**Sudan University of Science and Technology**
**College of Graduate Studies**

# STUDY OF RADIOACTIVITY FOR WASTE WATER OF KHARTOUM REFINERY

**دراسة النشاط الإشعاعي لمخلفات مياه مصفاة الخرطوم**

A thesis Submitted for Partial Fulfillment of M.Sc. Degree in Nuclear physics

## By

Nafisa Almahdi Altayeb Elfaki Hashim

## Supervisor:

Dr. Ahmed Elhassan Elfaki

March 2017

بسم الله الرحمن الرحيم

"وقل ربى زدنى علماً" 114

صدق الله العظيم

# Dedication

I dedicate this thesis to my Parents: father and mother to whom I owe everything in my life.

ACKNOWLEDGEMENTS

The author acknowledges the valuable endless, continuous supervision, guidance, and helps of **Dr.Ahmed Elhassan lfaki**, the dean of the college of Science, Sudan University of Science and Technology (SUST), for his endless help throughout the completion of this work. Thanks with endless appreciation are due to all staff of the Khartoum Refinery

Also thanks are to be passed to the laboratory staff of the Sudanese Atomic Energy Agency office.

The valuable encouragement received from Consultant Engineer: Elfatih Osman Ahmed Khalid is highly appreciated.

Finally , I would like to pass unlimited appreciations, to my parents; father and mother without their patient, encouragements and help, I could not keep on processing the work of this thesis.

TABLE OF CONTENTS

## List of Figures



# List of Tables

# Abstract

The hazardous waste water from industrial sector is now coming one of major threats to environment, the need to study the radioactivity from such kind of waste is of crucial importance, this study is carried out to path the way in studying the radioactivity of waste water in Sudan.

Since the industrial waste water is a threat to environment, the impacts should be accessed through study of radio activity of such materials.

To study the radio-activity of Khartoum Refinery waste water, total of twenty samples were collected and tested, the Cs-137, Ra-226 were found in the waste water.

The tested samples reflected that there is a good relationship between the **MDA** (Minimum Detect Activities) and Cs-137, with a correlation coefficient of 0.814, as well as a relationship between Ra-226 and MDA however the later relationship is seems to be weak due to limited data values.

It is recommended that more efforts is needed to study the radioactivity of waste water and other waste of the industrial parties in Sudan. Such studies are of crucial importance in anticipating and correcting the environmental impacts and minimization of hazards and safe the environment for the coming generation

# المستخلص

ماء النفايات الخطرة من القطاع الصناعي والآن تأتي أحد المخاطر الرئيسية التي تهدد البيئة والحاجة الماسة لدراسة النشاط الإشعاعي من مثل هذا النوع من النفايات له أهمية حاسمة, وهذه الدراسة مسار للطريق في تطوير المادة والنشاط الإشعاعي لمياه الصرف في السودان.

مياه الصرف الصناعي تشكل خطرا على البئية ينبغي الوصول إلى التأثيرات من خلال دراسة النشاط الإشعاعي من هذه المواد.

لدراسة النشاط الإشعاعي لمياه صرف مصفاة الخرطوم تم جمع 20 عينة وإختبارها . وتم العثور على عنصري السيزيوم والراديوم , العينات المختبرة تعكس أن هناك علاقة جيدة بين السيزيوم مع معامل الإرتباط وكذلك علاقة بين الراديوم والسيزيوم.

من المستحسن بذل المزيد من الجهود لدراسة النشاط الإشعاعي من المياه العادمة والنفايات الأخرى من الصناعات في السودان.

مثل هذه الدراسات ذات أهمية حاسمة في توقع وتصحيح الآثار البيئية والتقليل من المخاطر وأمن البيئة للأجيال القادمة.

# CHAPTER 1

# INTRODUCTION

# CHAPTER ONE

## 1.1Problem:-

In many of the drilling sites of oil wells, the deep drilling earth depth will accompany with emergence of radioactive materials as a deposits that are in the tubes which are dropped in the oil well for purpose of extraction it from the earth depth as a calcareous deposits that contains many of the earth elements that accompany the oil resources in the depths of earth

## 1.2 Aims of the Research:-

1- Knowledge of the radioactive elements that accompany the oil industry, the stage of exploration and drilling to the stages of treatment through oil refineries and treatment of waste from the process of refining.
2- Protect the environment from the risks of radioactive materials by studying and knowing the properties and effects of those substances on the environment and methods of safe disposal of those substances
3- Raising awareness of workers to protect them from the dangers of radioactive materials
4- Know how to measure the presence and standards of radioactive materials and methods of prevention from it
5- In order to attain the objective of this study a series of laboratory tests on waste water from Khartoum Refinery, experiments were carried out during period 2016 to 2017 to cover the task of study of radioactive radiation on waste water samples.

## 1.3 Back ground and Previous Researches

The hazardous waste water from industrial sector is now coming one of major threats to environment, the need to study the radioactivity from such kind of waste is of crucial importance, this study is carried out to path the way in studying the radioactivity of waste water in Sudan.

Takacs at al. (2008), studied the aqueous solution of dye textile waste water by using pulse radiolysis with kinetic spectroscopic detection for transient measurements and also by gamma radiolysis with UV-VIS spectroscopy and gradient HPLC separation with diode array detection for following the destruction of the dye molecules and measuring the products.

Trojanowicz et al. (2008) investigated the decomposition of selected pesticides and the formation of by-products during the application of ionizing radiation for the treatment of pesticides in synthetic aqueous solutions, as well as in real samples of industrial wastes, they recommend radiolytic degradation to be an effective method for treatment of industrial wastes.

Botelho et al (2008) recommended the implementation of ionizing radiation in agricultural wastewater treatment plants, as an effective, safe and profitable way to treat wastewater.

## 1.4Outline of the Thesis:-

The thesis constitutes five main parts. Each part deals with a section of the study but chapters are linked in their targets.

Chapter one gives a general review about the dissertation, its scope and outlines.

Chapter two consists of two parts, the first part reviews a bereave literature on Recitation and Radioactivity, the second part reviews a short literature about waste water process.

Chapter Three presents the methodology and results of laboratory tests on samples taken from Khartoum Refinery to Study the Radioactivity.

Chapter Four presents the analysis and discussion of laboratory tests. The findings are used to draw conclusions and Recommendations.

Chapter Five draws the conclusions obtained from the study, and recommendations for the future work in the same area of this study.

# Chapter Two

# Radiation and Radioactivity

# Chapter Two:

# Radiation and Radioactivity

## 1.1 Radiation

It is energy that comes from a source and travels through some material or through space. Light, heat and sound are types of radiation. Also it could be defined as an energy given off from unstable atoms in the form of waves or small particles of matter.

## 1.2 Ionization

It is the process by which an atom or a molecule acquires a negative or positive charge by gaining or losing electrons to form ions, often in conjunction with other chemical changes.[1] Ionization can result from the loss of an electron after collisions with subatomic particles, collisions with other atoms, molecules and ions, or through the interaction with light. Heterolytic bond cleavage and heterolytic substitution reactions can result in the formation of ion pairs. Ionization can occur through radioactive decay by the internal conversion process, in which an excited nucleus transfers its energy to one of the inner-shell electrons causing it to be ejected.

## 1.3 Ionizing radiation

It is radiation with enough energy so that during an interaction with an atom, it can remove tightly bound electrons from the orbit of an atom, causing the atom to become charged or ionized.

Here we are concerned with only one type of radiation, ionizing radiation, which occurs in two forms - waves or particles.

## 2.0 Radioactivity and Radiation

Atoms: All material is composed of atoms. The atom consists of a small, massive, positively charged core (nucleus) surrounded by electrons. The nucleus, containing most of the mass of the atom, is itself composed of neutrons and protons

**Radioactivity** : Most of the atoms in the nature are stable but there are some unstable, try to be stable by given off in the form of invisible particles or waves.

## 2.1 Types of Radiation:-

There are two types of radiation; ionizing and non ionizing radiations

### 2.1.1 Ionizing Radiation

Higher energy electromagnetic waves (gamma or x-rays ) or small particles (beta and alpha) have enough energy to pull electron out of the atom orbits.

Types of Ionizing Radiation

There are four types of ionizing radiation, namely : Alpha, Beta, X-ray , and Gama ray.

**Alpha Radiation**

Alpha particles consist of tightly bonded group of four sub-atomic particles (2 protons +2 neutrons). They posses an electrical positive charge (+2), are relatively heavy (4 atomic mass units), and have a very short range in air (about 3 cm). Alpha particles are easily stopped (absorbed) by a sheet of paper. Their range in tissue is about 0.04 mm; therefore they do not penetrate the outer layer of skin. Radioactivity materials that emit alpha particles can only be hazardous if taken into the body (by inhalation, ingestion or a break in the skin), figure 1.1 illustrate this type of radiation.

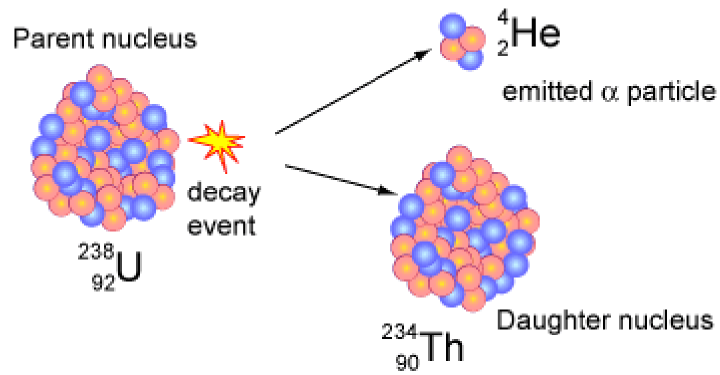



**Fig 1.1: Alpha Ray**

**Beta Radiation**

Beta particles are fast moving electron particles. They possess a negative electrical charge (-1). They are much lighter than alpha particles but are slightly more penetrating. Beta particles in air have a range up to a few meters but are easily stopped by a thin layer of material such as metal, wood, plastic or water. Their range in tissue is about 0.5cm; they can therefore be hazardous to the skin, figure1.2 illustrates this type of radiation.

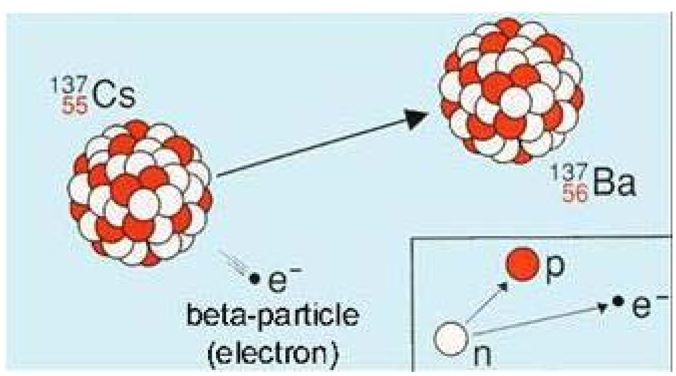



**Fig 1.2: Beta Ray**

**X-ray and gamma Radiation**

X-ray and gamma radiation are waveforms of energy similar to radio waves but of much shorter wavelength. They are very penetrating and have a very long range in air (many meters). They can shield material such as steel or lead. They can penetrate the whole body; figure 1.3 illustrates this type of radiation.

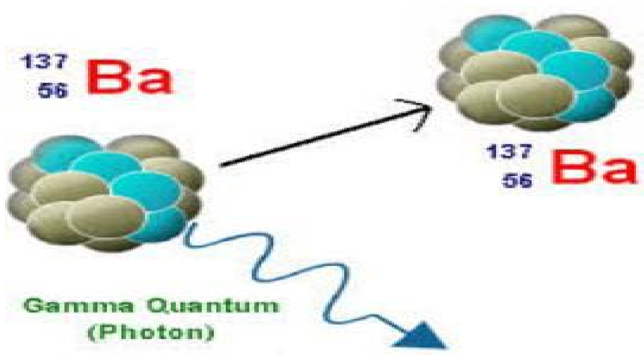



**Fig 1.3: X-ray and gamma Radiation**

### 2.1.2 None Ionizing Radiation

Lower energy electromagnetic waves do not have enough energy to pull electron out of atom orbits, but can excite the electron.

### 2.1.3 Radiation Types and the Degree of Penetration:-

Each type of radation exhabits a degree of penetration, most of them penetrate paper, thin boards, only X &Gama rays in addition to neutron rays can penetate thick boards, only neutron rays can penetrate water, concrete, and similar materials, figure 1.4 illustates the penetration degree.

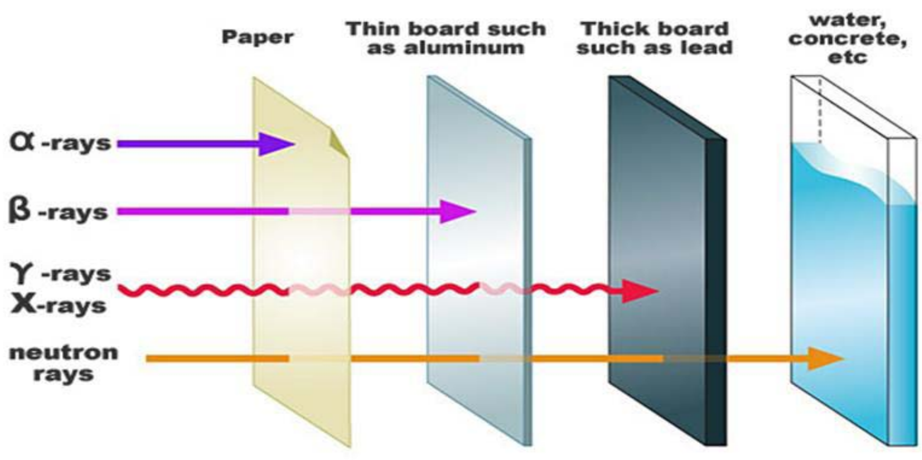



**Fig 1.4 : penetration of different types of radiation**

## 2.2 Health Effects from Exposure to Ionizing Radiation

Any release of radioactive material is a potential source of radiation exposure to the population. In addition to exposure from external sources, radiation exposure can occur internally from ingesting, inhaling, injecting, or absorbing radioactive materials. Both external and internal sources may irradiate the whole body or a portion of the body. The amount of radiation exposure is expressed in a unit called millirem (mrem). In the United States, the average person is exposed to an effective dose equivalent of approximatly 360 mrem (whole-body exposure) per year from all sources (NCRP Report No. 93).

