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ASSESSING THE IMPACT OF MEASUREMENT UNCERTAINTY IN CUSTODY TRANSFER TO THE DEVELOPMENT OF OIL & GAS INDUSTRY IN TANZANIA

Ishigita Lucas Shunashu, Department of Legal and Industrial Metrology, College of Business Education, Tanzania,
P.O. Box 1968, Dar es Salaam; E-mail:
And
Dr. Respickius Casmir (PhD), Department of Information Technology, College of Business Education, Tanzania,
P.O.Box 1968, Dar Es Salaam; E-mail:

ABSTRACT

This paper examined the best practise in custody transfer for oil and gas to supporting the development of economy and energy industry, as well as achieving competitiveness in the national and international energy market. The research examined and compared the performance as well as economic efficiently of both manual tank gauging (static tank measurement) and fiscal metering system (dynamic measurement) for oil and gas custody transfer. Tank inventory custody transfer namely Manual Tank Gauging (MTG) and Automatic Tank Gauging (ATG) as well as the Fiscal metering system were all studied. The performances of both tank inventory or tank gauging and fiscal metering system in custody transfer were established by evaluating their respective measurement uncertainty budgets. Both methods were experimentally tested by using field data which were collected from the petroleum products shore tanks and pipeline. Whilst the advantages of fiscal metering system over the imperial manual tank gauging were assessed using measurement uncertainty, and its effect on accounting the accuracy, the product loses the environment and worker's safety. The results obtained from this study proves that the uses fiscal metering system (FMS) in custody transfer has minimum measurement uncertainty compared to tank gauging, and that FMS has better accuracy five times other than the manual tank gauging (MTG). Therefore, this paper recommends FMS as an effective method in course of transfer of oil and gas from ship to shore tank, from lease tank to ship, from shore tank to rail/road tankers.

Keywords: *Custody transfer, measurement uncertainty, oil and gas, fiscal metering, tank gauging, energy industry and economy*

1.0 INTRODUCTION

Oil and gas economy depend on the tax and royalty calculation from measured quantity and quantity of hydrocarbon or gas. Custody transfer application occurs when possession of oil or gas is transferred from selling party to the buying party and hence high accuracy is critically involved(Emerson, 2016). Selecting selection of transfer method with high accuracy is significantly important to avoid economic loses. Custody transfer measurement provides quantity and quality information used for the physical and fiscal documentation of a change in ownership for oil and gas (API-18.2, 2005). The accurate and reliable measurement of oil and gas in custody transfer, is a key factor for economic development, consumer protection and fair trade. Measurement accuracy must be assured since the transactions are usually made as the function of quantity and quality of energy transferred(Gupta, 2017). Accuracy of measurement in custody transfer is paramount simply because a small error in measurement can cause a huge financial loses. The transfer of oil and gas from buyer to seller involves significant financial risk due to lack of accurate measurement in the transferred energy (GIIGNL, 2017). This uncertainty translates to financial risk to the buyer, seller and government taxation. However, the study examines the custody transfer methods and their possible associated uncertainty contributing factors in real operating condition(EURAMET, 2012). In this study applicable custody transfer measurement methods like manual tank gauging(Bush, Sales, & Neots, 1995), automatic tank gauging(Emerson, 2017) and fiscal metering systems(Frøysa, 2001) are explicitly studied.

Since the measurement of petroleum product and LNG for trading purposes are heavily influenced and regulated by directives and standards(Aramco, 2013), the research critically reviewed the implementation of the legal metrology association standards, International Standard Organisation (ISO), and the industrial association like International Group of Liquefied Gas Importers (GIIGNL) and American Petroleum Institute (API). This study investigated the effectiveness of custody transfer methods and then analysed their uncertainty budgets which has huge influence to the economy. The three applicable custody transfer namely the Manual Tank Gauging (MTG), Automatic Tank Gauging (ATG) and the Fiscal metering system were all studied.

A tank measurement system has to satisfy different aspects of a storage operation which includes inventory control, custody transfer, product movements and loss control and reconciliation(Bush et al., 1995). The high accuracy is essentially emphasized in custody transfer lather than other aspects and therefore uncertainty requirement should be assured(Gupta, 2017). In shore tanks, the measurement is associated with errors which amounted from their construction, strapping table or calibration, temperature and density measurements, gauging method and viscosity of the product measured(Ash, 2014). The uncertainty in shore tank measurement can be quantified based on number of batches transferred and the size of the patch in height (Bernard Spilsbury & Herman Hofstede, 2016)

Manual tank gauging method has been a commonly used method in custody transfer and considered to be the more accurate automatic tank gauging(Ash, 2014). However, over the recent, some studies shows that a well calibrated automatic tank gauging would be more accurate compared to hand gauging (Emerson, 2017), (OIML R85, 2008),(EMPIR 2018, 2018). The recommended uncertainty of $1mm$ prior installation and $4mm$ after installation for automatic tank gauging provided by OIML R85(OIML R85, 2001) are found to be fulfilled by radar and ultrasonic types of tank gauges.

Fiscal metering systems are used in custody transfer to assure accurate and reliable measurement of products. Considering that money changes hand in custody transfer transactions, an uncertainty of 0.25% for hydrocarbon and 0.1% for gas metering skid is recommended and clearly stated in API MPMS Ch. 18.2 standard(Emerson, 2016). These overall uncertainties are derived from an appropriate statistical combination of the component uncertainties in the measurement system. The uncertainty contributing parameters to fiscal metering includes size and structure of pipeline, meter calibration, pressure and temperature transmitters, density of product and compressibility for gaseous products(GIIGNL, 2010),(Chunovkina, 2000). The application of mass flow meter or coriolis(AGA-7, 1996), ultrasonic(Frøysa, 2001),(AGA Report No 9, 2007) and turbine meter(Emerson, 2016) in custody transfer have been obviously dominant in custody transfer metering station(Gupta, 2017).

The specific objectives addressed include; (i) to examine different applicable methods in custody transfer measurement and their traceability framework in oil and gas, (ii) to develop measurement uncertainty assessment approach for custody transfer, (iii) to analyse and compare uncertainty in fiscal metering and manual tank gauging, (iv) to ascertaining the influence of uncertainty budget to taxes and royalty charges in custody transfer measurement and the contribution to economy and industrial development.

