Performance Evaluation of the Food and Environmental Monitoring Radio-Analytical Laboratory in Ghana

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DECLARATION

This dissertation is the result of research work undertaken by Lilian Ataa Agyeman in the department of Nuclear Safety and Security, University of Ghana, under the supervision of Dr. A. Faanu and Prof. G. Emi-Reynolds.

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DEDICATION

I thank the Almighty God for how far He has brought me.

This work is dedicated to my Husband, Yaw Saarah Adu-Gyamfi for his Absolute Support, Prayers and Encouragement during this work; to my Children, Abena, Akwasi and Danyame Saarah Adu- Gyamfi and my Mother Ms. Margaret Adomako.

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LIST OF ABBREVIATIONS

ADC: Analogue- to- Digital Converter

Bq/Kg: Becquerel per Kilogram

Bq/m^2: Becqueral per square meter

Bq/m^3 : Becquerel per cubic meter

CL: Control Limit

CN: Channel Number

CRM: Certified Reference Material

DPS: disintegration per second

FEML: Food and Environmental Monitoring Laboratory

FWHM: Full Width at Half Maximum

GAEC: Ghana Atomic Energy Commission

GLP: Good Laboratory Practices

HPGe: High Purity Germanium detector

IAEA: International Atomic Energy Agency

IEC: International Electrotechnical Commission

ISO: International Standard Organization

K: Potassium

KeV: Kilo ElectronVolts

LCL: Lower Control Limit

LIMS: Laboratory Information Management System

LWL: Lower Warning Limit

MCA: Multichannel Analyser

MDA: Minimum Detectable activity

NaI: Sodium Iodide

NORM's: Naturally Occurring Radioactive Materials

PSDL: Primary Standard Dosimetry Laboratories

QA: Quality Assuarance

QC: Quality Control

RPB: Radiation Protection Board

RPI: radiation Protection Institute

SI: Systeme Internationale

SOP: Standard Operating Procedures

SSDL: Secondary Standard Dosimetry Laboratory

Th: Thorium

TRS: Technical Report Series

U: Uranium

UCL: Upper Control Limit

UNIDO: United Nations Industrial Development Organization

UNSCEAR: United Nations Scientific Committee on Effect of ATOMIC Radiation

UWL: Upper Warning Limit

WHO: World Health Organization

WNO: World Nuclear Organization

ABSTRACT

Since the establishment of the Radiation Protection Institute's Food and Environmental Laboratory in 1988, there has never been any thorough evaluation of the activities of the facility to provide assurance of the quality of analytical results produce by the laboratory. The objective of this study, therefore, was to assess the performance level of the Food and Environmental monitoring laboratory with respect to the requirements for a standard analytical laboratory (IAEA, 1989) and ISO 17025. The study focused on the performance of the Gamma Spectrometry laboratory of the Radiation Protection Institute, Ghana Atomic Energy Commission which has been involved in monitoring of radionuclides in food and environmental samples. In doing that, data from 1988 to 2015 was reviewed to ascertain whether the Laboratory has being performing as required in providing quality results on food and environmental samples measured. Besides this data (records kept), the evaluation also covered some Technical Quality Control measures, such as Energy and Efficiency Calibration, that need to be put in place for such laboratories. The laboratory meets almost all conditions and equipment requirements of IAEA (1989), however the laboratory falls short of the management requirements of ISO 17025. Based on the results it was recommended, among others, that management of the laboratory should ensure there are procedures for how calibration and testing is performed for different types of equipment and also the competence of all who operate specific equipment, perform tests, evaluate results and sign test reports ensured.

CHAPTER ONE

INTRODUCTION

The quest for a cost effective performance-based evaluation for the assessment of the technical ability of an analytical laboratory to perform acceptably over its lifetime, has been a subject of much concern in recent years. This chapter provides the background information and explains the reason for the study, its importance, objectives and scope.

1.1 Background

The world is said to be radioactive and has been since it was created. Over 60 radionuclides (radioactive elements) can be found in nature, and they can be placed in three broad categories namely:

a) Primordial – in existence since creation of the Earth
b) Cosmogenic - formed as a result of cosmic ray interactions with the atmosphere.
c) Human produced - enhanced or formed due to human actions (minor amounts compared to natural)

Radionuclides are found naturally in the atmosphere, water, soil as well as human beings. Every day, humans ingest and inhale radionuclides in the air, food and drinking water. This is because natural radioactivity is common in the rocks and soil that make up our planet, in water and oceans, and in building materials and homes. As a result of human activities such as industrial, nuclear accidents, weapon testing, radionuclide from both natural and artificial origin could widely spread in the environment.

In addition, humans can also be exposed to radiation in the environment from man-made activities, such as medical diagnostic intervention in nuclear medicine procedures. As a result of these human activities, radionuclides from both natural and artificial origin could be released into soil and water bodies. Human beings could possibly be exposed to these radionuclides through the direct ingestion of contaminated water. Indirectly, crops grown on contaminated soil could eventually be consumed by man. Similarly, animals grazing on contaminated grass could be a source of exposure through the consumption of meat and milk products.

Whether, man-made or natural in origin, radioactive element passes through the food chain in the same way as non-radioactive material. The level of harm to human health depends on the type, amount of radionuclides, and the exposure time. The exposure of radiation to humans differs from place to place and among individuals.

When there is a release of radioactivity following an emergency at a nuclear power plant; land, rivers, sea and structures in the vicinity of the power plant can become contaminated with a fission product generated inside the reactor. Individuals can therefore become exposed to these radionuclides released into the environment.

When these radioisotopes are discharged into the environment, they affect foods by either falling onto the surface of foods like fruits and vegetables or animal feed as deposits from the air or through contaminated rainwater. Radioactivity in water can also accumulate in rivers and the sea, contaminating fish and seafood. Once in the environment, radioactive material can also get into food as it is taken up by plants, seafood or ingested by animals. Assessment of any release of radioactivity into the environment is therefore important in ensuring protection of the public, especially if

the released radioactivity can enter the food chain. Such assessment demands rapid, reliable and practical techniques for analyses of various radionuclides.

In April 1986, the Chernobyl nuclear power plant disaster in Ukraine was the product of a flawed Soviet reactor design coupled with serious mistakes made by the plant operators. The accident caused the largest uncontrolled radioactive release into the environment ever recorded for any civilian operating nuclear power plant, and large quantities of radioactive substances were released into the environment for 10 days. This caused serious social and economic disruption for large populations in Belarus, Russia and Ukraine. Two radionuclides, the short-lived iodine-131 and the long-lived caesium-137, were particularly significant for the radiation dose delivered to members of the public, (WNO, 2016).

Several organisations reported on the impacts of the Chernobyl accident, but had problems assessing the significance of their observations because of the lack of reliable public health information before 1986 (WNO, 2016).

Some Member States of the International Atomic Energy Agency (IAEA) requested the assistance of the Agency in conducting radio analyses on a large number of food and environmental samples and in developing their own laboratory capabilities for this purpose. In the course of the IAEA's response to these requests it became evident that there was a need for laboratories capable of performing rapid and reliable measurements of radionuclides on a variety of sample materials and capable of handling large numbers of samples.

As a result of the above, Ghana instituted a monitoring programme to ensure food safety. Through the assistance of the IAEA, Ghana instituted the Food and Environmental monitoring programme during the 1980's. Through the IAEA's

support, Ghana was able to develop the basic manpower and acquired basic equipment to carry out food monitoring, particularly on milk and milk products imported into the country. The Radiation Protection Board (RPB) through the Radiation Protection Institute (RPI) of the Ghana Atomic Energy Commission (GAEC) was given the mandate to carry out the monitoring programme.

Since the food and environmental monitoring programme was instituted, the capability of the program has evolved, therefore this study seeks to evaluate the programme over the years and compare with the requirements as provided for in the IAEA Technical Report Series number 295 (IAEA, 1989).

1.2 Radiation Protection, Food and Environmental Monitoring Laboratory

a. **The Food and Environmental Monitoring Laboratory (FEML)**
b. **Food Monitoring Programme**

The Ghana Atomic Energy Commission (GAEC) has been monitoring food products both imports and exports since 1986 before the Radiation Protection Board was established in 1993. In pursuance of the provisions of the Radiation Protection Instrument of the Radiation Protection Board (RPB), Legislative Instrument (LI 1559) of 1993 (RPB, 1993), and in line with international requirements as well as to satisfy some importing countries requirements on some Ghana goods/products, for export, the RPB has continued to monitor milk and milk products for radioactivity contamination. The RPB carries out radiation contamination test on food products such as cocoa beans, cocoa cake, tuna fish, and Nestle products (such as Cerelac and other milk products), which are to be exported to countries like Egypt, Algeria Nigeria, Abidjan and Tunisia. It is important to note that before these products are

accepted into the importing countries, the product must be accompanied by an appropriate Radiation Contamination Test Certificate from the country of origin. In pursuance of the LI 1559, the RPB monitors food products such as meat/poultry, milk and milk products imported into Ghana in order to quantify the activity concentrations of caesium-134 (^{134}Cs) and caesium-137 (^{137}Cs) that might be found in the sample.

c. Environmental Monitoring Programme

Naturally occurring radionuclides are present in the environment at varying levels depending on the geological formation of the area. In addition, human activities including mining have the potential to increase the levels.

Mining has been identified as one of the potential sources of exposure to Naturally Occurring Radioactive Materials, [NORMs] (UNSCEAR, 2000). However, mining companies are not being regulated for NORM in most countries including Ghana. On the average, about 342 metric tonnes of gold ore is processed annually yielding about 13,365,000 oz. of gold (Goldfields, 2007). These mining operations turn out large volumes of solid and liquid wastes in the form of waste dams, slime dams and tailing dams, which could contain elevated levels of NORMs. These materials could wash off onto surface water bodies and farmlands during run-offs. Risk assessment and contamination test is conducted on environmental samples like soil and water from some of the mining areas by the Food and Environmental Monitoring Laboratory.

The laboratory has been in existence for over 25years, and therefore it has become necessary to carry out an assessment of the monitoring programme to ascertain the effectiveness and standard of measurements, procedures and processes at the Food and Environmental Laboratory, Radiation Protection Institute.

1.3 Statement of Problem

The food and environmental monitoring laboratory has been in existence since the late 1980's following the nuclear disaster in Chernobyl in 1986. The laboratory has provided services to various stakeholders in Ghana including exporters, researchers, and students.

However, since the establishment of the laboratory, there has never been a thorough evaluation of the activities of the laboratory to provide assurance of the quality of analytical results emanating from the laboratory. In addition, the laboratory does not participate in International Inter-comparison Exercises enabling the RPI-FEML to monitor its performance and to evaluate the quality of data churn out by the laboratory.

In view of that, this study is being conducted to help establish the status and performance of the laboratory in providing quality analytical services to its cherished clients.

1.4 Objectives

The objective of this study is to assess the performance level of the Food and Environmental monitoring laboratory of the RPI with respect to the requirements of the IAEA standard analytical laboratory practices (IAEA, 1989) and the Management and Technical Requirements of ISO 17025.

Specifically to:

i. To review records of the laboratory from 1988 to 2015;
ii. Evaluate the performance of the RPI-FEML radio-analytical laboratory against the requirements of the IAEA Guide for measurement of

Radionuclides in Food and the environment (IAEA Technical Report Series No.295; 1989), and the International Standard Organization's ISO/ IEC 17025 17025.

iii. To provide useful recommendations for laboratory management in the quest to obtain ISO/IEC 17025 accreditation.

1.5 Scope of the Study

This study is focused on the performance of the Food and Environmental Monitoring Laboratory of the Radiation Protection Institute of the Ghana Atomic Energy Commission which has been involved in monitoring of radionuclides in food and environmental samples.

1.6 Relevance of Study

In addition to routine radio-analytical measurements, the RPI's Food and Environmental Lab contributes knowledge to applied research projects funded by individuals and industries. These include studies in the field of radiation protection as well as scientific research targeted at development of improved radio-analytical methods. This study would contribute to improvement in the quality of data produced by the RPI's Food and Environmental Laboratory.

CHAPTER TWO

LITERATURE REVIEW

This Chapter reviews literature related to the concept of operations and laboratory standards. Literature on ISO 17025 and IAEA Technical Report Series 295 will also be reviewed.

2.0 ANALYTICAL LABORATORY

An analytical laboratory undertakes tests, or analyses, of samples or materials in a purpose built laboratory. The tests are undertaken to identify and to quantify, as necessary, the composition of the sample, or the material, that is analysed.

Different laboratories have different functions, and support either a single scientific discipline, example chemistry, or a number of different scientific disciplines, e.g., chemistry, biology and physics, within the same facility. For the purposes of this study, an analytical laboratory is a laboratory that practices one, or more, of these scientific disciplines in a purpose built laboratory facility. Traditionally, analytical laboratories have some level of interaction with their customers, who supply, or arrange to supply, laboratory samples to the laboratory for processing.

Laboratories also interact with their suppliers, who provide various inputs, such as chemical reagents, laboratory consumables and scientific technology, for use in the analysis processes and other associated activities. As a result of these various activities, there are many opportunities for improved, laboratory performance across all of the activities involved in delivering results of an analysis.

2.1 The Analytical Laboratory as a Service Organisation

Analytical laboratories are generally classified as being part of the service industry. They primarily act as a reporting service, which supplies analytical results, or data, to their customers in the form of a test report.

Customers then use the output analysis data to address their particular issues and problems. This perception of a laboratory as a service provider often means that laboratory selection by a customer is driven by factors such as quality, price, and turn-around time. These drivers have the potential, in turn, to influence laboratory decision-making in relation to the selection of test processes and analytical technology. Poor decisions by the laboratory may adversely influence the quality of the data provided. The potential also exists for environmental harm to arise from poorly conceived sampling and analysis programs driven only by financial considerations and operating under the traditional approach.

2.2.1 Primary Standard Dosimetry Laboratories (PSDLs)

A PSDL is a national laboratory designated by the government for the purpose of developing, maintaining and improving primary standards in radiation dosimetry. A PSDL participates in the international measurement system by making comparisons through the medium of the ″Bureau Internationale des Poids et Mesures″ (International Bureau of Weights and Measures), and provides calibration services for secondary standard instruments (ISO 17025).

2.2.2 Secondary Standard Dosimetry Laboratory

Secondary Standard Dosimetry Laboratory (SSDL) is an international network of dosimetry laboratories established by the International Atomic Energy Agency (IAEA) and the World Health Organization (WHO). The network provides a framework of international comparisons of the absorbed dose measurements that help to maintain consistency and accuracy particularly amongst the radiotherapy community. The SSDLs are designated by national laboratories (such as Primary Standard Dosimetry Laboratories, PSDL) to provide national and international radiation dosimetry traceability to users, (ISO 17025).

2.2.3 National Reference Laboratory

The national reference laboratory is an internationally recognised centre for the study of nuclear, non-nuclear, isotopic or elemental analysis of trace elements. Its wide-ranging roles encompass testing, non-testing, administrative, advisory and supervisory roles. Other roles include guiding the standards of training of personnel to be deployed in laboratories, standardisation of equipment, reagents and consumables, and the quality control of the testing procedures and results.

In order to perform these roles, the laboratory is expected to achieve and maintain certain minimum standards. Key considerations are the premises, the people working in them, policies that guide operations, the equipment and other tools of the trade, competency in the use of the equipment, mechanisms for the communication of test results and the availability of financial resources. Standards are essential for the realisation of these functions, (ISO 17025).

2.3 Analytical Laboratory Performance

There are several factors that influence laboratory operational performance, these include the equipment performance, adequacy of facility, trained personnel and QA/ QC, this section reviews the operations and the functions of analytical laboratories.

2.2 Laboratory Performance Evaluation

Some laboratories evaluate their performance based on the types of measures employed and the type of laboratory involved. In most cases, laboratory performance evaluation is based on outputs, but this is rarely applied across laboratories. For example, a university might look to the number and quality of publications and research; a routine laboratory to the number of samples completed, or profit generated; an industrial laboratory to the number of problems solved; and a government laboratory to the value to society (Lifshin, 1996). Another approach to performance evaluation suggests that a better evaluation of laboratory performance is the value contributed to achieving organisational goals and objectives (Collins, 2001).

Many laboratories support the need to achieve recognition from a parent organisation by applying performance evaluation and benchmarking based on cost effectiveness and the timely delivery of services. Laboratory benchmarking and performance evaluation has the potential to impact on the laboratory's management. Customer satisfaction measures not only the performance of the laboratory, but also reflect on the performance of the laboratory manager.

Laboratories are rated on the quality of results they submit. An individual result is acceptable if it falls within acceptable performance limits and is unacceptable if it

falls outside that limits. Once again, these performance limits are established by calculation of the mean and standard deviation from values reported by a pre-selected group of reference laboratories.

2.2.1 Evaluation of Performance Indicators

Performance indicators are measures of the analytical process that the laboratory monitors as part of its routine QC programme. Performance indicators demonstrate whether the analytical process is performing as planned, when it has exhibited a statistical anomaly that requires investigation, and when a system has failed. Accordingly, monitoring performance indicators using established statistical techniques provides the laboratory with an effective tool for self-assessment that allows the identification of trends or conditions that, while still within the established bounds of acceptability, are drifting or trending out of control. These conditions can be addressed prospectively, allowing the laboratory to maintain analytical control. Additionally, this process allows the development of a database regarding a protocol's or system's behavior over time or under a specified set of conditions.

2.2.1 Tolerance Limits

In some situations, the acceptance limits for a QC parameter may be based on professional judgment rather than statistics. Tolerance limits are used much like the control limits on a control chart to determine whether investigation and corrective action are required. Tolerance limits may be used when it is important to detect large changes in the variable. For example, tolerance limits could be used when variability within the limits has no significant impact on the measurement process.

An example of a variable that may sometimes appear to shift by small amounts is the resolution of a high-purity germanium detector. It also tends to be true that even statistically significant changes in the resolution are often so small that they have no practically significant effect on analytical results. So, it is reasonable to specify tolerance limits for the resolution at full width at half maximum (FWHM), rather than statistically based control limits.

Another example of a variable that is commonly monitored using tolerance limits is the chemical yield for an analytical process. Typically the yield is measured with relatively small uncertainty; so, fluctuations of the yield over some range of values may have no substantial impact on the quality of the measurement. However, a yield that is significantly greater than 100 percent generally indicates a spurious error of some kind, and a yield that is very low may indicate a spurious error or other problem in the measurement process that deserves investigation.

2.2.2 Measurement Uncertainty

Every analytical measured result is uncertain to some degree. If these measurement uncertainties are large relative to the tolerances needed for decision making, the data may not be useful for their intended purpose.

In order to determine the significance of a sample result, all reported values should be accompanied by the laboratory's best estimate of the uncertainty associated with the result. The "combined standard uncertainty" (one-sigma uncertainty) is obtained by propagating the uncertainties of all the input quantities that contribute to the calculation of the derived value.

The combined standard uncertainty is used to indicate the statistical confidence in interpreting the performance indicator's ability to assess analytical quality. The estimated statistical confidence level that is usually associated with 1 combined standard uncertainty is about 68%, the confidence level for 2 combined standard uncertainties is about 95%, and the confidence level for 3 combined standard uncertainties is about 99%. It is important that the combined standard uncertainty be a fair estimate because it will indicate when the analytical process could be approaching the limits of statistical control and corrective actions should be initiated. A performance indicator exceeding ±2 combined standard uncertainty limits from the indicator's historical mean value may indicate that corrective action should be considered, and a performance indicator exceeding ±3 combined standard uncertainty limits from the indicator's historical mean value may indicate that an investigation must be conducted and corrective action may be necessary. Because statistical confidence never reaches 100 percent, it probably would be prudent to confirm the measurement for the performance indicator when it exceeds ±2 combined standard uncertainty limits. If the performance indicator value for repeat measurements do not exceed ±2 combined standard uncertainty limits, one may conclude that the first measurement was a statistically allowable event. However, if the excursion is repeated, appropriate investigative actions should be considered.

2.2.2 Certified Reference Materials

Certified reference materials (CRMs) are well-characterized, stable, homogeneous materials with physical or chemical properties that are known within specified uncertainty limits. Laboratories that analyze CRMs can compare their performance to

the certified concentration and uncertainty levels. CRMs are used for the calibration of an apparatus or the assessment of a measurement method.

