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MOLYBDENUM-99 TECHNOLOGICAL DEVELOPMENT**

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**Progress Related to Mo-99 Separation, Precipitation
Prevention, and Clean-Up for SHINE System**

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ABSTRACT

Argonne is assisting SHINE Medical Technologies in their efforts to produce Mo-99 in the US. Plant-scale column designs have been generated and successfully tested on a small scale for the Mo recovery column and concentration column. Direct down-scale column experiments performed under constant irradiation at the Van de Graaff accelerator suggest that Mo redox chemistry is unaffected at dose rates of ~70 kRad/h. However, uranyl sulfate solutions irradiated at dose rates of 3400 MRad/h led to the precipitation of uranyl peroxide. Iron (metallic, ferrous, or ferric) is a catalyst for peroxide destruction. Lastly, Argonne has developed a process for sulfate-to-nitrate conversion using a mixture of $\text{Sr}(\text{NO}_3)_2$ and $\text{Ba}(\text{NO}_3)_2$. DU foils were irradiated at the linac and used as a spike for a uranyl-sulfate solution to gain an initial understanding of fission-product behavior during sulfate-to-nitrate conversion and with the UREX solvent. Rare-earth elements partitioned to the sulfate precipitate and iodine behavior was very complex.

Introduction

Argonne is assisting Morgridge Institute for Research (MIR) in their efforts to produce a domestic supply of Mo-99. MIR is developing an accelerator-driven process that will use a uranyl sulfate solution for Mo-99 production. The Subcritical Hybrid Intense Neutron Emitter (SHINE) proposed by MIR will use a pure titania sorbent to separate and recover Mo-99. After the initial recovery column, the Mo product solution will be acidified to pH 2 and passed through an additional titania column to reduce the volume of strip solution prior to entering the LEU-Modified Cintichem purification process. Direct down-scale column experiments have been performed using surrogate SHINE solutions (depleted uranyl sulfate solutions spiked with Mo-99, Np-239, Pu-239, and/or irradiated DU foils), and results indicate high Mo recovery (90-100%). Additionally, column experiments have been performed under constant irradiation using

the Van de Graaff accelerator as a source of radiation. It appears that Mo redox chemistry is unaffected when the solution and column are exposed to relatively low dose rates (~70 kRad/h); however, irradiation of uranyl-sulfate solutions at much higher dose rates (~3400 MRad/h) leads to precipitation of uranyl peroxide. Several different catalysts have been tested to prevent peroxide formation, but Fe is the most likely choice because it has been shown to be effective at concentrations as low as 1 ppm.

SHINE plans to clean-up the target solution after an undetermined number of irradiation/Mo recovery cycles. Argonne has examined four different methods for potential clean-up, but conversion to nitrate followed by UREX appears to be the most promising. Conditions have been successfully tested (50 mL uranyl sulfate solution spiked with irradiated DU foils) for conversion from sulfate to nitrate using a mixture of Sr(NO₃)₂ and Ba(NO₃)₂ with heat. The rare-earth elements precipitated during conversion, and iodine was found in multiple fractions in the irradiated DU foil experiments. Future experiments will utilize ~1L of uranyl-sulfate solution spiked with irradiated DU foils or uranyl-sulfate solution and irradiated mini-SHINE solution.

Experimental

Batch Studies

The uptake of Mo(VI) is determined by equilibrating 1 mL of a Mo-99 spiked aqueous solution with a known amount (10 ± 1 mg) of titania sorbent for 24 hours at 80°C using a thermostated shaker bath. Aqueous solutions of uranyl sulfate and sodium nitrate (pH 2 and pH 5) contained tracer Mo-99 and stable Mo added as Na₂MoO₄. After equilibration, the solution is withdrawn and filtered using a syringe fitted with a 0.22 μm pore size PVDF membrane filter.

Preparation of Mo-99 Spike Solution.

