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QUANTIFICATION OF UNCERTAINTY ASSOCIATED WITH 4E ASSAY RESULTS FROM REVERSE CIRCULATION SAMPLING OF THE MIDDLE GROUP SEAMS AT THARISA MINE.

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DECLARATION

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ABSTRACT

This research explores the sources of discrepancy between platinum, palladium, rhodium and gold (4E) g/t in Reverse Circulation (RC) drilling samples and Diamond Drillhole (DDH) samples, ultimately defining the applicability of RC drilling on the narrow seams of the Bushveld Middle Group at Tharisa Mine. The research also quantifies the sampling and analytical uncertainty associated with the 4E g/t grades in RC samples through measurement and statistical approach.

Twin-hole drilling is used where RC holes are drilled within a 10m radius of the DDH to understand and to demonstrate the difference between the seam intersections of RC sampling in relation to DDH. Sampling uncertainty was quantified by using replicate samples. Analytical method uncertainty was quantified by using Quality Assurance Quality Control (QAQC) data, blank samples, certified reference materials (CRMs) and duplicate samples. Two-way laboratory diamond drillholes (DDH) check samples and two-way laboratory RC check samples were used to determine the accuracy and repeatability of the analytical methods.

The research identified two main sources of uncertainty in the 4E analyses;

- Sampling method errors as the highest contributor to the uncertainty in the 4E assay results.
- The difference in the analytical methods contributes to the difference in the 4E grades in RC and DDH.

The identified issues can be resolved by re-designing the sampling method and procedures under the guidance of *Theory of Sampling* (TOS) principles. Analytical methods and procedures need to be improved for accurate reporting of assay results.

DEDICATION

In loving memory of my father Moyahabo Edward Ramusi 09/1944 to 02/2012. This report is also dedicated to my Mother Mampasa Kate Ramusi whose prayers has got me to where I am today. Lastly to Khutso Ramphisa, my son, anything is possible through hard work and determination.

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σ	Standard deviation
%	Percentage
m	Metre
g/t	grams per tonne
kg	Kilogram
ppm	parts per million
ppb	parts per billion
df	degree of freedom
$\overline{X}$	mean

LIST OF ACRONYMS

3E	Summation of Pt, Pd and Au
4E	Summation of Pt, Pd, Au and Rh
Pt	Platinum
Au	Gold
AMIS	African Minerals standards
DDH	Diamond drillholes samples
ICP	Inductive Coupled Plasma
ICP-OES	Inductive Coupled Plasma, optical emission Spectroscopy
CRM	Certified reference material
CV	Co-efficient of Variation
n	Number of observations
NiS	Nickel sulphide
NQ	Core size 47.6mm for diamond drilling
Pd	Palladium
QAQC	Quality Assurance and Quality Control
RC	Reverse Circulation
Rh	Rhodium
Sop	Standard operating procedure
XRF	X-ray fluorescence

1 INTRODUCTION

The credibility of decisions relies on understanding the uncertainty of measurement results, which can be categorized into two components; uncertainty derived from sampling a target and using samples to represent the whole target, and uncertainty derived from the analytical process. Underestimating measurement uncertainty can lead to erroneous decisions with significant financial consequences. Effective procedures are essential for estimating uncertainties from all parts of the measurement process, including sampling, physical preparation, material heterogeneity, and sample analysis.

The main purpose of sampling is to accurately and precisely estimate the quantity and quality of the mineralisation. Incorrect sampling can lead to sampling uncertainty and sample measurement errors (Dominy, Esbensen and Purevgerel, 2020) which, in turn, lead to financial losses. Measurement uncertainty is a term used in analytical chemistry for quality assurance and quality control (QAQC) purposes. In mining, the term ‘uncertainty’ is often associated with quantifying the risk associated with estimation of grades by simulation methods.

The ‘uncertainty’ of a measurement defines the magnitude of error or deviation from the true value; the interval which quantifies the degree of accuracy of the measurement. Scientific uncertainty is a measurable variability in the data (Carpi & Egger, 2008). In the context of this research, ’uncertainty’ refers to the uncertainty associated with the 4E g/t values from RC drilling.

This study investigates sampling and analytical uncertainties associated with reported 4E grades from Reverse Circulation drilling (RC) sampling of the Middle Group seams at Tharisa Mine using different methodologies.

Tharisa Minerals produces platinum group elements (PGE) concentrates as well as metallurgical and chemical grade chrome concentrates from a shallow open pit mine (Tharisa, 2020), PGE refers to a group of metals i.e. platinum, palladium, rhodium, osmium, ruthenium, and iridium and gold. The ore mining design cut at Tharisa is defined by lithology rather than grade, although grade is critical for resource and grade control estimation. The deposit is sampled using diamond drilling (DDH), reverse circulation drilling (RC) and test holes (blast holes). Sampling assay values from RC, DDH and test holes are mostly used for the estimation process.

Assay results from diamond drill holes were used for grade estimation in the resource model, whereas estimation for grade control is done through a combination of reverse circulation (RC) drilling, test holes and DDH assay results.

1.1 Research objectives

The objective of this research is to identify the sources of discrepancies between RC sampling and DDH sampling 4E values and evaluate whether the RC sampling method accurately define the grades in the Middle Group seams at Tharisa Mine. The detailed objectives are as follows:

- Quantifying the magnitude of the differences in grades between RC drilling and DDH in each of the mining seams through hypothesis testing;
- Investigating the appropriateness of sampling RC chips for (4E) grade values in the narrow seams of the Middle Group;
- Identifying the sources of bias and errors in the current protocols and procedures;
- To evaluate the suitability of RC sampling information in the grade prediction processes or whether it should be used for indicative purpose.

1.1.1 Location

The mine is located 35km east of Rustenburg and 120km north west of Johannesburg (See Figure 1).

Figure 1: Map showing the location of the Tharisa Mine. (Lomberg, 2016).

1.2 Geology of the Area

The Bushveld Complex comprises of mafic rocks of the Rustenburg Layered Suite, divided into five zones; Marginal Zone, Lower Zone, Critical Zone, Main Zone and Upper Zone. The thickness of the Marginal Zone varies from zero to hundreds of meters along the basal contact of the complex. The Marginal Zone comprises of mostly norites, quartz, clinopyroxenes, biotite and hornblende, with xenoliths from country rock. The Lower Zone comprises mostly of dunites, pyroxenites and hartzburgite. The thickness varies from 900m to 1600m. The Critical Zone is characterized by the cyclic layering of chromitite within pyroxenites, olivine rich rocks and plagioclase rich rocks subdivided into two zones; the lower critical zone and the upper critical zone (Viljoen, 2016).

- The two uppermost units of the Critical Zone are the Merensky and Bastard units. The former is also of great economic importance as it contains at its base the PGE-bearing Merensky Reef, a feldspathic pyroxenitic assemblage with associated thin chromitite layers that rarely exceed 1m in thickness. The top of the Critical Zone is generally

defined as the top of the robust anorthosite (the Giant Mottled Anorthosite) that forms the top of the Bastard cyclic unit.

- The Critical Zone may be subdivided into the Upper and Lower Critical Zones based on the last appearance of cumulus feldspar. This boundary is considered to be between the upper and middle group chromitite layers;
- Most economically viable reserves of platinum group elements and chromitite are hosted within the Critical Zone of the Bushveld Complex;
- Above the Critical Zone is the well-developed Main Zone consisting of norites and gabbro norites;
- Overlying the Main Zone is the Upper Zone, the boundary between the Upper Zone and Main Zone is marked by the appearance of cumulus magnetite.

Tharisa Mine is underlain by the Middle Group (MG) and Upper Group (UG) chromitite seams of the Upper Critical Zone of the Bushveld complex (Figure 1). The chromitite layers of the MG outcrop on the Tharisa property, striking east-west at a dip of 12- 15 degrees. The Middle Group is made up of six chromitite layers; MG0, MG1, MG2, MG3, MG4 and UG1. MG0 consists mostly of multiple thin lenses of chromite and is currently not mined. Above MG0 is pyroxenite interburden overlain by MG1. MG1 is well developed with higher concentrations of chromite and lower concentrations of PGEs. Above MG1 is a pyroxenite interburden overlain by MG2 which is subdivided into 2A, 2B and 2C. Between 2A and 2B lies a chromitite stringer with a high concentration of PGEs, this stringer is termed the PGE Marker and is mined as part of the MG2 package. MG3 is a well-developed chromitite layers bounded by chrome disseminated Norite above and banded anothorsite below MG4 is subdivided into three layers; MG4 (0), MG4 and MG4A. MG4 (0) and MG4 have a higher concentration of PGEs. UG1 is subdivided into two layers UG1A and UG1B, the two layers are separated by pyroxenite interburden. MG4A and MG1 seams are currently being mined and processed at the Tharisa Genesis plant due to the low PGE content whereas MG4 and MG4 (0), MG2 and MG3 are mined and processed at the Tharisa Voyager plant due to the higher PGE content.

Figure 2 presents a stratigraphic column of the lithological units at Tharisa showing the average thicknesses and grades of the chromitite layers and the interburden waste.

General Stratigraphy and Average Rock Data for Tharisa Mine. *Updated: 12 June 2019*

Unit	Width m	Layer	Width m	RD	% Cr_2O_3	4E g/t	Cr/Fe
Topsoil	1.50		1.50	*1.90*			
Overburden waste		Norite	18 - 55	2.89 (est.)			
		Pyroxenite	1 - 10	*3.11* (est.)			
UG1	**2.62**	UG1B	1.07	3.78	24.02	0.60	1.12
		Middling	0.55	3.14	7.00		
		UG1A	1.00	3.59	19.10	0.55	1.12
Overburden waste	18 - 165	Anorthosite	1 - 36	*2.77* (est.)			
		Norite	16 -163	2.89			
		Pyroxenite	1 - 6	3.11			
MG4A	**1.49**	MG4A	1.49	3.67	**25.07**	**0.68**	1.11
Interburden waste	4.19	Pyroxenite	4.19	3.32	**4.98**	**0.14**	
MG4	**2.90**	MG4	1.55	3.72	**28.28**	**1.76**	1.22
		Middling	0.79	3.21	**15.18**	**1.04**	0.99
		MG40	0.56	3.78	**29.00**	**1.31**	1.21
Interburden waste	9.68	Norite	9.68	2.95	2.70	0.20	
MG3	**4.19**	3D	1.61	3.08	**5.43**	**0.75**	
		MG3	1.41	3.64	**25.66**	**1.84**	1.16
		3ZEB	1.17	3.01	**5.14**	**0.54**	
Interburden waste	3.84	Anorthosite Marker	3.84	2.77	3.13	0.19	
MG2	**5.04**	MG2C	0.63	3.77	**28.89**	**2.07**	1.20
		PGEM+	0.86	3.27	**5.02**	**0.96**	
		PGEM	0.53	3.58	**16.21**	**2.66**	0.87
		PGEM-	1.03	3.28	**6.96**	**0.69**	
		MG2B	0.57	3.86	**31.49**	**1.27**	1.24
		Pyroxenite	0.82	3.34	**11.95**	**0.64**	
		MG2A	0.60	3.84	**29.09**	**2.01**	1.20
Interburden waste	11.03	Pyroxenite	11.03	3.24	**4.53**	**0.21**	
MG1	**1.21**	MG1	1.21	3.83	**31.92**	**0.64**	1.30
Interburden waste	3.70	Pyroxenite	*0.5 -2.0*	3.39			
		Pt Marker	*0.1 - 0.5*		*10 - 25*	*1.0 - 3.0*	
		Pyroxenite	*0.6 -1.5*	3.39			
MG0	***0.58***	MG0	0.58	3.75	**26.31**	**0.87**	1.19
		Pyroxenite					

Data for Width, Cr & 4E for **Total Mine** (from 2013 CPR, p86). Data from 2008 CPR (ave East).

Data for RD (from 2013 CPR) (*estimates*). UG1 data from 2012 Estimate (ave East).

Data for UCS (from 2007 Rocklabs & 2013 OHMS Reports). 2019 SLR Waste Rock Study

(NOTE: Diagram not to scale)

Figure 2: General stratigraphy of Tharisa Mine. (Steenekamp, 2019)

1.3 Background

Exploration at Tharisa Mine was initiated in the early 1900s in a form of trenching and small pits. Earlier mineral resource estimate in Tharisa was mostly based on the 2007 drilling campaign conducted by Thari managed by Coffey mining (Lomberg, 2016).

The 2007 initial exploration campaign used DDH on a 250m x 250m grid, which was later supplemented using infill DDH on a 100m x 100m grid. RC drilling was then introduced on a 17m x 17m grid spacing to infill the 100m x 100m grid, increasing the sampling resolution. The location of RC holes in relation to the DDH is indicated in Figure 3.

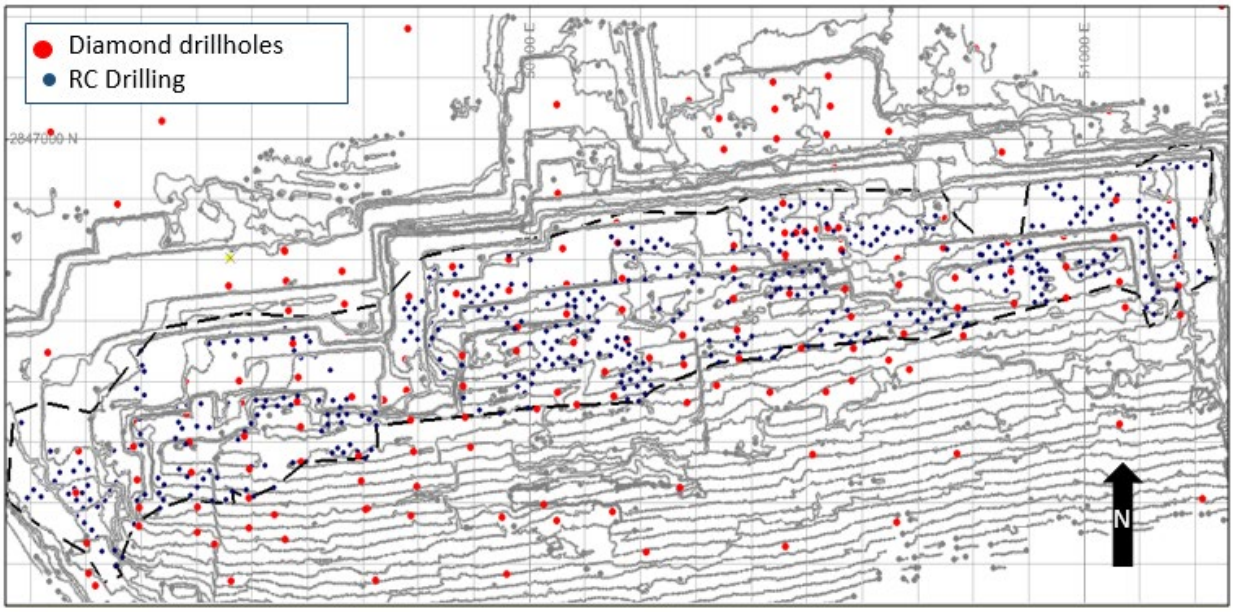

Figure 3: Plan indicating the location of RC and DDH

1.3.1 Test-hole sampling

Since the year 2016 the ore body at Tharisa Mine is sampled using DDH, test hole drilling and RC drilling. Test-holes are drilled to confirm the top reef and bottom reef contacts where there is poor RC coverage. Test-hole samples are taken from the heap of chips generated by a percussion drill rig, using a handheld flat shovel placed next to the drill-string before drilling commences to collect the sample. Test hole samples are taken to the bottom of the seam that is planned to be blasted and used in grade control model construction and estimation of chrome grades.

1.3.2 Diamond Drilling

DDH holes were drilled using NQ (47.6mm diameter) drill rods to a various depth, with an average core recovery of 98%. Half core samples were cut at 20cm to 30cm intervals depending on the lithological boundaries, with 10cm as the minimum allowable sample length. Half core samples from the DDH, at an average sample mass of 750g, were then analysed by Intertek laboratory using x-ray fluorescent (XRF) for oxides. Fire assay by Nickel Sulphide collector (NiS), with the use of inductively coupled plasma mass spectrometry finish (ICP-MS), was used to analyse the PGEs. A 50 g aliquot was used to analyse for PGEs and Gold. The platinum, palladium, gold and rhodium assay results from DDH were added together to give the so-called 4E grades.

1.3.3 RC Sampling

RC samples weighing approximately 1.25 kg and consisting of broken rock cuttings were collected at 50 cm intervals from a 125 mm diameter hole. Drilling was paused at every 50 cm interval for sample collection and compressed air was used to clean the cyclone after every sample collection. The sample mass of 1.25 kg is variable, and though the drill rig operator does their best to stop the drill at 0.5m intervals, there it is challenging to consistently manage to collect a 0.5m length for all samples. Quite often, the lithological contacts in RC samples lie anywhere within 50 cm interval, making it is impossible to accurately define lithological contacts and actual seam thickness from RC samples.

RC samples are sent to the internal laboratory where inductively-coupled-plasma with optical-emission spectrometry was used to analyse for chromium (III) oxide, iron (II) oxide and silicon dioxide. Fire assay by lead collection with a gravimetric finish (Pb collection) was used to analyse for 4E on 120 g aliquot, as the quality of the 4E assays depends heavily on the quality of the fusion. Typically, fire assay generally uses 20-50 g aliquots, but for this material a larger sample mass is required due to the lower PGE grades ranging from 0 to 5 g/t in the ore body.

1.3.4 Grade control process

Mining block grades are estimated from the grade control model. Estimated mining block grades are then assigned to run of mine stockpile grades. As the stockpile is built, samples are taken using a hand-held XRF machine and the XRF readings are used for stockpile grade estimation. The grades assigned to stockpiles are then used for ore blending to achieve the plant feed grade. It is important to know the expected grades of the ore material delivered to

the run of mine stockpiles for blending and processing purposes to ensure optimal extraction of the ore minerals.

Figure 4 illustrates the grade control process in which a combination of DDH samples, RC samples, test hole samples, and face samples are used in the construction of the grade control model.

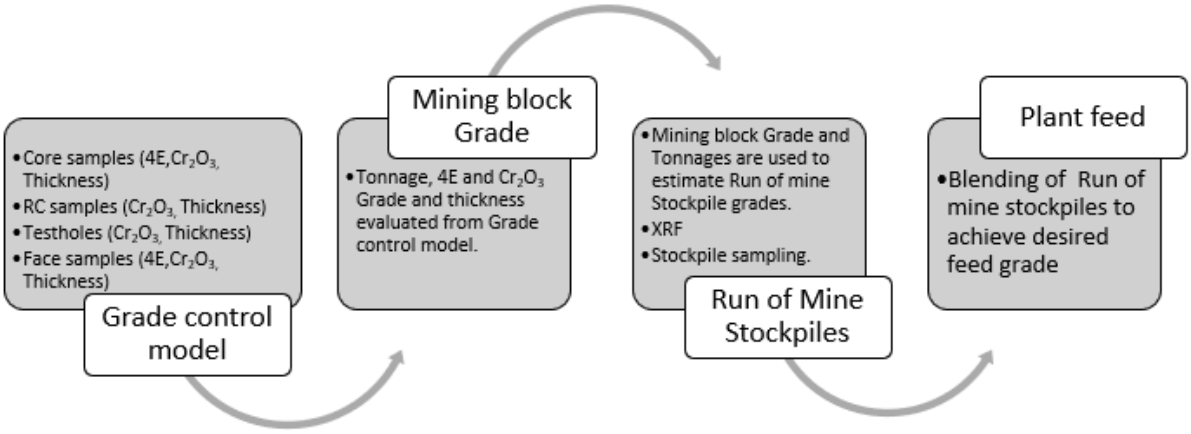

Figure 4: Grade control flow process

1.3.5 Uncertainty ("RC versus DDH Sampling and Assaying")

Historically, no evaluation was carried out to quantify the degree of uncertainty in the 4E values obtained from RC drilling and sampling. Reported 4E assay results from RC samples are generally lower than the diamond drill core sample assay results. This considered to be a result of dilution due to contamination as there is no means of determining where the contact of the seam is when using RC as a sampling technique. Currently, only core sample assay results from DDH are used for 4E grade estimation as 4E assay of RC drilling does not appear to be representative of the actual 4E values in the resource. 4E assays results were captured and stored whilst research is ongoing on the feasibility of finding a methodology of correlating the data to the DDH data. It is this aspect of RC sampling and representativity which is the focus of attention in the quantification of uncertainty associated with 4E assay results from reverse circulation sampling of the Middle Group seams at Tharisa Mine. RC samples are used in grade control modelling for thickness and chrome grade estimations.

1.4 Significance of the study

The thrust of this study is to highlight the financial implications of collecting “unusable data” for assaying. It is important for decision makers at Tharisa to understand the confidence level of the data that they are using in their decision making and align it to the associated risk.

1.5 The purpose of the study

Assay results are a critical input into the major decisions in the mining and processing activities in the mines (Minnitt,2007). In the majority of mines, the decision of where to send mined material, to the waste dump, low-grade stockpile, or high-grade ore stockpiles, is determined by the sample grades

The purpose of the study is to quantify and identify sources of uncertainty associated with 4E assay results from reverse circulation sampling of the middle groups at Tharisa Mine through an analysis of the data sets from the different sampling methods.

1.6 Research question and hypotheses

The study will answer the following hypotheses:

- Variances between 4E values in diamond drill core samples RC samples are statistically significant.
- The discrepancies between the 4E values in diamond drill and RC samples are due to identifiable factors.
- RC sample results are representative of the Middle Group seams in the Tharisa ore body under the current sampling protocol.
- The measurement uncertainty associated with RC sampling and analytical methods can be quantified.

1.7 Problem statement

Tharisa Mine drills an average of twenty RC holes per month for grade control purposes. These 20 holes yield a total of 1300 samples which are analysed for Cr_2O_3, FeO, SiO_2 and 4E g/t. It costs on average R400 to analyse for 4E g/t per sample, A total of R520 000 spent on RC 4E g/t samples per month.

Geological information from logging and assay results for Cr_2O_3, FeO and SiO_2 from RC drilling is then combined with DDH information and treated the same as DDH information for

construction of the grade control model. However, 4E grades from RC drilling are excluded as they are consistently reporting lower than 4E g/t in DDH. This translates to a monthly loss of R520 000 on assaying of 4E grades which are excluded from all the Tharisa 4E grade valuation processes.

The variances between 4E g/t in RC and 4E g/t in DDH lies firstly in the sampling locations, the sampling materials, and the sampling protocol and, secondly the two completely different analytical methods and processes involved in obtaining the assays values. The investigation of the sources of this discrepancy and quantification is necessary to reduce the cost associated with assaying for 4E g/t grades and to improve the reconciliation process.

1.8 Structure of the research report

Chapter 1 of the research is the introduction which consists of the following;

- A brief geology of the area, the background of the research focusing on the sampling that was done
- Grade control process, demonstrating the use of collected sampling data.

Chapter 1 further presents the purpose of the study, research questions and research objectives, statement of the problem

Chapter 2 outlines the literature review, previous work on the subject matter and presents an assessment of the RC sampling procedure, descriptive statistics and hypothesis testing on both DDH and RC. This provides a check of the differences between 4E values in RC and DDH; duplicate drilling data of RC holes drilled in close proximity to DDH are used to test for sampling uncertainty; RC dust samples, two-way RC and DDH pulp check samples for checking the difference between the analytical methods, RC duplicate samples and blind certified reference materials (CRMs) are analysed using statistical techniques to identify the sources of uncertainty and quantify uncertainty.