2.0 MATERIAL AND METHODS

The data for this paper were collected through field measurement conducted at the Dar es Salaam Kurasini Oil Jetty (KOJ) shore tanks and Panipat Indian Oil -Northern Region Pipeline (IOCL NRPL) delivery station. The tank measurement data were collected during the transfer of petroleum products from the ship to the oil importer's shore tanks through performing manual dipping of received inventory using dip tape while the measurement recorded by the automatic level tank gauge were as well collected in each received batch. Inventory transfer method performance for manual tank gauging (MTG) and automatic tank gauging (ATG) evaluation was done based on the measurement of tanks taken during batch receiving of diesel (HSD) at standard temperature. However, field data for fiscal metering system were recorded from the transfer of HSD product at Panipat Indian Oil -Northern Region Pipeline (IOCL NRPL) delivery station at standard temperature.

The analyses for each measurement method were made to establish the field measurement uncertainty and consequently determine the overall uncertainty of each method budget and their contribution to financial risk. Uncertainty analysis approach using ISO/GUM was developed to determine their performance (JCGM-GUM, 2008). The uncertainty budgets of each transfer method were ultimately employed to evaluate product losses, fiscal risk in custody transfer as well as damages in fare trade. The generalised approach of this study is detailed in the conceptual framework illustrated in Figure 1 below. Moreover, the approach for quantification of measurement uncertainty and the possible sources of uncertainty were stipulated in this section.

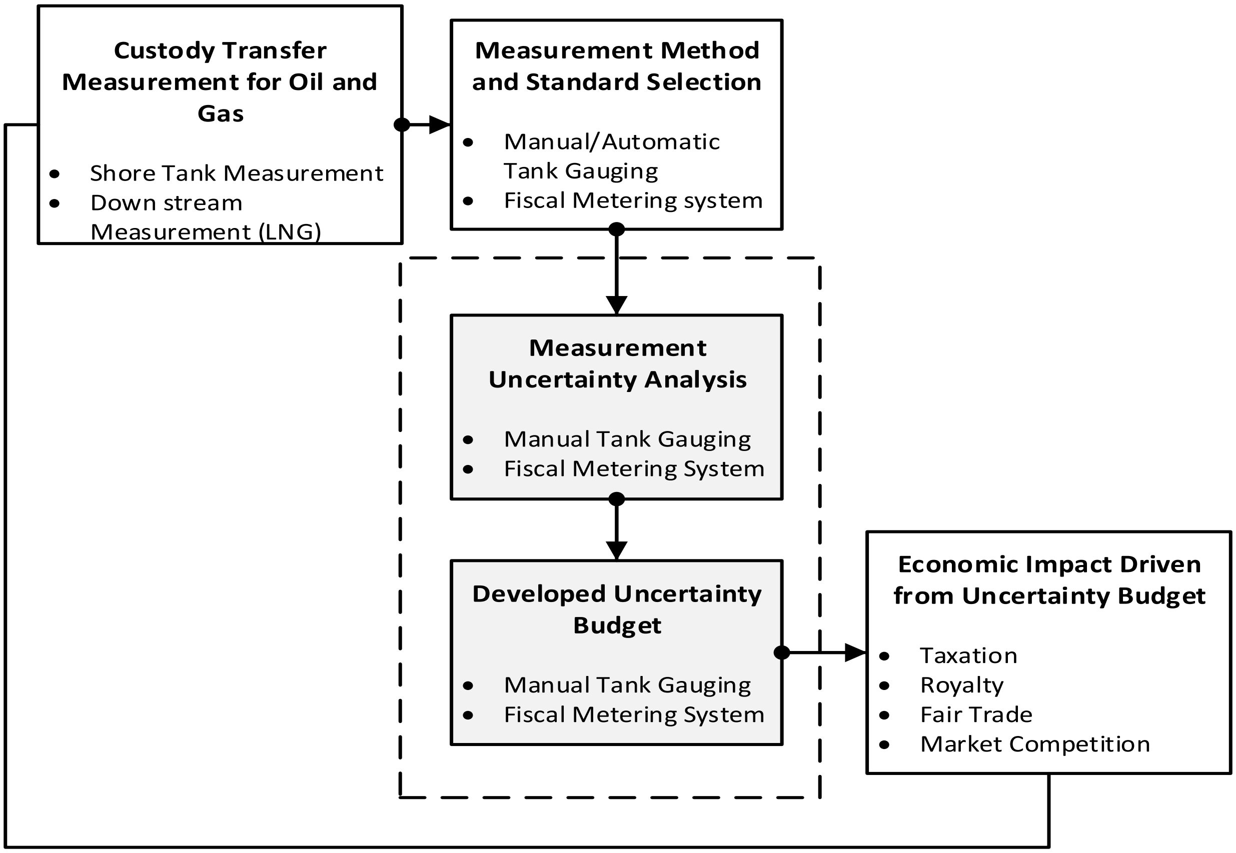

Figure 1: Generalised Research Conceptual Framework

2.1 Uncertainty Quantification for Fiscal Metering System (FMS)

Field measurements for multi-beam ultrasonic fiscal metering system (USM-FMS) used in the transfer of petroleum products were recorded. Some of information collected includes the meter calibration, fluid property, instrument installation and secondary instruments measurements. The uncertainty of USM system was estimated based on recommended reference standards like AGA Report no. 9 (AGA Report No 9, 2007) and ISO 5168(ISO-5168, 2005). However,(Upp & LaNasa, 2014), (Viana et al., 2012) and (Frøysa, 2001) clarify that USM performance among other factors can be influenced by fluid pressure, temperature, velocity, fluid contamination, asymmetric and swirling flow.

Table **1** summarises the major sources of ultrasonic meter installed for oil and gas transfer in custody transfer. Moreover, the reduced equation 1 and 2, provides the reduced uncertainty parameters for USM (AGA Report No 9, 2007).

$$q_b = q_f M_f \left(\frac{P_f}{P_b}\right)\left(\frac{T_b}{T_f}\right)\left(\frac{Z_b}{Z_f}\right) \quad (1)$$

$$V_b = V_f \left(\frac{P_f}{P_b}\right)\left(\frac{T_b}{T_f}\right)\left(\frac{Z_b}{Z_f}\right) \quad (2)$$

Where, q_b is the flow rate at base condition, P_f is an absolute pressure at flowing condition, P_b is an absolute pressure at base condition, T_b is the base temperature, T_f represents the flowing temperature, Z_b is the compressibility at base, Z_f is compressibility at flowing condition, M_f: meter factor, V_b is the volumetric flow at base condition, V_f is the volumetric flow at flowing condition.