# Chapter Three

# Waste Water Treatment Process

# Chapter Three

# Waste Water Treatment Processes

## 3.0 Introduction

The waste water Wastewater refers to all ***effluent*** from household, commercial establishments and institutions, hospitals, industries and so on. It also includes storm water and urban runoff, agricultural, horticultural and aquaculture effluent

The process of waste water treatment can be divided to four main sub processes, mechanical, physical, chemical, and biological treatments.

**Mechanical treatment:**

The oily waste water comes from process units pass through screen bar to remove the big practical and floating object to eliminate the wear problems in the pumps and the valves together with relative reduction in COD.

**Physical treatment:**

The objective of physical treatment is to control the oil and grease and reduce the COD, impact the biological environment. oily waste water pumped up to oil separator pond the free oil rise up due to differential in density between water and oil, the oil collected and send to oil pond

**Chemical Treatment:**

In this stage the chemical inject to produce an effluent suitable for biological treatment. The suspended solid conformed by flocculent and coagulation then floats on the water surface by dissolved air flotation, the control in this stage mainly depends on the flow rate, adequate skimming and scraping, the chemical dosing program& rate, dissolved oxygen quantity, PH adjustment.

**Biological Treatment:**

It is the conversion of the suspended, colloidal and dissolved organics remaining after primary treatment into a microbial mass which is then removed in a second sedimentation process. Secondary treatment includes both the biological process and the associated sedimentation process .this process termed as activated sludge process.

## 3.1 Types of waste water treatment

The waste water treatment could be divided to two main categories; domestic waste water treatment and industrial waste water treatment.

**Domestic waste water treatment**

It is type of waste water those produced from domestic (house hold sewerages, offices, etc…), waste are generally sludge's, and waste water from humans, this type of waste is out of scope of this research.

**Industrial waste water treatment**

Industrial wastewater contains a diversity of impurities and therefore for this reason alone, its treatment constitutes a special task. Furthermore, the emission limits for industrial effluent are constantly being tightened up. Closed circuits and product recovery in various production processes are becoming an increasing priority among manufacturing companies. These measures represent an additional contribution to the protection of aquatic eco-systems and possess great cost-cutting potential.

## 3.2 Sources of Industrial waste water

Industrial waste water comes from many activities, those are related to the type of manufactured materials, and generally most of them produce huge amounts of waste water, ten sources of industrial waste water will be discussed, they are: Complex Organic Chemicals industry, Electric power plants, Food industry, Iron and steel industry, Mines and Quarries, Pulp and Paper industry, Industrial Oil Contamination, Water Treatment, Wool Processing, and Nuclear industry

### Complex Organic Chemicals Industry

A range of industries manufacture or use complex organic chemicals. These include pesticides, pharmaceuticals, paints and dyes, petrochemicals, detergents, plastics, paper pollution, etc.

### Electric Power Plants

in this types of plants wastewater is discharged with significant levels of metals such as lead, mercury, cadmium and chromium, as well as arsenic, selenium and nitrogen compounds (nitrates and nitrites). Wastewater streams include flue-gas desulfurization, fly ash, bottom ash and flue gas mercury control. Plants with air pollution controls such as wet scrubbers typically transfer the captured pollutants to the wastewater stream.[2]

### Food Industry

Wastewater generated from agricultural and food operations has distinctive characteristics that set it apart from common municipal wastewater managed by public or private sewage treatment plants throughout the world: it is biodegradable and non-toxic, but has high concentrations of biochemical oxygen demand (BOD) and suspended solids (SS).[3]

**Iron and Steel Industry**

The production of iron from its ores involves powerful reduction reactions in blast furnaces. Cooling waters are inevitably contaminated with products especially ammonia and cyanide. Production of coke from coal in coking plants also requires water cooling and the use of water in by-products separation. Contamination of waste streams includes gasification products such as benzene, naphthalene, anthracene, cyanide, ammonia, phenols, cresols together with a range of more complex organic compounds known collectively as Polycyclic Aromatic Hydrocarbons (PAH).[4]

Mines and Quarries

The principal waste-waters associated with mines and quarries are slurries of rock particles in water. These arise from rainfall washing exposed surfaces and haul roads and also from rock washing and grading processes.

**Pulp and Paper Industry**

Effluent from the pulp and paper industry is generally high in suspended solids and BOD. Plants that bleach wood pulp for paper making may generate chloroform, dioxins , furans, phenols and Chemical Oxygen Demand (COD).[5]

## Industrial Oil Contamination

Industrial applications where oil enters the wastewater stream may include vehicle wash bays, workshops, fuel storage depots, transport hubs and power generation; typical contaminants can include solvents, detergents, grit, Lubricants and hydrocarbons.

## Water Treatment

Many industries have a need to treat water to obtain very high quality water for demanding purposes such as environmental discharge compliance. Water treatment produces organic and mineral sludge's from filtration and sedimentation. Ion exchange using natural or synthetic resins removes calcium, magnesium and carbonate ions from water, typically replacing them with sodium, chloride, hydroxyl and/or other ions. Regeneration of ion exchange columns with strong acids and alkalis produces a wastewater rich in hardness ions which are readily precipitated out, especially when in admixture with other wastewater constituents.

## Wool Processing

Insecticide residues in fleeces are a particular problem in treating waters generated in wool processing. Animal fats may be present in the wastewater, which if not contaminated, can be recovered for the production of tallow or further rendering.

## Nuclear Industry

The waste production from the nuclear and radio-chemicals industry is dealt with as Radio-active waste.

Radioactive waste is waste that contains radioactive material. Radioactive waste is usually a by-product of nuclear power generation and other applications of nuclear fission or nuclear technology, such as research and medicine. Radioactive waste is hazardous to most forms of life and the environment, and is regulated by government agencies in order to protect human health and the environment.

Radioactivity naturally decays over time, so radioactive waste has to be isolated and confined in appropriate disposal facilities for a sufficient period until it no longer poses a threat. The time radioactive waste must be stored for depends on the type of waste and radioactive isotopes. Current major approaches to managing radioactive waste have been segregation and storage for short-lived waste, near-surface disposal for low and some intermediate level waste, and deep burial or partitioning / transmutation for the high-level waste.

A summary of the amounts of radioactive waste and management approaches for most developed countries are presented and reviewed periodically as part of the International Atomic Energy Agency (IAEA) Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management.[12]

# Chapter Four

# Methods and Results for Laboratory Tests

# Chapter Three

# Methods and Results of Laboratory Tests

## 4.1 Introduction

This chapter outlines the test methods used to study parameters under consideration and displays the results of the laboratory experiments carried out to study ‹The radioactivity of Khartoum Refinery Waste Water.

Procedures and methods used for testing will be presented in the following paragraphs.

## 4.2 Method

The current study is based on experimental testing on waste water from Khartoum Refinery; samples were collected and transported to Sudanese Atomic Energy Agency Laboratory for Gama Spectrum processing for the waste water, results showed existence of Cs-137,ANNIGL, and Ra-226.

## 4.3 Waste Water Sampling

Total of twenty waste water sample were collected from Khartoum Refinery; which is located north of Khartoum

## 3.4 Waste Water Testing

Twenty samples were tested using BALTIC SCIENTIFIC INSTRUMENTS (BSI) of the Sudanese Atomic Energy Agency office laboratory, samples were tested using gamma spectrum processing to trace the Cs-137, Ra-226, and MDA, test results reports are presented in chapter four ; the reports presents the tested nuclides, area, activity, and relative uncertainties of each tested element.

Test results are summarized in Table 3.1, and Table 3.2 respectively

**Table 4.1: Summary of Gamma spectrum processing reposts for Cs-137 and MDA.**

| Sample ID | Area (impulse) | Cs-137 (Activity , Bq) | MDA, Bq | Relative uncertertinity % |
|---|---|---|---|---|
| 1 | 64 | 0.58 | 0.24 | 29 |
| 4 | 84 | 0.75 | 0.19 | 24 |
| 9 | 70 | 0.72 | 0.27 | 27 |
| 11 | 33 | 0.25 | 0.44 | 50 |
| 15 | 300 | 0.71 | 0.16 | 13 |
| 18 | 450 | 0.79 | 0.12 | 11 |
| 19 | 83 | 0.75 | 0.23 | 25 |

**Table 4.2: Summary of Gamma spectrum processing reposts for Ra-226 and MDA.**

| Sample ID | Area (impulse) | Ra -226(Activity , Bq) | MDA, Bq | Relative uncertertinity % |
|---|---|---|---|---|
| 11 | 44 | 0.59 | 0.55 | 40 |
| 15 | 74 | 0.71 | 0.37 | 40 |

**Table4.3: Summary of Gamma spectrum processing reposts for Area and MDA.**

| Sample ID | Area (impulse) | ANNIGL (Activity , Bq) | MDA, Bq | Relative Uncerteninty % |
|---|---|---|---|---|
| 20 | 290 | 0.18 | 0.19 | 40 |

# Chapter Five

# Analysis and Discussion of Laboratory Test Results

# Chapter Five

## Analysis and Discussion of Laboratory Test Results

### 5.1 Introduction

The objective of this chapter is to analyze the results of laboratory test carried out on waste water samples from Khartoum Refinery. The results of the laboratory tests are used to understand the degree of radioactivity.

### 5.2 Analysis of MDA and Cs-137 Existence

Seven out from twenty tested samples gives a reading of MDA and Cs-137 at the same time, the MDA values is correlated with Cs-137, a good fit is found; it was found that the relationship has a correlation coefficient of 0.814(Eq. 4.1); figure 4.1 illustrates the relationship between MDA and Cs-137.

$$MDA=-0.495\ (Cs\text{-}137)+0.557 \quad (R2=0.814) \qquad \text{Eq. 4.1}$$

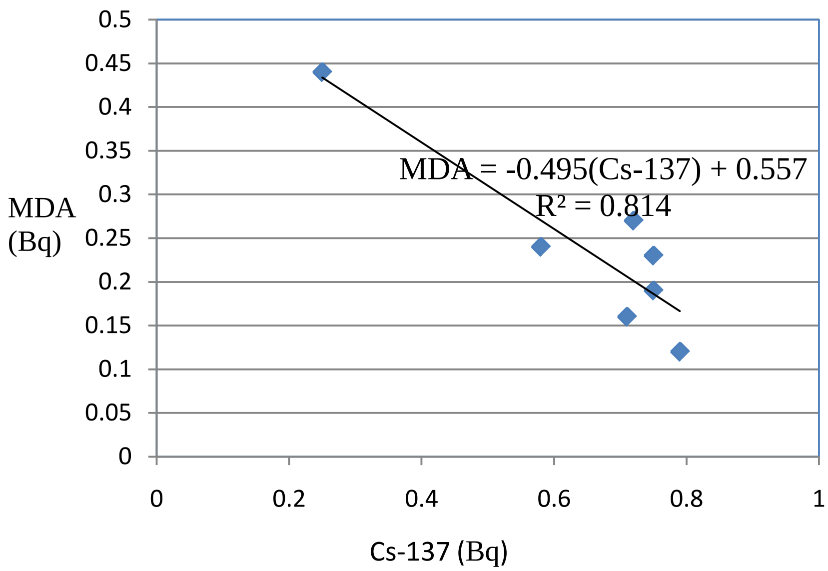



**Figure 4.1: Relationship between MDA and Cs-137**

### 5.3 Analysis of MDA and Ra-226 Existence

Only two out from twenty tested samples gives a reading of Ra-226 and Cs-137 at the same time, the Ra-226 values is correlated with MDA, due to limited data values the coefficient of 1.0 was obtained (Eq. 4.2); figure 4.2 illustrates the relationship between Ra-226 and MDA.

