

Substantiation of the ^{248}Cm Material Purification Method

O. I. Andreev^a, K. V. Rotmanov^{a,*}, G. V. Goncharova^a, E. V. Chernookaya^a,
R. G. Abdulloev^a, P. S. Butkalyuk^a, I. L. Butkalyuk^a, A. Yu. Enizerkina^a,
V. G. Abbyazova^a, and A. V. Borzova^a

^a “JSC SSC RIARRussia,” Dimitrovgrad, 433510 Russia
*e-mail: kvrotmanov@niiar.ru

Received August 31, 2021; revised June 13, 2022; accepted June 15, 2022

Abstract—The experimental data are presented on the purification of Am, Cm from Pu and Fe by anion-exchange chromatography with the Bio-Rad AG1-X8 sorbent (50–100 mesh) as well as data on the separation of Am, Cm, and Cf by ion-exchange chromatography with Bio-Rad AG50W-X8 cation exchange resin (200–400 mesh) in the NH_4^+ form. Sorption was carried out from a solution of 0.1 M HNO_3 , followed by elution with a solution of the ammonium salt of α -hydroxyisobutyric acid (hereinafter α -HIBA) with pH 5.0. The α -HIBA ammonium salt concentration was varied within 0.1–0.2 M. The best results were achieved with successive elution with α -HIBA ammonium salt solutions at concentrations of 0.1 and 0.15 M. The characteristics of the developed chromatographic process of cation exchange purification of Cm using an α -HIBA ammonium salt solution as an eluent were determined: the number of theoretical plates N , distribution coefficient D , selectivity (separation factor) α , and resolution R_S .

Keywords: curium-248, americium-243, chromatography, ion exchange, elution, α -HIBA ammonium salt, purification factor

DOI: 10.1134/S1066362222050071

INTRODUCTION

The synthesis and study of the properties of superheavy elements (SHE) is one of the fundamental areas of modern nuclear physics. Research in this area is being actively carried out both in Russia and in nuclear centers of other countries (Germany, Japan, USA). Thanks to the work performed at the Flerov Laboratory of Nuclear Reactions (Dubna) and RIAR, nuclear-physical properties of new elements with serial numbers 115, 116, and 118 were synthesized and examined. These nuclides were prepared by irradiating targets based on highly enriched isotopes ^{243}Am , ^{248}Cm and ^{249}Cf with ^{48}Ca ions.

Target materials are subject to high requirements for purity, as well as the content of radioactive impurities, which include Pu, Am, Cm, Cf isotopes and fission products. RIAR has an active production of ^{243}Am and ^{248}Cm radioactive materials [1]. Americium-243 is recovered from irradiated Pu by separation and precipitation methods [2, 3]. Curium-248 is recovered from aged ^{252}Cf by extraction chromatography using HDEHP-based sorbents. As a rule, trace amounts

of impurities, including Cf and Pu isotopes, fission products, and corrosion products of construction substances (stainless steel), remain in the materials after standard purification methods.

For preparing materials of pure transplutonium elements (TPE), ion exchange is widely used in radiochemical practice. In ion exchange chromatography, the separation is based on the selectivity of the ion exchange resin with respect to the counterions of the mixture. When separating ions with very similar properties [for example, rare earth elements (REE)], most ion exchange resins exhibit almost the same affinity relative to ions close to each other. Separation of rare-earth elements by elution from a column containing a cation exchange resin with a solution of a strong, non-chelating acid is practically impossible, since their distribution coefficients differ little from each other [4]. If you choose a chelating agent that, with the ions of the mixture gives complex compounds of various strengths, then successful separation of the ions becomes possible. The stronger the complex formed in solution by the counterion, the less this ion will be absorbed by the ion exchange resin. Thus, the separation completeness of the mixture

components can be enhanced. The chelating reagent α -hydroxyisobutyric acid (α -HIBA) and its salts (mainly ammonium) are used in ion-exchange processes of intra- and intergroup separation of REE and TPE radionuclides of [5–17]. Cation exchange methods are used to separate REE and TPE radionuclides by elution with solutions containing α -HIBA and its salts. Strongly acidic styrene–divinylbenzene sulfonic cation exchange resins, such as Dowex 50W-X8, Bio-Rad AG 50W-X8, and a number of their other analogues, are utilized as sorbents [6, 10, 12–16]. As a rule, in the technique used [5, 6, 9–12], trivalent actinides are first adsorbed from a dilute (<0.5 M) HNO_3 solution on a cation exchange resin. Then the sorbent is converted into the NH_4^+ form, and the actinides are eluted with a chelating reagent (α -HIBA). It was noted in [8, 14] that, without preliminary conversion of the cation exchange resin to the ammonium form by eluting with an α -HIBA ammonium salt solution, the released H^+ ions have a strong inhibitory effect on poorly sorbed elements, such as Cf.

Anion exchange chromatography using a strongly basic anionite Bio-Rad AG X8 was chosen as a method for purifying Am, Cm from Pu impurities. According to the literature data, Pu(IV) sorption on strongly basic anion exchange resins is possible from nitric acid and hydrochloric acid media [18–20]. In nitric acid media, Pu(IV) can be sorbed starting from 1 M HNO_3 , therewith the maximum concentration of the $\text{Pu}(\text{NO}_3)_6^{2-}$ anion is reached at 7.7 M HNO_3 [18]. Sorption of Pu on anion exchange resins is also possible from high concentration HCl solutions. The distribution coefficient of Pu(IV) increases monotonically with a rise in the HCl concentration and, starting from a 9 M concentration, exceeds 1×10^3 [19]. Under these conditions, Am(III) and Cm(III) are not retained by the sorbent.

