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QUANTIFICATION OF URANIUM AND THORIUM IN MINERALS AT CENTRAL AFRICAN COPPER BELT MINING INDUSTRIES

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ABSTRACT

Central African country North Zambia has some Uranium and Copper occurrence together as U3O8 and Tho 2 together with copper minerals. Lumwana mine is producing copper concentrate from minerals with concentrating procedure and Uranium and Thorium in ore level up to 100 ppm and 100 ppm in final copper concentrate. It has been found that low level Uranium and Thorium are accruing in African Base metals ores and minerals. The present study describes efforts to develop methodology to analyze Uranium and Thorium by ED XRF. Studies have been conducted for calibration for Uranium and Thorium elements analysis in copper concentrates by XEPOS (Spectro - Energy Dispersive X-Ray Fluorescence) at copper mine for Lumwana Mining Company Zambia.

Keywords : Lumwana mine ; Uranium ; Thorium ; Quantification ; XEPOS

INTRODUCTION

Central African country North Zambia has some Uranium and Copper occurrence together as U3O8 and Tho 2 together with copper minerals. Lumwana mine is producing copper concentrate from minerals with concentrating procedure and Uranium and Thorium in ore level up to 100 ppm and 100 ppm in final copper concentrate. It has been found that low level Uranium and Thorium are accruing in African Base metals ores and minerals.

Lumwana Copper Mine

Lumwana Mine is an open-cut copper mine project in the North West province of Zambia, 220km west of the Copper belt and 65km west of the town of Solwezi. Producer of Copper Location is North West province, Zambia.The mine was officially inaugurated in April 2009 and the bulk emulsion manufacturing plant was opened at the Lumwana copper mine in January 2009. It was recognized as Africa's biggest copper mine at that time.Copper production started in December 2008 instead of July 2008 due to a fire at the processing plant, which affected the main transformer and substation.In addition to copper, the Lumwana project also contains rich uranium deposits. Equinox completed a uranium feasibility study in 2008 that showed the output of 2Mlb a year of uranium oxide and 15,000t of copper could be mined simultaneously from the discrete uranium-enriched zones.

Lumwana announced plans to suspend operations at the mine in December 2014 following the Zambian Government's move to raise the royalty rates on open-pit mining operations in the country from 6% to 20%. The royalty rate was reduced to 9% in July 2015.

In summary, the Malundwe, Chimiwungo and Chimiwungo North tectono-stratigraphy can be considered a highly sheared and altered tectono-stratigraphic sequence produced by major D1Shear zone thrusts. The Ore Schists and the Footwall Quartzite/Muscovite-Quartz Schist units appear to be the most strongly sheared and metasomatically altered portions of the shear zone. Both deposits contain lenses (Malundwe) or internal horizons (Chimiwungo) of quartz-feldspar – biotite gneiss to schist, similar to the Hanging wall Gneiss. This suggests the Ore Schist was not a different lithology, but instead a hybrid tectonic rock produced by intense Lufilian age shearing and alteration of the Basement Hanging Wall Gneiss just below the Basement –

Katangan contact.

The Malundwe, Chimiwungo and Chimiwungo ore contains typically 5% sulphides dominated by copper-iron sulphides. Typically sulphide assemblages are:

- Chalcopyrite ($CuFeS_2$) - Pyrite (FeS_2)
- Chalcopyrite ($CuFeS_2$) - Bornite (Cu_5FeS_4)
- Chalcopyrite ($CuFeS_2$) - Pyrrhotite (FeS) - Cubanite ($CuFe_2S_3$)
- Chalcocite (Cu_2S) - Bornite (Cu_5FeS_4).

Malundwe has all four assemblages but is dominated by the Chalcopyrite – bornite assemblage. Chimiwungo has all except the Chalcocite – Bornite assemblage but is dominated by the Chalcopyrite – Pyrite and Chalcopyrite - Pyrrhotite – Cubanite assemblages. Barren rocks are commonly enriched with iron. Nickel is associated with the more pyritic zones of the ore bodies. High cobalt concentrations are related to carrolite [$Cu(Co, Ni)_2S_4$] enclosed in chalcopyrite, cobalt pentlandite $(Fe,Ni,Co)_9S_8$ and cobaltiferous pyrrhotite hosted predominantly in the Upper and Main Ore Schist units at Chimiwungo. Gold and uranium are present as discrete zones mainly within the Malundwe Ore Schist or immediate footwall, although sporadic zones of uranium and gold mineralization are observed at Chimiwungo.

DEVELOPMENT OF LUMWANA COPPER MINE

The mining licence covers 1,355km² and includes two major copper deposits, Malundwe and Chimiwungo, as well as 25 exploration prospects. The licence is valid for 25 years (from January 2004) and is renewable for a further 25 years. Although Lumwana was discovered in 1961, no serious work was carried out there until Equinox became involved in 1999. At the time, the property was controlled by Phelps Dodge Corp. Equinox formed a joint venture with Phelps in which Equinox could earn 51% of Lumwana by investing $10m and completing a feasibility study. Later, Equinox bought Phelps out for $5m, giving Equinox 100% ownership of Lumwana. Costing $760m, mine construction started in earnest in late 2006 and was carried out by 4,700 local workers. In 2006, Equinox completed three rounds of equity financing totalling $250m through a short-form prospectus equity issue managed by an international syndicate of underwriters, a private placement equity issue to ZCCM Investments Holdings managed by the company and a second short-form prospectus equity issue managed by an international syndicate of underwriters. The company also signed a $583.8m senior and subordinated project finance debt facility with a group of financial institutions for the completion of development and construction of Lumwana.In May 2008, Equinox Minerals secured a long-term (99 years) land title to 35,000ha for its township and mine operation areas.

Geology of copper mine in North West province

The Lumwana deposits of Malundwe and Chimiwungo are hosted within the Mwombezhi Dome, a north-east trending basement dome in the western arm of the Neoproterozoic Lufilian Arc thrust-fold belt. The Lufilian Arc is a major tectonic province characterized by broadly north-directed thrust structures and antiformal Basement inliers or domes surrounded by Katangan metasediments, which host the Central African Copper belt.

Copper mineralization at Lumwana

The copper mineralization at Lumwana is hosted almost entirely within high-grade metamorphosed, intensely mylonitised, recrystallised muscovite-phlogopite-quartz-kyanite schists with disseminated sulphides (typically <5%) dominated by chalcopyrite and bornite.

Of the two major deposits, Malundwe is smaller but with higher copper grade and contains discrete zones of uranium and gold mineralization with occasional sporadic high cobalt (>0.1%).Chimiwungo is much larger and lower in copper grade but has higher overall cobalt and contains a number of significant high-grade (>0.1%) cobalt zones plus some sporadic uranium mineralization.

Lumwana copper mine reserves

The proven and probable mineral reserves at the Lumwana mine as of December 2020 were estimated at 39Mt grading 0.49% copper and 460Mt grading 0.57% copper respectively. As of 31 December 2020, the proven and probable copper reserves at the mine stood at 6.3 billion pounds.

Processing

Metallurgical test work indicates greater than 95% recovery of copper by conventional flotation processing. Test work showed that Malundwe will produce a concentrate grading 41%–45% copper and Chimiwungo is expected to produce a concentrate grading 28%–32% copper.

Sulphide ore is processed on-site by conventional flotation to produce copper concentrates for shipment to off-site smelters. Concentrates are smelted and refined into metal at smelters. The copper concentrates produced during the fourth quarter of 2010 were delivered to the Chambishi Copper Smelter and the Konkola Copper Mines Smelter at Nchanga on the Zambian Copperbelt.

Trucks from the mine tip directly into a 400t capacity ROM dump hopper. A primary gyratory crusher crushes the ROM ore from a nominal top size of 1,500mm to less than 200mm. Oversize material is deposited on the ROM pad to be further broken by a mobile rock breaker.

Ore is reclaimed via apron feeders onto a conveyor belt providing direct feed, at a rate of about 2,500t/h, into the 38ft × 18ft SAG mill. The SAG mill trommel undersize discharges into a hopper and is pumped to conventional hydrocyclones, operating in closed circuit with a 26ft × 40ft ball mill. The hydrocyclone overflow (P_{80} of 280µm) reports to flotation, while the underflow returns to the ball mill.

The flotation plant consists of two parallel trains of rougher/scavenger cells. The rougher/scavenger concentrate reports to the regrind circuit to further liberate the copper minerals. After regrinding, the concentrate is cleaned in a conventional cleaner/recleaner circuit to reach final concentrate grade.

The concentrate is dewatered in a circuit consisting of high-rate thickening followed by pressure filtration to produce a filter cake suitable for transportation. Flotation tailings are thickened and pumped to the tailings dam. Most of the plant water is recovered and recycled from the thickener overflows and tailings dam return water. Fresh make-up water is supplied from a river-water dam as required.

OCCURRENCE OF URANIUM AND THORIUM IN ORE AND COPPER CONCENTRATE

General Occurrence and Uranium Chemistry in Mining Industries.

- In sea water, at about 0.003 ppm.
- In rocks of the Earth's crust generally, at up to 4 ppm, and incorporated into many minerals.
- In ore, as uraninite (UO_2) or pitchblende (U_3O_8) or as secondary minerals (complex oxides, silicates, phosphates, vanadates).
- African and Australian ores are up to O.5% U_3O_8, in Canada they range up to 25% U_3O_8.
- U_3O_8 is a stable complex oxide: $U_2O_5.UO_3$.
- Uranium is fairly soluble and uranium oxide precipitates from uranium-bearing groundwaters as they enter a reducing environment. It can be mobilized (redissolved) in situ by oxygenated leach solution.

Extraction from ore at the mine during mining and concentrating procedure

The ore is crushed and ground to liberate the mineral particles. It is then leached with sulfuric acid:

$UO_3 + 2H^+ ====> UO_2^{2+} + H_2O$
$UO_2^{2+} + 3SO_4^{2-} ====> UO_2\,(SO_4)_3^{4-}$

The UO_2 is oxidized to UO^{3-}

With some ores, carbonate leaching is used to form a soluble uranyl tricarbonate ion: $UO_2(CO_3)_3^{4-}$. This can then be precipitated with an alkali, eg . as sodium or magnesium diuranate. Alkaline leaching is not undertaken in Australia at present.

Two methods have been used for concentration and purification of uranium: ion exchange and solvent extraction. Early operations in Australia used ammonium type resins in polystyrene beads for ion exchange, but solvent extraction is now in general use.

In solvent extraction, tertiary amines* are used in a kerosene diluent, and the phases move counter currently.

$2R_3N + H_2SO_4$ ====> $(R_3NH)_2SO_4$
$2\ (R_3NH)_2SO_4 + UO_2(SO_4)_3^{4-}$ ====> $(R_3NH)_4UO_2(SO_4)_3 + 2SO_4^{2-}$

* "R" is an alkyl (hydrocarbon) grouping, with single covalent bond.

The loaded solvents may then be treated to remove impurities. First, cations are removed at pH 1.5 using sulfuric acid and then anions are dealt with using gaseous ammonia.

The solvents are then stripped in a countercurrent process using ammonium sulfate solution.

$(R_3NH)_4UO_2(SO_4)_3 + 2(NH_4)_2SO_4$ ====> $4R_3N + (NH_4)_4UO_2(SO_4)_3 + 2H_2SO_4$

Precipitation of ammonium diuranate is achieved by adding gaseous ammonia to neutralize the solution (though in earlier operations caustic soda and magnesia were used).

$2NH3 + 2UO_2(SO_4)_3^{4-}$ ====> $(NH_4)_2U_2O_7 + 4SO_4^{2-}$

The diuranate is then dewatered and roasted to yield U_3O_8 product, which is the form in which uranium is marketed and exported.

In situ leaching of sandy unconsolidated ore bodies is an important mining method in the USA, Kazakhstan and Australia.

Typically the uranium is recovered by circulating weakly acidified groundwater with oxygen added through injection and recovery wells. In the plant, the pregnant liquor then deposits uranium on a plastic ion exchange resin. The loaded resin is washed with sulfuric acid, hydrogen peroxide is added, and uranyl peroxide precipitated. With low temperature drying this becomes U_3O_8.