Ra-226= -1.5 (MDA)+1.435; ( R2=1 ) Eq. 4.2

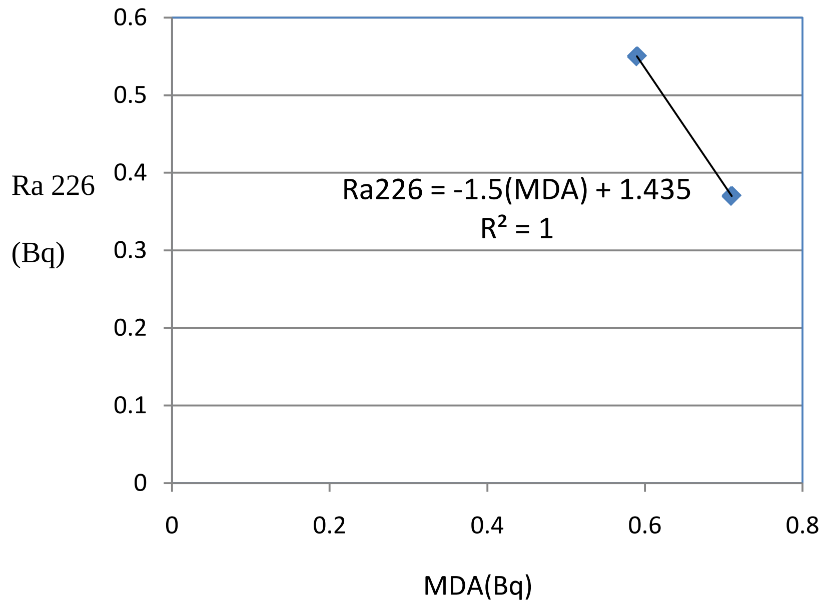



**Figure 4.2: Relationship between Ra 226 and MDA**

### 5.4 Results of Gamma Spectrum Processing Reports

In the following pages, the reports of Gama Spectrum will be presented; the reports showing lines/nuclides as well as area, activity, relative uncertainty, and MDA.

## 5.5 Conclusions

Detailed conclusions of the studies carried out in this thesis have been drawn at the end of each chapter; these conclusions were based on major findings, studies and experiments conducted in the respective chapters.

From test results obtained from waste water samples of Khartoum Refinery it could be concluded that there is a good relationship between MDA and Cs-137; with a correlation coefficient of 0.814; also there is a relationship between MDA and Ra-226, due to limited data values; the relationship between MDA and Ra-226 could not be well verified; more testing is needed to build a strong relationship.

## 5.6 Recommendations

Recommendations are presented to facilitate the way for more research and to give opinions on other researches related to this field.

It is recommended that more efforts is needed to study the radioactivity of waste water and other waste of the industrial parties in Sudan. Such studies are of crucial importance in anticipating and correcting the environmental impacts and minimization of hazards and safe the environment for the coming generation.

BALTIC SCIENTIFIC INSTRUMENTS

# Gamma-spectrum processing report from 07.11.2016

**Spectrum:** D:\NAFISA\N 1_Marinelli 1L.spe

**Configuration:** GCD30185X Ser.Nr.2293-16

**Measurement date:** 01-11-2016 08:04:13

**Live time:** 11388.16 s.

**Real time:** 11396.25 s.

**Geometry:** Marinelli 1L

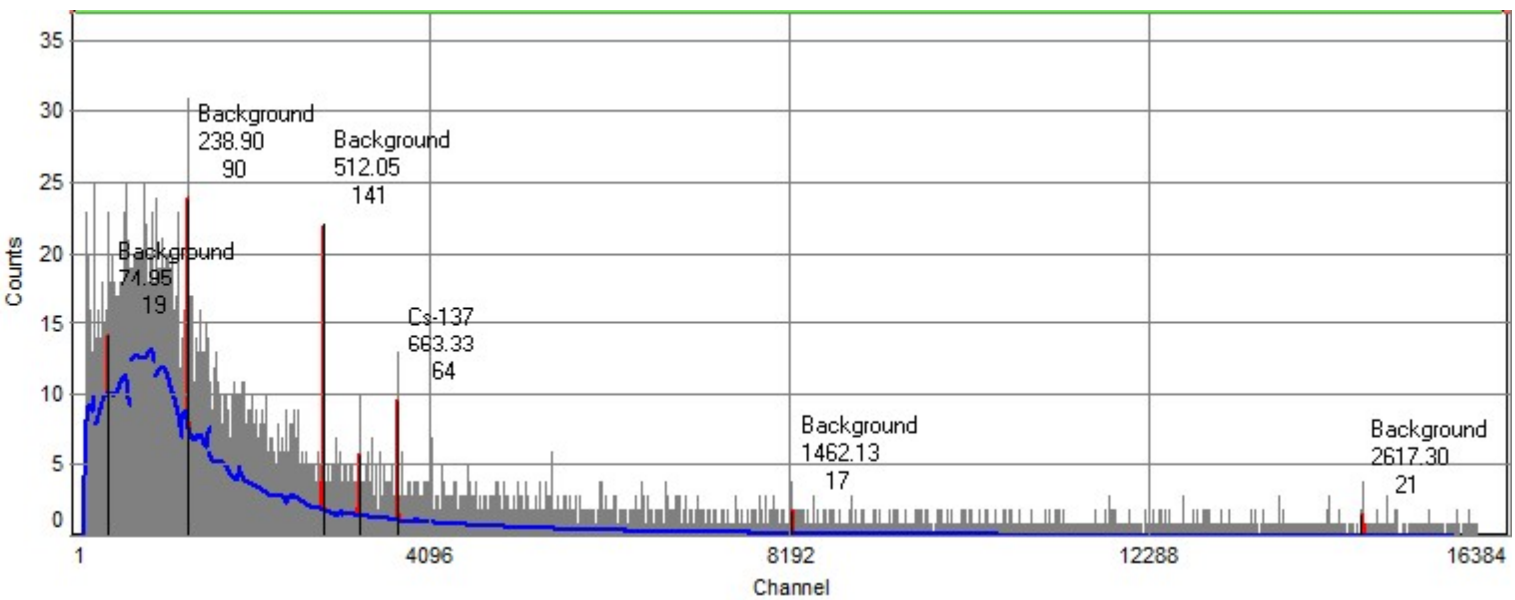
**Mass, g:** 0

**Volume, ml:** 1000

**Commentary** Am-241 A=2970 Bq dA=1% 01-01-2005

**Processing results: 01.11.2016 :**

| Nuclides/Lines | Area, [impulse] | Activity,Bq | Relative uncertainty, % | MDA, Bq |
|---|---|---|---|---|
| Cs-137 | 64 | 0.58 | 29 | 0.24 |
| Background | 320 | 0 | | 0.00 |



# Gamma-spectrum processing report from 07.11.2016

**Spectrum:** D:\NAFISA\N 2_Marinelli 1L.spe

**Configuration:** GCD30185X Ser.Nr.2293-16

**Measurement date:** 01-11-2016 11:16:17

**Live time:** 8149.54 s.

**Real time:** 8155.75 s.

**Geometry:** Marinelli 1L

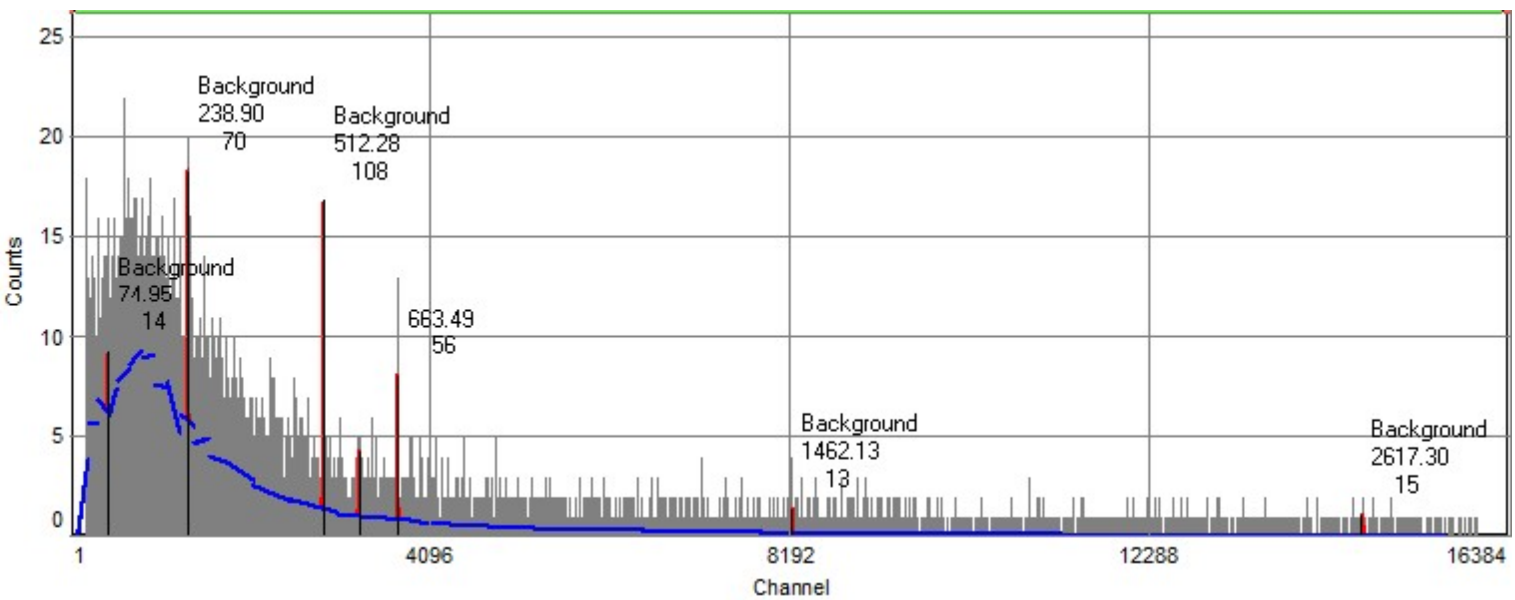
**Mass, g:** 0

**Volume, ml:** 1000

**Commentary** Am-241 A=2970 Bq dA=1% 01-01-2005

**Processing results: 01.11.2016 :**

| Nuclides/Lines | Area, [impulse] | Activity,Bq | Relative uncertainty, % | MDA, Bq |
|---|---|---|---|---|
| Unidentified | 56 | | | 0.00 |
| Background | 244 | 0 | | 0.00 |



# Gamma-spectrum processing report from 07.11.2016

**Spectrum:** D:\NAFISA\N3_Marinelli 1L.spe

**Configuration:** GCD30185X Ser.Nr.2293-16

**Measurement date:** 31-10-2016 08:34:21

**Live time:** 10947.00 s.

**Real time:** 10954.75 s.

**Geometry:** Marinelli 1L

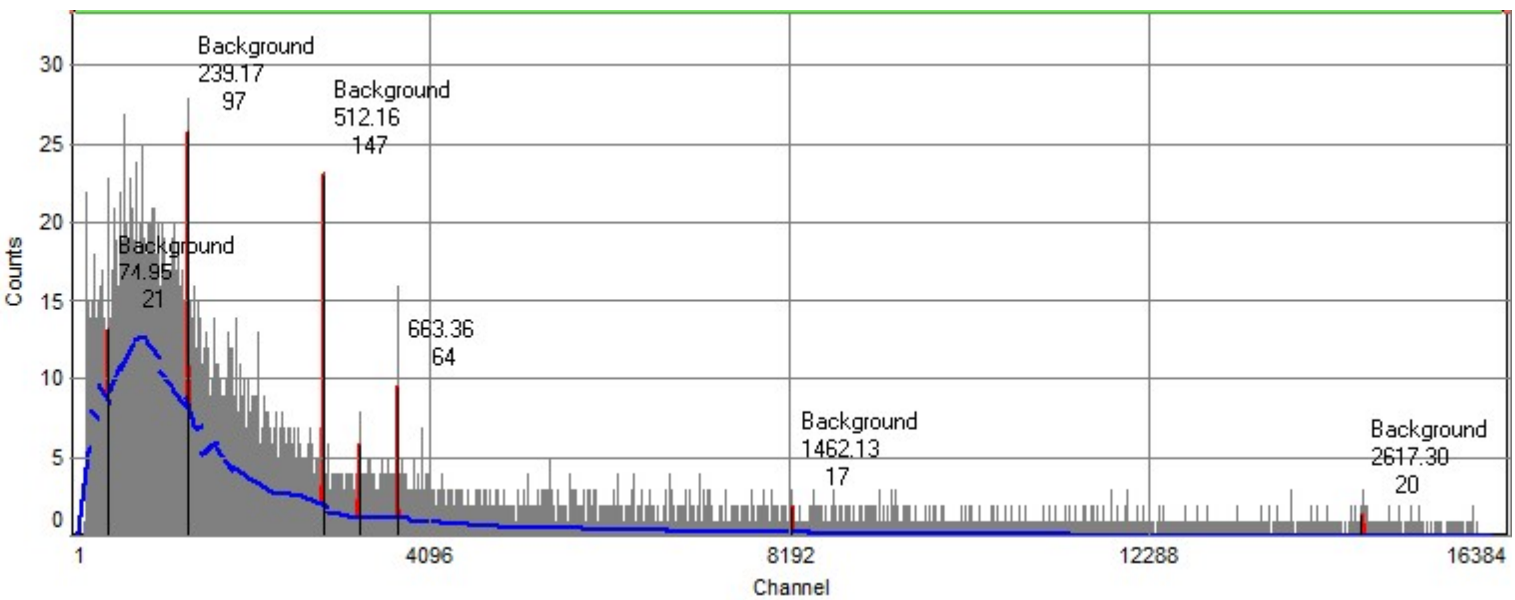
**Mass, g:** 0

**Volume, ml:** 1000

**Commentary** Am-241 A=2970 Bq dA=1% 01-01-2005

**Processing results: 31.10.2016 :**

| Nuclides/Lines | Area, [impulse] | Activity,Bq | Relative uncertainty, % | MDA, Bq |
|---|---|---|---|---|
| Unidentified | 64 | | | 0.00 |
| Background | 337 | 0 | | 0.00 |



