Evaluation of Spectral Interference of Lutetium on Analytes Including Specified Rare Earth Elements Using a CCD Detector-based ICP-AES

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INTRODUCTION

The radio-frequency-inductively coupled plasma (ICP) method has emerged as a very promising excitation source for atomic emission spectrometry (AES) with the advantages of good detection limits and high sensitivity with a large linear dynamic range (1-4). An ICP is a highly efficient atomization source, which means that every molecule should be dissociated provided that the operating conditions are optimized for this purpose. Many investigators have examined the analytical capabilities (5-7) of ICP sources for simultaneous multi-element optical emission analysis. In ICP-AES, the analytical response depends directly on the number of analyte atoms present in the plasma and, therefore, on the analyte concentration in the sample (8). However, ICP-AES suffers from some limitations which includes spectral interference due to spectrum richness, line broadening, and insufficient resolution from the matrices such as that of rare earth elements (REEs). Some kinds of interferences can be minimized or even eliminated by a judicious selection of the sample introduction system (9-10). Several authors have already indicated observable spectral interference either due to total or partial overlap of the lines (11-23) or to stray light (24-25). The major drawback of a photomultiplier tube (PMT) is that it is a single-channel detector which leads to a drastic waste of information, even when several detectors are set up in a polychromator. This

ABSTRACT

The contribution due to the spectral interference of Lu in inductively coupled plasma atomic emission spectrometry was studied on 28 analytes including some rare earth elements (Gd, Dy, Nd, Ce, Pr, and La). Based on the analytical performance (including detection limit, sensitivity, linear dynamic range, and precision) and spectral interference contribution of Lu, the best line(s) for the analytes were evaluated. The method was selected for the direct trace determination of the analytes in the presence of Lu without any chemical separation. An argon gas was used as the plasma source and a highly sensitive capacitatively coupled device (CCD) detector provided the selection of additional interference-free analytical lines of the elements. The method was validated using synthetic samples prepared from commercially available standard reference materials of the individual analytes and the correction factor was unified in the analysis.

drawback can be overcome by the use of multichannel detectors used with a commercially available ICP-AES system such as those based on charge transfer technology. 2-D CCD or an association of linear CCD arrays has been used as the detector system with ICP-AES for the present investigation. Because it provides the advantages such as full flexibility in analytical line selection, use of several lines of the same element to extend the dynamic range, use of a large number of

lines of the same element to improve accuracy and to verify possible matrix effects or spectral interferences, and qualitative analysis and fast diagnostic (26-29).

Lanthanides are found in nature in a number of minerals, but their separation process into individual metals is very complex. Lutetium can be used as catalyst in petroleum cracking in refineries, as organic synthesis, and as an internal standard in ICP-AES. Lutetium aluminum garnet has been proposed to be used as a lens material in immersion lithography (30) and in magnetic bubble memory devices (31). Lutetium also finds its application as detector in positron emission tomography (32) and as a phosphor in LED (33). The synthetic isotope lutetium-177 compounds are used in therapy for neuroendocrine tumors (34). For the above applications of Lu, especially in the medical field, there is a requirement of high purity Lu which leads to developing a methodology for the trace level determination of analytes in a Lu matrix.

Rare earth elements being multi-electronic systems exhibit line-rich emission spectra which can lead to spectral interference during the determination of elements in a rare earth matrix, mainly at trace levels. Therefore, in d.c. arc, the analytes are separated from the emission-rich matrix using a suitable carrier according to their volatilization properties (35-38), while ICP-AES involves chemical separation using suitable extractants (39-44). The poor analytical performance of the d.c. arc carrier distillation technique, including more sample handling in ICP-AES, neces-

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sitates a methodology for the direct determination of the analytes at trace levels in an emission-rich matrix without any separation. This requires a systematic study of the spectral interference of the emission-rich element on the analytes.

The present paper deals with the study of the spectral interference of Lu on different analytes (Ag, Al, B, Ba, Bi, Cd, Cr, Cu, Fe, Ga, Li, Mg, Mn, Na, Ni, Sr, Zn, Ce, La, Gd, Nd, Pr, Dy, Ca, Co, In, Pb, and Tl), involving identification of a suitable interference-free analytical tolerance level of Lu on the different analytical lines of these elements and evaluation of the correction factors for these lines. The analytical performance of these lines in a Lu matrix involving detection limits, sensitivity, precision, and linear dynamic range were studied systematically. Based on these factors, a method was developed for the direct determination of these analytes at trace level in a Lu matrix without any separation steps. The method was validated with synthetic samples prepared from a standard reference material solution of the individual elements.

EXPERIMENTAL

Instrumental and Operating Conditions

The analysis was carried out using a Spectro-Arcos inductively coupled plasma atomic emission spectrometer (Spectro-Arcos, Germany), equipped with a capacitatively coupled device (CCD) detector. The operating conditions and instrumental specifications were optimized and are listed in Table I. The detector system, consisting of linear arrays of the CCD detector (3648 pixels/array), thermally stabilized together with an optical system, provides the ability to select alternate analytical lines. The cross-sectional view of the CCD-based detector system is shown elsewhere (26-28).

Standard Solutions and Reagents

Standard solutions for all of the elements were prepared from CertiPUR® ICP standard solutions (E-Merck, Darmstadt, Germany) by proper dilution. SupraPur® HNO₃ (E-Merck, Darmstadt, Germany) and quartz double distilled water were used throughout the study. Since the ICP-AES exhibits a high degree of linear dynamic range and in order to obtain more precise calibration curves, multi-point standardization was carried out using 0.5 M HNO₃ as a blank and 0.05–1000 mg/L of the corresponding elemental standard as the higher standards for each line after proper peak search. For the analysis of each sample, 10 replicate measurements were

carried out, while for the determination of the detection limits and the sensitivity, 25 replicate measurements were taken into account.

Methods

A series of Lu standard reference material (SRM) elemental solutions (E-Merck, Darmstadt, Germany) of concentrations between 0.05 to 1000 mg/L were prepared and fed into the atmospheric argon plasma. The spectral interference of Lu was monitored by observing the contribution in different channels of the specified analytes. For each analyte, the least interfered analytical lines were identified along with evaluation of the correction factor. The tolerance levels of Lu on these lines were also evaluated. The analytical

TABLE I
Specifications and Operating Conditions of ICP-AES

Instrumental Specifications	
Optical design	Paschen-Runge mounting, Circular design
Focal length	750 mm
Grating	Holographic
Groove density	1800 grooves/mm (1), 3600 grooves/mm (2)
Wavelength range	130-800 nm
Entrance slit width	15 microns
Resolution (FWHM)	0.01 nm from 130–450 nm 0.02 nm from 450–800 nm
Thermal regulation	Controlled to 30 ± 1 °C
RF Frequency	27.12 MHz
Pump	Dual channel peristaltic pump
Detector	Linear arrays of CCD (3648 pixels/array)
Nebulizer	Pneumatic Concentric nebulizer with cyclonic spray chamber
ICP torch	Demountable, radial viewing
Operating Conditions	
Coolant flow	15 L/min
Auxiliary flow	0.5 L/min
Carrier gas flow	1 L/min
Sample consumption rate	1 mL/min
Total time of measurement	30 s
Pump speed	30 Rpm
RF power output	1.1 kW
Input power	230 V AC

performance, including detection limits, sensitivity, and linear dynamic range, were studied for all of the analytical lines.

