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NORM Analysis of the Reservoir Sand Section in the Dorado Natural Gas Discovery, Mannar Basin Offshore Sri Lanka

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ABSTRACT

Oil and Gas production always ties with drawing out of naturally-occurring radionuclides deposited beneath the earth, which are referred to as "NORM". Understanding the prevailing background levels of these elements in the sub-surface reservoir rock formations will be beneficial to all stakeholders, more importantly to regulatory authorities of the country.

The drill cutting samples from 5 m sampling intervals of natural gas reservoir sand section in the depth range 3025m to 3095m from deep water exploratory well "CLPL- Dorado 91 H/1z" drilled in the Mannar basin offshore Sri Lanka were tested in the laboratory using high-resolution Gamma-ray detectors.

Test results revealed that the activity concentration of ^{40}K, ^{210}Pb, ^{226}Ra and ^{232}Th levels and the calculated outdoor annual effective dose rate varies between considerably lower range when compared with the global standard limits.

NORM concentration ranges of the sedimentary rocks within the tested section were recorded on the lower side, when the test results compared with the International Atomic Energy Agency published data on NORM concentration ranges of the sedimentary rocks found elsewhere in the world. Study results proved that there is no harmful public exposure of NORM by disposing these drill cuttings to environment or storing at any site location as it is. Also, it can be predicted that there will be very low level of NORM contaminations occur, if Dorado reservoir taken in to the production stage and well operations conducted with proper solid control mechanisms in future.

INTRODUCTION

Background

The subsurface formations that contain hydrocarbons, also contain naturally-occurring radionuclides; uranium, thorium, potassium, radium and lead-210 which are referred to as "NORM" (Afif et al. 2004; Paranhouz, 2005). Industrial processes involved in oil and gas production, treating and refining activities lead naturally occurring radioactive materials which are trapped inside rock layers of the earth to flow to the surface and contaminate natural environment (Gray, 1993; Godoy and Petinatti da Cruz, 2003). Radionuclides, along with the other minerals which are dissolved in the salty water, precipitate out and forming various wastes at the surface during the different stages of the production operations.

Much of the petroleum in the earth's crust believed to be generated at the ancient seas by the transformation of sea life known as phytoplankton. Thus petroleum deposits often occur in aquifers containing salt water. Some of these NORM contaminated waste associated with the production operations of the petroleum industry are, hard mineral scales formed inside the pipes, sludge disposed after treating water and hydrocarbons, contaminated equipment and components and produced water etc (IAEA safety report 2003 and IAEA training course report, 2010). Since the petroleum production process collecting and concentrating these NORM associated waste, there is a potential of exposing them to the public and the environment.

Identification of background level of NORM in the sub-surface hydrocarbon bearing formations will be useful in predicting contamination levels during the production stage. This can be achieved by measuring the radiation of the drill cuttings and analyzing the gamma radiation spectrum. The experimented results can be verified by the correlation of available natural gamma ray well log results. Logging of natural gamma ray along a well section is a method of measuring naturally occurring gamma radiation to characterize the rock or sediment in a borehole or drill hole.

The radiation measurements results of drill cuttings allow comparing the NORM levels with global oil fields and standards in the other countries. The results can be used to predict NORM levels associated with upcoming petroleum production, which will be useful in planning future operational requirements and regulatory framework in the Sri Lankan petroleum industry.

This study was collaboratively conducted with the Petroleum Resources Development Secretariat and Atomic Energy Board as project of the Department of Physics, University of Sri Jayewardenepura. During the study, radionuclides and their concentration levels were analyzed in the drill cuttings obtained from the recently drilled offshore exploration well "CLPL- Dorado 91 H/1z" of Mannar basin.

The study results are important as baseline data and to make conclusions on future strategic plans of Sri Lankan Oil and Gas industry such as the direction for the management of solid waste, landfills, produced water and other environment sensitive operations in the petroleum production process with minimum impact on the community and the environment.

No previous study had been conducted regarding the NORM background levels of discovered reservoir sand sections in the drilled exploratory wells in the Mannar basin offshore Sri Lanka. Therefore, this research is a significant step which led to vital information for the future strategic actions of the Sri Lankan petroleum industry.

SRI LANKAN OIL AND GAS INDUSTRY

Sri Lankan upstream petroleum industry is still in the initial stage of exploration in which wells are drilled to discover and appraise hydrocarbon and to derive fundamental strategies for future development stages.