This work was aimed at developing regimes for the purification of Cm and Am from Fe and Pu impurities, as well as developing the regimes for the separation of Am and Cm and their purification from Cf and Eu by ion exchange chromatography.

EXPERIMENTAL

Materials and equipment. All reagents used had a qualification not lower than extra pyre grade. Solutions were produced based on water prepared using a Simplicity UV water purification system (Merck). Nitric acid was prepared on an isothermal

distillation apparatus Distillacid BSB-939-IR (Berghof) for obtaining ultrapure acids. Solutions of α -HIBA ammonium salt were prepared from a sample of α -HIBA (Alfa Aesar) by neutralization with ammonia solution to the required pH value. The concentration of hydrogen ions in solutions (pH) was determined with a Mettler-Toledo SevenExcellence multimeter. The temperature of working solutions during preparation and all experiments was $22 \pm 2^\circ\text{C}$. To maintain the required filtration rate of solutions through the column and separation of the filtrate into fractions, a programmable peristaltic pump Ismatec Reglo Digital MS-2/8 was employed.

We used solutions of $^{240}\text{Pu}(\text{IV})$, $^{241}\text{Am}(\text{III})$, $^{244}\text{Cm}(\text{III})$, $^{248}\text{Cm}(\text{III})$, and $^{249}\text{Cf}(\text{III})$ nitrates prepared in standard technological processes for the production of TPEs. $^{59}\text{Fe}(\text{III})$ nitrate was recovered by dissolving a fragment of the steel shell of the irradiated target and purifying it by anion exchange chromatography. $^{152}\text{Eu}(\text{III})$ nitrate was recovered from ^{153}Gd production waste and purified by cation exchange chromatography.

Analytical class sorbents were used in the study: Bio-Rad AG 1-X8 (50–100 mesh), Bio-Rad AG 50W-X8 (100–200 mesh), Bio-Rad AG 50W-X8 (200–400 mesh).

Experimental technique for purification of Am/Cm from Pu and Fe. The initial solution was a mixture of radionuclides $^{59}\text{Fe}(\text{III})$, $^{240}\text{Pu}(\text{IV})$, $^{241}\text{Am}(\text{III})$, $^{244}\text{Cm}(\text{III})$ in 9 M HCl. To stabilize plutonium in the +4 oxidation state, H_2O_2 was added to the solution to a concentration of 0.1 M. The initial solution (5 column volumes, hereinafter c.v.) was fed to a column with a Bio-Rad AG 1-X8 sorbent (50–100 mesh) in the Cl^- form (1 cm^3 column) at a rate of 1 $\text{mL}/(\text{cm}^2 \text{ min})$, then washed with 9 M HCl in the presence of 0.1 M H_2O_2 .

Experimental procedure for the separation of Am and Cm and their purification from Cf and Eu. The initial solution was a mixture of $^{241}\text{Am}(\text{III})$, $^{244}\text{Cm}(\text{III})$, $^{249}\text{Cf}(\text{III})$, and $^{152}\text{Eu}(\text{III})$ radionuclides in 0.1 M HNO_3 .

The initial solution (1 c.v.) was fed to a column with a Bio-Rad AG 50W-X8 sorbent (200–400 mesh) in the NH_4^+ form (10 cm^3 column) at a rate of 1 $\text{mL}/(\text{cm}^2 \text{ min})$, then washed 0.1 M HNO_3 and water. Desorption of the studied radionuclides was carried out with solutions of α -HIBA ammonium salt at various concentrations (0.1–0.2 M), but with a fixed pH value (pH 5.0). This pH value was chosen based on the results reported in [5, 7].

Analysis methods. The volumetric activity of γ -emitting radionuclides (^{241}Am , ^{59}Fe , ^{249}Cf , ^{152}Eu)