Since the correction factor is a function of the concentration of the interfering element, Lu, an ICP-AES-based method was also developed for the simultaneous determination of Lu along with the analytes. The analytical performance, including detection limits, sensitivity, linear dynamic range, etc., were studied for all of the identified analytical lines of Lu.

Synthetic samples were used to validate the methodology of direct trace level determination of these analytes in the Lu matrix without any separation. The method was also compared with existing analytical techniques used for the trace level determination of these analytes. For common analytes (except for Ag), the d.c. arc carrier distillation technique was used, while for the rare earth elements, the ion chromatographic technique was used for comparison purposes. Ag was added to the samples in the form of AgCl for the d.c. arc carrier distillation technique. An independent analytical technique, i.e., atomic absorption spectrometry, was used to compare the results obtained by the newly developed ICP-AES method.

RESULTS AND DISCUSSION

Determination of ICP-AES-based Methodology for Simultaneous Determination of Lu

Since the quantitative measure of spectral interference is a function of the concentration of interfering elements, it necessitates determining the interfering element with the highest merit of analytical performance, i.e., higher sensitivity, lower detection limit, higher precision, and larger linear dynamic range. In this study, an ICP-AES-based method was developed for

the simultaneous determination of Lu along with all of the other analytes under investigation. Four different lines of Lu, e.g., 219.554 nm, 261.542 nm, 291.139 nm, and 307.760 nm, were chosen. The emission profiles of the above-mentioned lines are shown in Figure 1, whereas the calibration curves using these lines are shown in Figure 2. From the calibration curve, the sensitivity of the above-mentioned lines was calculated and found to follow the trend: 261.542 nm > 307.760 nm > 291.139 nm > 219.554 nm. The detection limit followed the trend: 261.542 nm < 291.139 nm < 307.760 nm < 219.554 nm. The linear dynamic range of these lines was also evaluated. Synthetic samples with various Lu concentrations ranging from 1 to 1000 mg/L were analyzed by this method. It was found that all of these lines can be used for the determination of Lu up to 1000 mg/L with an acceptable %RSD (relative standard deviation). The analytical results for these synthetic samples and the analytical performance of these lines are summarized in Table II. Based on the above study, it is also clear that the Lu 261.542 nm line is the best line for its ICP-AES determination.

Spectral Interference of Lu on Ag, Al, B, Ba, Bi, Cd, Cu, Fe, Ga, Li, Mg, Mn, Na, Ni, Sr, Zn, and Cr

Four different analytical lines of Ag (338.289 nm, 328.068 nm, 224.641 nm, and 243.779 nm) were chosen to study their analytical performance and the spectral interference of Lu. The study revealed that the Ag 338.289 nm and 328.068 nm lines were free of spectral interference, and the detection limit of the above lines follows the trend: 328.068 nm < 338.289 nm < 243.779 nm < 224.641 nm. The sensitivity was found to follow the reverse trend of the detection limit. Other analytical performance figures of merit including %RSD, lin-

ear dynamic range, etc., indicated that the Ag 328.068 nm line was the best line for its determination in a Lu matrix. The detailed spectral interference of Lu revealed that the Al 396.152 nm, Al 394.401 nm, Al 309.271 nm, B 249.677 nm, B 208.959 nm, Ba 455.404 nm, Bi 306.772 nm, Cd 214.438 nm, Cd 226.502 nm, Cd 361.051 nm, Cu 327.396 nm, Fe 275.573 nm, Fe 373.486 nm, Ga 417.206 nm, Li 670.780 nm, Li 460.289 nm, Li 323.261 nm, Mg 279.553 nm, Mg 280.270 nm, Mg 285.213 nm, Mn 257.611 nm, Mn 259.373 nm, Na 330.237 nm, Ni 221.648 nm, Ni 300.249 nm, Ni 341.476 nm, Sr 407.771 nm, Sr 421.552 nm, Sr 460.773 nm, Zn 213.856 nm, Zn 202.613 nm, Cr 205.618 nm, and Cr 284.984 nm lines were interference-free in the presence of Lu up to 1000 mg/L. The experiment with higher concentrations of Lu was not carried out to avoid clogging of the nebulizer capillary during sample introduction into the ICP-AES system. The spectral interference of Lu on the above-mentioned analytical lines is listed in Table III. For some of the analytes, more than one analytical line showed no spectral interference from Lu. In that case, the analytical performance of these lines then becomes the deciding factor for selecting the best analytical lines of these elements in the Lu matrix.

Ag (Silver)

Four different analytical lines of Ag (338.289 nm, 328.068 nm, 224.641 nm and 243.779 nm) were chosen to study the spectral interference of Lu on Ag. Out of these four lines, the Ag 338.289 nm and 328.068 nm lines were found to be free of spectral interference from Lu. Though both of the lines are suitable for the determination of Ag in a Lu matrix and on the basis of the analytical performance, the Ag 328.068 nm line was found to be the best analytical line in a Lu matrix.

Fig. 1. Emission profiles of different analytical lines of Lu (a) 219.554 nm, (b) 261.542 nm, (c) 291.139 nm, (d) 307.760 nm.

Fig. 2. Calibration curves for different analytical lines of Lu.

TABLE II
Determination of Lu By ICP-AES

Lu (mg/L)	261.542 nm (mg/L)	291.139 nm (mg/L)	307.760 nm (mg/L)	219.554 nm (mg/L)
1	0.97 ± 0.05	0.95 ± 0.06	1.03 ± 0.05	1.15 ± 0.07
5	5.0 ± 0.07	5.2 ± 0.11	4.7 ± 0.09	4.6 ± 0.07
10	9.8 ± 0.3	10.4 ± 0.3	10.2 ± 0.5	9.5 ± 0.6
20	19.4 ± 0.9	18.8 ± 1.1	21.2 ± 1.3	21.5 ± 1.0
50	50 ± 2	46 ± 4	51 ± 3	53 ± 4
100	102 ± 4	95 ± 6	97 ± 5	103 ± 6
500	495 ± 8	492 ± 9	504 ± 10	507 ± 11
1000	993 ± 13	1018 ± 17	987 ± 18	1010 ± 17
D.L. (mg/L)	0.003	0.042	0.042	0.081
Sensitivity (counts/mg/L)	9686	2436	3180	999
Linear Dynamic Range (mg/L)	0.003-1000	0.042-1000	0.042-1000	0.081-1000