Metrology organizations issue CRMs in various matrices with critically evaluated concentration values for the radionuclide constituents. The usefulness of a reference material depends on the characterization of the radionuclide source, activity levels, and their estimated uncertainties.

CRMs can be used as internal laboratory QC samples to evaluate the ability of analytical methods to handle the matrix. CRMs need not be known to the analyst but can be introduced into the analytical stream as a blind.

A numerical performance indicator for the analysis of a CRM is essentially the same as that for a laboratory control sample.

Excursions in the CRM results can be used to identify various out-of-control situations. The advantage of the CRM is that the sample matrix is always the same, and the levels of analytes are known to a high degree, so uncertainties in matrix effects and radionuclide content should not be a factor in evaluating excursions. A rapid and one-time excursion in the Standard Reference Material usually indicates that a mistake was made in the procedure. A rapid change with continued occurrences suggest that something occurred that is out of the ordinary, such as a new analyst performing the procedure or the use of a new batch of calibration solutions or reagents. Slow changes showing a trend usually indicate degradation or contamination of equipment or reagents.

If a CRM result shows elevated concentrations, analysts should check for contamination sources or poor instrument or tracer calibration. If the results show

decreased concentrations, the analyst should check for poor techniques or expired or poorly prepared reagents and solutions.

CRM results may indicate a bias in the measurement process. Tracking the performance of several consecutive CRM measurements will show if the method or the laboratory consistently obtains high or low results. If the results are consistently higher or lower than the certified values, they should be evaluated for a statistical difference, example, tested. When the test indicates a statistical difference, a bias is indicated and the laboratory should investigate the cause of the bias and correct or characterize it.

2.2.3 Traceability

Comparing results from different laboratories or from the same laboratory at different times, with confidence is important. This can be achieved by ensuring that all laboratories are using the same measurement scale, or the same 'reference points'. This is also achieved by establishing a chain of calibrations leading to primary national or international standards, ideally (for long-term consistency) the Systeme Internationale (SI) units of measurement. A clear example is the case of analytical balances; each balance is calibrated using reference masses which are checked against national standards and to the primary reference kilogram. This chain of comparisons leads to a known reference value which provides 'traceability' to a common reference point, ensuring that different operators are using the same units of measurement. In routine measurement, the consistency of measurements between one laboratory and another is greatly aided by establishing traceability for all relevant intermediate measurements used to obtain or control a measurement result.

Traceability is therefore an important concept in all branches of measurement. (Eurachem, 2012)

2.3 Instrumentation Performance Indicators

Radiometric and non-radiometric instruments are used currently to quantify radionuclides in a variety of environmental matrices, and quality control measures are necessary to ensure proper instrument performance. This section presents radiometric instrument performance measures that indicate a measurement system is in control. The specific quality control procedures to be followed depend on the measurement equipment. Sufficient checks are needed to demonstrate that the measurement equipment is properly calibrated, the appropriate background has been recorded, and that all system components are functioning properly. QC measures for instrumentation should include at a minimum: (1) instrument background measurements, (2) instrument calibration with reference standards, and (3) periodic instrument performance checks subsequent to the calibration. Acceptable control limits should be specified in appropriate laboratory documents.

2.3.1 Instrument Background Measurements

Radiation detection instruments have a background response even in the absence of a sample or radionuclide source. In determining the instrument's response to radioactivity contributed by the sample alone (net), the instrument background response is subtracted from the sample-plus-background response (gross). Background correction is more critical when the instrument net response is small relative to the background. Control of contamination and routine monitoring of instrument background are therefore integral parts of a control program. Improper

background correction results in analytical error and will increase the uncertainty of data interpretation.

Differences in instrument backgrounds may indicate instrument malfunction. Variations may take the form of rapid increase or decrease in background, slow increase or decrease in backgrounds, and highly variable or erratic backgrounds. These variations can result in the measurement system's reduced precision and decreased detection capability. Rapid or significant increases in background measurements may be due to instrument or blank contamination, insufficient shielding with relocation of nearby radionuclide sources, or large scale equipment malfunction (example, a broken window on a gas proportional system).

When the instrument background is more variable than expected, the reliability of measurements becomes questionable, resulting in loss of confidence and increased uncertainty. This indicates a loss of control over the measurement environment, or limitations of the data handling software. The root cause of the variability should be identified and corrected to re-establish statistical control over the instrument background.

2.3.2 Efficiency Calibrations

The number of counts recorded by a detector is converted to activity (actual radionuclide transformations) by empirically determining this relationship with traceable radionuclide sources when available. This relationship is expressed in the system's efficiency calibration. A separate efficiency is determined for each detector-source combination and is typically energy or radionuclide specific.

Detector efficiency is critical for converting the detector's response to activity. Routine performance checks can evaluate several aspects simultaneously (sample geometry, matrix) and provide a means to demonstrate that the system's operational parameters are within acceptable limits. These are typically included in the assessment of the analytical method's bias and are specified in terms of percent recovery based on the source's known disintegration rate. Performance checks for measurement efficiency are usually determined statistically from repeated measurements with a specific check source. Detection of a shift in measurement efficiency should be investigated.

2.3.3 Energy Calibrations

All radiation measurements are energy dependent to a certain extent. However, spectrometric techniques such as gamma and alpha spectrometry identify radionuclides based on the energy of the detected radiations. For these techniques a correct energy calibration is critical to accurately identify radionuclides. Problem with energy calibration may result in misidentification of peaks.

Spectrometry systems should be calibrated so that each channel number is correlated with a specific energy. To identify radionuclides correctly, this energy calibration needs to be established initially and verified at regular intervals. The energy calibration is established by determining the channel number of the centroid of several peaks of known energy over the applicable energy range. Typically, a minimum of three peaks is used, and commercially available sources contain nine or ten photopeaks. The relationship between energy and channel number can be determined by a least squares fit. To account for non-linearity, a second or third order fit may be used. However, these require more points to define the curve. For example, a first order calibration requires at least two points, while a second order

calibration requires a minimum of three points. The end points of the curve define a range of applicability over which the calibration is valid, and peaks identified outside the curve's range should be used carefully. The uncertainty associated with the curve should be available at any point along the calibration curve.

Quality control checks for energy calibration can be combined with checks for efficiency calibration and resolution. Radiations emitted over the energy range of interest are measured, and two or more peaks are used to demonstrate that the energy calibration falls within acceptable limits. Check sources may consist of a single radionuclide or a mixture of radionuclides (example, mixed gamma). Because only the location of the peak is of concern, there is no requirement that the check source be calibrated or certified, except for ensuring that it does contain the radionuclide(s) of interest at a specified level of purity.

The energy calibration is determined by setting the system initially and then adjusting the gain of the amplifier, analog-to-digital conversion (ADC) gain, and zero. The criteria that indicate when readjustment is required because of gradual and abrupt changes in the energy versus channel calibration should be established as an integral part of the system's operating procedure. These changes usually are monitored by the measurement system's software, and the user specifies the allowable difference between that the system's response and the radionuclide's known energy. The tolerable difference often relates to the instrument's resolution. For example, a high resolution instrument such as an intrinsic germanium detector typically will have acceptable limits on the order of a few keV, while a low resolution instrument such as a NaI detector typically will have acceptable limits on the order of several tens of keV.

Spectra also can be analyzed by identifying each peak manually. With manual identification, the acceptable limits for the energy calibration are determined for each spectrum based on the professional judgment of the person analyzing the spectrum.

The frequency of QC checks for energy calibrations can be related to the expected resolution of the instrument, the electronic stability of the equipment, or the frequency needs of QC measurements for efficiency calibration or resolution. (MARLAP, 2004).

2.3.3 Calibration of Apparatus Used for Mass and Volume Measurements

Fundamental to quantitative analysis is the use of the proper masses and volumes. The analysts must be careful in performing gravimetric and volumetric measurements such as preparation of calibration solutions, test sources, and reagent in order to achieve the desired levels of precision and bias in each analytical method. Laboratory balances and volumetric glassware and equipment should be calibrated and checked periodically to maintain the desired method performance levels.

2.4 Statistical Means of Evaluating Performance Indicators - Control Charts

2.4.1 Statistical Quality Control

The term statistical quality control refers to QC based on statistical principles. Generally, statistical QC in the laboratory applies the principles of hypothesis testing, with varying degrees of rigor, to make inferences about a measurement system or process, (MARLAP, 2004).

An important reason to establish statistical QC in the laboratory is to ensure that measurement uncertainties are properly estimated. The uncertainty estimate that accompanies a measured value may be misleading unless the measurement process is in a state of statistical control. Statistical control implies that the distribution of measured results is stable and predictable. It exists when all the observed variability in the process is the result of random causes that are inherent in the process. The existence of variability due to .assignable causes, including instrumental and procedural failures and human blunders, which are not inherent in the process, implies that the process is unpredictable and hence "out of control" (MARLAP, 2004).

Statistical QC procedures are designed to detect variations due to assignable causes. When such variability is detected, specific corrective action is required to determine the cause and bring the measurement process back into a state of statistical control. Laboratory QC procedures should be definitive enough to detect variations in the measurement system that could have a significant impact on measurement uncertainties, (MARLAP, 2004).

Statistical QC also may be used in the laboratory to monitor method performance parameters, such as chemical yield, to ensure that the measurement system is performing as expected. However, the need for corrective action in the case of a low yield may not be as urgent as in the case of a malfunctioning radiation counter, since the latter is much more likely to cause underestimation of measurement uncertainties. The primary tool for statistical QC is the control chart. (MARLAP, 2004).

2.4.2 Control Charts for Instrument Response

Every control chart has control limits, which define the acceptable range of the monitored variable. Many charts have both upper and lower limits. However, when changes in only one direction are of concern, only one limit is necessary. Most control charts have a central line, or reference line, which is an estimate of the expected value of the monitored variable. Many control charts also have warning limits, which lie between the central line and the control limits (UNIDO, 2009)

By definition, control limits are action limits. A single measured value that falls outside these limits normally requires that one stop the measurement process, and investigate the problem, and if necessary take corrective action. The warning limits are optional but recommended, since they help one to identify and investigate possible problems before control limits are exceeded (UNIDO, 2009)

Control charts based on grouped observations often are more powerful tools for detecting shifts of the monitored variable than charts based on individual observations. Average charts, or $\overline{X}$ charts, are used to monitor the arithmetic means of measured values obtained in rational sub-groups, which are sub-groups of equal size chosen to ensure that the measurement variability within each sub-group is likely to represent only the inherent variability of the measurement process produced by non-assignable causes. When an $\overline{X}$ chart is used, a range chart, or R chart, is generally used in tandem to monitor within-group variability. (The range of a set of values is the difference between the largest value and the smallest.)

A control chart for individual values (X chart or I chart) is used when it is impractical to obtain measured values in the groups needed for an $\overline{X}$ chart. In this case, a moving range chart (MR chart) is often used as well to monitor variability.

The moving range chart is an R chart based on the absolute differences between consecutive measured values. (MARLAP, 2004)

A radioactive check source is normally used to monitor the radiation response/efficiency of every radiation counting instrument. It is recommended that the activity and count time for the source be chosen to give no more than 1 percent counting uncertainty (ANSI N42.23). In other words, at least 10,000 counts should be obtained in each measurement of the source. There may be cases when placing a high-activity source in a detector is undesirable, so obtaining 10,000 counts is impractical.

The instrument response may not have a Poisson distribution. In this case, if the check source is long-lived, an X or $\overline{X}$ chart based on replicate measurements should be set up. An X or $\overline{X}$ chart is the appropriate radiation response/efficiency chart for a high-purity germanium detector when the area of a specific photopeak is monitored, since the calculated size of the photopeak may have significant sources of uncertainty in addition to counting uncertainty. An X or $\overline{X}$ chart may be used even if the response is truly Poisson, since the Poisson distribution in this case is approximated well by a normal distribution, but slightly better warning and control limits are obtained by using the unique properties of the Poisson distribution.

2.5 Quality Assurance in the Laboratory Environment

Globally, everyone is concerned with the quality of services offered by the laboratories (Kiline, 2008). For a laboratory to be able to produce accurate and precise results, laboratory personnel must be well-trained, motivated, and have documented standard operating procedures. Standard operating procedures must be

formulated in a way that they can identify and correct erroneous results before they reach the customers (Kiline, 2008). Suksai et al. (2010) reported that hospital mortality rates can be lowered if testing laboratories produce the correct first time results that assist physicians with their diagnosis.

Kiline (2008) describes a quality management framework as one that will include the "5Q's". The "5Q's" stands for quality assurance, quality control; quality improvement; quality indicators and quality systems. A quality framework must be designed in a way that there is continuous feedback to ensure that root causes to arising issues are identified and corrective and/or preventive actions implemented.

Critical factors for a successful implementation of a quality standard include acceptance and commitment by each member of the team involved to generate "quality culture". The documentation of the system should be simple and flexible, so that employees can identify with it. The system as a whole should be self-sustainable and add value to the organization (Grochau et. al., 2010).

The main purpose of laboratories is to produce and deliver accurate and reliable measurement results at all times. In order to ensure that laboratories produce accurate and reliable results, there are control programs and quality assurance that can be implemented (Klinkner, 2008). Laboratories produce and issue a test/calibration certificate as their end product. The product produced by the laboratory is delivered to the customer in the form of a document, which is a test/calibration certificate. The test/calibration certificate is the only document which goes out of laboratory shelves in the form of 'product' (Gupta, 2010). When selecting a laboratory to provide service of testing or calibration, the potential customer needs to be sure that the supplier can issue valid results. There are a lot of factors that contribute to a

laboratory's technical competence. These include: the competence of laboratory personnel, the reliability of equipment, documented and validated test methods, proper sampling procedures and traceability of measurement to national and international standards (Robertson, 2010).

2.6 Laboratory Information Managing Systems

Dlamini (2005) reports that, the Laboratory Information Management System (LIMS) impacts operations of the laboratory positively. Nowadays managing information in the organisations has become an integral part of business. Test results issued by the laboratories are very important in the production processes. They have a direct impact on the process of meeting the requirements of the customers. Management must show leadership and implement corrective action and/or preventive actions. This can only be achieved using an effective laboratory management system (Dlamini, 2005). According to Van Eeden (2005) the implementation of LIMS results in major improvements within the laboratory. The major improvement in the laboratory is identified as the turn-around time from receiving the sample until the approved results are issued. The systems eliminate non-value-adding debates about who is responsible for delaying tests results because every activity is traceable.

Employing qualified and competent employees in laboratories gives them confidence when issuing results. Sometimes, the importance of hiring skilled laboratory personnel is taken lightly and not recognised. Highly automated measurement systems and test equipment cannot replace the importance of competent laboratory personnel. It is precisely when highly automated systems are used that competent

personnel are needed. Staffs that are competent would be able to utilise equipment to its full potential. Equipment reproducibility would be even more consistent (Apps, 2006).

2.7 Laboratory Personnel Competency and Performance Measurement

Laboratories face the challenge of running short of skilled personnel. This shortage and the availability of automated equipment tempt laboratories to go down the path of utilising sophisticated instruments that are operated by low skilled personnel. While this might appear to be a cost saving exercise and is attractive, it has costly consequences. There is higher throughput per person due to automated systems which means that one mistake affects output. Personnel depend largely on the supplier even for minor equipment service and troubleshooting. When laboratories use low skilled personnel, skilled personnel spend time verifying the results produced by those low skilled personnel. That practice is counter-productive (Apps, 2006).

One of the methods used by laboratories to measure the performance of laboratory personnel includes observing the person conducts a test or analysis. This method is time consuming and counterproductive. It can even be seen by personnel as discriminatory and unfair labour practice. Most laboratories have a procedure in place of handling an out of specification instrument. But most do not have an equivalent procedure for laboratory personnel, even though the testing of personnel plays a critical role in laboratory testing (Apps, 2006).

2.8 Description of ISO 17025

Requirements that laboratories have to satisfy according to ISO 17025 include validation protocols, measurement traceability, competence of personnel, and environmental conditions of the laboratory (Bednarova & Waddington, 2010). The clauses of ISO 17025 are discussed below.

2.8.1 Organisation

The laboratory or organisation should be an entity that can be held legally responsible. If the laboratory is part of an organisation it should not be directly under functions like production, finance or marketing. An arrangement like that will ensure that laboratory management is free from undue pressures where the quality of results may be sacrificed for profit, production volumes or speedy sample turnaround time. In cases of commercial laboratories, it should not act as a consultant for its customers. This could result in the laboratory's integrity of results and independent judgment being at stake (Gabi, 2006)

Clause 4.1.5(b) on organization of the ISO 17025 standard covers a requirement which ensures that both management and personnel are free from undue pressures that may adversely affect the quality of their work (Gabi, 2006). Factors like basic compensation, fringe benefits, leave, grievance procedures and economic protection against hazards are included in the employment contract of laboratory personnel and these factors help to reduce undue pressures, but they do not necessarily provide total protection unwarranted pressure and influences (Gabi, 2006).

The importance of deputies for key positions in the laboratory is very critical. This can relieve management from some of the pressures resulting from the heavy

workloads (Gabi, 2006). There must be adequate staffing in the entire laboratory to avoid pressures associated with work overload (Gabi, 2006).

2.8.2 Management System

The laboratory should establish, implement, and maintain a management system that is relevant to the scope of its activities (Gabi, 2006). The policies, systems, programmes, procedures to ensure the quality of results need to be documented and presented in the form of a quality manual (Gabi, 2006). Quality objectives should also form part of the quality manual and should be reviewed during the management reviews. The quality policy statement should be issued under the authority of top management (Gabi, 2006).

2.8.2.1 Document Control

According to Gabi (2006), a laboratory should establish and maintain procedures to control all the documents that form part of the management system. Documents could be of either internal or external origin and can include regulations, software, standards, drawings and specifications in any media (Gabi, 2006). The document control procedure should cover the process of approving documents, issuing documents and also the changes to documents (Gabi, 2006).

2.8.2.2 Review of Requests, Tenders and Contracts

The laboratory should have clearly defined procedures to review requests, tenders and contracts (Gabi, 2006). The lead times agreed upon should be within the laboratory's capability. Lead times should incorporate allowances for contingencies

(Gabi, 2006). All the records of reviews should be maintained in accordance with the document control procedures (Gabi, 2006).

2.8.2.3 Subcontracting of tests and calibrations

When a need for a laboratory to subcontract has been identified due to unforeseen reasons, competent suppliers should be used. A competent supplier could be one who is certified to ISO 17025 (Gabi, 2006). The customer whose work is tested by a subcontractor needs to be informed in writing and the laboratory will still be responsible to the customer for the subcontractor's work, except in the case where the customer or a regulatory authority specifies which subcontractor is to be used, (Gabi, 2006).

2.8.2.4 Purchasing services and supplies

The laboratory should have a documented policy and procedure for the selection and purchasing of services and supplies it uses that affect the quality of the results (Gabi, 2006). The laboratory needs to be given a reasonable budget to avoid undue financial pressures (Gabi, 2006). The laboratory should be at liberty to select quality brands and grades of analytical materials to be used in the testing processes (Gabi, 2006).

2.8.2.5 Service to the customer

The laboratory should be willing to cooperate with customers on clarifying the customer's requests and in monitoring the laboratory's performance in relation to the work performed. But the laboratory should always ensure confidentiality to other customers (Gabi, 2006).

2.8.2.6 Complaints

A systems approach to the analysis of root causes and corrective actions should be defined in the form of a policy and procedure (Gabi, 2006). Complaints from customers should not be regarded as an indication of poor performance of laboratory management and testing personnel (Gabi, 2006). They should be seen as an opportunity for continuously improving the quality management system. If complaints are not viewed from a systems perspective that may result to laboratory personnel issuing results that will please their customers in order to protect their jobs (Gabi, 2006).

2.8.2.7 Control of Non-Conforming Testing and/or Calibration Work

The laboratory should have policies and procedures that are implemented when any aspect of its testing or calibration work do not conform to its own procedures or the agreed requirements of the customer (Gabi, 2006).

2.8.2.8 Improvement

The only way to ensure continuous improvement in the laboratory system is through management reviews (Theodorou & Anastasakis, 2008). The management review agenda should include discussion points like suitability of policies and procedures, reports from managerial and supervisory personnel, outcome of recent internal audits, non-conformances, corrective/preventive actions, results of external quality assessments, inter-laboratory comparisons or proficiency testing schemes, changes in the volume and type of work, customer feedback, complaints and improvement suggestions (Theodorou & Anastasakis, 2008). Issues such as QC activities,

resources and staff training can also be included on the agenda (Theodorou & Anastasakis, 2008).

