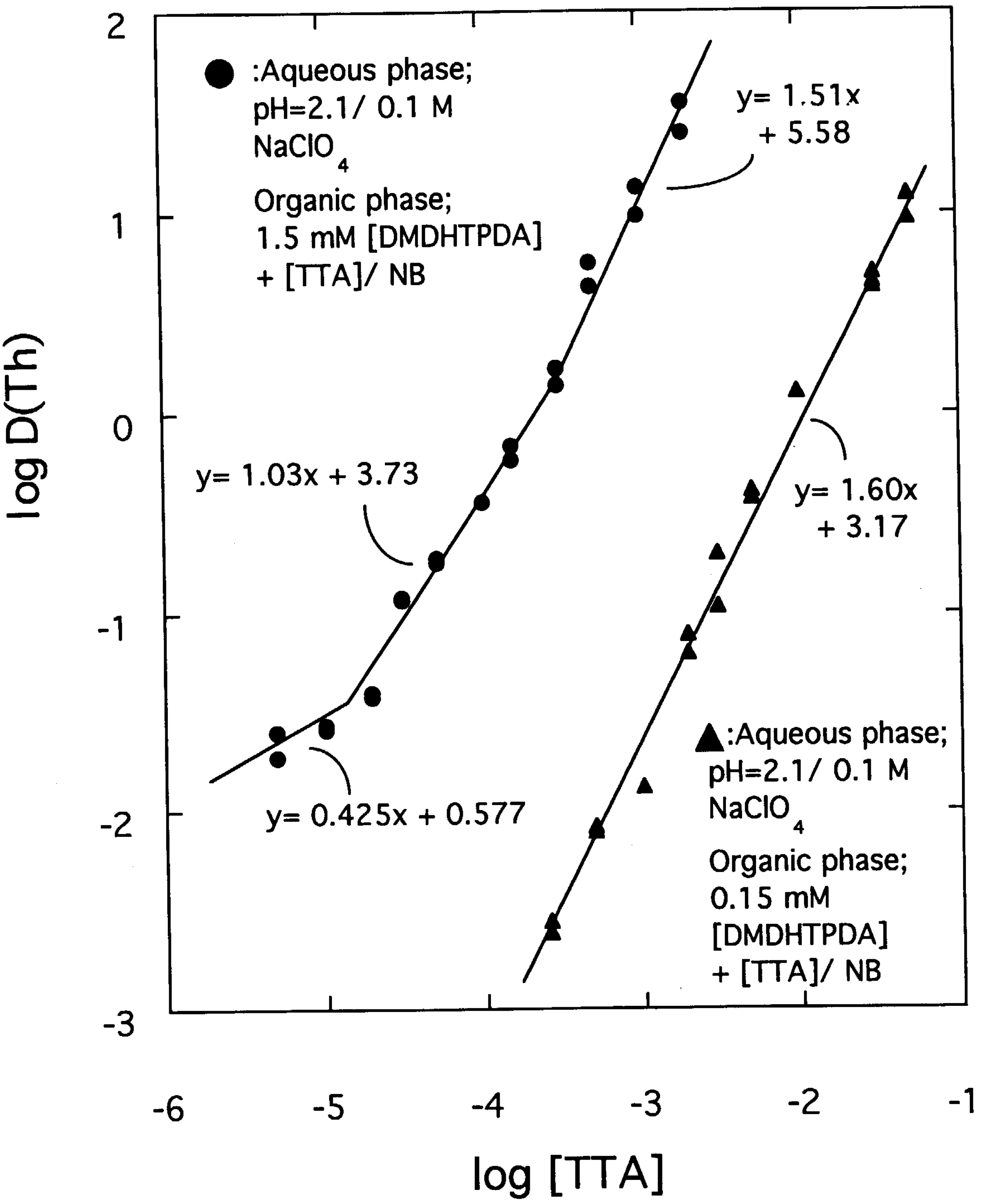

Fig. 4 Dependence of log D_{Th} on log [TTA] in the synergistic system. Organic phase: 0.15 mM(▲); 1.5 mM(●) [DMDHTPDA] + [TTA] in nitrobenzene, Aqueous phase: pH= 2.1 in 0.1 M [$NaClO_4$].