TABLE III
Spectral Interference of Lu on Ag, Al, B, Ba, Bi, Cd, Cr, Cu, Fe, Ga, Li, Mg, Mn, Na, Ni, Sr, and Zn

Elements	Analytical Lines (nm)	Contribution from 1000 mg/L of Lu	Correction Factor	Tolerance Level (mg/L)	Elements	Analytical Lines (nm)	Contribution from 1000 mg/L of Lu	Correction Factor	Tolerance Level (mg/L)
Ag	338.289	*	-	1000	Ga	417.206	*	-	1000
	328.068	*	-	1000		294.364	0.203	2.0×10^{-4}	500
	224.641	6.195	6.1×10^{-3}	500		287.424	0.764	7.6×10^{-4}	500
	243.779	0.605	6.0×10^{-4}	500	Li	670.78	*	-	1000
Al	396.152	*	-	1000		460.289	*	-	1000
	394.401	*	-	1000		323.261	*	-	1000
	308.215	0.262	2.6×10^{-4}	500	Mg	274.118	7.209	7.2×10^{-3}	200
	309.271	*	-	1000		279.553	*	-	1000
B	249.773	0.062	6.2×10^{-5}	1000		280.27	*	-	1000
	249.677	*	-	1000		285.213	*	-	1000
	182.641	0.123	1.2×10^{-4}	500		279.079	0.338	3.3×10^{-4}	500
	208.959	*	-	1000		202.647	0.17	1.7×10^{-4}	500
Ba	455.404	*	-	1000	Mn	257.611	*	-	1000
	233.527	0.396	3.9×10^{-4}	500		259.373	*	-	1000
	230.424	0.225	2.2×10^{-4}	200		260.569	0.098	9.8×10^{-5}	500
Bi	223.061	0.543	5.4×10^{-4}	200		294.921	0.133	1.3×10^{-4}	500
	190.241	2.106	2.1×10^{-3}	200	Na	403.076	0.736	7.3×10^{-4}	100
	306.772	*	-	1000		589.592	0.066	6.6×10^{-5}	1000
	222.825	3.497	3.5×10^{-3}	200		588.995	0.063	6.3×10^{-5}	1000
	206.17	0.95	9.5×10^{-4}	200		330.237	*	-	1000
Cd	214.438	*	-	1000	Ni	330.298	4.015	4.0×10^{-3}	500
	226.502	*	-	1000		231.604	0.17	1.7×10^{-4}	500
	228.802	0.074	7.4×10^{-5}	500		221.648	*	-	1000
	361.051	*	-	1000		232.003	0.245	2.4×10^{-4}	200
Cu	324.754	0.072	7.2×10^{-5}	1000	Sr	227.021	0.294	2.9×10^{-4}	200
	327.396	*	-	1000		300.249	*	-	1000
	224.7	0.126	1.2×10^{-4}	500		341.476	*	-	1000
	219.226	2.765	2.8×10^{-3}	200		407.771	*	-	1000
	219.958	0.284	2.8×10^{-4}	200		421.552	*	-	1000
Fe	259.941	0.195	1.9×10^{-4}	200	Zn	460.733	*	-	1000
	238.204	0.176	1.7×10^{-4}	500		213.856	*	-	1000
	239.562	0.472	4.7×10^{-4}	500		206.2	0.938	9.3×10^{-4}	200
	244.451	1.31	1.3×10^{-3}	200		202.613	*	-	1000
	261.187	3.663	3.7×10^{-3}	10	Cr	334.502	0.524	5.2×10^{-4}	500
	262.567	4.643	4.6×10^{-3}	100		267.716	2.702	2.7×10^{-3}	50
	262.829	1.724	1.7×10^{-3}	200		205.618	*	-	1000
	275.573	*	-	1000		283.563	0.078	7.8×10^{-5}	1000
	241.331	0.556	5.5×10^{-4}	500		284.325	*	-	1000
	373.486	*	-	1000		284.984	0.521	5.2×10^{-4}	200

* = No interference.

Al (Aluminum)

Of the three interference-free analytical lines of Al, the 309.271 nm line showed poor detection limit and linear dynamic range, while the best performance was seen for the Al 396.152 nm line with a detection limit of 0.038 mg/L, sensitivity of 6011 counts/mg/L, linear dynamic range of 0.038–1000 mg/L, and %RSD of 1.1. Therefore, the Al 396.152 nm line can be chosen as the best line for the trace determination of Al in the presence of a Lu matrix.

B (Boron)

Among the interference-free two analytical lines of B, the detection limit and the %RSD of the B 249.677 nm line was nearly two times higher than the B 208.959 nm line. Moreover, the sensitivity of the B 208.959 nm line was also ~ 4.5 times higher than the other line; hence, it is the best line for B in a Lu matrix.

Ba (Barium)

Even though the interference-free Ba 455.404 nm line was found to have a higher detection limit than the interfered Ba 230.424 nm line, the sensitivity and precision of the Ba 455.404 nm line were found to be better; hence, it can be chosen for further studies.

Bi (Bismuth)

The interference-free Bi 306.772 nm line showed poor detection limit (2.8 mg/L), while the sensitivity and the %RSD were found to be the best. The other Bi lines under investigation were significantly interfered by Lu. In this situation, we believe that the Bi 306.772 nm line can be considered to be the best line for its trace level determination in a Lu matrix.

Cd (Cadmium)

Of three interference-free analytical lines of Cd, the 361.051 nm line was found to have poor analytical performance, while the best

line was 226.502 nm, with a detection limit of 0.007 mg/L, sensitivity of 9090 counts/mg/L, and linear dynamic range up to 100 mg/L with ~ 0.8% RSD.

Cu (Copper) and Ga (Gallium)

Fortunately for Cu and Ga, the interference-free analytical lines (Cu 327.396 nm, Ga 417.206 nm) showed the best analytical performance and are unequivocally the best lines in a Lu matrix.

Na (Sodium)

The Na 330.237 nm line showed practically no interference from Lu, yet the analytical performance of the line was not at all satisfactory, i.e., poor detection limit, sensitivity, and precision, with a linear dynamic range up to 700 mg/L. In view of this, the Na 588.995 nm and 589.592 nm lines showed good analytical performance and are the most suitable lines for Na in a Lu matrix even though these lines were slightly interfered by Lu.

Fe (Iron)

Of the interference-free lines of Fe (275.573 nm and 373.486 nm), the detection limits of both lines were found to be the same, while the sensitivity, linear dynamic range, and precision of the 373.486 nm line was found to be slightly better than 275.573 nm. Though the Fe 373.486 nm line was the best line for Fe in a Lu matrix, the overall performance of the 275.573 nm line was also satisfactory.