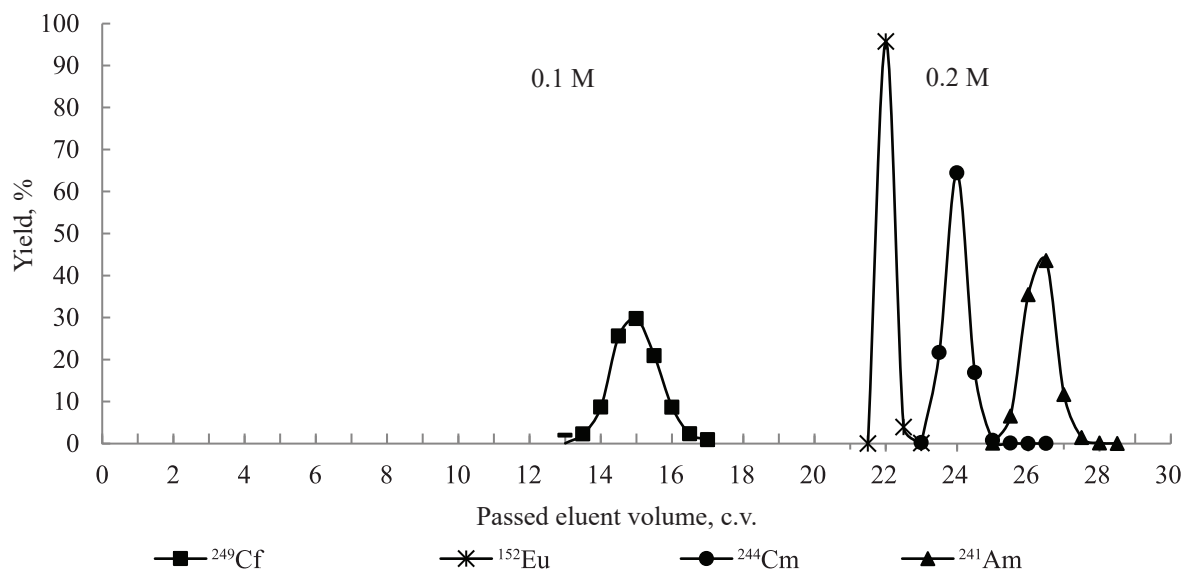


Fig. 1. Output curves of ^{249}Cf , ^{152}Eu , ^{244}Cm , ^{241}Am at sequential elution with 0.1 and 0.2 M α -HIBA ammonium salt solution (pH 5.0). Initial activity, Bq: ^{249}Cf 1.7×10^6 , ^{152}Eu 8.46×10^4 , ^{244}Cm 1.23×10^7 , ^{241}Am 1.40×10^5 .

was determined using an SBS-50 γ -spectrometer with a GeLi semiconductor detector of the DGDK-150 type. Solutions of 1.00 mL in glass test tubes 12 mm in diameter were used as sources for measurements.

The total activity of α -emitting radionuclides was measured using a Quantulus 1220 liquid scintillation counter. An Aspect α -spectrometer with a semiconductor detector based on an ion-implanted Si single crystal coated with an opaque Al layer was used to measure the contribution of individual nuclides to the total α -activity. The activity of the α -emitting radionuclide ^{244}Cm was measured with an ESBS-7x α -spectrometer. Sources for measurement were prepared by depositing an aliquot of the measured solution on a metal substrate, drying under a lamp, and calcining to remove the salt layer.

RESULTS AND DISCUSSION

Anion exchange chromatography using a strongly basic anionite Bio-Rad AG 1-X8 (50–100 mesh) was chosen as a method for purifying Am and Cm from Pu impurities [18–20]. Cation exchange chromatography with Bio-Rad AG 50W-X8 cation exchange resin (200–400 mesh) in the NH_4^+ form was chosen as a method for separating Am and Cm, as well as for their purification from Cf and Eu, with an α -HIBA ammonium salt solution as an eluent [8, 9, 15, 16]. After separation of Am and Cm, the target fractions must be separated from α -HIBA. For this purpose, cation exchange chromatography was

utilized with Bio-Rad AG 50W-X8 cation exchange resin (100–200 mesh). As a final purification stage, the Fe impurity was separated by sorption from 9 M HCl on Bio-Rad AG 1-X8 anion exchange resin (50–100 mesh).

Purification of Am/Cm from Pu and Fe.

Microamounts of Pu were separated from Am and Cm by sorption of Pu on a strongly basic anion exchange resin Bio-Rad AG 1-X8 (50–100 mesh) from 9 M HCl in the presence of 0.1 M H_2O_2 [20]. Americium and curium are practically not sorbed by the resin under these conditions. Purification in a hydrochloric acid medium is recommended in the presence of Fe(III) salts, since it allows achievement of simultaneous separation of Am and Cm from Pu and Fe. The fraction of Am and Cm contains no more than 0.5% Fe and no more than 0.1% Pu.

Behavior of ^{152}Eu , ^{249}Cf , ^{244}Cm , ^{241}Am in a mixture during stepwise elution with α -HIBA. The initial solution (0.1 M HNO_3) containing ^{152}Eu , ^{244}Cm , ^{241}Am , and ^{249}Cf was passed through a chromatographic column with a Bio-Rad AG 50W-X8 cation exchange resin (200–400 mesh) in the NH_4^+ form with a 10 cm³ volume. After washing the column with nitric acid and water, 20 c.v., 0.1 M and 0.2 M α -HIBA ammonium salt solutions were fed at the first and the second stages, respectively. The resulting output curves are shown in Fig. 1.

The data obtained indicate an acceptable purification of Cm from Eu (0.1% Eu enters the Cm fraction), but there occurs insufficient Am and Cm separation: 1.0%

Table 1. The width of the chromatographic peak at the base at various concentrations of eluent

Element A	Peak width at the base W_A , c.v.
0.1 M α -HIBA	
^{249}Cf	2.62
0.15 M α -HIBA	
^{152}Eu	1.5
^{244}Cm	3.1
^{241}Am	4.2
0.175 M α -HIBA	
^{152}Eu	1.1
^{244}Cm	1.85
^{241}Am	2.25
0.2 M α -HIBA	
^{152}Eu	1.0
^{244}Cm	1.56
^{241}Am	1.73

Table 2. Number of theoretical plates

Element A	Retention volume V_A , c.v.	Number of theoretical plates N_A
0.1 M α -HIBA–0.15 M α -HIBA		
Cf	15	524
Cm	34	1924
Am	41	1524
Eu	23	3762
0.1 M α -HIBA–0.175 M α -HIBA		
Cf	15	524
Cm	26.5	3283
Am	30	2844
Eu	22	6400
0.1 M α -HIBA–0.2 M α -HIBA		
Cf	15	524
Cm	24.5	3946
Am	26.5	3754
Eu	22	7744

Cm enters the Am fraction. Using this technique, the experiment was repeated with the replacement of the 0.2 M α -HIBA ammonium salt solution at the second stage of the elution process with its solution with a concentration of 0.175 (Fig. 2) and 0.15 M (Fig. 3).