Sri Lankan oil exploration was started in 1960's. From 1967-1968

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first seismic survey has been carried out and during 1972-1975 USSR drilled first three exploration wells Pesalai-1, Pesalai-2 and Pesalai-3 in the Cauvery basin of Sri Lanka. Later, Palk Bay-1 and Delft in 1976 and Pedro-1 and Pearl -1 in 1981 were drilled by several other companies. But there have not been any significant hydrocarbon discoveries except small discovery in Pesalai-1. The exploratory wells are shown in Fig.1.

After long period of inactivity explorations were resumed in 2001 by Norwegian geophysical company (TGS-NOPEC) which acquired 1,050 km two dimensional (2D) marine seismic data in the Sri Lankan side of the Gulf of Mannar basin. Then in 2005, 2009 and 2012 seismic surveys was carried out to acquire more data. Most recently starting from 2011 four new wells Dorado, Dorado-north, Barracuda, Wallago have been drilled, and natural gas discovered from Dorado and Barracuda wells (Premarathne et al. 2013).

LOCATION AND AREA OF THE STUDY

The Mannar basin is located at approximately 60°-90° North latitude by 78°-80° East longitude, and lies from southwest to north-west of Sri Lanka, southeast of India and south of the Cauvery basin. In terms of size, the SL side of the Mannar basin has an area of approximately 42,000 square kilometers with a sediment accumulation of possibly up to10 km in the deep water areas of the basin (PRDS-Sri Lanka, 2013). The Dorado well where drill cuttings were obtained is located in M2 block of Mannar basin as shown in Fig.1.

CLPL-Dorado-91H/1z (Dorado), well was drilled to a water depth of 1354 m, which penetrated a hydrocarbon rich sandstone between the depths of 3,044-3,069 m, measured depth (MD). Total depth of the well was 3288 m, MD. It is the first exploration well to discover hydrocarbons in Sri Lanka as well as in the Gulf of Mannar.