2.8.2.9 Corrective Action

The laboratory should establish a policy and a procedure that will assist them in implementing corrective action if any non-conformances occur in the form of non-conforming testing or deviations from procedures (Gabi, 2006). Once the corrective action to be implemented has been chosen, it should be implemented and monitored to ensure its effectiveness (Gabi, 2006). Additional audits can be conducted to verify the effectiveness of the implemented corrective action (Gabi, 2006).

2.8.2.10 Preventive Action

When improvements and potential sources of non-conformities have been identified, a preventive action should be developed, implemented and monitored to reduce the likelihood of the occurrence of non-conformance and to take advantage of the opportunities for improvement (Gabi, 2006). The preventive action procedure should include the initiation of the action and the application of controls to ensure that they are effective (Gabi, 2006).

2.8.2.11 Control of Records

The laboratory should establish and maintain procedures for identification, collection, indexing, access, filing, storage, maintenance and disposal of quality and technical records (Gabi, 2006). That should include records from internal audits, management reviews, as well as corrective and preventive action. Records should be stored in a secure space and in confidence (Gabi, 2006).

2.8.12 Internal Audits

The laboratory should develop a pre-determined audit schedule and procedure to conduct internal audits. The internal audit programme should address the elements of the management system including the testing or calibration activities (Gabi, 2006). If resources permit, audits should be conducted by qualified personnel who are independent of the activity being audited (Gabi, 2003).

2.8.13 Management Reviews

Certified laboratories or laboratories aiming at certification put a lot of effort into meeting the technical requirements of the accreditation standards (training, calibration and method validation) but some managerial requirements, for example management review are considered of lesser importance; however they are very critical (Theodorou & Anastasakis, 2008). Management reviews are key processes in many quality management systems. These include laboratory management systems like ISO 17025 and ISO 15189. These reviews are an opportunity to understand and manage all the inputs and outputs of a quality management system. In many quality management systems, management review is a critical requirement of the system. Laboratory standards like ISO 17025 are no exception (Theodorou & Anastasakis, 2008).

2.8.14 Technical Requirements

There are factors that determine the validity and reliability of the tests performed by the laboratory (Sithole, 2006). Those include human factors, accommodation and environmental conditions, test and calibration methods and method validation,

equipment, measurement traceability, sampling and the handling of test and calibration items (Sithole, 2006).

2.8.15 Personnel

The laboratory management should ensure the competence of all who operate specific equipment, perform tests, evaluate results and sign test reports (Sithole, 2006). If personnel are undergoing training, they need to work under the supervision of a person who has already been declared competent. Personnel's competence should be assessed on a continuous basis, to keep up with changes in technology (Sithole, 2006).

2.8.16 Accommodation and Environmental Conditions

The clause on accommodation and environmental conditions, stipulates that the environment in the laboratory should allow laboratory personnel to produce valid and reliable results (Gabi, 2006). Incompatible materials and activities should be segregated to avoid cross contamination (Gabi, 2006). The environmental conditions may be stated in the method but also requires the competency of personnel to be able to establish if the validity of result will be affected if there is no control (Sithole, 2006)

2.8.17 Test and Calibration Methods and Method Validation

The laboratory should use appropriate methods and procedures for all tests and calibrations within its scope (Sithole, 2006). Those include sampling, handling, transport, storage and preparation of items to be tested or calibrated, and where appropriate, an estimation of the measurement uncertainty as well as statistical techniques for analysis (Sithole, 2006). The laboratory can use laboratory developed

methods, non-standard methods, these must be done in consultation with the customer (Sithole, 2006). The test methods used by the laboratory should be validated, that is confirmed by objective evidence that the particular requirements for a specific intended use are fulfilled (Sithole, 2006).

2.8.18 Equipment

The laboratory should be properly furnished with items for sampling, measurement and test equipment required for the correct performance of the tests or calibrations (Sithole, 2006). All the equipment and software used for testing, calibration and sampling should be capable of achieving the accuracy required (Sithole, 2006).

2.8.19 Measurement Traceability

Laboratories need capable equipment that is maintained and calibrated at set intervals to ensure traceability to national and international standards (Sithole, 2006). Records of equipment maintenance and calibration should be maintained. Reference standards, reference material, and intermediate checks should be used to ensure traceability of testing or calibration (Sithole, 2006).

2.8.20 Sampling

The process of sampling is a critical requirement that needs to be taken into account to achieve valid results (Sithole, 2006). Where the laboratory is involved in sampling, the laboratory should have established and unbiased sampling procedures and adhere to that (Gabi, 2006).

Gabi (2006) points out that laboratories involved in the regulatory testing field, should receive samples that are identified by codes and true identities withheld. It

should be a practice for laboratory personnel not to be in direct contact with the sample owners. The arrangement guards laboratory personnel from being offered bribes and victimization by sample owners.

2.8.21 Handling of Test and Calibration Items

The laboratory should have procedures for the transportation, receipt, handling, protection, storage, retention and disposal of test or calibration items including all provisions necessary to protect the integrity of the test or calibration item, and to protect the interests of the laboratory and the customer (Sithole, 2006).

2.8.22 Assuring the Quality of Test and Calibration Results

The laboratory should have quality control procedures for monitoring the validity of tests and calibrations undertaken (Sithole, 2006). The monitoring of tests or calibration could include participation in inter-laboratory or proficiency testing programmes, retesting or recalibration of retained items, replicate tests or calibration using the same or different methods, regular use of certified material or internal quality control using secondary reference materials (Sithole, 2006).

2.8.23 Reporting the Results

The results of each test or calibration carried out by the laboratory should be reported accurately, clearly, objectively and in accordance with any specific instructions in the test or calibration methods (Sithole, 2006). An approved template needs to be used to generate all the test reports or calibration certificates (Sithole, 2006). When opinions and interpretation are included in the reports, the laboratory should document them on the basis upon which they have been made. Opinions and interpretation should be clearly marked as such in the report (Sithole, 2006).

2.9 Benefits of ISO 17025 certification

Governments and regulators can benefit a lot by using ISO 17025 certified laboratories. Certification to ISO 17025 increases confidence in data issued by laboratories. It reduces uncertainties associated with decisions that affect the protection of human health and the environment. It is seen as a seal of approval, and therefore increases public confidence. It facilitates trade and economic growth, gives laboratories a marketing advantage, international recognition and can be used as a benchmark for performance (Robertson, 2010).

Sithole (2006) reports that implementing a laboratory quality standard and certifying it can benefit laboratories. It serves as a standard to transmit information; encourages transparency as activities are documented and accessible to all personnel, assist personnel in the understanding and application of policies, it is a good marketing tool to give customers confidence about the reliability and consistency of their service providers. It is a training tool for new employees, ensures uniformity of the organisation's practices and tasks, and assists personnel to make decisions (Sithole, 2006).

Bailey (2003) warns that ISO 17025 has been criticised for the emphasis it places on documentation, records and record keeping. Experience has shown that this criticism is to some extent true, but careful drafting of laboratory policies and procedures can significantly reduce the record keeping workload (Bailey, 2003). Care must be taken to select the correct data and information for inclusion in laboratory records. Records are essential and the effective use and interpretation of recorded information and data is essential to maintaining a consistently high laboratory performance (Bailey, 2003).

2.10 IAEA Technical Report Series 295 Requirements for Food and Environmental Laboratories

During the course of the Supplementary Programme on Nuclear Safety, it became evident to the IAEA that there was a serious lack of analytical capabilities within its Member States to cope with nuclear releases. The IAEA therefore relied on experts and specialists in the radioanalytical field to provide guidelines for collecting, preparing and analysing relevant environmental material and basic food for radionuclides of interest. This resulted in the publication of Technical Report Series 295 (TRS 295).

2.10.1 Accommodation

Table 2.0 lists the number of rooms and the area recommended by TRS 295 for a central laboratory's activities. However, organizations that are just beginning to set up monitoring facilities need not establish a full-scale operation as outlined. However, good judgement in selecting the appropriate facilities and equipment will facilitate the establishment of a scaled down and adequate monitoring laboratory (IAEA, 1989)

Table 2. 1: Rooms and Area Recommended for a Central Environmental Laboratory

Operations	**No. of Rooms**	**Area (m)**
Sample registration, storage and preparation: Evaporation and drying Grinding Ashing Handling of higher activity samples	7-8	130-180
Gamma ray spectrometry laboratory: Preparation and storage of samples Counting room Computer room	3-4	90-120
Alpha spectrometry laboratory Radiochemical laboratory Counting room Computer room	3-4	60-70
Offices, Administration Social rooms, Library,	4-10	80- 150

Source: IAEA Technical Report Series 295(1989)

2.10.2 Laboratory Design

The central laboratory should be designed and built according to the requirements of a normal analytical laboratory with a few additional features such as special ventilation, specially designed rooms for receiving and storing samples, and specially constructed nuclear measurement facilities (counting room(s)). Storage space should be available to accommodate all types of sample materials. Storage shelves or bins should be constructed of materials that are easily decontaminated in case of spills. (IAEA TRS 295, 1989).

2.10.3 Ventilation

The ventilation system should be designed to filter incoming air to all areas and to maintain the lowest pressure in areas used for handling high activity samples and for preparing the samples. The sample receiving room(s) should be at low pressure to prevent any possible contamination of other laboratories by incoming samples.

Wet chemistry laboratories should have well ventilated fume hoods. Counting rooms should be under positive pressure at all times. (IAEA Technical Report Series 295, 1989)

2.10.4 Temperature

Constant temperature and humidity should be maintained in counting and computer rooms and should be set according to the recommendations of the manufacturers of instruments and equipment. Normal temperatures recommended for counting rooms are between 20 °C and 26 °C (IAEA Technical Report Series 295, 1989)

2.10.5 Instrumentation required for Gamma Radiation Measurement:

A fully integrated gamma spectrometry system for qualitative and quantitative determination of gamma emitters is required by Technical Report Series 295. According to IAEA (1989), the system should comprise a germanium detector, shield, multichannel analyser (MCA), high-speed printer, and (optionally) a plotter. NaI(Tl) detector (8% resolution), a 2048-channel analyser and a lead shield with an inside diameter of about 20 cm and a wall thickness of 5-10 cm.

Other laboratory equipment, for sample collection and preparation, listed in IAEA (1989) are:

i. Large refrigerator for preserving samples;
ii. Freezer for storing samples;
iii. Crusher and/or grinder ;
iv. Evaporator or evaporation lamps;
v. Large drying oven; and
vi. Freeze dryer (as an option).

2.10.4 Personnel requirements

Personnel required to staff a central environmental laboratory includes:

a. A Manager (Chief Scientist);
b. 2 Scientists;
c. 3 Senior Technicians;
d. 6 Technical Assistants;
e. 1 Secretary
f. 1 Field Technician to operate trucks, other vehicles and boats for sample collection;
g. 1 maintenance and service Technician familiar with electronic equipment.

2.10.6 TRAINING

The staff of local laboratories must undergo continuous training in order to maintain the radioactivity measurement capability adequate for routine measurements and to be ready for any possible emergency.

2.10.7 ANALYTICAL QUALITY CONTROL

Quality control measures are necessary to provide documentation to show that the analytical results are reliable.

2.10.7.1 Analysis by different methods.

In cases where agreement is good, results are assumed to be accurate. Control analysis with reference materials that are as similar as possible to the materials to be

analysed. Agreement between certified and observed values is then a direct measure of accuracy for that particular determination. (MARLAP, 2004)

2.10.7.1 Participation in an Inter-laboratory Comparison.

Samples used in such an inter-comparison should be, as far as possible, similar in composition and concentration to the samples to be analysed on a routine basis. The agreement of results received from a particular laboratory with the most probable mean value obtained from statistical evaluations of all the results will be a measure of the accuracy for that particular determination. Participation on a regular basis will detect a systematic error that is those due to improper calibration, contamination or incorrect methods of calculation.

2.10.7.2 Calibration and Standards

It is desirable and often necessary that calibrations of measurement systems be carried out with standards of the radionuclides to be determined. Standards should be accompanied by certificates which specify activity, purity and accuracy (IAEA Technical Report Series 295, 1989).

2.10.8 Internal Control Programmes

The laboratory should operate a routine programme to maintain the equipment and the validity of the results (IAEA Technical Report Series 295, 1989)

2.10.8.1 Equipment performance

The laboratory should routinely check the status of equipment by checking background and standard samples. Quality control charts be kept for each system on a routine basis. m

2.10.8.2 Analytical control samples

The validity of the analytical results should be checked by an internal standards programme which incorporates the use of blind duplicates, blanks and standards. These results often give the first indication of analytical difficulties. Analytical control samples, submitted with each group of samples to be analysed, generally constitute 10-15% of the total samples. Laboratory control standards can be developed by preparing large, homogeneous batches of material for various sample types. By analysing these controls in duplicate or triplicate, sufficient data will be available in a short time to establish the "standard" value. This material can also be run by several other reliable laboratories as a check.

2.10.9 Data Presentation

The results of the sample analysis should be presented in such a way that the reader can evaluate the data and the conclusions. The presentation should discuss as a minimum:

i. Location, collection method and preparation procedures;

ii. Analytical method and specifications of the equipment.

The report on environmental radioactivity should contain tables with the following characteristics:

(a) The International System (SI) units and symbols should be used

(b) Some standard units of presentation are:

a. Air in Bq/m^3

b. Water and milk in Bq/L

c. Deposition in Bq/m^2

d. Soil in Bq/kg dry mass and Bq/m^2

e. Grass in Bq/kg dry mass and Bq/m^2

f. Foods in Bq/kg fresh mass.

(c) The value should be given to the correct number of significant figures;

(d) The precision of the data should be indicated and the form of expressing this data should be clearly explained, for example the standard error, the two-sigma error, and the counting error. Where possible the accuracy of the data should be indicated, generally by reference to the supporting data for the particular method used.

(e) Where low levels of activity are indicated, the lower limit of detection should be indicated and the method used for its calculation should be referenced (IAEA Technical Report Series 295, 1989).

CHAPTER 3

METHODOLOGY

This Chapter presents the method for evaluating the performance indicators of the RPI Food and Environmental Monitoring Laboratory.

3.1 Description of the Facility

The Food and Environmental Monitoring Laboratory is part of the Environmental Protection and Waste Management Centre, Radiation Protection Institute, Ghana Atomic Energy Commission. The Laboratory is located within the same building with the Ghana Research Reactor- 1 on the premises of the Ghana Atomic Energy Commission (GAEC). The facility has a registry room which also serves as technologist office, sample preparation room, a counting/ computer room, store room and a wash room.

The Radiation Protection Institute serves as the technical arm of the Radiation Protection Board which is the competent national authority for environmental radioactivity monitoring among others. The RPI laboratory performs detailed analyses on all types of environmental materials such as water, soil and air, as well as imported and exported food samples, in order to quantify the radionuclides concentration in them. The laboratory is capable of performing the required radioactive contamination measurements for determination of Gamma emitters by non-destructive gamma ray spectrometry.

The Food and Environmental Laboratory is equipped with two low background gamma ray spectroscopic systems, the High Purity Germanium detectors (HPGe) and the Sodium Iodide Detector.

In-situ measurements are usually included in the environmental radioactivity monitoring programme. In situ measurements are performed for: the qualitative and the quantitative determination of a potential radiological contamination, Radon analysis and characterization of the materials.

The laboratory also serves as a National Central Reference Laboratory and a research laboratory for students from the School of Nuclear and Allied Sciences (SNAS), College of Basic and Applied Sciences, University of Ghana- Atomic.

3.2 Administration of Questionnaire

This took the form of a list of questions (Appendix A) given to twelve (12) respondents to answer with the rationale of getting data on the topic under study. The respondents included; the Director, previous Centre Managers, Research Scientist and Technologist working in the Laboratory. Self-administered questionnaires as opposed to the postal questionnaires was used. The questions in the questionnaire took the form of Close-ended Questions and offered a set of alternative answers from which the respondents were asked to choose the one that most closely represents their view. It is to be emphasized that the questionnaire allowed respondents time to think through the questions to provide accurate answers.

The researcher conducted pre-testing of the draft questionnaire with few potential respondents in an informal manner before following up with the full scale questionnaire administration. The purpose of the study was explained to officials and those who responded to the questionnaires and interviews.

The survey contained questions which respondents could choose from three relevant responses; No, Partially or Yes. The responses were coded (No = 0, partially = 1 and Yes = 2) and summarized on the basis of the information provided by the

respondents. The most straightforward form of analysis, and one that often supplies much of the basic information need, to tabulate results, question by question, are 'one-way tables' (Statistical Services Centre, 2001). This was done using the original questionnaire and writing on it the approximated average score of each question. Though this method does not identify which respondents produced particular combinations of responses, this is often useful when a quick and/or simple summary is required. The analysis was done using Microsoft Excel, 2016 quantitative tool.

3.3 Physical Examination and Observation of Documents and Procedures

This study was carried out by comparing information and data that existed in the Food and Environmental Laboratory of the RPI to the standard requirements that need to be available for the laboratory to perform effectively and efficiently.

The requirements were based on the ISO 17025 International standard as well as the IAEA Guide for Laboratories performing the Measurement of Radionuclides in Food and the Environment (IAEA, 1989). The assessment covered the suitability and performance of the facility with respect to the following areas:

i. **Laboratory Design**: Test facilities should be of suitable size, construction and location to meet the requirements of the study. The facility should be spacious enough to avoid overcrowding, cross contamination and confusion between projects.

The area should be big enough to accommodate the number of staff working in it, and allow them to carry on their work without risk of getting in one another's way or of mixing up different materials. Each operator should have a workstation sufficiently large to enable him/her to carry out the operation efficiently. To reduce

the chance of mix-up of materials or of cross-contamination, there should also be a degree of physical separation between the workstations.

The workstations must be built of materials that allow easy cleaning and that are not likely to allow test materials to accumulate and contaminate one another. There should be a ventilation system that provides air-flow away from the operator through filters which both protect personnel and prevent cross-contamination (GLP Hand, 2009).

Arrangement

There should be separate areas for:

a. Storage of test items under different conditions.
b. Storage of control items.
c. Handling of volatile materials.
d. Weighing.
e. Mixing of different chemicals.
f. Cleaning equipment.
g. Offices and Changing rooms (GLP Hand, 2009).

Table 3. 1: The checklist below developed to assist in the workplace inspection

Department: Environmental Protection and Waste Management Centre.	**Date: 10 /03/ 2016**
Area inspected: Food and Environmental Monitoring Laboratory	**Inspected by:** Lilian Ataa Agyeman

Laboratory Environment

Inspection item	Yes	No	N/A	Notes
Adequate number of rooms	**x**			Number of rooms was counted and compared to the required number in the TRS 295
Adequate Laboratory Space	**x**			Lab. Space was measured and compared to the required space for each room in the TRS 295
Availability of adequate Laboratory bench	**x**			
"AUTHORISED ENTRY ONLY" signage is displayed at the laboratory entrances		x		
The laboratory is locked when unattended	x			
Hand washing facilities are available adjacent to the main entry/exit	x			
Benches, floors and furniture surfaces are smooth, impervious, chemically resistant and easy to clean	x			
Benches are clean, tidy and uncluttered	x			
Floor is clean, dry and uncluttered	x			
All areas are adequately lit	x			
Adequate Ventilation	x			
Temperature is within acceptable limits e.g. 20-26^{0}C	x			

ii. Equipment available and Equipment Performance Test

iii. Availability of qualified and well trained personnel

iv. Reporting of results

v. Record keeping

vi. Maintenance: The requirement that equipment be properly maintained is based on the assertion that this ensures the constant performance of equipment to specifications and that it reduces the likelihood of an unexpected breakdown and consequent loss of data (GLP, 2009).

Routine maintenance should be documented such that users of equipment can be assured of its reliability. A label attached to the equipment or provision of a clear service plan may ensure this. Records of equipment calibration, checking and maintenance demonstrate that the respective SOPs have been followed and that equipment used was adequate for the task and operating within its specifications.