The major parameters that influences the uncertainty established in the custody transfer meter includes fluid property (viscosity or Re), meter bias, meter calibration, piping configuration and secondary measurement instrument like pressure measurement, and temperature measurement.

Table 1 Sources of Uncertainty for Fiscal Metering System

Uncertainty Input Parameters	References
USM flow meter accuracy $\boldsymbol{u(MUT_{cal})}$	USM flow meter(Flexim, 2016)
USM field calibration uncertainty $\boldsymbol{u(MUT_{sd})}$	Calibration
Pressure Measurements $\boldsymbol{u\ (P)}$	Rosemount 3051T (Rosemount, 2017)
Temperature Measurement $\boldsymbol{(u\ T)}$	Rosemount TIR-3155
Compressibility $\boldsymbol{u\ (Z)}$	State equation $u\ (Z_{eq})$, AGA-8(AGA-8, 2003)

To obtain the combined uncertainty for the fiscal metering, the uncertainty of each parameter was evaluated following evaluation procedures. The uncertainty estimation model for pressure measurement is provided in equation **(3)** and the calculations are detailed in figure 2 underneath. The estimation of combined relative uncertainty was performed based on equation **(4)** below and its overall estimation presented in the illustration figure 3 below. Moreover, according to ISO 6976 (ISO-6976, 2016) and (AGA-8, 2003), uncertainty in compressibility ratio for ultrasonic flow meter can be derived from the state equation, whereas both flow pressure and temperature parameters influence the compressibility of the air.

$$u_c{}^2(P) = u^2(P_{transmitter}) + u^2(P_{stability}) + u^2(P_{RFI}) + u(P_{temp}) + u^2(P_{atm}) + u^2(P_{cal}) + u^2(P_{acq}) \quad (3)$$

$$u_c{}^2(T) = u^2(T_{transmitter}) + u^2(T_{stability}) + u^2(T_{RFI}) + u(P_{temp}) + u^2(T_{atm}) + u^2(T_{cal}) \quad (4)$$

2.2 Uncertainty Quantification for the Tank Gauging

The measurement of single patch for high speed diesel product (HSD) transferred to the shore bulk tank was undertaken. The data collection process involved capturing strapping table information, measurement of contours of the tank floor, thickness of tank shell or plate thickness, temperature of the tank, reference temperature at time of calibration, level of the tank, tank reference height, and density of the product, product temperature, and water/sediments level. Manual tank measurement process was performed using instruments like dip gauge/tape, hydrometer, micrometre screw gauge, sample beaker, tank thermometer, sediments and water test equipment, temperature berth, sample thermometer, ASTM D1298 thermometer, and tank sample tape(Odina & Cko, 2012),(Aramco, 2013).

2.2.1 MTG Measurement Method Equation

The level measurement using dip tape for the vertical cylindrical tank and vessel carrier is given in the equation below(Justervesenet at el, 2011).

$$h = h_{ind}.C_{(T_{gauge})}.C_{(P_{gauge})} + \Delta h_{list} + \Delta h_{\rho} + \Delta h_{comp} + \Delta h_{cal} + \Delta h_{drift} \quad (5)$$

where, h is the corrected level gauge, h_{ind} is observed/ indicated level gauge, $C_{(T_{gauge})}$ is the correction for temperature (vapour and/ or liquid), $C_{(P_{gauge})}$ is the correction for pressure effect on level gauge and position level gauge, $\Delta h_{list}$is the correction for nonzero list, Δh_{ρ} is the correction for a density deviation from reference conditions, Δh_{comp}a correction for a composition deviation from reference conditions, Δh_{cal} is the correction according the calibration certificate and Δh_{drift} is a correction for drift of level gauge.

However, the volume measure can be estimated using the equation below. Where V is the tank volume, C_v is the correction for drift or hydrostatic pressure and $C_{tank,T}\ (T)$ $C_{tank,p}\ (P)$ are temperature and pressure correction respectively. In estimation of correction value by pressure the mean coefficient β of volumetric expansion, pressure of the tank $P_{tank,p}$ and reference pressure P_{ref} have to be measured. The equation **(7)** and **(8)** below provides the temperature correction, where α is the expansion coefficient, $T_{tank,t}$is the temperature of the tank and T_{ref} is the reference temperature.

$$V = (V_{table} + C_v).C_{tank,t}(T).C_{tank,p}(P) \quad (6)$$

$$C_{tank,p}(P) = 1 + \beta(P_{tank,p} - P_{ref}) \quad (7)$$

$$C_{tank,t}(T) = 1 + \alpha(T_{tank,t} - T_{ref}) \quad (8)$$

2.2.2 Sources of Uncertainty in Manual Tank Measurement for Custody Transfer

The accuracy of each tape and bob combination can be estimated following API Manual of Petroleum Measurement Standards (MPMS), Chapter 3.1A(API-MPMS, 2014). The uncertainty of ±2 mm at any length up to 30 meters is recommended for dip tape. However the reference tape may be estimated to have uncertainty of ±0.3 millimetres for any length up to 30 meters(Ash, 2014),(Aramco, 2013).However, the thermometers used to measure the temperature of hydrocarbon liquids in tanks conforms to the requirements of API Manual of Petroleum Measurement Standards (MPMS), Chapter 7, "Temperature Determinations" and American Society of Testing & Materials Standard E1, "Standard Specification for ASTM Liquid-in-Glass Thermometers": ASTM 59, measurement range -18 degree centigrade to 82, the scale error is ±0.3℃(Aramco, 2013).The temperature of hydrocarbon liquid measurement for static measurement in custody transfer can be alternatively performed using portable electronic thermometer with uncertainty of ±0.1℃ at a range of 0℃ to 100℃.

Another uncertainty parameter in MTG custody transfer is accuracy in measurement of Sediments and water (S&W). Both API MPMS Standards, Chapter 10.3 and (ASTM D4007) suggests the uncertainty for S&W to be ±1.00mL in the range of 25mL to 100mL(API-10.3, 2007) and (Aramco, 2013). The accuracy of hydrometer also can contribute to the combined uncertainty in MTG for hydrocarbon of density from600 kg/m^3 to 1100kg/m^3 by ±0.5 kg/m^3 as stated in ASTM D1298(Aramco, 2013). The typical ESTM 316H-86 has been used in this study as the density measurement device. Basic sources of uncertainty for manual tank gauging are summarised in Table 2 below.