Chapter 3 presents the research methods and data sources used in the research.

Chapter 4 summarizes the data analysis, starting with describing the nature of the ore body in the context of heterogeneity by looking at the mode of occurrence and the variography. The RC sampling process flow is also presented in order to provide context to the data analysis.

Chapter 5 summarizes the findings from the data analysis.

Chapter 6 outlines the conclusion made from the research and research recommendations.

2 LITERATURE REVIEW

2.1 Theory of sampling

Sampling is the process of taking a small portion of a whole mass to accurately represent the whole mass (Spangeberg & Minnit, 2014). A sample can be referred to as 'correct' only if each fragment in the lot has the same statistical chance as every other fragment of being in the sample (Minnitt, Rice, & Spangenberg, 2007). Gy's *Theory of sampling* (TOS) is a complete theory that provides guidance in terms of the possible sources of sampling errors and analytical errors and how to obtain representative samples. The primary key of Gy's TOS is its systematic approach of identifying different aspects of sample population variability before sampling begins (Minnitt, 2014).

(Esbensen & Wagner, 2015) state that the TOS focuses on the determination of the uncertainty components related to the sampling process. The aim of the TOS is to define the appropriate sampling procedures and frequencies.

To ensure that sampling outcomes are representative of the sample population, it is important for the variability and uncertainty of the sampled material to be understood (Minnitt, 2014) Variability refers to the inherent differences within the population, whereas uncertainty refers to the degree of precision towards the measurand. Determination of variability and uncertainty will result in a sampling method that eliminates or minimizes potential errors.

Dominy et al., (2018) compiled a list of sampling errors and defines the sources of the errors (Figure 5). Two different error types, *Protocol errors ("Correct sampling errors")* and Procedure errors ("*Incorrect sampling errors")*, are also indicated on the list. Correct sampling errors result from the heterogeneity of the sampling target; these errors are inherent and cannot be removed. The correct sampling error generates random errors that often affect the reproducibility of assays.

Applied sampling protocols, sampling equipment and material handling produce what are termed 'incorrect sampling errors. These errors are mostly systematic and can be corrected

by modifying the sampling protocol, using the right sampling equipment and handling materials appropriately. (Dominy, et al., 2018).

Sampling Error	Acronym	Error Type	Effect on Sampling	Source of Error	Error Definition
Fundamental	FSE	Correct Sampling Error (CSE)	Random Errors—Precision Generator	Characteristics of the ore type. Relates to constitution and distribution heterogeneity	Results from grade heterogeneity of the broken lot. Of all sampling errors, the FSE does not cancel out and remains even after a sampling operation is perfect. Experience shows that the total nugget effect can be artificially high because sample masses are not optimal.
Grouping and Segregation	GSE				Relates to the error due to the combination of grouping and segregation of rock fragments in the lot. Once rock is broken, there will be segregation of particles at any scale (e.g., surface stockpile or laboratory pulp).
Delimitation	DE	Incorrect Sampling Error (ISE)	Systematic Errors—Bias Generator	Sampling equipment and materials handling	Results from an incorrect shape of the volume delimiting a sample.
Extraction	EE				Results from the incorrect extraction of a sample. Extraction is only correct when all fragments within the delimited volume are taken into the sample.
Weighting	WE				Samples should represent a consistent mass per unit (e.g., kg/m).
Preparation	PE				Refers to issues during sample transport and storage (e.g., mix-up, damage, loss and alteration), preparation (contamination and/or losses), and intentional (sabotage and salting), and unintentional (careless actions and non-adherence of protocols) actions.
Analytical	AE	-		Analytical process	Relates to all errors during the assay and analytical process, including issues related to rock matrix effects, careless actions, and analytical machine maintenance and calibration.

Figure 5: Definition of Theory of Sampling errors (Dominy, et al., 2018).

The scope of this research does not include quantifying all errors listed in Figure 5; instead, the research uses the listed errors as a guide to identify sources of errors in reported 4E grades. The following errors stood out, during the assessment of the Tharisa sampling protocols:

- In situ fundamental error and nugget effect; which are highlighted in the preliminary studies done before commission of the metallurgical plant.
- Increment delimitation errors and extraction errors that could be introduced by the RC sampling method at a fixed 0.5m interval.
- Grouping and segregation errors during splitting and transportation of samples.

- Preparation and analytical errors; discrepancies have been observed between 4E grades analysed by different methods, at different laboratories.

2.2 Quality assurance and quality control

Quality assurance and quality control (QAQC) is the process set to measure and assure the quality of the samples and the reported assay results. Quality assurance refers to the set program that ensures that the samples taken and reported assay results are as accurate as possible. Quality control refers to the actual measures put in place to verify that the sampling and assaying are done correctly.

QAQC is a methodology which, when accurately implemented, has the potential to significantly reduce data acquisition costs and ensuring data reliability and data traceability across the entire mining value chain. This can be achieved through the high level of acceptance and implementation of the agreed standards.

Long (2009) compiled a QAQC manual entitled "*Assay quality assurance-quality control program for drilling projects at pre-feasibility to feasibility report level*". The main aim of this QAQC manual is to give guidance on designing QAQC programs for exploration projects at pre-feasibility to feasibility study levels. The guidance in the QAQC manual includes a selection of the primary and secondary laboratories, obtaining and making CRMs, quality control protocols and criteria, analysis of the presentation of quality control data, common errors quality control of the geological database and geotechnical considerations. Although the QAQC manual focuses on the exploration data, the guidance has been expanded to grade control estimation data as the actual grades are expected to reconcile with the feasibility study level estimates. The Author considers the guidance from Long (2009) when analysing Crm data in this research.

2.3 Comparison on sampling techniques.

Numerous sampling methods are available across the global mining industry, ranging from the traditional methods to advanced automated systems.

Mining companies on the Bushveld Complex use a variety of traditional sampling methods (Lomberg, 2014).

RC drilling method uses dual tube pipes consisting of an inner rod and an outer tube; high pressure air flow down the space between the inner tube and outer tube propels the sample cuttings along the inner tube back to surface in a continuous and stable flow. The drilling mechanism is most often a pneumatic which, in turn, drives a tungsten-steel drill bit to crush the rock. The hammer is used to remove rock samples that are pushed through the rod with compressed air. When air is blown down the annulus of the rod, the pressure shift creates a reverse circulation bringing the cuttings up the inner tube. When the cuttings reach a deflector box at the top of the rig, the chips move through the hose attached to the top of the cyclone. The drill cuttings will travel around the cyclone until they fall into the splitter and then into the sample bag (Castle drilling, 2020).

DDH is a technique that uses the drill bit encrusted with industrial rough diamond. The drill bit is threaded onto the core barrel and attached to a bottom of a hollow drill-rod string. The diamond bit cuts a cylindrical shaped solid column of rock called drill core, which moves up into the tubular drill rod as drilling progresses downward. The recovered drill core is placed in the core tray (Abzalov, 2016). Samples are selected and collected from the recovered core; controlled by lithological boundaries; the accuracy of the contacts in the DDH can be determined in centimetres to the second decimal.

A study by Hapugoda & Manuel (2010), compiled a comparison of drilling and sampling techniques on base and precious metal exploration in Mt Isa inlier of Northwest Queensland, and the Southern Lachlan fold belt in New South Wales. In the study, rotary air blast drilling (RAB) is compared to RC drilling and DDH. The author made the following conclusions:

- The samples collected via RC drilling got mixed within the drilled interval, leading to the exaggeration of thickness of the mineralized zone.
- Samples from the RAB method were contaminated and the thicknesses of mineralized zones were overly exaggerated as compared to the RC drilling.
- Inn DDH the lithological contacts could be identified. Hapugoda & Manuel (2010) concluded that RAB and RC offer minimum resolution of the chosen sampling width with unreliable structural information and should be complemented with DDH to confirm the dimensions of the mineralized zone contacts.

2.4 Uncertainty quantification in an open cast mine.

According to Macfarlane (2013, p. 679), "*Reconciliation is defined as the process of finding a way to make two different ideas, facts, etc. exist to be true at the same time. In mining, this refers to measurements and estimations along the mining value chain, in order to track and optimize metal recovery and highlighted reconciliation as governance issue that is required for a risk management perspective*". An article by (Parhizkar, et al,2011), concerning grade uncertainty and its impact on the reconciliation between the resource model and the mined ore grades, addressed the issue of poor reconciliation between the resource estimates and the actual mined grades in most open cast mines. The study identified the nature of the ore body, random uncertainty of the grade parameter and the systematic errors as major sources of uncertainty at exploration stage. Parhizkar, et al., (2011) developed a probabilistic model that quantifies the natural variability, random uncertainty and the uncertainty associated with the systematic error. The probabilistic model used the Coefficient of variation (CV) to express uncertainty. The developed model was tested on the Chardormalou Iron Ore Mine in Iran, where it was confirmed that the nature of the ore body, the random uncertainty of the grade parameter and the systematic errors are the main causes of poor reconciliation. According to the authors, the model can be applied to any type of deposit. The Parhizkar, et al., (2011) probabilistic model would not be adopted in this research as the research addresses the uncertainty associated with the raw RC sampling 4E values and 4E g/t values from DDH. The use of the CV, as a measure of uncertainty, is adopted.

2.5 Uncertainty Measurement

The main aim of each measurement is to attain the true value of the measurand. The term 'Measurand' refers to the quantity that we intend to measure, and in this research, 4E g/t is regarded as the measurand. In most cases, the true value of the measurand is unknown and the resulting measured value is an estimate, associated with a certain level of error. The 'Error' is the difference between the true value and the measured value (NDT Resource Centre, 2020). The relationship between true value, measured value, error and uncertainty is illustrated in Figure 6 below. Uncertainty is an expression of the size of error; it is the interval around the measured value, which characterizes the accuracy of the measurement. Uncertainty is always associated with confidence interval (University of Tartu, 2021). Scientific uncertainty is a measurable variability in the data (Carpi & Egger, 2008). In the

context of this research, 'uncertainty' refers to the uncertainty associated with the 4E g/t values from RC drilling, sampling and assaying.

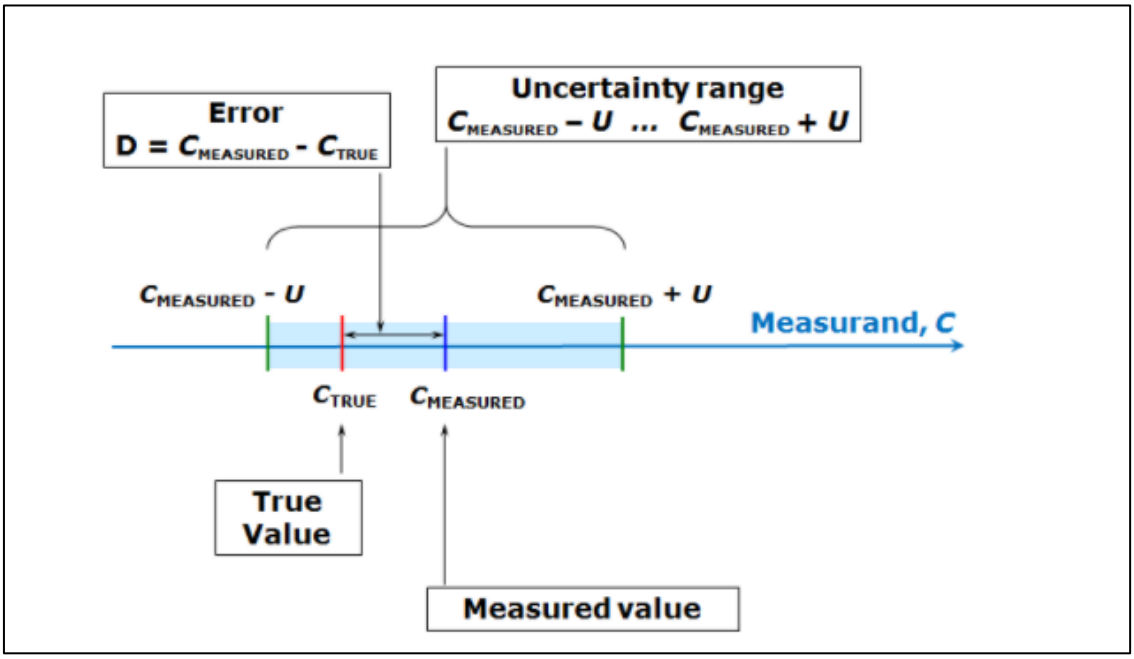

Figure 6: Illustration of a relationship between true value, measured value, error and uncertainty. (University of Tartu, 2021)

Uncertainty of the measurement is calculated by repeating the measurement and calculating the standard deviation or CV. Uncertainty can also be determined by repeating the measurement of material of known expected grade and calculating the bias. In this research, the sample replicates and repeated measurements of CRMs are used to calculate uncertainty.

In statistics, the Standard deviation is a measure of dispersion around the mean value. One standard deviation from the mean covers 68.3 % of the data, two standard deviation covers 95.4% of the data and three standard deviation covers 99% of the data. Standard deviation (σ) is calculated by this formula;

$$\sigma = \sqrt{\sum(Xi - \bar{X})}/n \qquad \text{Equation 2.1}$$

Where X_i is measured value

Where $\bar{X}$ is the mean of all measured values

n is the total number of samples

The CV is the ratio of standard deviation to the mean. CV is a preferred statistical tool as it allows comparison CV is generally expressed in percentages and does not depend on the unit of the measurement. CV is calculated by the use of this formula;

$$\mathrm{CV} = \frac{\sigma}{\overline{\mathrm{X}}} \qquad \textit{Equation 2.2}$$

Bias is the difference between the expected value and the mean, in this research the bias is calculated using CRMs. Formula for calculating bias is;

$$Bias = E(x) - \overline{\mathrm{X}} \qquad \textit{Equation 2.3}$$

Where $E(x)$ is the expected value of the mean

Uncertainty arises from four sources of error:

- Random errors from sampling
- Random errors from analysis
- Systematic errors from sampling
- Systematic errors from analysis methods.

Traditionally, these errors were quantified as sampling precision, analytical precision, sampling bias and analytical bias.

In the *Handbook for calculation of measurement uncertainty in environmental laboratories,* Magnusson, Naykki, Hovid, Krysell and Sahlin (2017) give guidance on how to check and validate the sampling, as well as analytical uncertainty.

There are three components of analytical uncertainty:

- Method and laboratory bias, whereby uncertainty is calculated by using CRMs, proficiency tests and performing recovery tests;
- Reproducibility between laboratories, whereby proficiency tests are done by Tharisa laboratory and Intertek laboratory; and
- Within laboratory reproducibility, this is done through duplicate analysis of measurements from the same laboratory;

The first component is expanded to sampling uncertainty, where duplicate samples are taken and assessed for sampling uncertainty. This is to avoid the notion that most uncertainty measurements focus on analytical uncertainty and ignores the contribution of uncertainty from sampling, (Thompson & Ramsey, 2007).

A literature review on measurement and sampling uncertainty done by (Ohenoja, 2015), focused on the features of the methods related to the uncertainty and sampling error. (Ohenoja, 2015) highlighted the methods of evaluating the measurement uncertainty at both the instrument and system levels. The research identified two main methods of quantifying uncertainty; the Empirical method, where all sources of uncertainty are included but the individual sources cannot be identified and the Model approach, where the individual sources of uncertainty are mathematically quantified by constructing a statistical model (Ohenoja, 2015).

2.6 Uncertainty calculation by statistical approach

Measurement uncertainty is obtained by measurement and statistical approach, where the different uncertainty sources are estimated and combined into a standard uncertainty. Ideally, the calculation can be done using already existing QAQC data, but sampling method bias is currently not catered for in the QAQC protocol. Duplicate field samples were collected to evaluate the sampling method uncertainty.

The statistical uncertainty measurements methods in this research were mostly adopted from the Eurachem guide titled *Measurement uncertainty arising from sampling* (Ramsey, .Ellison, & Rostron(eds), 2019). *MUkit* (Measurement uncertainty kit) software is used in quantifying uncertainty by using CRMs and duplicate samples.

Measurement uncertainty is quantified in six steps.

- **Step 1:** Specify the Measurand, range and target expanded uncertainty.
  The measurand in the research is 4E values in RC drilling samples (measured in g/t). Target uncertainty is $\pm$ 10%. Absolute uncertainty is calculated.
- **Step 2:** Estimate within laboratory reproducibility using CRMs AMIS0717 with an average 4E grade of 0.697g/t. and AMIS0723 with average grade of 0.994g/t

- **Step 3:** Quantify method and laboratory bias using CRM, check samples and pulp duplicates. In this research, AMIS0717 and AMIS0723 were used as they have a similar matrix as the mainstream samples.
- **Step 4:** Convert components to standard uncertainty. This is to ensure that all measurements are in the same units.
- **Step 5:** Calculate combined standard uncertainty by summation in Quadrature also known as root sum of squares. The formula is written as follows:

$$\text{Combined uncertainty} = \sqrt{(x^2) + (y^2) \ldots etc} \qquad \textit{Equation 2.4}$$

- **Step 6:** Calculate expanded uncertainty by multiplying the standard uncertainty by the coverage factor in order to report the uncertainty around a certain confidence interval. In this research, uncertainty was re-scaled to the 95confidence interval by using a coverage factor of 2.

2.7 PGE Analysis

Platinum Group Elements are commonly assayed by the fire-assay method, whereby different collectors such as lead, nickel sulphide, tellurium or silver nitrate may be used. The two most common methods used for PGE and Au are fire assay, coupled with NiS collection and fire assay, coupled with Pb collection (Lomberg, 2014).

Société Générale de Surveillance (SGS, 2020) describes the fire assay by NiS collection method; Fire assay by NiS collection method involves mixing a 30g-50g aliquot with nickel powder, sulfur, sodium carbonate, borax in a crucible and heating the mixture in a furnace at a temperature of 1000°C. As the temperature rises, the NiS extracts the PGEs, forming a NiS matte button containing PGEs. The NiS button is crushed and dissolved in either hydrochloric acid where the PGE-containing residue is filtered through a membrane, or the PGE containing residue can be dissolved in aqua regia and finished with inductively coupled plasma optical emission spectrometry (ICP-OES) or inductively coupled plasma mass spectrometry (ICP-MS) analysis (SGS, 2020).

Hofmeyr (n.d) described the fire assay lead collection method as follows; In fire assay by Pb collection analytical method, the 30g-50g aliquot is mixed with a litharge containing flux in a

clay crucible and heated in a furnace at a temperature of 1000°C-1200°C. This results in slag and molten lead which collects the precious metals at the bottom of the slag. Slag and molten lead are allowed to cool. The lead button is removed from the frozen mold and be placed in a cupel and heated in the cupelling furnace to remove lead by oxidation, resulting in a prill with only precious metals. In most commercial laboratories the prill will be dissolved in acid and the solution will get analysed through atomic absorption (AA) (Hofmeyr). At Tharisa internal laboratory, the resulting button from cupellation is further heated in the furnace to remove the silver, the remaining prill weighed and the mass is used to calculate 4E value. Tharisa requires a 120g aliquot for 4E analysis because of low grade 4E values in the mined ore. Tharisa Mine's laboratory is currently not 4E ISO accredited.

Fire assay by lead collection is fast but yields poor results as some of the PGEs are lost during the cupellation stage. In contrast, fire assay by NiS is more time consuming but considered to be more accurate (Hofmeyr). Fire assay by NiS coupled with ICP-MS has a lower detection limit as compared to fire assay by NiS. Table 1 indicates detection limits per method and element. The Tharisa laboratory has a lower detection limit for 4E compared to ALS, SGS and Intertek Laboratories The detection limit is the lowest concentration that the laboratory can measure using a particular method. The detection limit is a useful tool for comparing laboratory capabilities with similar analytical methods; detection limit can also be used to compare different method limitations and sensitivities within the laboratory. The Tharisa laboratory was compared to commercial laboratories in South Africa. Tharisa laboratory 4E detection limit is comparable to other laboratories. There is a significant discrepancy between the Tharisa laboratory aliquot used as compared to the other laboratories. Tharisa Mine uses Pb collection method to analyze for 4E in RC samples, test hole samples as well as process samples.

Table 1: Detection limits per method at commercial laboratories and Tharisa laboratory.

					Detection Limits							
Laboratory	***Method***	***Finish***	***Aliquot size***	***Units***	***Au***	***Pt***	***Pd***	***Rh***	***Ru***	***Ir***	***Os***	***4E***
Intertek	***Fire assay - NiS collection***	*ICP- MS*	*50g*	***ppb***	***2***	***1***	***1***	***1***	***1***	***1***	***1***	
	Lead collection fire assay	*ICP- MS*	*50g*	*ppb*	*1*	*1*	*1*	*5*				
SGS	***Fire assay - NiS collection -***	*ICP- MS*	*30g*	*ppm*	*0.02*	*0.02*	*0.02*	*0.02*	*0.05*	*0.02*		
	Lead collection fire assay	*Gravimetric*	*30g*	*ppm*	*0.001*	*0.001*	*0.001*					
ALS	***Fire assay - NiS collection***	*ICP- MS*	*30g*	*ppb*	*2*	*2*	*2*	*2*	*3*	*1*	*2*	
Tharisa internal laboratory	***Lead collection fire assay***	*Gravimetric*	*120g*	*ppm*								*0.03*

2.8 Previous work

2.8.1 The uncertainty associated with PGEs

A case-study of Mogalakwena Mine by Woollam (2017) is cited in this report to showcase how different mines approach sampling and grade-control. Anglo-owned Mogalakwena Mine is one of the few mines that uses RC drilling for grade control purposes. It must be noted that Mogalakwena mine exploits a massive, disseminated ore body where RC drilling would provide a useful sample in the ore zone, whereas mining at Tharisa is extracting narrow reefs 1.5-2 m thick and strongly controlled by lithological boundaries. This difference in the nature of the ore bodies, makes RC drilling at Mogalakwena a very useful tool, but it fails to meet the objectives for which it is intended at Tharisa. A study was done at the Mogalakwena mine to quantify sampling uncertainties at grade control decision points (Woollam, 2017). One of the findings by Woollam (2017) was that grade-control sampling (RC sampling) was positively biased at grades below 1.7 g/t 4E. It is negatively biased at grades above 2.5 g/t 4E when compared to grades obtained by sampling exploration diamond drill core, using same the analytical method. The differences between the two sampling techniques are the smallest at ore grades between 1.7 g/t and 2.5 g/t 4E (Woollam, 2017).

This finding is different to what was observed at Tharisa Mine where composited 4E grades for each of the seams ranged from 0.5 g/t to 1.4 g/t and RC grades generally reported lower than the grades in diamond exploration drill holes. This could be as a result of a difference in mineralization, poor sampling practice, inappropriate sampling protocols or because of different analytical techniques. The sources of errors will be investigated in this research.

2.8.2 Sampling in the Bushveld Complex

Lomberg (2014) wrote an article on best practice sampling methods, assay technique and quality control with reference to the platinum group elements in the Bushveld Complex and Great dyke of Zimbabwe. The study discusses a selection of sampling techniques, assaying techniques, the sample size in relation to the laboratory requirements and the potential mining cut. Lomberg (2014) concludes that all sampling systems should be driven by the understanding of the mineralization of the ore body.