Alternatively, an oxygenated carbonate leach may be employed, depending on the chemistry of the orebody. In that case a soluble uranyl tricarbonate ion: $UO_2(CO_3)_3^{4-}$ is formed and then precipitated with an alkali, eg. as sodium or magnesium diuranate.

RESEARCH AND DEVELOPMENT TO DEVELOP METHODOLOGY TO ANALYZE URANIUM AND THORIUM BY ED XRF.

Studies have been conducted to perform Calibration for Uranium and Thorium elements analysis in copper concentrates by XEPOS (Spectro - Energy Dispersive X-Ray Fluorescence) at copper mine for Lumwana Mining Company Zambia.

It is difficult task to view Uranium and Thorium L-Alpha peak due to base metal satellite peak, and high background, it is required to low down noise peak and base metals Iron and satellite peak to view U-Th peak, so use external Aluminum filter as secondary target to remove all unnecessary peak and noise.

Calibration of Xepos for application of U & Th analysis

Performed action for XRF Calibration:

1. Cleaning the instrument properly with inside and outside

   Cleaning the instruments with tissue paper and cloth wipers from outside and from inside with tissue paper. Open the shutter of X-ray and clean the all dust very gently with tissue paper. Some outside dark spot cleaned with mild acetonecleaner with tissue paper. Clean die and analytical surface with same acetonecleaner.

2. Perform the first MCA calibration and after Global calibration
   After the cleaning the instrument,give15minutes warm up to X-ray tube and after that first run the MCA calibration with single standard SP-1 and after that Global calibration with both standard SP-1 and SP-2. MCA calibration results are very same as before and any variation from original details was not found . And it is saved in backup file at original path. The noise from vacuum pump as observed is routine, nothing any abnormal during the MCA and Global calibration.

3. Installed the method from CD to Xepos computer in method list.

After the MCA, Global calibration inserts the CD disc in computer and copy the method on desktop and it is imported from the menu. And save it with Pallet list in method list. Select all standard and turn into reset measurement for all standards including Silica disc and Wax disc both also. This method is included in routine dialog system by configuration editor. And all methods were checked twice at routine dialog box.

Method details

Method Name : **LMC-CONC-AL-FIL-U-Th**
Elements : U, Th
Matrix : Lumwana Copper concentrates.

Standard details : 15 standard with U Calibration range : 9 – 136 ppm ,Th Calibration range : 24 –102ppm

Dilution Material : Spectro Wax (M_HWC)
Standard weight : 4.5000 gm
Dilution wax weight : 0.5000gm Ring
Diameter : 40mm
System : Pressed ring (Pressed pallet)
Analysis media : Vacuum
Measurements : Current 1.00 m A and Voltage 50.00 kV.
Mathematics : Lucas-tooth, price
Target : Compton/ secondary ,Molybdenum (No. 1 target)
Measurement time : 500 seconds.
Spectra Line : L*α* for U and L*α* forTh.
Filter : Pure Aluminum filter with 0.125mmThickness, 40 mm diameter filter s plate with steel support Surrounding rings

4. New background measurement with Silica disc and wax disc.

   As per our original calibration at UK we require creating new background with silica disc supply by Spectro and manually prepared Spectro wax disc. One disc has already been prepared. Both samples were used for new background setup. Run both sample discs in standard list through Routine dialog box and insert standard menu. After finishing the measurement turn into method development menu Standards and selected as Background-1 is Wax and Background-2 and Background-3 are Silica. Both standards analyses save as instrument standard list with A (Analytical) status. We are able to use or change it as per requirement.
5. Standard drying in oven for 1hr at 105’C.

Standard for calibration is removed from packets and took in paper pack. Transport pack is with polythene beg so. All standard weight is aprox. 15 gm each except first four standard 100043/3, 100045/3, 100049/3 and 100053/3. These four standards are same with earlier calibration.(All four rings were kept in desiccators after finishing calibration.) All 15 standards are as per the following with concentration of Th and U.

Calibration Standards for Lumwana Uranium and Thorium XEPOS Application

Standard ID	Reference	U(ppm)	Th(ppm)
CopperConcSTD02	100043/3	15	-
CopperConcSTD04	100045/3	9	-
CopperConcSTD07	100049/3	20	-
CopperConcSTD11	100053/3	28	-
CopperConcSTD15	TG027-377	82	47
CopperConcSTD20	TG015	45	26
CopperConcSTD23	TM006	33	24
CopperConcsSTD24	TM011	54	29
MixedSampleBlank	BLANK	37	28
MixedSampleA	SPIKEA	47	33
MixedSampleB	SPIKEB	62	43
MixedSampleC	SPIKEC	77	53
MixedSampleD	SPIKED	97	68
MixedSampleE	SPIKEE	117	83
MixedSampleF	SPIKEF	136	102

U Calibration range: 9–136ppm,Th Calibration range:24–102ppm

All above standards put in oven for one hour drying at 105 ‘C. After drying remove the standard from Oven to desiccators for cooling .And get ready to use for weighing.

6. Cleaning the weighing Bottle, Ring and dry it.

   Cleaning the bottle and lid with water and soap and again clean with plenty water so no shops are there. Same as all rings also clean with water and cleaning soap.After cleaning all bottles, lid and rings dry it with air or oven, for drying over 10minutes time. Some rings contain martial and spot so require properly cleaning with soap and dilute acid. And get back to weighing table with properly carrying box.
7. Weighing the binder in all bottle and standard samples.

   In all cleaned and empty bottle selected and weighed 0.5000 gm Spectra wax with analytical balance. During weighing the wax used the clean weighing boat and new brush. After weighed all wax start to weigh standard samples 4.5000gm one by one from desiccators, all standard weighed with duplicate (Except first four) and with proper marking name and number. Fist four standards weighed in only single replicate. After weighed wax and standard, mix it properly for two minutes shaking the bottle. Special care required during mixing to not change numbering from bottle.

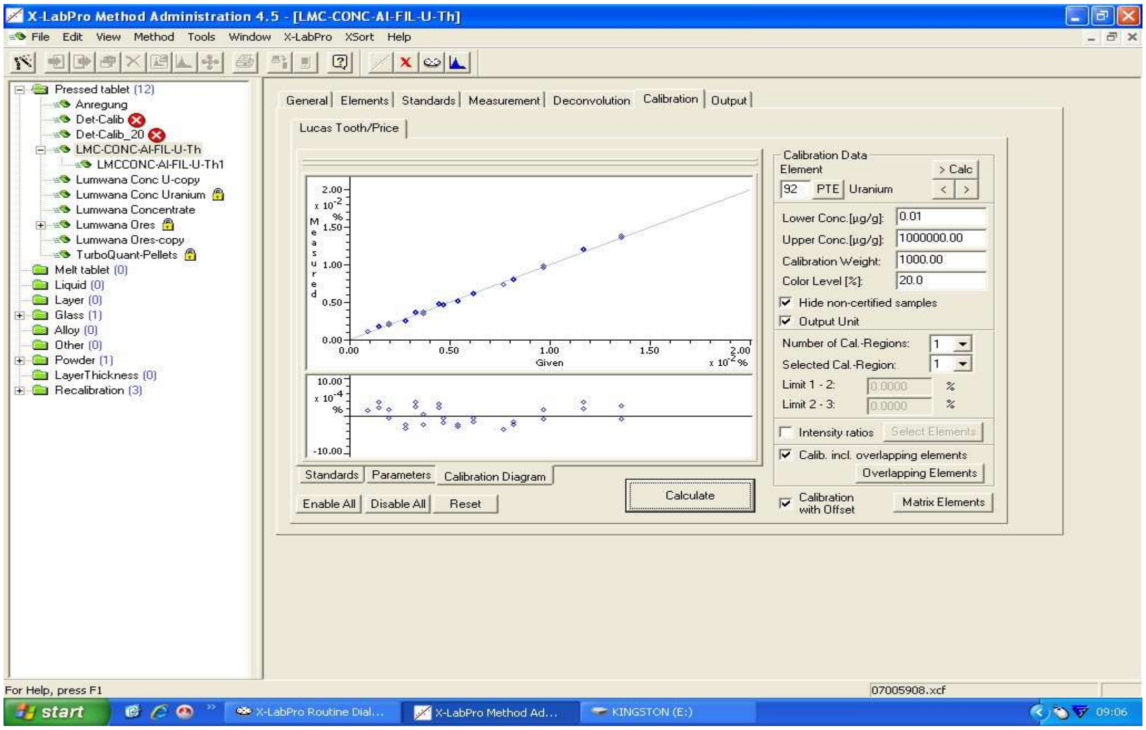
8. Sample preparation with Press the sample with myler film.
   After weighed and mixed standard ready to press it in rings. Cleaned the die and analytical surface. There is little problem that samples sticking to analytical surface and it is change the level of surface area. So for avoiding this problem, the Myler film was used to cover the analytical surface so sample will not stick with die. One box Myler film was carried from UK, so it was used for all standards. Pressed the all standard with 5.0 MT pressures, by using SPECAC press for 30 seconds times. All standard rings were kept with paper cover and dust free. There is difficult to get 30 sec times without watch or digital timer. We used our mobile with 30 sec. time setup. All rings are good with the level and with label at backside of the rings. But then also all rings with proper sequence of standard list. There was some concern with sample pressed system and it has been discussed on later points in observation with some photograph.
9. Run the calibration and finished the graph for both element U and Th.
   Standard setup on plate with aluminum filter, (Aluminum filter plate no. is towards up is true position) as per the no. and sequences no. 1 to 12. Same standards selected from the insert standard menu from routine dialog box.Checked the a list of standard with A and B reps from paper list and physical standard on analytical plate.After all confirmation start the analysis for calibration standards. Finished the measurement of all 15 standards (11 with duplicates and 4 in singles run two time same samples) back to method admin menu and open the **'LMC-CONC-AL-FIL-U-Th'** method for checking calibration graph and data. After calculation of U and Th graph, both graphs for U and Th are found linear and all standards are falling on line. As a result, U calibration graph was given the 2.4 ppm absolute error and Th graph was given 2.7 ppm absolute error.Use Both results and graph were used for the confirmation of calibration. And calculated its RMS error (ppm) and Estimated Uncertainty (95%) (ppm) as per table.

Calculation	U	Th
RMS error(ppm)	2.4	2.7
Tcrit (95%)	2.0796	2.0796
Estimated Uncertainty(95%)(ppm)	5.0	5.6

Table 1 : RMS error (ppm) and Estimated Uncertainty (95%) (ppm)

Pictures for a calibration graph for U and Th and all calibration standard data table

CALIBRATION GRAPH FOR U (500 SEC.)