Maintenance documentation in the laboratory was assessed.

vii. Standard Operating Procedures: A full set of good Standard Operating Procedures (SOPs) is a prerequisite for successful good laboratory Practice compliance.

All documents within the laboratory was reviewed but the was no written document or protocols found in the laboratory.

viii. Management system to ensure quality services

Data from 1988 to 2015 were reviewed to ascertain whether the Laboratory has been performing as required in providing quality results on food and environmental samples measured.

3.3 Equipment Performance Test

For Gamma spectroscopy, energy and efficiency calibration of the detector system of the gamma spectrometer is vital and it forms an important part of the analytical technique in analysing environmental and food samples for radioactivity. This is to enable the identification and quantification of radionuclides in the samples.

Standard sources are usually used for calibration. The calibration standard source must have the same geometry as the samples to be analysed, so that the deviation in the measured activity is minimized (Harb et al., 2008b).

The energy and efficiency calibration of the system was carried out by using a multinuclide certified reference standard. The standard consists of an aqueous mixture of nine radionuclides in a 1.0 Litre Marinelli beaker. The standard consist of the following radionuclides with their corresponding energies; ^{241}Am (4.694kBq), ^{109}Cd (14.54kBq), ^{139}Ce (1.355kBq), ^{57}Co (1.156), ^{60}Co (2.697), ^{137}Cs (2.689kBq), ^{113}Sn (4.000kBq), ^{85}Sr (4.570kBq), and ^{88}Y (5.323kBq). The standard was counted for 36,000 seconds.

3.3.1 Energy calibration

The above described reference standard was used for the calibration. The energy calibration of the germanium detector system was done by counting the standard for 36,000 seconds. The gain of the system was adjusted so as to position the 662 keV of ^{137}Cs to the channel number of the multichannel analyser in relation to the gamma ray energy.

After these adjustments are made, the gain of the system should remain fixed. The channel number that corresponds to the centroid of each Full Energy Peak on the Multichannel Analyser was recorded and plotted on a linear graph on the X-axis against the gamma ray energy on the Y-axis. A linear curve was obtained in the plot of the data. The slope and intercept of the energy calibration line was determined by least squares calculations.

The equation relating the energy and the channel number is given by the expression [Reguigui, 2006; Gilmore and Hemingway, 1995].

$$E_\gamma = A_0 + A_1 CN \qquad \text{(Eq. 3.1)}$$

where E_γ is the energy in keV, CN is the channel number for a given radionuclide, and A_o and A_1 are calibration constants for a given geometry.

3.3.2 Efficiency Calibration

The radiation detector must be calibrated to determine the relationship between the observed count rate of the detector and the emission rate of the source being assayed. This relationship is called the efficiency calibration, typically expressed as counts per second/emissions per second, or cps/dps-and is an integral part of the measurement protocol. For alpha spectrometry systems, the efficiency of detection is energy-independent. Efficiencies for gamma spectrometry are energy dependent, and an efficiency calibration typically covers a range for a specific counting geometry.

The mixed radionuclide standard used for the energy calibration was again used for the efficiency calibration by counting it on the High Purity Germanium Detector for another 36000 seconds. The net count for each of the spectrum was determined and their corresponding energies were used in finding the efficiencies.

The efficiency at each energy was plotted as a function of the peak energy and extrapolated to determine the efficiencies at other peak energies for each of the measurement. To calculate the efficiency, Equation 3.2 was used

$$\varepsilon(E_\gamma) = \frac{N}{(A * P * t)} \qquad \text{(Eq. 3.2)}$$

Where N is the full peak energy net count corresponding to the gamma photons with energy E_γ and gamma emission probability P, A is the activity of the radionuclide in the calibration standard and t is the counting time.

3.3.3 Instrument Background Measurement

In general, radionuclide detection covers more than 17 orders of magnitude of sample activity, from irradiated material that produces high radiation fields to environmental samples. All radiation detection instruments have a background response even in the absence of a sample or radionuclide source. (MARLAP, 2004).

The instrument's background measurement was determined in the absence of a radionuclide source. The background was counted for 24 hours with an empty well sterile 1L Marineli beaker, and then a second counting was done with the above described standard on the detector for another 24 hours as the gross count.

To determine the instrument's response to the radioactivity contributed by the sample (standard) alone (net), the instrument background response is subtracted from the sample (standard) - plus-background response (gross).

The instrument background is an important factor in determining the ability to achieve a specific minimum detectable activity (MDA).

3.3.4 Determination of Minimum Detectable Activity (MDA)

Detection limits of a Gamma- ray spectrometry detector is used to express the detection capability of a measurement system under certain conditions. MDA is an estimate for the lowest amount of activity of a specific gamma-emitting radionuclide that can be detected at the time of measurement. (MARLAP, 2004).

The background response of the detector was determined and then, the reference standard was counted on the detector for 36000 s. The average background peaks was used to determine the MDA.

The minimum detectable activities were calculated using the equation below: (DWAF, 2002)

$$MDA = \frac{\sigma\sqrt{B}}{\eta.P.T.W}(Bq/kg) \qquad \text{(Eq. 3.3)}$$

Where;

σ is the statistical coverage factor equal to 1.645 (confidence level 95%);

B is the background for the region of interest of each radionuclide;

T *is* counting time in seconds;

W is the weight of the sample container;

P is the gamma emission probability (gamma yield) of each radionuclide; and

η is the photopeak efficiency for the measured gamma ray energy.

3.4 Statistical Analysis of the Performance of the Gamma Spectrometry System

A radioactive check source (^{137}Cs of activity1μCi) was counted 60 seconds for 100 times. The central line, and, control and warning lines for the X chat, were determined using the following procedure (assuming the system is under statistical control):

Step 1: The sum of the counts ($\sum X_i$) and the mean of the counts ($\overline{X}$) were calculated

Step 2: The experimental standard deviation was calculated from the relation;

$$s = \sqrt{\left[\frac{1}{n-1}\sum_{i=1}^{n}\left(X_i - \overline{X}\right)^2\right]} \tag{3.5}$$

Step 3: The unbiased estimate $\overline{\sigma}$ of the standard deviation was calculated from the relation;

$$\overline{\sigma} = \frac{s}{c_4} \tag{3.6}$$

Where $c_4 = \frac{4n-4}{4n-3}$

The central line (CL), control limits (UCL and LCL) and warning limits (UWL and LWL) were calculated as follow:

$$CL = \overline{X} \tag{3. 7}$$

$$UCL = \overline{X} + 3\overline{\sigma} \tag{3.8}$$

$$LCL = \overline{X} - 3\overline{\sigma} \tag{3.9}$$

$$UWL = \overline{X} + 2\overline{\sigma} \tag{3.10}$$

$$LWL = \overline{X} - 2\overline{\sigma} \tag{3.11}$$

After the construction of the X-Chart, another set of 100 counts (60 seconds each) of the Cs source was carried out. The data obtained was used to statistically monitor the radiation response/efficiency of the gamma detector.

CHAPTER 4

RESULTS AND DISCUSSIONS

The results and discussions of the research conducted are presented in this chapter. Data collected from managers and staff of the Laboratory provided evidence of the extent to which ISO 17025 and Technical Report Series 295 are used in the operational performance of the RPI Laboratory.

4.1 Compliance with ISO 17025

4.1.1 Personnel Training Records

It is necessary for the laboratory to have staff training and competence records. These should include, at least, a record of each staff member's formal qualifications, previous experience and date of recruitment; a list of the activities for which the staff member has been trained and record of regular re-assessment of the staff member's competence at each of the activities. One purpose of the training records is to serve as a source of reference for supervisors who wish to ensure that the person whom they intend to allocate to a task is properly trained and that their training is up to date.

The laboratory does not have an established quality assurance system that clearly defines procedure for declaring employees competent. Methods like training of personnel by a competent person, taking part in proficiency testing schemes and intra-laboratory test samples are not used. There are no procedures in place to measure the effectiveness of training once training has been conducted.

The variability of the responses, as shown in Table 4.1, indicates there are no personnel records as such training records must be available in the laboratory. It must

be noted that assessors will not accept training records held in the personnel office at Ghana Atomic Energy Commission.

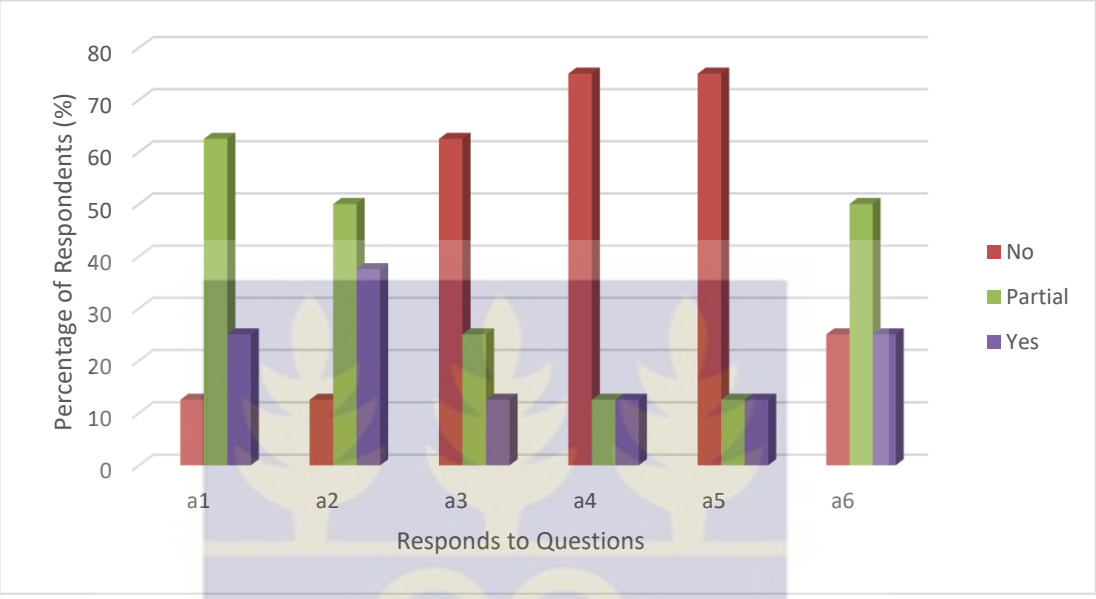

Figure 4. 1: Percentage responds to questions on personnel training records

Table 4. 1: Average response to questions on personnel training records

No.	Personnel Training Records	Approximated Average Score
a1	*Do you have a record of the qualifications and experience of your staff, with objective evidence of their qualifications, for example copies of certificates?*	1
a2	*Do you have a clear record with regard to your proposed scope of accreditation of which members of staff are authorized to conduct each test or calibration?*	1
a3	*Do you have a documented procedure for training staff in quality issues and technical procedures, including tests?*	1
a4	*Do you have a documented procedure for conducting evaluation of the competence of staff after training and before authorising them for the procedure in which they were trained?*	0
a5	*Do you have a system for recording training, including objective evidence of competence?*	0
a6	*Do you have a mechanism for identifying which staff conducted each procedure, test or calibration?*	1
		1

4.1.2 Accommodation and Environmental Conditions

Though staff members' response indicated that there are some environmental factors in the laboratory which might impact on the validity of tests or calibrations and activities which need to be separated to avoid, for example, cross contamination, much has not been done to put measures in place to determine and minimise environmental factors in the laboratory which might impact on the validity of tests or calibrations. Also there are no documented requirements for test or calibration to be done under specific environmental conditions (Table 4.2).

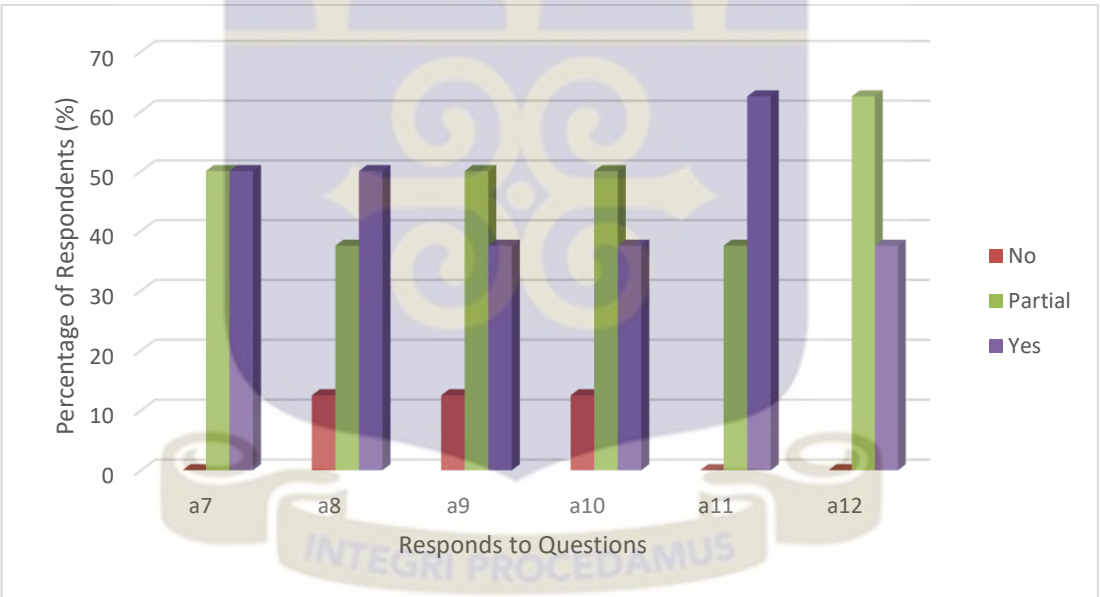

Figure 4. 2: Percentage responds to questions on accommodation and environmental conditions existing in the laboratory

Table 4. 2: Approximated Average Score of responds to questions on accommodation and environmental conditions existing in the laboratory

No.	Accommodation and environmental conditions	Approximated Average Score
a7	*Have you considered whether there are any environmental factors in your laboratory which might impact on the validity of tests or calibrations?*	2
a8	*Are you conducting any tests or calibrations where the published procedure which you claim to follow includes a requirement for the work to be done under specific environmental conditions, for example temperature or humidity?*	1
a9	*If there are such factors, do you have procedures in place to control and monitor them?*	1
a10	*Do you have any activities which need to be separated to avoid, for example, cross contamination?*	1
a11	*Do you have any activities which need to be separated to avoid, for example, cross contamination?*	2
	Average	**1**

4.1.3 Quality assurance for the screening process

From Table 4.3, the laboratory seems to have determined the accuracy, precision and, where relevant, the limit of detection of the methods which are used, including standard published methods. However, all the other indicators of a good assurance for the screening process have not been properly established.

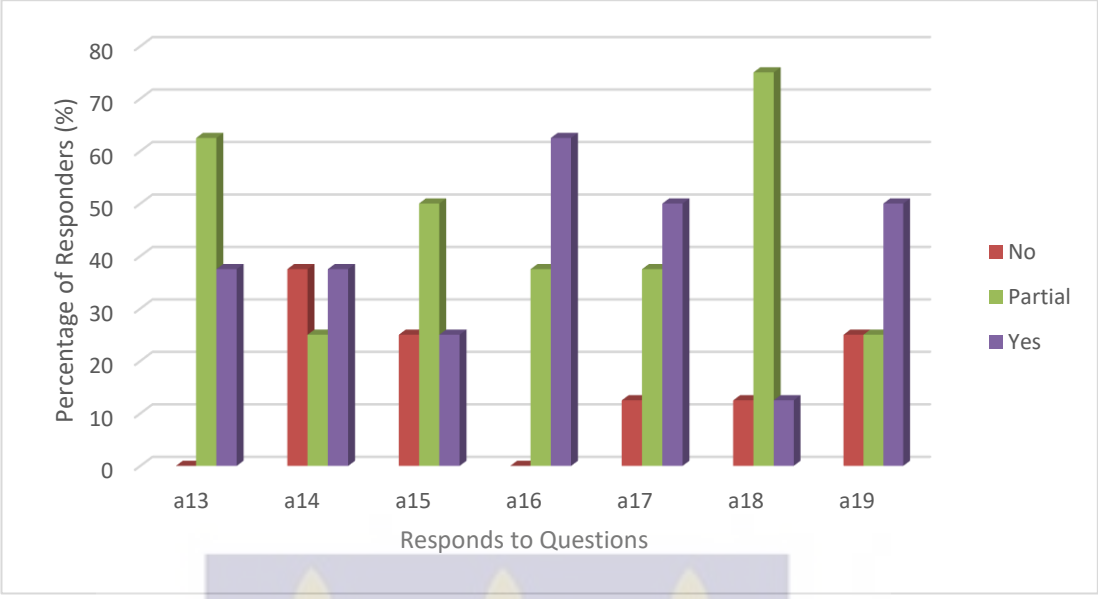

Figure 4. 3: Percentage responds to questions on quality assurance for the screening process

Table 4. 3: Approximated Average Score of responds to questions on quality assurance for the screening process

No.	Quality assurance for the screening process	Approximated Average Score
a13	*Do you have a set of methods specified as acceptable for use in your laboratory?*	1
a14	*Are they documented to the extent necessary to ensure they are applied properly and consistently?*	1
a15	*If not, have you evidence to show that the methods you are using are fit for the purpose claimed and acceptable to your clients?*	1
a16	*Have you determined the accuracy, precision and, where relevant, the limit of detection of the methods which you use, including standard published methods?*	2
a17	*Do you run routine quality control samples and evaluate the results before releasing data?*	1
a18	*Do you monitor trends in quality control results in order to anticipate possible problems?*	1
a19	*Have you tested your methods and laboratory by use of certified reference methods and/or inter-laboratory comparison?*	1
	Average	1

4.1.4 Equipment

The respondents indicated there is a plan for periodic calibration and verification of the performance of all equipment which affects the validity of measurements (Table 4.4). Nevertheless, there is only a partial system for commissioning equipment and verifying its performance and calibration before it is used for test or calibration work and to some extent there are some measures in place for commissioning equipment and verifying its performance and calibration.

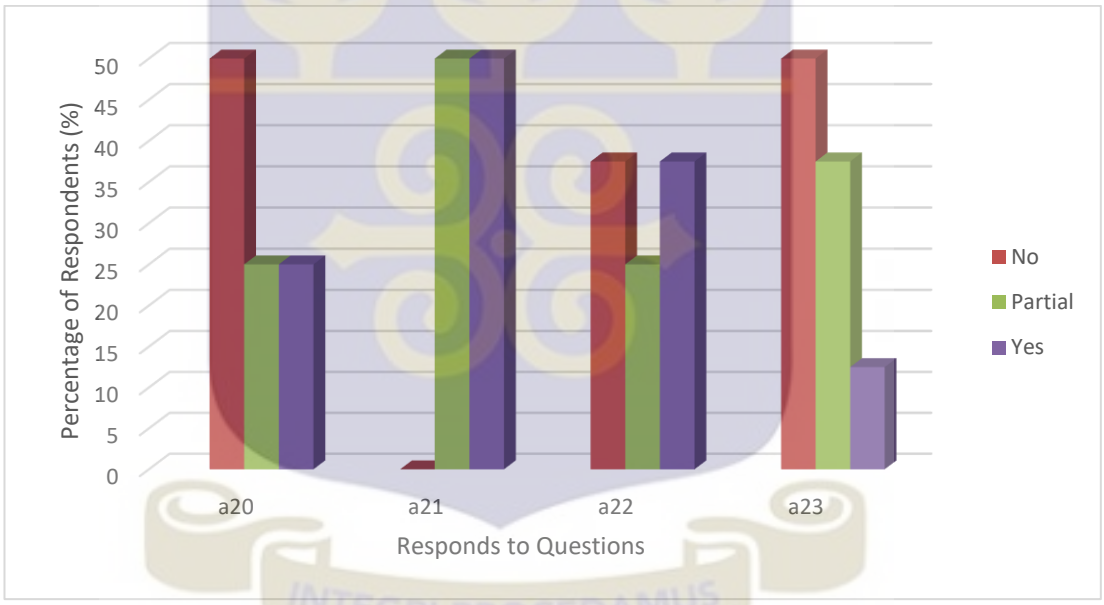

Figure 4. 4: Percentage responds to questions on equipment in the RPI lab

Table 4. 4: Approximated Average Score of responds to questions on equipment in the RPI lab

No.	Equipment	Approximated Average Score
a20	*Do you have a system for commissioning equipment and verifying its performance and calibration before it is used for test or calibration work?*	1
a21	*Do you have a plan for periodic calibration and verification of the performance of all equipment which affects the validity of measurements?*	2
a22	*Do you have records showing that this plan is followed and which enable the status of any equipment to be verified at any point in its history of use?*	1
a23	*Is equipment subject to regular checks or calibrations labelled so that its status can be seen immediately by users?*	1
	Average	1

4.1.5 Traceability of measurement

Management policy to ensure that the calibration is maintained at all times, records which could be audited to confirm the calibration status of the equipment at any point in the past and means of identifying all the measuring equipment which is involved, directly or indirectly, in measurement are not well developed (Table 4.5). Despite this it must be noted the respondents claimed equipment are calibrated in a manner which provides traceability to the international measurement system.