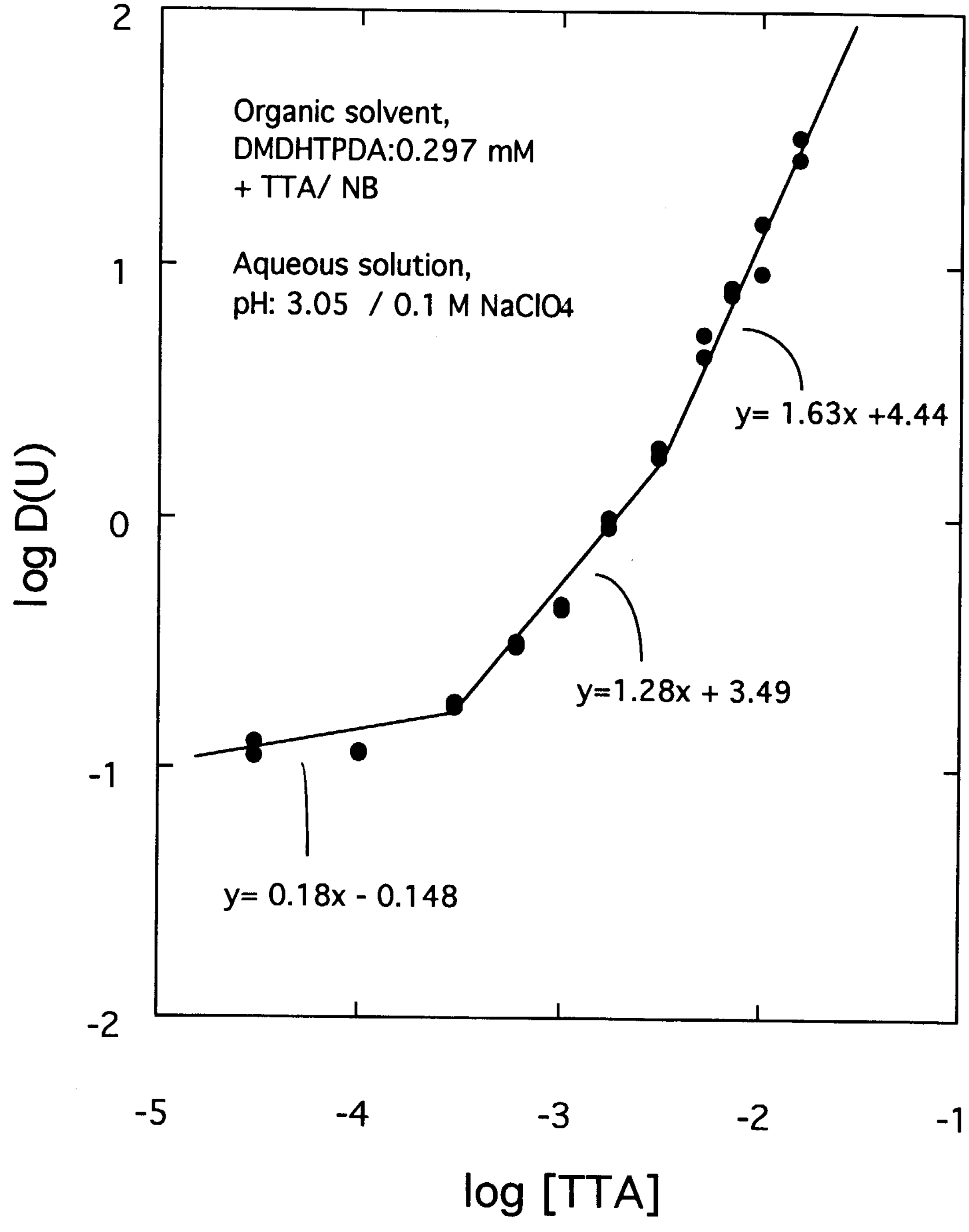

Fig. 5 Dependence of log D_U on log [TTA] in the synergistic system. Organic phase: 0.297 mM [DMDHTPDA] + [TTA] in nitrobenzene, Aqueous phase: pH= 3.1 in 0.1 M [$NaClO_4$].