Li (Lithium)

Of the three interference-free analytical lines of Li (670.780 nm, 460.289 nm, and 323.260 nm), Li 670.780 nm showed the best analytical performance (detection limit: 0.0014 mg/L, sensitivity: 129515 counts/mg/L, linear dynamic range: 0.0014–1000 mg/L, %RSD: 0.70) and can, therefore, be considered the most suitable line in a Lu matrix.

Mg (Magnesium)

For Mg, all three analytical lines were interference-free (279.553 nm, 280.270 nm and 285.213 nm) with very good analytical performance. Therefore, each of these lines can be used for the determination of Mg in a Lu matrix, even at trace levels without any separation.

Sr (Strontium)

For Sr, the analytical performance of the 460.773 nm line was not as good as that of the other two interference-free analytical lines (407.771 nm, 421.552 nm), the overall performance was also quite satisfactory. Thus, the three lines can be chosen for trace level estimation in a Lu matrix. However, the Sr 407.771 nm and Sr 421.552 nm lines are considered to be the most suitable.

Mn (Manganese) and Zn (Zinc)

For the analytes Mn and Zn, the interference-free analytical lines (Mn 257.611 nm and Mn 259.373 nm; Zn 213.856 nm and Zn 202.613 nm) showed comparable analytical performance; hence, they can be chosen for the trace level determination of Mn and Zn in a Lu matrix.

Cr (Chromium)

For Cr, the 205.618 nm analytical line was found to have better analytical performance than 284.984 nm, with a detection limit of 0.0093 mg/L, sensitivity of 2380 counts/mg/L, linear dynamic range of 0.0093–1000 mg/L, and a precision of 1.7 % RSD.

Ni (Nickel)

Of the three interference-free analytical lines of Ni (221.648 nm, 300.249 nm, and 341.476 nm), the 341.476 nm line showed the best performance.

The spectral interference of the above-mentioned elements is listed in Table III, while Table IV summarizes their analytical performance. Since the effect of spectral interfer-

TABLE IV
Analytical Performance of Ag, Al, B, Ba, Bi, Cd, Cr, Cu, Fe, Ga, Li, Mg, Mn, Na, Ni, Sr, and Zn

Ele- ments	Analytical Lines (nm)	D.L. (mg/L)	Sensitivity (counts/ mg/L)	Linear Dynamic Range (mg/L)	(%) RSD	Ele- ments	Analytical Lines (nm)	D.L. (mg/L)	Sensitivity (counts/ mg/L)	Linear Dynamic Range (mg/L)	(%) RSD
Ag	224.641	1.1	40	1.1-580	4.1	Ga	287.424	0.69	154	0.69-700	2.9
	243.779	0.25	227	0.25-790	2.5		294.364	0.11	719	0.11-900	2.1
	328.068	0.012	10714	0.012-1000	1.0		417.206	0.023	4813	0.023-1000	1.6
	338.289	0.038	5432	0.038-1000	1.5	Li	274.118	1.7	33	1.7-700	4.7
Al	308.215	0.063	1586	0.063-1000	2.1		323.261	0.65	119	0.65-800	4.0
	309.271	1.1	2280	1.1-800	1.6		460.289	0.75	136	0.75-900	4.1
	394.401	0.061	1797	0.068-990	1.3		670.78	0.0014	129515	0.0014-1000	0.7
B	396.152	0.038	6011	0.038-1000	1.1	Mg	202.647	0.035	414	0.035-800	3.7
	182.641	0.019	625	0.019-800	2.9		279.079	0.13	331	0.13-700	3.1
	208.959	0.056	3568	0.056-1000	1.0		279.553	0.0014	52244	0.0014-1000	0.9
	249.677	0.097	877	0.097-800	2.2		280.270	0.0012	40151	0.0012-1000	0.94
Ba	249.773	0.050	1305	0.050-1000	3.1	Mn	285.213	0.0018	14017	0.0018-1000	1.0
	230.424	0.014	784	0.014-980	3.7		257.611	0.007	10526	0.007-1000	0.9
	233.527	0.24	350	0.24-500	4.6		259.373	0.0091	8047	0.0091-1000	0.9
	455.404	0.083	1439	0.083-1000	1.9		260.569	0.018	5084	0.018-950	1.5
Bi	190.241	0.21	27	0.21-750	4.1	Na	294.921	0.084	1432	0.084-950	1.3
	206.17	0.26	66	0.26-650	4.0		403.076	0.026	5889	0.026-950	1.2
	222.825	0.39	36	0.39-800	3.9		330.237	2.1	82	2.1-700	4.1
	223.061	0.19	285	0.19-800	2.6		530.298	2.3	64	2.3-800	4.5
Cd	306.772	2.8	1112	2.8-800	1.0	Ni	588.995	0.0051	33736	0.0051-1000	1.3
	214.438	0.012	4193	0.012-1000	1.1		589.592	0.011	21676	0.011-1000	2.1
	226.502	0.007	9090	0.007-1000	0.8		221.648	0.14	745	0.14-800	2.9
	228.802	0.051	1897	0.051-950	1.5		227.021	0.031	126	0.031-900	3.8
Cu	361.051	0.51	193	0.51-700	3.1	Sr	231.604	0.072	743	0.072-890	3.2
	219.226	0.18	330	0.18-900	4.2		232.003	0.084	589	0.084-900	3.0
	219.958	0.075	672	0.075-500	4.0		300.249	0.19	618	0.19-900	2.8
	224.7	0.012	1695	0.012-800	2.6		341.476	0.073	2585	0.073-990	1.1
Fe	324.754	0.0016	39510	0.0016-1000	0.8	Zn	407.771	0.0003	215159	0.0003-1000	0.8
	327.396	0.002	26650	0.002-1000	0.8		421.552	0.0011	168621	0.0011-1000	0.9
	238.204	0.049	886	0.049-675	2.9		460.733	0.096	1295	0.096-800	1.1
	239.562	0.060	1684	0.060-800	1.9		202.613	0.001	1740	0.001-990	1.7
	241.331	0.45	216	0.45-500	4.1	Cr	206.2	0.3	149	0.3-600	4.1
	244.451	0.43	122	0.43-500	4.5		213.856	0.0045	14408	0.0045-1000	0.9
	259.941	0.34	1586	0.34-950	2.7		334.502	0.28	378	0.28-800	3.8
	261.187	0.078	931	0.078-750	2.6		205.618	0.0093	2380	0.0098-1000	1.7
	262.567	0.46	85	0.46-900	3.1		267.716	0.15	560	0.15-850	2.8
	262.829	0.28	174	0.28-900	2.8		283.563	0.035	2893	0.035-1000	1.4
	275.573	0.11	260	0.11-800	2.6		284.325	0.086	1363	0.086-950	1.9
	373.486	0.11	1354	0.11-900	2.2		284.984	0.088	503	0.088-800	2.8

ence on the interfered line is a function of the concentration of the interfering element, a systematic study was carried out to understand the effect of Lu concentration on the different interfered analytical lines of the elements. Based on the linear relationship, the correction factors for the different interfered analytical lines were calculated.