X-LabPro Method Administration 4.5 - [LMC-CONC-AI-FIL-U-Th]

Calibration Data

Element: 92 Uranium

Lower Conc.[µg/g]: 0.01

Upper Conc.[µg/g]: 1000000.00

Calibration Weight: 1000.00

Color Level [%]: 20.0

☑ Hide non-certified samples

☑ Output Unit

Number of Cal.-Regions: 1

Selected Cal.-Region: 1

Limit 1 - 2: 0.0000 %

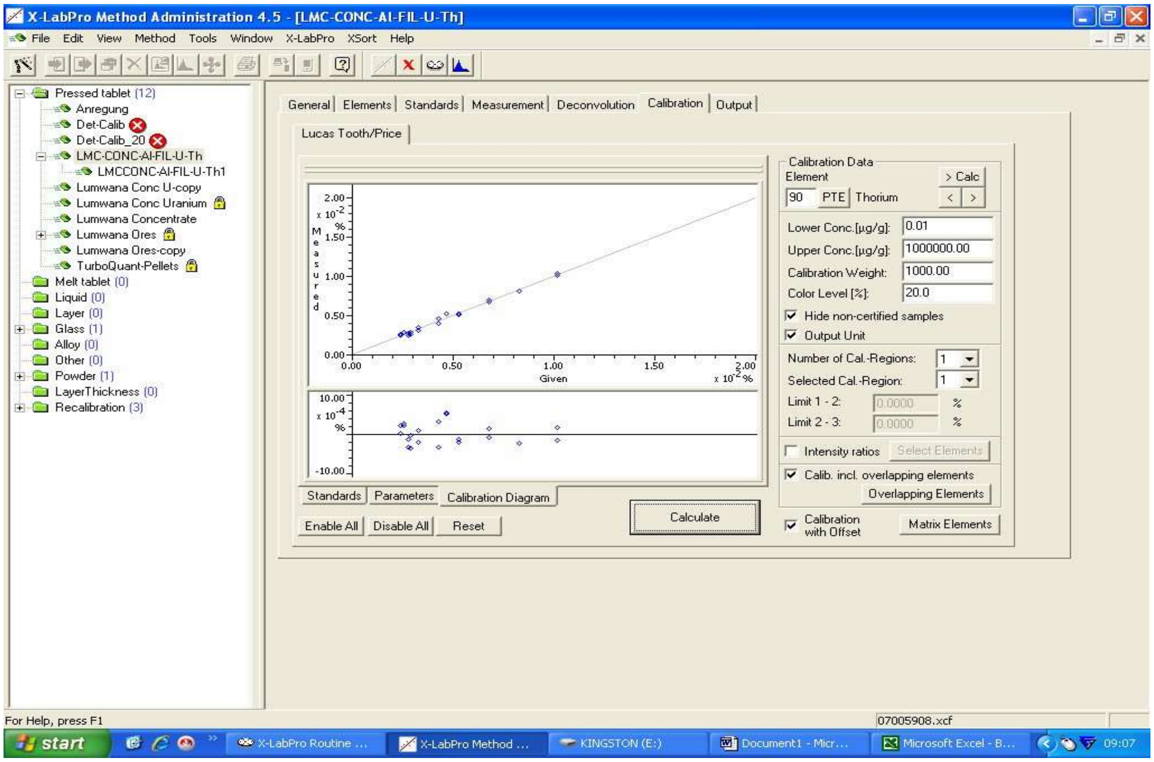
Limit 2 - 3: 0.0000 %

☐ Intensity ratios

☑ Calib. incl. overlapping elements

☑ Calibration with Offset

CALIBRATION GRAPH FOR– Th (500 SEC.)



X-LabPro Method Administration 4.5 - [LMC-CONC-AI-FIL-U-Th]

Calibration Data
Element: 90 PTE Thorium
Lower Conc.[µg/g]: 0.01
Upper Conc.[µg/g]: 1000000.00
Calibration Weight: 1000.00
Color Level [%]: 20.0
☑ Hide non-certified samples
☑ Output Unit
Number of Cal.-Regions: 1
Selected Cal.-Region: 1
Limit 1 - 2: 0.0000 %
Limit 2 - 3: 0.0000 %
☐ Intensity ratios
☑ Calib. incl. overlapping elements
☑ Calibration with Offset

CALIBRATION STANDARD DATA FOR U (500 SEC.)

NO.	NAME OF STANDARD	NORM. IMP.	GIVEN CONC. %	CALC. CONC. %	DIFF. %
1	COPPERCONCS-04A	15.74	9	10.3	1.3
1	COPPERCONCS-04B	15.73	9	10.3	1.3
1	COPPERCONCS-02A	18.71	15	17.2	2.2
1	COPPERCONCS-02B	19.36	15	18.7	3.7
1	COPPERCONCS-07A	20.59	20	21.5	1.5
1	COPPERCONCS-07B	19.7	20	19.5	-0.5
1	COPPERCONCS-11A	21.96	28	24.7	-3.3
1	COPPERCONCS-11B	22.43	28	25.7	-2.3
1	COPPERCONCS-23A	27.12	33	36.5	3.5
1	COPPERCONCS-23B	26.6	33	35.3	2.3
1	MIXED-BLANK-1	27.5	37	37.4	0.4
1	MIXED-BLANK-2	26.27	37	34.6	-2.4

1	COPPERCONCS-20A	32.2	45	48.2	3.2
1	COPPERCONCS-20B	31.74	45	47.1	2.1
1	MIXEDSAMPLE-A-1	30.88	47	45.2	-1.8
1	MIXEDSAMPLE-A-2	31.4	47	46.4	-0.6
1	COPPERCONCS-24A	33.65	54	51.6	-2.4
1	COPPERCONCS-24B	33.47	54	51.1	-2.9
1	MIXEDSAMPLE-B-1	37.97	62	61.5	-0.5
1	MIXEDSAMPLE-B-2	37.5	62	60.4	-1.6
1	MIXEDSAMPLE-C-1	43.18	77	73.5	-3.5
1	MIXEDSAMPLE-C-2	43.09	77	73.3	-3.7
1	COPPERCONCS-15A	46.15	82	80.3	-1.7
1	COPPERCONCS-15B	45.83	82	79.6	-2.4
1	MIXEDSAMPLE-D-1	54.17	97	98.7	1.7
1	MIXEDSAMPLE-D-2	53.06	97	96.2	-0.8
1	MIXEDSAMPLE-E-1	62.86	117	118.8	1.8
1	MIXEDSAMPLE-E-2	63.63	117	120.5	3.5
1	MIXEDSAMPLE-F-1	69.99	136	135.1	-0.9
1	MIXEDSAMPLE-F-2	71.55	136	138.7	2.7

CALIBRATION STANDARD DATA FOR Th

NO.	NAME OF STANDAD	NORM.IMP.	GIVEN CONC. %	CALC. CONC. %	DIFF. %
1	COPPERCONCS-23A	22.34	24	26.2	2.2
1	COPPERCONCS-23B	21.57	24	24.2	0.2
1	COPPERCONCS-20A	23.12	26	28.2	2.2
1	COPPERCONCS-20B	23.24	26	28.6	2.6
1	MIXED-BLANK-1	21.77	28	24.7	-3.3
1	MIXED-BLANK-2	22.45	28	26.5	-1.5
1	COPPERCONCS-24A	23.25	29	28.6	-0.4
1	COPPERCONCS-24B	22.03	29	25.4	-3.6
1	MIXEDSAMPLE-A-1	24.13	33	30.9	-2.1
1	MIXEDSAMPLE-A-2	25.3	33	33.9	0.9
1	MIXEDSAMPLE-B-1	27.48	43	39.6	-3.4
1	MIXEDSAMPLE-B-2	30	43	46.1	3.1
1	COPPERCONCS-15A	32.43	47	52.4	5.4
1	COPPERCONCS-15B	32.32	47	52.2	5.2
1	MIXEDSAMPLE-C-1	31.84	53	50.9	-2.1
1	MIXEDSAMPLE-C-2	32.1	53	51.6	-1.4
1	MIXEDSAMPLE-D-1	38.92	68	69.3	1.3
1	MIXEDSAMPLE-D-2	38.1	68	67.2	-0.8

1	MIXEDSAMPLE-E-1	43.29	83	80.6	-2.4
1	MIXEDSAMPLE-E-2	43.3	83	80.7	-2.3
1	MIXEDSAMPLE-F-1	52.13	102	103.6	1.6
1	MIXEDSAMPLE-F-2	50.89	102	100.4	-1.6

These calibration details and calculation were found satisfactory as per our prime planning to install Aluminum filter method for analysis of U and Th in Copper concs. This method's results were same as found by UK method.

10. Same calibration was done with 300 seconds measurement time.

    For above method, setup our analysis time is 500 seconds so it is long time. Efforts were made to try to reduce the analysis time if possible. And as per task the experiment was finished with main application and method calibration, the experiment was tried with same standards with 300 seconds analysis time. We have this idea for in future if some points come for minimizing the Xepos analysis time so we analyze more number of samples. After calculation of U and Th graph, both graph for U and Th are found linear and all standards are falling on line but some reps are flyer. As a result of U graph given the 4.4 ppm absolute error and Th graph given 2.8 ppm absolute error. The both results and graph for 300 seconds method were sent to user team for their view and comments of 300 seconds analysis time method calibration. We calculated RMS error (ppm) and Estimated Uncertainty (95%) (ppm) as per table but we both are not happy as same as earlier with 500 seconds analysis time. But still, the authors like to share all the data and calculation in report for any future development work.

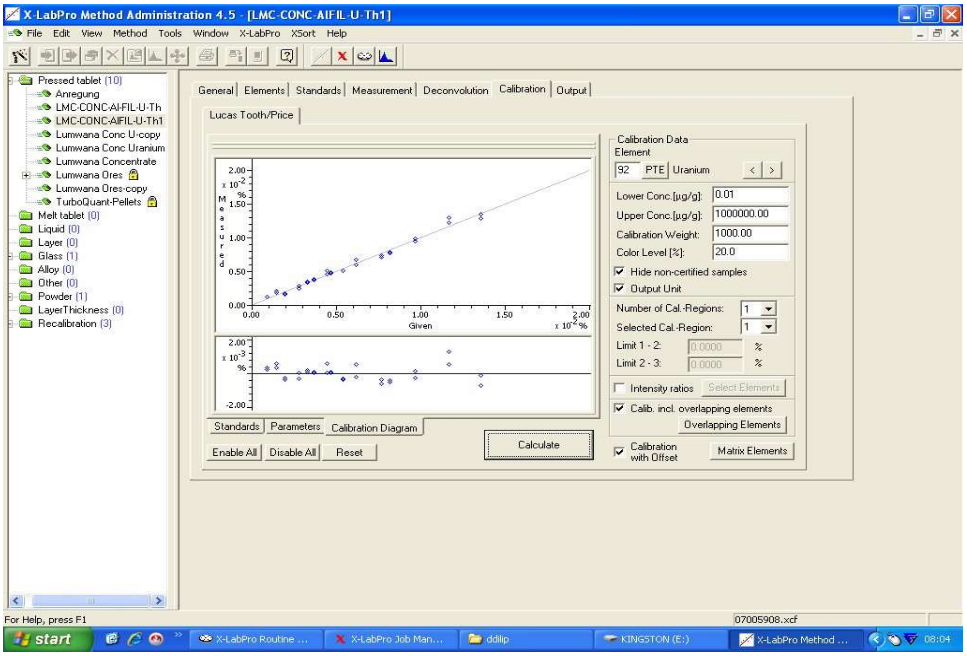
Calculation	**U**	**Th**
RMS error(ppm)	4.6	2.8
Tcrit (95%)	2.0796	2.0796
Estimated Uncertainty(95%)(ppm)	9.7	5.8

Table 2 : RMS error (ppm) and Estimated Uncertainty (95%) (ppm)

This method was kept in method list in Method admin but not allowed in Routine dialog box, so it is not usable for any routine work.