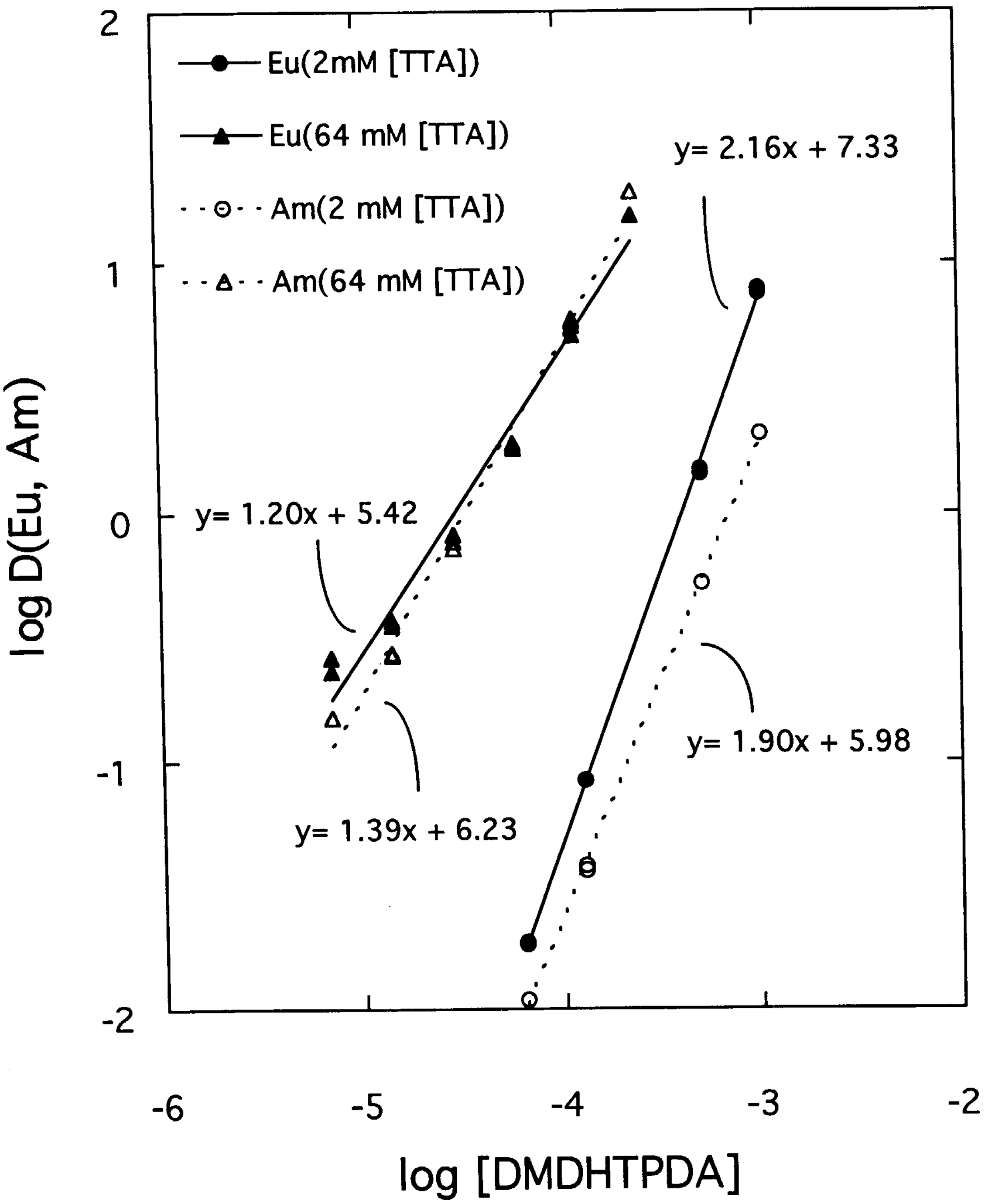

Fig. 6 Dependence of log D_{Eu} and log D_{Am} on log [DMDHTPDA] in the synergistic system. Organic phase: 2 mM(● ○); 64 mM(▲ △) [TTA] + [DMDHTPDA] in nitrobenzene, Aqueous phase: pH= 3.1 in 0.1 M [$NaClO_4$].