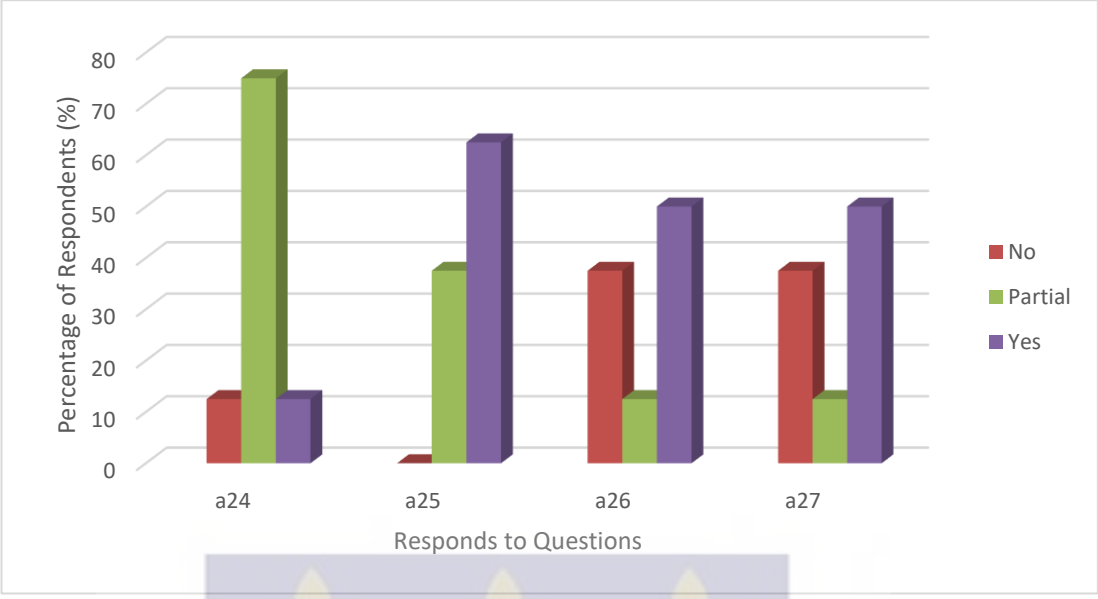

Figure 4. 5: Percentage responds to questions on traceability of measurement

Table 4. 5: Approximated Average Score of responds to questions on traceability of measurement

No.	Traceability of measurement	Approximated Average Score
a24	*Have you identified all the measuring equipment which is involved, directly or indirectly, in measurement or calibration and which, if not properly calibrated, would affect the validity of measurements?*	1
a25	*Is this equipment calibrated in a manner which provides traceability to the international measurement system?*	2
a26	*Do you have a management procedure to ensure that the calibration is maintained at all times, i.e. recalibration is conducted as necessary and, where possible, equipment is monitored so that any drift away from calibration will be detected?*	1
a27	*Do you have records which could be audited to confirm the calibration status of the equipment at any point in the past?*	1
	Average	1

4.1.6 Administration of work and sample tracking

The answers to the questions on administration of work and sample tracking revealed that procedure for receiving samples into the laboratory, storage of samples and the procedures required to be carried out on samples by laboratory staff are not clearly spelt out. Samples are however numbered as soon as possible (Table 4.6).

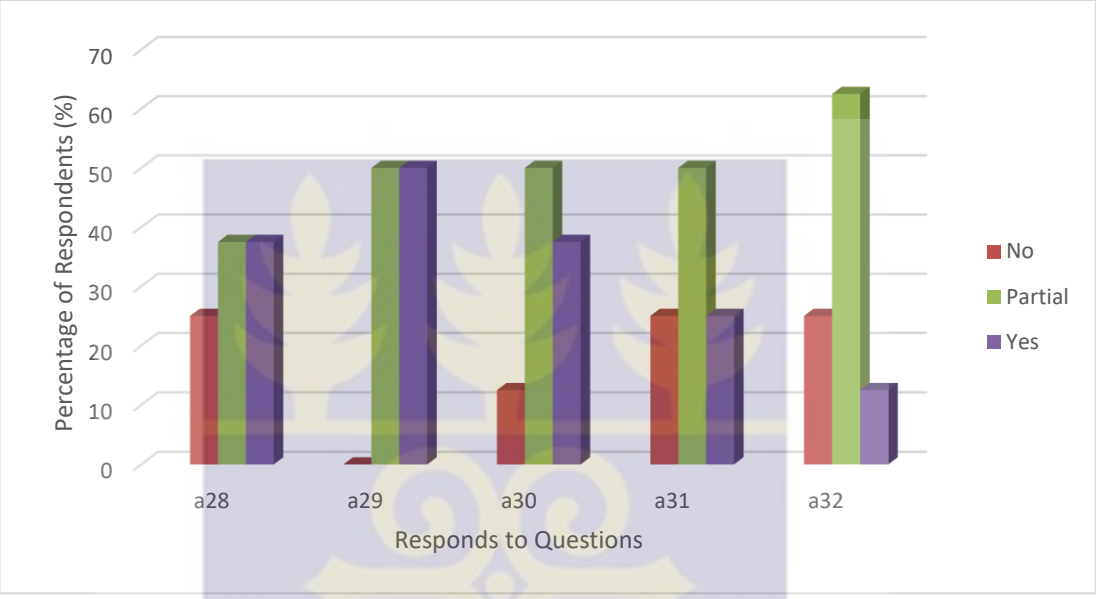

Figure 4. 6: Percentage responds to questions on administration of work and sample tracking

Table 4. 6: Approximated Average Score of responds to questions on administration of work and sample tracking

No.	Administration of work and sample tracking	Approximated Average Score
a28	*Do you have procedure for logging samples into your laboratory?*	1
a29	*Are all samples uniquely numbered as soon as practicable after receipt?*	2
a30	*Does your system ensure that samples are stored securely and in a way that will preserve them against any changes which may affect data generated from them?*	1
a31	*Do you have a system for ensuring that the procedures required to be carried out on samples are clearly communicated to laboratory staff?*	1
a32	*Do you have a procedure to ensure reports are checked to make sure they correspond to the raw data?*	1
	Average	1

4.1.7 Recording of Results and Associated Data

According to the responses, there is a system in place to ensure that all observations are recorded at the time they are made (Table 4.7). Data recorded by the Laboratory in 2014 using a Sodium iodide detector is as shown in Appendix B. Though a recording has been established, data preservation, policy on how amendments to entries are to be made and the means of identification of persons making entries are not fully in operation.

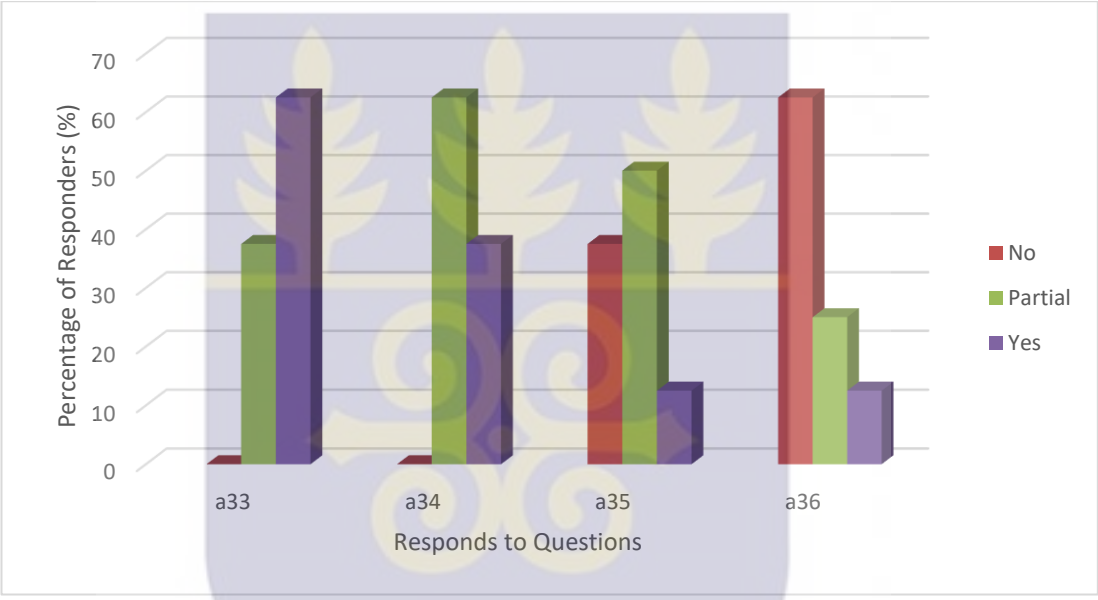

Figure 4. 7: Percentage responds to questions on Recording of Results and Associated Data

Table 4. 7: Approximated Average Score of responds to questions on Recording of Results and Associated Data

No.	Recording of Results and Associated Data	Approximated Average Score
a33	*Does your system ensure that all observations are recorded at the time when they are made?*	2
a34	*In this record, is the raw data always preserved so that any problems can be investigated?*	1
a35	*Do you have a policy on how amendments to entries on laboratory records are to be made?*	1
a36	*Does the system allow the person making any record to be identified?*	1
	Average	1

4.1.8 Computer Systems

There are no procedures for regular backup of data held on computers and software used is not secured against unauthorised changes. From Table 4.8, respondents insisted that there is control of what software may be loaded onto any of laboratories computers, and all computer systems are checked to ensure that they record and process data correctly.

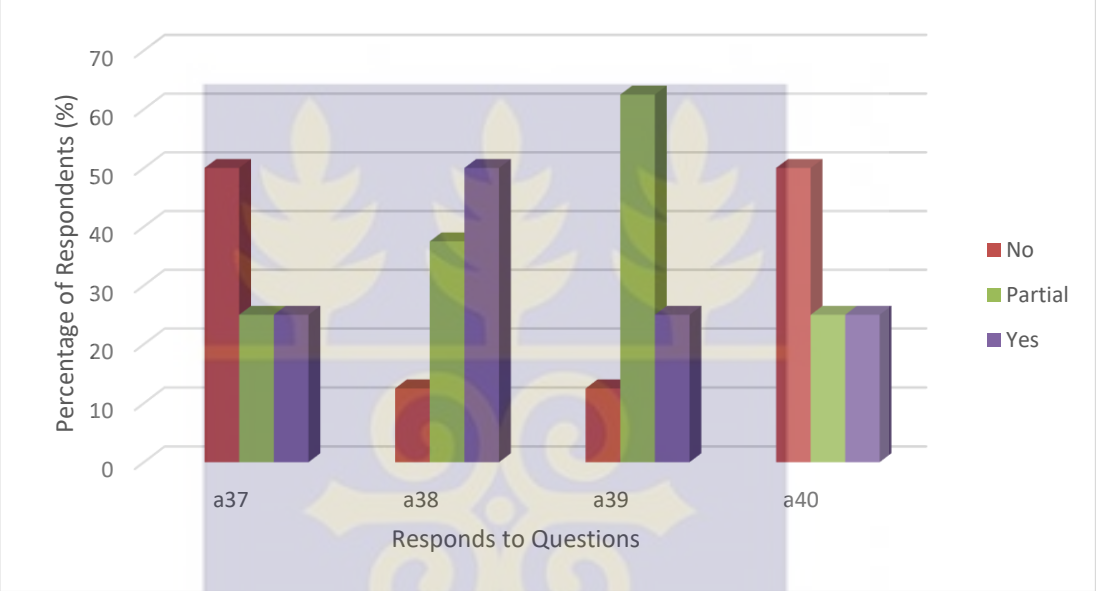

Figure 4. 8: Percentage responds to questions on computer systems

Table 4. 8: Approximated Average Score of responds to questions on computer systems

No.	Computer systems	Approximated Average Score
a37	*Do you have control of what software may be loaded onto any of your computers?*	1
a38	*Are all computer systems, including software, checked to ensure that they record and process data correctly?*	1
a39	*Is all software secured against unauthorised changes?*	1
a40	*Do you have a procedure for regular backup of data held on computers?*	1
	Average	1

4.1.9 Reporting Requirements

There is no defined or documented reporting format in use at the laboratory. There is on the other hand a partial system to ensure reports reach only those entitled to receive them.

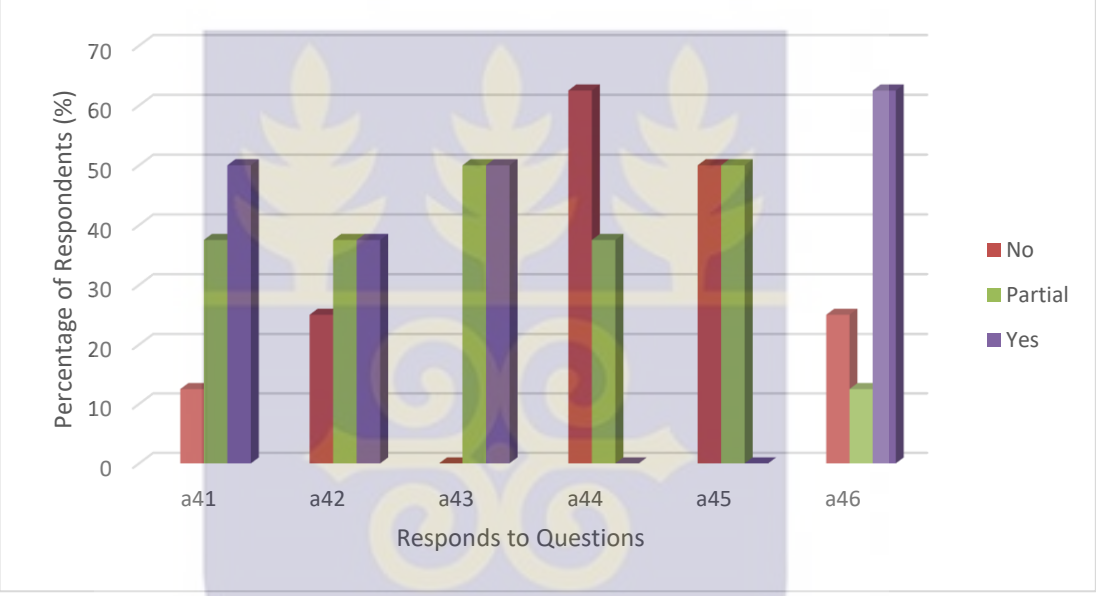

Figure 4. 9: Percentage responds to questions on reporting requirements

Table 4. 9: Approximated Average Score of responds to questions on reporting requirements

No.	Reporting requirements	Approximated Average Score
a41	*Do you have a defined report format?*	1
a42	*Does this comply with the detailed requirements of ISO 17025?*	1
a43	*Does your system ensure reports always reach only those entitled to receive them?*	2
a44	*Does the report acknowledge subcontracted work?*	0
a45	*Do you have a policy on how to deal with situations where it becomes apparent that suspect data has been reported?*	1
a46	*Do you have a clear identification of staff authorised to approve reports?*	1
	Average	1

4.1.10 Purchasing Services and Supplies

The laboratory attaches great value to the quality of any purchased goods or services which might affect the quality of data; as such a system for checking all received materials for conformity is in place. However, policies on selection and rejection of suppliers have not been established as stated in Table 4.10.

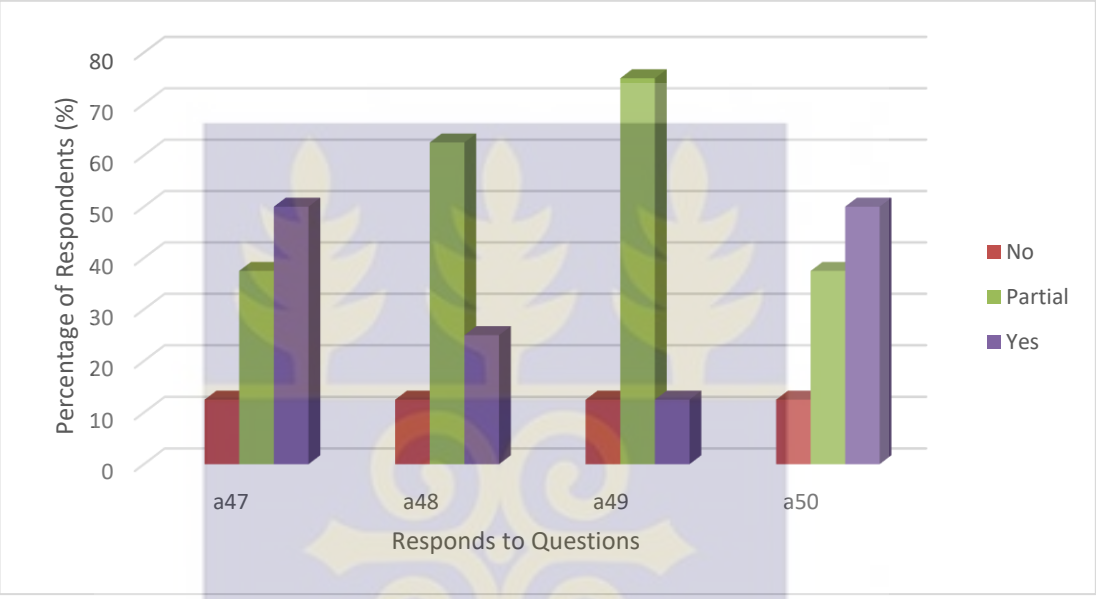

Figure 4. 10: Percentage responds to questions on Purchasing services and supplies

Table 4. 10: Approximated Average Score of responds to questions on purchasing services and supplies

No.	Purchasing services and supplies	Approximated Average Score
a47	*Do you take steps to control the quality of any purchased goods or services which might affect the validity of your data?*	1
a48	*Do you have a list of approved suppliers and a policy on their selection?*	1
a49	*Do you keep this list under review and remove any suppliers found to be inadequate from a quality perspective?*	1
a50	*Do you have a system for checking all received materials against the order specifications?*	1
	Average	1

4.2 Complying with IAEA Technical Report Series 295 (TRS 295)

The RPI Environmental Laboratory complies with all the conditions and equipment as required by TRS 295, except provisions for a ventilation system that has not been provided (Table 4.11).

From the study, the number of personnel in the RPI Laboratory is about 38% below the requirement for a typical analytical laboratory. Technically, the Laboratory can be said to be rated as good.

Table 4. 11: Comparison of facilities recommended by TRS 295 and existing Infrastructure at the RPI Lab.

