



## Trace elemental analysis of bulk uranium materials using an inline automated sample preparation technique for ICP-OES



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### ABSTRACT

An automated inline method for the separation of trace element impurities from uranium matrices using a 200  $\mu\text{L}$  column packed with UTEVA resin is presented here utilizing an Elemental Scientific, Inc. prepFAST IC in combination with a Perkin Elmer Avio 500 ICP-OES. This method reduces human exposure to highly concentrated acids and uranium-rich samples by automating the chemistry and introduction to the ICP. Calibration standards were prepared using inline dilutions requiring a single stock standard. The separation of trace elements from uranium matrices requires samples to be prepared in 8 M  $\text{HNO}_3$ , which can be detrimental to the ICP, thus a post-column dilution step was employed to dilute the eluent matrix to 4 M  $\text{HNO}_3$ . The method was optimized for a sample-to-sample time of < 9 min and monitored 21 elements in total. Proof of concept experiments for 1  $\mu\text{g mL}^{-1}$  trace elements spiked into 0.1 vol%, 0.5 vol%, and 1.0 vol% uranium matrices resulted in < 5% relative difference and < 10% relative standard deviation for triplicate measurements of each uranium matrix analyzed. Inline dilutions (pre-column) of 2 vol% uranium + 20  $\mu\text{g mL}^{-1}$  trace elements resulted in accurate and precise measurements using dilution factors of 2 $\times$ , 4 $\times$ , 5 $\times$ , and 20 $\times$ . Method detection limits for the 21 elements (Al, B, Ba, Be, Cd, Ca, Co, Cu, Fe, Li, Pb, Mg, Mn, Ni, K, Sr, Na, V, Zn, Zr, and U) analyzed for ranged from 7 to 326  $\text{ng mL}^{-1}$  for 70  $\mu\text{L}$  volume injections.

### 1. Introduction

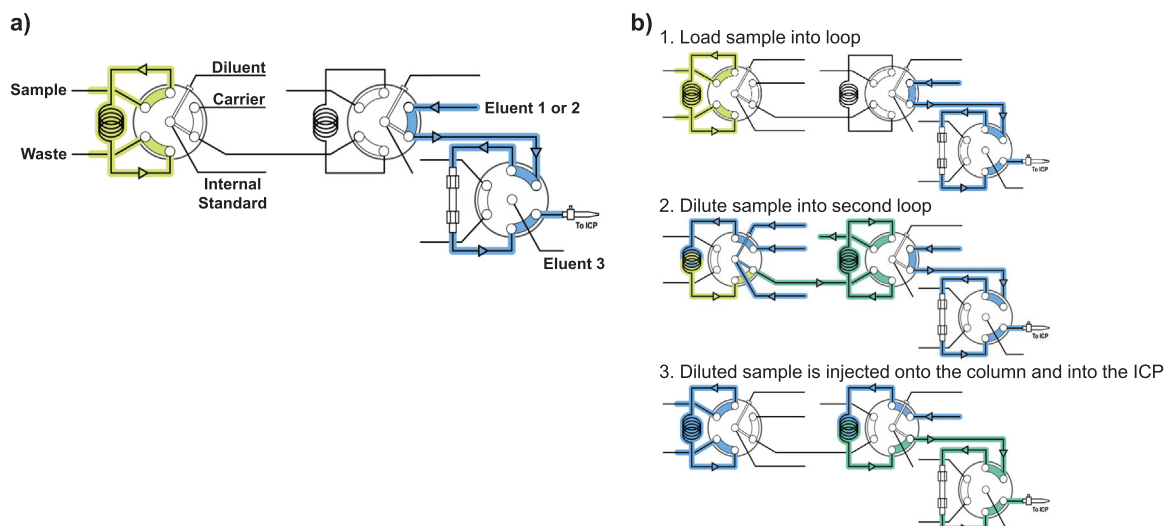
Nuclear materials (e.g. U and Pu) are commonly used for a variety of applications including energy, military, and space exploration. Due to the sensitivities of the associated systems, many of these applications require high purity material. Trace impurities, however, are introduced or found in various stages of production ranging from mining, purification, fabrication, or assembly. The determination of trace element impurities is critical for quality control and production. For example, in nuclear energy applications, the ability to produce efficient nuclear fuel can readily be altered based on the presence of certain trace level ( $\mu\text{g g}^{-1}$ ) impurities. Certain trace metals may affect the performance of fuel due to their neutron absorption properties (e.g. Cd, B), impact the metallurgical properties (e.g. Al, Fe), or impact other components of the reactor [1]. Additionally, pertaining to nuclear forensics and safeguards, trace element analysis and impurity patterns are vital as this can be used to trace the origin of the material or provide information on how the material was fabricated [2,3]. While the characterization of these materials consist of many techniques employed to determine various properties of the materials [4,5], determining trace elemental

impurities, as mentioned above can provide insight on the nature of the nuclear material processing including potential leaching of construction materials or whether declared processes were implemented [6,7].