Mo-99 is removed from a Tc-99m generator by placing a serum vial containing 1 M NH₄OH on the needle labeled “Saline Charge”. Then an evacuated serum vial is placed on the needle labeled “Receiver”. The Mo-99 spiked solution is prepared by bringing the solution to dryness on a hot plate, and re-dissolving it in 0.1 M H₂SO₄ or H₂O.

Counting of Mo-99

The amount of activity in the aqueous samples is determined using a germanium detector. Mo-99 is quantified by measurement of its 739 keV γ-ray. The activity of Mo-99 in each sample is corrected for decay. The extent of radionuclide uptake is expressed in terms of a distribution coefficient, K_d , shown in equation (1).

$$K_d = \left(\frac{A_o - A_s}{W} \right) \bigg/ \frac{A_s}{V} \quad (1)$$

Here, A_o and A_s represent the aqueous phase activity (μCi) before and after equilibration, W is the dry weight of the sorbent (g), and V is the volume of the aqueous phase (mL).

Column Tests

An AKTA liquid chromatography system is used to pass solution through titania columns of variable size. A titania sorbent with 110 μm particles and 60 Å pores is used for the initial Mo recovery column, and a titania sorbent with 40 μm particles and 60 Å pores is used for the

concentration column. The feed solution containing stable Mo and tracer Mo-99 is loaded onto the column in the up-flow direction. After loading is complete, the column is washed with acid (pH 0 – 2) (sulfuric or nitric) and water in the up-flow direction. Mo is eluted from the column using 0.1 M NaOH for the initial recovery column and 1 M NH₄OH for the concentration column in the down-flow direction, and a final water wash is performed in the up-flow direction.

Van de Graaff Column Experiments

Direct down-scale column experiments of the plant-scale column designs for SHINE have been performed under a constant source of radiation at the Van de Graaff accelerator. The target solution and column have been exposed to dose rates of ~70 kRad/h for approximately 3 hours. Once the solution has been loaded onto the column, the column is disconnected from the VDG setup and connected to the AKTA liquid chromatography system to complete the acid and water washes and elution with base. Feed solutions have been spiked with Mo-99, Np-239, and Pu-239.

Van de Graaff Setup for Peroxide Catalysis Tests

Figure 1 shows the setup for the peroxide catalysis and gas-analysis experiments, which is designed with two interconnected systems, the process loop and the sampling manifold. The process loop is a closed loop of stainless steel tubing that consists of the target sample, the electron beam, and a peristaltic pump. The target sample is inserted into a holder directly in the accelerator beam path. The holder is attached to a re-circulating pump and water bath to provide continuous cooling to the sample. The electron beam impinges on the cooling water and quartz tube in the setup. Mainly electrons and some X-rays interact with the test solution causing generation of hydrogen peroxide, oxygen, and hydrogen in the sample tube. The sample tube has an inlet and outlet valve, so headspace gases can be continuously recirculated throughout the process loop. Recirculation of gas is achieved using a peristaltic pump. The Van de Graaff accelerator has a 2.5 MeV DC electron beam.

The sampling manifold is connected to the process loop by a bellows valve. The sampling manifold consists of a capacitance monometer, vacuum pump, and two analytical instruments connected by stainless steel tubing and a series of valves used to either evacuate, measure pressure, or analyze the gases in the manifold. The gases are analyzed using a SRI-8610C gas chromatograph with a Thermal Conductivity Detector (TCD) and a Helium Ionization Detector (HID). Separation is achieved using a 13X molecular sieve and Haysep-d columns.