When using the 0.175 M and 0.15 M α -HIBA ammonium salt solutions at the second stage, 0.2 and 0.01% Cm enters the Am fraction, respectively.

Characteristics of the chromatographic process. The characteristics of the developed chromatographic

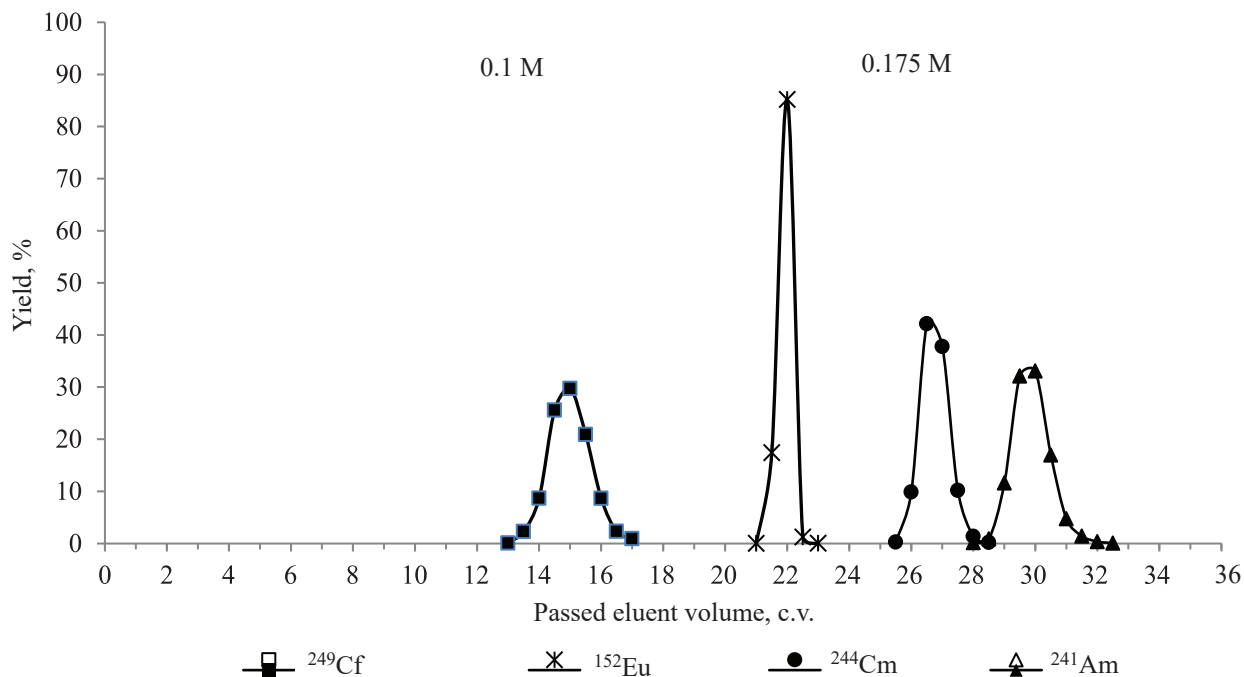


Fig. 2. Output curves of ^{249}Cf , ^{152}Eu , ^{244}Cm , ^{241}Am at sequential elution with 0.1 and 0.175 M α -HIBA ammonium salt solution (pH 5.0). Initial activity, Bq: ^{249}Cf 1.7×10^6 , ^{152}Eu 8.86×10^4 , ^{244}Cm 5.80×10^7 , ^{241}Am 1.25×10^5 .