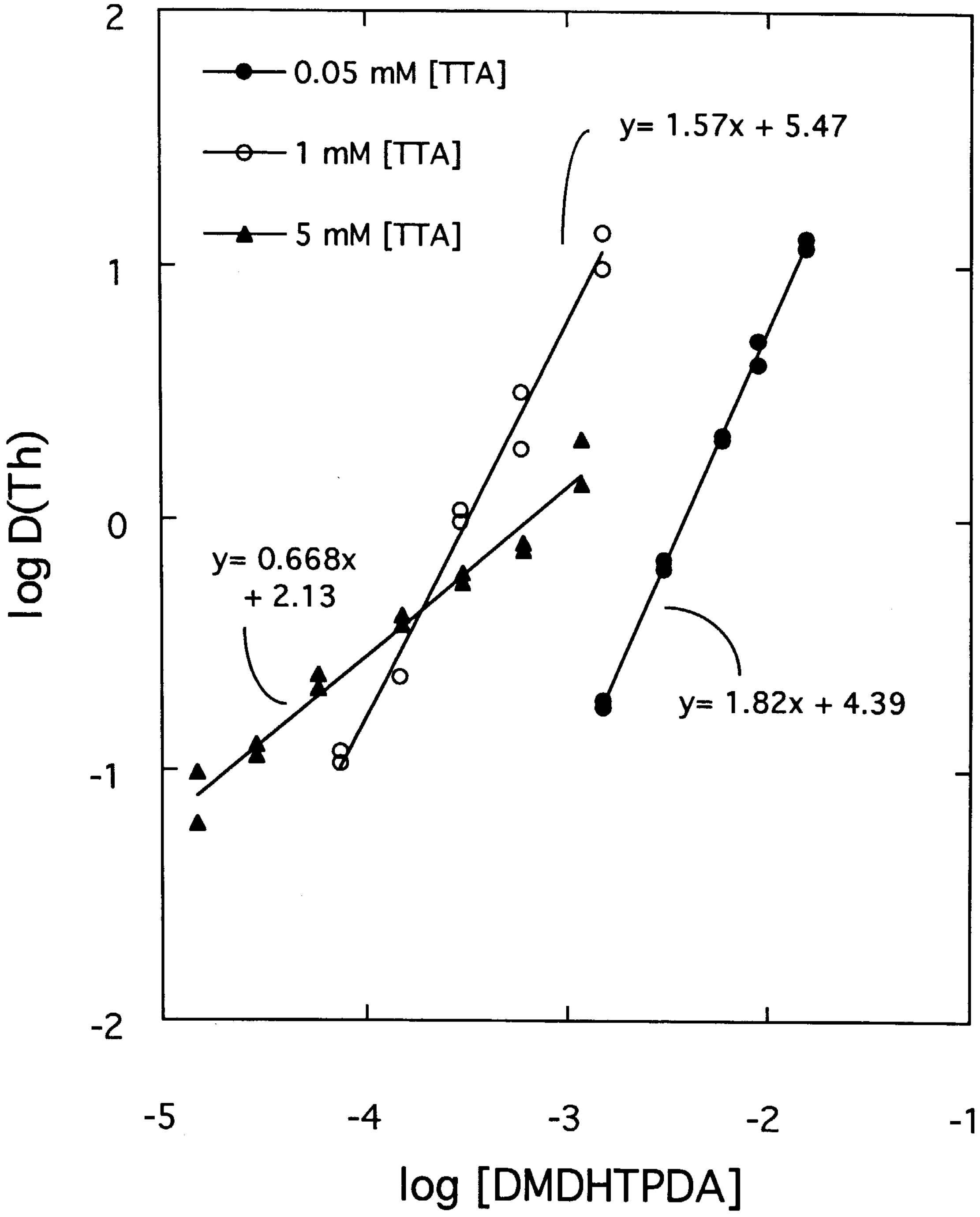

Fig. 7 Dependence of log D_{Th} on log [DMDHTPDA] in the synergistic system. Organic phase: 0.05 mM(●); 1 mM (○); 5 mM(▲) [TTA] + [DMDHTPDA] in nitrobenzene, Aqueous phase: pH= 2.1 in 0.1 M [$NaClO_4$].