Typically trace element impurities are determined using inductively coupled plasma-mass spectrometry (ICP-MS) or -optical emission spectroscopy (ICP-OES). According to Mahan et al., it is recommended that laboratories measuring nuclear material use both ICP-MS and ICP-OES to report trace element impurities [8]. Certain elements (e.g.  $^{56}\text{Fe}$  and  $^{52}\text{Cr}$ ) suffer from polyatomic or isobaric interferences when measuring by ICP-MS, although reaction and collision cell technology have made these interferences more manageable [9,10]. ICP-OES does not have the hindrance of polyatomic interferences as it is a spectroscopic based technique; however, elements such as uranium have many emission lines that present interferences for trace element analysis, therefore the uranium matrix must be removed from the trace elements for accurate quantitative analysis [1,11]. It is well known that the removal of uranium matrices can be achieved using UTEVA resin [12,13]. Recent advances have modified the separation procedure in an effort to reduce the amount of resin, sample, and solvents for these types of separations [14,15]. Wylie et al., reported an off-line automated

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**Fig. 1.** a) Schematic showing the identity of each channel for the sample loop valve, dilution loop valve, and column valve. b) Schematic showing how the sample is loaded into the sample loop (step 1), diluted into the dilution loop (step 2), and finally diluted sample being introduced onto the column (step 3). Original sample is loaded (yellow) into loop 1 (sample loop), valve is toggled and original sample is pushed into loop 2 (dilution loop) where it is diluted based on software settings. In this step diluent is mixed with the original sample based on the dilution factor set in the software. Once the dilution is complete (green), valve 2 is toggled and the diluted sample is introduced onto the column. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

procedure for separating trace elemental impurities from uranium matrices using UTEVA resin with high fidelity measurements [16]. This separation process will not only achieve sample preparation automation, but also decrease the required sample size, process time, and radiological waste generation.

The focus of this work is to further expand on the separation process by Wylie et al. and develop an *inline* separation method that would reduce time and sample volume while maintaining the chemistry required to reliably separate trace elements from uranium matrices. For these experiments, the prepFAST IC from Elemental Scientific, Inc. was employed to automate the inline chromatography. The components of most high performance liquid chromatography (HPLC) systems are not traditionally equipped to handle the high concentration acids required for separating trace elements from uranium matrices using UTEVA resin, but the prepFAST IC has no metal components making it ideal for these types of separations. Another aspect that should be considered is that uranium is bound to the UTEVA resin in 8 M HNO<sub>3</sub> which is not ideal for introduction into the ICP spray chamber and torch. The prepFAST IC has a column valve feature which allows for a post-column dilution prior to ICP introduction. The use of this post-column dilution was evaluated for diluting the 8 M HNO<sub>3</sub> prior to introduction into the ICP, but was not used for the elution of uranium in 0.1 M HCl. In the previous work, the separation was performed on the microFAST MC, an offline separation system, and the collected fractions were transferred to a microFAST autosampler for introduction to the ICP-OES. Unlike the previous work, the calibration standards were also introduced through the UTEVA column in the same fashion as the samples, thus the calibration curves would need to be evaluated for linearity and accuracy. The instrument does include an option to bypass the column for the standards, but in these experiments, the column was used for both the standards and samples (similar to traditional inline chromatography methods). The results of this current work demonstrates the ability to rapidly characterize uranium materials for their trace elemental impurities. This completely automated technique allows for the separation and detection of these impurities rapidly with high throughput via unattended operations. These attributes are ideal for analytical chemistry operations of radioactive materials as they minimize the user interaction with the radiological materials present, hence, reduces the worker radiation exposure. In addition, it is expected that user error

would be nearly eliminated from the process, especially considering the number of samples routinely analyzed.