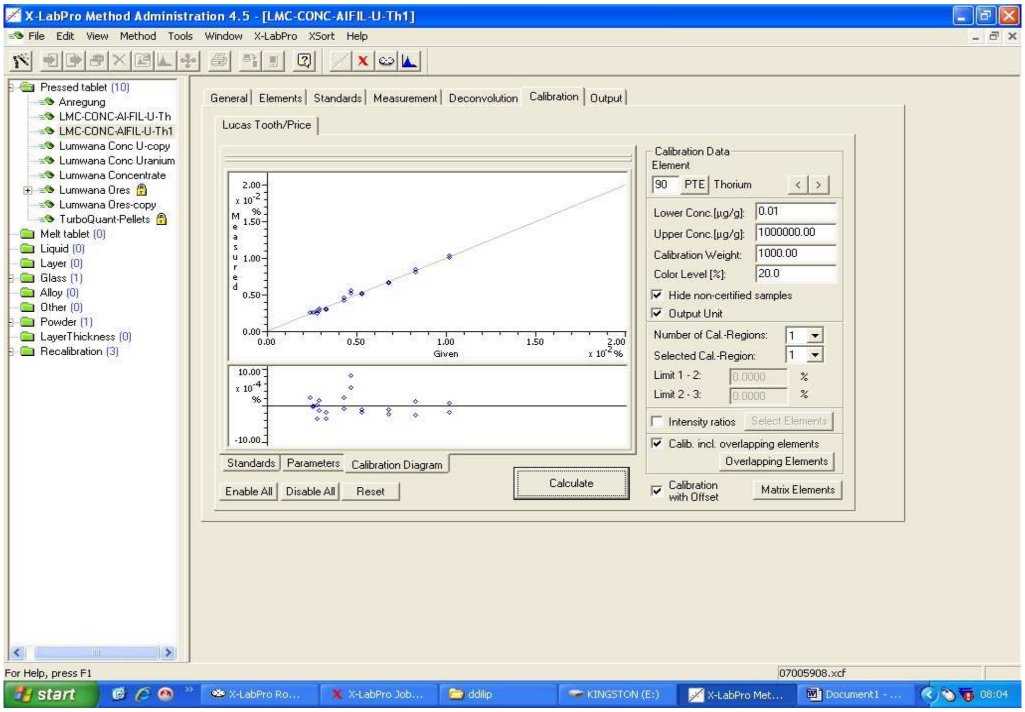
PICTURES FOR A CALIBRATION GRAPH FOR U AND TH AND ALL CALIBRATION STANDARD DATA TABLE

CALIBRATION GRAPH FOR U (300 SEC.)



Calibration Data
Element: 92 PTE Uranium
Lower Conc.[µg/g]: 0.01
Upper Conc.[µg/g]: 1000000.00
Calibration Weight: 1000.00
Color Level [%]: 20.0
☑ Hide non-certified samples
☑ Output Unit
Number of Cal.-Regions: 1
Selected Cal.-Region: 1
Limit 1 - 2: 0.0000 %
Limit 2 - 3: 0.0000 %
☐ Intensity ratios
☑ Calib. incl. overlapping elements
☑ Calibration with Offset

CALIBRATION GRAPH FOR Th (300 SEC.)



Calibration Data
Element: 90 PTE Thorium
Lower Conc.[µg/g]: 0.01
Upper Conc.[µg/g]: 1000000.00
Calibration Weight: 1000.00
Color Level [%]: 20.0
☑ Hide non-certified samples
☑ Output Unit
Number of Cal.-Regions: 1
Selected Cal.-Region: 1
Limit 1 - 2: 0.0000 %
Limit 2 - 3: 0.0000 %
☐ Intensity ratios
☑ Calib. incl. overlapping elements
☑ Calibration with Offset

CALIBRATION STANDARD DATA FOR– U (300 SEC.)

NO.	NAME OF STANDARD	NORM. IMP.	GIVEN CONC. %	CALC. CONC. %	DIFF. %
1	COPPERCONCS-04A	16.45	9	11.4	2.4
1	COPPERCONCS-04B	16.71	9	12	3
1	COPPERCONCS-02A	20.54	15	20.8	5.8
1	COPPERCONCS-02B	19.5	15	18.5	3.5
1	COPPERCONCS-07A	18.44	20	16	-4
1	COPPERCONCS-07B	19.01	20	17.3	-2.7
1	COPPERCONCS-11A	23.75	28	28.2	0.2
1	COPPERCONCS-11B	22.16	28	24.6	-3.4
1	COPPERCONCS-23A	26.55	33	34.7	1.7
1	COPPERCONCS-23B	26.08	33	33.6	0.6
1	MIXED-BLANK-1	27.76	37	37.5	0.5
1	MIXED-BLANK-2	27.84	37	37.6	0.6
1	COPPERCONCS-20A	31.18	45	45.3	0.3
1	COPPERCONCS-20B	33.44	45	50.5	5.5
1	MIXEDSAMPLE-A-1	32.02	47	47.3	0.3
1	MIXEDSAMPLE-A-2	32.19	47	47.6	0.6
1	COPPERCONCS-24A	33.22	54	50	-4
1	COPPERCONCS-24B	33.59	54	50.9	-3.1
1	MIXEDSAMPLE-B-1	37.48	62	59.8	-2.2
1	MIXEDSAMPLE-B-2	40.72	62	67.3	5.3
1	MIXEDSAMPLE-C-1	42.14	77	70.5	-6.5
1	MIXEDSAMPLE-C-2	43.4	77	73.4	-3.6
1	COPPERCONCS-15A	44.83	82	76.7	-5.3
1	COPPERCONCS-15B	45.21	82	77.6	-4.4
1	MIXEDSAMPLE-D-1	54.12	97	98.1	1.1
1	MIXEDSAMPLE-D-2	52.55	97	94.5	-2.5
1	MIXEDSAMPLE-E-1	67.9	117	129.8	12.8
1	MIXEDSAMPLE-E-2	64.72	117	122.5	5.5
1	MIXEDSAMPLE-F-1	67.39	136	128.6	-7.4
1	MIXEDSAMPLE-F-2	70.01	136	134.7	-1.3

CALIBRATION STANDARD DATA FOR Th (300 SEC.)

NO.	NAME OF STANDARD	NORM. IMP.	GIVEN CONC. %	CALC. CONC. %	DIFF. %
1	COPPERCONCS-23A	22.42	24	26.2	2.2
1	COPPERCONCS-23B	22.37	24	26.1	2.1
1	COPPERCONCS-20A	22.29	26	25.9	-0.1
1	COPPERCONCS-20B	22.17	26	25.6	-0.4
1	MIXED-BLANK-1	21.75	28	24.5	-3.5
1	MIXED-BLANK-2	23.18	28	28.2	0.2
1	COPPERCONCS-24A	23.99	29	30.4	1.4
1	COPPERCONCS-24B	22.93	29	27.6	-1.4
1	MIXEDSAMPLE-A-1	24.31	33	31.2	-1.8
1	MIXEDSAMPLE-A-2	23.62	33	29.4	-3.6
1	MIXEDSAMPLE-B-1	29.56	43	45	2
1	MIXEDSAMPLE-B-2	28.45	43	42.1	-0.9
1	COPPERCONCS-15A	33.37	47	55.1	8.1
1	COPPERCONCS-15B	32.18	47	51.9	4.9
1	MIXEDSAMPLE-C-1	32.13	53	51.8	-1.2
1	MIXEDSAMPLE-C-2	31.89	53	51.2	-1.8
1	MIXEDSAMPLE-D-1	37.37	68	65.6	-2.4
1	MIXEDSAMPLE-D-2	37.84	68	66.8	-1.2
1	MIXEDSAMPLE-E-1	44.41	83	84.2	1.2
1	MIXEDSAMPLE-E-2	42.96	83	80.3	-2.7
1	MIXEDSAMPLE-F-1	51.43	102	102.7	0.7
1	MIXEDSAMPLE-F-2	50.46	102	100.1	-1.9

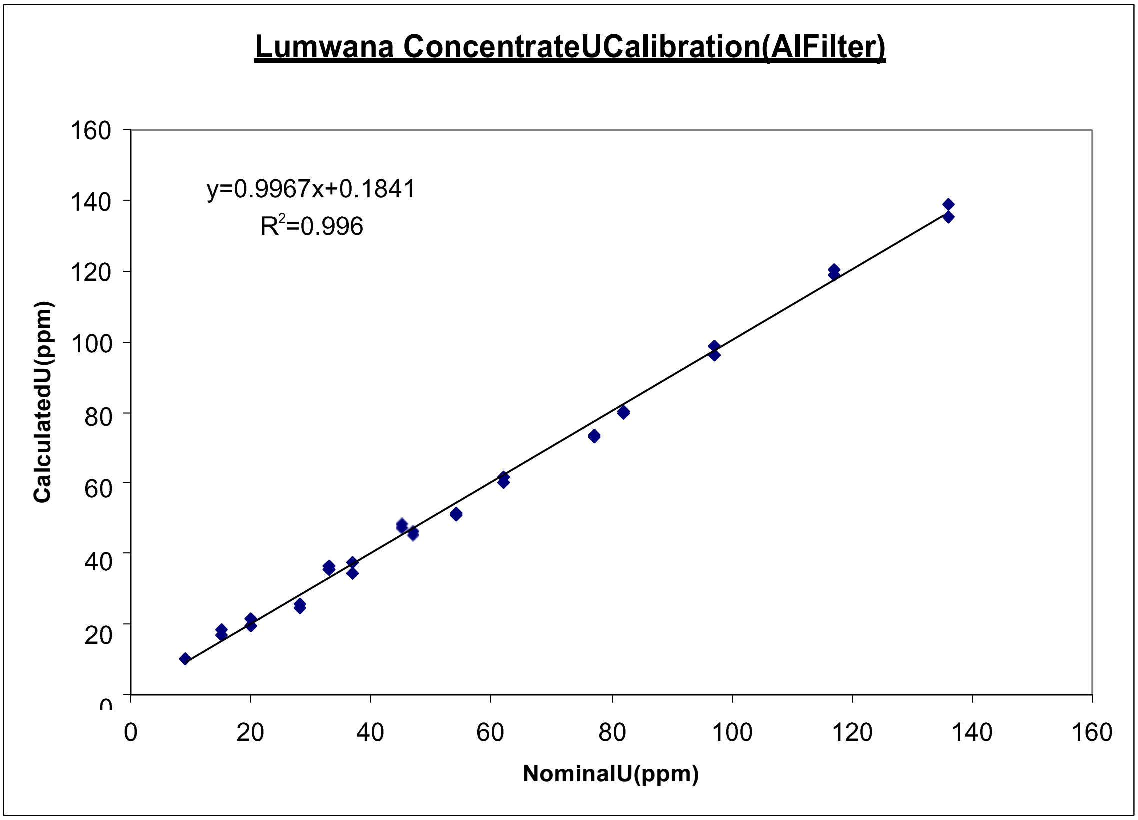
11. After both calibration for final calculation and confirmation of Standard Deviation and Absolute Error, all above data were used for the calibration confirmation and calculated all details at their end. All calculation and data were included in research work for more understanding of calibration and its calculation. This calculation was included with excels calculation and graph as per following tables and graph.

LMC Copper Concentrate (Al Filter) Uranium Calibration data (500sec.)