Spectral Interference of Lu on Some REEs: Ce, Dy, La, Gd, Nd, and Pr

Due to the line-rich emission spectra of rare earth elements (REEs), even though additional analytical lines are available, the chance of interference also increases. Moreover, due to the similar chemistry of this group of elements, the trace level determination of REEs in a rare earth matrix becomes very complicated.

Ce (Cesium)

Four different analytical lines of Ce were chosen for the present study (393.373 nm, 413.765 nm, 418.660 nm, and 413.380 nm). The Ce 418.660 nm and 413.380 nm lines were found to be free from the spectral interference of Lu, while the Lu 393.373 nm line was severely interfered by Lu. The detection limits of these lines were found to be similar with the trend: 413.380 nm < 413.765 nm ~ 418.660 nm < 393.373 nm, whereas the sensitivity followed the trend: 413.380 nm ~ 413.765 nm > 418.660 nm > 393.373 nm. The reproducibility was $\geq 3\%$ RSD. From the above results, it can be concluded that both the Ce 418.660 nm and 413.380 nm lines can be used for trace level determination in a Lu matrix.

Dy (Dysprosium)

In case of Dy, the five analytical lines chosen (353.170 nm, 394.468 nm, 340.780 nm, 353.602 nm, and 364.540 nm) were free of Lu spectral interference even at trace levels up to 1000 mg/L concentration of

Lu. The detection limits of these lines followed the order: 364.540 nm < 353.170 nm < 394.468 nm < 340.780 nm ~ 353.602 nm, while their sensitivity followed the trend: 353.170 nm > 364.540 nm > 340.780 nm > 394.468 nm > 353.602 nm. Based on the above study and even though the Dy 353.170 nm and 364.540 nm analytical lines were found to be the best in a Lu matrix, all of the above-mentioned lines can be used for the trace level determination of Dy in a Lu matrix.

La (Lanthanum)

For La, three lines (408.672 nm, 333.749 nm and 379.478 nm) were interference-free from Lu. Surprisingly, the different merits of the analytical performance of these lines, including detection limits, sensitivity, %RSD, and linear dynamic range, were similar and good. Therefore, all of these lines are suitable in a Lu matrix.

Gd (Gadolinium)

Among the four analytical lines of Gd (342.247 nm, 335.047 nm, 336.223 nm, and 335.862 nm), there was practically no spectral interference from Lu up to 1000 mg/L. The analytical performance of these lines was highly satisfactory and can be chosen for further investigation. In accordance with the overall performance, the Gd 335.047 nm line was believed to be the best line for Gd in a Lu matrix.

Nd (Neodymium)

Of the four analytical lines of Nd (401.225 nm, 430.358 nm, 406.109 nm, and 417.731 nm), only 401.225 nm was slightly interfered by Lu with a tolerance level of 500 mg/L. The detection limit of these lines followed the trend: 401.225 nm < 430.358 nm < 406.109 nm < 417.731 nm, while the reverse trend was seen in case of their sensitivity. Though the analytical performance of all of these lines was good, unfortunately the best per-

formed analytical line (401.225 nm) had a slight interference from Lu. Therefore, the rest of the analytical lines were taken as suitable lines for further investigation.

Pr (Praseodymium)

Of the four analytical lines of Pr (411.846 nm, 417.939 nm, 422.535 nm and 414.311 nm), only two lines (417.939 nm and 422.535 nm) were interference-free from Lu up to 1000 mg/L. Though the analytical performance of the 422.535 nm line was found to be satisfactory, the Pr 417.846 nm line showed the best performance (detection limit: 0.04 mg/L, sensitivity: 2799 counts/mg/L, % RSD: 1.2, linear dynamic range: 0.04-1000 mg/L), and thus the most suitable choice for Pr determination in a Lu matrix.

The systematic study and the results of the spectral interference of Lu on these rare earth elements are tabulated in Table V, while the analytical performance of the different analytical lines of these rare earth elements are summarized in Table VI.

Spectral Interference of Lu on Ca, Co, In, Pb, and Tl

Ca (Calcium)

Among six identified analytical lines for Ca (396.847 nm, 393.366 nm, 317.933 nm, 315.887 nm, 183.801 nm, and 422.673 nm), the 315.887 nm line was found to be free of Lu interference, whereas the analytical performance was very poor. On the contrary, one of the best performing analytical lines of Ca, i.e., 396.847 nm, showed appreciable spectral contribution from Lu. Based on the spectral interference as well as the analytical performance, it was observed that the Ca 393.366 nm and 422.673 nm lines should be the best lines of choice.

TABLE V
Spectral Interference Of Lu on Ce, Dy, La, Gd, Pr, and Nd

Elements	Analytical Lines (nm)	Contribution from 1000 mg/L of Lu	Correction Factor	Tolerance Level (mg/L)	Elements	Analytical Lines (nm)	Contribution from 1000 mg/L of Lu	Correction Factor	Tolerance Level (mg/L)
Ce	418.66	*	-	1000	Gd	342.247	*	-	1000
	413.765	0.302	3.0×10^{-4}	500		335.047	*	-	1000
	413.38	*	-	1000		336.223	*	-	1000
	393.373	15.204	1.5×10^{-2}	0.05		335.862	*	-	1000
Dy	353.17	*	-	1000	Nd	401.225	0.286	2.8×10^{-4}	500
	394.468	*	-	1000		430.358	*	-	1000
	340.78	*	-	1000		406.109	*	-	1000
	353.602	*	-	1000		417.731	*	-	1000
	364.54	*	-	1000	Pr	411.846	0.425	4.2×10^{-4}	200
La	408.672	*	-	1000		417.939	*	-	1000
	333.749	*	-	1000		422.535	*	-	1000
	379.478	*	-	1000		414.311	0.134	1.3×10^{-4}	500

* = No interference.