## 2. Materials and methods

### 2.1. Materials and reagents

All reagents, diluents, and eluents were prepared using 18 MΩ cm water from an EMD Millipore high purity filtration system (MilliporeSigma, Burlington, MA, USA). Hydrochloric acid (35% (v/v), HCl, SEASTAR, Sidney, BC, CAN) and nitric acid (70% (v/v), HNO<sub>3</sub>, SEASTAR) were used to prepare the 0.1 M HCl and 8.0 M HNO<sub>3</sub>, respectively. Samples and standards were prepared using a uranium standard (100,000 mg L<sup>-1</sup> U, High Purity Standards, Charleston, SC, USA), multi-element standard A (1000 mg L<sup>-1</sup> Al, As, Cd, Ca, Cr, Co, Cu, Fe, Pb, Mg, Mn, Ni, K, Se, Na, Tl, V, and Zn, High Purity Standards), and multi-element standard B (1000 mg L<sup>-1</sup> Ba, Be, B, Ga, Li, P, Sr, and U, High Purity Standards) in 8 M HNO<sub>3</sub>. Inline chromatographic separations were carried out using UTEVA resin (100–160 μm, Eichrom, Lisle, IL, USA) packed into 200 μL columns.

### 2.2. prepFAST IC

The chromatographic separation of trace element impurities from uranium was performed using a prepFAST IC (Elemental Scientific, Inc., Omaha, NE, USA). The prepFAST IC is a syringe-driven liquid chromatography system (4 syringes). The syringes are used for ICP tuning (1), eluents for separations (2,3), and post-column addition eluent (4) [17]. The UTEVA column is attached to a switchable valve that allows the column to be in-line or bypassed, with respect to the ICP-OES, during analysis. The system is also equipped with a prepFAST M5 (S500V2), which is a syringe driven unit that allows for inline dilutions of standards or samples prior to introduction onto the chromatographic column (Fig. 1) [17]. Two sample loops are utilized to perform the inline dilutions, the first loop (500 μL) is for loading sample (yellow) and the second loop (500 μL) is for diluting the original sample. During the sample dilution step the prepFAST M5 syringe pushes the original sample and diluent into the dilution syringe based on the desired dilution factor set in the software. The diluted sample (green) from the

**Table 1**

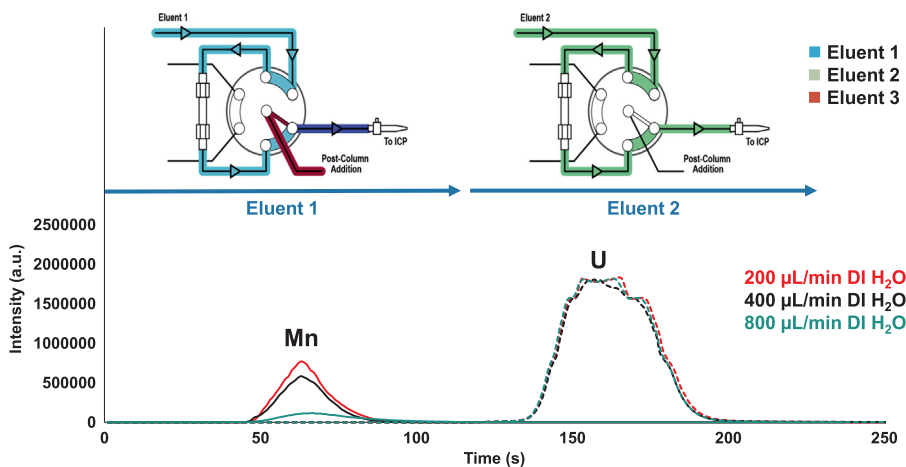
Wavelengths monitored for each element. The instrument recommended wavelength was chosen for this study since the interferences from the uranium matrix will be removed by chromatography.

Elements	Wavelength (nm)
Al	396.15
Cd	228.80
Ca	317.93
Cu	327.39
Ni	231.60
Co	228.62
Fe	238.20
Mn	257.61
Pb	220.35
Mg	285.21
K	766.49
Na	589.59
Li	670.78
Be	313.11
V	290.88
Zn	206.20
Ba	233.53
B	249.68
Sr	407.77
Zr	343.82
U	385.96

second loop is introduced onto the column by switching the valve position to inline for 10 s (~ 70  $\mu\text{L}$  of sample). This timing can be adjusted according to the amount of sample introduced onto the column.