3 RESEARCH METHODOLOGY

3.1 Research method

The research method used in this research report is quantitative research methods use quality control data, supported by primary and secondary data sources. The available data comprises of DDH and RC drilling 4E assay results, duplicate 4E assay results and CRM 4E values.

A desktop study and field studies were conducted whereby Tharisa Mine's current sampling procedures were reviewed. A site visit to an active RC drill rig was conducted to observe sample collection on-site.

3.2 Data collection method and tools

Ten different datasets generated from RC sampling and DDH were used to identify and quantify sampling and analytical uncertainties and to identify the sources of uncertainties.

Dataset 1: RC drilling 4E results and Diamond drilling 4E results.
A total of 414 RC holes from the commencement of the RC drilling program and 113 DDH are used to quantify the difference between RC drilling 4E results and DDH 4E results. The RC drilling 4E results dataset is validated and stored in the Sable database.

Dataset 2: Two–Way Twin drilling program.
Three pairs of DDH and RC were drilled at Tharisa; each DDH is drilled within 10m of the corresponding RC hole. This set of holes was originally drilled to check the variation in the seam thickness intersections between diamond drillholes and seam thickness intersections in RC drilling. Collar information, geological logging information and assaying data from these holes are currently stored in the Tharisa Sable database. QAQC checks and data validation were done to ensure the validity and integrity of the data. This data will be used to assess the 4E values in the RC holes as compared to the 4E values in diamond holes in order to understand the sources of discrepancies between 4E values in RC holes and DDH.

Dataset 3: Replicate design for estimating sampling uncertainty.
A total of 88 replicates samples were created by collecting two sample splits from the built-in splitter at the rig. Both samples were split further at the laboratory into two samples using a

rotary splitter after pulverising. This is done to test both analytical and sampling uncertainty. The samples were assayed at Tharisa laboratory for 4E g/t, using the Pb collection method.

Dataset 4: Two-way laboratory DDH pulp check samples.
A total of 225 DDH pulp samples, initially analysed by NiS from the Intertek laboratory, were sent to the Tharisa internal laboratory to be analysed using Pb Collection.

Dataset 5: Two-way laboratory RC drilling pulp check samples.
A total of 40 RC drilling pulp check samples initially analysed by Pb collection at Tharisa laboratory, were sent to Intertek laboratory to be analysed by NiS.

Dataset 6: RC samples Laboratory pulp duplicates.
A total of 1576 Blind pulp duplicates were submitted at Tharisa laboratory to test for repeatability. These are pulp rejects returned from the laboratory after each analysis. One sample from the rejects is submitted in the new batch as a duplicate sample. Duplicates are used to check the precision of the assay results reported by the laboratory. Correlation plots are used to check the relationship between the original sample and duplicate sample, Results of the comparisons are illustrated in the Data analysis section.

Dataset 7: “Blind” CRM inserts
A range of CRMs are used to check the accuracy of the laboratory assay results (Table 2, Table 3 and Table 4). Two CRMs, AMIS0717 and AMIS0723, comprising of the Tharisa Middle Group seam material, were added to the list of CRMs inserted with RC sample batches. The CRMs were selected for the anticipated average PGE and chrome grades and a suitable matrix in order to do accuracy test on the similar matrix. A total of 166 samples of AMIS0723 and 163 samples of AMIS717 is used for uncertainty quantification.

Table 2: List of historic CRMs used in exploration at Tharisa Mine. (Lomberg, 2013).

	AMIS0006		AMIS0010		SARM 8		
Element	**Grade**	**Range**	**Grade**	**Range**		**Grade**	**Range**
Pt (g/t)	1.43	±0.15	2.05	±0.29	Al_2O_3 (%)	10.5	10.4 - 10.6
Pd (g/t)	0.94	±0.10	1.33	±0.10	CaO (%)	0.26	0.24 – 0.27
Rh (g/t)	0.29	±0.03	0.41*	±0.08	Cr_2O_3 (%)	48.9	48.9 – 49.0
Au (g/t)	0.02*		0.026*		Fe (%)	14.1	14.0 – 14.1
Cu (ppm)	838	±79	716*	±0146	MgO (%)	14.6	14.6 – 14.7
Ni (ppm)	820*	±65	1116	±118	MnO (%)	0.25	0.24 – 0.26
Cr (%)	7.89*	±0.41	15.84	±1.08	SiO_2 (%)	4.3	4.26 – 4.34
AMIS0006: Certified Feed Grade UG2 PGE Reference Material supplied by African Mineral Standards							
AMIS00010: Certified High Feed Grade UG2 PGE Reference Material supplied by African Mineral Standards							
SARM 8: Certified Chromium ore (Potgietersrus) Reference Material supplied by Mintek							
* - Provisional results or indicated grade							

Table 3: List of CRMs used in exploration at Tharisa Mine. (Lomberg, 2013)

	AMIS0027		AMIS0053		AMIS00209		AMIS00387		
Element	**Grade**	**Range**	**Grade**	**Range**	**Grade**	**Range**	**Major Element**	**Grade**	**Range**
Pt (ppm)	2.45	±0.30	2.52	±0.20	1.2	±0.10	Al_2O_3 (%)	11.03	±0.22
Pd (ppm)	1.62	±0.18	1.23	±0.08	0.64	±0.06	CaO (%)	1.22	±0.06
Rh (ppm)	0.49*	±0.08	0.18	±0.016	0.09*	±0.02	Cr_2O_3 (%)	28.49	±0.80
Ru (ppm)	0.77*	±0.14	0.33	±0.03	0.17*		Fe (%)	22.84	±0.40
Ir	0.18*	±0.02	0.06*	±0.01	0.031*				
Cr (%)	13.74	±0.87					MgO (%)	14.08	±0.38
Cr2O3(%)			0.71	±0.02	0.48	±0.02			
Au (g/t)	0.05*		0.22*		0.09*	±0.02	MnO (%)	0.21	±0.02
Cu (ppm)	142*	±20	810	±46	445*	±65	SiO_2 (%)	19.29	±0.48
Ni (ppm)	1197	±94	1719	±118	909*	±35	TiO_2 (%)	0.49	±0.04
AMIS00027: Certified UG2 PGE Reference Material supplied by African Mineral Standards									
AMIS00053 and AMIS0209: Certified Merensky PGE Reference Material supplied by African Mineral Standards									
AMIS0387: Certified Chrome ore LG6 Reference Material supplied by African Mineral Standards									
* - Provisional results or indicated grade									

Table 4: List of Tharisa CRMs used in RC drilling at Tharisa Mine.

	AMIS0717		AMIS0723	
Element	**Grade**	**Range**	**Grade**	**Range**
Pt (ppm)	0.5	±0.05	0.421	±0.055
Pd (ppm)	0.2	±0.1	0.128	±0.0175
Rh (ppm)	0.09	±0.01	0.086	±0.015
Ru (ppm)	0.2	±0.02	0.265	±0.22
Ir (ppm)	0.05	±0.01	0.05	±0.01
4E (ppm)	0.697	±0.08	0.994	±0.21
Cr2O3(%)			18.18	±0.85
Au (g/t)			0.294	0.06
Cu (ppm)				
Ni (ppm)				
AMIS0717: Certified MG Tharisa Reference Material supplied by African Mineral Standards				
AMIS0723: Certified MG Tharisa Reference Material supplied by African Mineral Standards				

Dataset 8: Used Cupels to check for PGE losses

Cupels are shallow pots, made from bone ash, and used in most laboratory for assaying. 30 used cupels were submitted to the lab to check for losses of PGEs into the cupels. The cupels were previously used for Pb collection 4E analysis at the Tharisa laboratory.

Dataset 9: Dust samples

Three samples of dust collected from an RC rig were assayed to check for losses of PGE to RC drilling dust.

3.3 Datasets application

Nine datasets form the basis of the analysis:

- **Dataset 1:** RC drilling and DDH 4E results were used in descriptive statistics and for statistical analysis using histograms; this is done to compare the thicknesses and the 4E grade distribution in the Middle Group seam. Dataset 2 is also used in hypothesis testing, to check if the 4E grades in DDH and RC sampling are significantly different.
- **Dataset 2:** Two-way twin drilling where three DDH were each drilled within a 10m radius of an RC hole were used to check the differences between the two-hole types. The Relative Difference Calculation method is used in this case.
- **Dataset 3:** Replicate design samples were used for estimating sampling uncertainty. One way analysis of variances (ANOVA) is applied to estimate the variability in the assays arising from analytical and sampling processes.
- **Dataset 4:** Two-way laboratory DDH pulp-check samples were used in constructing the histograms and QQ-plots in comparing 4E values in RC sampling and in DDH.
- **Dataset 5:** Two-way laboratory RC pulp-check samples were used in constructing the histograms, scatter-plots and QQ-plots in comparing 4E values in RC sampling and 4E values in DDH.
- **Dataset 6:** Scatter plots were constructed using Laboratory RC samples pulp duplicates to check the correlation between 4E original sample values and 4E duplicate samples, to check the precision of the analytical methods.
- **Dataset 7:** Levey-Jennings plots are used to present CRM values, providing graphical representation of the performance of the laboratory. Laboratory reported values are plotted against the expected values and the bounding 2 standard deviation lines. Laboratory reported values are expected to fall within the 2 standard deviation

boundaries. CRM samples inserted in RC samples from the start of the project were used in uncertainty calculations CRM plots of some of the listed CRMs can be found in Appendix 1

- **Dataset 8:** Reported 4E values analysed from used cupels were assessed for possible losses of PGE's during cupellation stages.
- **Dataset 9:** Reported 4E values analysed from used dust were assessed for possible losses of PGE's during RC drilling.

3.4 Data analysis

Exploratory data analysis was done on DDH 4E assay results to analyze the two datasets to understand the difference between the two datasets. The following statistical tools were used for data characterization:

- Histograms and frequency polygons were used to illustrate the frequency distribution of the data by comparing the DDH and RC data sets;
- Arithmetic mean, median and mode for measurement of central tendencies;
- Standard deviations and variances for measures of dispersion; and
- QQ-Plots were used to compare 4E analysis from Pb collection and 4E values from NiS analysis.

One way analysis of variances (ANOVA) was applied to estimate the variability in the assays due to analytical and sampling processes.

The CV was calculated to compare 4E values in DDH and 4E values in RC drilling.

Two methods of hypothesis testing were selected for significance testing the difference between 4E grades in RC samples and 4E grades in DDH samples. *Fischer's hypothesis test* is used to contrast the similarities between the sample variances, Fischer's hypothesis test is selected due to the normal sample distribution and the samples are independent of one another. T-test with unequal variance is selected for testing the similarities between two population means. The T-test method was selected because the sampling population is of normal distribution, samples are independent, the sample size is unequal, and the population variance is unknown.

4 DATA ANALYSIS

4.1 Process flow

At every 50cm run of RC drilling, 3 samples with sample mass ranging from 1kg to 2.5kg are discharged from the RC cyclone chutes, one sample is discarded, and two samples are taken to the sample preparation area. At the preparation area, one sample is stored as a sample reference and the other sample gets prepared for dispatch to the laboratory. The Tharisa Mine RC sampling process flow is indicated in Figure 7

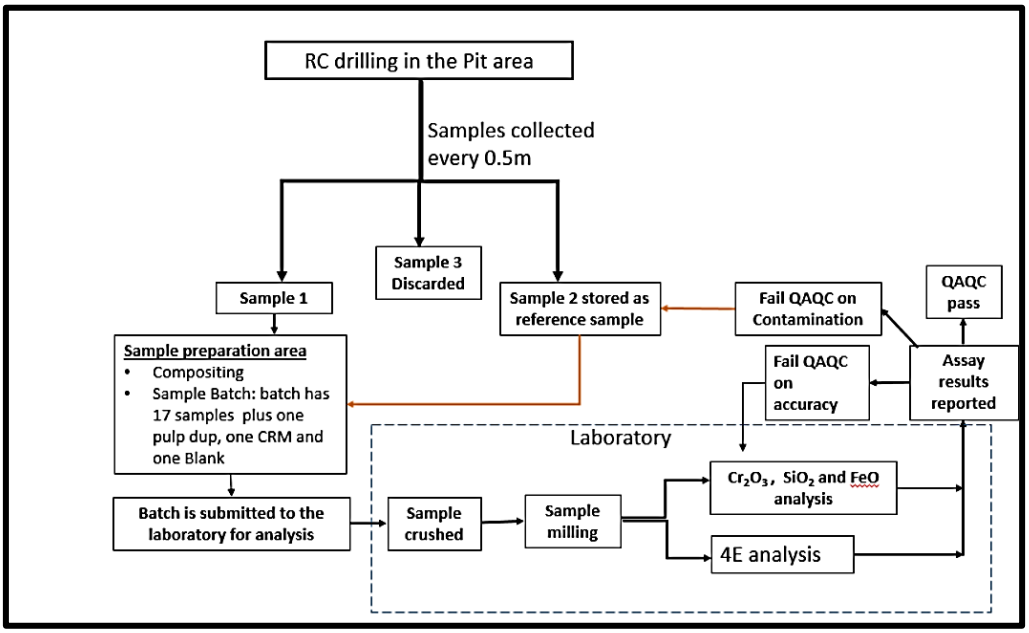

Figure 7: Tharisa RC sample process flow.

Samples are dispatched in batches of 20. Three of the 20 samples in the batch are quality control samples: one blank, one CRM and one pulp duplicate. Table 5 illustrates the quality control sample insertion rate.

Table 5: Tharisa quality control sample insertion rate

Quality Control Samples	RC Drilling	Diamond Drilling
CRM	5%	10%
Blank (Pool sand for DD and commercial blank for RC)	5%	5%
Duplicate	5%	5%

At the laboratory samples are crushed and pulverised, a split of the sample is then taken for oxides analysis and the other for 4E analysis. Assay results are reported, QAQC is run on the reported analysis.

4.2 Quality Control and Quality Assurance (QAQC)

QAQC programmes are employed at Tharisa to quantify and demonstrate the reliability of the assay data. Blanks samples are used to check for contamination; grades exceeding ten times the detection limit of each analyte are rejected, and a reference batch is submitted for re-assaying.

Levey-Jennings plots are used to present CRM values, visually reflecting the quality performance of the laboratory. Laboratory reported values are plotted against the expected value and the bounding three standard deviation lines. Laboratories with good quality performance report values which fall within the three standard deviation boundaries.

Sample batches are currently not failed on duplicates. Scatter plots of the duplicated data are drawn where the Pearson correlation coefficient, (R^2) are computed; values below 0.75 are communicated to the laboratory.

Sample batches which satisfy the QAQC processes are captured in the Tharisa database, where those that fail on accuracy are re-assayed, and reference samples are submitted for batches that fail on contamination.

AMIS0387 is one of the common CRMs used for quality checks in both RC assay results and DDH assay results. AMIS0387 is made up of materials from the LG6 chromitite seam from Glencore, Kroondal Mine, which is similar in mineralogy, grade and composition to the Middle Group seams mined at Tharisa.

RC samples are analysed at Tharisa laboratory, where the Pb collection method was used to analyse for 4E grades. Diamond core samples were analysed at the Intertek laboratory where the NiS method was used to assay for gold, platinum, rhodium and palladium which are summed up to get the 4E grades. The 4E values from the Tharisa internal analytical laboratory are highly erratic with a bias to a slightly lower grade compared to the 4E assays analysed at the Intertek Analytical Laboratory (Figure 8). The mean value of 4E grades from the Intertek laboratory is 1.268g/t whereas the mean value for 4E grades from the Pb

collection is 0.978g/t. The difference in the mean of the 4E grades shown in Figure 5 is attributable to the difference in the Pb Collection assay technique compared to that of the NiS Intertek analytical method. Pb collection method indicates a high degree of variability and reports lower than the NiS. Pb collection method appears to report lower 4E grades than the Nis method. Pb collection has higher confidence intervals which would make the grade prediction difficult.

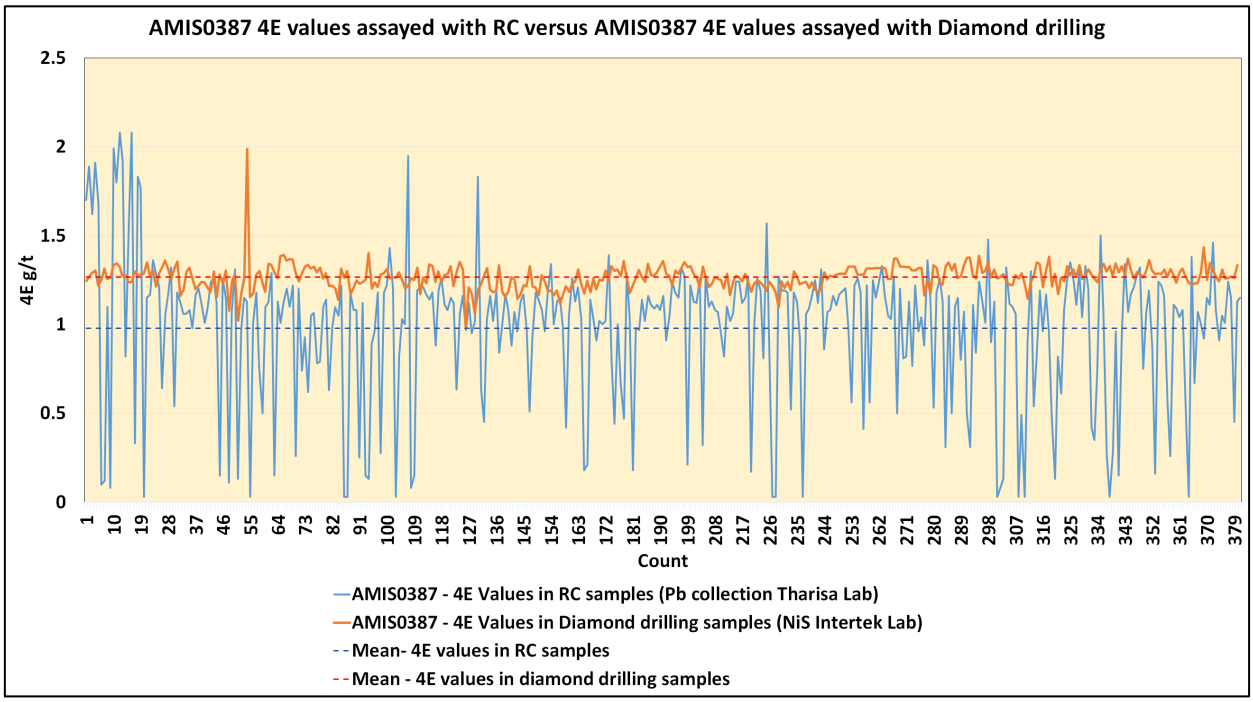

Figure 8: Plot of AMIS0387 4E values submitted with RC samples versus AMIS0387 4E values submitted with DDH samples.

Figure 9 is a plot comparing the 4E values in the blank samples submitted with RC and DDH samples. For DDH, store-bought pool sand was simultaneously analysed to gauge any contamination whereas for RC samples, AMIS0439, AMIS0484 and AMIS0681, comprising of silica chips were used to measure contamination. The levels of contamination were measured in parts per billion (ppb) in the DDH and in grams per tonne in RC holes. It can be observed that the levels of contamination in the blank samples analysed by Pb collection with RC samples was ten times higher than the blank samples analysed by NiS with DDH samples. This indicates a high level of carry-over contamination in the analytical process or sample swaps. The RC assay results cannot be trusted due to the high levels of contamination.

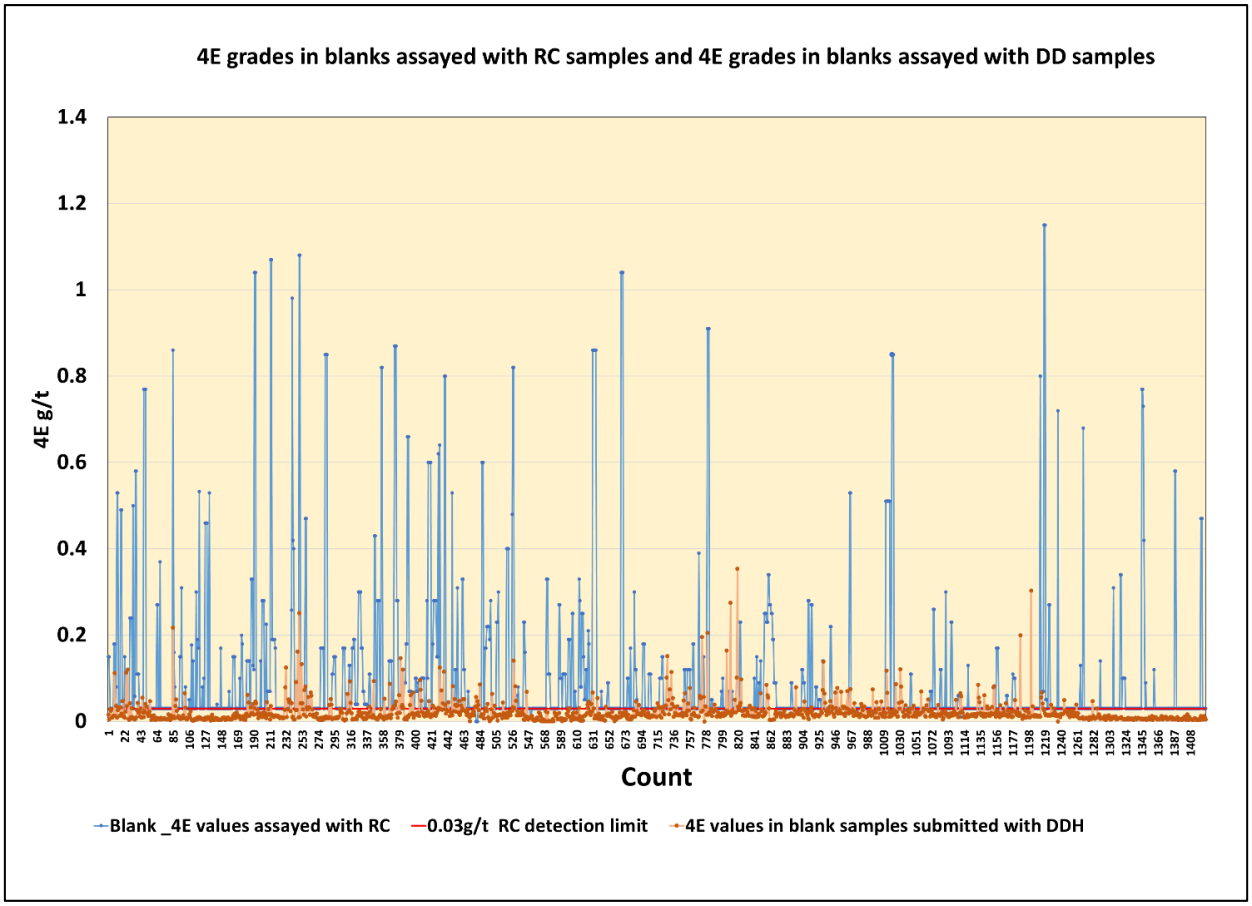

Figure 9: DDH 4E values in blank samples analysed by NiS and RC drilling 4E values in blank samples analysed by Pb collection plot.