Table 2 Sources of uncertainty for manual tank gauging

Uncertainty Input Parameters	References
Temperature of the tank $u(T_{tank})$	API MPMS, Chapter 7
Temperature measurement $u(T)$	API MPMS, Chapter 7
Tape Gauge (Dip Tape)$u\ (h_{ind})$	Calibration(Odina & Cko, 2012)
Density$u(\rho)$Hydrometer (ASTM 316H-82)	API MPMS Chapter 9.1
Sediments& Water Test Equipment $u(ws)$	API MPM Chapter 10.3
Thermo-hydrometer (Temp & Density) $u(T)^*$	API MPMS Chapter 9.1
Tape Gauge Reference $u(h_{ref})$	ISO 4512

2.3 Uncertainty Quantification for Automatic Tank Gauging (ATG)

The automatic tank gauging (ATG) has been used in industrial process and reservoirs for safety and level monitoring (Emerson, 2017). The IOML-R85 (2014) provides the recommendation for automatic level measurement in custody transfer which indicates that ATG has to meet 4mm uncertainty for the transfer of 1m to 30m(OIML R85, 2001),(EMPIR 2018, 2018). In this study the uncertainty budget for ATG has been evaluated based on field measurement of the high speed diesel (HSD) tank. The uncertainty estimated has been used in the comparison to recommended uncertainty for custody transfer. Parameters that contributes to ATG uncertainty in custody transfer comprises of both systematic and random error. Common sources of uncertainty are from volume determination, individual measurement and partial sources caused by instrument operators.

3.0 RESULTS AND DISCUSSION

3.1 The Uncertainty Budget for USM

A multiphase multi-beam ultrasonic meter (USM) of ±0.15% accuracy was used in HSD transfer. The meter must therefore be calibrated with the reference standard meter of±0.1% as per gas custody transfer requirements. The field measurement of batches through the USM meter ascertained to record the uncertainty of 0.125%. In the transfer metering system, a Rosemount 3051 Pressure Transmitter of accuracy of ±0.05% was installed. The combined uncertainty for the pressure transmitter installed in fiscal metering station by considering all influences to it accuracy was estimated to be ±0.1599%.

With this fiscal metering system, a smart temperature transmitter Rosemount Model 3155 was used. Frøysa (2001) performed an experimental study on custody transfer temperature transmitter and observed Rosemount Model 3155 accuracy of $\pm$0.02% to have a combined relative uncertainty of $\pm$0.047% (95% confidence level). The contribution parameter to uncertainty in temperature uncertainty for custody transfer USM is presented in the appendix

Table **1**. Moreover, the contribution relative uncertainty of compressibility in multi-beam ultrasonic meter was estimated to be 0.30803% (at 95% level of confidence).

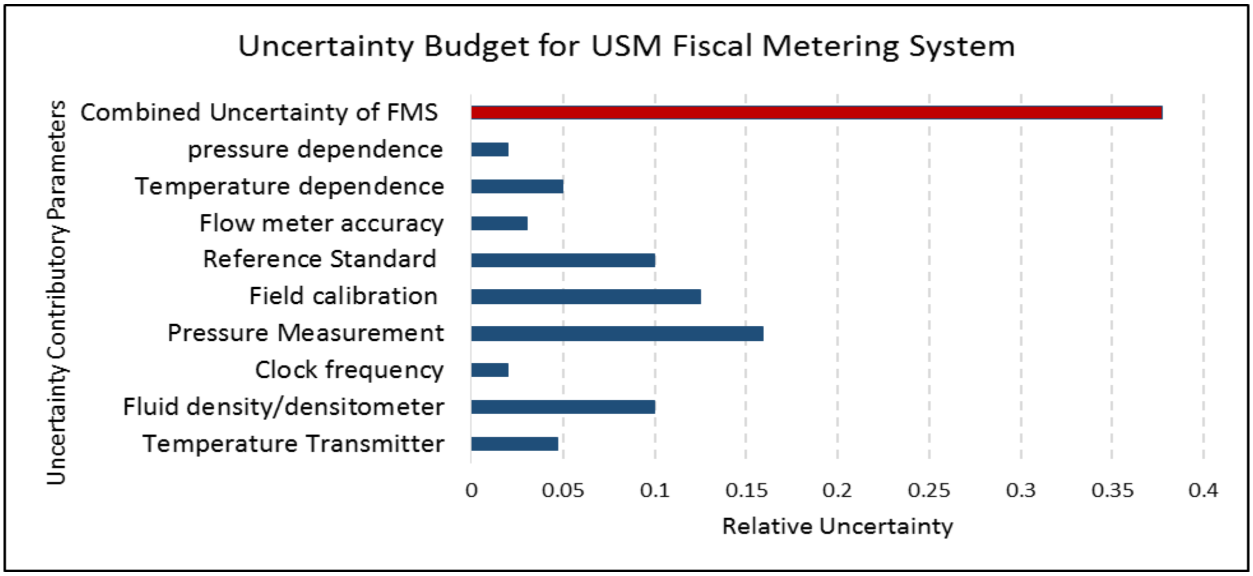

Figure 2: Combined uncertainty for Custody Transfer USM (liquid petroleum products)

3.2 The Uncertainty Budget for Manual Tank Gauging (MTG)

The uncertainty budget for manual tank gauging or static measurement driven from the contributing parameters has been presented in the appendix **Error! Reference source not found.** below. However, Figure 3 illustrates the summarised details of contributory relative standard uncertainty of each parameter. The combined relative expanded uncertainty for MTG estimated from field measurement is ±1.8% at 95% level of confidence. The increases of uncertainty from the initial tape gauge accuracy of ±0.4% (or standard uncertainty of ±0.2%) in measuring one metre batch of transferred HSD conferred by the error in measurement of associated conditions like temperature and density. The results indicate that, temperature measurement has huge influence to accuracy of the MTG method in custody transfer.