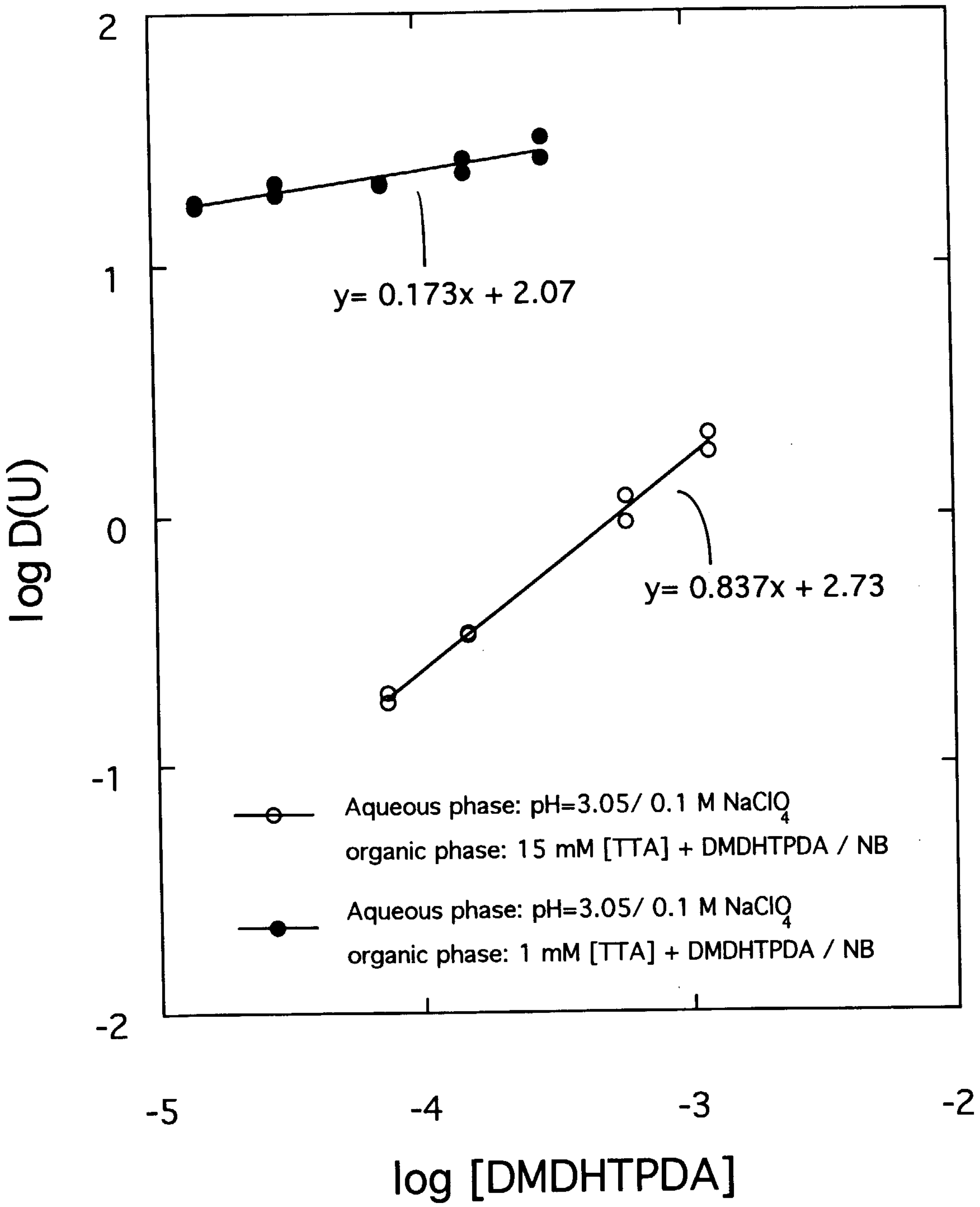

Fig. 8 Dependence of log D_U on log [DMDHTPDA] in the synergistic system. Organic phase: 1 mM(●); 15 mM(○) [TTA] + [DMDHTPDA] in nitrobenzene, Aqueous phase: pH= 3.1 in 0.1 M [$NaClO_4$].

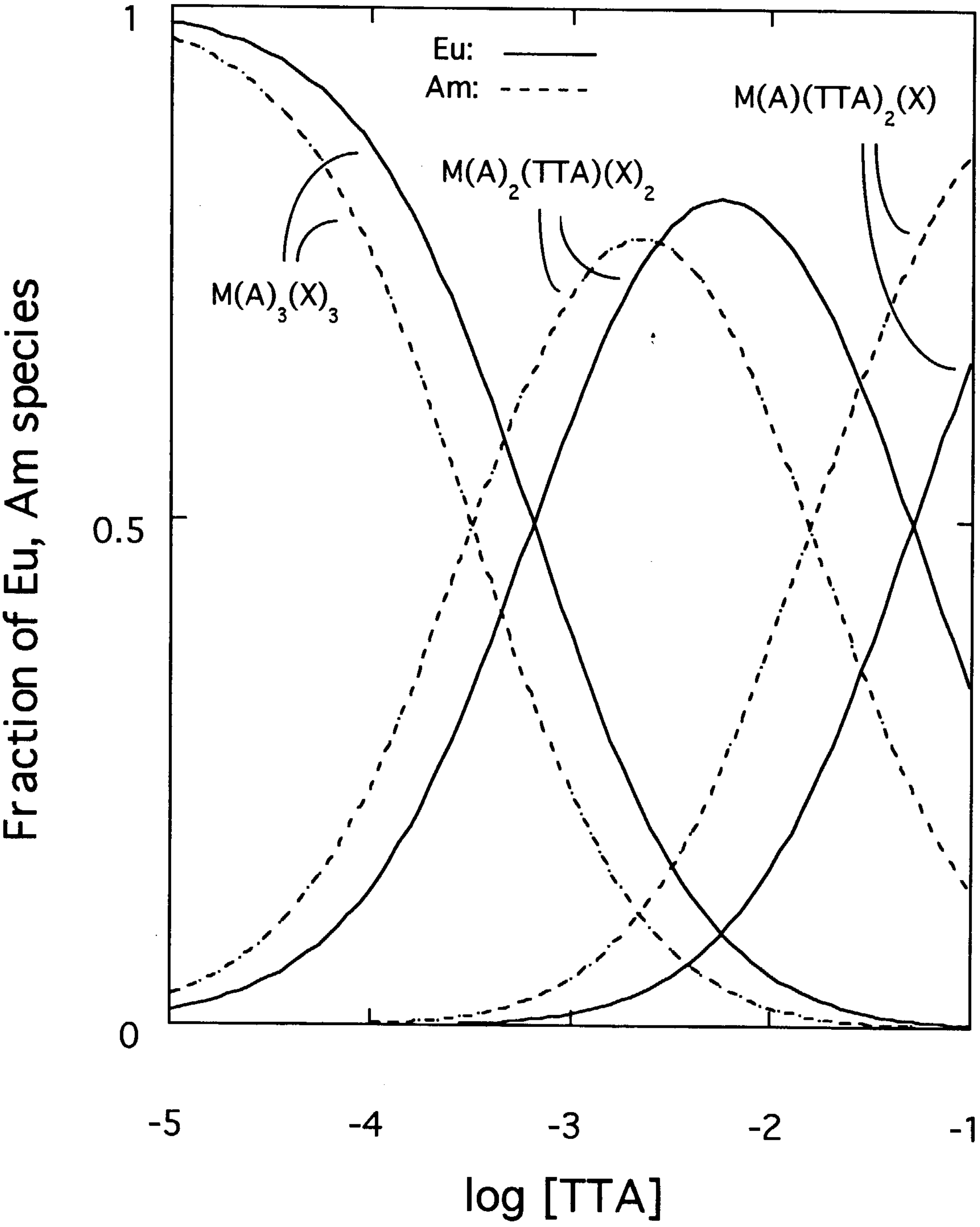

Fig. 9 Fraction diagram of extracted Eu and Am species by DMDHTPDA + TTA. Organic phase: 0.322 mM [DMDHTPDA] + [TTA] in nitrobenzene, Aqueous phase: pH =3.1 in 0.1 M $NaClO_4$.