4E ppb duplicate assay results were plotted against the original 4E ppb assay results to define the degree of correlation between the two sets of results (Figure 10 and Figure 11).

The Pearson correlation coefficient (R^2) measures the strength of the relationship between two datasets. R^2 returns values between -1 and 1, where 1 indicates a strong positive relationship, -1 indicates a strong negative relationship and zero indicates no relationship. The correlation coefficient of 0.95 between the original and duplicate DDH 4E ppb results indicates a good correlation between original samples and duplicate assays compared to a R^2 value of 0.18 in RC 4E g/t duplicate plot.

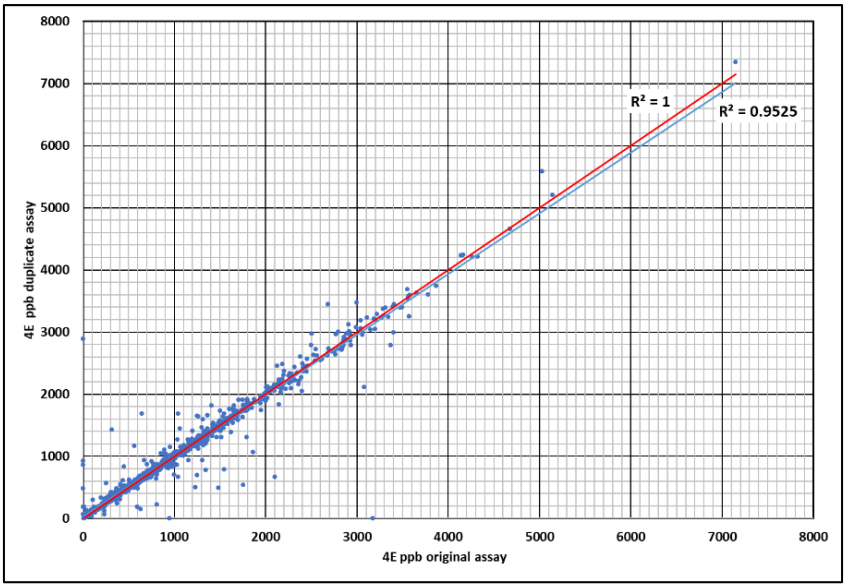

Figure 10: Comparison of duplicate pairs of 4E ppm grade in DDH with NiS collection method.

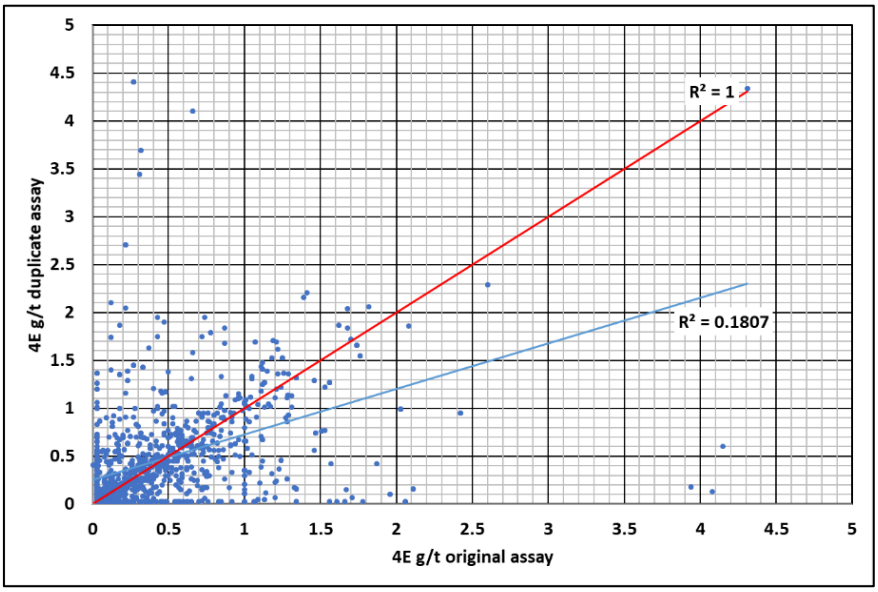

Figure 11: Comparison of duplicate pairs of 4E g/t grade in RC with Pb collection.

QAQC charts of the data indicate that there is significant difference between the NiS method and the Pb collection method; there are also high levels of contamination or possible sample swaps, and the duplicate samples indicates a low degree of reproducibility. Reported 4E results cannot be trusted and should not be utilised in any of the estimation processes.

Identified sources of uncertainties are;

- Random and systematic errors from RC sampling method,
- Possible contamination between samples,
- Increment delimitation errors when splitting the samples, within laboratory random and systematic errors from laboratory sample preparation
- Systematic errors from Fire assay by Pb collection.

4.2.1 Sampling procedures

The sampling procedures and equipment must be designed under the guidance of theory of sampling principles to ensure that the collected sample will be fit for the intended purpose. The equipment used for sample should be designed in a way that each sample will have an equal chance of being selected.

The Standard Operating Procedure (SoP) for RC sampling at Tharisa Mine is presented in Table 6.

Table 6: Tharisa RC sampling procedures (Landane, 2017)

Sampling Process	**RC sampling (**RC samples were collected at 50cm intervals from a 125mm diameter hole)
1	Mark a clean, intact plastic sample bag and chip tray with hole ID, sample ID and "From-To" meters using a permanent marker pen
2	Attach the plastic bag securely to the discharge chute at the base of the cyclone and tie it.
3	Sampling pans are placed under the stand-alone splitter
4.	Driller drills a 0.5m run. As the rod is drilled the sample will be discharged into the 20kg sample collects into the clean sampling bag.
5	When the 0.5m interval is drilled remove the sample plastic carefully, secure the neck of the bag tightly with your hand and turn the bag back and forth two-three times to mix the material.
6	Take the sample to the riffle splitter.
7	Sampler empties contents of plastic bag into the second tier of the riffle splitter. NB: When pouring move the bag from side to side across the width of the pan to ensure a fair distribution of the material.
8	The sample will be discharged directly into two sampling trays. The contents of 1 of these trays is emptied onto the riffle splitter discharging into two separate sampling trays again. The contents of 1 of these sampling trays (which is approximately 1.5kg in weight) is bagged into a clean sample bag.
9	Steps 6, 7 and 8 were recently replaced with a built-in splitter (See Figure 12). Two samples between 1kg -2.5kg are collected from the splitter by tying two sample bags of the chutes and the third sample is collected through a sampling tray (See Figures 12 and 13).
10	The sample is scooped from the chip tray and sieved to remove fines so that only sample chips are left in the sieve. The remaining chips are transferred to the chip boxes for logging purpose.
11	NB: Samples should always be organized in numerical order of sample number and put in a safe place where they can be easily accessed for collection but cannot be contaminated, damaged or destroyed by water/mining activities/vehicles/machinery, etc.
12	Cleaning stage; Sampler stakes rubber mallet and strikes stand-alone splitter until the residual sample is gone. The cyclone is then flushed with compressed air, for every 0.5m sample collected.

RC Sample preparation for dispatch to the Laboratory	
1	In the early stages of RC drilling seam intersections in some holes were composited to the total length of the seam intersections. RC Seam samples are composited to the maximum length of 1m. samples remaining after compositing and seam samples less than 1m are submitted as collected to the laboratory.
3	Compositing is done by emptying the two sample bags collected at the rig into the sampling tray, sample is then poured into the rotatory splitter, where the sample is split into eight cups. Sample material from four cups is poured into one sample bag.
4	Batching for dispatch; A total of 17 mainstream samples along with 1 duplicate sample, 1 blank and 1 CRM is placed in 1 big sampling to create a batch of 20 samples. samples are then dispatched to the lab

The following are the list of issues identified with the RC sampling procedure during the author's site visit to an active RC drilling rig:

- According to the SoP, the Driller must drill a 0.5m and stop for sample collection. It was observed that there was no depth counter on the RC rig; instead, a 50cm piece of iron is used to mark the rods (Figure 12 and Figure 13). This compounds the already existing issue of seam thickness exaggeration, as there is no accuracy in the drilled sample length.

Figure 12: A 50cm steel rod is used to mark the rods.

Figure 13: Rod with 50cm measurements marked.

- The plastic bags were tied loosely on the cyclone chutes, which violates the golden rule of each sample having equal opportunity to be selected as a portion of the sample would be lost (Figure 14).

Figure 14: Sample bags tied to the cyclone chutes. The tray is placed underneath the cyclone in the middle to collect the third sample.

- The built-in cone splitter results in the sampling bias as the drilling surface is not always level and result with samples channeled to the lowest side of the surface (Figure 15).

Figure 15: Built-in cone sample splitter in the cyclone.

Observations from the site visit clearly demonstrate that the collected RC sample is not a true representative of the bulk material being sampled.

4.3 Descriptive statistics

Sample data (Dataset 1) was composited over a full MG seam thickness for both RC and DDH intersection, and the histograms for 4E values were drawn per stratum (Figure 16).

4.3.1 MG1

MG1 DDH and RC descriptive statistics indicate that the 4E values in DDH have a higher mean grade than 4E values in RC samples (Table 7). The CV of 4E values in DDH is lower than that in RC samples. The mean thickness in the RC samples is larger than the mean thickness in DDH. This large thickness at a lower 4E grade in the RC sample is a function of

vertical dilution introduced by the 50cm fixed sampling interval. The CV of the sample thicknesses in RC is lower than that in DDH.

Figure 16 is a graphical presentation of the 4E grades in RC samples and 4E grades in DDH, as well as histograms of seam thicknesses observed in RC and DDH. Both 4E grades and thicknesses in RC holes and DDH holes are of Normal distribution.

Table 7: Descriptive statistics of MG1 4E g/t and Thicknesses in RC and DDH

Statistical Parameter	*DDH 4E_g/t*	*RC 4E_g/t*	*DDH Thickness (m)*	*RC Thickness (m)*
Mean	0.59	0.47	1.54	1.69
Standard Error	0.01	0.02	0.06	0.03
Median	0.57	0.42	1.58	1.50
Mode	#N/A	0.47	1.62	1.50
Standard Deviation	0.09	0.24	0.53	0.48
Sample Variance	0.01	0.06	0.28	0.23
Coefficient of Variation	1%	13%	18%	14%
Kurtosis	-31%	267%	529%	668%
Skewness	0.41	1.39	0.73	0.94
Range	0.40	1.53	3.63	4.50
Minimum	0.42	0.03	0.32	0.50
Maximum	0.81	1.56	3.95	5.00
Count	61.00	251.00	72.00	300.00

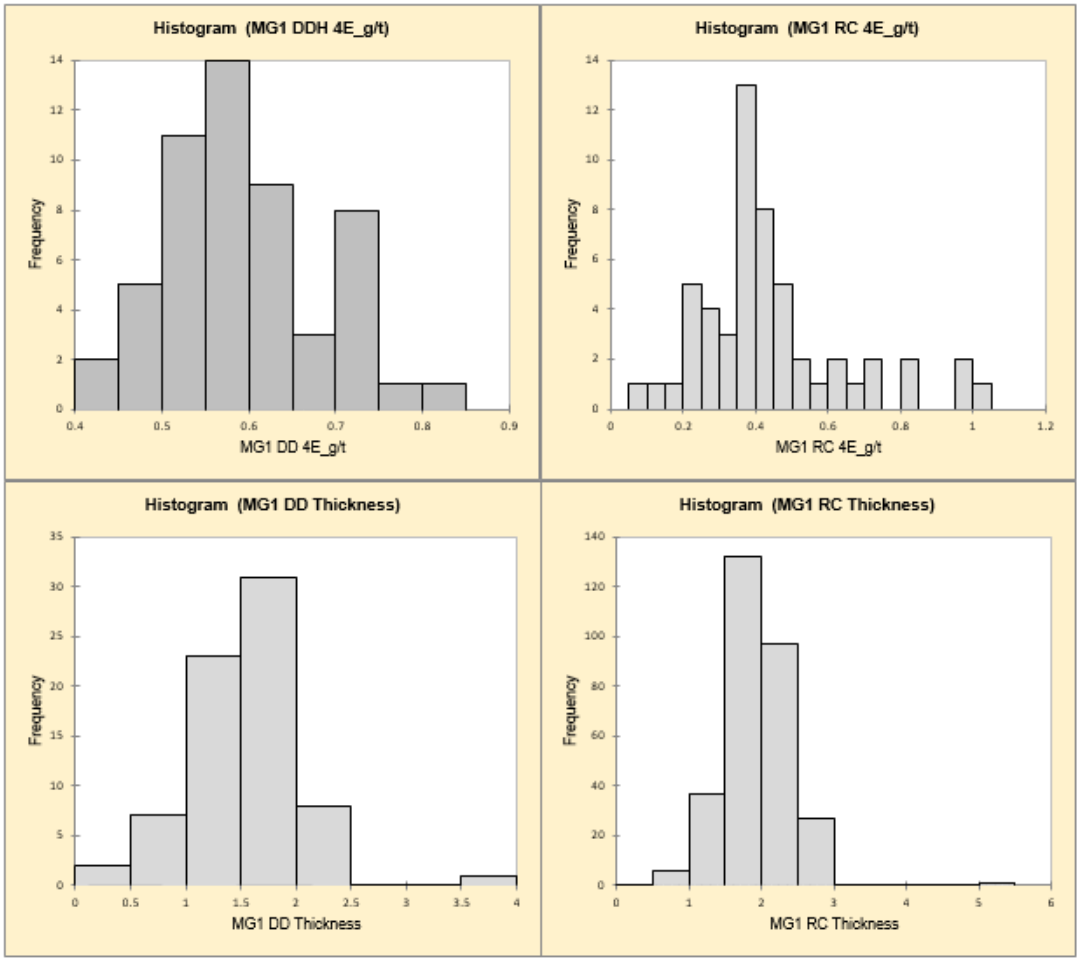

Figure 16: Histogram of MG1 4E g/t and Thicknesses in RC and DDH

4.3.2 MG2

MG2 DDH and RC descriptive statistics indicate that the 4E values in DDH have a higher mean grade than 4E values in RC samples CV in DDH is lower than the CV in RC samples (Table 8). The mean thickness in RC samples is higher than the mean thickness in DDH. This large thickness at a lower 4E grade in RC sample is a function of vertical dilution introduced by the 50cm fixed sampling interval. The CV for sample thickness in RC is lower than that in DDH, signifying the unreliability of the RC data.

A graphical representation of the 4E grades in RC samples and 4E grades in DDH, as well as histograms of seam thicknesses observed in RC and DDH are indicated below in Figure 17. This shows that both 4E grades and thicknesses in RC holes and DDH are of normal distribution.

Table 8: Descriptive statistics of MG2 4E g/t and Thicknesses in RC and DDH

Statistical Parameter	*DDH 4E_g/t*	*RC 4E_g/t*	*DDH Thickness (m)*	*RC Thickness (m)*
Mean	1.38	0.80	4.69	4.82
Standard Error	0.02	0.02	0.09	0.04
Median	1.36	0.79	4.68	5.00
Mode	#N/A	0.78	4.66	5.00
Standard Deviation	0.17	0.30	0.96	0.85
Sample Variance	3%	9%	93%	73%
Coefficient of Variation	2%	11%	20%	15%
Kurtosis	-0.04	0.15	1.97	2.70
Skewness	0.11	0.33	0.36	-0.24
Range	0.89	1.55	5.71	7.00
Minimum	0.92	0.12	1.98	1.00
Maximum	1.81	1.67	7.69	8.00
Count	96	353	108	401

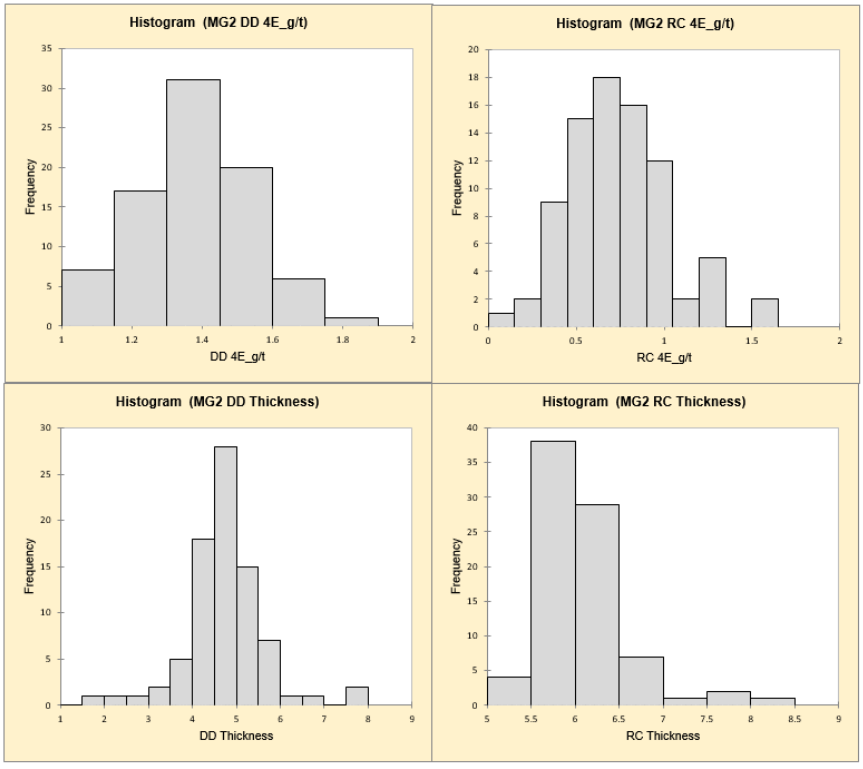

Figure 17: Histograms of MG2 4E g/t and Thicknesses in RC and DDH

4.3.3 MG3

MG3 DDH and RC descriptive statistics indicate that the 4E values in DDH have a higher mean grade than 4E values in RC samples CV in DDH is lower than the cv in RC samples (Table 9). The mean thickness in RC samples is lower than the mean thickness in DDH. This lower thickness at a lower 4E grade in the RC sample is related to the geology of the MG3 seam; The MG3 seam comprises of two chromitite bands with a noritic parting. The top band is thin; the width ranges from 1 cm to 30cm, making it difficult to identify in RC samples. The Coefficient of variation of the thickness in RC is lower than the CV of the thicknesses in DDH.

Figure 18 is a graphical presentation of the 4E grades in RC samples and 4E grades in DDH as well as histograms of seam thicknesses observed in RC and DDH. 4E grades and Thicknesses DDH are of Normal distribution. Thicknesses in RC samples are of positively skewed distribution.

Table 9: Descriptive statistics of MG3 4E g/t and Thicknesses in RC and DDH

Statistical Parameter	*DDH 4E_g/t*	*RC 4E_g/t*	*DDH Thickness (m)*	*RC Thickness(m)*
Mean	1.27	0.84	3.70	3.14
Standard Error	0.04	0.02	0.15	0.06
Median	1.24	0.82	3.79	3.00
Mode	#N/A	0.63	4.78	2.00
Standard Deviation	0.37	0.31	1.47	1.14
Sample Variance	0.13	0.10	2.16	1.29
Coefficient of Variation	11%	12%	58%	41%
Kurtosis	215%	155%	-29%	-46%
Skewness	1.16	0.62	-0.07	0.27
Range	2.03	2.27	7.32	6.50
Minimum	0.59	0.03	0.40	0.50
Maximum	2.61	2.30	7.71	7.00
Count	83.00	343.00	100.00	395.00

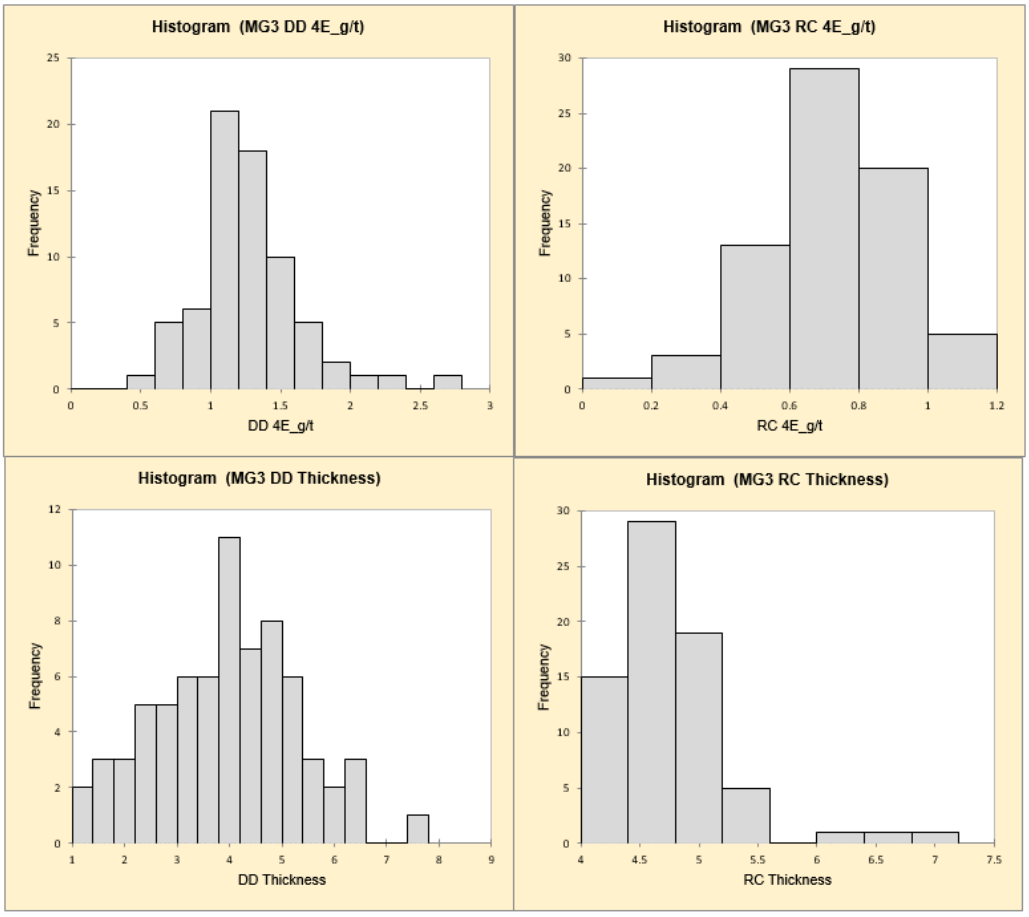

Figure 18: Histograms of MG3 4E g/t and Thicknesses in RC and DDH

4.3.4 MG4

MG4 DDH and RC descriptive statistics indicate that the 4E values in DDH have a higher mean grade than 4E values in RC samples (Table 10) The CV of 4E grades in DDH is lower than the CV in RC samples. The mean thickness in RC samples is higher than the mean thickness in DDH. The higher thickness at a lower 4E grade in the RC sample can be attributed to dilution introduced by the 50cm fixed sampling interval. The CV in RC is lower than in DDH, The thickness of MG4 in RC is not as variable as MG4 thickness in DDH.

Figure 19 is a graphical presentation of the 4E grades in RC samples and 4E grades in DDH as well as histograms of seam thicknesses observed in RC and DDH. 4E grades and thicknesses DDH are of normal distribution. Thicknesses in RC samples are of a positively skewed distribution.