Description	**Recommendation by IAEA, 1989**	**Existing Infrastructure at RPI Gamma Lab**
Number of rooms a) Gamma ray spectrometry laboratory: b) Preparation and storage of samples c) Counting room d) Computer room	3-4	3
a) Sample registration, storage and preparation, Evaporation and drying b) Grinding c) Ashing d) Handling of higher activity	7-8	4
Room size	90-120	90-162
Ventilation	Low pressure	-
Temperature	20-26 ^{o}C	16-26 ^{o}C
Personnel	- 1 Manager (Chief Scientist); - 3 Scientists; - 3 Senior Technicians - 6 Technical Assistants; - 1 Secretary; - 1 field technician to operate trucks, other vehicles and boats for sample	- 1 Manager - 3 Scientists; - 3 Technologists - 1 Secretary; - Maintenance and service section - National Service personnel

	collection; - 1 maintenance and service technician familiar with electronic equipment. - Further assistance personnel according to the customs of the country.	
Equipment	- Refrigerator - Crusher and/or grinder - Evaporator ; - Large drying oven; - Large muffle furnace - Freeze dryer - Fume chamber - Beta/gamma survey instruments - Portable gamma measurement systems	- Refrigerator - Crusher - Evaporator - Large drying oven - Freeze dryer - Fume chamber - Beta/gamma survey instruments - Portable gamma measurement systems

4.3 Quality Assurance Tests

4.3.1 Energy Calibration

Figure 4.1 shows the plot of gamma ray energy against channel number for the HPGe detector in use at the RPI Food and Environmental Laboratory. The linear curve obtained from the data points is an indication that the system is operating properly (IAEA, 1989)

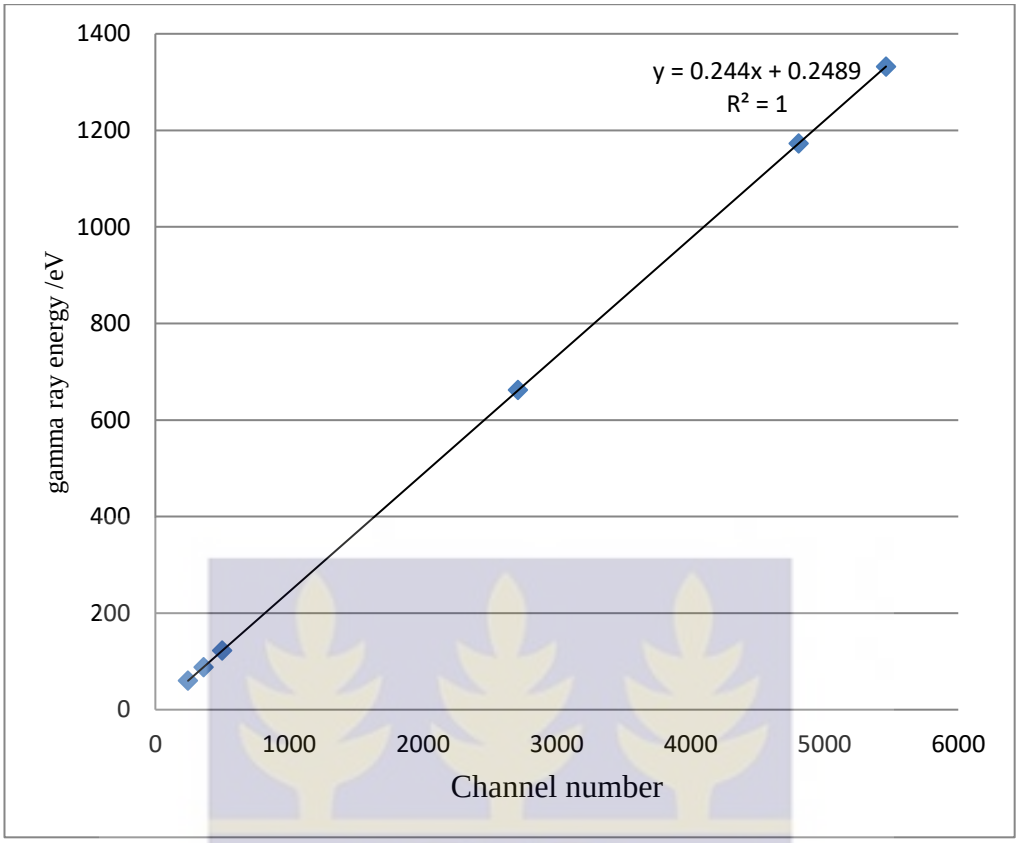

Figure 4. 11: Plot of gamma ray energy against channel number.

4.3.2 Efficiency Calibration

Efficiency calibration curve as a function of energy for mixed radionuclides standard is shown in Figure 4.2

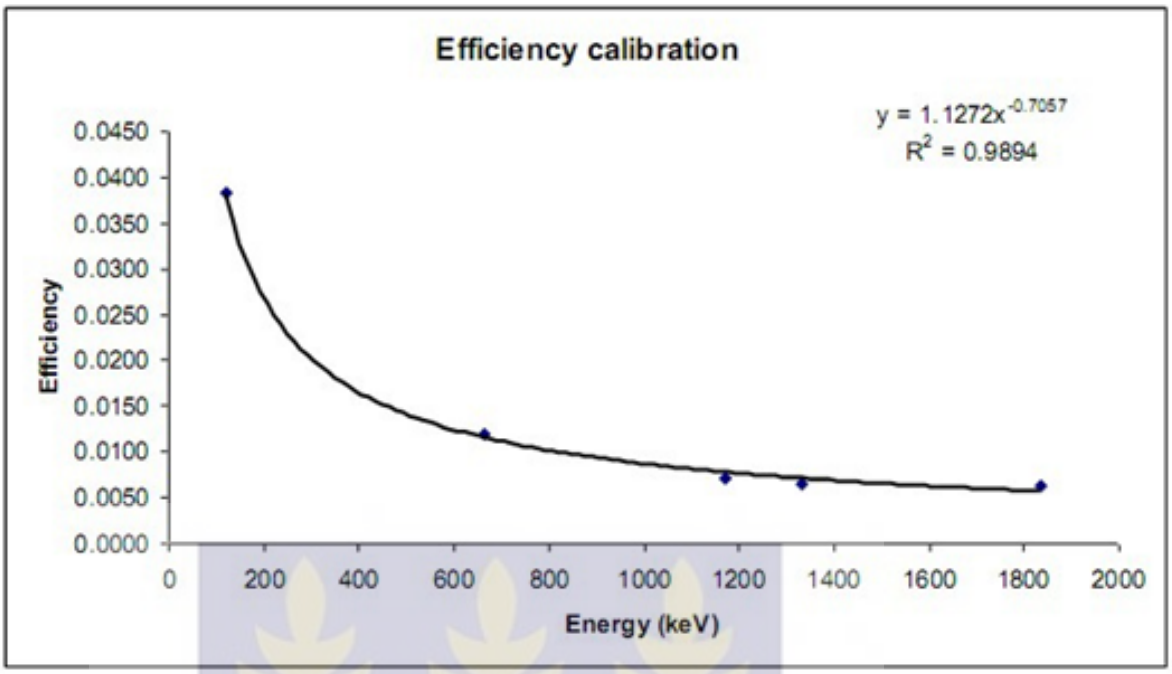

Figure 4. 12: Efficiency calibration curve as a function of energy for mixed radionuclides standard

4.3.3 Minimum Detectable Activities

The results of the Minimum Detectable Activities of the ^{238}U, ^{232}Th and ^{226}Ra are presented in Table 4.12 below. The minimum detectable concentration is defined as the smallest concentration of radioactivity in a sample that can be detected with a 5% probability of erroneously detecting radioactivity, when in fact none was present (Type I error) and also, a 5% probability of not detecting radioactivity, when in fact it is present (Type II error).

Table 4. 12: Minimum Detectable Activities of the ^{238}U, ^{232}Th and ^{226}Ra and ^{137}Cs

Radionuclide	MDA (Bq/kg)
^{238}U	4.67
^{232}Th	5.32
^{226}Ra	1.02
^{137}Cs	2.42

4.3.4 Background Measurements

The background of a gamma- ray detection system has a very significant influence on the detection limit and accuracy of the measurement of low levels of activity. The counting system must have a background as low as is attainable with a minimum of spectral lines originating from natural radionuclides which may be present in the system components and the surrounding environment, that is the walls, floor, and benches of the counting facility IAEA (1989).

The background measured produced a spectral line of energy 25.28 keV and 25.1 Counts /second originating from an X-ray from the components of the shielding. The shielding of the Gamma spectrometer of the RPI Food and Environmental Laboratory can therefore said to be intact.

4.3.5 Calibration of other Measuring Instruments

An observation of the Balance and Marinelli beakers, used in the laboratory, reveals that the instruments have never been calibrated putting into doubt the quality of data fron the laboratory. The instruments were therefore sent to the Ghana Standards Authority's laboratories for calibration. The results are presented in Appendix C. The

results show that, while the Balance was 100% accurate, the beakers were not delivering 1000 mL as indicated.

Test Results:

Nominal Volume (ml)	Mean Measured Volume (EUT) ml	Deviation (ml)	Uncertainty %
1000	930.540	-69.460	0.05

4.3.6 Statistical Quality Control

Figure 4.3 shows a statistical quality control chart that was developed. The test Cs source was, after two months of development of the control chart, counted 100 successive times. All the results obtained were within the warning limits. This indicated a good instrument response.

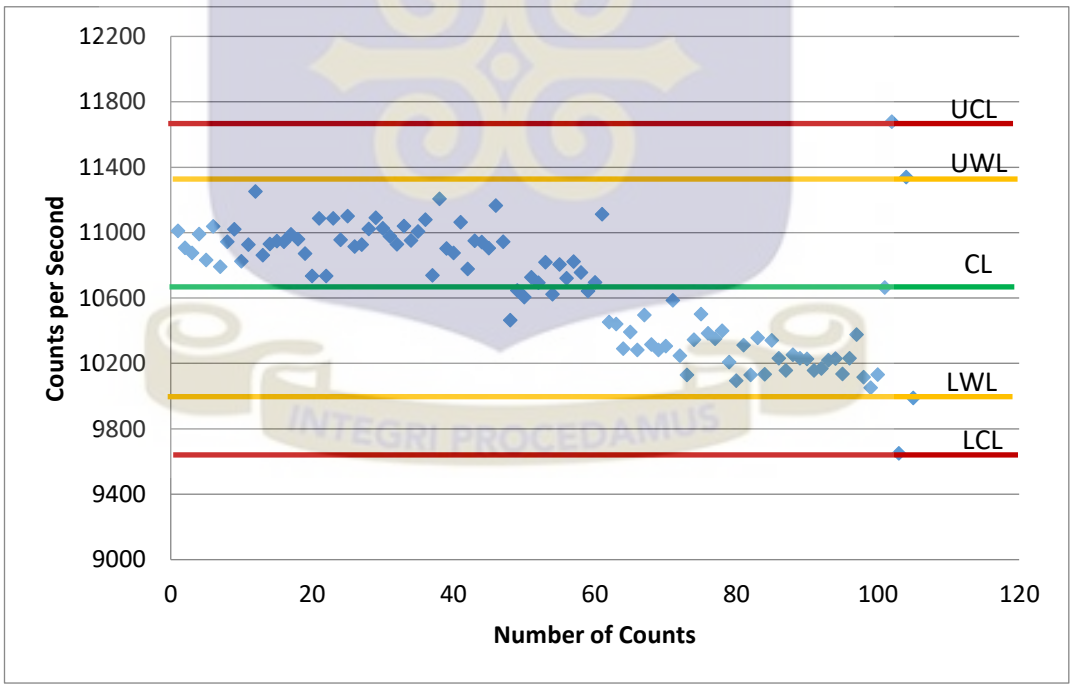

Figure 4. 13: Statistical Control chart for daily counting of a check source

CHAPTER 5

CONCLUSIONS AND RECOMMENDATION

This chapter focuses on the conclusions and recommendations based on the study conducted.

5.1 Conclusions

The following conclusions are drawn after evaluating the operational performance of the RPI laboratory using ISO 17025 and the IAEA's Technical Report Series 295:

a. From the study, the number of personnel in the RPI Laboratory is 62% of the requirement for a typical analytical laboratory. Technically, the laboratory can rated as good.

b. The laboratory does not have established staff training and competence records. List of activities showing training and record of regular re-assessment of the staff member's competence at each of the activities was not available

c. The laboratory does not have a quality assurance system that clearly defines procedure for declaring employees competent. Methods like taking part in proficiency testing schemes and intra-laboratory competencies have not been utilised.

d. There are no documented requirements for test or calibration to be done under specific environmental conditions.

e. Though the laboratory meets almost all conditions and equipment requirements of the IAEA Guide (1989), there is only a partial system for

commissioning equipment and verifying its performance and calibration before it is used for test or calibration work.

Management should take the necessary steps to work on these findings; it could accelerate the accreditation drive of the Laboratory. By having the laboratory management system accredited to ISO/IEC 17025, the laboratory stands to gain substantial benefits financially as well as gain the confidence of its clients. One of the main advantages is that the laboratory will gain international recognition for its commitment to quality, competency and reliable results. In addition, ISO/IEC 17025 accreditation will signify that the laboratory complies with an internationally recognized standard.

5.2 Recommendations

The following recommendations are made, based on the findings of the study:

i. The laboratory's management should ensure the competence of all who operate specific equipment, perform tests, evaluate results and sign test reports.

ii. The laboratory should have a plan for how to ensure adequate equipment function and performance before and during sample measurement.

iii. Each laboratory should have processes for how calibration and testing is performed for different types of equipment.

iv. Background measurements should be taken as frequently as is practicable and for counting times as long as possible in order to obtain good counting statistics. A good practice is to record the background measurements on a control chart with statistically fixed limits. This provides a means both for

checking the stability of the electronics of the system and of checking for contamination of the detector and/or shield. Should the background exceed the control limits, an immediate and thorough investigation should be made and appropriate steps taken to maintain a minimum background.

v. Equipment used for measurement should be tested before initial use to ensure acceptable performance. This should be performed through calibration of balance, and volume of the Marinelli beaker.

vi. Equipment characteristics and performance can change over time. Therefore, equipment quality programs should be put in place to ensure that equipment is routinely tested on an ongoing basis.

vii. The laboratory should have a maintenance plan to carry out preventive maintenance activities and a procedure for unplanned repair to ensure ongoing performance and reliability.

viii. Computer systems and software used for acquisition, processing, recording, reporting, storage and retrieval of test and calibration data must be validated when the software is developed, configured, or customized by the user.

ix. The laboratory should develop Quality manuals, Process & Standard Procedures, Step-by-step Operating Procedure and Work Instructions, Checklists, Forms and Records for use. Such documents when developed must be controlled.

x. The management of the laboratory should, have a documented policy for deciding when the control chart indicates a condition where the method should come under investigation, and this policy should be expressed quantitatively so that it will be applied consistently.

xi. There should be proper record keeping and these records must be kept for a considerable time frame. There should also be a computer backup system in place for all records in the laboratory.

xii. The laboratory should have a clear policy in place for retention and disposal of samples.

xiii. All observations, raw data, calculations and derived data in the form of work sheets, notebooks, instrument output, must be dated and should all be traceable to the person who made the observation or measurement and to the equipment used.

xiv. The notebooks used in the laboratory must be properly controlled. The books should have numbered pages such that a record can be referenced by notebook numbers and that pages cannot be torn out without being detected.

xv. Staff should not be allowed to remove notebooks from the laboratory except for field work, and books should be returned to management for archiving before a new one is issued.

xvi. The laboratory should solicit for client feedback and must investigate client complaints thoroughly.

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APPENDIX A

Performance Evaluation of a Food and Environmental Monitoring Radio-Analytical Laboratory in Ghana Questionnaire

Please provide your responses for this questionnaire for the study entitled Performance Evaluation of a Food and Environmental Monitoring Radio-Analytical Laboratory in Ghana

Since this research is for academic purpose any information provided would be treated with utmost confidentiality.

For each question below, indicate, with a tick, in the space provided your response

Equipment, Documents and Procedures	**No**	**Partially**	**Yes**
a. Personnel			
Do you have a record of the qualifications and experience of your staff, with objective evidence of their qualifications, for example copies of certificates?			
Do you have a clear record with regard to your proposed scope of accreditation of which members of staff are authorized to conduct each test or calibration?			
Do you have a documented procedure for training staff in quality issues and technical procedures, including tests?			
Do you have a documented procedure for conducting evaluation of the competence of staff after training and before authorising them for the procedure in which they were trained?			
Do you have a system for recording training, including objective evidence of competence?			
Do you have a mechanism for identifying which staff conducted each procedure, test or calibration?			
b. Accommodation and environmental conditions			
Have you considered whether there are any environmental factors in your laboratory which might impact on the validity of tests or calibrations?			
Are you conducting any tests or calibrations where the published procedure which you claim to follow includes a requirement for the work to be done under specific environmental conditions, for example temperature or			

humidity?			
If there are such factors, do you have procedures in place to control and monitor them?			
Do you have any activities which need to be separated to avoid, for example, cross contamination?			
Do you have any activities which need to be separated to avoid, for example, cross contamination?			
*Do you have clear instructions to staff on actions to be taken when conditions move out of specification***?**			
c. Quality assurance for the screening process			
Do you have a set of methods specified as acceptable for use in your laboratory?			
Are they documented to the extent necessary to ensure they are applied properly and consistently?			
If not, have you evidence to show that the methods you are using are fit for the purpose claimed and acceptable to your clients?			
Have you determined the accuracy, precision and, where relevant, the limit of detection of the methods which you use, including standard published methods?			
Do you run routine quality control samples and evaluate the results before releasing data?			
Do you monitor trends in quality control results in order to anticipate possible problems?			
Have you tested your methods and laboratory by use of certified reference methods and/or inter-laboratory comparison?			
d. Equipment			
Do you have a system for commissioning equipment and verifying its performance and calibration before it is used for test or calibration work?			
Do you have a plan for periodic calibration and verification of the performance of all equipment which affects the validity of measurements?			

Do you have records showing that this plan is followed and which enable the status of any equipment to be verified at any point in its history of use?			
Is equipment subject to regular checks or calibrations labelled so that its status can be seen immediately by users?			
e. Traceability of measurement			
Have you identified all the measuring equipment which is involved, directly or indirectly, in measurement or calibration and which, if not properly calibrated, would affect the validity of measurements?			
Is this equipment calibrated in a manner which provides traceability to the international measurement system?			
Do you have a management procedure to ensure that the calibration is maintained at all times, i.e. recalibration is conducted as necessary and, where possible, equipment is monitored so that any drift away from calibration will be detected?			
Do you have records which could be audited to confirm the calibration status of the equipment at any point in the past?			
Administration of work and sample tracking			
Do you have procedure for logging samples into your laboratory?			
Are all samples uniquely numbered as soon as practicable after receipt?			
Does your system ensure that samples are stored securely and in a way that will preserve them against any changes which may affect data generated from them?			
Do you have a system for ensuring that the procedures required to be carried out on samples are clearly communicated to laboratory staff?			
Do you have a procedure to ensure reports are checked to make sure they correspond to the raw data?			
f. Recording of results and associated data			

Does your system ensure that all observations are recorded at the time when they are made?			
In this record, is the raw data always preserved so that any problems can be investigated?			
Do you have a policy on how amendments to entries on laboratory records are to be made?			
Does the system allow the person making any record to be identified?			
g. Computer systems			
Do you have control of what software may be loaded onto any of your computers?			
Are all computer systems, including software, checked to ensure that they record and process data correctly?			
Is all software secured against unauthorised changes?			
Do you have a procedure for regular backup of data held on computers?			
h. Reporting requirements			
Do you have a defined report format?			
Does this comply with the detailed requirements of ISO 17025?			
Does your system ensure reports always reach only those entitled to receive them?			
Does the report acknowledge subcontracted work?			
Do you have a policy on how to deal with situations where it becomes apparent that suspect data has been reported?			
Do you have a clear identification of staff authorised to approve reports?			
i. Purchasing services and supplies			
Do you take steps to control the quality of any purchased goods or services which might affect the validity of your data?			
Do you have a list of approved suppliers and a policy on			

their selection?			
Do you keep this list under review and remove any suppliers found to be inadequate from a quality perspective?			
Do you have a system for checking all received materials against the order specifications?			