# Gamma-spectrum processing report from 07.11.2016

**Spectrum:** D:\NAFISA\N 4_Marinelli 1L.spe

**Configuration:** GCD30185X Ser.Nr.2293-16

**Measurement date:** 29-10-2016 10:39:28

**Live time:** 11569.65 s.

**Real time:** 11579.00 s.

**Geometry:** Marinelli 1L

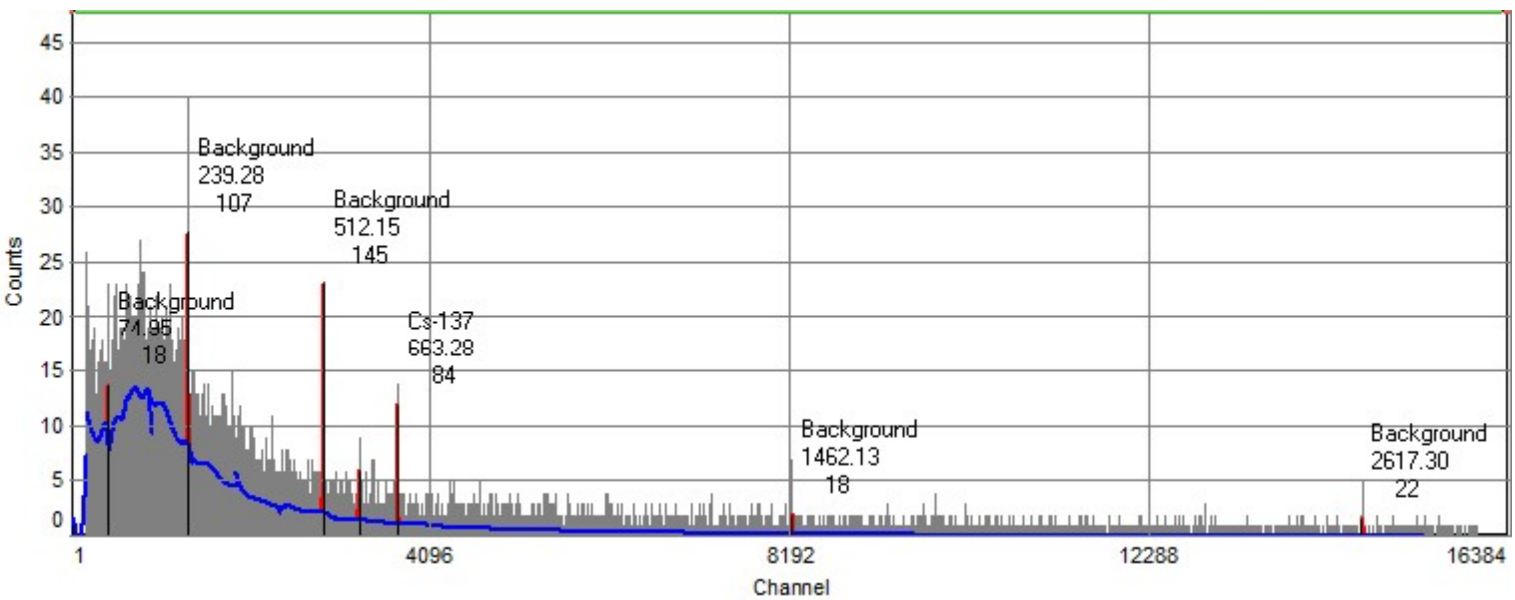
**Mass, g:** 0

**Volume, ml:** 1000

**Commentary** Am-241 A=2970 Bq dA=1% 01-01-2005

**Processing results: 29.10.2016 :**

| Nuclides/Lines | Area, [impulse] | Activity,Bq | Relative uncertainty, % | MDA, Bq |
|---|---|---|---|---|
| Cs-137 | 84 | 0.75 | 24 | 0.19 |
| Background | 342 | 0 | | 0.00 |

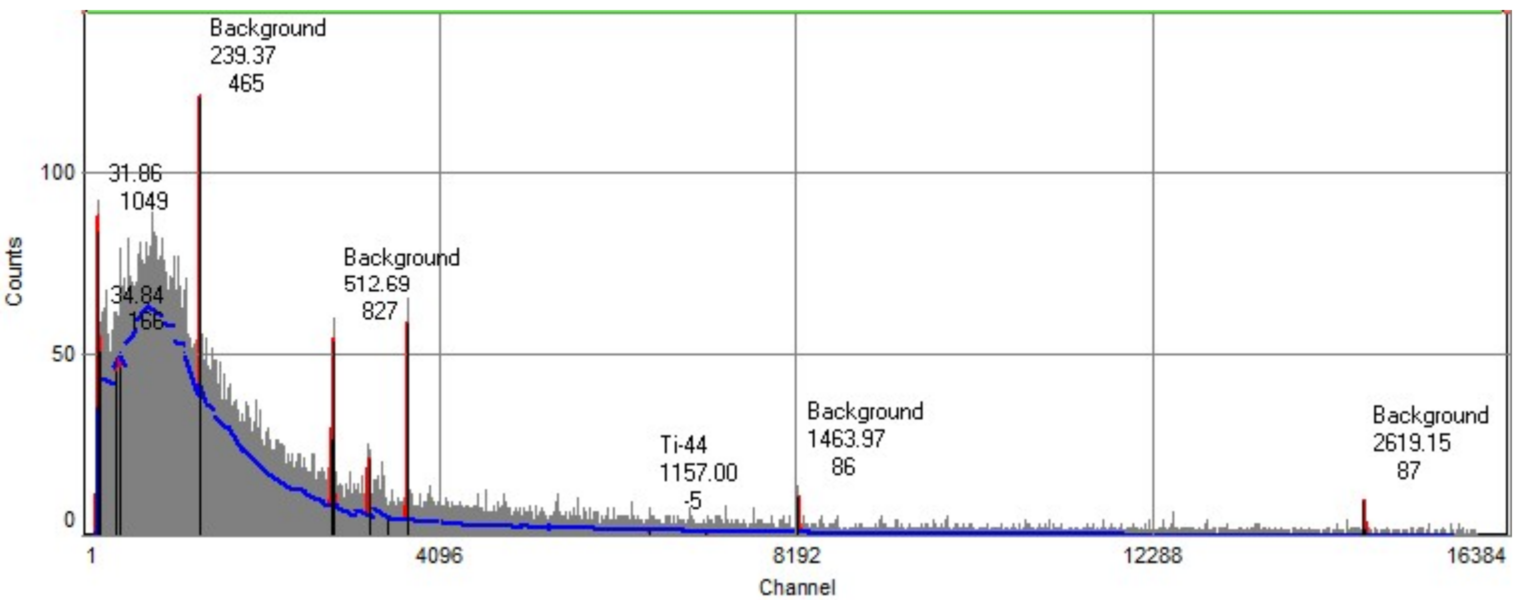


# Gamma-spectrum processing report from 07.11.2016

**Spectrum:** D:\NAFISA\N 5``_Marinelli 1L.spe
**Configuration:** GCD30185X Ser.Nr.2293-16
**Measurement date:** 01-11-2016 17:12:46
**Live time:** 52268.80 s.
**Real time:** 52305.25 s.
**Geometry:** Marinelli 1L
**Mass, g:** 0
**Volume, ml:** 1000
**Commentary** Am-241 A=2970 Bq dA=1% 01-01-2005

**Processing results: 01.11.2016 :**

| Nuclides/Lines | Area, [impulse] | Activity,Bq | Relative uncertainty, % | MDA, Bq |
|---|---|---|---|---|
| Unidentified | 1520 | | | 0.00 |
| Background | 1610 | 0 | | 0.00 |



# Gamma-spectrum processing report from 07.11.2016

**Spectrum:** D:\NAFISA\N6_Marinelli 1L.spe

**Configuration:** GCD30185X Ser.Nr.2293-16

**Measurement date:** 30-10-2016 11:40:38

**Live time:** 11009.03 s.

**Real time:** 11019.25 s.

**Geometry:** Marinelli 1L

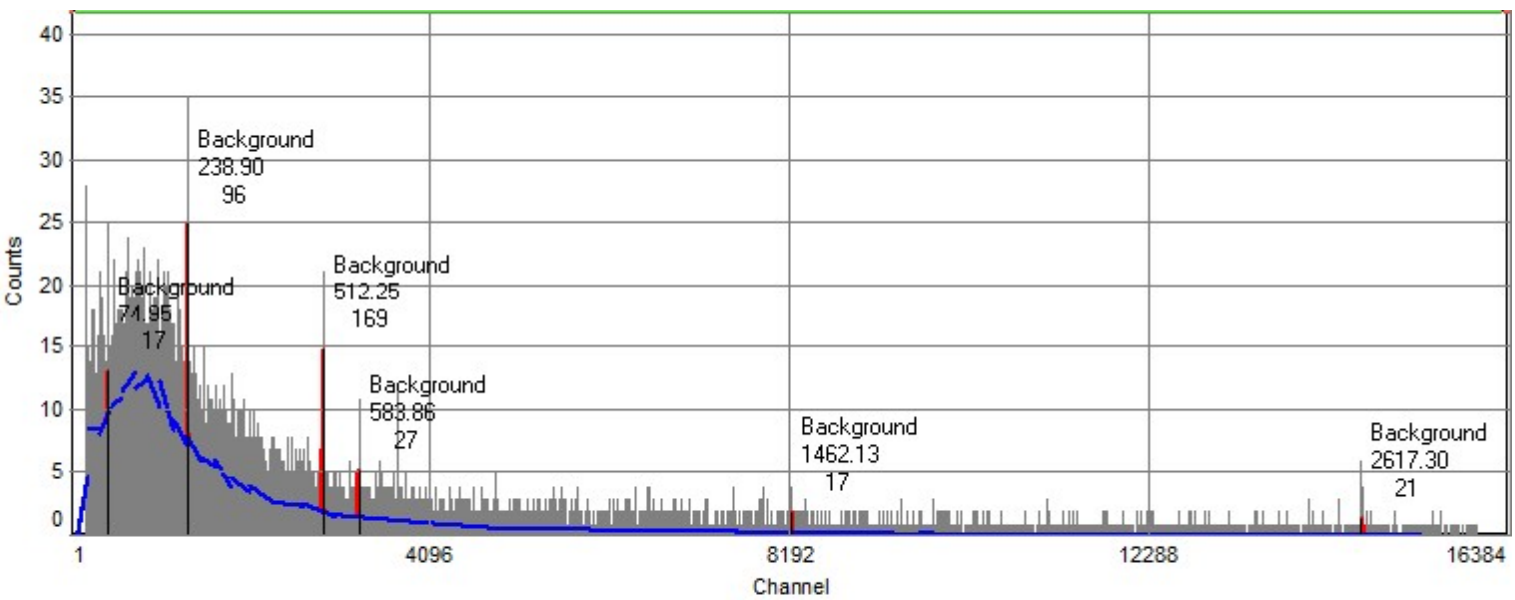
**Mass, g:** 0

**Volume, ml:** 1000

**Commentary** Am-241 A=2970 Bq dA=1% 01-01-2005

**Processing results: 30.10.2016 :**

| Nuclides/Lines | Area, [impulse] | Activity,Bq | Relative uncertainty, % | MDA, Bq |
|---|---|---|---|---|
| Background | 347 | 0 | | 0.00 |



# Gamma-spectrum processing report from 07.11.2016

**Spectrum:** D:\NAFISA\N 7_Marinelli 1L.spe

**Configuration:** GCD30185X Ser.Nr.2293-16

**Measurement date:** 01-11-2016 13:37:27

**Live time:** 12582.46 s.

**Real time:** 12589.75 s.

**Geometry:** Marinelli 1L

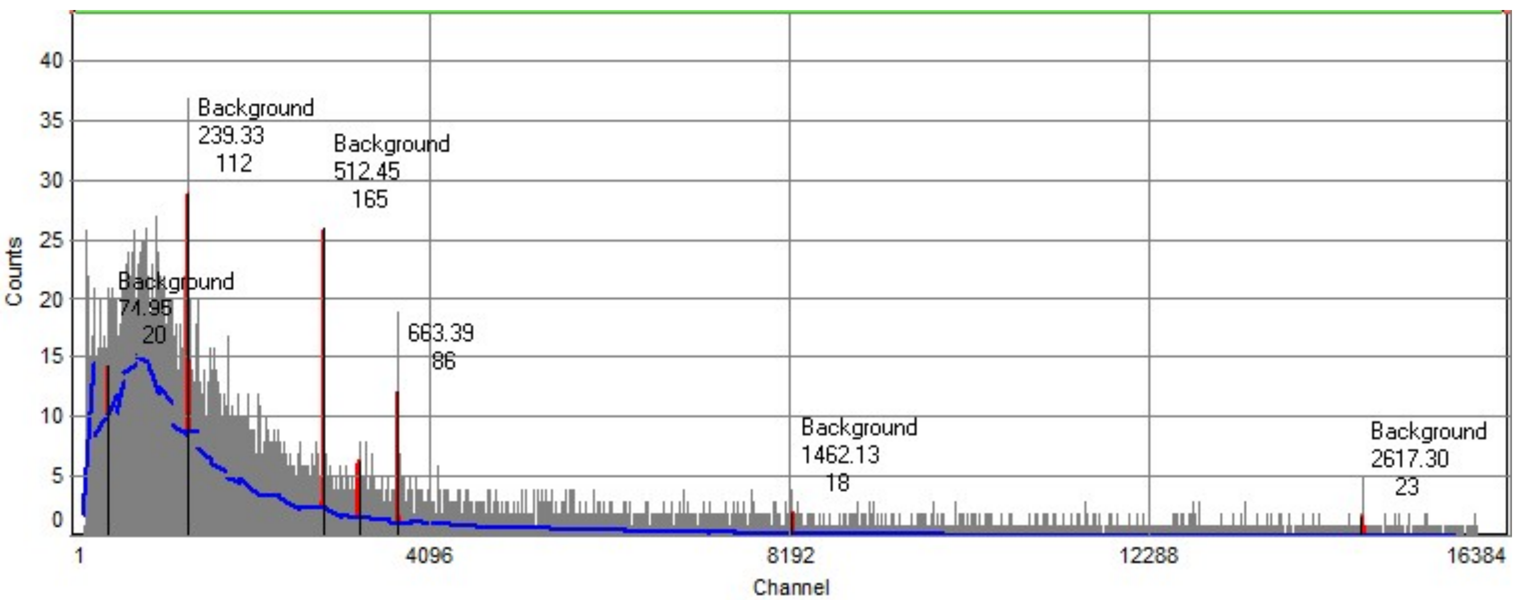
**Mass, g:** 0

**Volume, ml:** 1000

**Commentary** Am-241 A=2970 Bq dA=1% 01-01-2005

**Processing results: 01.11.2016 :**

| Nuclides/Lines | Area, [impulse] | Activity,Bq | Relative uncertainty, % | MDA, Bq |
|---|---|---|---|---|
| Unidentified | 86 | | | 0.00 |
| Background | 373 | 0 | | 0.00 |