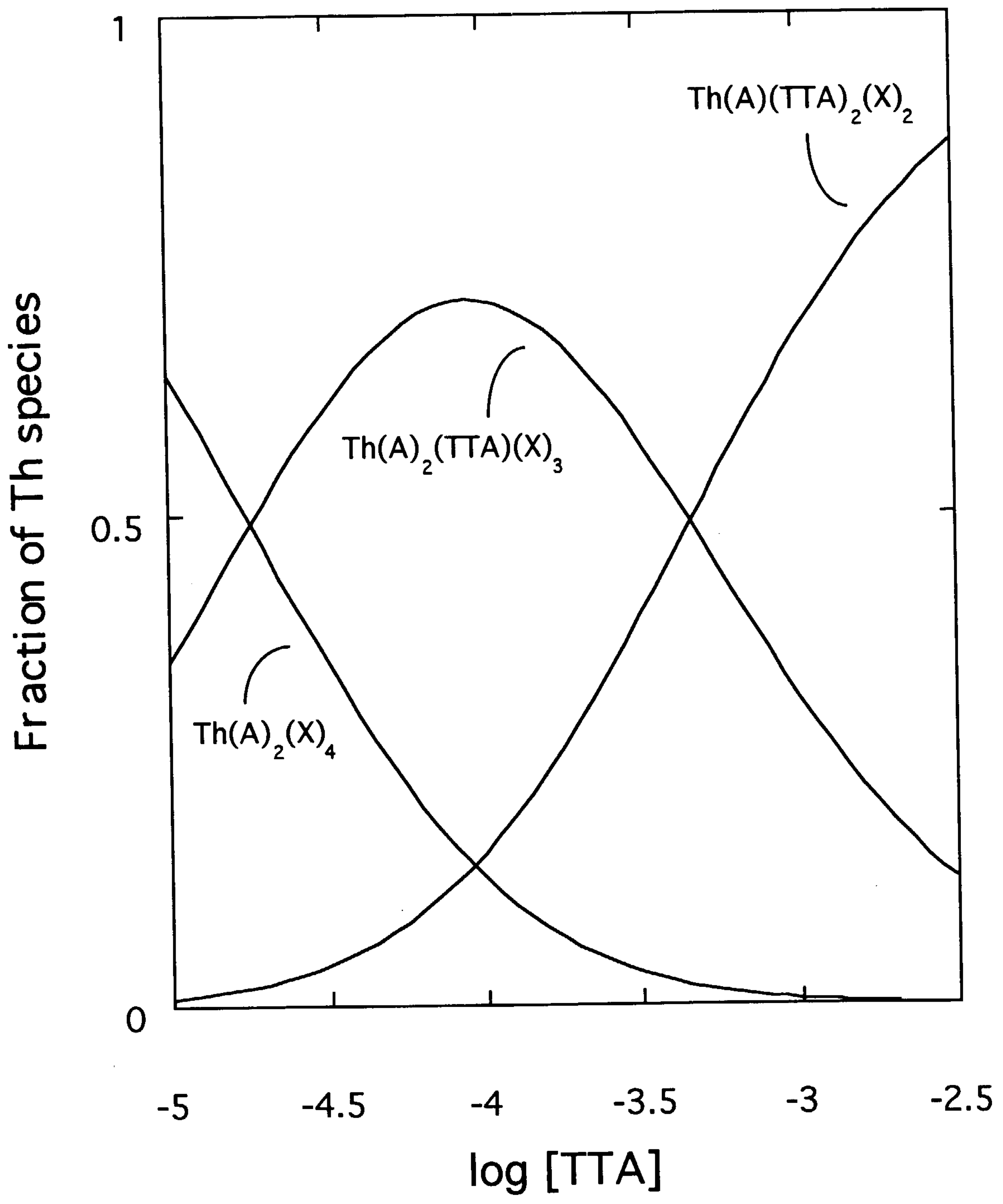

Fig. 10 Fraction diagram of extracted Th species by DMDHTPDA + TTA
Organic phase: 1.5 mM [DMDHTPDA] + [TTA] in NB, Aqueous phase: pH =2.1 in 0.1 M $NaClO_4$.