Table 10: Descriptive statistics of MG4 4E g/t and Thicknesses in RC and DDH

Statistical Parameter	*DDH 4E_g/t*	*RC 4E_g/t*	*DDH Thickness (m)*	*RC Thickness(m)*
Mean	1.33	0.75	3.34	3.39
Standard Error	0.02	0.02	0.10	0.05
Median	1.32	0.76	3.25	3.50
Mode	#N/A	0.88	3.41	3.50
Standard Deviation	0.19	0.29	1.03	0.92
Sample Variance	0.04	0.08	1.06	0.85
Coefficient of Variation	3%	11%	32%	25%
Kurtosis	71%	17%	307%	114%
Skewness	0.53	-0.04	1.14	0.17
Range	0.96	1.65	6.01	6.50
Minimum	0.90	0.05	1.22	0.50
Maximum	1.87	1.70	7.23	7.00
Count	95.00	353.00	113.00	414.00

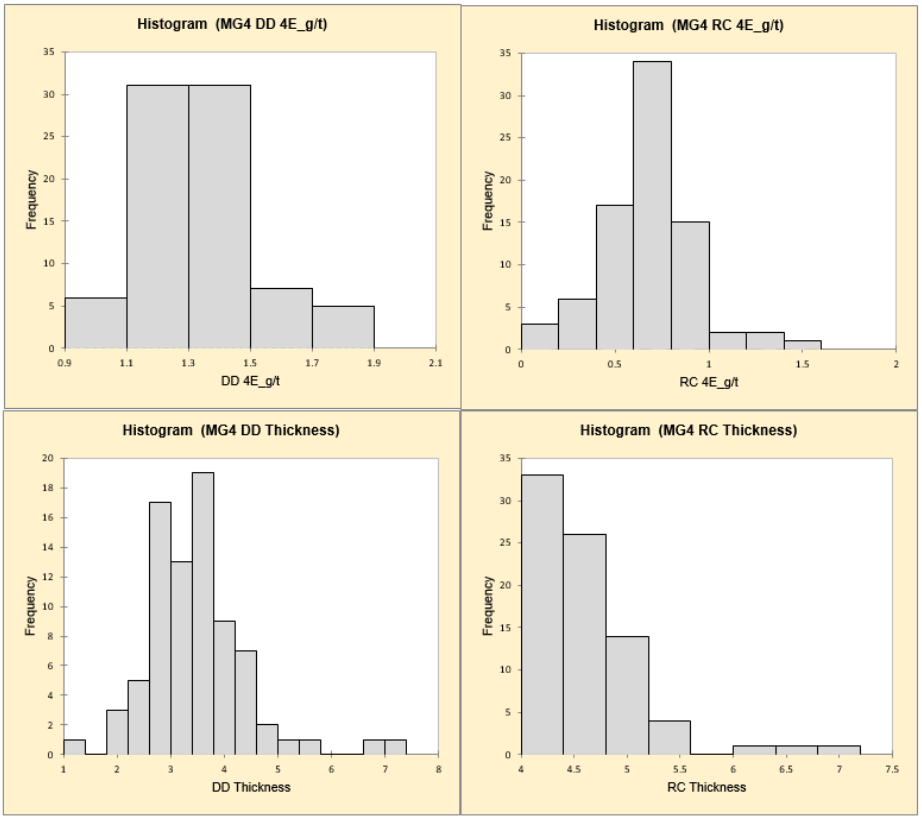

Figure 19: Histograms of MG4 4E g/t and Thicknesses in RC and DDH

4.3.5 MG4A

MG4A DDH and RC descriptive statistics indicate that the 4E values in DDH have a similar mean grade to the 4E values in RC samples (Table 11). The CV of grades in DDH is lower than in the RC samples. The mean thickness in RC samples is higher than the mean thickness in DDH. The higher thickness at a lower 4E grade in the RC sample can be attributed to dilution introduced by the 50cm fixed sampling interval. The CV of sample thickness in RC is lower than in DDH.

Figure 20 is a graphical presentation of the 4E grades in RC samples and 4E grades in DDH as well as histograms of seam thicknesses observed in RC and DDH. 4E grades and Thicknesses DDH are of Normal distribution. Thicknesses in RC samples are of positively skewed distribution.

Table 11: Descriptive statistics of MG4A 4E g/t and Thicknesses in RC and DDH

Statistical Parameter	*DD 4E_g/t*	*RC 4E_g/t*	*DD Thickness (m)*	*RC Thickness (m)*
Mean	0.56	0.40	2.27	2.27
Standard Error	0.01	0.01	0.06	0.03
Median	0.55	0.39	2.29	2.00
Mode	#N/A	0.40	2.80	2.00
Standard Deviation	0.09	0.20	0.65	0.66
Sample Variance	0.01	0.04	0.42	0.44
Coefficient of Variation	1%	10%	18%	19%
Kurtosis	711%	2271%	208%	431%
Skewness	1.85	3.30	-0.33	0.70
Range	0.60	2.07	4.12	6.03
Minimum	0.40	0.00	0.15	0.47
Maximum	1.00	2.07	4.27	6.50
Count	92.00	340.00	113.00	405.00

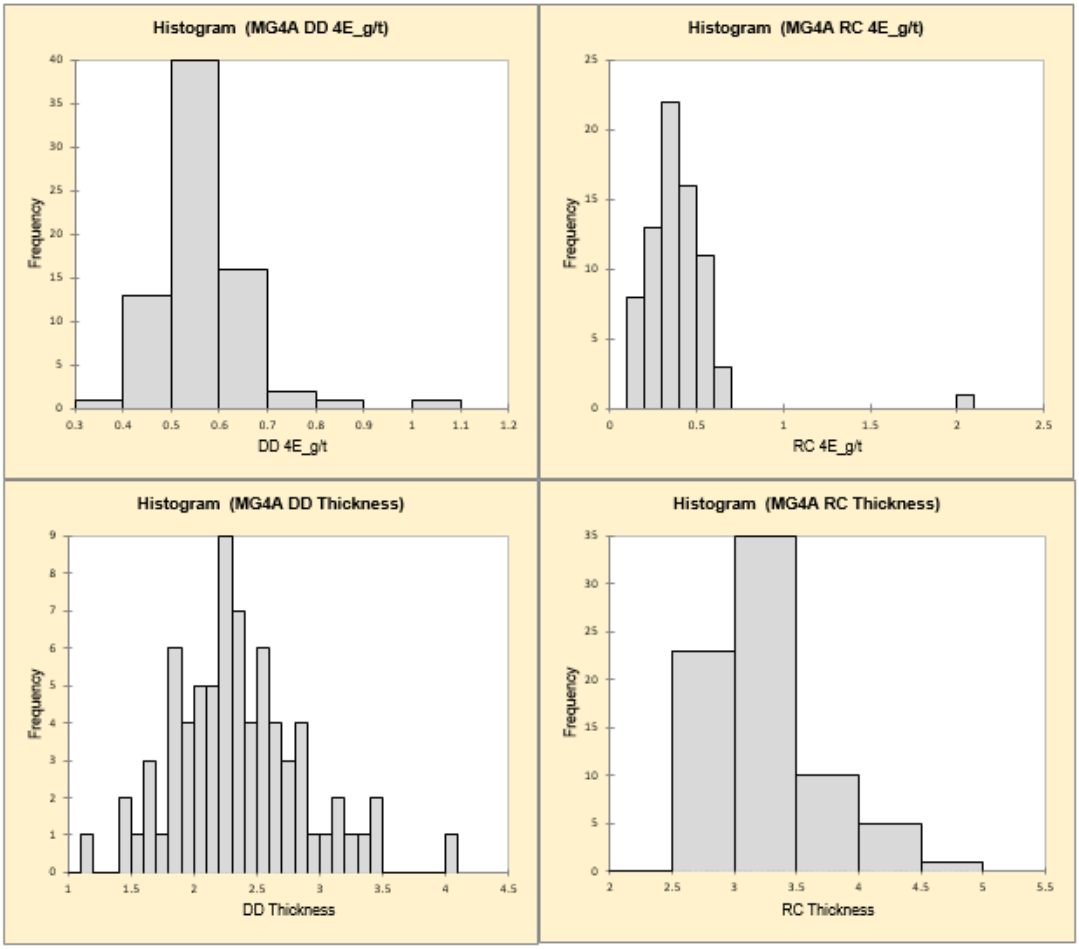

Figure 20: Histograms of MG4A 4E g/t and Thicknesses in RC and DDH

The descriptive statistics indicates that the RC samples misrepresents the seam thicknesses and the grades (4E g/t). The RC drilling method is not reliable for the sampling of Middle Group seams at Tharisa Mine.

In summary the following observations can be drawn from the histograms and descriptive stats.

- Overall, the reported 4E grades in RC samples are lower than the 4E grades in DDH due to contamination across the lithological boundaries.
- RC chip samples tend to exaggerate the seam thickness of the MG1, MG2 and MG4 due to the inability to pinpoint the contacts between the barren zones and ore zones
- RC understates the thickness of MG3 as the top stringer is not easily recognized.
- There is high variability in DDH thicknesses, which is not captured in the RC data, due to the regular sampling interval.
- There is high variability in 4E grades from RC sampling than in DDH assay results.

In conclusion, RC sampling is not an appropriate method to use for the thickness estimation/identification as it does not give a true representation of the seam intersections. The discrepancy in the 4E grades could not be solely attributed to the RC sampling method as there were two different methods of assay analysis used.

4.3.6 Hypothesis testing

Hypothesis testing is a statistical method used to test an assumption regarding a population distribution parameter. The purpose of hypothesis testing is to draw conclusions on the basis of data obtained from a sample of that population. Hypothesis testing is a method used to assess the strength of evidence from the sample and provides context for deciding how well one can extrapolate observations in the studied sample to the larger population where the sample was taken.

The first step in hypothesis testing is to formulate a null hypothesis and alternative hypothesis. The second step is to decide on the significance level, which sets the level of probability of rejecting the null hypothesis. Once the significance level is set, the areas of rejections are drawn. In step 3, an appropriate statistical test is conducted. In Step 4, the last step, the investigator decides whether to accept or reject the null hypothesis.

Two methods of hypothesis testing were selected for significance testing the difference between 4E grades in RC samples and 4E grades in DDH samples. *Fischer's hypothesis test* is used to test for similarities between the sample variances, *T-test* with unequal variance is selected for testing the similarities between two sample means.

4.3.7 Fisher's F-test / Two-tailed test:

95% confidence interval on the ratio of variances:

Test interpretation:

H0: The ratio between the variances is equal to 1.

Ha: The ratio between the variances is different from 1.

Table 13 that indicates that a computed p-value for all seam values is less than the significance level alpha=0.05; one should accept the reject the null hypothesis H0 for all seams except for MG3 where the computed p-value for all seam values is greater than the

significance level alpha=0.05, the null hypothesis H0 cannot be rejected. It can be observed that for all seams except for MG3 that there is a significant difference between F observed and F critical value (Figure 21).

Table 12: F-test results for all seams

	MG1	MG2	MG3	MG4	MG4A
Ratio	0.125	0.317	1.381	0.428	0.202
F (Observed value)	0.125	0.317	1.381	0.428	0.202
|F| (Critical value)	1.458	1.359	1.383	1.364	1.369
DF1	60	95	82	94	91
DF2	249	352	342	334	331
p-value (Two-tailed)	<0.0001	<0.0001	0.051	<0.0001	<0.0001
Alpha	0.050	0.050	0.050	0.050	0.050

4.3.8 T-test for two independent samples / Two-tailed test:

95% confidence interval on the difference between the means:

H0: The difference between the means is equal to 0.

Ha: The difference between the means is different from 0.

Table 14 that indicates that the computed p-value is lower than the significance level alpha=0.05 on all seams; one should reject the null hypothesis H0, and accept the alternative hypothesis, Ha. It can be observed that for all seams except for MG3 that there is a significant difference between t-observed and t-critical value (Figure 22). It is, therefore, concluded that there is a statistically significant difference between 4E values in RC and 4E values in DDH. The t- observed value is 6 to 23 units away from the t critical value. This indicates that RC sampling may not be an appropriate method to use for the Middle Group seams.

Table 13: T-test results for all seams

Difference	0.125	0.574	0.432	0.589	0.155
t (Observed value)	6.615	24.740	10.954	23.759	10.750
|t| (Critical value)	1.969	1.969	1.966	1.970	1.967
DF	272.357	273.759	424	231.221	337.071
p-value (Two-tailed)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Alpha	0.050	0.050	0.050	0.050	0.050

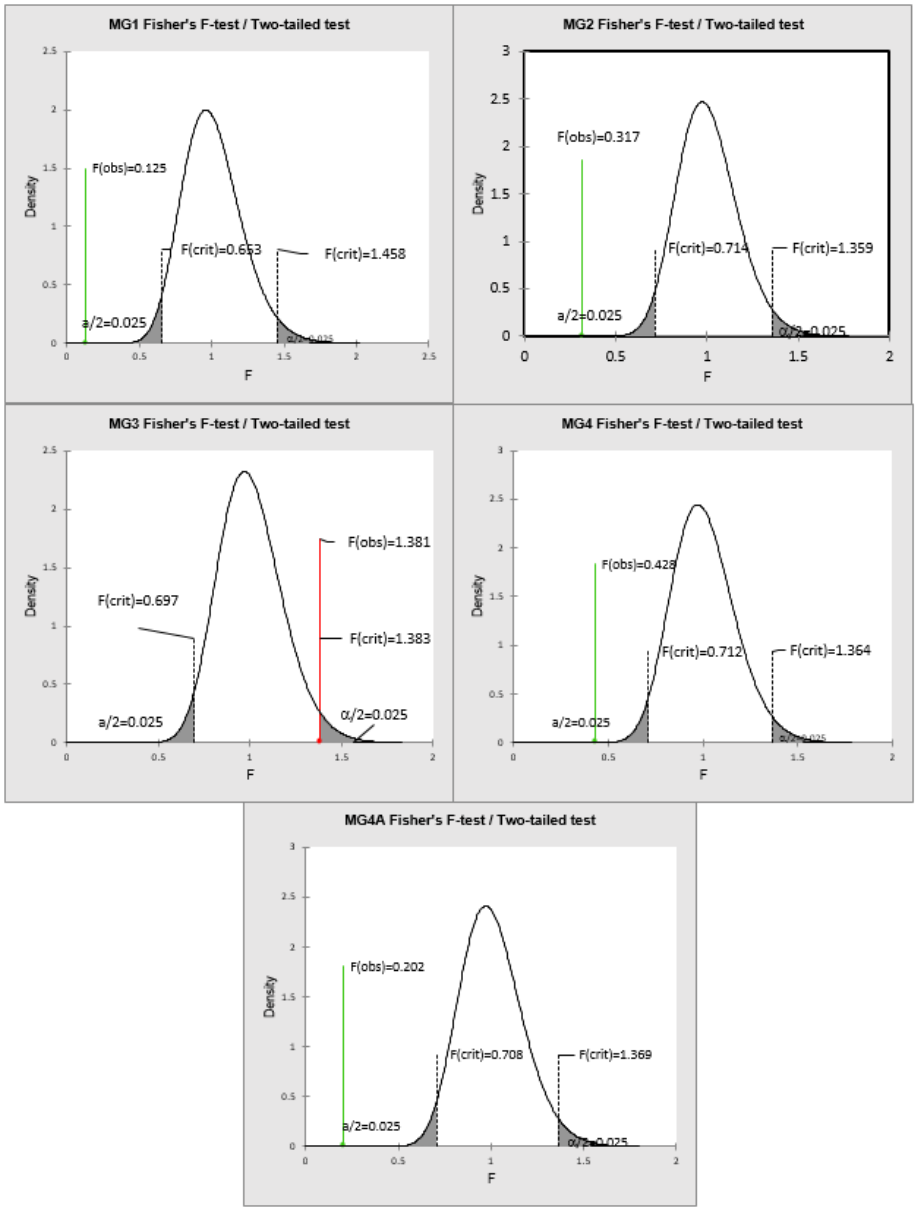

Figure 21: F-test distribution plots illustrating areas of rejection.

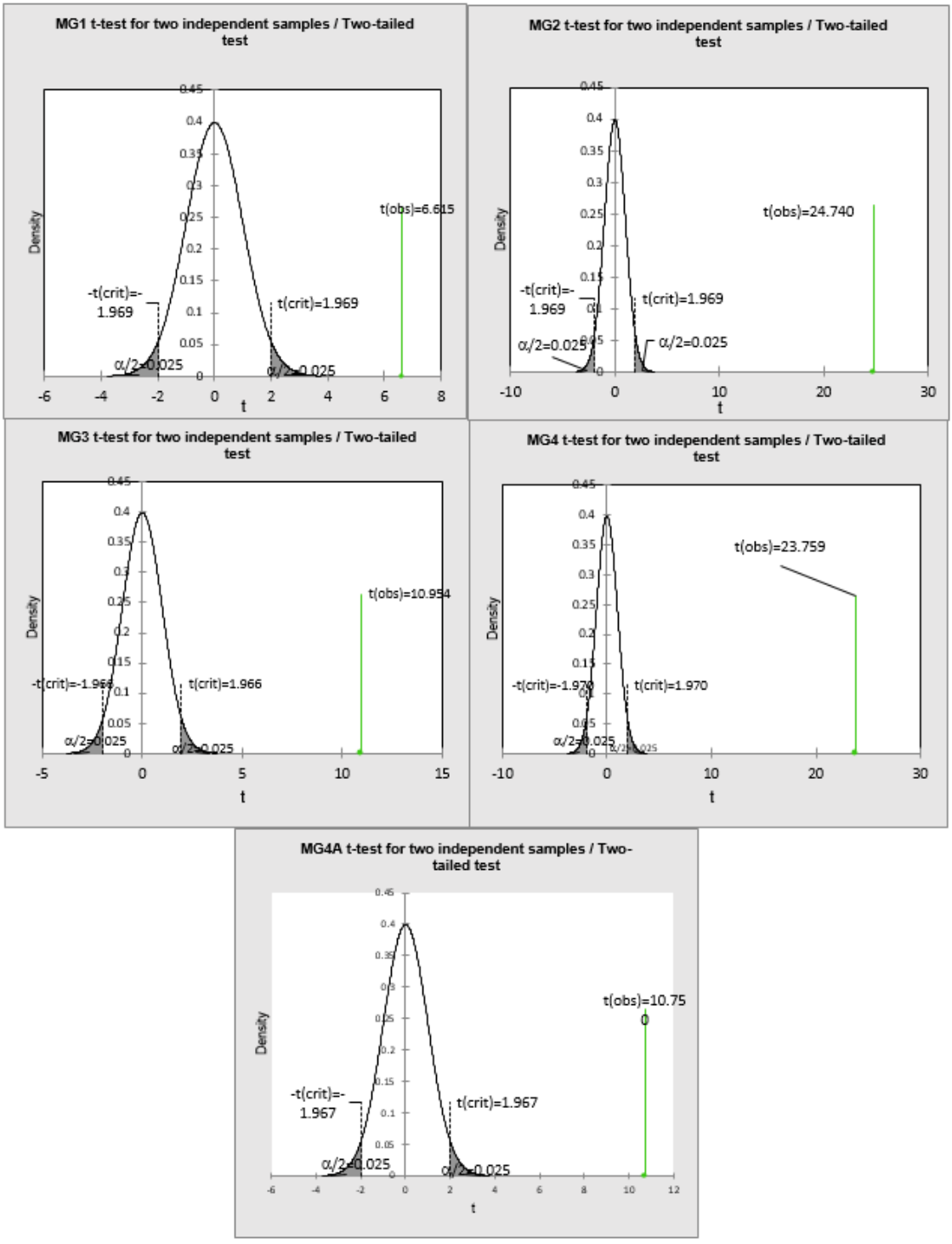

Figure 22: T-test distribution plots illustrating areas of rejection.

In conclusion, the hypothesis test indicates strong evidence that there is significant difference between 4E values in DDH and RC drilling samples.

4.4 Sampling uncertainty

4.4.1 Twin drilling

Although twin drilling has been used as a traditional technique for verification of intersection of high-grade mineralization and testing of historic data, it also finds use in understanding uncertainty in sampling (Abzalov, 2009). Twinned diamond holes (dataset 2) were drilled at Tharisa Mine to compare RC seam intersection to the DDH seam intersections. It is important to note that the drilled twin holes are not in the same position and cannot be used for a direct comparison. The location of the twinned holes is shown in Figure 23, the holes with prefix "KIP" are DDH holes whereas the holes with prefix "E" are RC drilled holes. The twins of interest are shown in red circles, both in the North and the South of the area. The distance between KIP359 and E1017RCD696 is 4.2m, distance between KIP360 and E1017RCD697 is 6.8m and distance between KIP283 and E1015RC390 is 10m.

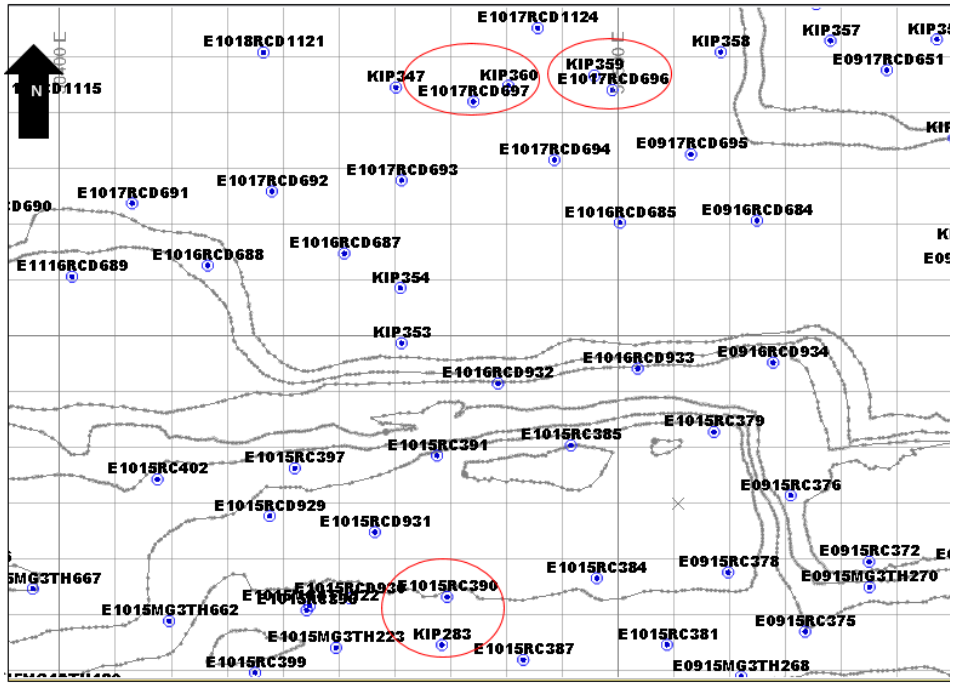

Figure 23 : Location plot of twinned drillholes

An indicative comparison, for both thickness and 4E grades, between RC and Diamond drillholes is shown in Table 15 below. The figures clearly indicate that the thicknesses estimated in RC holes are greater than those actually measured in diamond drillholes. Furthermore, the 4E values in RC are generally lower than the grades in DDH; this is attributed to dilution from the fixed sampling interval of 0.5m which includes sampling across

lithological boundaries. The comparison is further illustrated by means of the percentage-absolute relative difference (ARD) plot (Figure 24). The ARD plot indicates that the variance in weighted 4E g/t per seam increases as the distance between RC and DDH increases. It is noteworthy to point out that there tends to be no relationship between thickness and distance.