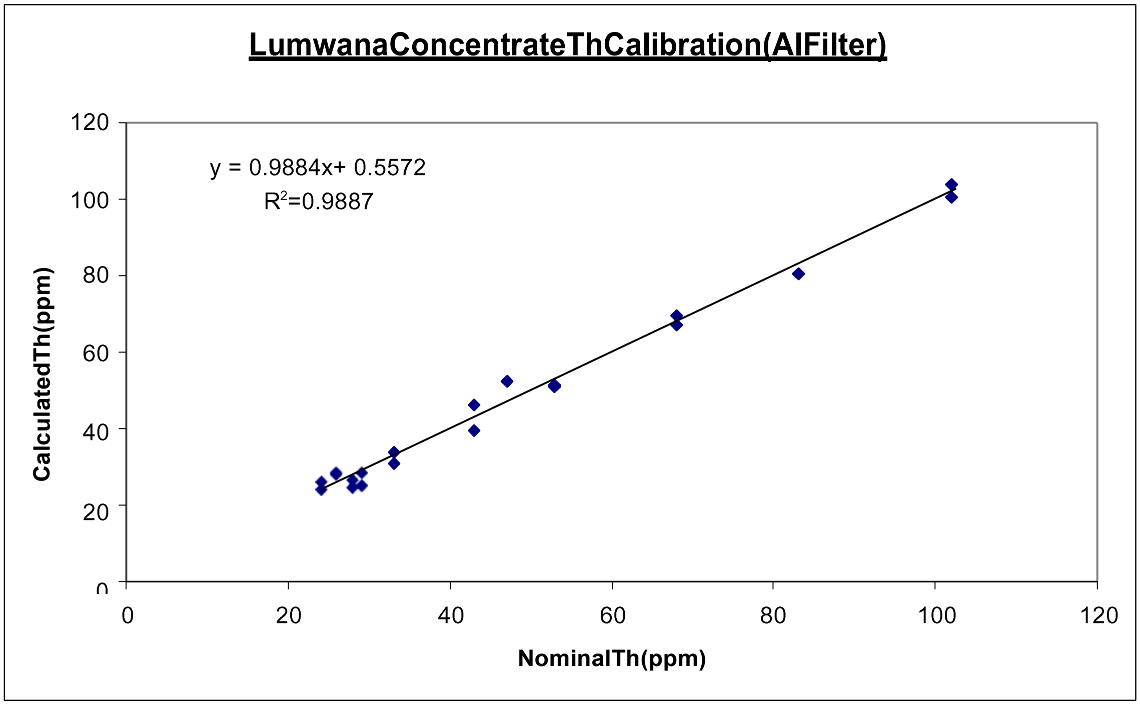
Standard ID	U Nominal Concentration (ppm)	U Calculated Concentration (ppm)	Difference (ppm)	DifferenceSquared
COPPERCONCS-04A	9	10.3	1.3	1.69
COPPERCONCS-04B	9	10.3	1.3	1.69
COPPERCONCS-02A	15	17.2	2.2	4.84
COPPERCONCS-02B	15	18.7	3.7	13.69
COPPERCONCS-07A	20	21.5	1.5	2.25
COPPERCONCS-07B	20	19.5	-0.5	0.25
COPPERCONCS-11A	28	24.7	-3.3	10.89
COPPERCONCS-11B	28	25.7	-2.3	5.29
COPPERCONCS-23A	33	36.5	3.5	12.25
COPPERCONCS-23B	33	35.3	2.3	5.29
MIXED-BLANK-1	37	37.4	0.4	0.16
MIXED-BLANK-2	37	34.6	-2.4	5.76
COPPERCONCS-20A	45	48.2	3.2	10.24
COPPERCONCS-20B	45	47.1	2.1	4.41
MIXEDSAMPLE-A-1	47	45.2	-1.8	3.24
MIXEDSAMPLE-A-2	47	46.4	-0.6	0.36
COPPERCONCS-24A	54	51.6	-2.4	5.76
COPPERCONCS-24B	54	51.1	-2.9	8.41
MIXEDSAMPLE-B-1	62	61.5	-0.5	0.25
MIXEDSAMPLE-B-2	62	60.4	-1.6	2.56
MIXEDSAMPLE-C-1	77	73.5	-3.5	12.25
MIXEDSAMPLE-C-2	77	73.3	-3.7	13.69
COPPERCONCS-15A	82	80.3	-1.7	2.89
COPPERCONCS-15B	82	79.6	-2.4	5.76
MIXEDSAMPLE-D-1	97	98.7	1.7	2.89
MIXEDSAMPLE-D-2	97	96.2	-0.8	0.64
MIXEDSAMPLE-E-1	117	118.8	1.8	3.24
MIXEDSAMPLE-E-2	117	120.5	3.5	12.25
MIXEDSAMPLE-F-1	136	135.1	-0.9	0.81
MIXEDSAMPLE-F-2	136	138.7	2.7	7.29

Sum of Squares	120.4
n-1	21
RMS error (ppm)	**2.4**
Tcrit (95%)	2.0796
Estimated Uncertainty (95%)(ppm)	**5.0**

LMC Copper Concentrate (Al Filter) Uranium Calibration Graph (500sec)



LMC Copper Concentrate (Al Filter)Thorium Calibration Graph (500sec)



LMC Copper Concentrate (Al Filter) Thorium Calibration data (500sec.)

Standard ID	Th Nominal Concentration (ppm)	Th Calculated Concentration (ppm)	Difference (ppm)	DifferenceSquared
COPPERCONCS-23A	24	26.2	2.2	4.84
COPPERCONCS-23B	24	24.2	0.2	0.04
COPPERCONCS-20A	26	28.2	2.2	4.84
COPPERCONCS-20B	26	28.6	2.6	6.76
MIXED-BLANK-1	28	24.7	-3.3	10.89
MIXED-BLANK-2	28	26.5	-1.5	2.25
COPPERCONCS-24A	29	28.6	-0.4	0.16
COPPERCONCS-24B	29	25.4	-3.6	12.96
MIXEDSAMPLE-A-1	33	30.9	-2.1	4.41
MIXEDSAMPLE-A-2	33	33.9	0.9	0.81
MIXEDSAMPLE-B-1	43	39.6	-3.4	11.56
MIXEDSAMPLE-B-2	43	46.1	3.1	9.61
COPPERCONCS-15A	47	52.4	5.4	29.16
COPPERCONCS-15B	47	52.2	5.2	27.04
MIXEDSAMPLE-C-1	53	50.9	-2.1	4.41
MIXEDSAMPLE-C-2	53	51.6	-1.4	1.96
MIXEDSAMPLE-D-1	68	69.3	1.3	1.69
MIXEDSAMPLE-D-2	68	67.2	-0.8	0.64
MIXEDSAMPLE-E-1	83	80.6	-2.4	5.76
MIXEDSAMPLE-E-2	83	80.7	-2.3	5.29
MIXEDSAMPLE-F-1	102	103.6	1.6	2.56
MIXEDSAMPLE-F-2	102	100.4	-1.6	2.56

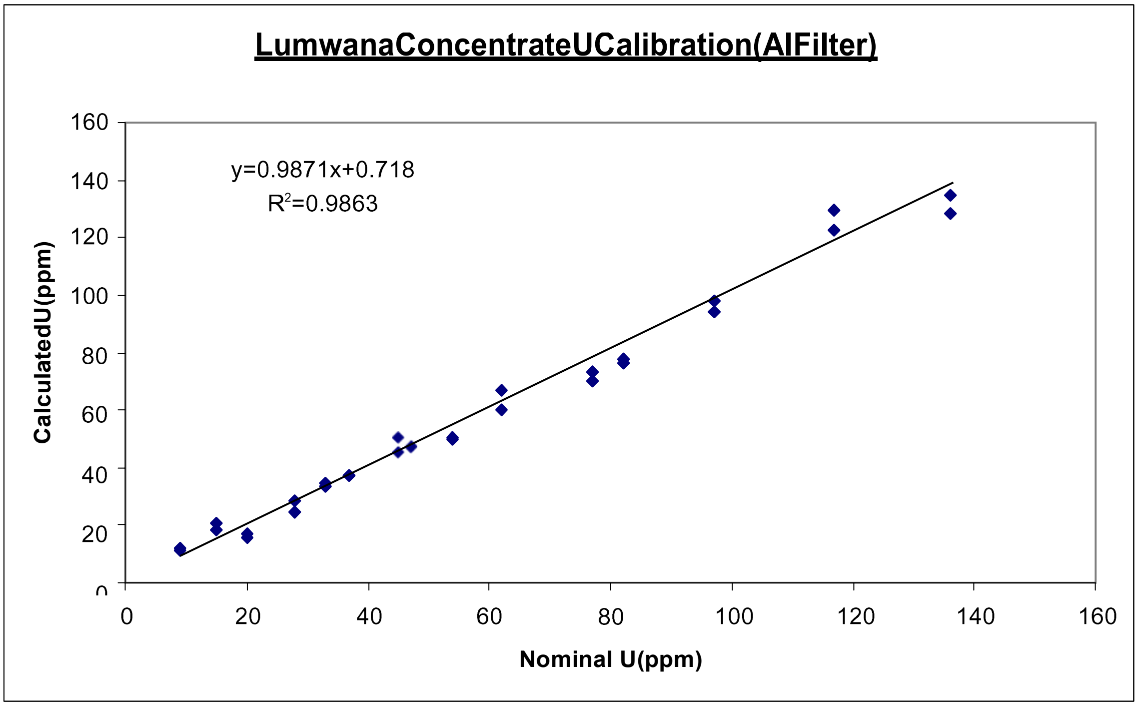
Sum of Squares	150.2
n-1	21
RMSerror(ppm)	**2.7**
Tcrit(95%)	2.0796
Estimated Uncertainty (95%)(ppm)	**5.6**

LMC Copper Concentrate (Al Filter) Uranium Calibration data (300sec.)

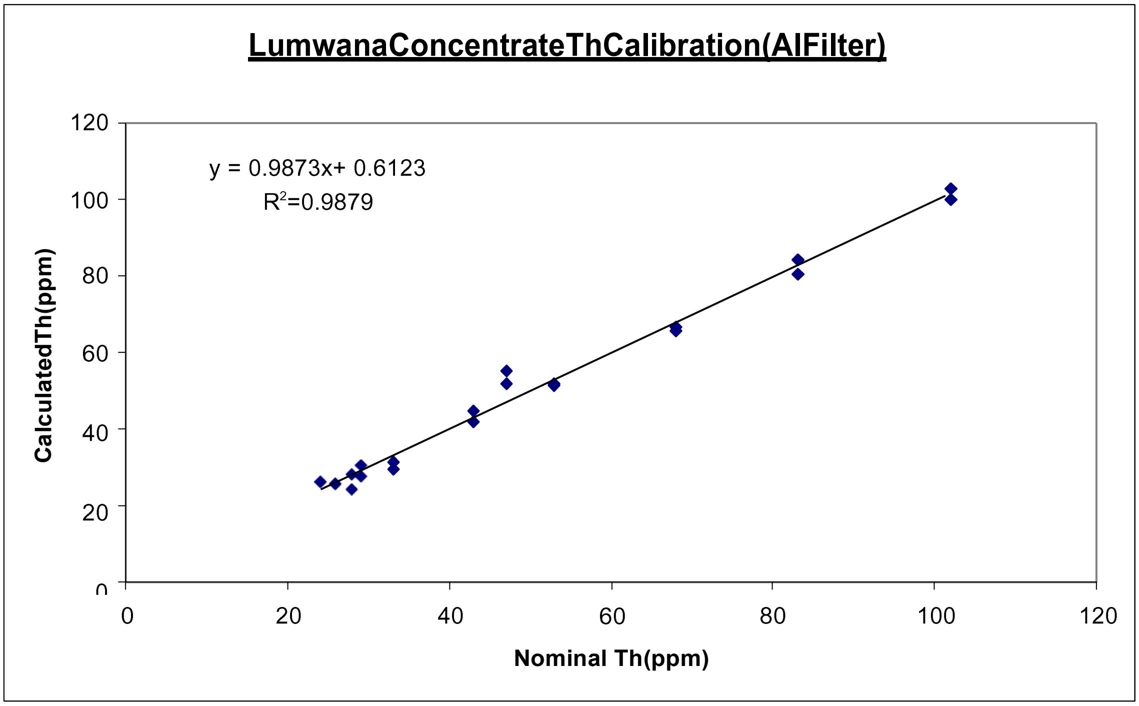
Standard ID	U Nominal Concentration(ppm)	U Calculated Concentration(ppm)	Difference (ppm)	DifferenceSquared
COPPERCONCS-04A	9	11.4	2.4	5.76
COPPERCONCS-04B	9	12	3	9
COPPERCONCS-02A	15	20.8	5.8	33.64
COPPERCONCS-02B	15	18.5	3.5	12.25
COPPERCONCS-07A	20	16	-4	16
COPPERCONCS-07B	20	17.3	-2.7	7.29
COPPERCONCS-11A	28	28.2	0.2	0.04
COPPERCONCS-11B	28	24.6	-3.4	11.56
COPPERCONCS-23A	33	34.7	1.7	2.89
COPPERCONCS-23B	33	33.6	0.6	0.36
MIXED-BLANK-1	37	37.5	0.5	0.25
MIXED-BLANK-2	37	37.6	0.6	0.36
COPPERCONCS-20A	45	45.3	0.3	0.09
COPPERCONCS-20B	45	50.5	5.5	30.25
MIXEDSAMPLE-A-1	47	47.3	0.3	0.09
MIXEDSAMPLE-A-2	47	47.6	0.6	0.36
COPPERCONCS-24A	54	50	-4	16
COPPERCONCS-24B	54	50.9	-3.1	9.61
MIXEDSAMPLE-B-1	62	59.8	-2.2	4.84
MIXEDSAMPLE-B-2	62	67.3	5.3	28.09
MIXEDSAMPLE-C-1	77	70.5	-6.5	42.25
MIXEDSAMPLE-C-2	77	73.4	-3.6	12.96
COPPERCONCS-15A	82	76.7	-5.3	28.09
COPPERCONCS-15B	82	77.6	-4.4	19.36
MIXEDSAMPLE-D-1	97	98.1	1.1	1.21
MIXEDSAMPLE-D-2	97	94.5	-2.5	6.25
MIXEDSAMPLE-E-1	117	129.8	12.8	163.84
MIXEDSAMPLE-E-2	117	122.5	5.5	30.25
MIXEDSAMPLE-F-1	136	128.6	-7.4	54.76
MIXEDSAMPLE-F-2	136	134.7	-1.3	1.69

SumofSquares	453.85
n-1	21
RMS error(ppm)	**4.6**
Tcrit(95%)	2.0796
EstimatedUncertainty (95%)(ppm)	**9.7**

LMC Copper Concentrate (Al Filter) Uranium Calibration Graph (300 sec)



LMC Copper Concentrate (Al Filter) Thorium Calibration Graph (300 sec)



LMC Copper Concentrate (Al Filter) Thorium Calibration data (300 sec.)