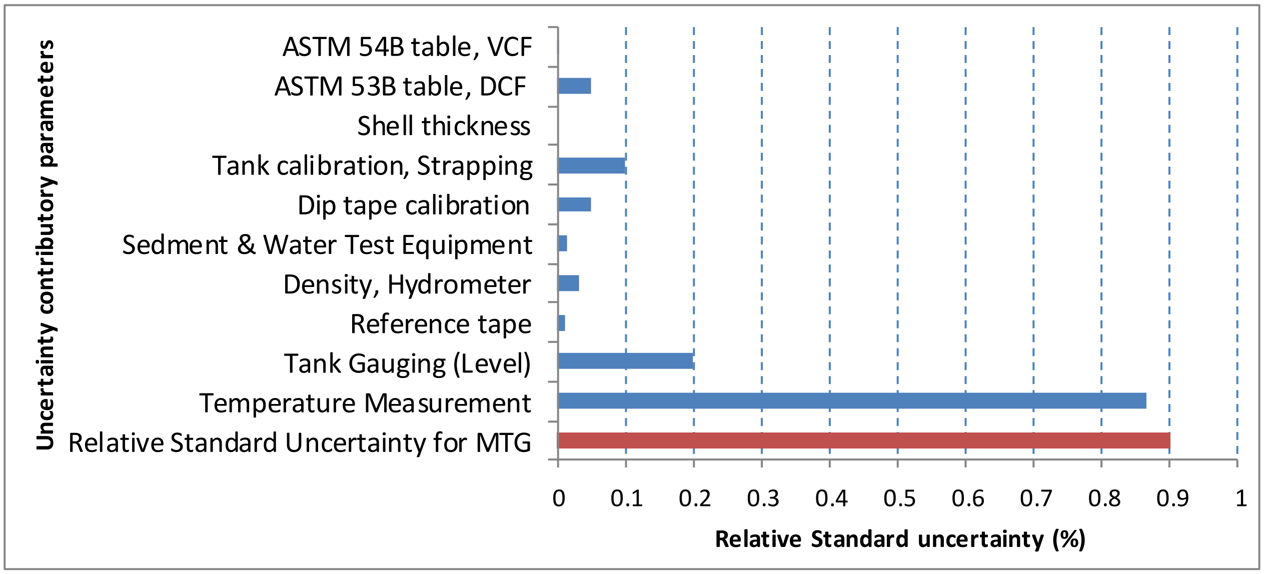

Figure 3: Combined Uncertainty for Manual Tank Gauging

3.3 Uncertainty for ATG Systems in Custody Transfer

In tank level measurements, the uncertainty of ±2mm to ±4mm was observed but can vary depending to the size or volume of the batch being transferred. For example the batch volume of 1m tank height will reach 0.4% while the batch level of 8m, the uncertainty decreases to 0.05% . However, the tank was observed to have average temperature error of 2°C which was then evaluated and gave uncertainty of 0.2%. The multisport temperature measurement was applied to enhance accurate estimation. Moreover, the API correction table for hydrocarbon was used to estimate the Gross Standard Volume (GSV) from the measured Gross Observed Volume (GOV) using the volume correction factor (VCF), ASTM table 54B for oil products. The recommended API/ASTM table uncertainty contribute to measured batch uncertainty by 0.05% (Bernard Spilsbury & Herman Hofstede, 2016). Appendix **Error! Reference source not found.** represents the uncertainty budget for radar type Automatic Tank Gauging System employed in this study.

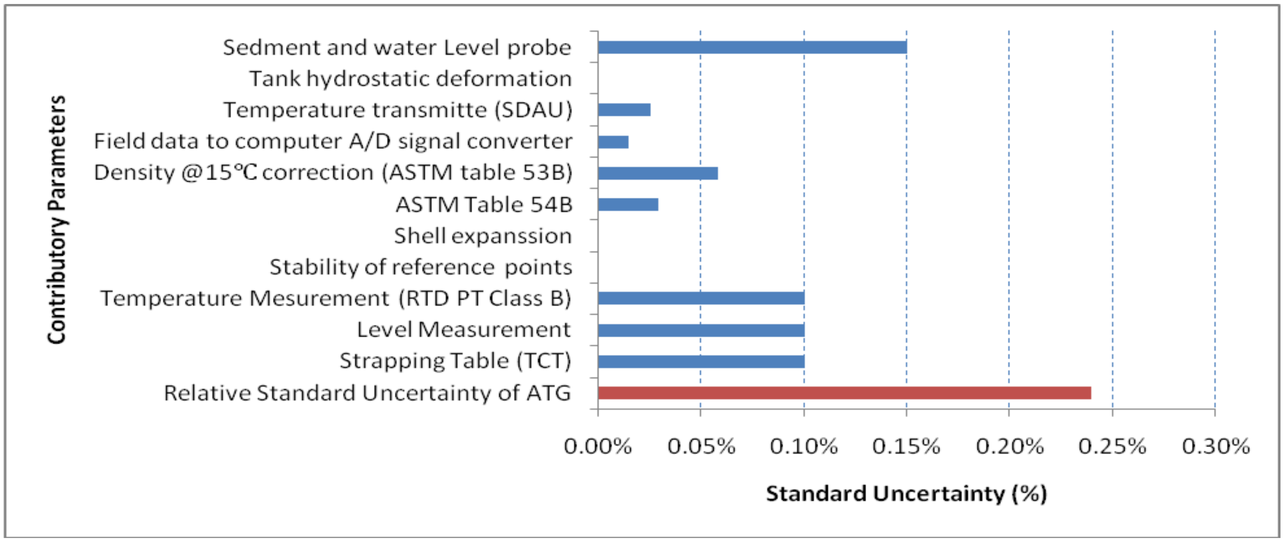

Figure 4: Combined Uncertainty for Automatic Tank Gauging

3.4 The Effect of Batch Size and Temperature to Tank Gauging

From the observation in this study, the accurate measurement in custody transfer measurement depends upon the type of method and the type of instrument used in a particular method. Temperature measurement for hydrocarbon oil and gas in custody transfer has substantive influence and therefore it should be clearly determined in order to make accurate and confident estimations in transactions. Therefore, temperature measurement has been seriously taken in consideration especially when it comes to liquid product with high density like HSD and crude oil. Provided that the mixing of product in the tank cannot be even throughout the bulk tank, therefore average tank temperature should be calculated from the temperature taped from different sport of tank to reduce error in estimation. Section 4.3 of this study indicates that, the accuracy in temperature measurement can contribute to 90% of the overall uncertainty of tank inventory measurement. The correction in volume gross standard volume using API table or ASTM 54B for hydrocarbon products depends on the accurate determination of temperature. However, Aramco (2013) suggests the use of combined ASTM thermo-hydrometer (ASTM D6822) in temperature and density measurement of hydrocarbon liquid to minimise the temperature uncertainty in custody transfer. ASTM thermo-hydrometer can have inherent uncertainty of ±1℃ which is less than ±1℃ of ASTM tank thermometer (Aramco, 2013).