Table 14: Comparison between RC holes and DDH.

	Diamond drillholes			RC holes			Stats			
Stratigraphy	BHID	DD SeamThickness	DD Tharisa lab 4E g/t	BHID	RC Seam Thickness	RC Tharisa lab 4E	Mean 4E g/t	Mean Thickness (m)	%Absolute difference 4E g/t	%Absolute difference Thickness (m)
MG2	KIP359	7.12	0.49	E1017RCD696	6	0.56	0.53	6.56	13%	17%
MG2	KIP360	4.17	1.01	E1017RCD697	4.5	0.87	0.94	4.34	15%	8%
MG2	KIP283	3.68	1.48	E1015RC390	5	0.61	1.05	4.34	83%	30%
MG3	KIP359	5.05	0.7	E1017RCD696	6	0.66	0.68	5.53	6%	17%
MG3	KIP360	1.12	1.2	E1017RCD697	1.5	1.23	1.22	1.31	2%	29%
MG3	KIP283	2.27	1.22	E1015RC390	2.5	0.93	1.08	2.39	27%	10%
MG4	KIP359	3.25	1.48	E1017RCD696	3	1.06	1.27	3.13	33%	8%
MG4	KIP360	2.87	1.37	E1017RCD697	2.5	0.884	1.13	2.69	43%	14%
MG4	KIP283	3.82	0.87	E1015RC390	4	0.81	0.84	3.91	7%	5%
MG4A	KIP359	1.7	1.2	E1017RCD696	2	0.69	0.95	1.85	54%	16%
MG4A	KIP360	1.17	1.4	E1017RCD697	2	0.36	0.88	1.59	118%	52%
MG4A	KIP283	1.21	1.07	E1015RC390	1.5	0.18	0.63	1.36	142%	21%
Average									45%	19%

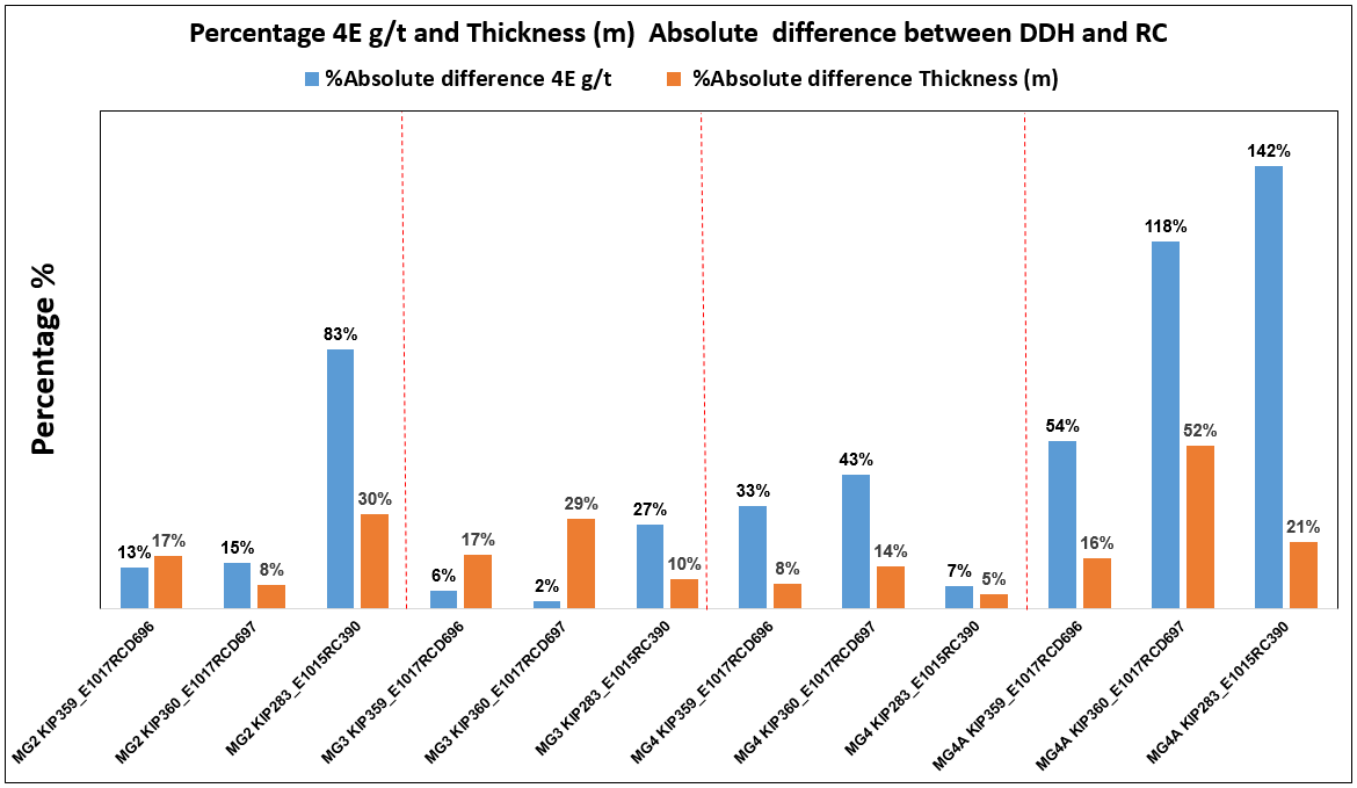

Figure 24: Comparison between RC holes and DDH within 10m radius.

Overall, RC sampling exaggerates the thicknesses of the seams. The reported 4E grades in RC are lower than the 4E grades reported in the DDH. The biggest factor contributing to the variation in 4E g/t grades is mostly the fact that the Twin holes are not in the exact same location.

4.4.2 Replicate design for estimating sampling uncertainty

A replicate design method is said to be the simplest and most cost-effective method of calculating uncertainty associated with sampling and analytical processes. The basic principle of replicate design is to apply the same sampling procedure two or more times on the same or different targets with the aim of estimating the contribution of sampling and analytical processes to measurement uncertainty.

Replicates samples (dataset 3) for this research were created by collecting two sample splits from the built-in splitter at the rig. Both samples were split further at the laboratory into two samples using a rotary splitter after pulverising (Figure 25). This is done to test both analytical and sampling uncertainty. The samples were assayed at Tharisa laboratory for 4E g/t, using Pb collection method.

The calculations presented in Figures 27 and 28 were drawn from a Nordtest handbook for sampling planners and sampling quality assurance and uncertainty estimation. (Grøn, et al., 2007).

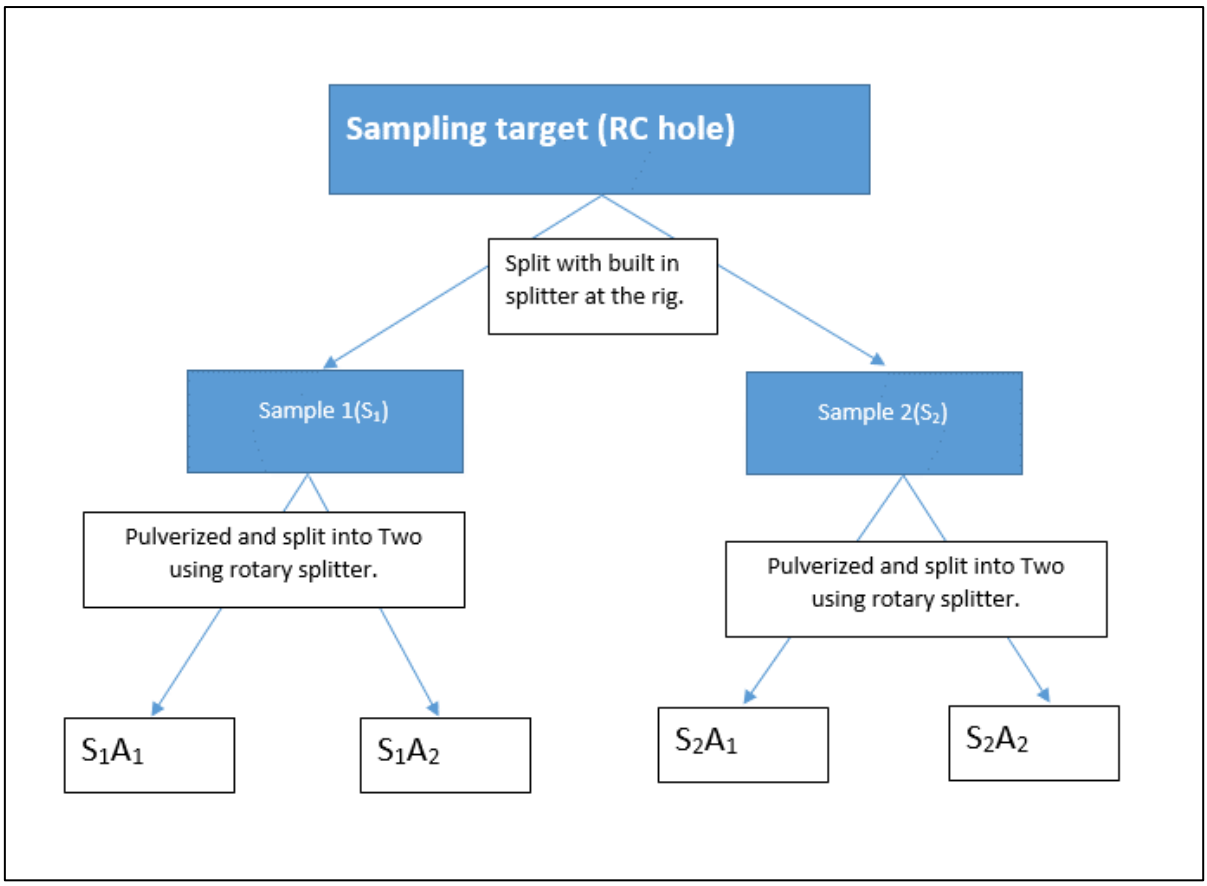

Figure 25 : The principle of replicate design with double split.

Table 12 indicates the descriptive statistics of the replicate samples; it is clear that the four groups of samples are similar, with S1A1 and S1A2 having a slightly higher mean than S2A1 and S2A2. All sample groups have similar standard deviation, with S2A1 having the lowest standard deviation. The graphical representation of the relationships between sample pairs is captured by means of box plots (Figure 26). The box plots indicates that S1A1 and S1A2 have wider range and higher mean than S2A1 and S2A2.The replicate samples appear to be from a normal distribution.

Table 15: Descriptive statistics (Quantitative data)

Statistic	S1A1	S1A2	S2A1	S2A2
Number of observations	22	22	22	22
Minimum	0.250	0.280	0.140	0.030
Maximum	1.660	1.910	1.610	1.680
1st Quartile	0.643	0.635	0.668	0.655
Median	0.925	0.895	0.890	0.880
3rd Quartile	1.230	1.358	1.033	1.000
Mean	0.939	0.965	0.883	0.852
Variance (n-1)	0.162	0.206	0.151	0.168
Standard deviation (n-1)	0.403	0.454	0.389	0.410

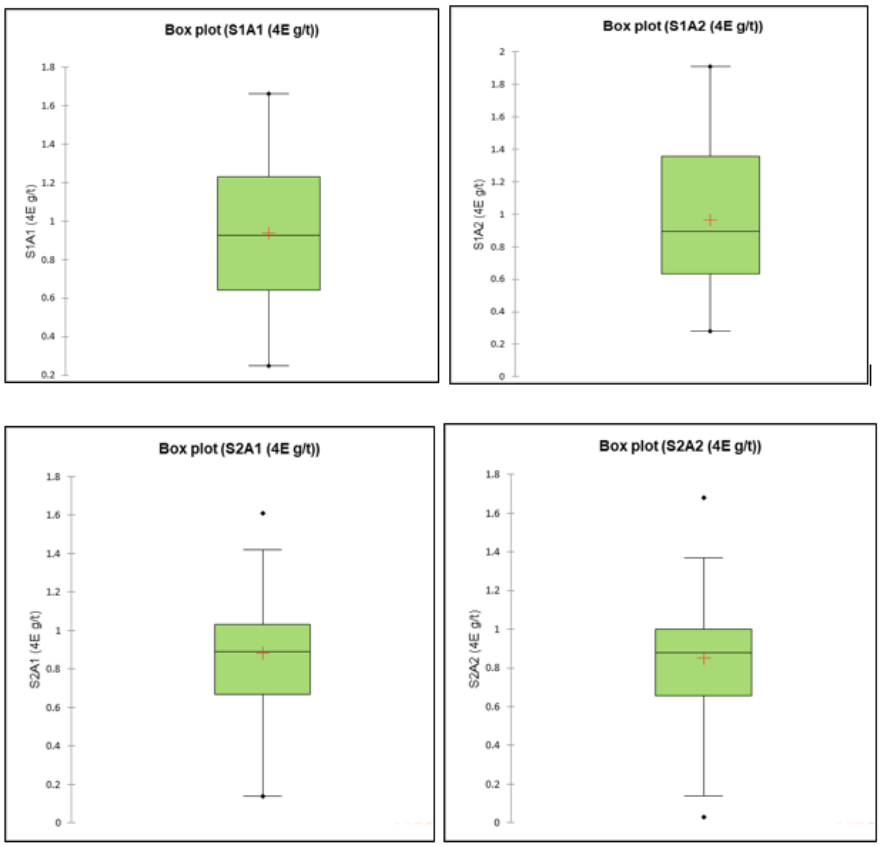

Figure 26: Box plot of replicate samples

One way Analysis Of Variances (ANOVA) is applied to estimate the variability in the assays due to analytical and sampling processes (Grøn, et al., 2007), (Figure 27 and Figure 28). Calculations from ANOVA indicate that the analytical standard deviation is 0.13g/t with a coefficcient of variation of 14%, whereas the sampling standard deviation is 0.19g/t with a coefficient of variation of 21%. Tharisa laboratory's acceptable analytical coeeficicient of

variation for 4E is 15%, which is more than the industry norm of 10%. Part of the reason for this is historical, to account for apparent heterogeneity of the material. The calculated sampling uncertainty is 0.041g/t. The variance between theSample 1 and Sample 2 can be attributed to sample heterogeneity.

Sample 1		Sample 2		S1	S2	S1	S2
S_1A_1	S_1A_2	S_2A_1	S_2A_2	$\bar{X}_{i1}$	$\bar{X}_{i2}$	$2 * D_{i1}^2$	$2 * D_{i2}^2$
1.08	0.95	1.04	0.95	1.015	0.995	0.01	0.00
1.66	1.45	1.42	1.37	1.555	1.395	0.02	0.00
1.37	1.43	0.97	0.99	1.4	0.98	0.00	0.00
0.62	0.82	0.64	0.78	0.72	0.71	0.02	0.01
0.84	0.74	0.61	0.70	0.79	0.655	0.00	0.00
1.07	1.23	0.94	0.92	1.15	0.93	0.01	0.00
1.46	1.71	1.61	1.58	1.585	1.595	0.03	0.00
1.58	1.91	1.59	1.68	1.745	1.635	0.05	0.00
1.28	1.59	0.82	1	1.435	0.91	0.05	0.02
0.83	0.61	0.79	0.64	0.72	0.715	0.02	0.01
0.71	0.76	0.84	0.7	0.735	0.77	0.00	0.01
0.91	0.87	1	0.84	0.89	0.92	0.00	0.01
1.46	1.40	1.14	1.10	1.43	1.12	0.00	0.00
0.46	0.44	0.72	0.60	0.45	0.66	0.00	0.01
0.40	0.53	1.01	1.00	0.465	1.005	0.01	0.00
0.95	0.92	0.99	0.99	0.935	0.99	0.00	0.00
0.71	0.71	0.79	0.79	0.71	0.79	0.00	0.00
0.44	0.36	0.37	0.27	0.4	0.32	0.00	0.01
1.03	1.02	0.14	0.03	1.025	0.085	0.00	0.01
0.94	0.92	1.21	1.15	0.93	1.18	0.00	0.00
0.6	0.57	0.65	0.52	0.585	0.585	0.00	0.01
0.25	0.28	0.14	0.14	0.265	0.14	0.00	0.00
					Sum	0.25	0.10

Mean	0.91 g/t	
df **analysis**	**44**	
$V_{analysis}$	**= $SS_{E\text{-}analysis}$ / $df_{analysis}$ = 0.02**	
$s_{analysis}$	**= 0.13g/t**	
CV	**= $s_{analysis}$/Mean* 100 = 14 %**	
u	**= $s_{analysis}$/sqrt(n)**	**= 0.02g/t**

$$SS_{E\text{-}analysis} = 2 * \sum_{i=1}^{10} [D_{i1(\bar{x})}^2 + D_{i2(\bar{x})}^2]$$

= 0.6976g/t

Figure 27: ANOVA calculation for analytical uncertainty

The analytical CV of 14% implies that the laboratory is consistent in analyzing the samples; it indicates a higher level of precision on the analytical process and it is within the laboratory accepted CV.

Sample 1		Sample 2		S1	S2	$\bar{X}_i$	$(D_{i(\bar{x})})^2$
X_{i11}	X_{i12}	X_{i21}	X_{i22}	$\bar{X}_{i1}$	$\bar{X}_{i2}$	$(X_{i1}+X_{i2})/2$	$(\bar{X}_i-\bar{x}_{i1})^2=(\bar{X}_i-\bar{x}_{i2})^2$
1.08	0.95	1.04	0.95	1.015	0.995	1.01	0.00
1.66	1.45	1.42	1.37	1.555	1.395	1.48	0.01
1.37	1.43	0.97	0.99	1.4	0.98	1.19	0.04
0.62	0.82	0.64	0.78	0.72	0.71	0.72	0.00
0.84	0.74	0.61	0.70	0.79	0.655	0.72	0.00
1.07	1.23	0.94	0.92	1.15	0.93	1.04	0.01
1.46	1.71	1.61	1.58	1.585	1.595	1.59	0.00
1.58	1.91	1.59	1.68	1.745	1.635	1.69	0.00
1.28	1.59	0.82	1	1.435	0.91	1.17	0.07
0.83	0.61	0.79	0.64	0.72	0.715	0.72	0.00
0.71	0.76	0.84	0.7	0.735	0.77	0.75	0.00
0.91	0.87	1	0.84	0.89	0.92	0.91	0.00
1.46	1.40	1.14	1.10	1.43	1.12	1.28	0.02
0.46	0.44	0.72	0.60	0.45	0.66	0.56	0.01
0.40	0.53	1.01	1.00	0.465	1.005	0.74	0.07
0.95	0.92	0.99	0.99	0.935	0.99	0.96	0.00
0.71	0.71	0.79	0.79	0.71	0.79	0.75	0.00
0.44	0.36	0.37	0.27	0.4	0.32	0.36	0.00
1.03	1.02	0.14	0.03	1.025	0.085	0.56	0.22
0.94	0.92	1.21	1.15	0.93	1.18	1.06	0.02
0.6	0.57	0.65	0.52	0.585	0.585	0.59	0.00
0.25	0.28	0.14	0.14	0.265	0.14	0.20	0.00
					Sum	20.01	0.49

Mean	**0.91 g/t**	
$df_{sampling}$	**22**	$SS_{sampling}=4*\sum_{i=1}^{10}\left[\left(D_{i(\bar{x})}\right)^2\right]$ = 1.9685 g/t
$SS_{E-analysis}=2*\sum_{i=1}^{10}[D^2_{i1(\bar{x})}+D^2_{i2(\bar{x})}]$ = 0.6976g/t		
$V_{sampling}$	**= ((SS$_{sampling}$ / df$_{sampling}$) -(SS$_{E\text{-}analysis}$ / df$_{analysis}$))/2 = 0.0368**	$df_{analysis}$ 44
$s_{sampling}$	**= 0.192g/t**	
$CV_{sampling}$	**= s$_{sampling}$/Mean* 100 = 21 %**	
$u_{sampling}$	**= s$_{sampling}$/sqrt(n) = 0.041g/t**	

Figure 28: ANOVA calculation for sampling uncertainty

The coefficient of variation of 21% for sampling is slightly higher than the accepted 20% for the coarse splits. This indicates that sampling method contributes more to the overall uncertainty of the grades than the analytical method. This emanates from the sampling errors introduced during sample collection.

4.4.3 RC dust sample

A sample (dataset 49) of dust was collected from the cyclone chimney after three days of drilling. The sample was split into three samples and submitted to Intertek laboratory for analysis. Although the collected data was insufficient for a proper statistical analysis, assay results of dust samples indicated that there is about 0.3g/t of 4E lost to dust per three drilled hole over three days, with platinum making up 83% of the lost PGEs. The details of dust analysis are presented in Table 16.

Table 16: 4E g/t analysed by NiS in assayed RC dust.

Sample ID	Sample type	Au g/t	Pt g/t	Pd g/t	Rh g/t	4E g/t
E1693	RC Dust	0,002	0,257	0,025	0,021	0,305
E1694	RC Dust	0,003	0,252	0,022	0,019	0,296
E1695	RC Dust	0,003	0,273	0,025	0,017	0,318

More data must be collected for a proper statistical analysis, as the assayed samples indicates that there might be a significant loss over the seam intersections. The assay results indicate that more effort needs to be directed towards minimizing losses of PGE to dust in the RC drilling process.

4.5 Analytical uncertainty

4.5.1 Two-way laboratory DDH pulp check samples

A split sample of DDH pulps (dataset 4) with existing NiS assay results were submitted to the Tharisa laboratory for 4E analysis using Fire assay with Pb collection. In comparing the distributions of the two datasets 4E values analysed by NiS histogram (Figure 29) appeared to be positively skewed and 4E values analysed by Pb collection appeared to positively skew with lower frequency between 1.2g/t and 0.4g/t (Figure 30).