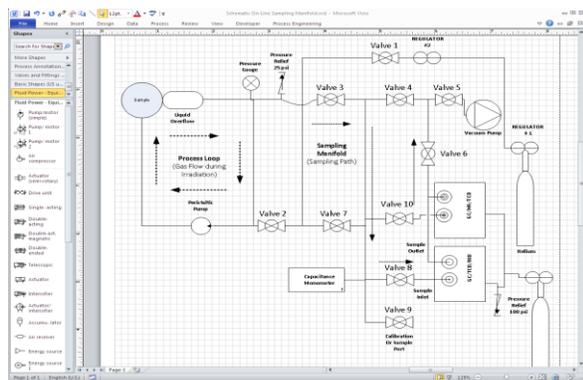


Figure 1. Setup for Van de Graaff peroxide catalysis and gas analysis experiments.

Catalyst Tests

A 2 mL uranyl-salt solution is placed in a quartz sample tube. The sample tube is connected to the process loop in the beam path. The system is then evacuated and purged with helium several times to remove atmospheric gases. The process loop is pressurized to 800 torr with Ultra High Purity (UHP) helium.

The 2.5-MeV electron beam is set to 20 μ A, and the sample is irradiated for approximately 5 hours. At 30-minute intervals, a sample of the headspace gas is withdrawn into the evacuated "Sampling Manifold" for analysis. The gas removed is replaced with helium to keep a constant pressure in the system. Prior to these experiments, oxalic-acid dosimetry was performed to determine the dose deposited into the sample.

Uranyl-sulfate solutions were tested at various concentrations. Several known and potential hydrogen peroxide catalysts were tested, such as Fe, Zr, I, Cu, and stainless steel.

Conversion Tests: Sulfate Precipitation

A 10 mL aliquot of a uranyl sulfate solution, containing ~90-150 g-U/L and ~0.5 M SO_4^{2-} is placed in a reaction vessel. The reaction vessel is placed in a 60°C water bath and allowed to equilibrate for 30 minutes, while being agitated. After temperature equilibration, solid strontium nitrate is added to the reaction vessel and allowed to react with the uranyl-sulfate solution for 30 minutes, while the solution is agitated. Barium nitrate is then added to the reaction vessel and allowed to react for 60 minutes under constant agitation. The reaction vessel is removed from the water bath, agitation is ceased and the solution is cooled for 30 minutes to bring it to room temperature. The solution is then filtered using a 1 μ m Nucliopore filter.

A precipitation procedure has been developed resulting in Ba levels of ~70 mg/L, which is below RCRA levels (100 mg/L) and a sulfate concentration of 0.005 M, which is below the maximum sulfate concentration of 0.01 M allowed for successful uranium recovery by the UREX process. This procedure includes, temperature control using a water bath, a constant Sr to sulfate ratio of 1.05:1 equivalents, a constant Ba to sulfate ratio of 0.05:1 equivalents, and constant reaction times.

UREX Batch Contacts

The UREX batch contacts were divided into 5 series. The first contact series was meant to simulate extraction of species in an irradiated SHINE target solution into the UREX solvent (1 M tributyl phosphate in n-dodecane) without the presence of acetohydroxamic acid (AHA) in the aqueous solution to complex and retard the extraction of transuranic elements and transition-metal fission products. It was also a source of loaded organic to use in subsequent contact series.

The second series was meant to simulate conditions in the extraction section in the UREX process developed for use by SHINE. Loaded organic from this series was mixed with loaded organic from the first contact series to provide loaded organic for the third contact series.

The third contact series was meant to simulate conditions in the first scrub section of the UREX process. The loaded organic from this series was the organic feed to the fourth contact series.

The fourth contact series was meant to simulate conditions in the second scrub section. The loaded organic from this series became the organic feed for the fifth contact series.

The fifth contact series was meant to simulate the strip section of the UREX process. Due to the fact that a significant amount of iodine could not be stripped from the organic solvent, a series of tests have been completed to examine alternative ways to strip iodine.