### 2.3. ICP-OES

A Perkin Elmer Avio 500 ICP-OES (Perkin Elmer, Shelton, CT, USA) was employed for the detection of the chromatographically separated analytes. The plasma gas ( $14 \text{ L min}^{-1}$  argon (Ar)), auxiliary gas ( $0.8 \text{ L min}^{-1}$  Ar), nebulizer ( $0.65 \text{ L min}^{-1}$  Ar), RF power (1500 W), peristaltic pump ( $2.00 \text{ mL min}^{-1}$ ), and axial viewing distance of 15 mm were controlled in the Syngistix ICP software. Table 1 displays the wavelengths that were monitored simultaneously with an integration time of 1 s per data point, with 300 replicates, equating to 300 s of time resolved data. An autosampler wash time was set to 225 s to allow for the prepFAST IC to reset and wash/equilibrate the column prior to the next sample being introduced. The total sample-to-sample time was 525 s (8 min 45 s). The prepFAST IC was connected to the ICP via a PFA MicroFlow nebulizer (ES-2040 PFA-ST, Elemental Scientific, 0–2 mL  $\text{min}^{-1}$  flow rate) and a quartz cyclonic spray chamber (Elemental Scientific).



**Fig. 2.** Separation of trace element impurities (e.g.,  $5 \mu\text{g mL}^{-1}$  Mn) from uranium matrix (1 vol% U) using three post-column addition flow rates (200, 400, and  $800 \mu\text{L min}^{-1}$  DI water). Eluent 1 =  $400 \mu\text{L min}^{-1}$  8 M  $\text{HNO}_3$ , Eluent 2 =  $800 \mu\text{L min}^{-1}$  0.1 M HCl. Eluent 1 +  $200 \mu\text{L min}^{-1}$  DI water = 5.3 M  $\text{HNO}_3$  entering the ICP. Eluent 1 +  $400 \mu\text{L min}^{-1}$  DI water = 4 M  $\text{HNO}_3$  entering the ICP. Eluent 1 +  $800 \mu\text{L min}^{-1}$  DI water = 2.7 M  $\text{HNO}_3$  entering the ICP. The arrows depict the timing for switching the method from eluent 1 to eluent 2.

## 3. Results and discussion

### 3.1. prepFAST IC method parameters

The optimal method conditions for removing trace elemental impurities from bulk uranium materials were previously described [16]. The process is achieved by loading the uranium sample in 8 M  $\text{HNO}_3$  onto the UTEVA column, followed by rinsing of the column with 8 M  $\text{HNO}_3$  (eluent 1, teal, Fig. 2) which will elute most trace element impurities leaving trivalent and hexavalent uranium bound to the UTEVA resin surface. Uranium is removed subsequently by introducing 0.1 M HCl (eluent 2, green, Fig. 2) through the column. It should be noted that eluent 2 is delivered over a duration of 230 s, longer than the actual elution of the uranium (~ 50 s), to ensure complete removal of the matrix. In the previous work, the 8 M  $\text{HNO}_3$  eluent was diluted with DI water to bring the acid concentration down to 4 M  $\text{HNO}_3$ . In this experiment the column valve was equipped with a post-column dilution syringe that allows for mixing of a 3rd eluent (red, Fig. 2). This post-column dilution was performed during the elution of eluate 1 (trace element fraction), resulting in 4 M  $\text{HNO}_3$  (purple, Fig. 2) prior to introduction into the ICP-OES; this dilution was not necessary during the elution of the uranium fraction. Fig. 2 displays the column valve flow diagram and an example chromatogram showing the possibilities for multiple flow rate options for the post-column dilution syringe. In this example, the trace elements (Mn displayed) were completely resolved from the uranium matrix. The method steps, timing, and flow rates can be found in Table 2. The sample-to-sample time was reduced down to 8 min 45 s per sample as compared to the off-line method which was ~ 30 min per sample [16]. For the purposes of these experiments the uranium eluate was also measured by ICP-OES to show that there was excellent recovery and no carry-over from sample-to-sample. Although in real applications, the prepFAST IC can be set up to send the uranium fraction to a separate waste container for proper disposal without going through the ICP torch.

To verify that the method was operating properly, the separation of  $1 \mu\text{g mL}^{-1}$  trace elements from 1 vol% uranium matrix was performed while collecting the spectral window for each element of interest. Fig. 3 displays an example chromatogram depicting the separation of the trace eluate and the uranium eluate, with the resulting spectra overlaid for Al 396.15 nm. The spectrum for aluminum clearly shows that there is no uranium in the trace element fraction, however the uranium fraction has a very high background at the wavelength used for measuring aluminum. Uranium has many emission lines which results in exceptionally high backgrounds that would result in false positive values for the trace elements of interest, thus there is a need to remove uranium for accurate quantification of trace elements. Fig. 4 displays the overlaid spectra for the trace element and uranium eluate

**Table 2**

Chromatographic method for separating trace element impurities from uranium matrix using a 200  $\mu\text{L}$  UTEVA resin column.