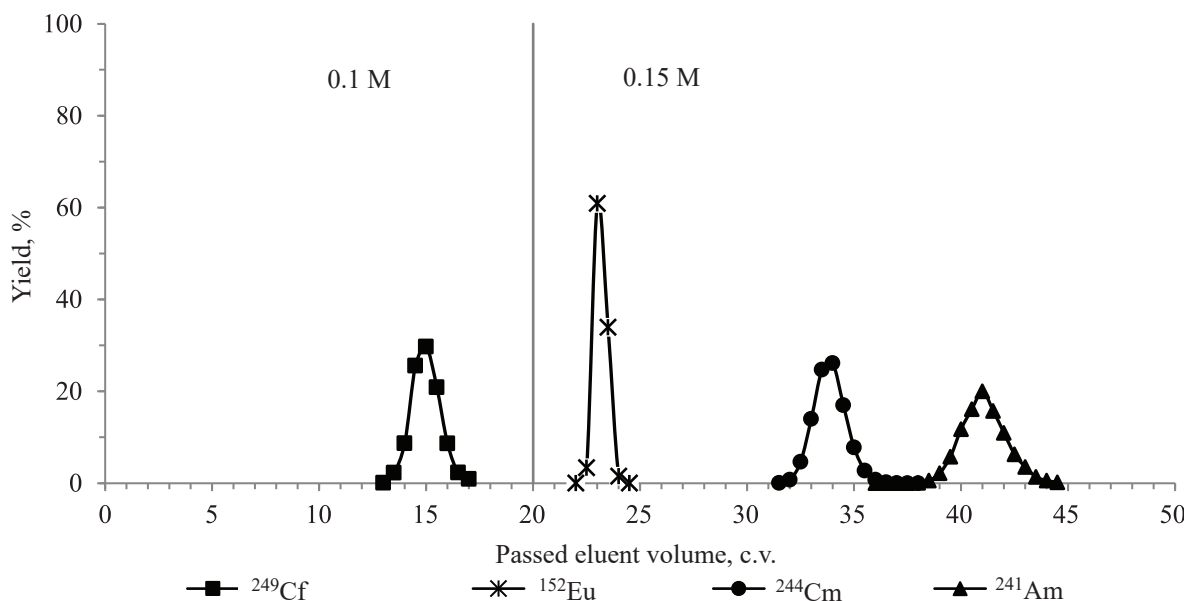


Fig. 3. Output curves of ^{249}Cf , ^{152}Eu , ^{244}Cm , ^{241}Am at sequential elution with 0.1 and 0.15 M α -HIBA ammonium salt solution (pH 5.0). Initial activity, Bq: ^{249}Cf 1.7×10^6 , ^{152}Eu 8.19×10^4 , ^{244}Cm 3.22×10^7 , ^{241}Am 1.32×10^5 .

process for the cation exchange separation and purification of Am and Cm with an α -HIBA ammonium salt solution as an eluent were determined: the number of theoretical plates N , distribution coefficient D , selectivity (separation factor) α , and resolution R_S [21–23].

The number of theoretical plates N_A was calculated from the retention parameters of substance A by Eq. (1):

$$N_A = 16(V_A/W_A)^2, \quad (1)$$

where V_A is the retention volume of substance A, c.v. (volume of mobile phase used to elute a sample of a substance; it is determined between the point of sample injection and the point at which the maximum chromatographic peak is registered); W_A is the substance A peak width at the base, c.v. (segment of the peak base cut off by two tangents drawn at the inflection

points of the ascending and descending branches of the chromatographic peak). The experimentally determined values of the chromatographic peak width at the base and the number of theoretical plates for Cf, Cm, Am, Eu at various eluent concentrations are given in Tables 1, 2, respectively.

Dynamic (volumetric) distribution coefficient D_A of substance A was calculated by Eq. (2):

$$D_A = V'_A/V = (V_A - V_M)/V, \quad (2)$$

where V is the volume of the sorbent layer (1 c.v.); V'_A is the reduced retention volume of substance A, c.v.; V_M is dead volume, c.v.

The dead volume V_M required to calculate the volume distribution ratio includes the free volume of the column and the volume of communications between the eluent injection point and the column. The free volume of the column is taken to be 0.38 c.v., based on the data of [24] for the Dowex 50-X8 cation exchange resin (200–400 mesh). The volume of communications between the eluent injection point and the column was determined experimentally and was equal to 0.05 c.v. Thus, the dead volume of the V_M is 0.43 c.v. The values of dynamic (volumetric) distribution coefficients are listed in Table 3.

Table 3. Dynamic (volumetric) distribution coefficients

Eluent	Distribution coefficient, D_A			
	Cf	Am	Cm	Eu
0.1 M α -HIBA	14.57	—	—	—
0.15 M α -HIBA	—	40.57	33.57	22.57
0.175 M α -HIBA	—	29.57	26.07	21.57
0.2 M α -HIBA	—	26.07	24.07	21.57

The selectivity α (separation factor) of the chromatographic system. Quantitatively, the selectivity is expressed as a dimensionless value characterizing the separating power of the column with respect to the separated substances A and B and numerically equal to the ratio of the reduced retention volumes. It was calculated by Eq. (3):

$$\alpha = V'_A/V'_B. \quad (3)$$

Peak resolution R_S was calculated by Eq. (4):

$$R_S = 2(V_A - V_B)/(W_A + W_B), \quad (4)$$

where V_A , V_B are the retention volumes of substances A and B, c.v.; W_A (W_B) is the peak width at the base of substances A and B, c.v.

The values of the dynamic characteristics of the Cf, Eu, Am, Cm separation are listed in Table 4.

The results in Tables 1–4 show that with an increase in the α -HIBA concentration at the second stage of the stepwise elution process, the width of the chromatographic peak at the base diminishes and the number of theoretical plates rises, i.e., peak blurring is reduced. At the same time, the selectivity α and the resolution R_S decrease, i.e., the overlapping degree of chromatographic peaks increases. It was noted in [25] that two substances will be separated if the selectivity $\alpha > 1$; for a satisfactory separation, R_S must be equal to 1. The separation is considered complete if R_S is equal to or greater than 1.5. Therefore, the Cm and Am separation, as well as their purification from Eu and Cf, is recommended to be carried out by stepwise elution with 0.1 M (pH 5.0) and 0.15 M (pH 5.0) α -HIBA ammonium salt solutions at the first and second stage, respectively.