Results and Discussion

Column Designs

An integral part of the SHINE process is the development of a column for the separation and recovery of Mo-99 followed by a concentration column to reduce the product volume from 15-25 L to < 1 L. Argonne has collected data from batch studies and breakthrough column experiments to utilize the VERSE (Versatile Reaction Separation) simulation program (Purdue University) to design plant-scale columns. Plant-scale column designs for the initial Mo recovery and concentration column have already been generated and tested on a small-scale.¹ Table I shows the plant-scale designs generated by VERSE from data collected in a batch mode and small-scale column setting. The designs assume a uranium concentration of 130 g-U/L, a Mo concentration of 2.1×10^{-3} mM, a 2 h loading time, and a solution and column temperature of 80°C. The column length was increased by 10% above the mass transfer zone (MTZ) and rounded up to the nearest centimeter to account for system parameter uncertainties. The column volume, mass of sorbent, pressure drop, and sorbent loading were calculated from the column geometry. Table II shows results from direct down-scale column experiments for the SHINE plant-scale column design. Several other column experiments were performed for different target solution configurations, and overall, results suggest that reducing the stripping velocity by half of the loading velocity and heating the strip solution to 70°C are necessary to achieve 90 -100% Mo recoveries on a consistent basis.

Table I. Plant-scale column designs for recovery of Mo from 262 L of 130 g-U/L, 2.10×10^{-3} mM Mo, at 80°C. Titania -110 μ m, 99.9% recovery, 2 h loading time, 2.2 L/min.

column ID (cm)	velocity (cm/min)	MTZ _{0.1%} (cm)	Column length (cm)	Column volume (L)	Sorbent weight (kg)	Δ P (atm.)	Mo-99 / sorbent mass (Ci/g)
10	27.8	17.4	20	1.6	2.04	0.63	1.90
12	19.3	12.0	14	1.6	2.06	0.30	1.89
15	12.4	7.8	9	1.6	2.07	0.13	1.88
20	7.0	4.4	5	1.6	2.04	0.04	1.90

Table II. Direct down-scale column experiments.

U Conc. (g-U/L)	Mo Conc. (mM)	Feed Volume (mL)	Column ID (cm)	Column L (cm)	% Mo Effluent	% Mo Recovered	Loading Velocity (cm/min)	Stripping Velocity (cm/min)	Feed Temp. (°C)
130	2.10E-03	665	1	5	0.08	100	7	3.5	80
130	2.10E-03	665	1	5	0.11	86	7	7	80
130	2.10E-03	665	1	5	0.33	81*	7	3.5	80

*Strip solution not heated to 70°C.

TiO₂ (40 μm) and acidic and neutral Al₂O₃ (32-63 μm) were evaluated for the recovery of Mo from a 0.1 M NaNO₃ solution at pH 2 and 5 for the design of the concentration column. The data from batch equilibrium experiments were used to estimate the effective Mo isotherm parameters for TiO₂ and Al₂O₃ sorbents. Solutions and sorbents for all batch equilibrium data were equilibrated for 24 hours at 80°C. Langmuir isotherm parameters were fitted using Origin 8.5.1. The Langmuir isotherm model parameters at pH 2 for TiO₂ are $a = 223000$, $b = 1530$ mM^{1.2}. Langmuir adsorption constants at pH 2 are 2 orders of magnitude higher than at pH 5. Therefore, loading conditions at pH 2 were chosen for the concentration column designs. Figure 2 shows the Langmuir curve for titania-40 μm sorbent in the presence of 0.1 M NaNO₃.