TABLE VI
Analytical Performance of Ce, Dy, La, Gd, Pr, and Nd

Elements	Analytical Lines (nm)	D.L. (mg/L)	Sensitivity (counts/mg/L)	Linear Dynamic Range (mg/L)	(%) RSD	Elements	Analytical Lines (nm)	D.L. (mg/L)	Sensitivity (counts/mg/L)	Linear Dynamic Range (mg/L)	(%) RSD
Ce	393.373	0.21	1260	0.21-900	2.5	Nd	401.225	0.081	1821	0.081-1000	2.6
	413.38	0.12	1539	0.12-1000	2.3		406.109	0.16	1206	0.16-1000	2.3
	413.765	0.15	1528	0.15-1000	2.1		417.731	0.25	1203	0.25-1000	2.1
	418.66	0.16	1277	0.16-990	3.1		430.358	0.098	1748	0.098-1000	1.8
Dy	340.78	0.057	3565	0.057-1000	2.6	Pr	411.846	0.08	2440	0.08-800	2.9
	353.17	0.017	10816	0.017-1000	0.9		414.311	0.06	3013	0.06-1000	1.5
	353.602	0.053	2890	0.053-900	2.1		417.939	0.04	2799	0.04-1000	1.2
	364.54	0.011	4402	0.011-1000	1.6		422.535	0.097	2154	0.097-1000	1.1
	394.468	0.039	3027	0.039-900	2.5	Gd	335.047	0.015	5115	0.015-1000	1.2
La	333.749	0.038	4051	0.038-1000	1.7		335.862	0.075	3320	0.075-950	2.0
	379.478	0.044	4462	0.044-1000	1.9		336.223	0.079	3862	0.079-1000	1.8
	408.672	0.042	4789	0.042-1000	1.5		342.247	0.034	3502	0.034-1000	1.7

Co (Cobalt)

A difficult situation arises for Co. The spectral contribution from Lu followed the trend: 237.862 nm < 228.616 nm < 230.786 nm < 238.892 nm. The tolerance level was found to be 500 mg/L of Lu for all of the lines, except for Co 238.892 nm, with a tolerance level of 200 mg/L. The detection limits of these lines follow the trend: 237.862 nm ~ 238.892 nm < 228.616 nm ~ 230.786 nm,

whereas the sensitivity followed: 238.892 nm > 237.862 nm > 228.616 nm > 230.786 nm. Based on the above analysis, the Co 237.862 nm and 238.892 nm lines were chosen as the best lines in a Lu matrix for further investigation.

In (Indium)

For In, four different analytical lines were chosen (230.606 nm, 303.936 nm, 325.609 nm, and 451.131 nm). It was observed that

the interference-free analytical line of 451.131 nm showed very poor analytical performance, while the other three lines showed similar contribution from 1000 mg/L of Lu.

The spectral interference of Lu on Ca, Co, In, Pb, and Tl are tabulated in Table VII, while the analytical performance of the different analytical lines of these elements is summarized in Table VIII.

TABLE VII
Spectral Interference of Lu on Ca, Co, In, Pb, and Tl

Elements	Analytical Lines (nm)	Contribution from 1000 mg/L of Lu	Correction Factor	Tolerance Level (mg/L)	Elements	Analytical Lines (nm)	Contribution from 1000 mg/L of Lu	Correction Factor	Tolerance Level (mg/L)
Ca	396.847	0.376	3.8×10^{-4}	100	In	230.606	0.284	2.8×10^{-4}	500
	393.366	0.292	2.9×10^{-4}	100		325.609	0.192	1.9×10^{-4}	500
	317.933	0.303	3.0×10^{-4}	200		451.131	*	-	1000
	315.887	*	-	1000		303.936	0.322	3.2×10^{-4}	500
	183.801	4.423	4.4×10^{-3}	500	Pb	220.353	1.106	1.1×10^{-3}	200
	422.673	0.162	1.6×10^{-4}	200		405.778	0.312	3.1×10^{-4}	500
Co	228.616	0.17	1.7×10^{-4}	500		283.305	0.251	2.5×10^{-4}	200
	238.892	0.31	3.1×10^{-4}	200	Tl	261.418	#	Rejected	-
	230.786	0.25	2.5×10^{-4}	500		190.864	0.117	1.2×10^{-4}	500
	237.862	0.096	9.6×10^{-5}	500		276.787	3.753	3.8×10^{-3}	500

* = No interference, # = Significant interference.

TABLE VIII
Analytical Performance of Ca, Co, In, Pb, and Tl

Elements	Analytical Lines (nm)	D.L. (mg/L)	Sensitivity (counts/mg/L)	Linear Dynamic Range (mg/L)	(%) RSD	Elements	Analytical Lines (nm)	D.L. (mg/L)	Sensitivity (counts/mg/L)	Linear Dynamic Range (mg/L)	(%) RSD
Ca	183.801	3.1	17	3.1-800	4.1	In	230.606	0.13	425	0.13-950	2.1
	315.887	0.2	848	0.2-800	3.8		303.936	0.14	448	0.14-950	2.0
	317.933	0.048	2738	0.048-900	2.7		325.609	0.095	1201	0.095-1000	1.5
	393.366	0.0016	306574	0.0016-1000	1.3		451.131	4.9	61	4.9-800	4.4
	396.847	0.0007	226491	0.0007-1000	1.2	Pb	220.353	0.34	236	0.34-800	2.8
	422.673	0.0024	15538	0.0024-1000	1.1		261.418	0.052	98	0.052-1000	4.1
Co	228.616	0.10	747	0.10-800	2.2		283.305	0.049	580	0.049-1000	1.2
	230.786	0.15	555	0.15-850	2.8	Tl	405.778	0.2	509	0.2-950	2.1
	237.862	0.044	1295	0.044-1000	9.6		190.864	0.083	597	0.083-1000	3.1
	238.892	0.047	1761	0.047-1000	1.1		276.787	1.8	27	1.8-900	4.3

Direct Determination of Analytes in a Lu Matrix Without Chemical Separation: Validation Using Synthetic Samples

Based on these studies, a methodology was developed for the trace level determination of the above-mentioned analytes without chemical separation using synthetic samples prepared from the SRMs of the individual element solutions. The content of each synthetic sample was as followed:

(a) Synthetic sample 1 (S 1):
0.1 mg/L of Ag, Al, B, Ba, Bi, Cd, Cu, Fe, Ga, Li, Mg, Mn, Na, Ni, Sr, Zn, and Cr in 1000 mg/L of Lu.

(b) Synthetic sample 2 (S 2):
1 mg/L of Ag, Al, B, Ba, Bi, Cd, Cu, Fe, Ga, Li, Mg, Mn, Na, Ni, Sr, Zn, and Cr in 1000 mg/L of Lu.

(c) Synthetic sample 3 (S 3):
0.1 mg/L of Ce, Dy, La, Gd, Nd, and Pr in 1000 mg/L of Lu.

(d) Synthetic sample 4 (S 4):
1 mg/L of Ce, Dy, La, Gd, Nd, and Pr in 1000 mg/L of Lu.

(e) Synthetic sample 5 (S 5):
0.2 mg/L of Ca, Co, In, Pb, and Tl in 1000 mg/L of Lu.

(f) Synthetic sample 6 (S 6):
2 mg/L of Ca, Co, In, Pb, and Tl in 1000 mg/L of Lu.

The synthetic samples were of analytes using the best analytical lines of these elements as obtained above. The analytical results revealed that the common analytes (Ag, Al, B, Ba, Bi, Cd, Cu, Fe, Ga, Li, Mg, Mn, Na, Ni, Sr, Zn, and Cr) can be determined in a Lu matrix without any separation and without any correction factor, even at 0.1 mg/L. Similar results were obtained for the rare earth elements Ce, Dy, La, Gd, Nd, and Pr. For analytes such as Ca, Co, In, Pb, and Tl, the method is useful for the determination of these elements at the 0.2 mg/L level in the presence of 1000 mg/L

of Lu. The analytical results of the synthetic samples are listed in Tables IX – XI.