Purification of weight quantities ^{248}Cm . The initial solution contained 26.6 mg (4.08×10^6 Bq) ^{248}Cm , 2.60×10^{-2} mg (3.3×10^6 Bq) ^{241}Am , and 2.38×10^{-3} mg (3.6×10^5 Bq) ^{249}Cf . The radiometric methods used in this work show no Pu isotopes in the initial solution (the Pu content is below the detection limits), so the preliminary Pu separation on an anion exchange resin was not performed.

A mixture of ^{248}Cm , ^{241}Am , and ^{249}Cf radionuclides was separated on a column containing 10 cm³ of strongly acid Bio-Rad AG 50W-X8 cation exchange resin (200–400 mesh) in the NH_4^+ form. The geometrical parameters of the column are similar to the parameters

Table 4. Dynamic separation characteristics of Cf, Eu, Am, Cm

Element A	Element B	Selectivity (separation factor) α	Resolution R_S
0.1 M α -HIBA–0.15 M α -HIBA			
Cm	Cf	2.30	6.64
Am	Cf	2.78	7.62
Eu	Cf	1.55	3.89
Am	Cm	1.21	1.92
Am	Eu	1.80	6.32
Cm	Eu	1.49	4.35
0.1 M α -HIBA–0.175 M α -HIBA			
Cm	Cf	1.79	5.15
Am	Cf	2.03	6.16
Eu	Cf	1.48	3.76
Am	Cm	1.13	1.71
Am	Eu	1.37	4.78
Cm	Eu	1.21	3.05
0.1 M α -HIBA–0.2 M α -HIBA			
Cm	Cf	1.65	4.55
Am	Cf	1.79	5.29
Eu	Cf	1.48	3.87
Am	Cm	1.08	1.22
Am	Eu	1.21	3.30
Cm	Eu	1.12	1.95

of the columns used when working with indicator amounts of ^{249}Cf , ^{152}Eu , ^{244}Cm , ^{241}Am . The order of elution and the concentrations of α -HIBA ammonium salt solutions are similar to those used in experiments with indicator amounts of ^{249}Cf , ^{152}Eu , ^{244}Cm , ^{241}Am (Fig. 3). The content of ^{248}Cm and ^{241}Am and their distribution by fractions are shown in the output elution curves (Fig. 4).

On the output elution curve of ^{248}Cm (Fig. 4), the leading edge is more diffuse than in experiments with indicator amounts of this element (Fig. 3). Based on the data in [10], this phenomenon can be explained by the fact that the distribution coefficient of Cm probably increases with a rise in its concentration. The relationship between the amount of a substance sorbed from the liquid phase and its concentration in this phase at a constant temperature is expressed by the sorption isotherm.

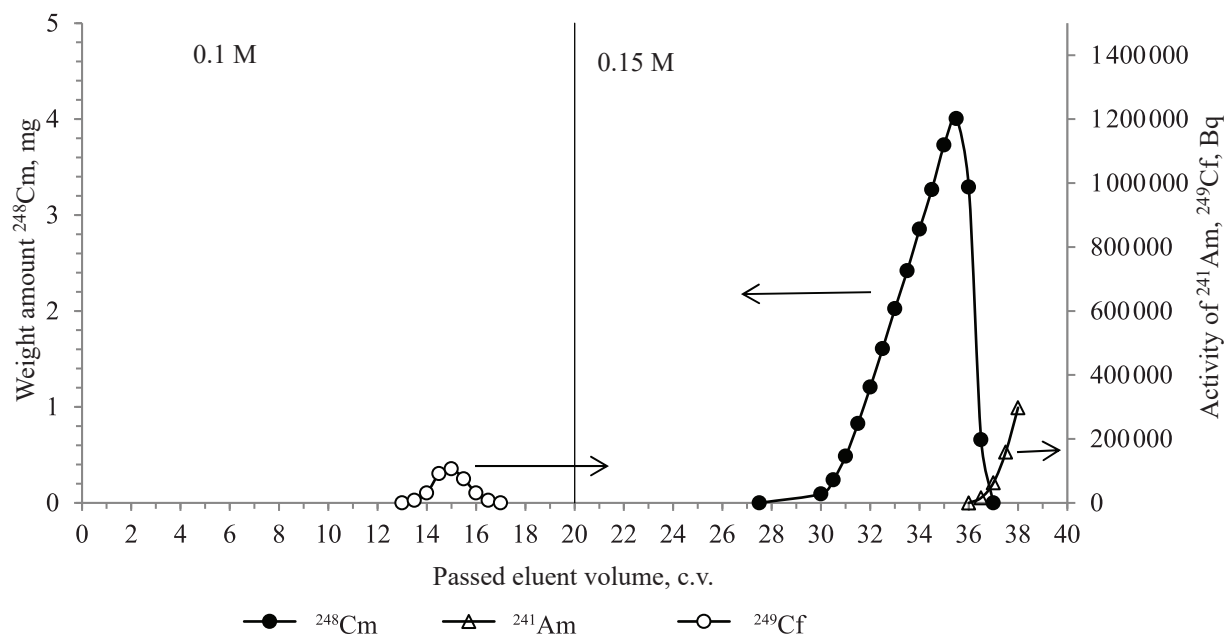


Fig. 4. Output curves of elution of weight amounts of ^{248}Cm (^{248}Cm 26.6 mg, ^{241}Am 3.3×10^6 Bq, ^{249}Cf 3.6×10^5 Bq) with α -HIBA ammonium salt solution, pH 5.0.