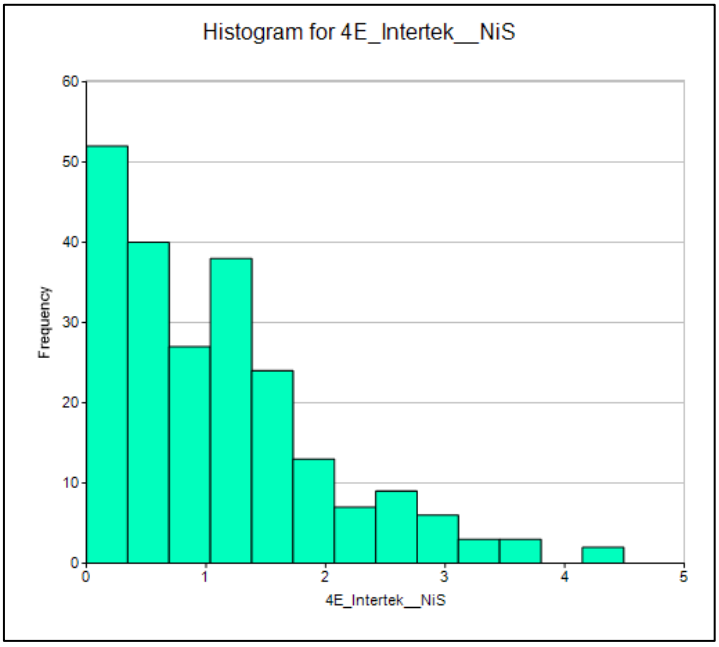

Figure 29: Histogram of 4E values analysed by fire assay with NiS

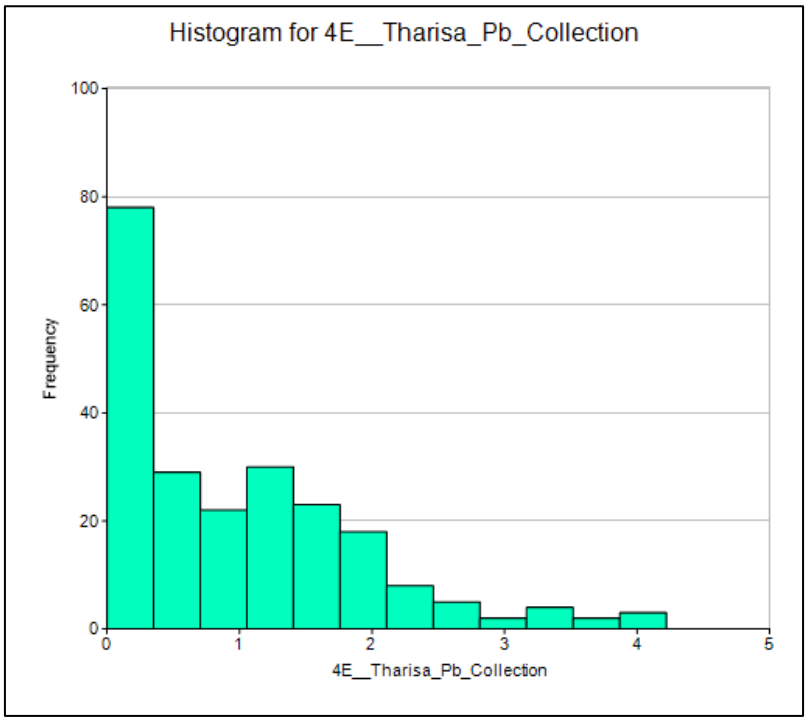

Figure 30: Histogram of 4E values analysed by fire assay with Pb collection

The cumulative probability plot suggests that there are three distinct populations (Figure 31). This corresponds to what is known about the ore body, MG4A and MG1 have 4Eg/t of <1 g/t MG3, MG4 has 4E grades between 1g/t and 2g/t and MG2 has grades greater than 2g/t in the chromitite bands. Where the results exhibit a skewed distribution, the calculated uncertainty (x) will be reflected in terms of the skewed interval as $x - Ul$ to $x + Uu$, where Ul refers to the lower limit and Uu refers to the upper limit of uncertainty. The skewness must be taken into consideration when reporting an uncertainty interval greater than 15 to 20% where transformation should be done prior to calculating uncertainty.

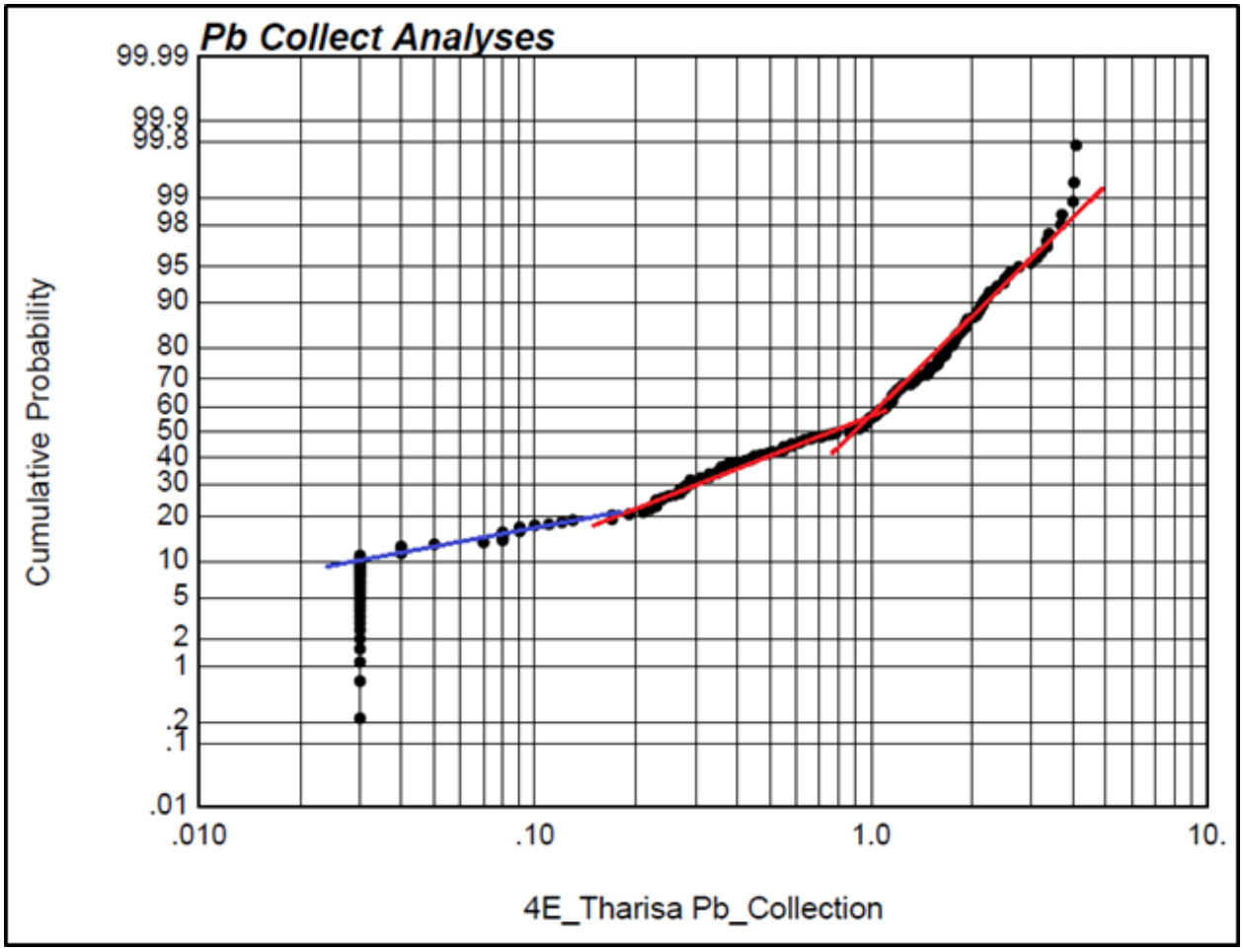

Figure 31: Cumulative probability plot of 4Eg/t Pb collection and 4Eg/t NiS

Quantile quantile (QQ) plot of the of the 4E values analysed Pb collection samples and 4E values analysed by NiS indicates Tharisa laboratory 4E by Pb collection under reports values less than 0.98 g/t and values above 2g/t (Figure 32). This is due to the difference in assaying techniques. There is a moderate, positive linear correlation between 4E Pb collection and 4E NiS, with a coefficient of correlation of 0.59 (Figure 33). This indicates that the difference in assaying techniques contributes to the difference in the 4E values from DDH and RC samples.

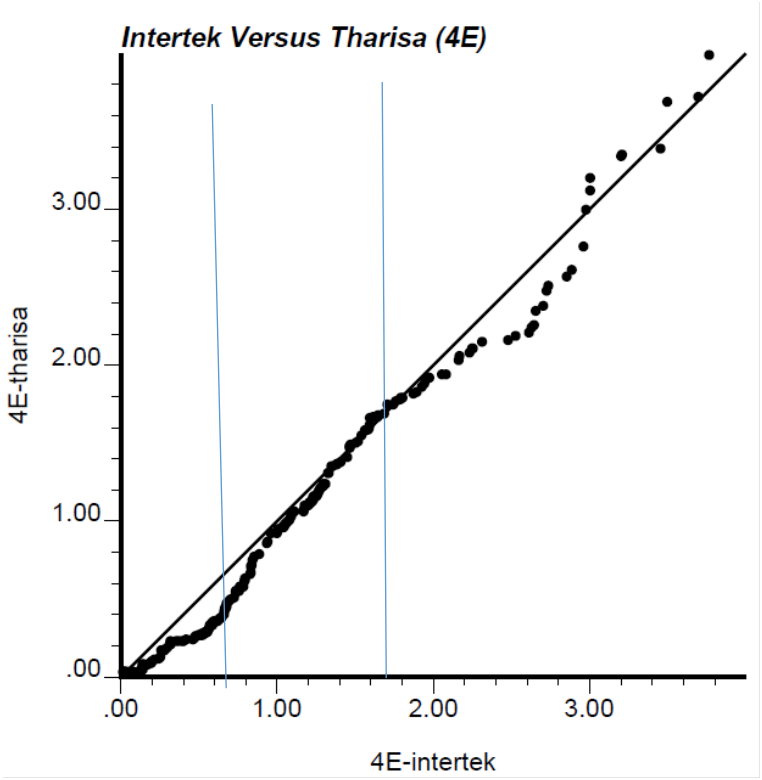

Figure 32: QQ-Plot 4E g/t Intertek Nis versus 4E g/t Tharisa Pb Collection from DDH

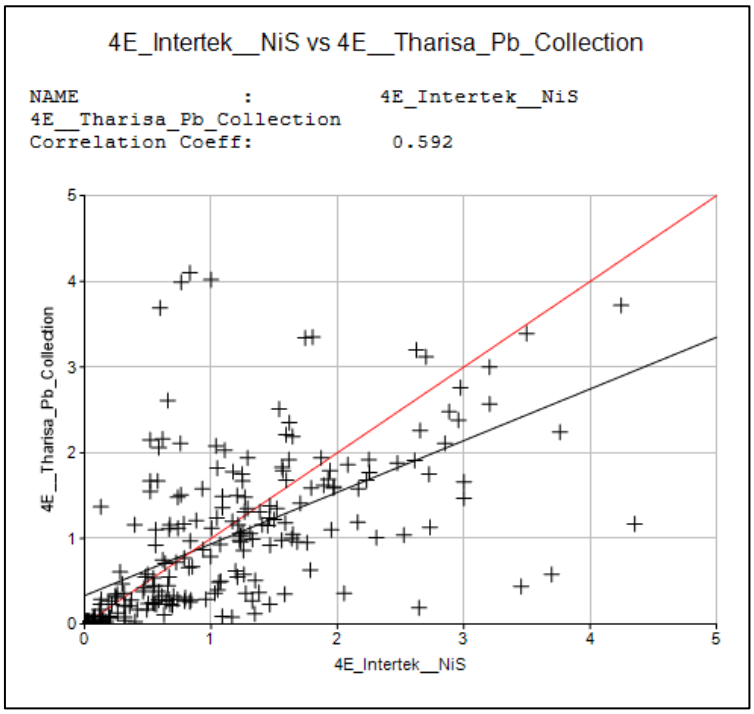

Figure 33: Scatter Plot 4E g/t Intertek NiS versus 4E g/t Tharisa Pb Collection from DDH samples

4.5.2 Two–way laboratory RC drilling pulp check samples

RC drilling pulp samples (dataset 5) from Tharisa laboratory were sent to Intertek laboratory to be analysed by NiS. The RC drilling samples were initially analysed by Pb collection at Tharisa laboratory.

QQ plot of the two RC samples 4E values analysed by NiS versus 4E values analysed by Pb collection indicates Tharisa laboratory 4E by Pb collection under reports values less than 0.95 g/t and over reports values above 1.5g/t (Figure 34). Similarly, this is due to the difference in assaying techniques. The Scatter plot (Figure 35) indicates a similar correlation of 0.602 as compared DDH samples coefficient of correlation of 0.592. This reiterates that the difference in assaying techniques contributes to the difference in the4E values from DDH and RC samples.

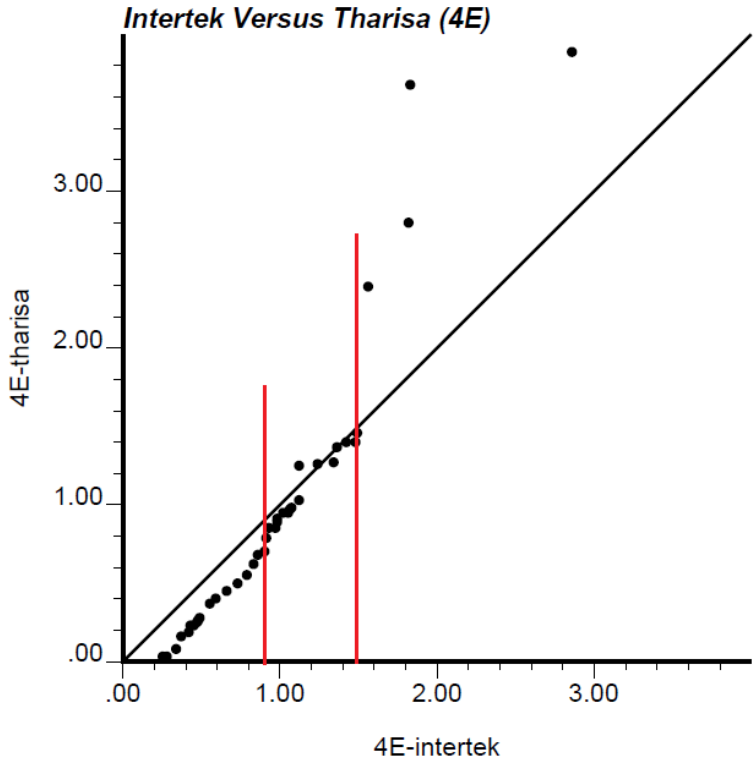

Figure 34: QQ- Plot 4E g/t Intertek NiS versus 4E g/t Tharisa Pb Collection from RC holes

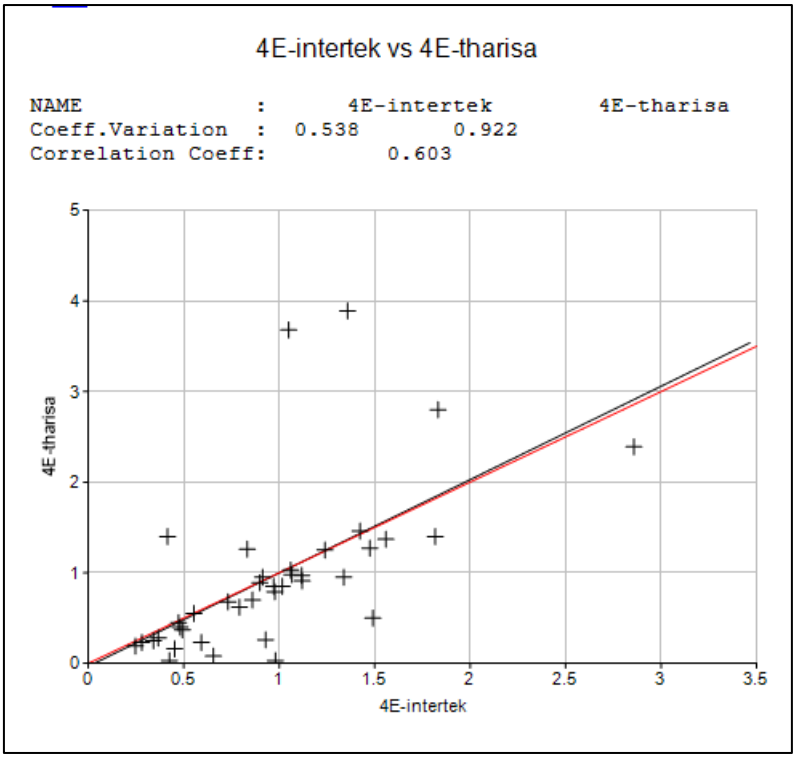

Figure 35: Scatter Plot 4E g/t Intertek NiS versus 4E g/t Tharisa Pb Collection from RC hole samples.

4.5.3 "Blind" CRM inserts and RC Field duplicates

Uncertainty calculations were carried out using 4E g/t values from 163 samples of CRM AMIS0717, 166 samples of CRM AMIS723 and 155 field duplicates (dataset 6 and 7) analysed with RC samples between 1st August 2018 and 1st February 2021 (Figure 36). Calculations on laboratory reproducibility using field duplicates and AMIS0723 showed a laboratory reproducibility of 0.43g/t; the highest contributing source was field duplicates indicated at standard uncertainty of 0.40g/t.

4E values from AMIS0717 and AMIS0723 samples were then used to calculate the bias. Calculated bias for AMIS723 analysed 4Eg/t is negative 0.18g/t whereas the calculated bias for AMIS0717 is negative 0.03g/t. The resulting average bias is 0.13g/t, with the total bias of 0.14g/t that is taking the CRM into account.

The high systematic uncertainty calculated from the duplicates indicates that the 4E g/t Pb collection measurements are not precise and the bias shows that there are accuracy issues.

<table>
<tr><th>Step</th><th>Action</th><th>Pb Collection</th><th>2/25/2021</th></tr>
<tr><td>1</td><td>Specify Measurand</td><td colspan="2">Measurand: 4E
Concentration range: 0.003 - 5 ppm
Sample Type (Matrix): Pulp of Middle group seams</td></tr>
<tr><td>2</td><td>Quantify within-laboratory reproducibility, $u(R_w)$

A: Control sample
B: Possible steps not covered by control sample</td><td colspan="2">A: Control samples:
Number of control samples: 166
Average concentration: 0.81596 ppm
Standard deviation, s_{Rw} : 0.16 ppm

B: Routine replicate samples :
Number of routine replicate series: 1576
Number of parallell measurements: 2
Concentration range: 0.03 - 4.325 ppm
Pooled standard deviation, s_r : 0.40 ppm

$u(R_w) = \sqrt{s_{Rw}{}^2 + s_r{}^2}$ = 0.43 ppm</td></tr>
<tr><td>3</td><td>Quantify method and laboratory bias, $u(bias)$</td><td colspan="2">Method and laboratory bias from certified reference material:
Different certified reference materials count, N : 2
<table>
<tr><td>i</td><td>1</td><td>2</td></tr>
<tr><td>Certified concentration, $c_{ref\,i}$</td><td>0.994 ppm</td><td>0.697 ppm</td></tr>
<tr><td>Standard uncertainty of certified concentration, $u(c_{ref})$</td><td>0.10 ppm</td><td>0.01 ppm</td></tr>
<tr><td>Measured concentration, c_i</td><td>0.81596 ppm</td><td>0.66264 ppm</td></tr>
<tr><td>Standard deviation of measured concentration, s_{bias}</td><td>0.16 ppm</td><td>0.01 ppm</td></tr>
<tr><td>Number of Measurements, n_i</td><td>166</td><td>163</td></tr>
<tr><td>$bias_i = c_i - c_{ref\,i}$</td><td>-0.18 ppm</td><td>-0.03 ppm</td></tr>
<tr><td>Period of measurements</td><td>-</td><td>-</td></tr>
<tr><td>Sample Type (Matrix)</td><td>Pulp of Middle group seams</td><td>Pulp of Middle group seams</td></tr>
<tr><td>Additional information</td><td></td><td></td></tr>
</table>
$u(c_{ref}) = \frac{\sum_{i=1}^{N} u(c_{ref\,i})}{N}$ = 0.06 ppm

$RMS_{bias} = \sqrt{\frac{\sum_{i=1}^{N} bias_i{}^2}{N}}$ = 0.13 ppm

$u(bias) = \sqrt{RMS_{bias}{}^2 + u(c_{ref})^2}$ = 0.14 ppm</td></tr>
<tr><td>4</td><td>Convert components to standard uncertainty</td><td colspan="2">$u(R_w)$ = 0.43 ppm
$u(bias)$ = 0.14 ppm</td></tr>
<tr><td>5</td><td>Calculate combined standard uncertainty, u_c</td><td colspan="2">$u_c = \sqrt{u(Rw)^2 + u(bias)^2}$ = 0.45 ppm</td></tr>
<tr><td>6</td><td>Calculate expanded uncertainty, U</td><td colspan="2">$U = 2 \cdot u_c$ = 1 ppm</td></tr>
</table>

Figure 36: Uncertainty calculation using 4Eg/t of duplicate AMIS0723 and AMIS0717 samples analysed by Pb collection at Tharisa laboratory.

4.5.4 Cupels

Cupels were analysed by NiS method. The 3E g/t (platinum, palladium and gold) values in the cupels were all below Tharisa laboratory's detection limit of 0.03 g/t. The losses are therefore regarded as insignificant.

Table 17 indicates the assay results of the analyzed cupels.

Table 17: 3E g/t analysed by NiS in assayed Cupels.

Sample ID	Sample ty	Au	Pt	Pd	3E ppb	3Eg/t
E1654	cupel	X	9.8	15.5	25.3	0.0253
E1655	cupel	X	1.1	4.1	5.2	0.0052
E1656	cupel	X	2.3	3.6	5.9	0.0059
E1657	cupel	1	1.1	5.3	7.4	0.0074
E1658	cupel	X	1.2	6	7.2	0.0072
E1659	cupel	X	1.2	5.6	6.8	0.0068
E1660	cupel	X	1.3	5.5	6.8	0.0068
E1661	cupel	X	2.1	3.9	6	0.006
E1662	cupel	X	1.1	3.3	4.4	0.0044
E1663	cupel	X	1.6	6.8	8.4	0.0084
E1664	cupel	X	X	X		0
E1665	cupel	X	8.1	23.9	32	0.032
E1666	cupel	X	2.5	6.5	9	0.009
E1667	cupel	X	6.5	19.1	25.6	0.0256
E1668	cupel	X	18.2	68.7	86.9	0.0869
E1669	cupel	X	5.7	31.1	36.8	0.0368
E1670	cupel	X	16.3	38.9	55.2	0.0552
E1671	cupel	X	5.7	16.7	22.4	0.0224
E1672	cupel	X	16.2	57.8	74	0.074
E1673	cupel	X	16	22.4	38.4	0.0384
E1674	cupel	X	5	12.4	17.4	0.0174
E1675	cupel	X	X	0.9	0.9	0.0009
E1676	cupel	X	2.7	9.5	12.2	0.0122
E1677	cupel	X	3.1	6.5	9.6	0.0096
E1678	cupel	X	14.4	46.4	60.8	0.0608
E1679	cupel	X	8.6	28.8	37.4	0.0374
E1680	cupel	X	2.4	8.3	10.7	0.0107
E1681	cupel	5	1	2.1	8.1	0.0081
E1682	cupel	X	1.4	3.5	4.9	0.0049
E1683	cupel	X	5.5	13	18.5	0.0185
E1684	cupel	3	1.1	3.7	7.8	0.0078
E1685	cupel	3	1	3.2	7.2	0.0072
E1686	cupel	X	X	X		0
E1687	cupel	X	1.1	2.1	3.2	0.0032
E1688	cupel	2	4.6	8.6	15.2	0.0152
E1689	cupel	X	3.7	11.8	15.5	0.0155

5 SUMMARY OF FINDINGS

The uncertainty in the 4E assay results arises from a combination of errors in the sampling methods and the analytical processes.