Moreover, the observation from field measurement suggests that, among other parameters, the size of batch in the inventory has a big influence to the uncertainty. The study sanctions the fact that, as the size of the batch increases the uncertainty in measurement using ATG reduces to a certain extent until it converges. In reference to section 5.1 of this study, the measurement of one metre batch size using radar ATG can trigger uncertainty of ±0.48% of measured tank level while the same instrument can vindicate ±0.005% uncertainty or less when the batch size is increased to eight metres (Bernard Spilsbury & Herman Hofstede, 2016). The figure 5 provides a detailed batch size (in meter) observed influence of the inventory measurement using ATG method, whereas the uncertainty decreases with the increase of the batch size.

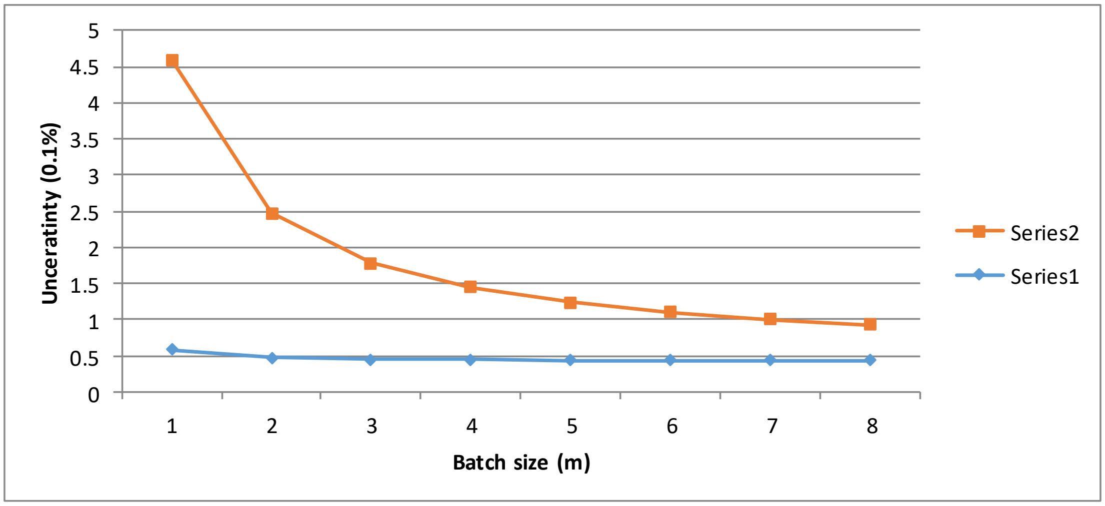

Figure 5: Uncertainty of measured inventory at different batch size, using ATG

3.5 The Comparison of Fiscal Metering System over Tank Inventory Level Gauging

The direct and indirect quantification of measured hydrocarbon or gas volume or mass using fiscal metering system (FMS) or tank inventory level gauging is the common difference of the methods. FMS gives direct reading of the quantity transferred in form of mass or volume while the translation of measured tank level into mass/volume is required in both ATG and MTG methods. The conversion of measured level of inventory requires precise calculation and standard corrections as discussed in section **3.1** of this paper. For example in MTG, human intervention is required at all stages ranging from closing valves, turn off tank mixer, water drain, tank content sampling, gauging free water level , gauging inventory liquid level, obtaining inventory ambient and liquid temperature, perform API gravity test and calculation of gross standard volume using API table. Manual tank gauging requires very high operator competency, is subject to human errors when performed in harsh weather condition (Emerson, 2016).

Apart from safety implications in tank gauging, the uncertainty variation in MTG custody transfer compared to that of fiscal metering system has been examined in this paper. From the field measurement observation and uncertainty analysis for both methods, the extreme high expanded uncertainty of ±1.8% was observed in MTG compared to ±0.38% of the FMS and ±0.48% of ATG as examined in subsections **4.3**, **3.2** and **5.2** respectively of this paper. Theoretically the custody transfer uncertainty requirement for petroleum products using fiscal metering systems is 0.25% and 0.1% for gas (API-18.2, 2005).

Moreover, the accuracy of MTG and ATG can be influenced by the size of the batch being transferred. The very small batch below 3 metre is susceptible to big error and would increase the uncertainty in custody transfer. Spilsbury et al (2016) suggests that, a difference of 1m batch inventory to 8m inventory size may range from ±0.4% to ±0.05% respectively(Bernard Spilsbury & Herman Hofstede, 2016). The batch size has no any influence in the accuracy of fiscal metering system. Strapping table is another influencing constraint in tank inventory level gauging. The calculation depends on the calibration of the tank presented in the strapping table. Acko et al (2012) recommends the traceability framework for bulk tank and dip tape calibration to suppress the possibility of strapping table error (Odina & Cko, 2012). In fiscal metering system, the strapping table can only be used for proof of transferred inventory.

3.6 Economic Implication of Uncertainty in Custody Transfer

EIA (2019) report the total consumption of refined petroleum in Tanzania to be 35,000 barrel per day which is equivalent to 2.03 trillion litres per year Considering the custody transfer to be made using both fiscal metering and tank gauging method, the expected loss of about 36.6 million tonnes of petroleum products could be encountered by its selling or buying due to a lack of accurate measurement of 1.8% uncertainty of manual tank gauging. Conversely the loss of 7.8 million tonne of petroleum products would be shared by transaction parties when fiscal metering would be used in the transfer process from uncertainty of 0.38%. This loss translates big financial impacts to exchanging parties, to fixing petroleum product price as well as to government taxation and royalty payments. The 2019 world energy reports, links Tanzania to be among selected African countries with high fixing price rate for petroleum products (IEA, 2019); this rate could be contributed by methods of custodial transfer, whereas manual tank gauging is the preferable method in Tanzania.