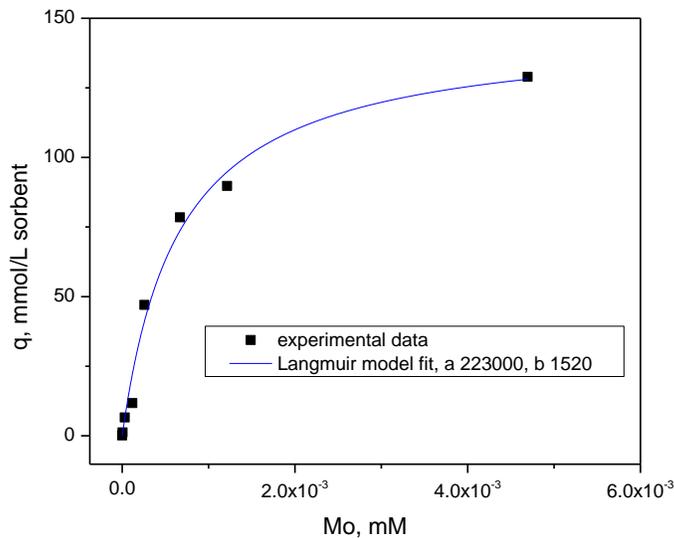


Figure 2. Isotherm data from batch tests and Langmuir isotherm model fit for adsorption of Mo on 40 μm titania sorbent from 0.1 M NaNO₃, pH 2 solutions at 80°C.

Column designs were developed for concentrating the Mo product separated from a 130 g-U/L uranyl sulfate solution and stripped with 0.1 M NaOH. A concentration column loading time of 1 h was chosen to enable utilization of the 40 μm particle size sorbent and remain within a ΔP of 0.5 atm. Column lengths were calculated by adding 10% to the MTZ length and rounding up to the nearest 0.5 or whole number. It is difficult and unreliable to pack a column with a greater

accuracy than 0.5 cm. Table III shows the plant-scale column designs, which assume 99.9% Mo recovery. The 4 cm ID x 1.5 cm L column is the optimum design for the plant-scale concentration column because it will generate the least amount of strip volume prior to purification. Table IV shows results from a direct down-scale concentration column experiment, where 99.7% Mo was loaded and 89% was recovered.

Table III. 40 μm titania sorbent, 99.9% recovery concentration column designs following a 2 h loading Mo recovery from a 130 g-U/L uranyl sulfate solution.

column ID (cm)	velocity (cm/min)	MTZ _{0.1%} (cm)	Column length (cm)	Column volume (mL)	Sorbent weight (g)	ΔP (atm)	Mo-99 / sorbent mass (Ci/g)	strip volume (mL)
4	31.20	1.11	1.5	19	24	0.32	163.45	301.6
5	19.97	0.72	1.0	20	25	0.14	156.91	314.2
6	13.87	0.52	1.0	28	36	0.09	108.97	452.4
8	7.80	0.31	0.5	25	32	0.03	122.59	402.1

Table IV. Mo loading results for 99.9% loading designed column. Direct down-scale column dimensions: 0.66 cm ID X 1.5 cm L.

Stream	% Mo-99
Effluent	0.3
0.01 M HNO ₃ Wash	0.01
H ₂ O wash	0.03
1 M NH ₄ OH strip	89

Van de Graaff Column Experiments

Results from the Van de Graaff column experiments suggest that Mo redox chemistry is unaffected when solutions are exposed to dose rates near ~ 70 kRad/h. Less than 1% Mo is found in the effluent under these radiation conditions. Solutions were also spiked with Pu-239 and Np-239 to gain insight into their behavior under irradiation. Initial results suggest that washing the column with 0.5 M H₂SO₄ does not fully remove Pu from the column because about 50% remained adsorbed on the column. However, increasing the acidity of the acid wash changed Mo chemistry and prematurely eluted 8-10% Mo off the column during the acid wash. Experiments are ongoing to develop conditions for Pu removal without changing Mo chemistry. Most of the Np-239 ($\sim 90\%$) does not adsorb on the column and is found in the effluent. The remaining 10% comes off in the acid and first water wash. Van de Graaff column experiment results for Mo-99 are given in Table V.

Table V. Results from Van de Graaff column experiments.