At low concentrations, the amount of sorbed substance is proportional to its concentration in the liquid phase, and a linear sorption isotherm is observed (the distribution coefficient does not depend on the concentration of the substance in the liquid phase). Each component of the zone moves at a constant rate, since the linear rate of its migration depends on the flow rate of the mobile phase, which is set constant. The entire zone moves with the same rate, remaining symmetrical: the concentration of the component is maximum in the center of the zone and decreases symmetrically towards the edges. Therefore, the peak on the chromatogram is also symmetrical (Figs. 1–3). If for high concentrations of a substance the distribution coefficient is greater than for low concentrations, then the center of the zone with a higher concentration moves more slowly than the edges of the zone with a low concentration (concave sorption isotherm). As a result, the leading edge of the chromatographic peak is blurred and the peak is asymmetric. Since the leading edge of the chromatographic peak is blurred when Am and Cf are removed from Am and Cf (Fig. 4), it can be assumed that the Cm sorption isotherm has a concave character. For a concave isotherm, the chromatographic peak has an asymmetric shape with a diffuse leading edge; the retained volume increases with increasing ion concentration.

For the specified Cm weight, the following characteristics were experimentally determined: the retention volume $V = 35.4$ c.v., the width of the chromatographic peak at the base $W = 6.1$ c.v., the dynamic (volumetric) distribution coefficient $D = 35$, the number of theoretical plates $N = 539$. Comparison with the experimental results with indicator amounts of ^{244}Cm (Table 2) shows that the number of theoretical plates N decreased when purifying the weight amounts of Cm. The result obtained agrees with the data of [9], in which the elutive separation of Am and Cm on a sulfonic cation exchange resin with α -HIBA was studied. It was shown in [9] that with an increase in the initial loading of the column with the mixture to be separated, the chromatographic separation efficiency of Am and Cm decreases (the number N of theoretical plates decreases).

Using the developed technology, for the first time at RIAR, a ^{248}Cm radionuclide material with a radionuclide and chemical purity significantly exceeding the indicators of preparations obtained using standard technology was produced [1–3]. The characteristics of the ^{248}Cm preparation are as follows: the content of fission products (an activity fraction of the target radionuclide) $\leq 2.1\%$, the weight fraction of non-radioactive impurities $\leq 1.0\%$, the weight fraction of ^{248}Cm in a mixture of curium isotopes 94.99%.

CONCLUSIONS

The regimes of Cm and Am purification from Fe and Pu impurities, as well as the Am and Cm separation regimes and their purification from Cf and Eu by ion exchange chromatography were determined. It was established that the separation of Pu microamounts from Am and Cm can be carried out by its sorption on a strongly basic Bio-Rad AG 1-X8 anion exchange resin (50–100 mesh) from 9 M HCl in the presence of 0.1 M H_2O_2 .

The Am and Cm separation and their purification from Cf and Eu by cation exchange chromatography with the α -HIBA ammonium salt solution as an eluent were tested. The REE and TPE separation is carried out in the regime of stepwise elution with the α -HIBA ammonium salt solutions of 0.1 (pH 5.0) (first stage) and 0.15 M (pH 5.0) (second stage) concentrations. At the first stage of the process, Cf is recovered; at the second stage, Eu, Cm, and Am are separated.

In experiments with indicator amounts of ^{249}Cf , ^{152}Eu , ^{244}Cm , ^{241}Am , the characteristics of the chromatographic process of cation exchange purification were determined: the number of theoretical plates N , distribution coefficient D , selectivity (separation factor) α , resolution R_S . It was noted that upon purification of weight amounts of Cm, the chromatographic peak has an asymmetric shape with a diffuse leading edge, i.e., the concentration Cm corresponds to the nonlinear section of the sorption isotherm. With a nonlinear sorption isotherm, the blurring of chromatographic zones increases and the efficiency of the chromatographic column diminishes (the number of theoretical plates N decreases and the resolution of the Am and Cm peaks decreases), resulting in reducing the separation completeness of these elements

Purification of weight quantities of ^{248}Cm was carried out, and the ^{248}Cm preparation was produced with the following characteristics: the content of fission products (the activity fraction of the target radionuclide) $\leq 2.1\%$, the weight fraction of non-radioactive impurities $\leq 1.0\%$, the weight fraction of ^{248}Cm in a mixture of curium isotopes 94.99%.

CONFLICT OF INTERESTS

The authors declare no conflict of interest.