Action	Time	$\mu\text{L min}^{-1}$			Total Flow
		Eluent 1	Eluent 2	Eluent 3	
Remove trace elements	0–70 s	400	0	400	800
Remove uranium	70–300 s	0	800	0	800
Equilibrate column	301–480 s	400	0	400	800

Eluent 1 = 8 M  $\text{HNO}_3$ , Eluent 2 = 0.1 M HCl, Eluent 3 = DI  $\text{H}_2\text{O}$ .

corresponding to the detection of Ca 317.93 nm, Mg 285.21 nm, V 290.88 nm, Zr 343.82 nm, Si 251.61 nm, and U 385.96 nm, respectively. As can be seen in the comparison to the uranium versus the trace elution, the uranium signal is equal or greater to the signal for the trace element.

### 3.2. Quantification

The prepFAST IC is equipped with a prepFAST M5 component that allows for inline dilutions of standards or samples prior to introduction

to the UTEVA column. The inline dilution (pre-column) was utilized to prepare a calibration curve from two stock standards, the first containing a  $10 \mu\text{g mL}^{-1}$  multi-element standard and the second containing 1.0 vol% uranium. Fig. 5 displays the calcium and uranium calibration curves and corresponding chromatograms for  $100 \times -1 \times$  inline dilutions of the multi-element standard and  $200 \times -10 \times$  inline dilutions of the uranium standard. Linear calibration curves were obtained for all elements but for brevity are not shown.

### 3.3. Method validation

A series of samples, with no inline dilution factor applied, was analyzed that contained  $1 \mu\text{g mL}^{-1}$  trace elements spiked into 0.1 vol%, 0.5 vol%, and 1.0 vol% uranium matrices to verify that the amount of uranium loaded onto the column ( $\sim 70 \mu\text{L}$  loaded) would not affect the accuracy of the trace element detection. Fig. 6 shows the accuracy of the  $1 \mu\text{g mL}^{-1}$  trace elements (average of all elements detected) recovered in the varying uranium matrices. The results show good accuracy ( $< 5\%$  relative difference (RD)) with precision ranging from 5.1% to 9.4%RSDs for triplicate measurements.

To further validate the method, a  $20 \mu\text{g mL}^{-1}$  multi-element standard was spiked into a 2 vol% uranium sample and analyzed using an inline dilution (pre-column) factor of  $2 \times$ ,  $4 \times$ , and  $20 \times$  (Table 3). For

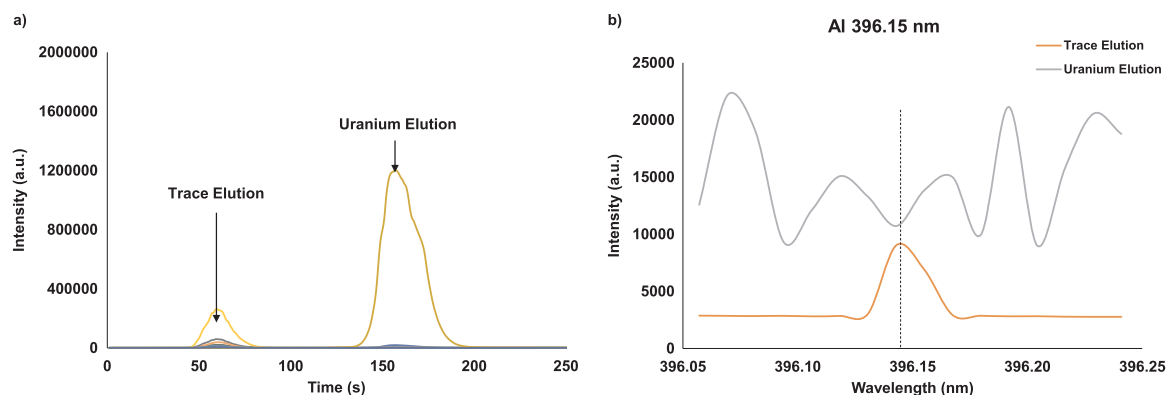


Fig. 3. a) Example chromatogram showing the separation of trace element impurities from the uranium matrix. b) Overlay of the emission spectra from the trace elution and uranium elution for the Al 396.15 nm spectral window.