Nevertheless, uncertainty in custody transfer can have economic implication in custody transfer depending on the quantity of product or gas transferred in the particular transaction. For example, a study by the United States Bureau of Land Management (BLM), they reported that a typical manual tank gauging uncertainties ranges from 0.6% to 2.5%. Using a midpoint of 1.5% uncertainty and applying that to a well producing 100m^3/day of oil, at a sales price of US dollar 45 per barrel, this would result in a potential annual loss of US dollar 148,000(Emerson, 2016).

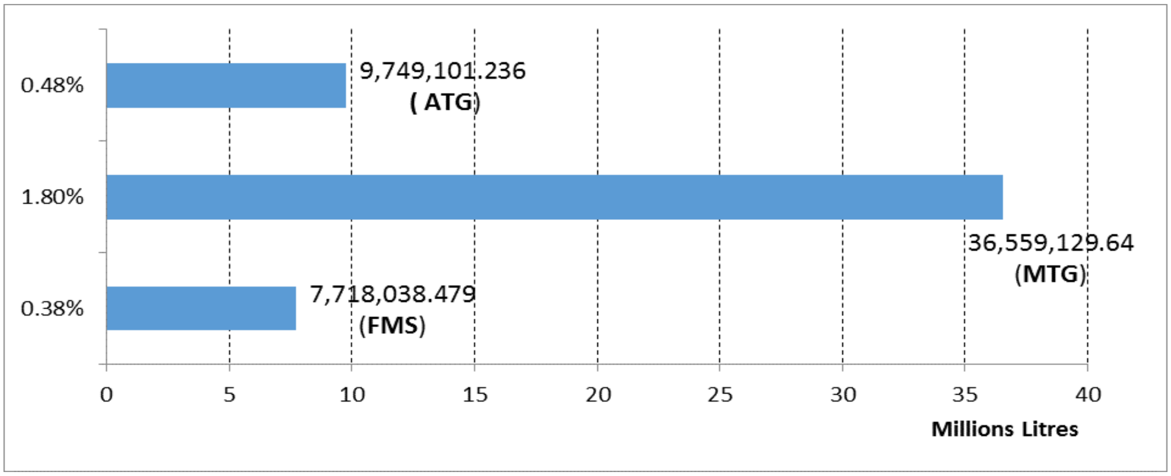

Figure 6: Estimated Annual Loss of Petroleum Product Consumed in Tanzania in 2019

4.0 CONCLUSION AND RECOMMENDATION

This paper has examined the measurement uncertainty in oil and gas custody transfer and their impact to the fair trade and economy. The study has investigated and analysed the three custody transfer methods namely ATG, MTG and FMS through quantification and comparison of their respective uncertainty budgets. It has been revealed by the study that the use of FMS in custody transfer is far better than that of tank inventory gauging methods i.e. MTG and ATG which are inherently susceptible to the influence of human error, instrument errors, and size of the batch being transferred. It is further reported that, a proper calibration of the tank, gauging tape or level gauge sensor can reduce the measurement uncertainty of ATG and MTG transfer methods but above all FMS remains to have a very minimum measurement uncertainty compared to the two methods. In this study the FMS was observed to have better accuracy five times than that of manual tank gauging, which is commonly used in Tanzania and in other developing countries. Furthermore, the study suggests that, the use of FMS in Tanzania custody transfer would save up to 36.6 million tonnes uncertain loss of petroleum product which would be caused by MTG in a year. The bigger the measurement uncertainties in custody transfer the lager the impact to transaction and finance. Further research should be done to investigate the variation which can be caused by inaccurate estimation of temperature in the tank.

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APPENDIX

Table 3: Estimation of Uncertainty in Pressure measurement for Ultrasonic metering system

Source	Nominal value	Confidence level and Distribution	Coverage factor	Relative Uncertainty (Pa)	Sensitivity coefficient	Variance of Relative uncertainty
Transmitter Uncertainty	3500Pa	99% (normal)	3	0.01167%	1	0.000136%
Stability, element	13800Pa	95% (normal)	2	0.0690%	1	0.004761%
RFI effect	7000Pa	99% (normal)	3	0.0233%	1	0.000544%
Ambient temperature effect, transmitter	2100Pa	99% (normal)	3	0.0140%	1	0.000049%
Atmospheric Pressure	9000Pa	99% (normal)	3	0.0600%	1	0.000900%
Transmitter Pressure Reading Relative expanded uncertainty (95% confidence level,$k = 2$)				P $U(P)k$		10Mpa 0.159882%
Sum of the variances **Relative Standard Uncertainty**				$\boldsymbol{U_c^2(P)}$ $\boldsymbol{U(P)}$		**0.006391%** **0.079941%**

Table 4: Estimation of Uncertainty in Temperature Measurement for the Ultrasonic Metering System

Source	Nominal value	Confidence level and Distribution	Coverage factor	Standard Uncertainty (Pa)	Sensitivity coefficient	variance
Transmitter Uncertainty	0.1000℃	99% (normal)	3	0.03300℃	1	0.00111℃^{2}
Stability, element	0.1615℃	95% (normal)	2	0.0540℃	1	0.00290℃^{2}
RFI effect	0.1000℃	99% (normal)	3	0.0330℃	1	0.00111℃^{2}
Ambient temperature effect, transmitter	0.0300℃	99% (normal)	3	0.0100℃	1	0.00010℃^{2}
Calibration process	0.0500℃	95% (normal)	3	0.02500℃	1	0.00063℃^{2}
Sum of the variances Combined standard uncertainty Expanded uncertainty (95%, $k = 2$)				$u_c^2(T)$ $u_c(T)$ $U(T)$		0.00548 ℃^{2} 0.07650 ℃ 0.15000 ℃
Operating Temperature **Relative expanded uncertainty (95% confidence level)**				$\boldsymbol{T}$ $\boldsymbol{U(T)/T}$		**25.0000 ℃** **0.3060%**

Table 5: Estimation of Uncertainty in Compressibility Ratio for gas Flow Measurement using USM System