REFERENCES

- Toporov, Yu.G., Shimbarev, E.V., Tarasov, V.A., Romanov, E.G., and Kupriyanov, A.V., *Izv. Samarского nauch. tsentra RAN*, 2014, vol. 16, no. 6–1, p. 142.
- Lebedev, V.M., Kornilov, A.S., *Nekotorye osobennosti razdeleniya vesovogo kolichestva ameritsiya i kyuriya* (Some Features of the Separation of the Weight Amounts of Americium and Curium), Dimitrovgrad: NIIAR, 2019.
- Toporov, Yu.G., Tarasov, V.A., Romanov, E.G., Kupriyanov, A.V., Andreev, O.I., Shimbarev, E.V., Gordeev, Ya.N., Petelin, A.L., Sazontov, S.A., Uzikov, V.A., *Sb. tr. AO "GNTs NIIAR"* (Proceedings of JSC "SSC RIAR"), Dimitrovgrad: NIIAR, 2018
- Tremilln, B., *Les Séparations par les résines échangeuses d'ions*, Paris : Gauthier-Villars, 1965.
- Perdue, H.D., Conover, A., Sawley N, Anderson, R., *Anal. Chem.*, 1968, vol. 40, no. 12, p. 1773.
- Campbell, D.O., *Sep. Purif. Meth.*, 1976, vol. 5, no. 1, p. 97.
- Chen, X., Goff, G.S., Ewing, W.C., Scott, B.L., Runde, W., *Inorg. Chem.*, 2012, vol. 51, no. 24, p. 13254–13263.
- Elesin, A.A., Karaseva, V.A., *Radiokhimiya*, 1977, vol. 19, no. 5, p. 678.
- Elesin, A.A., Karaseva V.A., Frolov, V.I., *Radiokhimiya*, 1979, vol. 21, no. 4, p. 511.
- Benker, D.E., Chattin, F.R., Collins, E.D., Knauer, J.B., Orr, P.B., Goss, R.B., Wiggins, J.T., *Transplutonium Elements—Production and Recovery*, Navratil, J.D., Ed., Washington: ACS, 1981.
- Elesin, A.A., Nikolaev, V.M., Shalimov, V.V., Popov, Yu.S., Kovantsev, V.N., Tselishchev, I.V., Filimonov, V.T., Mishenev, V.B., Yadovin, A.A., Golosovskii, L.S., Chetverikov, A.P., Efremov, Yu.V., *Radiokhimiya*, 1986, vol. 28, no. 6, p. 786.
- Mikheev, N.B., Kamenskaya, A.N., Auerman, L.N., Kulyukhin, S.A., Rumer, I.A., Novichenko, V.L., *Radiokhimiya*, 1987, vol. 29, no. 2, p. 194.
- Vobecký, M., *J. Radioanal. Nucl. Chem.*, 1989, vol. 135, no. 3, p. 165.
- Malmbeck, R., Apostolidis, C., Carlos, R., Glatz, J.-P., Molinet, R., Morgenstern, A., Nicholl, A., Pagliosa, G., Römer, K., Schädel, M., Sätmark, B., Trautmann, N., *Radiochim. Acta*, 2001, vol. 89, no. 9, p. 543.
- Boll, R.A., Van Cleve, S.M., Sims, N.J., Felker, L.K., Burns, J.D., Owen, G.D., Smith, E.H., White, C.S., Ezold, J.G., *J. Radioanal. Nucl. Chem.*, 2015, vol. 305, no. 3, p. 921.
- Burns, J.D., Van Cleve, S.M., Smith, E.H., Boll, R.A., *J. Radioanal. Nucl. Chem.*, 2015, vol. 305, no. 1, p. 109.

17. Robinson, S.M., Benker, D.E., Collins, E.D., Ezold, J.G., Garrison, J.R., Hogle, S.L., *Radiochim. Acta*, 2020, vol. 108, no. 9, p. 737.
18. Ryan, J.L., *J. Phys. Chem.*, 1960, vol. 64, no. 10, p. 1375.
19. Chilton, J.M., Fardy, J.J., *J. Inorg. Nucl. Chem.*, 1969, vol. 31, no. 4, p. 1171.
20. Larsen, R.P., Oldham, R.D., *Talanta*, 1975, vol. 22, no. 7, p. 577.
21. Shpigun, O.A. and Zolotov, Yu.A., *Ionnaya khromatografiya i ee primeneniye v analize vod* (Ion Chromatography and Its Application in Water Analysis), Moscow: Izd MGU, 1990.
22. Dolgonosov, A.M., Rudakov, A.B., Prudkovskii, A.G., *Kolonochnaya analiticheskaya khromatografiya: praktika, teoriya, modelirovaniye* (Column Analytical Chromatography: Practice, Theory, Modeling), St. Petersburg: Lan', 2015.
23. Aivazov, B.V., *Vvedeniye v khromatografiyu* (Introduction to Chromatography), Moscow: Vysshaya shkola, 1983.
24. Marhol, M., *Ion Exchangers in Analytical Chemistry. Their Properties and Use in Inorganic Chemistry (Comprehensive Analytical Chemistry)*, Amsterdam: Elsevier, 1982.
25. Bol'shova, T.A., Brykina, G.D., Garmash, A.V., Dolmanova, I.F., Dorokhova, E.N., Zolotov, Yu.A., Ivanov, V.M., Fadeeva, V.I., Shpigun, O.A., *Osnovy analiticheskoi khimii. Kn. 1: Obshchie voprosy. Metody razdeleniya* (Fundamentals of Analytical Chemistry. Book. 1: General Questions. Separation Methods.), Moscow: Vysshaya Shkola, 2000.