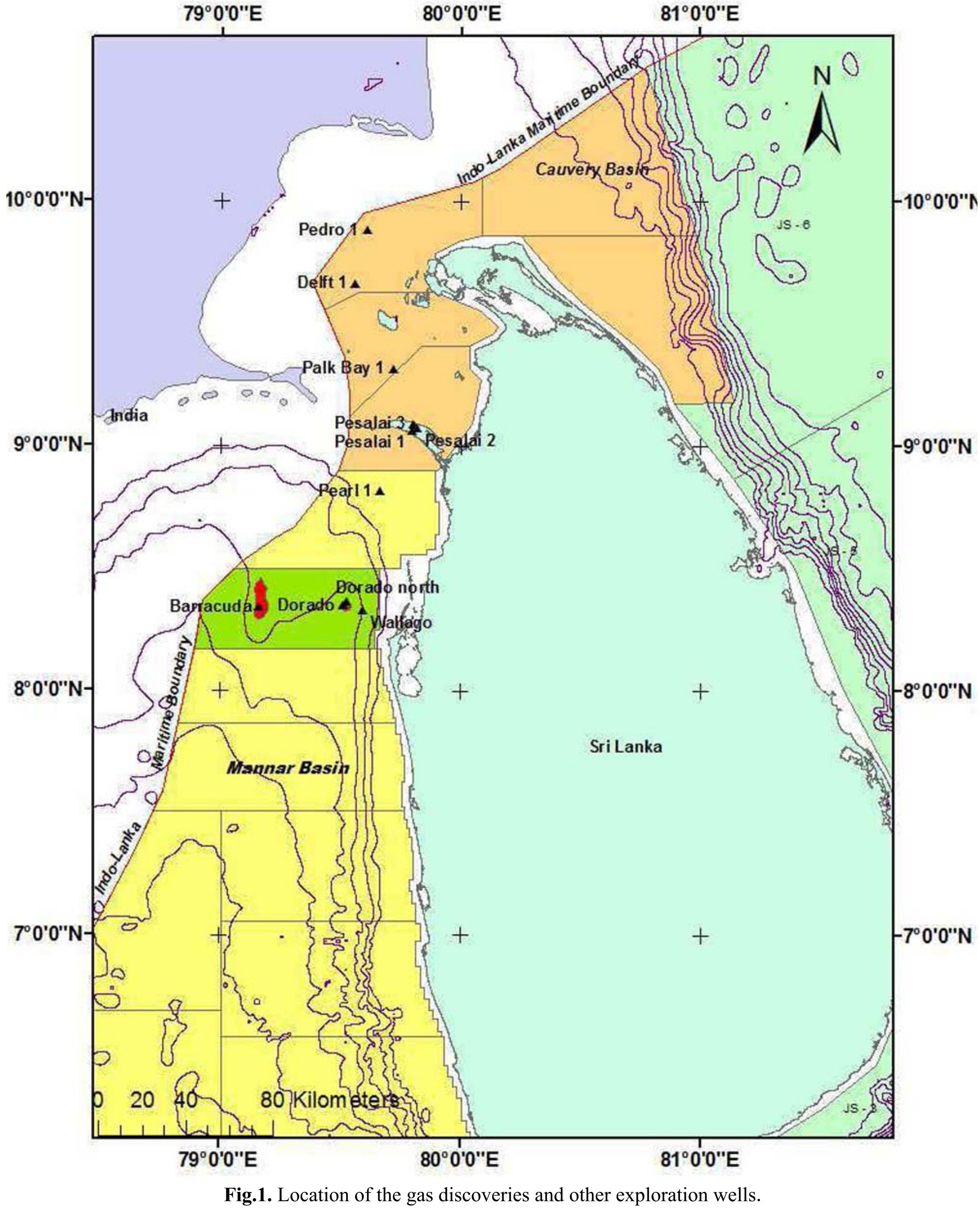

Fig.1. Location of the gas discoveries and other exploration wells.

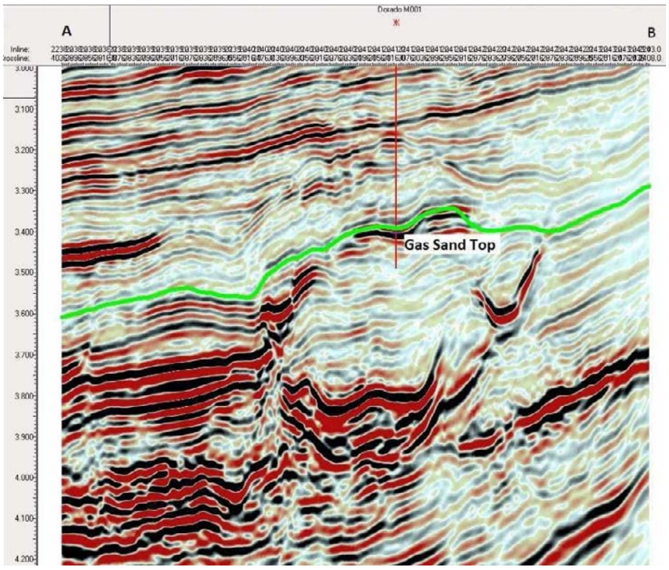

Fig.2. Seismic cross section of Dorado gas discovery.

(Premarathne et al. 2013). The seismic cross section of the well is showed in the Fig.2.

METHODOLOGY

Sample selection and Preparation

An appropriate depth range was decided to collect samples considering the gas reservoir interval, using seismic and well log data. Then a total of 15 samples, each weighing about 250 g were collected from 3025m to 3095m depth range with five meter intervals. After that the drill cutting samples were air-dried in a clean place and then oven dried at 100°C temperature for 10 hours to get rid of all the moisture. The samples were then transferred into sealed labeled polyethylene bags (Hushari et al. 2015)

200g of dried drill cutting samples from each depth range was grinded (crushing, rolling) without contamination into break down aggregates. Then the samples were sieved through a sieve of 2 mm size until considerable amount of samples were obtained. Finally, fine powdered samples were packed and sealed in an airtight G1 geometry container for gamma spectrometry testing and labeled according to their respective depths. Then they were stored for 21 days before testing radioactivity to achieve the secular equilibrium between elements.

Radioactive isotope identification and measurements were carried out at the Atomic Energy Board of Sri Lanka, using a stand-alone high-resolution gamma spectrometer. The gamma spectrometry system was equipped with a coaxial n-type high purity germanium (HPGe) detector connected through amplifiers and multi-channel analyzer driven by a computer based operating system. Genie 2000 software package (Canberra) was used for data acquisition and analysis. The detector had a coaxial closed facing geometry with the following specifications. Detector mode GX3020 with a resolution of full width at half maximum (FWHIM) at 122 Kev of Co- 57. The detector was shielded by a cylindrical lead shield, which had average thickness of 10 cm to reduce the background radiation.