StandardID	Th Nominal Concentration(ppm)	Th Calculated Concentration(ppm)	Difference (ppm)	DifferenceSquared
COPPERCONCS-23A	24	26.2	2.2	4.84
COPPERCONCS-23B	24	26.1	2.1	4.41
COPPERCONCS-20A	26	25.9	-0.1	0.01
COPPERCONCS-20B	26	25.6	-0.4	0.16
MIXED-BLANK-1	28	24.5	-3.5	12.25
MIXED-BLANK-2	28	28.2	0.2	0.04
COPPERCONCS-24A	29	30.4	1.4	1.96
COPPERCONCS-24B	29	27.6	-1.4	1.96
MIXEDSAMPLE-A-1	33	31.2	-1.8	3.24
MIXEDSAMPLE-A-2	33	29.4	-3.6	12.96
MIXEDSAMPLE-B-1	43	45	2	4
MIXEDSAMPLE-B-2	43	42.1	-0.9	0.81
COPPERCONCS-15A	47	55.1	8.1	65.61
COPPERCONCS-15B	47	51.9	4.9	24.01
MIXEDSAMPLE-C-1	53	51.8	-1.2	1.44
MIXEDSAMPLE-C-2	53	51.2	-1.8	3.24
MIXEDSAMPLE-D-1	68	65.6	-2.4	5.76
MIXEDSAMPLE-D-2	68	66.8	-1.2	1.44
MIXEDSAMPLE-E-1	83	84.2	1.2	1.44
MIXEDSAMPLE-E-2	83	80.3	-2.7	7.29
MIXEDSAMPLE-F-1	102	102.7	0.7	0.49
MIXEDSAMPLE-F-2	102	100.1	-1.9	3.61

Sum ofSquares	160.97
n-1	21
RMSerror(ppm)	**2.8**
Tcrit(95%)	2.0796
Estimated Uncertainty(95%)(ppm)	**5.8**

At last we are considering only one method with 500 second measurement time for Lumwana work. It was used for further more analysis and validation.

Analysis:

1. All ready prepared standards were analyzed as unknown samples with newly calibrated method for confirmation of performance. The following samples were analyzed and the results were obtained as given in table. This table has actual analysis and Lumwana's Xepos analysis results.

2009_W15

Element Dimension	Method	Th ppm	Th ACTUAL	U ppm	U ACTUAL
BLANK#1	LMC-CONC-Al-FIL-U-Th	25.5	28	39.8	37
MIXEDSAMPLE-D-2	LMC-CONC-Al-FIL-U-Th	61.6	68	94.9	97
TG023-377_A	LMC-CONC-Al-FIL-U-Th	53.1	47	75.9	82
TM006_B	LMC-CONC-Al-FIL-U-Th	24.5	24	36.1	33
TM011_A	LMC-CONC-Al-FIL-U-Th	28.8	29	48.3	54
TM015_A	LMC-CONC-Al-FIL-U-Th	26.8	26	46.5	45

2. Validation of samples analysis:

   As per plan we have to select two samples apart from our calibration standard for covering lower point and higher point. Two samples TG-010 (U-34 ppm and Th -25 ppm) and TM-18-359 (U-80 ppm and Th -50 ppm) wrer selected for validation to the new calibration. The 10 reps were prepared as 10 preparations from the TG-010 and TM-18-359 and analyzed all 20 samples. After this one sample was selected from 10 for both samples and run both for 10 repeated analyses. Main purpose is to find variation between reproducibility (preparation) and repeatability (repeat) from analysis. Following analysis table is indicating the all value of analysis for its validation calculation.

10 PREPARATION OF TG-010 FOR TESTING NEW METHOD- U-Th
2009_W15

Element Dimension	Description	Method	InputDate	Thp pm	U ppm
TG-010-A	10PREPARATION	LMC-CONC-Al-FIL-U-Th	04/07/2009	24.9	36.4
TG-010-B	10PREPARATION	LMC-CONC-Al-FIL-U-Th	04/07/2009	25.9	37.8
TG-010-C	10PREPARATION	LMC-CONC-Al-FIL-U-Th	04/07/2009	27.8	37.4
TG-010-D	10PREPARATION	LMC-CONC-Al-FIL-U-Th	04/07/2009	26.1	37.4
TG-010-E	10PREPARATION	LMC-CONC-Al-FIL-U-Th	04/07/2009	24.1	41.7
TG-010-F	10PREPARATION	LMC-CONC-Al-FIL-U-Th	04/07/2009	24.7	35.5
TG-010-G	10PREPARATION	LMC-CONC-Al-FIL-U-Th	04/07/2009	27.4	40.6
TG-010-H	10PREPARATION	LMC-CONC-Al-FIL-U-Th	04/07/2009	25.4	36.0
TG-010-I	10PREPARATION	LMC-CONC-Al-FIL-U-Th	04/07/2009	23.2	36.7
TG-010-J	10PREPARATION	LMC-CONC-Al-FIL-U-Th	04/07/2009	26.1	40.4
			AVG	**25.56**	**37.99**
			SDR	**1.3417898**	**2.0363939**
			SD	**5.2495691**	**5.3603419**

10 REPEAT ANALYSIS (A REPS.) OF TG-010 FOR TESTING NEW METHOD -U-Th
2009_W15

ElementDimension	Description	Method	InputDate	Th ppm	U ppm
TG-010-A	10REPEATANALY.	LMC-CONC-Al-FIL-U-Th	04/07/2009	24.3	40.0
TG-010-A_R01	10REPEATANALY.	LMC-CONC-Al-FIL-U-Th	04/07/2009	25.6	39.4
TG-010-A_R02	10REPEATANALY.	LMC-CONC-Al-FIL-U-Th	04/07/2009	25.4	38.7
TG-010-A_R03	10REPEATANALY.	LMC-CONC-Al-FIL-U-Th	04/07/2009	25.9	37.0
TG-010-A_R04	10REPEATANALY.	LMC-CONC-Al-FIL-U-Th	04/07/2009	27.6	39.4
TG-010-A_R05	10REPEATANALY.	LMC-CONC-Al-FIL-U-Th	04/07/2009	25.8	38.0
TG-010-A_R06	10REPEATANALY.	LMC-CONC-Al-FIL-U-Th	04/07/2009	26.6	39.0
TG-010-A_R07	10REPEATANALY.	LMC-CONC-Al-FIL-U-Th	04/07/2009	29.3	37.4
TG-010-A_R08	10REPEATANALY.	LMC-CONC-Al-FIL-U-Th	04/07/2009	27.2	40.3
TG-010-A_R09	10REPEATANALY.	LMC-CONC-Al-FIL-U-Th	04/07/2009	27.6	38.9
			AVG	**26.53**	**38.81**
			SDR	**1.3587126**	**1.0153325**
			SD	**5.1214196**	**2.616162**

10 PREPARATION OF TM-018-359 FOR TESTING NEW METHOD U-Th

2009_W15

Element Dimension	Description	Method	InputDate	Th ppm	U ppm
TM018-359-A	10-PREPARATION	LMC-CONC-Al-FIL-U-Th	04/08/2009	41.5	84.9
TM018-359-B	10-PREPARATION	LMC-CONC-Al-FIL-U-Th	04/08/2009	42.5	84.8
TM018-359-C	10-PREPARATION	LMC-CONC-Al-FIL-U-Th	04/08/2009	42.4	92.6
TM018-359-D	10-PREPARATION	LMC-CONC-Al-FIL-U-Th	04/08/2009	46.6	85.7
TM018-359-E	10-PREPARATION	LMC-CONC-Al-FIL-U-Th	04/08/2009	45.2	85.5
TM018-359-F	10-PREPARATION	LMC-CONC-Al-FIL-U-Th	04/08/2009	44.5	85.3
TM018-359-G	10-PREPARATION	LMC-CONC-Al-FIL-U-Th	04/08/2009	42.1	88.3
TM018-359-H	10-PREPARATION	LMC-CONC-Al-FIL-U-Th	04/08/2009	44.4	88.3
TM018-359-I	10-PREPARATION	LMC-CONC-Al-FIL-U-Th	04/08/2009	43.3	89.8
TM018-359-J	10-PREPARATION	LMC-CONC-Al-FIL-U-Th	04/08/2009	42.9	87.2
			AVG	**43.54**	**87.24**
			SDR	**1.5120847**	**2.410892**
			SD	**3.4728632**	**2.7635167**

10 REPEAT ANALYSIS (A REPS.) OF TM-018 -359 FOR TESTING NEWMETHOD -U-Th

2009_W15

Element Dimension	Description	Method	InputDate	Th ppm	U ppm
TM018-359-A	10REPEATANA.	LMC-CONC-Al-FIL-U-Th	04/08/2009	45.1	84.3
TM018-359-A_R01	10REPEATANA.	LMC-CONC-Al-FIL-U-Th	04/08/2009	43.9	84.4
TM018-359-A_R02	10REPEATANA.	LMC-CONC-Al-FIL-U-Th	04/08/2009	42.0	84.2
TM018-359-A_R03	10REPEATANA.	LMC-CONC-Al-FIL-U-Th	04/08/2009	44.8	84.4
TM018-359-A_R04	10REPEATANA.	LMC-CONC-Al-FIL-U-Th	04/08/2009	43.3	85.6
TM018-359-A_R05	10REPEATANA.	LMC-CONC-Al-FIL-U-Th	04/08/2009	43.0	87.7
TM018-359-A_R06	10REPEATANA.	LMC-CONC-Al-FIL-U-Th	04/08/2009	45.5	85.0
TM018-359-A_R07	10REPEATANA.	LMC-CONC-Al-FIL-U-Th	04/08/2009	46.5	84.6
TM018-359-A_R08	10REPEATANA.	LMC-CONC-Al-FIL-U-Th	04/08/2009	42.2	85.7
TM018-359-A_R09	10REPEATANA.	LMC-CONC-Al-FIL-U-Th	04/08/2009	44.6	85.5
			AVG	**44.09**	**85.14**
			SDR	**1.3917255**	**1.0101485**
			SD	**3.156556**	**1.1864558**

Lumwana Copper Concentrate (Al Filter) U and Th Validation Data

Reproducibility:

Sample ID	**Th (ppm)**	**U (ppm)**			**Sample ID**	**Th (ppm)**	**U (ppm)**
TG-010-A	24.9	36.4			TM018-359-A	41.5	84.9
TG-010-B	25.9	37.8			TM018-359-B	42.5	84.8
TG-010-C	27.8	37.4			TM018-359-C	42.4	92.6
TG-010-D	26.1	37.4			TM018-359-D	46.6	85.7
TG-010-E	24.1	41.7			TM018-359-E	45.2	85.5
TG-010-F	24.7	35.5			TM018-359-F	44.5	85.3
TG-010-G	27.4	40.6			TM018-359-G	42.1	88.3
TG-010-H	25.4	36.0			TM018-359-H	44.4	88.3
TG-010-I	23.2	36.7			TM018-359-I	43.3	89.8
TG-010-J	26.1	40.4			TM018-359-J	42.9	87.2
Average	25.6	38.0			Average	43.5	87.2
S.D.	1.41	2.15			S.D.	1.59	2.54
Nominal (Std Adds)	**25**	**34**			Nominal(StdAdds)	**50**	**80**
Bias(ppm)	0.6	4.0			Bias(ppm)	6.5	7.2
Max (95%) Error(Bias+Tinv*S.D.)	**3.7**	**8.8**			Max(95%) Error(Bias +Tinv*S.D.)	**10.0**	**12.9**