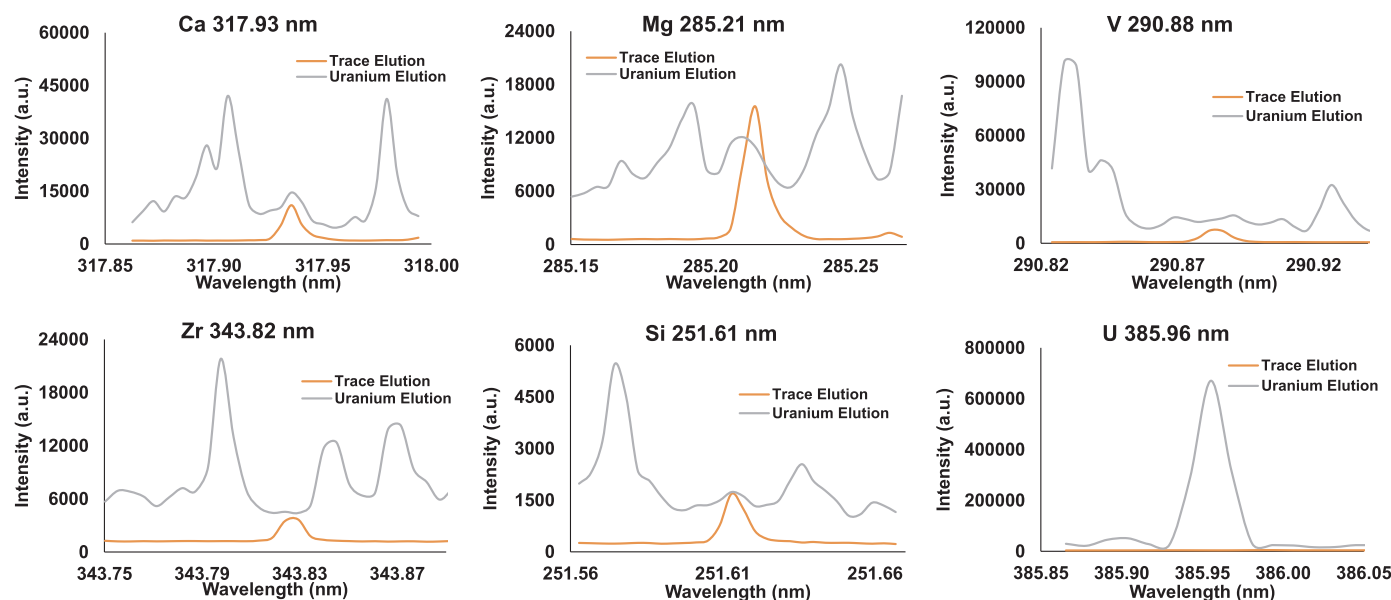


Fig. 4. Overlays of the emission spectra from the trace elution and uranium elution for Ca 317.93 nm, Mg 285.21 nm, V 290.88 nm, Zr 343.82 nm, Si 251.61 nm, and U 385.96 nm.