APPENDIX B

Recorded Data for 2014

Country	Sample type	Cs - 134 Bq /kg	Cs - 137 Bq/kg	Total count	Error Bq /kg
Brazil	Poultry	0.7	0.74	1.44	0.05
Brazil	Poultry	0.43	0.51	0.94	0.02
Germany	Food stuff	0.44	0.45	0.89	0.03
The Netherlands	Fat filled milk powder	0.17	0.14	0.31	0.03
Ireland	Cowbell vegetable fat filled milk	0.31	0.27	0.58	0.02
Belgium		0.17	0.29	0.46	0.07
Poland	Whey powder	0.22	0.13	0.35	0.02
Poland	Skimmed milk powder	0.59	0.34	0.93	0.04
Poland	Whey powder	0.43	0.12	0.55	0.02
Holland	Poultry	0.44	0.47	0.91	0.02
Belgium Antwerp	Poultry	0.37	0.19	0.56	0.03
New Zealand	Poultry	0.12	0.29	0.41	0.02
Brazil	Poultry	0.32	0.21	0.53	0.03
Ireland	Cowbell vegetable fat filled milk	0.17	0.31	0.48	0.02
Ireland	Miksi vegetable fat filled milk	0.43	0.29	0.72	0.02
The Netherlands	Poultry	0.41	0.31	0.72	0.02
Brazil	Poultry	0.34	0.39	0.73	0.02
Altaics		0.72	0.57	1.29	0.03
Altaics	Poultry	0.43	0.51	0.94	0.04
Poland	Whey powder	0.34	0.41	0.75	0.03

Poland	Whey powder	0.45	0.39	0.84	
Poland	Whey powder	0.27	0.31	0.58	0.03
Poland	Whey powder	0.31	0.39	0.7	0.02
Poland	Full cream milk powder	0.24	0.18	0.42	0.04
India	Skimmed milk powder	0.29	0.34	0.63	0.02
Ghana	Nescafe 3 in 1 cream chank sip	0.7	0.41	1.11	0.04
Ghana	Nescafe 3 in 1 cream chank sip	0.65	0.61	1.26	0.04
Ireland	Cowbell dairy based instant fortified	0.52	0.41	0.93	0.03
Ireland	Miksi vegetable fat filled milk	0.82	0.9	1.72	0.07
Ghana	Frozen tuna skipjack round	0.75	0.71	1.46	0.07
Ghana	Frozen tuna skipjack round	1.02	1.01	2.03	0.42
Ghana	Frozen tuna skipjack round	1.03	0.94	1.97	0.26
Ghana	Frozen tuna skipjack round	0.56	0.5	1.06	0.06
Ghana	Frozen tuna skipjack round	0.74	0.92	1.66	0.06
	Beef feet	0.91	0.49	1.4	0.05
Ghana	Nescafe 3 in 1 cream chank sip	0.42	0.4	0.82	0.04
Poland	Moudy milk powder	0.31	0.28	0.59	0.02
Brazil	Poultry	0.32	0.29	0.61	0.02
Modiglaus	Beef feet	0.2	0.27	0.47	0.03
Ghana	Nescafe 3 in 1 cream chank kp	0.21	0.28	0.49	0.03
Ghana	Nescafe 3 in 1 cream sip	0.37	0.21	0.58	0.02
Ghana	Nescafe 3 in 1 breakfast cup	0.41	0.43	0.84	0.03

Ghana	Nescafe 3 in 1 cream	0.24	0.41	0.65	0.02
New Zealand	Skimmed milk powder (medium heat)	0.53	0.31	0.84	0.08
Australia	Skimmed milk powder	0.59	0.26	0.85	0.06
Brazil	Poultry	0.39	0.28	0.67	0.02
Argentina	Poultry	0.41	0.37	0.78	0.04
Brazil	Poultry	0.43	0.29	0.72	0.04
The Netherlands	Poultry	0.42	0.37	0.79	0.04
Poland	Demicoralised whey powder	0.2	0.28	0.48	0.03
New Zealand	Skimmed milk powder	0.43	0.29	0.72	0.02
Australia	Skimmed milk powder (medium heat)	0.49	0.37	0.86	0.03
USA	Whey powder	0.31	0.29	0.6	0.04
New Zealand	Butter milk powder	0.25	0.38	0.63	0.03
New Zealand	Skimmed milk powder			0	
UK	Skimmed milk powder	0.27	0.35	0.62	0.03
Ghana	Milo actigen e	0.2	0.23	0.43	0.02
Ghana	Nescafe 3 in 1	0.4	0.11	0.51	0.03
Ghana	Nescafe 3 in 1 breakfast cup	0.24	0.28	0.52	0.02
Ghana	Nescafe 3in 1	0.19	0.21	0.4	0.03
Ghana	Nescafe 3 in 1	0.24	0.17	0.41	0.02
Ghana	Nescafe 3 in 1	0.19	0.18	0.37	0.02
Ireland	Filled milk powder	0.42	0.49	0.91	0.03
New Zealand	Butter milk powder	0.29	0.31	0.6	0.02
Tunisia	Tuna	0.27	0.19	0.46	0.02

Ghana	Nescafe 3 in 1 breakfast	0.21	0.17	0.38	0.02
Ghana	Nescafe 3 in 1	0.12	0.09	0.21	0.02
Ghana	Nescafe 3 in 1	0.17	0.12	0.29	0.03
Ghana	Nescafe 3 in 1	0.21	0.11	0.32	0.02
Ghana	Nescafe 3 in 1 cream	0.09	0.12	0.21	0.02
Ghana	Nescafe 3 in 1 chank	0.14	0.11	0.25	0.02
Ghana	Nescafe 3 in 1 breakfast bulk	0.21	0.17	0.38	0.03
Ghana	Nescafe 3 in 1 breakfast bulk	0.22	0.17	0.39	0.02
Ghana	Nescafe 3 in 1 breakfast cup	0.17	13	13.17	0.02
Brazil	Poultry	0.09	0.21	0.3	0.02
Brazil	Poultry	0.21	0.11	0.32	0.03
Poland	Millac milk powder	0.09	0.17	0.26	0.02
England	Beef	0.14	0.17	0.31	0.03
The Netherlands	Beef	0.14	0.09	0.23	0.02
England	Beef product	0.09	0.11	0.2	0.02
Ghana	Nescafe 3 in 1 cream chank pk	0.05	0.09	0.14	0.02
Ghana	Nescafe 3 in 1	0.07	0.11	0.18	0.02
Ghana	Nescafe 3 in 1 breakfast cup	0.09	0.14	0.23	0.03
Ghana		0.19	0.08	0.27	0.02
Ghana	Nescafe classic tin	0.11	0.18	0.29	0.02
Ghana	Nescafe classic tin	0.09	0.07	0.16	0.03
Ireland	Vegetable fat filled milk	0.09	0.07	0.16	0.02
Ireland	Dairyvale vegetable fat milk	0.11	0.06	0.17	0.02
The Netherlands	Simmed milk powder	0.19	0.11	0.3	0.03

Ireland	Filled milk powder	0.11	0.02	0.13	0.02
Demark	Poultry	0.12	0.19	0.31	0.02
USA	Sweet whey powder	0.12	0.11	0.23	0.02
New Zealand	Butter milk powder	0.17	0.21	0.38	0.03
Netherland	Skimmed milk powder	0.17	0.16	0.33	0.02
USA	Sweet whey powder	0.14	0.18	0.32	0.03
Poland	Full cream milk powder	0.09	0.11	0.2	0.02
Ireland	Miskivegetable milk	0.19	0.13	0.32	0.03
Singapore	Tuna	0.34	0.21	0.55	0.02
Brazil	Poultry	0.09	0.17	0.26	0.02
Ghana	Nescafe 3 in 1 breakfast cup	0.11	0.13	0.24	0.04
Ghana	Nescafe 3 in 1 breakfasr bulk	0.05	0.1	0.15	0.02
Ghana	Nescafe 3 in 1 cream	0.13	0.18	0.31	0.02
Ghana	Nescafe 3 in 1 cream	0.07	0.09	0.16	0.02
Ghana	Nescafe 3 in 1 cream sip	0.07	0.09	0.16	0.02
Ghana	Nescafe 3 in 1 cream sachet	0.09	0.13	0.22	0.03
Ghana	Nescafe 3 in 1 breakfast cup	0.13	0.18	0.31	0.02
England	Beef feeder olf	0.19	0.18	0.37	0.03
Netherland	Beef	0.19	0.29	0.48	0.02
Italy	Fatted whey powder	0.04	0.08	0.12	0.02
Denmark	Poultry	0.07	0.09	0.16	0.03
England	Beef feeder olf	0.11	0.09	0.2	0.03
Denmark	Beef	0.19	0.12	0.31	0.02
Ireland	Cowbell vegetable fat filled milk	0.17	0.09	0.26	0.02
Ireland	Cowbell vegetable fat filled milk	0.15	0.23	0.38	0.02

Ireland	Cowbell vegetable fat filled milk	0.09	0.18	0.27	0.02
Netherland	Skimmed milk powder	0.18	0.19	0.37	0.03
Germany	Skimmed milk powder high heat	0.31	0.28	0.59	0.02
Germany	Skimmed milk powder	0.19	0.31	0.5	0.02
Netherland	Skimmed milk powder	0.09	0.59	0.68	0.02
Germany	Skimmed milk powder	0.13	0.09	0.22	0.02
France	Procream	0.13	0.21	0.34	0.02
Ireland	Cowbell vegetable fat filled milk	0.21	0.37	0.58	0.02
New Zealand	Skimmed milk powder dry mix	0.09	0.12	0.21	0.2
Ireland	Filled milk powder	0.11	0.08	0.19	0.03
Netherland	Skimmed milk powder medium heat	0.45	0.23	0.68	0.02
Ireland	Filled milk powder	0.43	0.41	0.84	0.02
USA	Sweet whey powder	0.41	0.37	0.78	0.02
Australia	Skimmed milk powder medium heat	0.19	0.18	0.37	0.02
New Zealand	Butter milk powder	0.23	0.19	0.42	0.02
Germany	Colli food stuff (meat)	0.71	0.67	1.38	0.05
Netherland/ Germany	Poultry/pig feet	0.63	0.61	1.24	0.05
Belgium, Antwerp	Poultry	0.5	0.51	1.01	0.04
Ghana	Nescafe 3 in 1 cream chank sip	0.51	0.44	0.95	0.05
Ghana	Nescafe 3 in 1 cream chank sip	0.78	0.52	1.3	0.05
Ghana	Nescafe 3 in 1 breakfast bulk	0.9	0.74	1.64	0.06
South	Meat	0.7	0.44	1.14	0.07

Africa					
USA	Poultry	0.51	0.39	0.9	0.04
Australia, Sydney	Meat	0.91	0.71	1.62	0.09
Netherlands	Poultry	0.7	0.5	1.2	0.05
Poland	Full cream milk powder	0.32	0.3	0.62	0.02
Poland	Whey powder	0.41	0.95	1.36	0.04
Poland	Skimmed milk powder	0.26	0.23	0.49	0.03
Poland	Skimmed milk powder	0.51	0.51	1.02	0.05
Ireland	Cowbell vegetable fat filled milk powder	0.42	0.24	0.66	0.05
Netherlands	Poultry/cow feet	0.81	0.62	1.43	0.05
USA	Poultry	0.62	0.42	1.04	0.04
Ghana	Nescafe 3 in 1 breakfast bulk	0.19	0.29	0.48	0.02
Ghana	Nescafe 3 in 1 breakfast bulk	0.11	0.14	0.25	0.03
Ghana	Nescafe 3 in 1 cream chank sip	0.17	0.19	0.36	0.04
Ghana	Nescafe 3 in 1 cream sachet	0.21	0.34	0.55	0.02
Holland	Poultry	0.34	0.29	0.63	0.02
Brazil	Poultry	0.14	0.28	0.42	0.02
Ghana	Nescafe 3 in 1 cream chank sip	0.43	0.23	0.66	0.02
Ghana	Nescafe 3 in 1 cream sachet	0.49	0.09	0.58	0.03
Ghana	Nescafe 3 in 1 cream chank kp sip	0.31	0.37	0.68	0.02
Ghana	Nescafe classic tin	0.27	0.19	0.46	0.02
Tunisia	Skipjack tuna	0.49	0.47	0.96	0.05
Brazil	Poultry	0.78	0.49	1.27	0.02

Netherlands	Poultry	0.48	0.43	0.91	0.02
Netherlands	Meat Product	0.45	0.43	0.88	0.02
Italy	Meat Product	0.49	0.58	1.07	0.02
Ghana	Nescafe 3 In 1 Breakfast	0.43	0.29	0.72	0.02
Ghana	Nescafe Cerelac Rice	0.37	0.48	0.85	0.03
Ghana	Nescafe Cerelac	0.32	0.17	0.49	0.03
Poland	Skimmed Milk Powder	0.49	0.23	0.72	0.02
Ghana		0.49	0.31	0.8	0.04
Ghana	Nestle Cerelac	0.15	0.29	0.44	0.02
Ghana	Nestle Cerelac	1	0.12	1.12	0.06
Ghana	Nestle Cerelac	0.09	0.56	0.65	0.03
Ghana	Nestle Cerelac	0.81	0.21	1.02	0.04
		0.09	0.15	0.24	0.02
Ghana	Nido Fortified	0.49	0.21	0.7	0.02
Ghana	Nido Fortified	0.53	0.33	0.86	0.02
Ghana	Nido Fortified	0.27	0.41	0.68	0.03
Ghana	Nido Fortified	0.71	0.81	1.52	0.05
Ghana	Nido Fortified	0.54	0.21	0.75	0.001
Netherlands	Poultry/Beef Feet	0.53	0.21	0.74	0.04
Belgium	Skimmed Milk Powder	<MDA	<MDA	<MDA	
Ireland	Miksi Vegetable Fat Filled Milk Powder	<MDA	<MDA	<MDA	
Ireland	Cowbell Filled Milk Powder	<MDA	<MDA	<MDA	
Ireland	Dairyvale Filled Milk Powder	<MDA	<MDA	<MDA	
USA	Poultry	0.19	0.34	0.53	0.03
Ghana	Filled Milk Powder	0.61	0.37	0.98	0.03
Ghana	Filled Milk Powder	0.19	0.41	0.6	0.03
Ghana	Nido Fortified	0.9	0.21	1.11	0.02

Ghana	Nido Nitripak Fortified	0.38	0.16	0.54	0.03
Ghana	Nescafe 3 In 1 Breakfast Bulk	0.12	0.19	0.31	0.05
Ghana	Nescafe 3 In 1 Breakfast Cup	0.42	0.21	0.63	0.03
Ghana	Nescafe 3 In 1 Chank Sip	0.53	0.22	0.75	0.04
Ghana	Nescafe 3 In 1 Cream Chank Sip	0.31	0.54	0.85	0.05
Netherlands	Meat Product	0.42	0.45	0.87	0.02
Ireland	Meat Feet	0.39	0.35	0.74	0.03
Ghana	Nescafe 3 In 1 Cream Chank Sip	0.23	0.18	0.41	0.03
Ghana	Nescafe 3 In 1 Cream Chank Sip	0.71	0.2	0.91	0.04
UK	Meat	0.52	0.39	0.91	0.04
New Zealand	Beef	0.21	0.42	0.63	0.01
UK	Meat Product	0.53	0.16	0.69	0.05
Ireland	Miksi Filled Milk Powder	0.21	0.39	0.6	0.06
Ireland	Cowbell Filled Milk Powder	1	0.19	1.19	0.04
Ireland	Dairyvale Filled Milk Powder	0.71	0.6	1.31	0.03
Ireland	Cowbell Filled Milk Powder	0.43	0.28	0.71	0.02
Ireland	Cowbell Filled Milk Powder	0.23	0.22	0.45	0.06
Argentina	Doliat Full Cream Milk Powder	0.47	0.39	0.86	0.03
Ghana	Nestl Cerelac Bl Millet	0.17	0.23	0.4	0.06
Ghana	Nestle Cerelac Bl W.Frt	0.22	0.73	0.95	0.04
Ghana	Nescafe 3 In 1 Breakfast Bulk	0.24	0.19	0.43	0.05
Ghana	Nescafe 3 In 1 Breakfast	0.76	0.29	1.05	0.02

	Cup				
Ghana		0.51	0.38	0.89	0.02
Ghana	Nescafe Cerelac Bl Wheat	0.23	0.17	0.4	0.04
Ireland	Beef Feet	0.43	0.38	0.81	0.02
Ghana	Nido Fortified	0.29	0.36	0.65	0.02
Ghana	Nido Fortified	0.16	0.39	0.55	0.04
Ghana	Nescafe 3 In 1 Breakfast Bulk	0.26	0.28	0.54	0.02
Ghana	Nescafe 3 In 1 Cream Chank Sip	0.16	0.29	0.45	0.03
Ghana	Nescafe 3 In 1 Cream Chank Sip	0.28	0.41	0.69	0.06
Ghana	Nescafe Classic Tin	0.17	0.19	0.36	0.04
Ghana	Nescafe 3 In 1 Cream Chank Pk Sip	0.63	0.32	0.95	0.02
Ghana		0.09	0.26	0.35	0.05
Spain	Beef Feet	0.11	0.32	0.43	0.02
Netherlands	Poultry	0.21	0.37	0.58	0.03
USA	Ecmu 4686792	0.65	0.12	0.77	0.08
Ghana	Ideal Milk Coffee			0.18	0.01
Ghana	Ideal Mliky Choco	0.03	0.07	0.1	0
Ghana	Ideal Milky Tea	0.04	0.09	0.13	0.02
Ghana	Cerelac Maize	0.09	0.11	0.2	0.03
Ghana	Nido Fortified	0.21	0.38	0.59	0.02
Ghana	Nestle Cerelac Bl Honey	0.11	0.21	0.32	0.02
Ghana	Nescafe 3 In 1 Breakfast Bulk	0.1	0.29	0.39	0.02
Ghana	Nestle Cerelac Bl Honey	0.11	0.38	0.49	0.03
Ghana	Nestle Cerelac Millet	0.09	0.21	0.3	0.02
Ghana	Nestle Cerelac Bl Frt Pcs	0.18	0.34	0.52	0.03
Ireland	Beef	<MDA			

India	Skimmed Milk Powder(Chl/268/14)	MDA	MDA	MDA	
UK	Poultry	0.035	0.247	0.282	0.02
Scotland UK	Poultry	<MDA	MDA	MDA	
Netherlands	Poultry	MDA	MDA	MDA	
Denmark	Poultry	MDA	MDA	MDA	
Belgium	Poultry	MDA	MDA	MDA	
Ghana	Nestle 3 In 1	MDA	MDA	MDA	
Ghana	Nescafe 3 In 1 Breakfast	MDA	MDA	MDA	
Ghana	Nescafe Classic Tin	MDA	MDA	MDA	
Ghana	Nido Fortified	MDA	MDA	MDA	
Ghana	Nesccafe 3 In 1 Cream	MDA	MDA	MDA	
Ghana	Nescafe 3 In 1 Cream	MDA	MDA	MDA	
Ghana	Nescafe 3 In 1 Cream Chank	MDA	MDA	MDA	
France	Procream 151a	MDA	MDA	MDA	
Belgium	Skimmed Milk Powder	MDA	MDA	MDA	
Netherlands	Skimmed Milk Powder	MDA	MDA	MDA	
UK	Skimmed Milk High Heat	MDA	MDA	MDA	
Poland		MDA	MDA	MDA	
Netherlands		MDA	MDA	MDA	
USA	Poultry	MDA	MDA	MDA	
Brazil	Poultry	MDA	MDA	MDA	
India	Meat Product	MDA	MDA	MDA	
BELGIUM Antwerp	Meat Product	MDA	MDA	MDA	
Denmark	Poultry	MDA	MDA	MDA	
South africa	Poultry	MDA	MDA	MDA	
Denmark	Poultry	MDA	MDA	MDA	

Ghana	Nescafe 3 In 1 Creamchank Sip	MDA	MDA	MDA	
Ghana	Nescafe 3 In 1 Breakfast Bulk	MDA	MDA	MDA	
Ghana	Nescafe 3 In 1 Breakfast Bulk	MDA	MDA	MDA	
Ghana	Nescafe 3 In 1 Breakfast Cup	MDA	MDA	MDA	
Ghana	Nescafe 3 In 1 Breakfast Cup	MDA	MDA	MDA	
Ghana	Nestle Cerelac Bl Honey	MDA	MDA	MDA	
Ghana	Nestle Cerelac Rice	MDA	MDA	MDA	
Ghana	Nestle Cerelac Bl Frt Pcs	MDA	MDA	MDA	
Ghana	Nescafe 3 In 1 Cream Chank Kp Sip	MDA	MDA	MDA	
Ghana	Nescafe Classic Tin	MDA	MDA	MDA	
USA	Poultry	MDA	MDA	MDA	
Belgium, Antwerp	Poultry	MDA	MDA	MDA	
Ireland	Skimmed Milk Powder	0.11	0.18	0.29	0.03
Belgium	Poultry	MDA	MDA	MDA	
Belgium	Poultry	`MDA	MDA		
Belgium	Poultry	MDA	MDA		
Netherlands /Italy	Poultry	MDA	MDA		
USA	Poultry	MDA	MDA		
Ghana	Nescafe Classic Tin	MDA	MDA		
Ghana	Nescafe Classic Tin	0.43	0.39	0.82	0.04
Ghana	Nescafe Classic Tin	0.17	0.29	0.46	0.04
Ghana	Nescafe Classic Tin	0.4	0.28	0.68	0.02
Ghana	Nescafe 3 In 1breakfast Cup	0.19	0.17	0.36	0.04