# Gamma-spectrum processing report from 07.11.2016

**Spectrum:** D:\NAFISA\N8_Marinelli 1L.spe

**Configuration:** GCD30185X Ser.Nr.2293-16

**Measurement date:** 29-10-2016 16:44:43

**Live time:** 56771.24 s.

**Real time:** 56818.00 s.

**Geometry:** Marinelli 1L

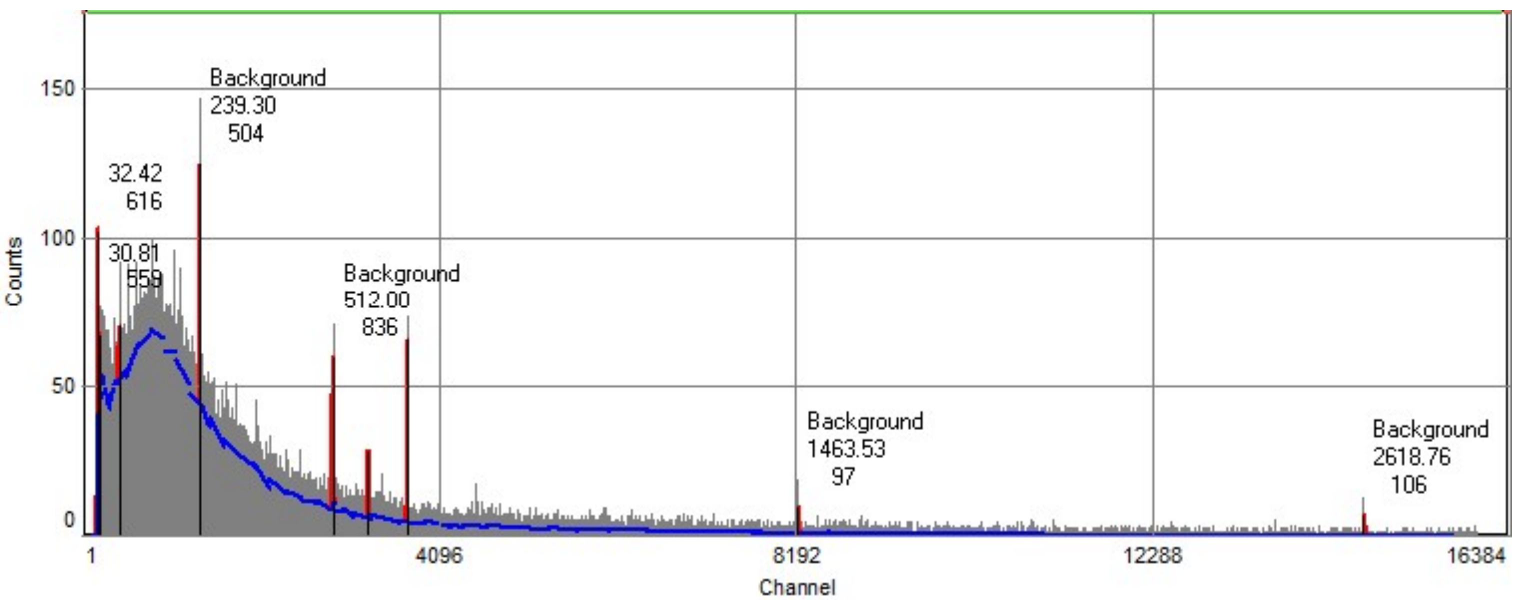
**Mass, g:** 0

**Volume, ml:** 1000

**Commentary** Am-241 A=2970 Bq dA=1% 01-01-2005

**Processing results: 29.10.2016 :**

| Nuclides/Lines | Area, [impulse] | Activity,Bq | Relative uncertainty, % | MDA, Bq |
|---|---|---|---|---|
| Unidentified | 1810 | | | 0.00 |
| Background | 1790 | 0 | | 0.00 |



# Gamma-spectrum processing report from 07.11.2016

**Spectrum:** D:\NAFISA\N 9_Marinelli 1L.spe

**Configuration:** GCD30185X Ser.Nr.2293-16

**Measurement date:** 29-10-2016 13:54:32

**Live time:** 10012.96 s.

**Real time:** 10020.50 s.

**Geometry:** Marinelli 1L

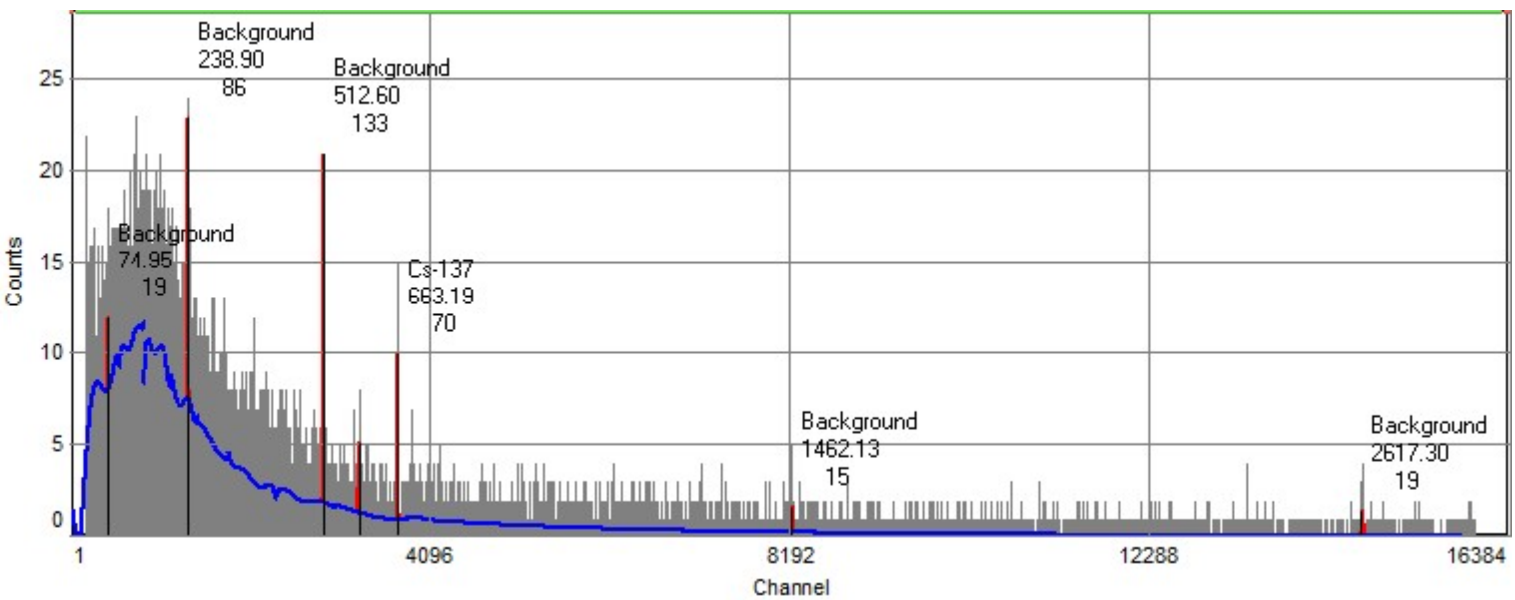
**Mass, g:** 0

**Volume, ml:** 1000

**Commentary** Am-241 A=2970 Bq dA=1% 01-01-2005

**Processing results: 29.10.2016 :**

| Nuclides/Lines | Area, [impulse] | Activity,Bq | Relative uncertainty, % | MDA, Bq |
|---|---|---|---|---|
| Cs-137 | 70 | 0.72 | 27 | 0.27 |
| Background | 300 | 0 | | 0.00 |




33

# Gamma-spectrum processing report from 07.11.2016

**Spectrum:** D:\NAFISA\N 10_Marinelli 1L.spe

**Configuration:** GCD30185X Ser.Nr.2293-16

**Measurement date:** 02-11-2016 07:54:17

**Live time:** 10859.61 s.

**Real time:** 10868.75 s.

**Geometry:** Marinelli 1L

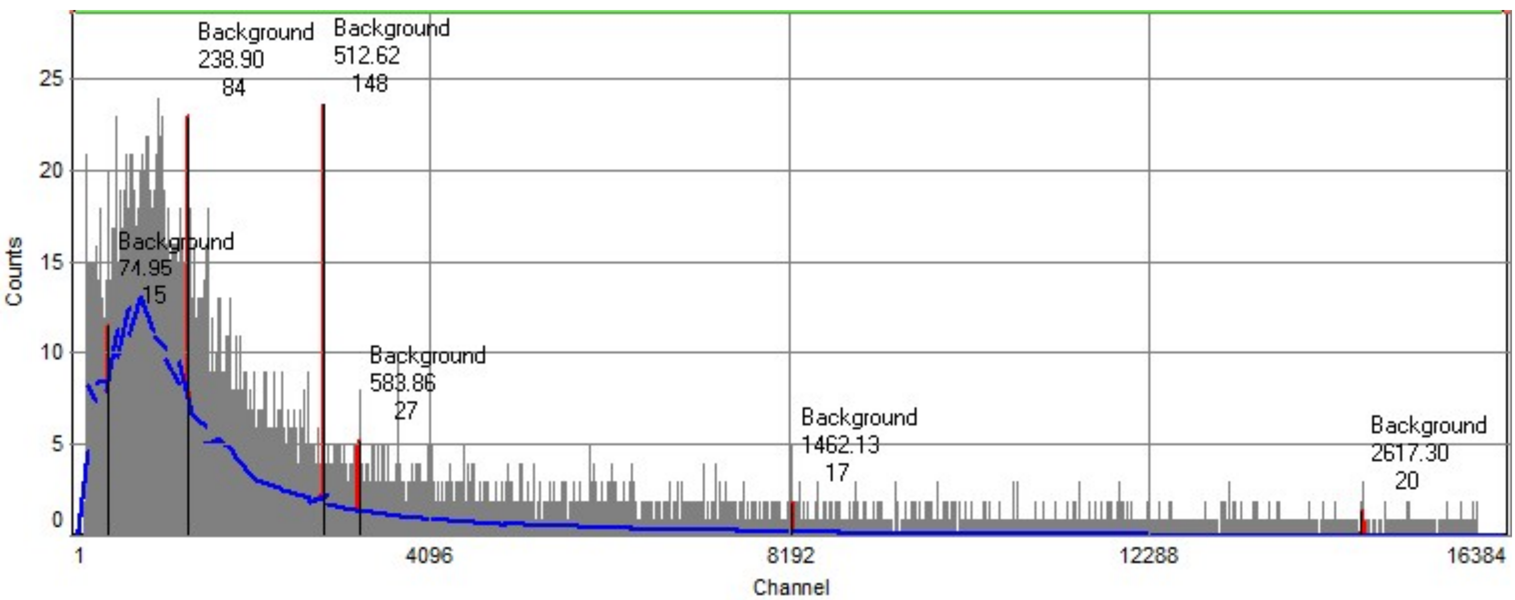
**Mass, g:** 0

**Volume, ml:** 1000

**Commentary** Am-241 A=2970 Bq dA=1% 01-01-2005

**Processing results: 02.11.2016 :**

| Nuclides/Lines | Area, [impulse] | Activity,Bq | Relative uncertainty, % | MDA, Bq |
|---|---|---|---|---|
| Background | 310 | 0 | | 0.00 |