Comparison of Present Method With Other Analytical Methods

A comparison of the present methodology was carried out with atomic absorption spectrometry and d.c. arc AES. The synthetic

TABLE IX
Analyses of Ag, Al, B, Ba, Bi, Cd, Cr, Cu, Fe, Ga, Li, Mg, Mn, Na, Ni, Sr, and Zn Using Synthetic Samples Prepared From Commercially Available Standard Reference Materials

Element	Analytical Lines (nm)	S1		S2	
		Actual Concentration (mg/L)	Amount Estimated After Incorporating Correction Factor (mg/L)	Actual Concentration (mg/L)	Amount Estimated After Incorporating Correction Factor (mg/L)
Ag	328.068	0.1	0.104 ± 0.004	1	1.02 ± 0.05
	338.289	0.1	0.094 ± 0.006	1	0.97 ± 0.06
Al	396.152	0.1	0.097 ± 0.005	1	0.95 ± 0.05
	394.401	0.1	0.102 ± 0.004	1	0.92 ± 0.07
B	208.959	0.1	0.110 ± 0.008	1	1.03 ± 0.03
	249.677	0.1	0.103 ± 0.004	1	1.07 ± 0.06
Ba	455.404	0.1	0.097 ± 0.005	1	0.94 ± 0.04
Bi	306.772	0.1	0.096 ± 0.007	1	0.98 ± 0.04
	214.438	0.1	0.104 ± 0.004	1	0.99 ± 0.06
Cd	226.502	0.1	0.101 ± 0.003	1	0.97 ± 0.05
	205.618	0.1	0.098 ± 0.005	1	0.98 ± 0.06
Cr	327.396	0.1	0.093 ± 0.007	1	1.03 ± 0.06
Cu	373.486	0.1	0.107 ± 0.006	1	1.04 ± 0.07
	275.573	0.1	0.097 ± 0.004	1	1.06 ± 0.07
Ga	417.206	0.1	0.096 ± 0.006	1	1.04 ± 0.05
	670.78	0.1	0.103 ± 0.005	1	1.02 ± 0.04
Li	279.553	0.1	0.104 ± 0.004	1	1.03 ± 0.04
	280.27	0.1	0.104 ± 0.004	1	1.03 ± 0.05
Mn	285.213	0.1	0.104 ± 0.004	1	1.07 ± 0.05
	257.611	0.1	0.104 ± 0.004	1	1.04 ± 0.06
Na	259.373	0.1	0.104 ± 0.004	1	1.03 ± 0.06
	588.995	0.1	0.104 ± 0.004	1	1.06 ± 0.07
Ni	589.592	0.1	0.104 ± 0.004	1	1.03 ± 0.07
	221.648	0.1	0.104 ± 0.004	1	1.06 ± 0.06
Sr	300.249	0.1	0.104 ± 0.004	1	0.98 ± 0.06
	341.476	0.1	0.104 ± 0.004	1	0.94 ± 0.05
Zn	407.771	0.1	0.104 ± 0.004	1	0.97 ± 0.08
	421.552	0.1	0.104 ± 0.004	1	0.97 ± 0.08
	460.733	0.1	0.104 ± 0.004	1	0.96 ± 0.07
	202.613	0.1	0.104 ± 0.004	1	0.98 ± 0.07
	213.856	0.1	0.104 ± 0.004	1	1.02 ± 0.05

TABLE X
Analyses of Ce, Dy, La, Gd, Pr, and Nd Using Synthetic Samples
Prepared From Commercially Available Standard Reference Materials

Elements	Analytical Lines (nm)	S3		S4	
		Actual Concentration (mg/L)	Amount Estimated After Incorporating Correction Factor (mg/L)	Actual Concentration (mg/L)	Amount Estimated After Incorporating Correction Factor (mg/L)
Ce	413.38	0.1	0.096 ± 0.004	1	1.01 ± 0.05
	418.66	0.1	0.102 ± 0.03	1	0.97 ± 0.06
La	408.672	0.1	0.101 ± 0.005	1	0.96 ± 0.07
	333.749	0.1	0.097 ± 0.003	1	0.94 ± 0.06
	379.478	0.1	0.095 ± 0.005	1	1.12 ± 0.06
Gd	342.247	0.1	0.096 ± 0.05	1	0.97 ± 0.07
	335.047	0.1	0.103 ± 0.004	1	1.10 ± 0.06
	336.223	0.1	0.102 ± 0.004	1	1.05 ± 0.06
	335.862	0.1	0.107 ± 0.005	1	1.07 ± 0.07
Nd	430.358	0.1	0.11 ± 0.006	1	1.06 ± 0.04
	406.109	0.1	0.095 ± 0.004	1	0.98 ± 0.04
	417.731	0.1	0.099 ± 0.004	1	0.95 ± 0.03
Pr	417.939	0.1	0.098 ± 0.003	1	0.99 ± 0.05
	422.535	0.1	0.098 ± 0.003	1	1.04 ± 0.07
Dy	353.17	0.1	0.097 ± 0.004	1	1.04 ± 0.05
	394.468	0.1	0.96 ± 0.04	1	1.05 ± 0.04
	340.78	0.1	0.96 ± 0.04	1	0.95 ± 0.07
	364.54	0.1	0.96 ± 0.04	1	0.97 ± 0.05
	413.38	0.1	0.96 ± 0.04	1	0.96 ± 0.03

samples containing 0.3 mg/L of Ag, Al, B, Ba, Bi, Cd, Cu, Fe, Ga, Li, Mg, Mn, Na, Ni, Sr, Zn, and Cr and 1.5 mg/L of Ca, Co, In, Pb, and Tl in 1000 mg/L of Lu were directly fed into the plasma and the analytical results were compared with the results obtained from the d.c. arc carrier distillation technique (45) for all of the analytes, except Ag. For Ag, the atomic absorption spectrometric technique was used for comparison purposes (46). Table XII shows good agreement between the comparative techniques. For the rare earth elements La, Ce, Pr, Nd, Dy, and Gd, separate synthetic samples were prepared containing

0.5 mg/L of these analytes in 1000 mg/L of Lu matrix. The results of the newly developed method compared well with that of the ion chromatographic analysis (47) (see Table XIII).