Experiment Date	Solution Dose Rate (kRad/h)	Column Dose Rate (kRad/h)	% Mo in Effluent	% Mo in Washes	% Mo Recovered	Acid Wash
2/14/2013	64.3	15.5	0.9	0.3	100	0.5 M H ₂ SO ₄
2/27/2013	74.1	17.8	0.7	15	92	1 M H ₂ SO ₄
3/6/2013	67.8	16.3	0.6	11	100	1 M H ₂ SO ₄
3/12/2013	68.8	16.6	0.2	2	95	0.5 M H ₂ SO ₄

Peroxide Catalysis

In order to prevent precipitation of uranyl peroxide, a catalyst must be added to the uranyl sulfate solution to inhibit the production of radiolytically generated hydrogen peroxide. Fe(II) added as FeSO₄ has been shown to accomplish this at a concentration of ~ 1 ppm.³ In order to expand the available options for use in the SHINE system, other salts were tested because of their known catalytic activity with H₂O₂. Experiments were performed using copper sulfate, potassium iodide, and Iron (III) sulfate in solution. Potential fabrication materials for the target and holding vessels (304 stainless steel and zirconium ASME 658) were tested as well.

Table VI provides experimental data for the irradiation of uranyl-sulfate solutions containing different catalysts. Zirconium was not effective in preventing the precipitation of uranyl-peroxide. The zirconium target-solution vessel will not serve as an effective catalyst for peroxide destruction. The solution containing 304 stainless steel turnings showed no uranyl-peroxide precipitation, which is most likely due to the chromium or iron acting as a peroxide catalyst. Irradiations using salts as catalysts (copper sulfate, potassium iodide, and ferric sulfate) showed no precipitation.

Zirconium metal exhibited the behavior of an untreated uranyl-sulfate solution with high volumes of both hydrogen and oxygen generated with H₂-to-O₂ ratios >2. The 304 Stainless steel test showed low overall gas production and a low H₂:O₂ ratio. All of the salt catalysts reduced the overall gas production and reduced the H₂-to-O₂ ratios below two. Figure 3 shows a graph of the H₂:O₂ ratios for samples where precipitation did not occur.

Table VI. Data from the irradiation of uranyl sulfate solutions with various catalysts added.

Catalyst	UO ₂ SO ₄ (g-U/L)	Energy Deposited (Gy)	Precipitation	Initial pH	Final pH	μmoles H ₂ Produced	μmoles O ₂ Produced	H ₂ to O ₂ Ratio
Cu(II), 62.5 mg-Cu/L	126	2.20E+08	NO	1.4	N.A.	406	286	1.42
KI, 9.94 mg-I/L	126	2.28E+08	NO	1.4	N.A.	206	147	1.40
Fe(III) 0.96 mg/L	126	2.28E+08	NO	1.4	N.A.	566	369	1.53
304 Stainless Steel	126	2.24E+08	NO	1.4	N.A.	261	223	1.17
Zirconium Metal	298	2.32E+08	YES	1.0	N.A.	1112	460	2.42

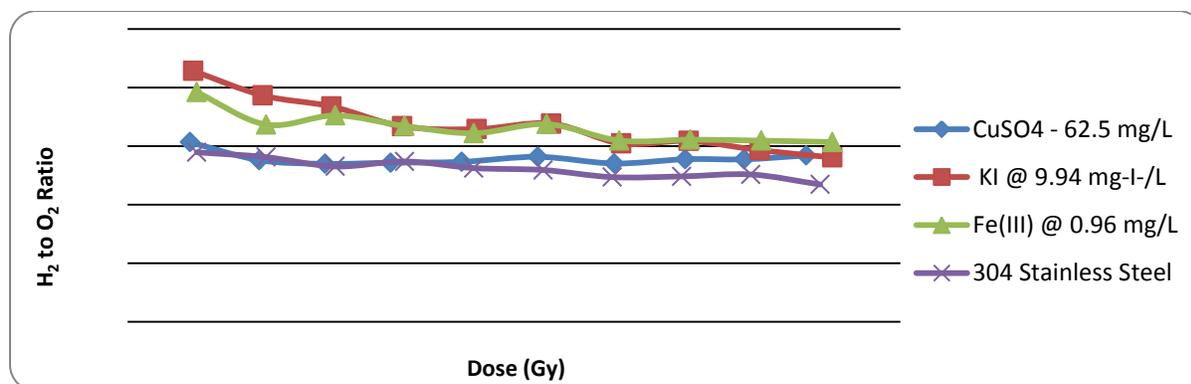


Figure 3. Hydrogen to Oxygen Ratios versus Dose for 126 g-U/L UO_2SO_4 Solutions with various peroxide catalysts added.