# Gamma-spectrum processing report from 07.11.2016

**Spectrum:** D:\NAFISA\N 11_Marinelli 1L.spe

**Configuration:** GCD30185X Ser.Nr.2293-16

**Measurement date:** 03-11-2016 11:25:42

**Live time:** 13500.22 s.

**Real time:** 13510.50 s.

**Geometry:** Marinelli 1L

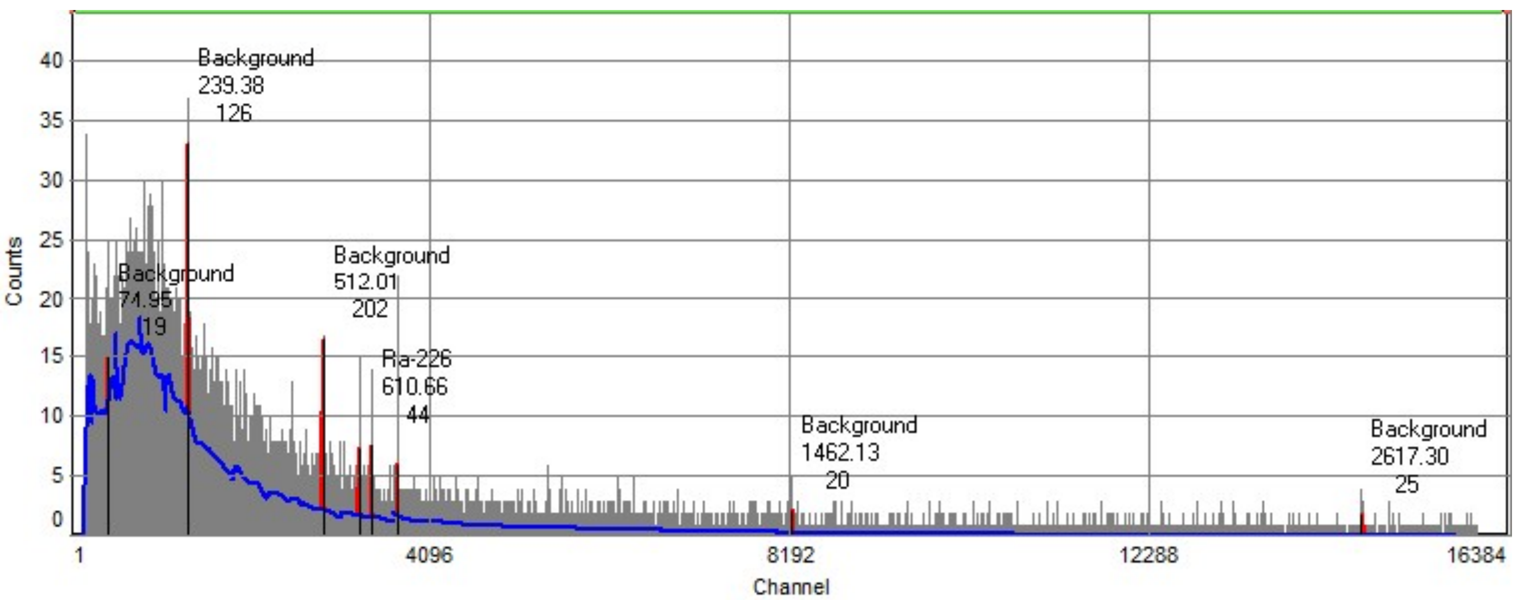
**Mass, g:** 0

**Volume, ml:** 1000

**Commentary** Am-241 A=2970 Bq dA=1% 01-01-2005

**Processing results: 03.11.2016 :**

| Nuclides/Lines | Area, [impulse] | Activity,Bq | Relative uncertainty, % | MDA, Bq |
|---|---|---|---|---|
| Ra-226 | 44 | 0.59 | 40 | 0.55 |
| Cs-137 | 33 | 0.25 | 50 | 0.44 |
| Background | 434 | 0 | | 0.00 |



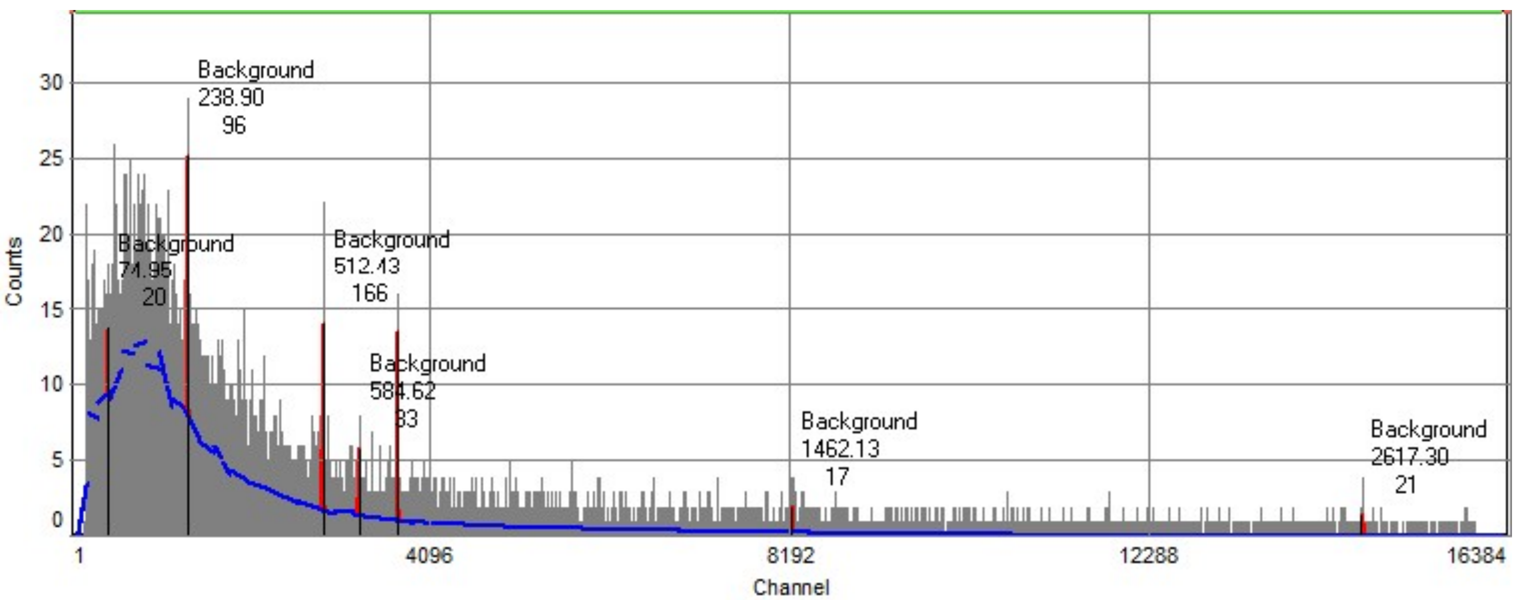

35

# Gamma-spectrum processing report from 07.11.2016

**Spectrum:** D:\NAFISA\N12_Marinelli 1L.spe
**Configuration:** GCD30185X Ser.Nr.2293-16
**Measurement date:** 30-10-2016 08:36:30
**Live time:** 10831.71 s.
**Real time:** 10838.00 s.
**Geometry:** Marinelli 1L
**Mass, g:** 0
**Volume, ml:** 1000
**Commentary** Am-241 A=2970 Bq dA=1% 01-01-2005

**Processing results: 30.10.2016 :**

| Nuclides/Lines | Area, [impulse] | Activity,Bq | Relative uncertainty, % | MDA, Bq |
|---|---|---|---|---|
| Unidentified | 96 | | | 0.00 |
| Background | 354 | 0 | | 0.00 |




36

# Gamma-spectrum processing report from 07.11.2016

**Spectrum:** D:\NAFISA\N 13_Marinelli 1L.spe

**Configuration:** GCD30185X Ser.Nr.2293-16

**Measurement date:** 02-11-2016 17:31:45

**Live time:** 9625.75 s.

**Real time:** 9631.25 s.

**Geometry:** Marinelli 1L

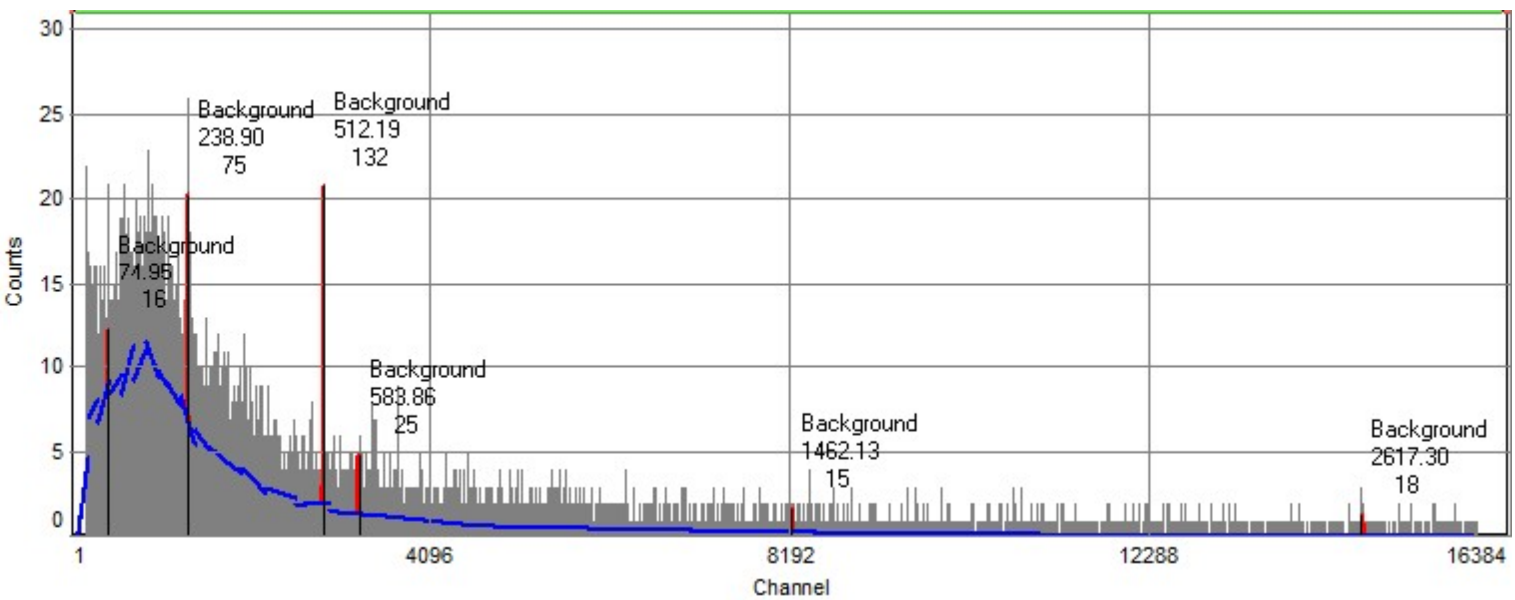
**Mass, g:** 570

**Volume, ml:** 1000

**Commentary** Am-241 A=2970 Bq dA=1% 01-01-2005

**Processing results: 02.11.2016 :**

| Nuclides/Lines | Area, [impulse] | Activity,Bq | Relative uncertainty, % | MDA, Bq |
|---|---|---|---|---|
| Background | 282 | 0 | | 0.00 |




37

# Gamma-spectrum processing report from 07.11.2016

**Spectrum:** D:\NAFISA\N 14_Marinelli 1L.spe

**Configuration:** GCD30185X Ser.Nr.2293-16

**Measurement date:** 02-11-2016 13:57:25

**Live time:** 10534.54 s.

**Real time:** 10542.00 s.

**Geometry:** Marinelli 1L

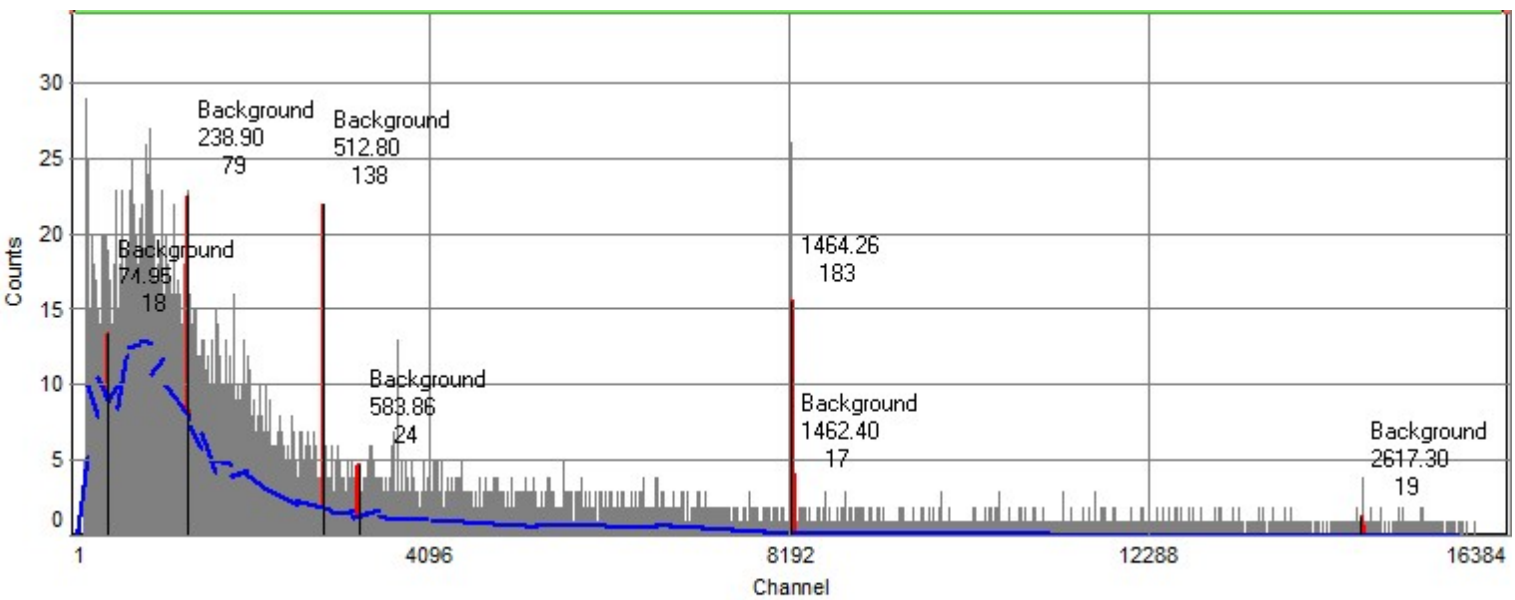
**Mass, g:** 0

**Volume, ml:** 1000

**Commentary** Am-241 A=2970 Bq dA=1% 01-01-2005

**Processing results: 02.11.2016 :**

| Nuclides/Lines | Area, [impulse] | Activity,Bq | Relative uncertainty, % | MDA, Bq |
|---|---|---|---|---|
| Unidentified | 183 | | | 0.00 |
| Background | 296 | 0 | | 0.00 |