CONCLUSION

Based on the systematic study of the spectral interference of Lu on 28 analytes (Ag, Al, B, Ba, Bi, Cd, Cu, Fe, Ga, Li, Mg, Mn, Na, Ni, Sr, Zn, Cr, Ca, Co, In, Pb, and Tl, including the rare earth elements Ce, Dy, La, Gd, Nd, and Pr) and the analytical performance of the different analytical lines of these analytes, the most suitable lines of

these elements in the presence of a Lu matrix were identified. A new approach was adopted for the direct determination of these analytes using ICP-AES at trace levels in the presence of a Lu matrix without chemical separation. This newly developed method was found to be simple, precise, sensitive, and less time-consuming. Furthermore, the developed methodology was validated using synthetic samples prepared from commercially available standard reference material solutions of each element, and the results were found to be satisfactory. The method was also compared with other existing techniques such as d.c. arc, ion chromatography, and atomic absorption spectrometry. Moreover, an ICP-AES-based method for the simultaneous determination of Lu revealed that the Lu 261.542 nm line is the best line for its determination.

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TABLE XI
Analyses of Ca, Co, In, Pb, and Tl Using Synthetic Samples
Prepared From Commercially Available Standard Reference Materials

Elements	Analytical Lines (nm)	S5			S6		
		Actual Concentration (mg/L)	Amount Estimated Before Incorporating Correction Factor (mg/L)	Amount Estimated After Incorporating Correction Factor (mg/L)	Actual Concentration (mg/L)	Amount Estimated Before Incorporating Correction Factor (mg/L)	Amount Estimated After Incorporating Correction Factor (mg/L)
Ca	393.366	0.2	0.50 ± 0.02	0.21	2	2.32 ± 0.06	2.03
	422.673	0.2	0.35 ± 0.02	0.19	2	2.19 ± 0.08	2.03
Co	237.862	0.2	0.30 ± 0.02	0.20	2	2.01 ± 0.05	1.91
	238.892	0.2	0.50 ± 0.03	0.19	2	2.37 ± 0.04	2.06
In	325.609	0.2	0.40 ± 0.02	0.21	2	2.02 ± 0.07	1.83
Pb	283.305	0.2	0.42 ± 0.03	0.17	2	2.02 ± 0.06	1.77
Tl	190.864	0.2	0.31 ± 0.02	0.19	2	2.19 ± 0.04	2.07

TABLE XII
Comparison Of the Present Methodology with Existing Analytical Techniques For Common Analytes

Ele-ments	Analytical Lines (nm)	Estimated by Present Method (mg/L)	Comparison With Other Method (mg/L)	Ele-ments	Analytical Lines (nm)	Estimated by Present Method (mg/L)	Comparison With Other Method (mg/L)
Ag	328.068	0.30 ± 0.03	0.27 ± 0.04*	Mn	257.611	0.31 ± 0.03	0.33 ± 0.06**
	338.289	0.31 ± 0.02	0.34 ± 0.02*		259.373	0.32 ± 0.02	0.33 ± 0.05**
Al	396.152	0.28 ± 0.04	0.29 ± 0.06**	Na	588.995	0.33 ± 0.02	0.26 ± 0.04**
	394.401	0.30 ± 0.02	0.33 ± 0.04**		589.592	0.30 ± 0.03	0.27 ± 0.05**
B	208.959	0.29 ± 0.03	0.28 ± 0.05**	Ni	221.648	0.28 ± 0.03	0.31 ± 0.04**
	249.677	0.28 ± 0.02	0.28 ± 0.04**		300.249	0.29 ± 0.02	0.32 ± 0.04**
Ba	455.404	0.31 ± 0.03	0.32 ± 0.06**		341.476	0.28 ± 0.03	0.33 ± 0.04**
Bi	306.772	0.30 ± 0.02	0.27 ± 0.04**	Sr	407.771	0.27 ± 0.03	0.32 ± 0.05**
Cd	214.438	0.28 ± 0.03	0.29 ± 0.05**		421.552	0.30 ± 0.02	0.28 ± 0.05**
	226.502	0.32 ± 0.04	0.33 ± 0.06**		460.733	0.31 ± 0.03	0.27 ± 0.04**
Cr	205.618	0.30 ± 0.01	0.32 ± 0.05**	Zn	202.613	0.32 ± 0.02	0.28 ± 0.05**
Cu	327.396	0.33 ± 0.03	0.27 ± 0.04**		213.856	0.30 ± 0.01	0.29 ± 0.04**
Fe	373.486	0.29 ± 0.03	0.28 ± 0.05**	Ca	393.366	1.51 ± 0.03	1.60 ± 0.08**
	275.573	0.27 ± 0.02	0.31 ± 0.05**		422.673	1.48 ± 0.02	1.43 ± 0.08**
Ga	417.206	0.30 ± 0.02	0.26 ± 0.04**	Co	237.862	1.49 ± 0.03	1.47 ± 0.07**
					238.892	1.50 ± 0.04	1.48 ± 0.06**
Li	670.78	0.28 ± 0.03	0.27 ± 0.05**	In	325.609	1.46 ± 0.07	1.52 ± 0.07**
Mg	279.553	0.30 ± 0.04	0.28 ± 0.04**	Pb	283.305	1.53 ± 0.06	1.59 ± 0.08**
	280.27	0.30 ± 0.03	0.33 ± 0.04**	Tl	190.864	1.45 ± 0.07	1.50 ± 0.07**
	285.213	0.30 ± 0.02	0.30 ± 0.05**				

* = Analysis was done in atomic absorption spectrometry.

** = Analysis was done by D.C. arc atomic emission spectrometry, matrix: 1000 mg/L Lu.

TABLE XIII
Comparison of Present Method With Existing Analytical Technique
For the Rare Earth Elements

Elements	Analytical Lines (nm)	Estimated by Present Method (mg/L)	Comparison With Other Method (mg/L)
Ce	413.380	0.53 ± 0.04	0.52 ± 0.04#
	418.660	0.47 ± 0.03	0.51 ± 0.03#
La	408.672	0.52 ± 0.04	0.49 ± 0.04#
	333.749	0.48 ± 0.04	0.47 ± 0.04#
	379.478	0.49 ± 0.03	0.51 ± 0.03#
Gd	342.247	0.50 ± 0.03	0.52 ± 0.04#
	335.047	0.51 ± 0.04	0.48 ± 0.04#
	336.223	0.53 ± 0.02	0.53 ± 0.02#
	335.862	0.50 ± 0.04	0.53 ± 0.04#
Nd	430.358	0.49 ± 0.04	0.51 ± 0.04#
	406.109	0.47 ± 0.02	0.50 ± 0.02#
	417.731	0.50 ± 0.04	0.47 ± 0.03#
Pr	417.939	0.52 ± 0.02	0.47 ± 0.04#
	422.535	0.46 ± 0.04	0.51 ± 0.04#
Dy	353.17	0.50 ± 0.03	0.48 ± 0.04#
	394.468	0.49 ± 0.04	0.49 ± 0.03#
	340.78	0.52 ± 0.03	0.49 ± 0.04#
	364.54	0.52 ± 0.04	0.50 ± 0.04#

= Analysis was done by ion chromatographic technique, Matrix: 1000 mg/L Lu.

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