Repeatability:

Sample ID	Th (ppm)	U (ppm)			Sample ID	Th (ppm)	U (ppm)
TG-010-A	24.3	40.0			TM018-359-A	45.1	84.3
TG-010-AR01	25.6	39.4			TM018-359-A_R01	43.9	84.4
TG-010-AR02	25.4	38.7			TM018-359-A_R02	42.0	84.2
TG-010-AR03	25.9	37.0			TM018-359-A_R03	44.8	84.4
TG-010-AR04	27.6	39.4			TM018-359-A_R04	43.3	85.6
TG-010-AR05	25.8	38.0			TM018-359-A_R05	43.0	87.7
TG-010-AR06	26.6	39.0			TM018-359-A_R06	45.5	85.0
TG-010-AR07	29.3	37.4			TM018-359-A_R07	46.5	84.6
TG-010-AR08	27.2	40.3			TM018-359-A_R08	42.2	85.7
TG-010-AR09	27.6	38.9			TM018-359-A_R09	44.6	85.5
Average	26.5	38.8			Average	44.1	85.1
S.D.	1.43	1.07			S.D.	1.47	1.06

3. At Lumwana, there are some in-house QC samples which they are using for copper analysis so as per assignment these QC samples have to analyze again for validation of the method. QC samples are four named LMC 806, LMC 808, LMC 817 and CHIB-Cu (Th 443 & U126 ppm)), First three QC samples have no analysis of U and Th. U and Th were analyzed in all QC samples with 10 preparation with first three (UK job ref. no. is 328874/1, 328874/2 and 328874/3) QC samples and four times CHIMB.

QCSAMPLE-LMC 806(328874/1):

2009_W15

Element Dimension	Description	Method	Input Date	Thppm	U ppm
LMC-806-A-1	QCSAMPLE	LMC-CONC-AI-FIL-U-Th	04/09/2009	31.6	50.4
LMC-806-A	QCSAMPLES(8)	LMC-CONC-AI-FIL-U-Th	04/09/2009	27.4	43.6
LMC-806-B-1	QCSAMPLE	LMC-CONC-AI-FIL-U-Th	04/09/2009	27.8	45.3
LMC-806-B	QCSAMPLES(8)	LMC-CONC-AI-FIL-U-Th	04/09/2009	29.5	48.1
LMC-806-C	QCSAMPLES(8)	LMC-CONC-AI-FIL-U-Th	04/09/2009	30.6	50.0
LMC-806-D	QCSAMPLES(8)	LMC-CONC-AI-FIL-U-Th	04/09/2009	30.9	46.6
LMC-806-E	QCSAMPLES(8)	LMC-CONC-AI-FIL-U-Th	04/09/2009	30.6	52.2
LMC-806-F	QCSAMPLES(8)	LMC-CONC-AI-FIL-U-Th	04/09/2009	30.1	44.6
LMC-806-G	QCSAMPLES(8)	LMC-CONC-AI-FIL-U-Th	04/09/2009	29.8	45.3
LMC-806-H	QCSAMPLES(8)	LMC-CONC-AI-FIL-U-Th	04/09/2009	31.1	48
			AVGSDRSD	29.9	47.4
				1.31011	**2.671872**
				4.3758	**5.635672**

QCSAMPLE-LMC808(328874/2)

2009_W15

Element Dimension	Description	Method	Input Date	Thppm	U ppm
LMC-808-A-1	QCSAMPLE	LMC-CONC-Al-FIL-U-Th	04/09/2009	31.1	51.8
LMC-808-A	QCSAMPLES(8)	LMC-CONC-Al-FIL-U-Th	04/09/2009	31.7	54.5
LMC-808-B-1	QCSAMPLE	LMC-CONC-Al-FIL-U-Th	04/09/2009	27.9	54.5
LMC-808-B	QCSAMPLES(8)	LMC-CONC-Al-FIL-U-Th	04/09/2009	35.5	55.1
LMC-808-C	QCSAMPLES(8)	LMC-CONC-Al-FIL-U-Th	04/09/2009	37.7	56.0
LMC-808-D	QCSAMPLES(8)	LMC-CONC-Al-FIL-U-Th	04/09/2009	34.1	49.5
LMC-808-E	QCSAMPLES(8)	LMC-CONC-Al-FIL-U-Th	04/09/2009	29.0	50.2
LMC-808-F	QCSAMPLES(8)	LMC-CONC-Al-FIL-U-Th	04/09/2009	35.0	48.5
LMC-808-G	QCSAMPLES(8)	LMC-CONC-Al-FIL-U-Th	04/09/2009	33.0	55.1
LMC-808-H	QCSAMPLES(8)	LMC-CONC-Al-FIL-U-Th	04/09/2009	32.7	59.0
			AVGSDRSD	**32.8**	**53.4**
				2.83586	**3.135857**
				8.65383	**5.870193**

QC SAMPLE- LMC817(328874/3):

2009_W15

Element Dimension	Description	Method	Input Date	Thppm	U Ppm
LMC-817-A-1	QCSAMPLE	LMC-CONC-Al-FIL-U-Th	04/09/2009	38.1	63.5
LMC-817-B-1	QCSAMPLE	LMC-CONC-Al-FIL-U-Th	04/09/2009	39.7	61.3
RM-817A	QC(Sample8)	LMC-CONC-Al-FIL-U-Th	04/09/2009	42.9	61.6
RM-817B	QC(Sample8)	LMC-CONC-Al-FIL-U-Th	04/09/2009	41.1	59.9
RM-817C	QC(Sample8)	LMC-CONC-Al-FIL-U-Th	04/09/2009	37.5	68.3
RM-817D	QC(Sample8)	LMC-CONC-Al-FIL-U-Th	04/09/2009	41.0	61.9
RM-817E	QC(Sample8)	LMC-CONC-Al-FIL-U-Th	04/09/2009	40.2	60.2
RM-817F	QC(Sample8)	LMC-CONC-Al-FIL-U-Th	04/09/2009	42.1	65.0
RM-817G	QC(Sample8)	LMC-CONC-Al-FIL-U-Th	04/09/2009	42.7	64.6
RM-817H	QC(Sample8)	LMC-CONC-Al-FIL-U-Th	04/09/2009	41.6	65.2
			AVGSDRSD	**40.7**	**63.2**
				1.73519	**2.510478**
				4.26442	**3.97542**

QC SAMPLE–CHIB-CU:

2009_W15

Element Dimension	Description	Method	Input Date	Thppm	U ppm
CHIB-Cu_A	QCSAMPLE	LMC-CONC-Al-FIL-U-Th	04/09/2009	441.8	127.5
CHIB-Cu_B	QCSAMPLE	LMC-CONC-Al-FIL-U-Th	04/09/2009	443.5	124.4
CHIB-CU-A	QCSAMPLE	LMC-CONC-Al-FIL-U-Th	04/09/2009	446.6	124.1
CHIB-CU-B	QCSAMPLE	LMC-CONC-Al-FIL-U-Th	04/09/2009	442.3	126.6
			AVG	443.55	125.65
			SD	1.86615	1.439618
			RSD	0.42073	1.145737

4. Lumwana management submitted one sample SWK-SC0001 to Lab for analysis as unknown with SGS packing label. To support the analysis team and for confirmation of our new method, experiment was conducted to analyze the SWK–SC001,SGS marked sample. The authors like to share these results also in the report.

2009_W15

Element Dimension	Description	Method	Input Date	Th ppm	U Ppm
SWK-SC001-A	SGSSAMPLE	LMC-CONC-Al-FIL-U-Th	04/09/2009	30.1	52.9
SWK-SC001-A	SGSSAMPLE	LMC-CONC-Al-FIL-U-Th	04/09/2009	30.8	50.4
			AVG	30.5	51.7

5. Efforts were made to find the homogeneity for Lumwana samples and after some analysis, further preparation for analysis of samples. Due to this process and communication with team at Lumwana, we did some exercise for sample TM048-2079,but results were not found satisfactory. Meanwhile , we communicated for same analysis with new method for U and Th. So as per this plan also, 10 preparations of the TM048-2079 were prepared for analysis. All 10 samples with new method were analyzed and results were very good and it was up to satisfactory level for us. Analysis report for TM048-2079 was presented in following table .This analysis with10 preparations and comparison to old method analysis got the SD 3.8 ppm with new method where old method was SD 10 ppm.

10 PREPARATION OF TG-048-2079 FOR COMPARISON WITH NEW METHOD-U-Th
2009_W15

Element Dimension	Description	Method	Input Date	Thppm	U ppm
TG-048-2079-A	10PREPARATION	LMC-CONC-Al-FIL-U-Th	04/08/2009	45.6	60.3
TG-048-2079-B	10PREPARATION	LMC-CONC-Al-FIL-U-Th	04/08/2009	43.9	61.7
TG-048-2079-C	10PREPARATION	LMC-CONC-Al-FIL-U-Th	04/08/2009	45.2	63.5
TG-048-2079-D	10PREPARATION	LMC-CONC-Al-FIL-U-Th	04/08/2009	46.0	59.9
TG-048-2079-E	10PREPARATION	LMC-CONC-Al-FIL-U-Th	04/08/2009	47.0	66.8
TM048-2079-F	10PREPARATION	LMC-CONC-Al-FIL-U-Th	04/08/2009	44.9	58.9
TM048-2079-G	10PREPARATION	LMC-CONC-Al-FIL-U-Th	04/08/2009	44.5	69.1
TM048-2079-H	10PREPARATION	LMC-CONC-Al-FIL-U-Th	04/08/2009	44.0	57.4

TM048-2079-I	10PREPARATION	LMC-CONC-Al-FIL-U-Th	04/08/2009	42.1	58.4
TM048-2079-J	10PREPARATION	LMC-CONC-Al-FIL-U-Th	04/08/2009	42.7	66.0
			AVGSDRSD	**44.6** **1.410284** **3.16278**	**62.2** **3.773857** **6.067295**

6. Lumwana Lab has some disputed samples with Chambeshi copper smelter. Samples were analyzed with old method for U. Due to dispute samples we analyzed next with our new method and compared both analysis. During this analysis, we found that some samples were changed during the preparation or weighing, We analyzed it again and confirm its results. But it is requiring to great care when the disputed samples were analyzing. We like to share the both results here in the report for comparison of old and new method.