HPGe gamma spectrometry system was calibrated using the point sources of 137Cs, 60Co and 241Am and calibration was verified using the IAEA reference materials. The efficiency calibration was done by Geometric Composure method (Lab SOCS, Canberra) and the test method was validated by analyzing standard reference material, IAEA-134 and IAEA-414. Genie 2000 software package (Canberra) was used for data acquisition and analysis. The radioactivity of all the samples were calculated according to the date of sample collection.

Gamma Ray Spectroscopy Data analysis

Count rates for each detected peak and activity per mass unit specific activity for each of the detected nuclides are calculated. The specific activity (in Bq kg–1) by following Equation 1 (Tsertos et al., 2003)

$$A\varepsilon_i = \frac{N\varepsilon_i}{\varepsilon_E \times t \times r_d \times M_s} \qquad (1)$$

Total Activity Concentration

Total Activity Concentration (TAC) for uranium and thorium series in the following Equation 2 was used by Malaysian Atomic Energy Board (Omar et al. 2008)

$$\begin{aligned} TAC = & (4x^{238}U) + (^{230}Th) + (6x^{226}Ra) + (3x^{210}Pb) + \\ & (^{232}Th) + (2 \times {}^{228}Ra) + (7 \times {}^{228}Th) \end{aligned} \qquad (2)$$

This equation has been altered accordingly considering the significant of the individual concentrations of the NORM elements. If the element concentrations are considerably at low levels the equation can be reduced. Therefore, according to the experiment results the equation can be written as Equation 3

$$TAC = 6 \times {}^{226}Ra + 3 \times {}^{210}Pb + {}^{232}Th \qquad (3)$$

Since the aim is to calculate overall total activity concentration and the activity concentration level of ^{40}K is significantly high the contribution of ^{40}K have to be considered. Therefore, the equation has been modified as following Equation 4

$$TAC = {}^{40}K + 6 \times {}^{226}Ra + 3 \times {}^{210}Pb + {}^{232}Th \qquad (4)$$

By using equation 4 the total activity concentration for each tested sample was calculated.

Radioactivity Dose Rate and Annual Effective Dose Rate

The gamma dose rate (D) in the outdoor air at 1 m above the ground level can obtained from Equation 5 (Rafique, 2011)

$$D = \Sigma\, A.C \qquad (5)$$

Where A is the activity of radioactive element; C is the dose rate conversion factor

The corresponding conversion factors were used from the UNSCEAR report (2000)

The annual effective dose is obtained from the equation below from UNSCEAR report (2000)

$$AEDE(\mu Sv/y) = D(nGy/h) \times 8760(h/y) \times 0.2 \times 0.7(Sv/Gy) \times 10^{-3}$$

RESULTS AND DISCUSSION

According to the results of the tested samples between 3020 m to 3095 m depth interval, ^{40}K activity concentration has a maximum of 0.514 Bq/g and a minimum value of 0.338 Bq/g. The activity concentration levels of ^{210}Pb varied from 0.007 Bq/g to 0.015 Bq/g, while ^{226}Ra showed an activity concentration range of 0.0145 Bq/g to 0.012 Bq/g. Similarly activity concentration of ^{232}Th varied from 0.030 Bq/g to 0.040 Bq/g.

^{40}K activity concentrations levels are most prominent and considerably higher than the other NORM elements. ^{210}Pb, ^{226}Ra and ^{232}Th levels statistically remains in the same range throughout the depth interval. The graph (Fig.3) indicates the variation of activity concentration with depth which is an indication that the sediments were accumulated at the same rate in this depth area and no major

Table 1. Table of Activity concentration, Total Activity concentration, Effective dose rate