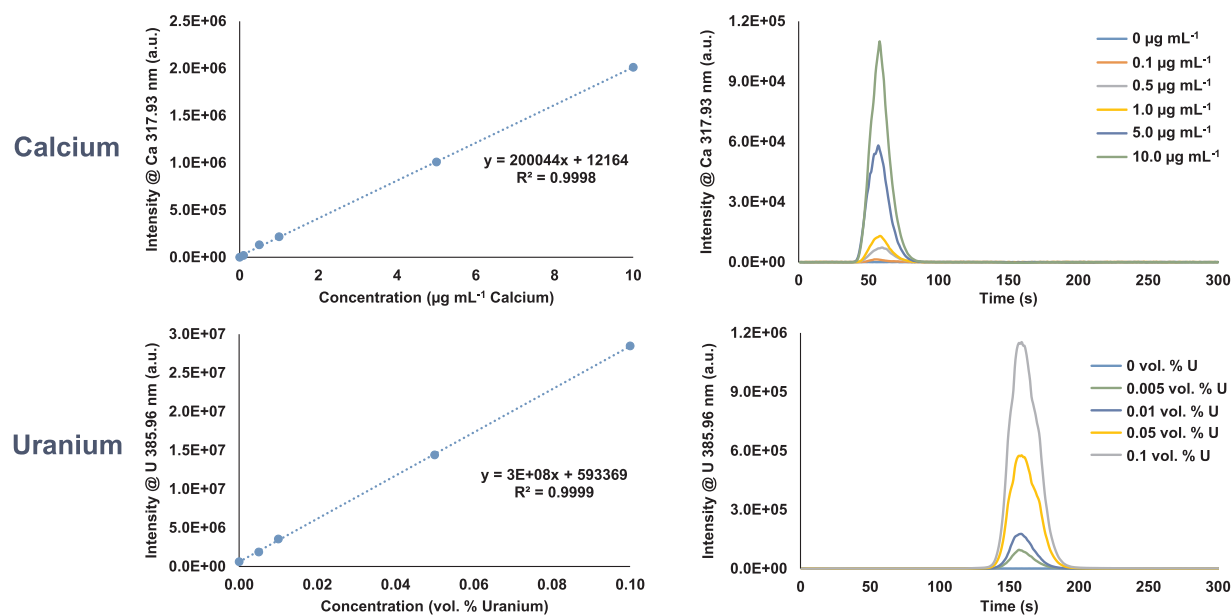


Fig. 5. Calibration curves for calcium (0–10  $\mu\text{g mL}^{-1}$ ) and uranium (0–0.1 vol% U), along with the respective chromatograms for each element.

the  $2\times$  inline dilution (10  $\mu\text{g mL}^{-1}$  trace elements) the accuracy ranged from 9.61 to 10.4  $\mu\text{g mL}^{-1}$ , for  $4\times$  inline dilution (5  $\mu\text{g mL}^{-1}$  trace elements) the accuracy ranged from 4.70 to 5.51  $\mu\text{g mL}^{-1}$ , and for the  $20\times$  inline dilution (1  $\mu\text{g mL}^{-1}$  trace elements) the accuracy ranged from 0.938 to 1.11  $\mu\text{g mL}^{-1}$ . The inline dilution scheme allows for over calibration range samples to be easily repeated with a higher dilution factor and eliminates the need for and the error associated with the manual dilution. For radioactive material analysis, this reduces personal contamination hazard by reducing the user interaction with the samples.

For the manual separations of trace elements from uranium the UTEVA columns are single-use. However, in most cases  $\leq 10$  samples are prepared at a time. Since there is no bench mark on how many times a column can be used, a 2 vol% uranium sample spiked with 20  $\mu\text{g mL}^{-1}$  trace elements was analyzed 10 consecutive times using a 5X inline dilution factor to determine the method precision and check for any potential carry-over (Table 4). The average concentration for all elements tested equated to 4.05  $\mu\text{g mL}^{-1}$  and the average precision for all elements was 5.6%RSD. The overall accuracy for this test resulted in a 1.3%RD (target value = 4.00  $\mu\text{g mL}^{-1}$ ).

The comparison of two UTEVA packed columns resulted in identical retention times for the trace element and uranium eluate. It is expected that an automated separation will be more reliable and reproducible within run and day-to-day than a manual/gravity based separation. Furthermore, over 100 separations were performed with zero memory

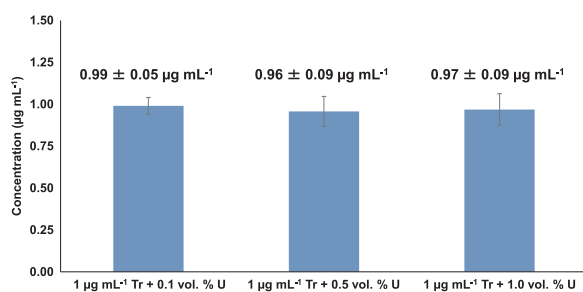


Fig. 6. Proof of concept study to determine the accuracy of 1 ppm trace elements (Tr) spiked into 0.1 vol% U, 0.5 vol% U, and 1.0 vol% U. The 21 elements measured were averaged to represent one single data point for brevity. The standard deviation for each data point is from the average of the 21 elements measured.

effects detected (blanks resulted in no detectable trace elements or uranium response, with ICP-OES, after highest concentrated samples). This suggests that the UTEVA columns in combination with the separation conditions aforementioned result in a robust and reliable method.

### 3.4. Figures of merit

Table 5 list the limits of detection (LOD) and method detection limit (MDL) for the inline UTEVA separation method. For most elements the LODs are in the single digit  $\text{ng mL}^{-1}$  range. While the axial view provides the best detection limits, the analysis could be done in radial view to increase the dynamic range of the method [18]. However, this method was performed in axial mode due to the need to record

Table 3

Accuracy to  $2\times$ ,  $4\times$ , and  $20\times$  inline dilutions of 20  $\mu\text{g mL}^{-1}$  trace elements spiked into 2 vol% uranium.  $n = 3$  for each dilution factor.