Solution Clean-Up

Four grams of depleted-uranium (DU) foil (eight 0.5-g foils) were irradiated at the linac at 30 MeV and 100 μA for 8 hours using a 5-mm W convertor. Two major reactions take place in DU—(1) a photofission reaction on U-238 to produce fission products and (2) a γ, n reaction on U-238 to produce U-237. Six of the irradiated foils were dissolved in nitric acid, the solution was brought to dryness to drive nitrate off, and the residue was used as a spike for a uranyl sulfate solution. The sulfate-to-nitrate conversion was performed by transferring a 25-mL aliquot of the 130 g-U/L pH 1 solution to a small digestion vessel. After the addition of 2.83 g of $\text{Sr}(\text{NO}_3)_2$, the slurry was stirred and heated at 70° C for ~1 h. At this time, 0.35 g of $\text{Ba}(\text{NO}_3)_2$ was added to the slurry and heated/stirred for an additional hour. The slurry was then filtered through a 5- micron 25-mm Nuclepore polycarbonate filter with vacuum. The filtrate was transferred to a poly bottle, and the precipitate was washed 3 times with 2 mL of dilute HNO_3 . To adjust the solution to 1 M HNO_3 , 1.6 mL of 15.2 M HNO_3 was added to filtrate. Aliquots of this solution were used in the UREX batch-contact studies.⁴

The overall conclusions from the data analysis from the conversion from sulfate to nitrate are:

- Most if not all of the alkaline earths (Ba and Sr) partition to the precipitate.
- Most of the transition metals and iodine partition to the filtrate.
- Essentially all the uranium partitions to the filtrate.
- A large fraction of the rare-earth elements partition to the precipitate.

Some interesting data were obtained in these experiments that may lead to some rethinking of the target-solution cleanup and waste disposition strategy. It is important to remember, especially with iodine chemistry, that these were tracer tests and the radioisotopes were not generated in solution, but rather in a metallic foil. They do indicate, however, that further study is required in the target-solution cleanup. The next-stage test will also use a small volume of accelerator-irradiated micro-SHINE solution, and the solvent-extraction portion will be performed in a centrifugal contactor bank, providing more realistic UREX data. The third-stage test will use irradiated mini-SHINE solution for the clean-up process.

The partitioning of the rare-earth elements to the sulfate precipitate in the sulfate-to-nitrate conversion was not anticipated, and its effect on disposition of this waste needs to be examined.

Gaining an understanding of iodine behavior in the UREX process and means to control it are also required. A study using solvent extraction and liquid chromatography has been initiated to find a means to remove iodine from the UREX solvent. Approximately, 50% radio-iodine partitioned into a 30% TBP/n-dodecane phase from an aqueous phase of 1 M HNO₃ and 10⁻⁶ M stable I₂. Stripping the radio-iodine from the loaded organic phase proved to be insufficient when using 1 M HNO₃, Na₂CO₃, hydroxylamine, or water. NaOH showed some slight stripping capabilities. Activated charcoal and AMBERCHROM CG116 resin exhibited reasonable separation capabilities as a stationary phase. Hydrazine was able to slightly mitigate the extraction of iodine; U⁴⁺ had little to no effect. Figure 4 shows the extractions of radio-iodine by 30% TBP from various aqueous phases containing tracer I-131 (3 x 10⁻⁴ – 9 x 10⁻³ μCi/μL) in the presence of 0.7 x 10⁻⁶ M stable I₂ carrier (red diamonds) and absence of KI (green squares) at room temperature. Addition of stable potassium iodide to the aqueous phase lowered the distribution ratio of radioiodine by isotopic dilution; iodide is less extractable than iodine.