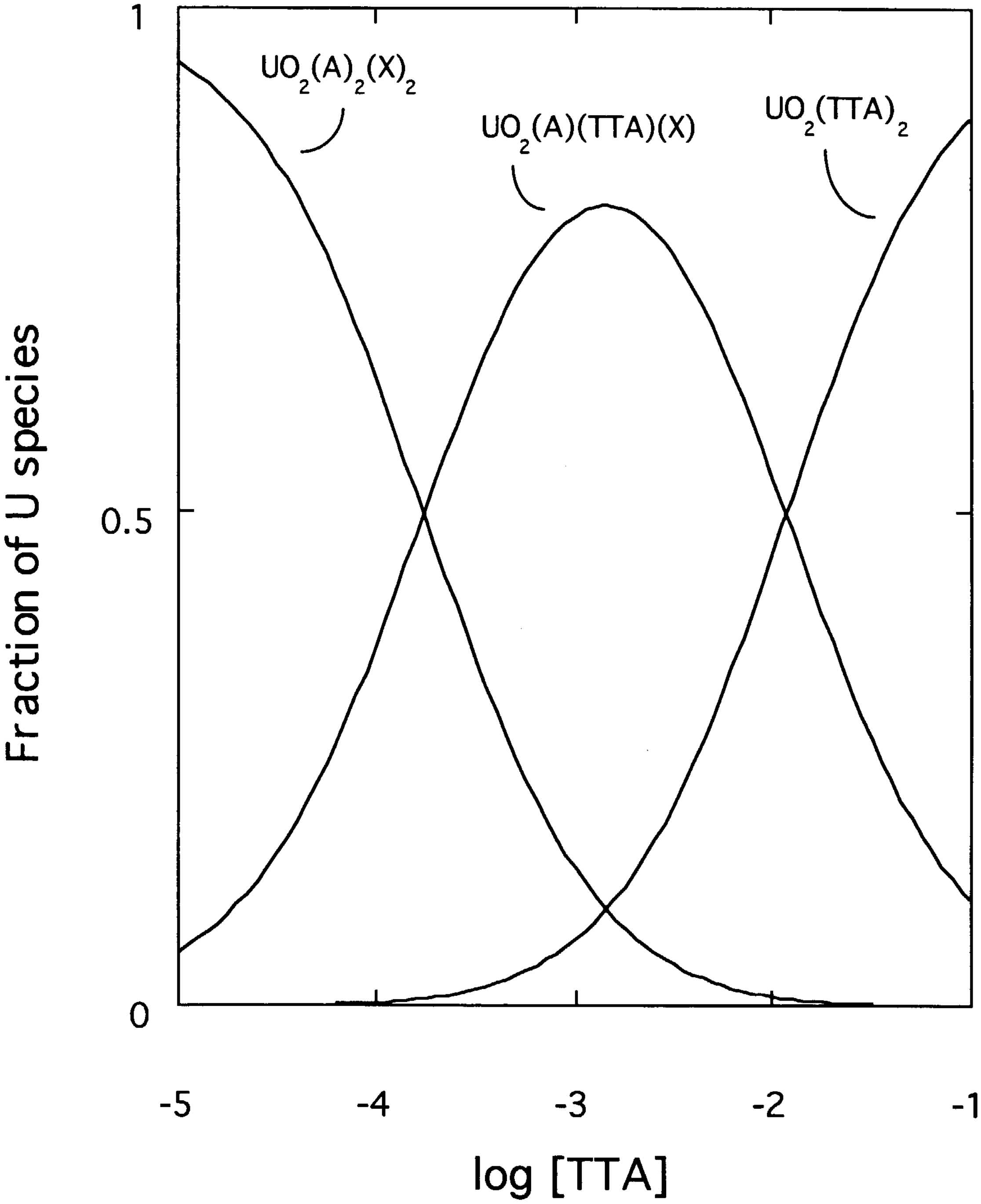

Fig. 11 Fraction diagram of extracted U species by DMDHTPDA + TTA
Organic phase: 0.297 mM [DMDHTPDA] + [TTA] in nitrobenzene,
Aqueous phase: pH =3.1 in 0.1 M $NaClO_4$.

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国際単位系（SI）と換算表

表 1　SI基本単位および補助単位

量	名　称	記　号
長さ	メートル	m
質量	キログラム	kg
時間	秒	s
電流	アンペア	A
熱力学温度	ケルビン	K
物質量	モル	mol
光度	カンデラ	cd
平面角	ラジアン	rad
立体角	ステラジアン	sr

表 2　SIと併用される単位

名　称	記　号
分，時，日	min, h, d
度，分，秒	°, ′, ″
リットル	l, L
トン	t
電子ボルト	eV
原子質量単位	u

1 eV=1.60218×10^{-19}J

1 u=1.66054×10^{-27}kg

表 5　SI接頭語

倍数	接頭語	記　号
10^{18}	エクサ	E
10^{15}	ペタ	P
10^{12}	テラ	T
10^{9}	ギガ	G
10^{6}	メガ	M
10^{3}	キロ	k
10^{2}	ヘクト	h
10^{1}	デカ	da
10^{-1}	デシ	d
10^{-2}	センチ	c
10^{-3}	ミリ	m
10^{-6}	マイクロ	μ
10^{-9}	ナノ	n
10^{-12}	ピコ	p
10^{-15}	フェムト	f
10^{-18}	アト	a