# Gamma-spectrum processing report from 07.11.2016

**Spectrum:** D:\NAFISA\N 15_Marinelli 1L.spe

**Configuration:** GCD30185X Ser.Nr.2293-16

**Measurement date:** 02-11-2016 20:16:48

**Live time:** 42012.00 s.

**Real time:** 42043.50 s.

**Geometry:** Marinelli 1L

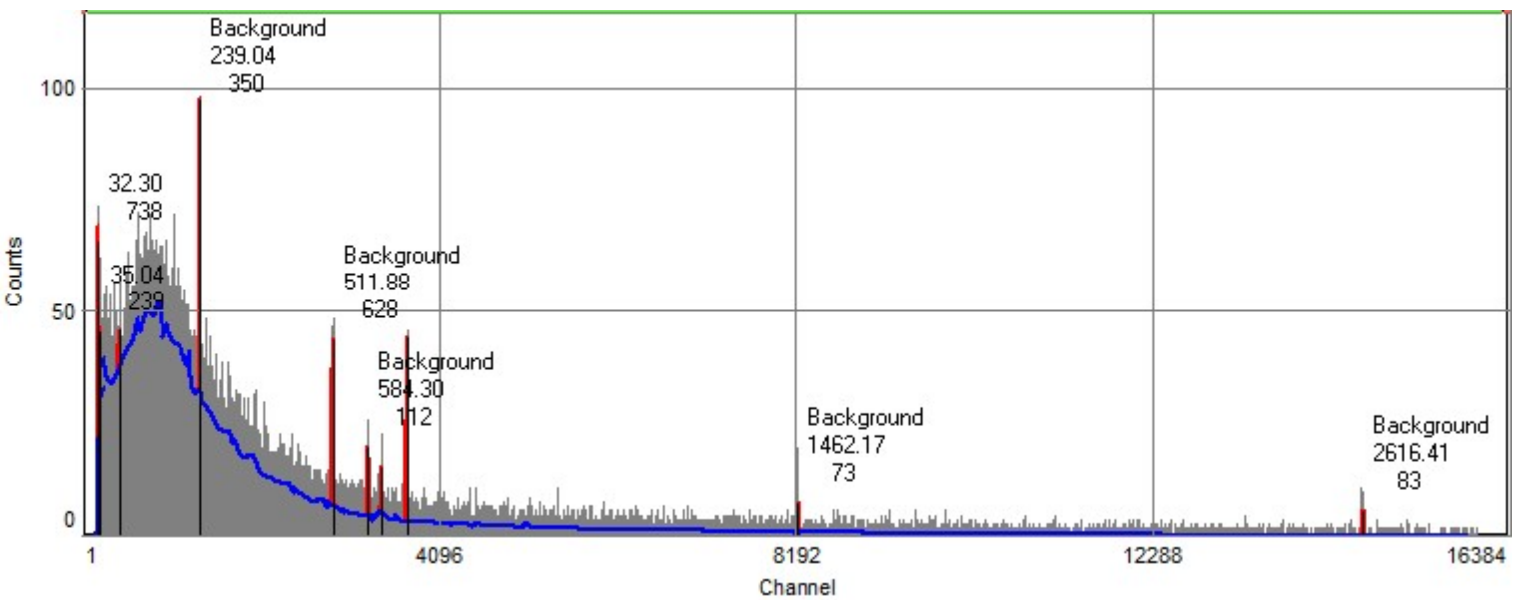
**Mass, g:** 570

**Volume, ml:** 1000

**Commentary** Am-241 A=2970 Bq dA=1% 01-01-2005

**Processing results: 02.11.2016 :**

| Nuclides/Lines | Area, [impulse] | Activity,Bq | Relative uncertainty, % | MDA, Bq |
|---|---|---|---|---|
| Cs-137 | 300 | 0.71 | 13 | 0.16 |
| Ra-226 | 74 | 0.31 | 40 | 0.37 |
| Unidentified | 980 | | | 0.00 |
| Background | 1290 | 0 | | 0.00 |

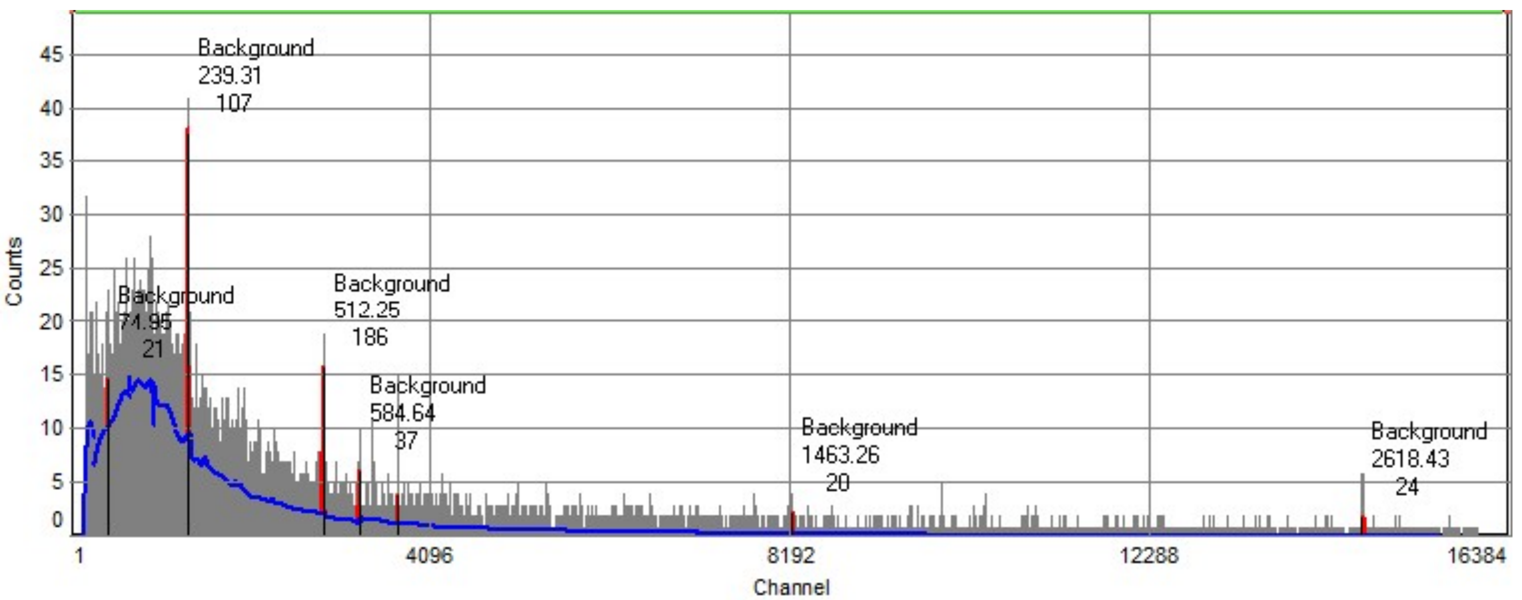


# Gamma-spectrum processing report from 07.11.2016

**Spectrum:** D:\NAFISA\N 16_Marinelli 1L.spe
**Configuration:** GCD30185X Ser.Nr.2293-16
**Measurement date:** 03-11-2016 08:01:51
**Live time:** 11951.92 s.
**Real time:** 11961.50 s.
**Geometry:** Marinelli 1L
**Mass, g:** 0
**Volume, ml:** 1000
**Commentary** Am-241 A=2970 Bq dA=1% 01-01-2005

**Processing results: 03.11.2016 :**

| Nuclides/Lines | Area, [impulse] | Activity,Bq | Relative uncertainty, % | MDA, Bq |
|---|---|---|---|---|
| Background | 396 | 0 | | 0.00 |

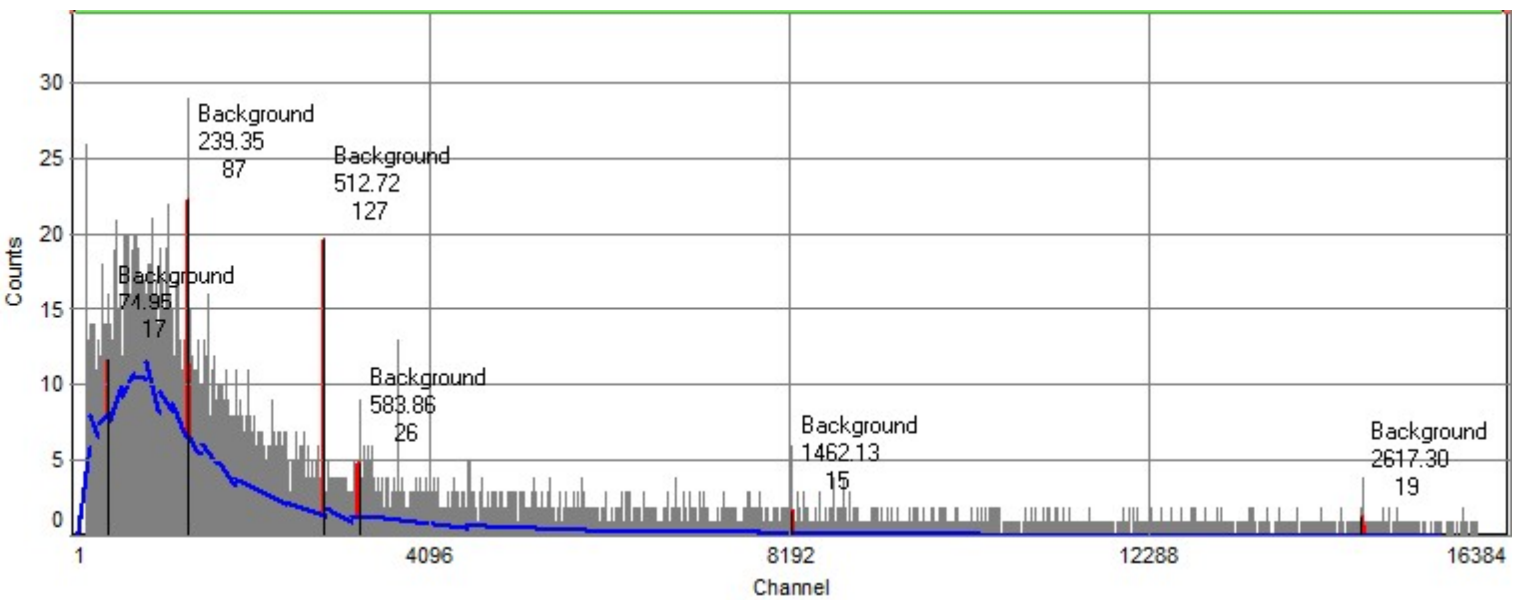


# Gamma-spectrum processing report from 07.11.2016

| | |
|---|---|
| **Spectrum:** | D:\NAFISA\N 17_Marinelli 1L.spe |
| **Configuration:** | GCD30185X Ser.Nr.2293-16 |
| **Measurement date:** | 02-11-2016 14:47:33 |
| **Live time:** | 9751.34 s. |
| **Real time:** | 9759.75 s. |
| **Geometry:** | Marinelli 1L |
| **Mass, g:** | 570 |
| **Volume, ml:** | 1000 |
| **Commentary** | Am-241 A=2970 Bq dA=1% 01-01-2005 |

**Processing results: 02.11.2016 :**

| Nuclides/Lines | Area, [impulse] | Activity,Bq | Relative uncertainty, % | MDA, Bq |
|---|---|---|---|---|
| Background | 291 | 0 | | 0.00 |