Depth interval	Average Depth	K40 Bq/g	Pb-210 Bq/g	Ra-226 Bq/g	Th-232 Bq/g	TAC Bq/g	Effective dose rate (μSVy–1)
3020-3025	3022.5	0.38817	0.00708	0.012	0.03	0.51141	42.07372339
3025-3030	3027.5	0.40972	0.01057	0.0125	0.031	0.54743	43.91655495
3030-3035	3032.5	0.42966	0.00894	0.014	0.032	0.57248	45.6770497
3035-3040	3037.5	0.40097	0.01536	0.013	0.031	0.55605	43.46907225
3040-3045	3042.5	0.42141	0.00782	0.014	0.035	0.56387	47.47737424
3045-3050	3047.5	0.41291	0.00926	0.0142	0.0346	0.56049	46.74637852
3050-3055	3052.5	0.41298	0.00749	0.013	0.036	0.54945	47.78700222
3055-3060	3057.5	0.41970	0.00048	0.01447	0.0346	0.54256	47.0936251
3060-3065	3062.5	0.42218	0.00875	0.014	0.037	0.56943	48.99824392
3065-3070	3067.5	0.40574	0.00881	0.014	0.036	0.55217	47.41674225
3070-3075	3072.5	0.42215	0.01095	0.014	0.038	0.577	49.73745529
3075-3080	3077.5	0.43467	0.01070	0.015	0.04	0.59677	51.85923031
3080-3085	3082.5	0.42622	0.01174	0.014	0.035	0.58044	47.72336187
3085-3090	3087.5	0.51386	0.00898	0.012	0.031	0.6438	49.2423662
3090-3095	3092.5	0.41928	0.00829	0.012	0.035	0.55115	47.36844417

environmental changes occurred during that time period.

Further this high amount of ^{40}K activity concentrations levels can be explained in terms of depositional environment of sediments of the studied interval. As in Sri Lanka the hinterland consist of metamorphic basement hence after the disintegration and chemical weathering of minerals for instance potassium feldspar, clay minerals are formed such as kaolinite. In these clay minerals ^{40}K are abundant elements.

The area where the Dorado well was drilled are being fed by the sediments from Sri Lankan basement which is composed of high-grade metamorphic rocks with minerals such as K-feldspar and mica. These minerals forms clay minerals with abundance of ^{40}K isotopes enabling the emission of high gamma radiations. It is confirmed that the Dorado well was drilled in deep marine environment where fine grain sediments have been deposited. The microfossil and basin modeling from 3-D seismic data and the well logs proved that the depositional environments at that time was deep marine (PRDS interpretation reports). This interesting depth segment composed of clay stone, siltstone and marl (lithology logs PRDS) and higher amount of ^{40}K isotopes are present in those rocks due to feldspar and illite.

The total activity concentration has a maximum value of 0.64 Bq/g and minimum value of 0.51 Bq/g within the tested depth interval. It is relatively consistence throughout the 3020-3095 depth as shown in Fig.4. NORM levels of reservoir section were compared with the accepted NORM levels in shale and limestone data from IAEA safety report (2003) as indicated in Table 2 and comparison shows that the activity concentration result levels for each are within the accepted ranges.

The effective dose rate obtained varied between 52 (μSv y–1) to 41 (μSv y–1).The annual global per capita effective dose due to natural radiation sources is 2.4 mSv/y. But the range of individual doses varies according to the locations and concentrations of specific radionuclides in any large population and about 65% would be expected to have annual effective doses between 1 mSv and 3 mSv, 25% would have annual effective doses less than 1 mSv and 10% would have annual effective doses greater than 3 mSv according to the IAEA training course report (2010). Hence the resulting effective dose rates compared with the global values clearly indicates the dose rates of reservoir section samples are not at hazardous levels.

Table 2. NORM concentrations in rocks. IAEA safety report 2003

Type of rocks		Activity concentration, Bq/g			
		^{226}Ra (=^{238}U+)		^{228}Ra(=^{232}Th+)	
		Mean	Range	Mean	Range
Acid intrusive	Granite	0.078	0.001-0.37	0.111	0.004-0.103
Basic intrusive	Basalt	0.011	0.0004-0.041	0.01	0.0002-0.036
Chemical sedimentary	Lime-stone	0.045	0.0004-0.34	0.06	0.0001-0.54
Detrital sedimentary	Clay. shale	0.06	0.001-0.99	0.05	0.0008-0.147
Metamorphic igneous	Gneiss	0.05	0.001-1.8	0.06	0.0004-0.42
Metamorphic sedimentary	Schist	0.037	0.001-0.66	0.049	0.004-0.37

CONCLUSIONS AND RECOMMENDATIONS

The results indicate that the activity concentrations of the NORM existing in the Dorado gas reservoir sand section falls on the lower side when compared with the International Atomic Energy Agency (IAEA) published levels for NORM in sedimentary rocks.