Element	Dilution factor		
	$2\times$	$4\times$	$20\times$
Al	9.83	5.39	1.01
Cd	10.1	4.77	0.971
Ca	10.1	4.92	1.05
Cu	10.1	5.21	1.07
Ni	10.3	4.94	1.04
Co	10.4	5.01	1.10
Fe	9.64	5.08	0.979
Mn	10.3	5.09	1.03
Pb	9.61	4.82	1.11
Mg	10.4	5.03	1.06
K	10.2	4.79	0.951
Na	9.90	5.40	0.962
Li	10.0	5.38	0.938
Be	9.92	5.27	1.11
V	9.73	4.70	1.04
Zn	10.0	5.31	1.11
Ba	9.89	5.51	1.06
B	10.0	4.88	0.951
Sr	10.2	5.32	0.973
Zr	10.3	4.91	1.04
Si	10.3	5.03	1.00

Dilution factor:  $2\times = 10 \mu\text{g mL}^{-1}$  trace and 1 vol% U,  $4\times = 5 \mu\text{g mL}^{-1}$  trace and 0.5 vol% U, and  $20\times = 1 \mu\text{g mL}^{-1}$  trace and 0.1 vol% U.



**Table 4**  
Reproducibility to  $5 \times$  inline dilutions of  $20 \mu\text{g mL}^{-1}$  trace elements spiked into 2 vol% uranium.  $n = 10$ .

Element	Avg. ( $\mu\text{g mL}^{-1}$ )	$\pm$ ISD	%RSD	%RD
Al	3.92	0.22	5.6	-2.0
Cd	3.91	0.23	5.8	-2.2
Ca	3.87	0.21	5.4	-3.3
Cu	4.13	0.23	5.7	3.3
Ni	4.28	0.25	5.9	6.9
Co	4.07	0.25	6.0	1.8
Fe	4.30	0.25	5.8	7.5
Mn	4.05	0.25	6.2	1.2
Pb	3.78	0.20	5.4	-5.4
Mg	4.11	0.23	5.7	2.7
K	4.08	0.23	5.7	2.0
Na	3.84	0.19	4.9	-3.9
Li	4.13	0.22	5.2	3.2
Be	3.98	0.25	6.2	-0.4
V	3.78	0.22	5.8	-5.6
Zn	4.13	0.23	5.7	3.4
Ba	3.99	0.23	5.9	-0.2
B	4.05	0.23	5.7	1.4
Sr	4.34	0.13	3.1	8.4
Zr	4.27	0.30	7.0	6.9
Si	4.07	0.17	4.1	1.7

Dilution factor:  $5 \times = 4 \mu\text{g mL}^{-1}$  trace and 0.4 vol% U.

**Table 5**  
Limit of detection (LOD) and method detection limit (MDL).

Element	LOD ( $\text{ng mL}^{-1}$ )	MDL ( $\text{ng mL}^{-1}$ )
Al	2.9	17
Cd	5.0	15
Ca	1.2	61
Cu	27	122
Ni	24	90
Co	11	44
Fe	1.7	7.0
Mn	1.1	15
Pb	37	224
Mg	5.5	9.0
K	21	55
Na	1.1	34
Li	0.30	22
Be	3.1	25
V	82	326
Zn	2.3	12
Ba	3.6	23
B	5.5	53
Sr	0.10	7.0
Zr	3.0	16
Si	22	71

$\text{LOD} = (3 \times \sigma_{\text{blank.int.}})/m$ ,  $\text{MDL} = \text{blank conc. mean} + (3.143 \times \sigma_{\text{blank conc.}})$ .

transient signals. It is conceivable that future methods could be developed, assuming there is enough sample, to run two sequential methods with one being radial and one being axial. The MDL reported by Montoya et al. were lower than the values in Table 5, however in that work  $800 \mu\text{L}$  of sample was being introduced to the ICP in a steady state, compared to  $70 \mu\text{L}$  of sample in this work that is loaded onto the column and then introduced to the ICP in a transient measurement mode [15]. In addition, the amount of sample loaded onto the column in the previous work was  $\sim 250 \text{ mg}$  as compared to  $\sim 700 \mu\text{g}$  in this work.

#### 4. Conclusion

These data support that the inline separations methodology using the UTEVA resin columns directly into the ICP-OES is suitable for the analysis of trace elements in uranium materials. The precision and

accuracy were not affected by the smaller columns and sample volumes. This is the first report of the novel use of a post-column dilution to reduce the acid strength prior to introduction to the ICP-OES. The goal of reducing sample volume ( $67 \mu\text{L}$  of  $\leq 2 \text{ vol\%}$  uranium), resin volume ( $200 \mu\text{L}$  column) and reducing time ( $\sim 8 \text{ min}$  per sample) were all met. Future work will investigate the effects of column volume and sample size as well as transfer the method to a lab suitable for radioactive materials.

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#### Conflicts of interest

There are no conflicts of interest to declare.

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