CHAMBESHI COPPER SMELTER DISPUTED SAMPLE ANALYSIS WITH OLD METHOD

2009_W14 Element Dimension	Description	Method	Input Date	U %	Avg.ppm
9043	F/A	Lumwana Conc Uranium	04/05/2009	0.00798	**82.9**
9043	Chambeshi	Lumwana Conc Uranium	04/05/2009	0.00860	
9044	F/A	Lumwana Conc Uranium	04/05/2009	0.00846	**80.4**
9044	Chambeshi	Lumwana Conc Uranium	04/05/2009	0.00762	
9045	F/A	Lumwana Conc Uranium	04/05/2009	0.00881	**84.3**
9045	Chambeshi	Lumwana Conc Uranium	04/05/2009	0.00804	
9046	F/A	Lumwana Conc Uranium	04/05/2009	0.00675	**60.1**
9046	Chambeshi	Lumwana Conc Uranium	04/05/2009	0.00526	

CHAMBESHI COPPER SMELTER DISPUTED SAMPLE ANALYSIS WITH NEW METHOD

2009_W15 Element Dimension	Description	Method	Input Date	Thppm	U ppm
9043A	Dilip	LMC-CONC-Al-FIL-U-Th	04/09/2009	42.8	71.4
9043B	Dilip	LMC-CONC-Al-FIL-U-Th	04/09/2009	44.0	74.9
			Avg	**43.4**	**73.2**

9044A	Dilip	LMC-CONC-Al-FIL-U-Th	04/09/2009	41.6	74.8
9044B	Dilip	LMC-CONC-Al-FIL-U-Th	04/09/2009	39.9	71.8
			Avg	**40.8**	**73.3**
9046A	Dilip	LMC-CONC-Al-FIL-U-Th	04/09/2009	41.7	73.0
9046B	Dilip	LMC-CONC-Al-FIL-U-Th	04/09/2009	40.4	70.0
			Avg	**41.1**	**71.5**
9045A	Dilip	LMC-CONC-Al-FIL-U-Th	04/09/2009	39.4	60.5
9045B	Dilip	LMC-CONC-Al-FIL-U-Th	04/09/2009	40.4	56.5
			Avg	**39.9**	**58.5**

7. After successful setup of new method, Lab starts to use it as routine work for U and Th analysis. They analyze some process samples and transport samples .Analyze routine transport samples analysis. Routine analysis is here to understand the level of Th and U from the process and copper concs.

2009_W15

Element Dimension	Description	Method	Input Date	Thppm	U ppm
9189		LMC-CONC-Al-FIL-U-Th	04/08/2009	24.9	32.1
9194	07Hrs	LMC-CONC-Al-FIL-U-Th	04/08/2009	27.1	30.3
9201	11Hrs	LMC-CONC-Al-FIL-U-Th	04/08/2009	35.6	39.2
9204	15HRS	LMC-CONC-Al-FIL-U-Th	04/08/2009	40.7	63.8
9215	D/Shift08	LMC-CONC-Al-FIL-U-Th	04/09/2009	33.4	38.1
9216	ConcShed	LMC-CONC-Al-FIL-U-Th	04/09/2009	29.7	41.4
9217	ConcShed	LMC-CONC-Al-FIL-U-Th	04/09/2009	30.9	35.6
9220	19HRS	LMC-CONC-Al-FIL-U-Th	04/09/2009	24.6	45.7
9221	ConcU/F	LMC-CONC-Al-FIL-U-Th	04/09/2009	31.2	52.8
9224	23HRS	LMC-CONC-Al-FIL-U-Th	04/09/2009	24.5	51.1
9243	ConcU/F	LMC-CONC-Al-FIL-U-Th	04/09/2009	32.8	38.6
9263	03Hrs	LMC-CONC-Al-FIL-U-Th	04/09/2009	33.4	35.2
CC1040902426	Transports	LMC-CONC-Al-FIL-U-Th	04/09/2009	36.5	67.4
CC1040902427	Transports	LMC-CONC-Al-FIL-U-Th	04/09/2009	35.4	51.2
CC1040902428	Transports	LMC-CONC-Al-FIL-U-Th	04/09/2009	34.5	45.4
CC1050902429	Transports	LMC-CONC-Al-FIL-U-Th	04/09/2009	37.5	78.8
CC1050902430	Transports	LMC-CONC-Al-FIL-U-Th	04/09/2009	35.0	56.2
CC1050902431	Transports	LMC-CONC-Al-FIL-U-Th	04/09/2009	40.0	70.0
CC1050902432	Transports	LMC-CONC-Al-FIL-U-Th	04/09/2009	39.9	60.9
CC1050902435	Transports	LMC-CONC-Al-FIL-U-Th	04/09/2009	33.7	54.8
CC1060902437	Transports	LMC-CONC-Al-FIL-U-Th	04/09/2009	39.9	66.4
CC1060902438	Transports	LMC-CONC-Al-FIL-U-Th	04/09/2009	31.4	44.4
CC1060902439	Transports	LMC-CONC-Al-FIL-U-Th	04/09/2009	30.4	41.8
CC1060902440	Transports	LMC-CONC-Al-FIL-U-Th	04/09/2009	34.1	45.9
KC054/2441	Transport	LMC-CONC-Al-FIL-U-Th	04/09/2009	29.8	45.0
KC054/2442	Transport	LMC-CONC-Al-FIL-U-Th	04/09/2009	32.6	46.8
KC054/2443	Transport	LMC-CONC-Al-FIL-U-Th	04/09/2009	34.2	51.3

KC054/2444	Transport	LMC-CONC-Al-FIL-U-Th	04/09/2009	34.8	54.0
KC054/2445	Transport	LMC-CONC-Al-FIL-U-Th	04/09/2009	31.9	47.2
KC054/2446	Transport	LMC-CONC-Al-FIL-U-Th	04/09/2009	41.8	67.1
KC054/2447	Transport	LMC-CONC-Al-FIL-U-Th	04/09/2009	41.9	67.0
KC054/2448	Transport	LMC-CONC-Al-FIL-U-Th	04/09/2009	41.3	68.8
KC054/2449	Transport	LMC-CONC-Al-FIL-U-Th	04/09/2009	40.9	69.6
KC054/2450	Transport	LMC-CONC-Al-FIL-U-Th	04/09/2009	39.9	65.0

REQUIREMENTS FOR USE OF XEPOS LOW URANIUM ME THOD FOR ANALYSIS OF ORES / FEEDS

Scope

The Xepos low uranium method has a working calibrated range of 5 - 50ppm. Its development has been carried out to facilitate more precise and accurate analysis of uranium in Lumwana copper ores, plant feeds and tails in this range, particularly at concentrations of 5 – 20 ppm where precision is critical to process control. The method should not be used to analyze uranium in samples other than Lumwana copper ores / plant feeds and tails, or samples with uranium concentration >50ppm.

Application of Method

- All samples should be analyzed, as per existing requirements, using the “Geologicals” method which measures Cu, Co, Fe, S, and U. This analysis is performed on a single replicate pellet.
- If the uranium result obtained from the “Geologicals” method is less than 30ppm the uranium must be re-analyzed using the “Low Uranium” method
- Prepare a second pellet of the test sample
- Measure both pellets using the “Low Uranium” method
- Report the average uranium concentration from the duplicate results, conditional on acceptable Quality Control performance, as below.

Quality Control

Quality control is by measurement of in-house QC samples. The QC samples should be measured at the beginning of each shift and assay results only accepted if the QC results obtained are within the specified tolerances. Details of the QC samples and tolerances are as follows:

QC Sample ID	Nominal U (ppm)	Minimum Tolerance U (ppm)	Maximum Tolerance U (ppm)
1	9.6	7.6	11.6
2	5.9	3.9	7.9
3	30.0	28.0	32.0

Any failure against the above QC tolerances should be referred to a member of the Laboratory Management team and the necessary corrective actions should be taken prior to performing any further analysis on the affected instrument(s).

Precision between duplicate measurements should be assessed for all analyses. Difference between duplicates should be no greater than 4ppm. An assessment should be made of the validity of any duplicate results with a greater spread than this and extra replicates prepared and measured as necessary.

CALIBRATION STANDARDS FOR LUMWANA URANIUM AND THORIUM XEPOS APPLICATION

Standard ID	Reference	U (ppm)	Th (ppm)
Copper Conc STD 02	100043/3	15	-
Copper Conc STD 04	100045/3	9	-
Copper Conc STD 07	100049/3	20	-
Copper Conc STD 11	100053/3	28	-
Copper Conc STD 15	TG027-377	82	47
Copper Conc STD 20	TG015	45	26
Copper Conc STD 23	**TM006**	33	24
Copper Concs STD 24	TM011	54	29
Mixed Sample Blank	BLANK	37	28
Mixed Sample A	**SPIKE A**	47	33
Mixed Sample B	SPIKE B	62	43
Mixed Sample C	SPIKE C	77	53
Mixed Sample D	SPIKE D	97	68
Mixed Sample E	SPIKE E	117	83
Mixed Sample F	SPIKE F	136	102

U Calibration range: 9 – 136ppm
Th Calibration range: 24 – 102ppm

DISCUSSION

Central African country North Zambia has some Uranium and Copper occurrence together as U3O8 and Tho 2 together with copper minerals. Lumwana mine is producing copper concentrate from minerals with concentrating procedure and Uranium and Thorium in ore level up to 100 ppm and 100 ppm in final copper concentrate. It has been found that low level Uranium and Thorium are accruing in African Base metals ores and minerals. The present study describes efforts to develop a methodology to analyze Uranium and Thorium by ED XRF. Studies have been conducted for calibration for Uranium and Thorium elements analysis in copper concentrates by XEPOS (Spectro - Energy Dispersive X-Ray Fluorescence) at copper mine for Lumwana Mining Company Zambia. The advantages of the above novel method are summarized as under

- An elemental analyzer designed for demanding applications – the SPECTRO XEPOS energy dispersive X-ray fluorescence (ED-XRF) spectrometer redefines XRF analysis with exceptional new levels of performance

- Measure lower than ever and faster than ever: Adaptive excitation, advanced tube design and high-count throughput detection system result in outstanding low detection limits for a wide range of elements at even shorter measurement times (up to a factor 2)
- Improved accuracy based on optimized spectra handling: Master the unknown using the benchmark in ED-XRF screening, SPECTRO's TurboQuant II application package for the unprecedented ability to analyze unknown samples, whether they are liquids, solids or powders – whether they are tree leaves, plastics, oil, granite or glass…
- Application range extended to multilayer analysis, up to 8 layers and up to 55 elements

The SPECTRO XEPOS spectrometer represents an analytical performance in a class by itself in energy dispersive X-ray fluorescence (ED-XRF) technology. It provides breakthrough advances in multi-elemental analysis of major, minor, and trace element concentrations. New developments in signal processing and spectra handling deliver remarkable gains in precision and accuracy.
The amazing SPECTRO XEPOS excels at critical tasks from rapid screening analysis to precise product quality control. Apply it for at-line processing in a variety of industries, for geology and mining, for environmental and waste monitoring, and for research and academia.
Different versions maximize performance for selected elemental groups in specific matrices. An innovative X-ray tube and unique new adaptive excitation technology furnish the highest possible sensitivity, optimized to target elements of choice.

It is difficult task to view Uranium and Thorium L-Alpha peak due to base metal satellite peak, and high background , it is required to low down noise peak and base metals Iron and satellite peak to view U-Th peak, therefore external Aluminum filter as secondary target is used to remove all unnecessary peak and noise during experimentation. The XEPOS low uranium method has a working calibrated range of 5 - 50ppm. Its development has been carried out to facilitate more precise and accurate analysis of uranium in Lumwana copper ores, plant feeds and tails in this range, particularly at concentrations of 5 – 20 ppm where precision is critical to process control. The method should not be used to analyze uranium in samples other than Lumwana copper ores / plant feeds and tails, or samples with uranium concentration >50ppm. Quality control is by measurement of in-house QC samples. The QC samples should be measured at the beginning of each shift and assay results only accepted if the QC results obtained are within the specified tolerances. Any failure against the above QC tolerances should be referred to a member of the Laboratory Management team and the necessary corrective actions should be taken prior to performing any further analysis on the affected instrument(s). Precision between duplicate measurements should be assessed for all analyses. Difference between duplicates should be no greater than 4ppm. An assessment should be made of the validity of any duplicate results with a greater spread than this and extra replicates prepared and measured as necessary.

It may be emphasized that the study of uranium and thorium occurrences is required in establishing a data base which can be used by health and safety personnel, government agencies in planning impact studies, uranium geologists, mineralogists, and the general public. Mineral resources play a major role and act as a basic ingredients to meet energy, defence ,space research, industrial, civilian and technological requirements of a nation. Uranium exploration plays a pivotal role in meeting global energy demands and advancing nuclear technology.

The exploration, mining, extraction and utilization of these minerals are guided by national goals and perspectives and closely integrated with the overall strategy of the country's economic development . To reduce import dependency, it is essential to discover large tonnage high grade deposits so as to secure the sustained supply-chain of industrial mineral resources.

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