Ghana	Nido Nitripak Fortified	0.11	0.17	0.28	0.02
Ghana	Nido Fortified	0.09	0.2	0.29	0.03
Ghana	Nido Fortified	0.21	0.4	0.61	0.03
Ghana	Nido Fortified	0.19	0.21	0.4	0.02
Ghana	Nido Fortified	0.21	0.23	0.44	0.04
Ghana	Nestle Cerelac Bl Wheat	0.01	0.06	0.07	0
Ghana	Nestle Cerelac Bl Wheat	0.23	0.14	0.37	0.04
Ghana	Nestle Cerelac Bl Wheat	0.09	0.17	0.26	0.02
Ghana	Nestle Cerelac Bl Wheat	0.52	0.16	0.68	0.05
Ghana	Nescafe 3 In 1 Cream Chanpk Sip	0.29	0.18	0.47	0.02
Ghana	Nescafe 3 In 1 Cream Chanpk Sip	0.11	0.46	0.57	0.06
Ghana	Nestle Cerelac Bl W Frt Pcs	0.19	0.28	0.47	0
Ghana	Nestle Cerelac Bl Honey	0.27	0.51	0.78	0.06
Ghana	Nestle Cerelac Bl Rice	0.34	0.29	0.63	0.03
Ghana	Nescafe Classic Tin	0.71	0.18	0.89	0.05
Ghana	Nescafe Classic Tin	0.39	0.21	0.6	0.05
Ghana	Nescafe Classic Tin	0.29	0.16	0.45	0.03
Netherlands	Frozen Pork	0.05	0.11	0.16	0.03
Denmark	Poultry	0.19	0.21	0.4	0.02
Netherlands	Beef	0.19	0.23	0.42	0.04
Netherlands	Beef	0.39	0.18	0.57	0.03
USA	Beef	0.19	0.08	0.27	0.05
USA	Poultry	0.16	0.23	0.39	0.02
Ireland		0.57	0.11	0.68	0.03
USA	Poultry	0.16	0.09	0.25	0.05
New Zealand	Skimmed Milk Powder Dry Mix	0.17	0.19	0.36	0.04

New Zealand	Skimmed Milk Powder Dry Mix	0.31	0.21	0.52	0.03
Ireland	Filled Milk Powder 18%	0.24	0.29	0.53	0.03
New Zealand	Butter Milk Powder	0.23	0.19	0.42	0.02
Belgium	Skimmed Milk Powder Medium Heat	0.21	0.18	0.39	0.02
Germany	Golden Royal Unsweetened Evaporeted Milk	0.14	0.17	0.31	0.02
Ghana	Nestle Cerelac Bl W Frt Pcs	0.08	0.36	0.44	0.02
Ghana	Nestle Cerelac Bl Rice	0.29	0.09	0.38	0.06
Ghana	Nestle Cerelac Bl Honey	0.19	0.17	0.36	0.03
Ghana	Nescafe 3 In 1 Breakfast Cup	0.51	0.17	0.68	0.05
Ghana	Nescafe 3 In 1 Cream	0.29	0.33	0.62	0.04
Ireland	Cowbell Vegetable Fat Filled	0.29	0.27	0.56	0.03
Ireland	Cowbell Filled Milk	0.19	0.23	0.42	0.02
Belgium	Poultry	1	0.19	1.19	0.06
Netherlands	Nescafe 3 In 1 Breakfast Cup	0.23	0.19	0.42	0.03
Ghana	Nescafe 3 In 1 Breakfast Bulk	0.39	0.15	0.54	0.02
Ghana	Nescafe 3 In 1 Breakfast Cup	0.27	0.08	0.35	0.04
Ghana	Nescafe 3 In 1 Breakfast Bulk	0.28	0.15	0.43	0.03
Ghana	Nescafe 3 in 1 Breakfast Bulk	0.16	0.18	0.34	0.04
Ghana	Nescafe 3iIn 1 Breakfast Bulk	0.39	0.22	0.61	0.03
Ghana	Nescafe 3 in 1 Breakfast Cup	0.43	0.29	0.72	0.06

Ghana	Nestle Cerelac Bl Wheat	0.08	0.21	0.29	0.04
Ghana	Nestle Cerelac Bl Wheat	1	0.16	1.16	0.06
Ghana	Nescafe 3 In 1 Cream Chank Sip	0.17	0.09	0.26	0.05
Ghana	Nescafe 3 In 1 Cream Chank Kp Sip	0.31	0.29	0.6	0.04
Ghana	Nescafe 3 In 1 Breakfast Cup	0.23	0.13	0.36	0.05
Ghana	Nescafe 3 In 1 Cream Chanpk Sip	0.17	0.29	0.46	0.05
Ghana	Nescafe 3 In 1 Cream Chanpk Sip	0.37	0.33	0.7	0.04
Ghana	Nescafe 3 In 1 Cream Chanpk Sip	0.19	0.54	0.73	0.04
Ghana	Nido Nutripak Fortified	0.22	0.13	0.35	0.03
Ghana	Nido Nutripak Fortified	0.91	0.21	1.12	0.04
Ghana	Nescafe 3 In 1 Breakfast Cup	0.2	0.16	0.36	0.02
Malaysia	Moi Sweetened Condensed Milk	0.49	0.23	0.72	0.05
Germany	Golden Burger Long Life Milk	0.81	0.21	1.02	0.06
Belgium	Skimmed Milk Powder	0.21	0.32	0.53	0.02
Malaysia	Foodie Sweetened Condensed Milk	0.68	0.38	1.06	0.04
Malaysia	Jago Sweetened Condensed Milk	1.02	0.21	1.23	0.06
Netherlands	Skimmed Milk Powedr	0.17	0.16	0.33	0.03
USA	Poultry	0.38	0.09	0.47	0.03
Ghana	Natural Cocoa Cake	0.21	0.14	0.35	0.03
New Zealand	Skimmed Milk	0.18	0.35	0.53	0.04
Germany	Skimmed Milk Powder	0.32	0.19	0.51	0.03
Poland	Sweet Whey Powder	0.21	0.15	0.36	0.04

Netherlands	Skimmed Milk Powder`	0.21	0.14	0.35	0.03
New Zealand	Skimmed Milk Powder	0.09	0.13	0.22	0.02
New Zealand	Skimmed Milk Powder High Heat	0.16	0.29	0.45	0.05
Ghana	Nescafe 3 In 1 Cream Chanpk Sip	0.21	0.09	0.3	0.03
Ghana	Nescafe 3 In 1 Cream Sip	0.2	0.21	0.41	0.04
Ghana	Nescafe 3 In 1 Crem Chanpk	0.31	0.28	0.59	0.03
Ghana	Nescafe 3 In 1 Crem Chanpk	0.2	0.29	0.49	0.03
Ghana	Nescafe 3 In 1 Crem Chanpk	0.28	0.27	0.55	0.02
Ghana	Nescafe 3 In 1 Breakfast	0.17	0.23	0.4	0.02
Ghana	Nescafe 3 In 1 Breakfast Bulk	0.11	0.19	0.3	0.03
Ghana	Nestle Cerelac Bl Wheat	0.26	0.21	0.47	0.02
Ghana	Nestle Cerelac Bl Wheat	0.17	0.18	0.35	0.03
Ireland	Skimmed Milk Powder	0.16	0.41	0.57	0.05
Poland	Sweet Whey Powder	0.14	0.13	0.27	0.02
Poland	Demineralised Whey Powder	0.23	0.26	0.49	0.04
Poland	Full Cream Milk Powder	0.13	0.15	0.28	0.04
Ireland	Cowbell Vegetable Fat Milk	0.23	0.19	0.42	0.03
Ireland	Cowbell Vegetable Fat Filled Milk	0.7	0.21	0.91	0.03
Ghana	Nescafe 3 In 1 Crem Chanpk Sip	0.31	0.25	0.56	0.04
Ghana	Nestle Cerelac Bl Millet	0.13	0.15	0.28	0.05
Ghana	Nido Nutripak Fortified	0.21	0.09	0.3	0.04
Germany/Belgium	Skimmed Milk Powder	0.52	0.24	0.76	0.02

UK	Skimmed Milk Powder	0.21	0.35	0.56	0.03
Ghana	Nestle Milo Actigen	0.32	0.16	0.48	0.02
Ghana	Milo Actigen E	0.13	0.16	0.29	0.03
Ghana	Nestle Cerelac Bl Wheat	0.14	0.21	0.35	0.02
Ghana	Nescafe 3 In 1 Crem Chanpk Sip	0.11	0.13	0.24	0.04
Ghana	Nestle Cerelac Bl Millet	0.24	0.11	0.35	0.02
Ghana	Nestle Cerelac Bl Wheat	0.15	0.09	0.24	0.04
Ghana	Nido Fortified	0.17	0.29	0.46	0.05
Ireland	Beef Feet	0.11	0.19	0.3	0.03
Ireland	Beef Feet	0.24	0.19	0.43	0.02
Holland	Full Cream Powder	0.21	0.25	0.46	0.03
UK	Whole Milk Powder	0.24	0.19	0.43	0.03
Germany	Frozen Meat Product	0.24	0.4	0.64	0.03
Ghana	Nestle Cerelac Bl Wheat	0.24	0.31	0.55	0.03
Ghana	Nestle Cerelac Bl Honey	0.17	0.29	0.46	0.05
Ghana	Nescafe 3 In 1 Breakfast Cup	0.21	0.4	0.61	0.05
Ghana	Milo Actigen E	0.33	0.29	0.62	0.03
Ghana	Milo Actigen E	0.13	0.36	0.49	0.03
Ghana	Milo Actigen E	0.11	0.16	0.27	0.02
Ghana	Milo Actigen E	0.43	0.15	0.58	0.05
Ghana	Milo Actigen E	0.51	0.34	0.85	0.06
Poland	Skimmed Milk Powder	0.23	0.17	0.4	0.04
Ireland	Cowbell Filled Milk Powder	0.28	0.19	0.47	0.04
Ireland	Dairyvale Filled Milk Powder	0.63	0.36	0.99	0.03
Ireland	Cowbell Filled Milk Powder	0.18	0.23	0.41	0.03
Ireland	Cowbell Filled Milk	0.16	0.15	0.31	0.04

	Powder				
UK	Skimmed Milk Powder	0.39	0.14	0.53	0.03
UK	Sweet Whey Powder	0.19	0.33	0.52	0.02
Ghana	Nestle Cerelac Bl Wheat	0.16	0.09	0.25	0.06
Ghana	Nescafe 3in 1 Breakfast Cup	0.61	0.42	1.03	0.04
Ghana	Milo Actigen E	0.29	0.15	0.44	0.05
Ghana	Milo Actigen E	0.21	0.33	0.54	0.03
Ghana	Milo Actigen E	0.41	0.24	0.65	0.02
Ghana	Milo Actigen E	0.31	0.25	0.56	0.05
Ghana	Milo Actigen E	0.72	0.51	1.23	0.06
Ghana	Milo Actigen E	0.53	0.22	0.75	0.02
Ghana	Milo Actigen E	0.49	0.26	0.75	0.04
Ghana	Nido Fortified	0.16	0.29	0.45	0.03
Ghana	Nido Nutripak Fortified	0.23	0.45	0.68	0.05
Ghana	Nido Nutripak Fortified	0.59	0.42	1.01	0.06
Denmark	Poultry/Beef	0.14	0.29	0.43	0.06
Germany	Beef Product	0.36	0.2	0.56	0.05
Poland	Sweet Whey Powder	0.3	0.35	0.65	0.03
Netherlands	Skimmed Milk Powder Medium Heat	0.31	0.41	0.72	0.05
New Zealand	Skimmed Milk Powder Dry Mix	0.12	0.14	0.26	0.02
New Zealand	Beef/Poultry	0.32	0.54	0.86	0.06
Ghana	Nestle Cerelac Bl Rice	0.39	0.21	0.6	0.02
Ghana	Nestle Cerelac Bl Millet	0.21	0.15	0.36	0.05
Ghana	Nestle Cerelac Bl Wheat	0.08	0.17	0.25	0.03
Ghana	Milo Chocomilo	0.32	0.26	0.58	0.05
Ghana	Nescafe Classic Tin	0.17	0.29	0.46	0.04

Ghana	Nestle Cerelac Bl	0.22	0.13	0.35	0.06
Ghana	Nestle Cerelac Bl Millet	0.09	0.3	0.39	0.05
Ghana	Tuna Skipjack Round	0.29	0.43	0.72	0.03
Ghana	Tuna Skipjack Round	0.15	0.34	0.49	0.05

APPENDIX C

Calibration Certificates

GHANA STANDARDS AUTHORITY
P. O. BOX MB 245. ACCRA, GHANA.
TEL: 0302-500065/6, 500086, Fax: 0302-500092
E-Mail: smetrology@yahoo.com

CALIBRATION CERTIFICATE

CERTIFICATE NO.: GSA/MED/114.14 (A)/VL/203

LABORATORY NO.: SM/VL/053.1-2/16

CUSTOMER: R.P.I. – G.A.E.C.
P. O. BOX LG 80
LEGON, ACCRA

DATE OF CALIBRATION: 2016-05-26

ITEM CALIBRATED: MARINELLI BEAKER
- Serial No. : RPI/079
- Range : 1000 ml
- Readability: 1000 ml
- Manufacturer: AEA TECHNOLOGY

PLACE OF CALBRATION: Volume Laboratory, Ghana Standards Authority

CALIBRATION METHOD: *GRAVIMETRIC*

DATE OF ISSUE: **2016-05-26**

THIS CERTIFICATE IS VALID TILL: **MAY, 2017**

CALIBRATED BY:..... (Daniel Kwakofi)
CHECKED BY:..... (Paul Date) (Head of Department)
APPROVED BY:..... (George Omane - Twumasi) (Quality Coordinator)

GHANA STANDARDS AUTHORITY
METROLOGY DIVISION

CALIBRATION CERTIFICATE

CERTIFICATE NO.: GSA/MED/114.14 (A)/VL/203

EQUIPMENT : MARINELLI BEAKER

READABILITY : 1000 ml

AMBIENT CONDITIONS : Temperature : 22.10 °C

Relative Humidity: 53.3 %

Air Pressure : 1008.37 mbar

TEST RESULTS:

Nominal Volume ml	Mean Measured Volume (EUT) ml	Deviation ml	Uncertainty %
1000	930.540	-69.460	0.05

EUT = Equipment Under Test

Deviation = Mean Measured Volume of EUT – Nominal Volume

Traceability: *The working scale was calibrated with reference mass pieces serial number 05424 traceable to DKD through calibration certificate number 03-0152/DKD-K-06901/06-04*

Measurement uncertainty: *The expanded uncertainty reported on the certificate is based on combined uncertainty multiplied by coverage factor k=2 providing a level confidence of 95%.*

GHANA STANDARDS AUTHORITY
P. O. BOX MB 245. ACCRA, GHANA.
TEL: 0302-500065/6, 500086, Fax: 0302-500092
E-Mail: smetrology@yahoo.com

CALIBRATION CERTIFICATE

CERTIFICATE NO.: GSA/MED/114.14 (A)/VL/204

LABORATORY NO.: SM/VL/053.2-2/16

CUSTOMER: R.P.I. – G.A.E.C.
P. O. BOX LG 80
LEGON, ACCRA

DATE OF CALIBRATION: 2016-05-26

ITEM CALIBRATED: **MARINELLI BEAKER**
- Serial No. : VL/053.2/16
- Range : 1000 ml
- Readability: 1000 ml
- Manufacturer: AEA TECHNOLOGY

PLACE OF CALBRATION: Volume Laboratory, Ghana Standards Authority

CALIBRATION METHOD: *GRAVIMETRIC*

DATE OF ISSUE: 2016-05-26

THIS CERTIFICATE IS VALID TILL: MAY, 2017

CALIBRATED BY:..... (Daniel Kwakofi)
CHECKED BY:..... (Paul Date) (Head of Department)
APPROVED BY:..... (George Omane - Twumasi) (Quality Coordinator)

GHANA STANDARDS AUTHORITY
METROLOGY DIVISION

CALIBRATION CERTIFICATE

CERTIFICATE NO.: GSA/MED/114.14 (A)/VL/204

EQUIPMENT : MARINELLI BEAKER

READABILITY : 1000 ml

AMBIENT CONDITIONS : Temperature : 21.4 °C

Relative Humidity: 50.0 %

Air Pressure : 1008.39 mbar

TEST RESULTS:

Nominal Volume ml	Mean Measured Volume (EUT) ml	Deviation ml	Uncertainty %
1000	934.953	-65.047	0.05

EUT = Equipment Under Test

Deviation = Mean Measured Volume of EUT – Nominal Volume

Traceability: *The working scale was calibrated with reference mass pieces serial number 05424 traceable to DKD through calibration certificate number 03-0152/DKD-K-06901/06-04*

Measurement uncertainty: *The expanded uncertainty reported on the certificate is based on combined uncertainty multiplied by coverage factor k=2 providing a level confidence of 95%.*

Ghana Standards Authority
Metrology Division

accredited by the / *accrédité par la*

Deutsche Akkreditierungsstelle GmbH

DAkkS Deutsche Akkreditierungsstelle D-K-15209-01-00

as calibration laboratory in the / *comme laboratoire d'étalonnage en*

Deutschen Kalibrierdienst DKD

BL- 00170
D-K-15209-01-00
2016-05

Calibration certificate
Certificat d'étalonnage

Calibration mark
Marque d'étalonnage

Object *Objet*	PRECISION BALANCE
Manufacturer *Fabricant*	METTLER TOLEDO
Type *Type*	XP2001S
Serial number *Numéro de série*	B044082755
Customer *Client*	R.P.I - GAEC P.O. BOX LG 80 LEGON, ACCRA
Order number *Numéro de commande*	SM/BL/118/16
Number of pages of the certificate *Nombre de pages de certificate d'étalonnage*	3
Date of calibration *Date d'étalonnage*	2015-05-24

This calibration certificate documents the traceability to national standards, which realize the units of measurement according to the International System of Units (SI).
The DAkkS is signatory to the multilateral agreements of the European co-operation for Accreditation (EA) and of the International Laboratory Accreditation Cooperation (ILAC) for the mutual recognition of calibration certificates.
The user is obliged to have the object recalibrated at appropriate intervals.

Ce certificat d'étalonnage documente la traçabilité des grandeurs mesurées par raccordement aux étalons nationaux en conformité avec le Système international d'unités (SI).
La DAkkS est signataire des accords multi-latéraux de l'European co-operation for Accreditation (EA) et de l'International La-boratory Accreditation Cooperation (ILAC) pour la reconnaissance mutuelle des certificats d'étalonnage.
L'utilisateur est tenu de faire étalonner le matériel référencé ci-dessus à des intervalles appropriés.

Date *Date*	Head of the calibration laboratory *Directeur du laboratoire d'étalonnage*	Person in charge *Personne responsable*
2016-05-24	Paul M. Date	Francis Boateng

Ghana Standards Authority, Metrology Division
Calibration laboratory for Mass, Pressure, Temperature, Volume and Balance
P. O. Box MB 245. Accra, Ghana.
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E-Mail: smetrology@yahoo.com

BL- 00170
D-K-15209-01-00
2016-05

The French version of the calibration certificate is not a binding translation. If any matter gives rise to controversy, the English original text must be used.

Calibration object Precision Balance

Type: XP2001S		Capacity:	2100 g
Serial No: B044082755		Scale Division (d):	0.1 g
Accuracy Class: II		Min. Capacity:	5 g

Calibration procedure The calibration was done according to guideline EURAMET/cg-18v3.
The calibration comprised:

- Repeatability
- Test of errors of indication
- Eccentricity *test*

Standards Set of weights of class F1 (Serial No.:MED/T16/B/002)
Calibration: ML-0115 D-K-15209-01-00/2015-11

Place of test BALANCE LABORATORY, GSA

Environmental conditions

Temperature during calibration	Start:23.5 °C	End: 24.0 °C
High Air circulation	Yes ( )	No (√)
High vibration	Yes ( )	No (√)