表 3　固有の名称をもつSI組立単位

量	名　称	記号	他のSI単位による表現
周波数	ヘルツ	Hz	s^{-1}
力	ニュートン	N	m·kg/s^2
圧力，応力	パスカル	Pa	N/m^2
エネルギー，仕事，熱量	ジュール	J	N·m
工率，放射束	ワット	W	J/s
電気量，電荷	クーロン	C	A·s
電位，電圧，起電力	ボルト	V	W/A
静電容量	ファラド	F	C/V
電気抵抗	オーム	Ω	V/A
コンダクタンス	ジーメンス	S	A/V
磁束	ウェーバ	Wb	V·s
磁束密度	テスラ	T	Wb/m^2
インダクタンス	ヘンリー	H	Wb/A
セルシウス温度	セルシウス度	℃	
光束	ルーメン	lm	cd·sr
照度	ルクス	lx	lm/m^2
放射能	ベクレル	Bq	s^{-1}
吸収線量	グレイ	Gy	J/kg
線量等量	シーベルト	Sv	J/kg

表 4　SIと共に暫定的に維持される単位

名　称	記　号
オングストローム	Å
バーン	b
バール	bar
ガル	Gal
キュリー	Ci
レントゲン	R
ラド	rad
レム	rem

1 Å=0.1nm=10^{-10}m

1 b=100fm^2=10^{-28}m^2

1 bar=0.1MPa=10^{5}Pa

1 Gal=1cm/s^2=10^{-2}m/s^2

1 Ci=3.7×10^{10}Bq

1 R=2.58×10^{-4}C/kg

1 rad=1cGy=10^{-2}Gy

1 rem=1cSv=10^{-2}Sv

（注）

1．表1－5は「国際単位系」第5版，国際度量衡局1985年刊行による。ただし，1 eVおよび1 uの値はCODATAの1986年推奨値によった。

2．表4には海里，ノット，アール，ヘクタールも含まれているが日常の単位なのでここでは省略した。

3．barは，JISでは流体の圧力を表わす場合に限り表2のカテゴリーに分類されている。

4．EC閣僚理事会指令ではbar，barnおよび「血圧の単位」mmHgを表2のカテゴリーに入れている。

換　算　表

力	N(=10^{5}dyn)	kgf	lbf
	1	0.101972	0.224809
	9.80665	1	2.20462
	4.44822	0.453592	1

粘　度　1 Pa·s(N·s/m^2)=10 P(ポアズ)(g/(cm·s))

動粘度　1m^2/s=10^{4}St(ストークス)(cm^2/s)

圧力	MPa(=10bar)	kgf/cm^2	atm	mmHg(Torr)	lbf/in^2(psi)
	1	10.1972	9.86923	7.50062×10^3	145.038
	0.0980665	1	0.967841	735.559	14.2233
	0.101325	1.03323	1	760	14.6959
	1.33322×10^{-4}	1.35951×10^{-3}	1.31579×10^{-3}	1	1.93368×10^{-2}
	6.89476×10^{-3}	7.03070×10^{-2}	6.80460×10^{-2}	51.7149	1

エネルギー・仕事・熱量	J(=10^7 erg)	kgf·m	kW·h	cal(計量法)	Btu	ft·lbf	eV
	1	0.101972	2.77778×10^{-7}	0.238889	9.47813×10^{-4}	0.737562	6.24150×10^{18}
	9.80665	1	2.72407×10^{-6}	2.34270	9.29487×10^{-3}	7.23301	6.12082×10^{19}
	3.6×10^6	3.67098×10^5	1	8.59999×10^5	3412.13	2.65522×10^6	2.24694×10^{25}
	4.18605	0.426858	1.16279×10^{-6}	1	3.96759×10^{-3}	3.08747	2.61272×10^{19}
	1055.06	107.586	2.93072×10^{-4}	252.042	1	778.172	6.58515×10^{21}
	1.35582	0.138255	3.76616×10^{-7}	0.323890	1.28506×10^{-3}	1	8.46233×10^{18}
	1.60218×10^{-19}	1.63377×10^{-20}	4.45050×10^{-26}	3.82743×10^{-20}	1.51857×10^{-22}	1.18171×10^{-19}	1

1 cal= 4.18605J（計量法）
　= 4.184J（熱化学）
　= 4.1855J（15℃）
　= 4.1868J（国際蒸気表）

仕事率　1 PS(仏馬力)
　= 75 kgf·m/s
　= 735.499W

放射能	Bq	Ci
	1	2.70270×10^{-11}
	3.7×10^{10}	1

吸収線量	Gy	rad
	1	100
	0.01	1

照射線量	C/kg	R
	1	3876
	2.58×10^{-4}	1

線量当量	Sv	rem
	1	100
	0.01	1

（86年12月26日現在）

ESTIMATION OF DIFFERENT SPECIES OF Eu(III), Th(IV), U(VI) AND Am(III) EXTRACTED INTO NITROBENZENE BY N, N'-DIMETHYL-N, N'-DIHEXYL-3-THIOPENTANEDIAMIDE AND THENOYLTRIFLUOROACETONE