But in comparison with several other NORM levels published by different institutions like Canadian Association of Petroleum Producers (Canadian Association of Petroleum Producers, 2000) and Malaysian Atomic Energy Board (Omar et al. 2008), 0.3Bq/g is considered as control limit for NORMs associated waste. The total activity concentration of test results varies between 0.65Bq/g to 0.5 Bq/g. NORM contaminated materials with activities above 0.3 Bq/g can be hazardous while a competent radiation expert must perform a risk analysis before disposal. Waste recording total activity concentration above 0.3 Bq/g can be disposed in a regular fashion depending on the total amount of waste (Canadian Association of Petroleum Producers, 2000).

Since the hydrocarbon production is yet to be started in Sri Lanka, it is not possible to predict the exact NORM levels of the future petroleum productions. As results indicate the NORM concentration levels of the Dorado gas reservoir sand section is low compared to the sedimentary rocks found elsewhere in the world, hence the mobility of NORM levels to the earth surface have to be lower than the levels of the reservoir which are significantly in the lower side when compared to the IAEA levels, therefore, to lower the amount of contamination proper production and waste disposal procedures must be implemented.

Hence, if strong regulatory framework is established in cohesion with production procedures according to the American Petroleum Institute and International Atomic Energy Agency standards (Environmental Protection for Onshore Oil and Gas Production Operations and Leases, 2009), (Overview of exploration and production waste volumes and waste management practices in the united states,2000), (Guidelines for Commercial Exploration and Production Waste Management Facilities, 2001) and IAEA (2010), (2003), to follow in the production process such as treatment of