Source	Given Relative Uncertainty	Confidence level and Distribution	Coverage factor	Relative Standard Uncertainty (Pa)	Sensitivity coefficient	Relative variance
Air compressibility factor at line condition $u(Z_f)$	0.1%	95% (normal)	2	0.0500%	1	2.5×10^{-7}
Air compressibility factor at standard condition $u(Z_b)$	0.052%	95% (normal)	2	0.0260%	1	6.76×10^{-8}
Analysis Uncertainty at line condition$u(Z_f)$	0.16%	standard	standard	0.1600%	1	2.56×10^{-6}
Analysis Uncertainty at Standard Condition $u(Z_b)$	-	Standard	standard	-	1	0.0000%
Sum of the relative variances Relative Combined standard uncertainty				$U^2(Z_b/Z_f)$ $U(Z_b/Z_f)$		2.877610^{-6} 0.001696
Relative expanded uncertainty (95% confidence level $k = 2$)				$kU(Z_b/Z_f)$.		**0.3080%**

Table 3: Uncertainty Budget for Automatic Tank Gauging System (aTG)

Symbol	Uncertainty Parameters for ATG	Unit	Relative expanded uncertainty	Distribution	Coverage factor	Relative standard uncertainty	sensitivity coefficient	Contributory variances
$u\ (TCT)$	Strapping Table (TCT)	millimetre	0.200%	normal (95%)	2	0.100%	1	0.000100%
$u(h)$	Level Measurement	millimetre	0.200%	normal (95%)	2	0.100%	1	0.000100%
$u(T)$	Temperature Measurement (RTD PT Class B)	Degree centigrade	0.200%	normal (95%)	2	0.100%	1	0.000100%
$u(S)$	Stability of reference points							0.000000%
e	Shell expansion	millimetre						0.000000%
$u(VCF)$	ASTM Table 54B	cubic millimetre	0.050%	rectangular	1.7321	0.029%	1	0.000008%
$u\ (DCF)$	Density @15℃ correction (ASTM table 53B)	kilogram per cubic meter	0.100%	rectangular	1.7321	0.058%	1	0.000033%
$u\ (Comp)$	Field data to computer A/D signal converter		0.025%	rectangular	1.7321	0.014%	1	0.000002%
$u(TT)$	Temperature transmitter (SDAU)	degree centigrade	0.050%	normal (95%)	2	0.025%	1	0.000006%
$u(Tank)$	Tank hydrostatic deformation							0.000000%
$u(S\&W)$	Sediments and water Level probe	millimetre	0.300%	rectangular	2	0.150%	1	0.000225%
$u_c(x)$	**Sum of contributory variances**							**0.000575%**
$u(x)$	**Relative Standard Uncertainty of ATG**							**0.239791%**
U	**Relative expanded uncertainty of ATG (95% degree of freedom, coverage factor 2)**							**0.480%**

Symbol	Uncertainty Parameters	Source/ Reference	Error	units	Distribution	Divisor	Standard Uncertainty	Units	Relative uncertainty (%)	k	Expanded uncertainty (%)	Contributory Variances (%)
$u(T)$	Temperature Measurement	API MPMS, Chapter 7	0.3	°C	Type B, Rectangular	1.7321	0.1732	°C	0.87	2	1.7320	3.000
$u(h)$	Tank Gauging (Level)	API MPMS Chapter 3.1A	2	mm	Type B, Rectangular	1.7321	1.1546	mm	0.2	2	0.4000	0.160
$u(R_T)$	Reference tape	API MPMS Chapter 3.1A	0.3	mm	Rectangular	1.7321	0.1732	mm	0.01	2	0.0200	0.000
$u(D)$	Density, Hydrometer	API MPMS Chapter 9.1	0.5	kg/m^3	Type B, Rectangular	1.7321	0.2886	kg/m^3	0.03	2	0.0663	0.004
$u(S\&W)$	Sediments & Water Test Equipment	API MPM Chapter 10.3	0.2	mm	Type B, Rectangular	1.7321	0.11546	mm	0.02	2	0.0300	0.001
$u(DTcal)$	Dip tape calibration	ISO 1518		mm	Type B, Normal	2		mm	0.05	2	0.1000	0.010
$u(T_{cal})$	Tank calibration, Strapping	Calibration Chart		mm	Type B, Normal	2		mm	0.10	2	0.2000	0.040
$u(S)$	Shell thickness	Measurement		mm	Type B, Normal	2		mm	0.00	2		0.000
$u(DCF)$	ASTM 53B table, DCF	API Table		kg/m^3	Type B, Normal	1.7321		kg/m^3	0.05	2	0.1000	0.010
$u(VFC)$	ASTM 54B table, VCF	ASTM Table		m^3	Type B, Normal	1.7321		m^3	0.00	2	0.0030	0.000
Total contributory variances of MTG												**3.23**
Combined uncertainty of MTG (at 95% degree of freedom, coverage factor k=2)												**1.80**

Table 4: Uncertainty Budget for USM Fiscal Metering System (FMS)

Symbol	Sources of Uncertainty	Unit	Expanded Relative Uncertainty (%)	Probability Distribution	*k*	Standard uncertainty (%)	Sensitivity Coefficient	u(x).c	Contributory Variances
$u(T)$	Temperature Transmitter	Degree Celsius	0.047	normal (95%)	2	0.0235	2	0.047	0.002209
$u(D)$	Fluid density/densitometer	kilogram per cubic metre	0.1	normal (95%)	2	0.05	0.5	0.025	0.000625
$u(Ts)$	Clock frequency	second	0.02		2	0.01	1	0.01	0.0001
$u(Z)$	Compressibility Coefficient	Per Degree Celsius	0.308	normal (95%)	2	0.154	1	0.154	0.023716
$u(P)$	Pressure Measurement	Pascal	0.159	normal (95%)	2	0.0795	0.5	0.0398	0.001580063
$u(cal)$	Field calibration	Kilogram per second	0.125	normal (95%)	2	0.0625	1	0.0625	0.00390625
$u(ref)$	Reference Standard	Kilogram per second	0.1	normal (95%)	2	0.05	1	0.05	0.0025
$u(M)$	Flow meter accuracy	kilogram per hour	0.03	Normal (95%)	2	0.015	1	0.015	0.000225
$u(Td)$	Temperature dependence	Degree Celsius	0.05		2	0.025	1	0.025	0.000625
$u(Pd)$	pressure dependence	Pascal	0.02		2	0.01	1	0.01	0.0001
$U(x)^2$	**sum of the contributory variances**								**0.035586313**
$U(x)$	**USM flow meter Relative Uncertainty of the span**								**0.188643347**
U	**Expanded Relative Uncertainty at 95% confidence level (k=2)**								**0.377286695**