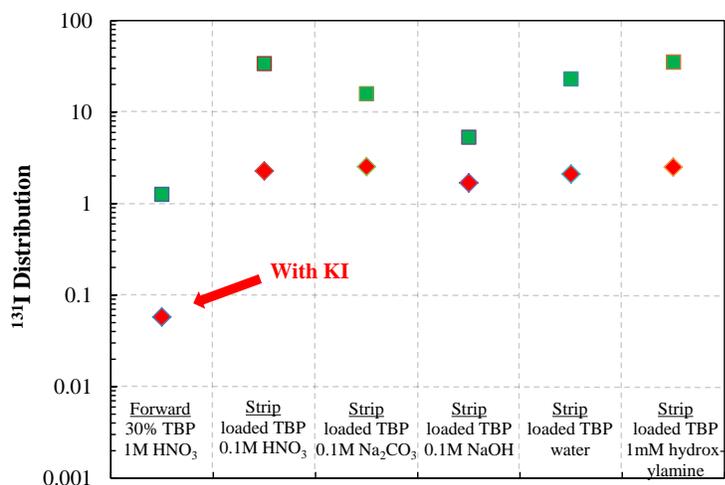


Figure 4. Extractions of I-131 by 30% TBP from various aqueous phases containing 0.7X10⁻⁶M stable I₂ carrier at room temperature. Red diamonds show data with KI carrier.

Conclusions

SHINE plant-scale column designs have been generated and small-scale column tests have been performed to confirm the validity of the designs. Results show ~90-100% Mo recovery when the strip solutions for the initial column and concentration column are heated to 70°C, and the stripping velocity is decreased. Column experiments performed under constant irradiation at the VDG suggest Mo redox chemistry is unchanged when exposed to relatively low dose rates (~70 kRad/h); however, when uranyl sulfate solutions are exposed to much higher dose rates (~3400 MRad/h), uranyl peroxide will precipitate unless a catalyst is added to the solution. The mini-SHINE experiments will provide information for the effect of higher dose rates on Mo redox chemistry and its subsequent adsorption on and/or recovery from titania sorbents.

A process for conversion from sulfate-to-nitrate has been demonstrated using irradiated DU foils as a spike for a uranyl sulfate solution and strontium and barium nitrate. Results show that the alkaline earth elements will partition to the precipitate. Iodine and most transition metals are

found in the filtrate. After batch contacts with the UREX solvent, about 50% iodine remained in the organic phase. Results from preliminary tests suggest that hydrazine is effective at stripping radioiodine from the UREX solvent by reducing it to the less extractable iodide, but it may not be the best choice due to its explosive behavior in the presence of oxidants.

References

[1] Youker, A.J., Stepinski, D.C., Ling, L. & Vandegrift, G.F. Mo Recovery Updates and Physical Properties of Uranyl Sulfate Solutions, Argonne Topical Report to be published.

[2] Stepinski, D.C., Youker, A.J. & Vandegrift, G.F. Plant-scale concentration column designs for SHINE target solution, Argonne Topical Report to be published.

[3] Kalensky, M., Chemerisov, S., Youker, A.J., Tkac, P., Krebs, J. Quigley, K., Lowers, R., Bakel, A. & Vandegrift G.F. Means to Eliminate Uranyl Peroxide Precipitation in SHINE Target Solution, Argonne Topical Report to be published.

[4] Vandegrift, G.F., Bowers, D., Bennett, M., Sullivan, V., Makarashvili, V., Chemerisov, S., Youker, A. & Byrnes, J. First Stage Spent SHINE Target Cleanup Experiments, Argonne Topical Report to be published.

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