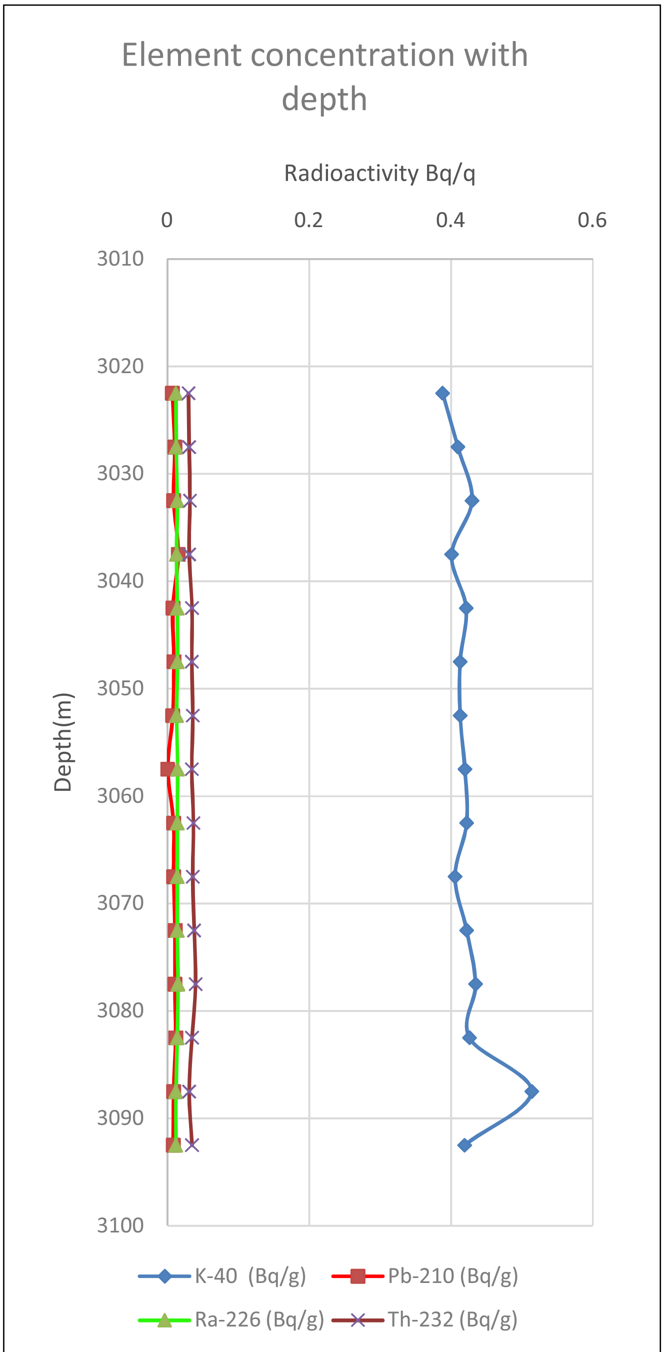

Fig. 3. Activity concentration of elements with depth

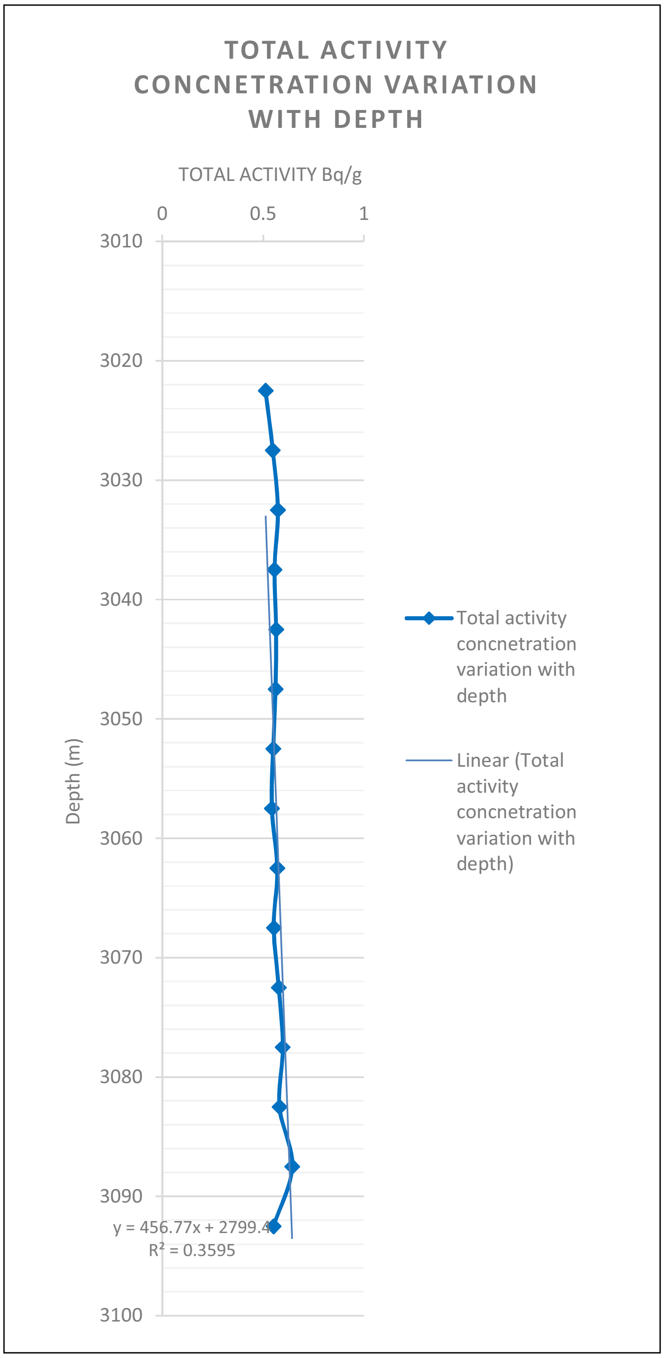

Fig.4. Graph of Total Activity concentration variation with the depth

produced water before disposal or reusing in well operations, procedure for disposal of sludge and solid waste with minimum environmental impact, health and safety rules and regulations for workers in the oil and gas fields, The amount of contaminations from NORM can be further minimized.

The calculated outdoor annual effective dose rate varies between 52- 41 (μSv y–1) which is considerably lower when compared with the global annual effective dose rate. This indicates there is no risk involved in storing or disposing the drill cuttings without pretreatment.

When considering the XRF results apart from NORMs the attention should be given to the other non-radioactive hazardous element concentrations, since the long term accumulations can pose a threat in future.

The acceptable NORM levels can be vary around the world according to the geographical conditions and environmental sensitivity. Therefore conducting the gamma-ray spectroscopy testing for drill cutting samples obtained from the other remaining wells to get a generalized value range for sedimentary rocks in the Mannar basin, Sri Lanka would be important for future operations. This will enable Sri Lanka to decide whether to establish its own NORM standards or to follow the IAEA and API standards for NORM in future operations of the oil and gas industry.

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