5.1.1 Sampling errors

- The sampling procedure and sampling equipment violate sampling best practice because the conical splitter in the cyclone attached to the RC drill rig does not conform to the golden rule of equiprobability for sampling methods.
- The relatively narrow reef widths, the sharp contacts between the reef and the adjacent host rock, and the inability to measure the depth of the RC drill string accurately, means that estimates of reef thickness using the RC cuttings, are exaggerated. No matter how careful and diligent the RC driller is, the nature of the RC equipment and fine definition of the reef contacts make it impossible to measure the sample length accurately.
- The record of measurements and the twin hole drilling exercise indicate that the reef thickness measured by means of cuttings from RC holes is invariably greater than the thickness measured in the core recovered from DDH. The calculated average relative difference between RC and DDH measurements of reef thickness is 19%. This is mostly due to the fact that the samples were not taken at the exact spatial location.
- The 4E grades measured in sample material collected from RC cuttings are invariably lower than those in samples of core collected from DDH. A twin-drill hole exercise in which the RC and DDH holes were drilled as close to one another as possible, indicated that the average relative difference of 4E assay values in the RC samples compared to DDH samples is 45%.

  Hypothesis testing of the 4E grades in assays of samples from RC and DDH indicates a statistically significant difference between the assays at the 10% level of significance.
- The replicate experiment for sampling uncertainty indicated a coefficient of variation of 21% compared to an analytical uncertainty coefficient of variation of 14%. This proves that sampling method contributes more to the overall uncertainty of the grades than the analytical method.
- The dust sampling indicated that there are possible losses of PGEs to dust. More samples of RC dust must be analysed to confirm this assumption.

5.1.2 Analytical uncertainty

- The difference in analytical techniques is the principal contributor to the difference in the 4E values from DDH and RC samples. The NiS and Pb-collection analytical procedures differ significantly. NiS is used to assay the accurately selected core samples from the DDH, while Pb-collection is used to assay samples of chip cuttings from the RC drilling. The QQ-plots indicate that the two assay methods are unbiased at grades between 1g/t and 2g/t.
- QAQC analysis of CRMs, which is a generally used as a measure of accuracy, indicated that Pb collection method reports lower grades with high variability than the NiS. High levels of contamination were found in most blanks. Duplicate samples were inserted into the overall sample batches for submission, as part of QAQC to measure precision Poor correlation between original and duplicate samples using the Pb collection method suggests that there is poor repeatability, which translates to imprecision in reported 4E grades in RC samples. Assay results from Pb collection method are considered unreliable.

6 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

Sampling plays a significant role in day-to-day grade control and plant feed decisions at Tharisa Mine. Significant financial resources are spent monthly on RC drilling and assaying of RC samples for 4E grades but the results are currently not utilised in any grade estimation processes. It was necessary to investigate the sources of errors associated with the RC 4E grades to ensure that value is realised from RC drilling.

Hypothesis testing of assays indicates a statistically significant difference between 4E grade values in samples from RC drilling and DDH drilling in all seams mined. The over-estimation of seam thickness and sampling errors associated with the RC sampling suggests that this method cannot be used for measuring either the thicknesses or 4E grades of Middle Group seams of Tharisa Mine.

The QAQC of 4E result of RC samples indicates that the sampling preparation and analytical procedures needs to be reviewed in order to improve the quality of the reported 4E results.

In conclusion, the research findings indicate that RC sampling method is not a representative method for narrow seams as seam contacts cannot be accurately identified and this leads to misrepresentation of the 4E g/t values in the sampled ore body. The use of RC samples in the grade control model has a significant impact on the estimated grades and tonnages; this further affects the reconciliation and the ore blending strategies. RC sampling data may, however, be used for indicative research purposes.

The high levels of contamination, poor repeatability and low bias from QAQC of 4E result of RC samples indicates that sampling preparation and analytical procedures need to be reviewed in order to improve the quality of the reported 4E results.

6.2 Recommendations

There is an overall need for improvement on the sampling method and analytical processes. The value-in-use of the RC drilling, compared to its overall cost is considered to be low, meaning that the strategy for the use of RC drilling going forward should be reconsidered, albeit with the full knowledge of the limitations.

On sampling method: RC samples should be excluded from tonnage or thickness estimation process as RC seam intersection misrepresents the actual seam thicknesses. RC sampling method on its own does not give a representative sample of Middle Group seams.

If the use of RC drilling as indicative of reef thickness is to be continued, a more accurate means of estimating depth must be installed on the rig, this can be done by using a depth counter on the rig. The importance of accurate drill depth estimation means that drillers will have to be sensitized to importance of this aspect of their work.

All cuttings at the RC drill site must be passed through a Jones Riffle splitter to ensure that the principle of equiprobability for sampling is upheld in order to obtain a more representative sample.

Current in-pit DDH grid can also be reduced from 100m by 50m to 50m by 50m grid in order to improve the estimation of seam thickness and 4E g/t grade estimation. RC should be used for indicative study purposes only. The grid of 50m X 50m would increase drilling cost but the quality of the data would out weigh the drill costs..

Further investigations can be done in looking into pairing RC drilling with geophysical techniques in order to accurately identify lithological contacts

On assaying processes: Cease assaying of 4E g/t in RC samples as the data is currently not used for any process. This will save costs, increase laboratory capacity and improve RC assay turnaround time. QAQC results to be presented to laboratory personnel on a regular basis in order to improve the quality of the reported grades. Laboratory audits to be conducted.

A further study can be done on dust samples to ascertain the losses of PGE to dust in RC sampling process.

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APPENDIX

Levey- Jennings plot of PGE CRMs submitted to the laboratory with exploration and RC samples

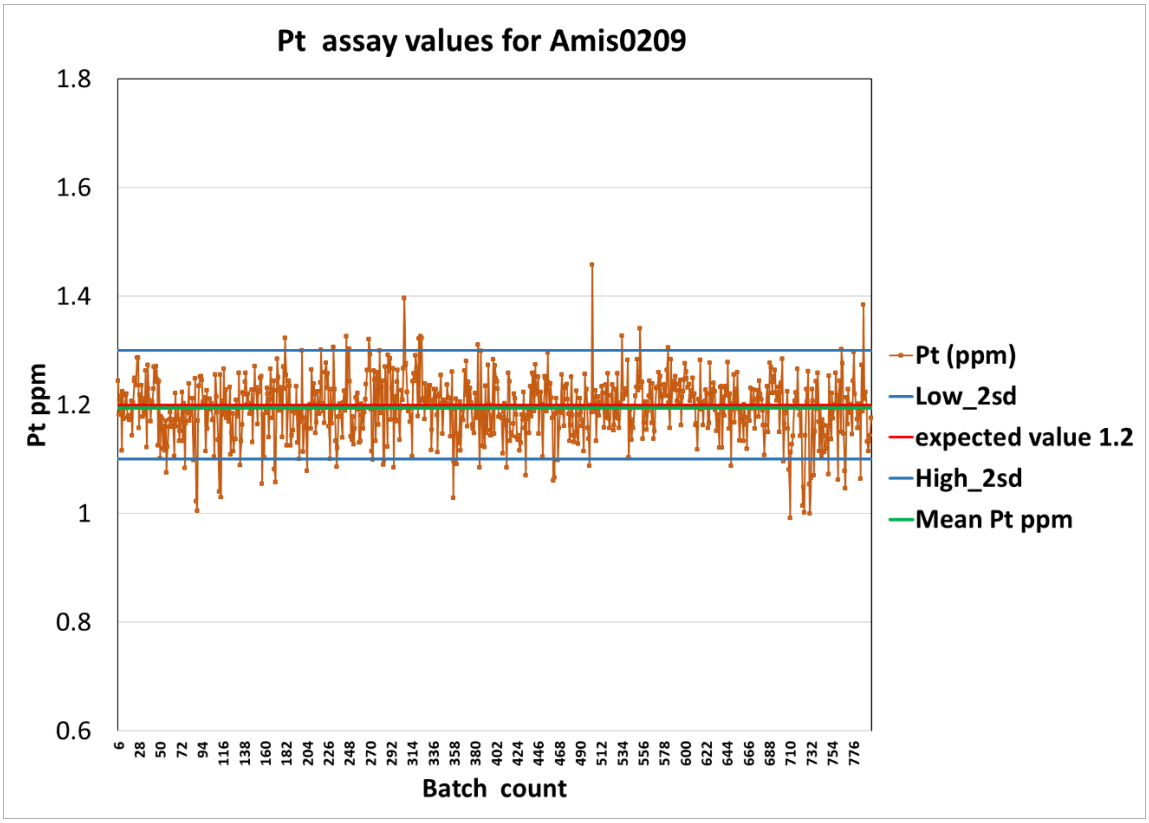

Figure 37: Plot of AMIS0209 Platinum (Pt) values submitted with diamond drill samples analysed by NiS Method.

Table 18: Descriptive statistics for Pt values in AMIS0209

Standard:	AMIS0209		No. of Analyses:	796
Element:	Pt		Minimum:	0.992
Units:	ppm		Maximum:	1.458
Detection Limit:	0.001		Mean:	1.19
Exepected value (ev):	1.2		Std Deviation:	0.056
EV range	1.1 to 1.3		% in tolerance	92%
			%Bias	-0.47%
			%RSD	5%

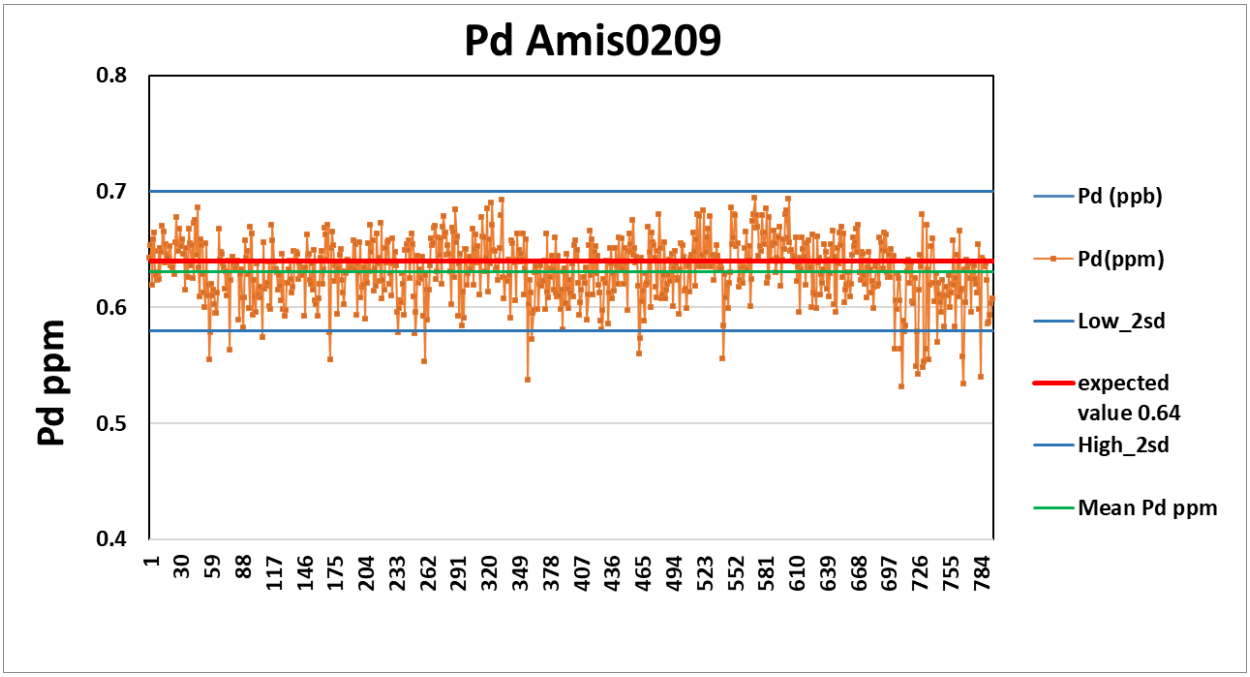

Figure 38: Plot of AMIS0209 Palladium (Pd) values submitted with DDH samples analysed by NiS method.

Table 19: Descriptive statistics for Pd values in AMIS0209

Standard:	AMIS0209		No. of Analyses:	795
Element:	Pd		Minimum:	0.531
Units:	ppm		Maximum:	0.694
Detection Limit:	0.001		Mean:	0.63
Expected value (ev):	0.64		Std Deviation:	0.03
EV range	0.58 to 0.7		% in tolerance	98%
			%Bias	-1.34%
			%RSD	4%

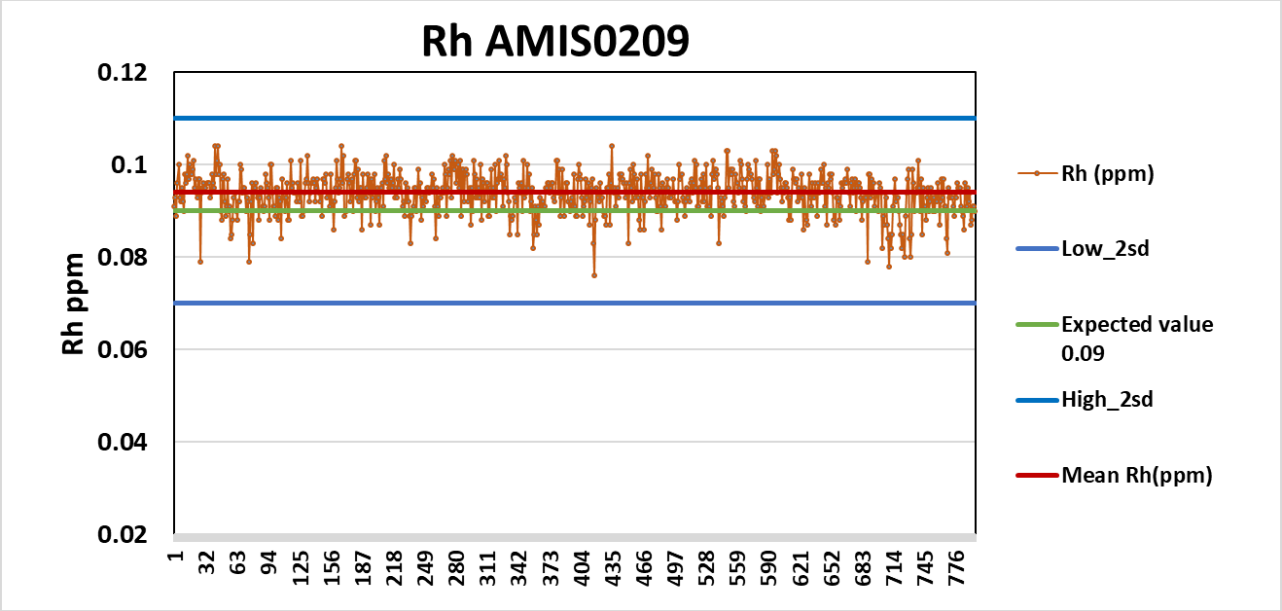

Figure 39: Plot of AMIS0209 Rhodium (Rh) values submitted with DDH samples analysed by NiS.

Table 20: Descriptive statistics for Rh values in AMIS0209

Standard:	AMIS0209		No. of Analyses:	795
Element:	Rh		Minimum:	0.076
Units:	ppm		Maximum:	0.104
Detection Limit:			Mean:	0.094
Expected value (ev):	0.09		Std Deviation:	0.004
EV range	0.07 to 0.11		% in tolerance	100%
			%Bias	0.38%
			%RSD	5%

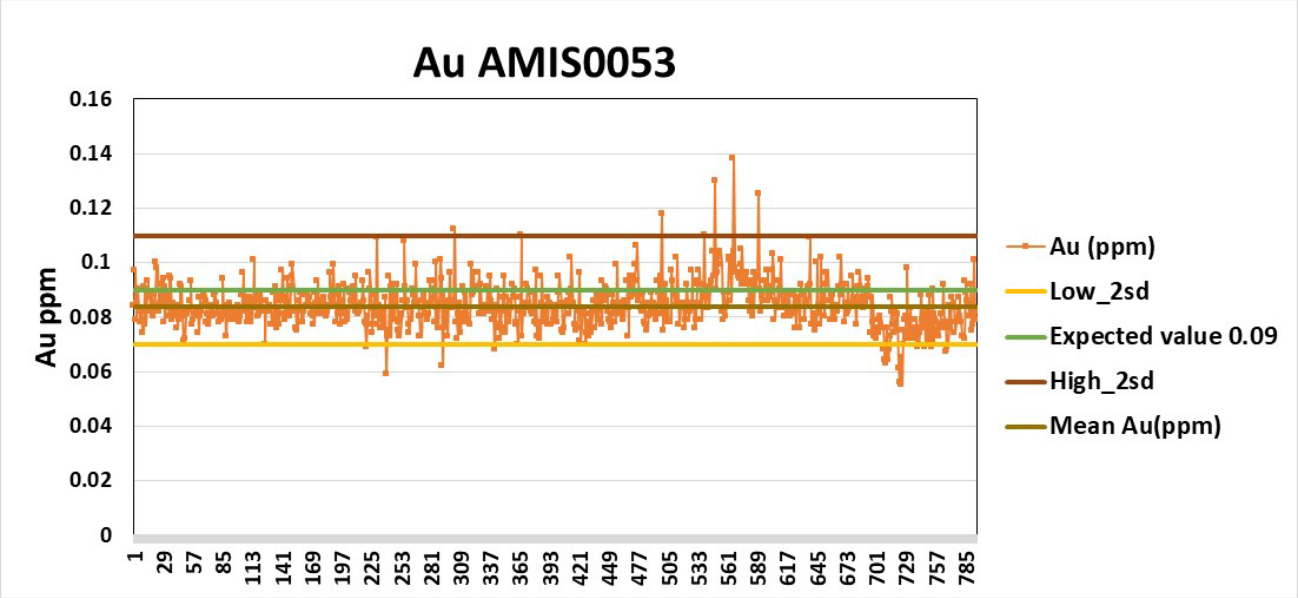

Figure 40: Plot of AMIS0053 Gold (Au) values submitted with DDH samples analysed by NiS.

Table 21: Descriptive statistics for Au values in AMIS0053

Standard:	AMIS0053		No. of Analyses	795
Element:	Au		Minimum:	0.055
Units:	ppm		Maximum:	0.138
Detection Limit:	0.001		Mean:	0.084
Exepected value (ev):	0.09		Std Deviation:	0.0084
EV range	0.07 to 0.11		% in tolerance	97%
			%Bias	-6.37%
			%RSD	10%

2.2. Levey- Jennings plot of CRMs inserted in RC samples

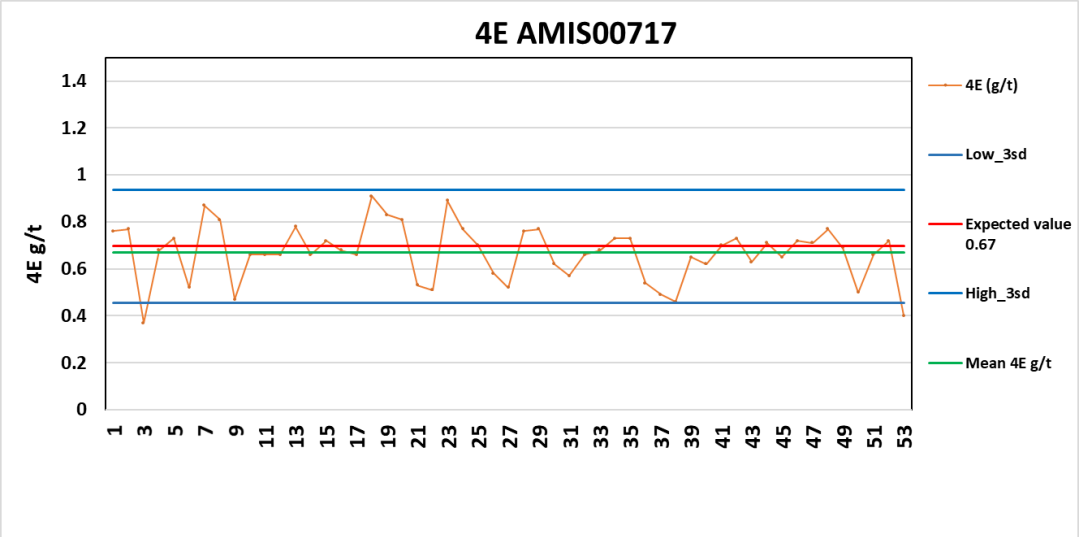

Figure 41: Plot of AMIS0717 4E values submitted with RC samples analysed by Pb collection method.

Table 22: Descriptive statistics for 4E values in AMIS0717.

Standard:	AMIS00717		No. of Analyses:	53
Element:	4E		Minimum:	0.37
Units:	g/t		Maximum:	0.91
Detection Limit:			Mean:	0.67
Expected value (ev):	0.697		Std Deviation:	0.12
EV range	0.457 to 0.937		% in tolerance	94%
			%Bias	-4.23
			%RSD	18%

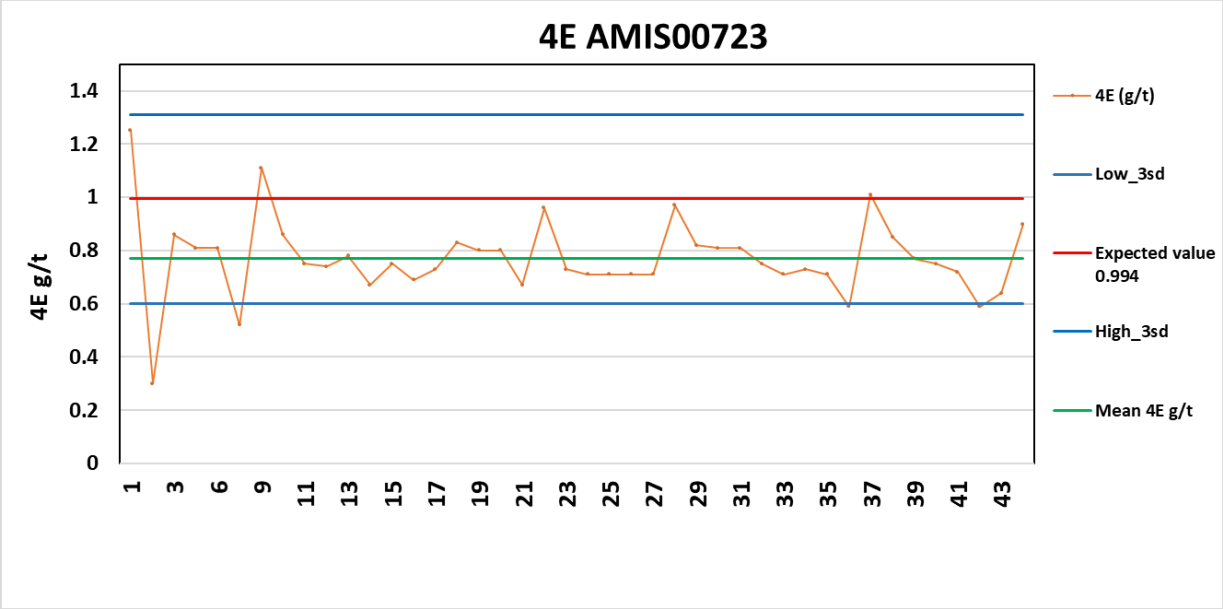

Figure 42: Plot of AMIS0723 4E values submitted with RC samples analysed by Pb collection method.

Table 23: Descriptive statistics for 4E values in AMIS0723.

Standard:	AMIS00723		No. of Analyses:	42
Element:	4E		Minimum:	0.3
Units:	g/t		Maximum:	1.25
Detection Limit:			Mean:	0.77
Expected value (ev):	0.994		Std Deviation:	0.15
EV range	0.599 to 1.309		% in tolerance	95%
			%Bias	-22%
			%RSD	20%