BALTIC SCIENTIFIC INSTRUMENTS

# Gamma-spectrum processing report from 07.11.2016

**Spectrum:** D:\NAFISA\N18_Marinelli 1L.spe

**Configuration:** GCD30185X Ser.Nr.2293-16

**Measurement date:** 05-11-2016 16:06:33

**Live time:** 58497.76 s.

**Real time:** 58542.00 s.

**Geometry:** Marinelli 1L

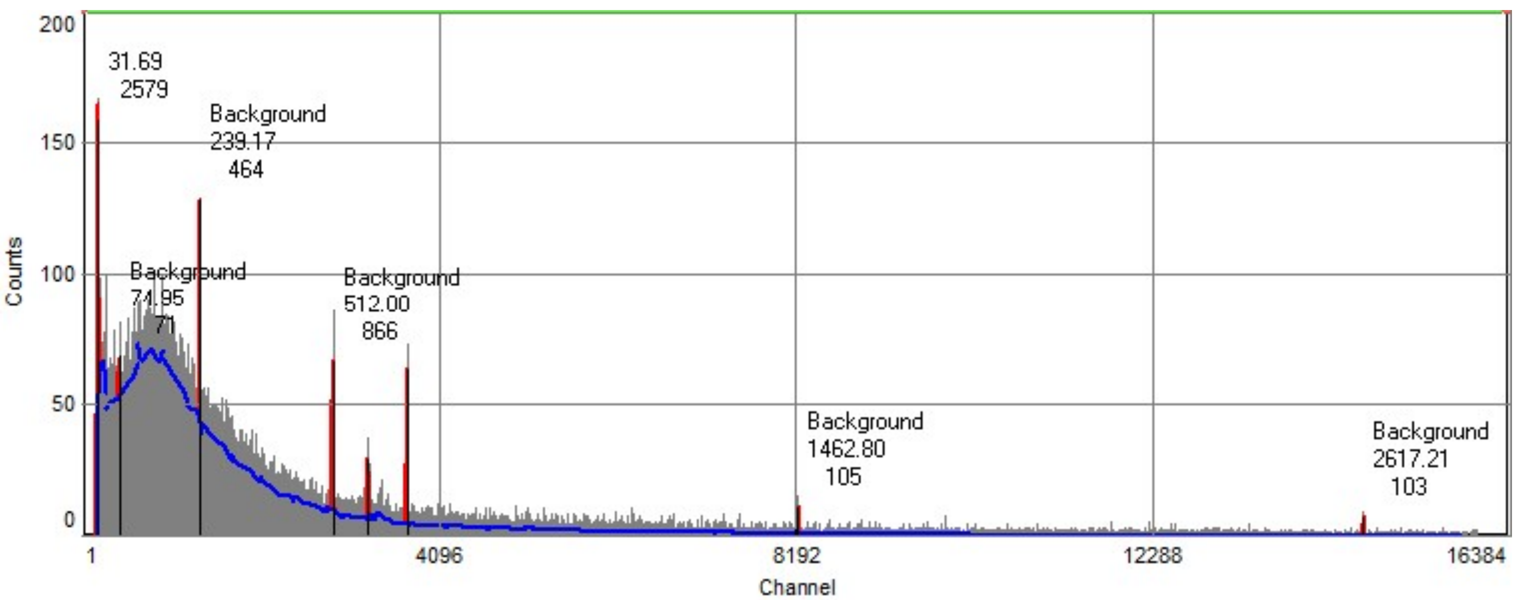
**Mass, g:** 0

**Volume, ml:** 1000

**Commentary** Am-241 A=2970 Bq dA=1% 01-01-2005

**Processing results: 05.11.2016 :**

| Nuclides/Lines | Area, [impulse] | Activity,Bq | Relative uncertainty, % | MDA, Bq |
|---|---|---|---|---|
| Cs-137 | 450 | 0.79 | 11 | 0.12 |
| Unidentified | 2580 | | | 0.00 |
| Background | 1770 | 0 | | 0.00 |



# Gamma-spectrum processing report from 07.11.2016

**Spectrum:** D:\NAFISA\N19_Marinelli 1L.spe

**Configuration:** GCD30185X Ser.Nr.2293-16

**Measurement date:** 31-10-2016 11:41:07

**Live time:** 11409.74 s.

**Real time:** 11416.75 s.

**Geometry:** Marinelli 1L

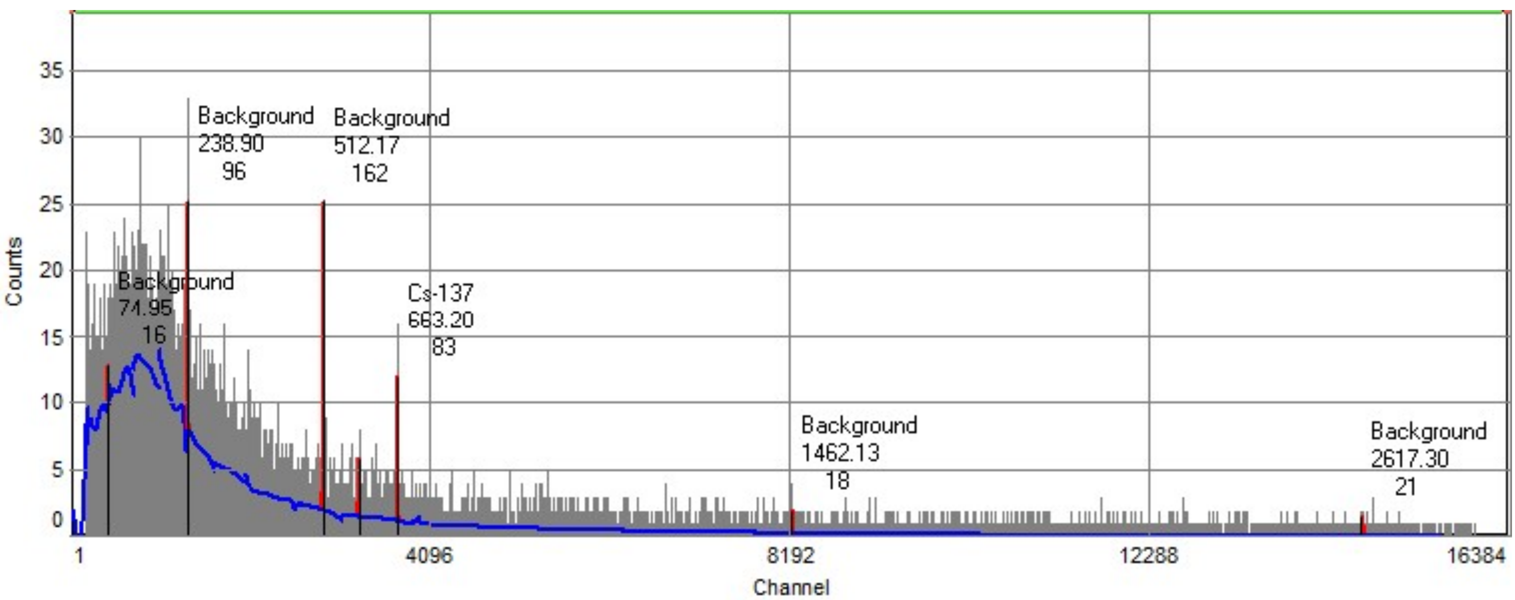
**Mass, g:** 0

**Volume, ml:** 1000

**Commentary** Am-241 A=2970 Bq dA=1% 01-01-2005

**Processing results: 31.10.2016 :**

| Nuclides/Lines | Area, [impulse] | Activity,Bq | Relative uncertainty, % | MDA, Bq |
|---|---|---|---|---|
| Cs-137 | 83 | 0.75 | 25 | 0.23 |
| Background | 344 | 0 | | 0.00 |



# Gamma-spectrum processing report from 07.11.2016

**Spectrum:** D:\NAFISA\N 20_Marinelli 1L.spe

**Configuration:** GCD30185X Ser.Nr.2293-16

**Measurement date:** 31-10-2016 15:16:05

**Live time:** 60216.78 s.

**Real time:** 60260.75 s.

**Geometry:** Marinelli 1L

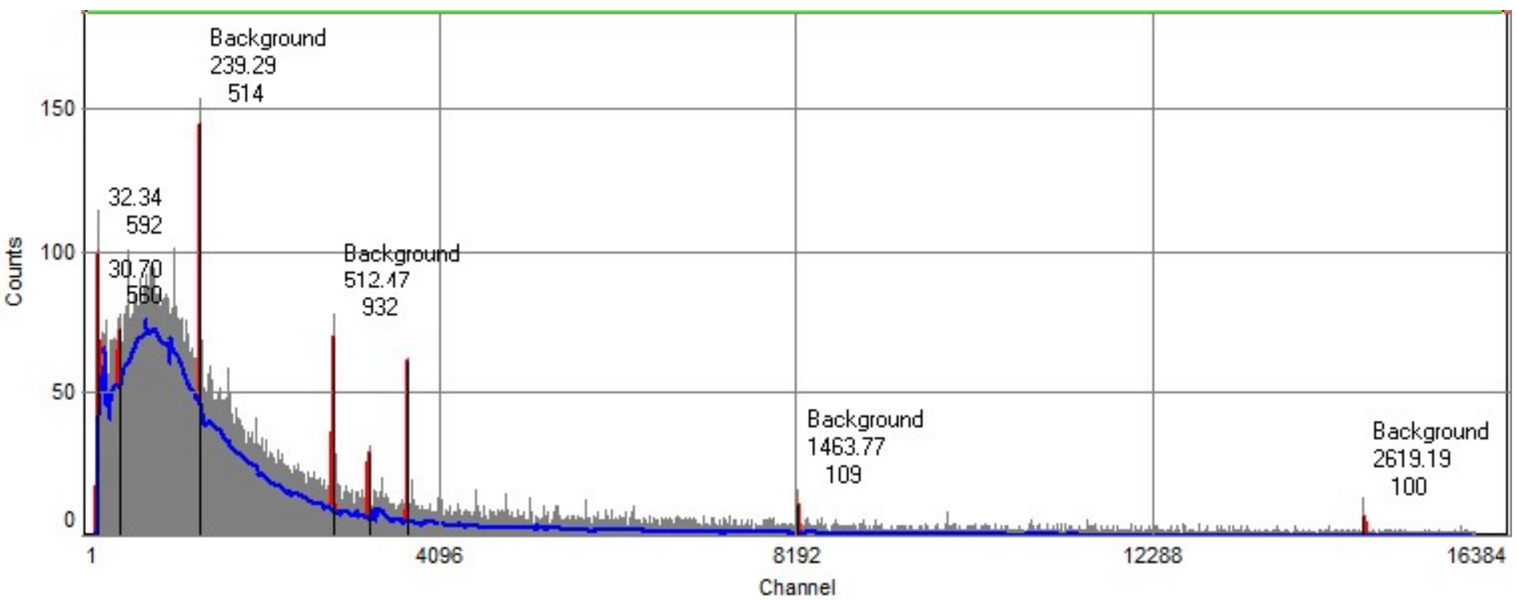
**Mass, g:** 0

**Volume, ml:** 1000

**Commentary** Am-241 A=2970 Bq dA=1% 01-01-2005

**Processing results: 31.10.2016 :**

| Nuclides/Lines | Area, [impulse] | Activity,Bq | Relative uncertainty, % | MDA, Bq |
|---|---|---|---|---|
| ANNIGL | 290 | 0.18 | 40 | 0.19 |
| Unidentified | 1790 | | | 0.00 |
| Background | 1920 | 0 | | 0.00 |



# References

## References


1. IUPAC, Compendium of Chemical Terminology, 2nd ed. (the "Gold Book") (1997). Online corrected version: (2006–) "Ionization
2. Kashiwaya, Mamoru; Yoshimoto, Kameo (May 1980). "Tannery Wastewater Treatment by the Oxygen Activated Sludge Process". Journal (Water Pollution Control Federation). Alexandria, VA: Water Environment Federation. **52** (5): 999–1007. JSTOR 25040825.
3. U.S. Environmental Protection Agency (EPA), Washington, D.C. "Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category." Final Rule. 2015-09-30.
4. European Environment Agency. Copenhagen, Denmark. "Indicator: Biochemical oxygen demand in rivers (2001)."
5. EPA (2002). "Section 7: Wastewater Characterization." Development Document for Final Effluent Limitations Guidelines and Standards for the Iron and Steel Manufacturing Point Source Category. Document no. EPA-821-R-02-004. pp. 7-1ff.
6. EPA (2000). "Permit Guidance Document: Pulp, Paper and Paperboard Manufacturing Point Source Category." Document no. EPA-821-B-00-003. pp. 4-1ff.
7. Tchobanoglous, G., Burton, F.L., and Stensel, H.D. (2003). Wastewater Engineering (Treatment Disposal Reuse) / Metcalf & Eddy, Inc. (4th ed.). McGraw-Hill Book Company. ISBN 0-07-041878-0. Beychok, Milton R. (1967). Aqueous Wastes from Petroleum and Petrochemical Plants (1st ed.). John Wiley & Sons. LCCN 67019834

8. Hobson, Tom (May 2004). "The Scoop on Oil Skimmers". Environmental Protection (formerly Water and Wastewater News). Dallas, TX: 1105 Media, Inc.

9. American Petroleum Institute (API) (February 1990). Management of Water Discharges: Design and Operations of Oil-Water Separators (1st ed.). American Petroleum Institute.

10. American Petroleum Institute (API) (February 1990). Management of Water Discharges: Design and Operations of Oil-Water Separators (1st ed.). American Petroleum Institute.

11. Beychok, Milton R. (December 1971). "Wastewater treatment". Hydrocarbon Processing: 109–112. ISSN 0887-0284.

12. Cleanawater (Virtues Industries Pty. Ltd.), Melbourne, Australia (2013). "Oil Water Separators Product Range." Brochure. "The Joint Convention". IAEA.

13. E. Takács, L. Wojnárovits, T. Pálfi, S. S. Emmis (2008), Irradiation treatment of textile dye containing wastewater, IAEA-TECDOC-1598, 2008, Radiation Treatment of Polluted Water and Wastewater

14. M. Trojanowicz, P. Drzewicz, A. Bojanowska-Czajka, G. Nałęcz-Jawecki, M. Gryz, J. Sawicki, K. Kulisa, S. Wołkowicz, G. Nichipor, Z. Zimek, (2008),’’ Application of ionizing radiation for removal of pesticides from groundwater’s and wastes’’ IAEA-TECDOC-1598, 2008, Radiation Treatment of Polluted Water and Wastewater.

15. M.L.Botelho, J. Branco, C. Freitas, P. Ferreira , A. Belchior, A. Costa,Í. De Sousa, L. Alves, L. Machado, P. Matos, R. Cordeiro, R. Melo,R. Ribeiro, R. Zeinou, S. Cabo Verde, T. Silva, V. Farinha, (2008), Implementation of ionising radiation on wastewater treatment:The Portuguese study case, IAEA-TECDOC-1598, 2008, Radiation Treatment of Polluted Water and Wastewater .