Baseline TENORM/NORM Survey for Radionuclide Concentration and Background Ionizing Radiation at Seplat Energy Facilities

Charles Emeka Oduah[1], Augustine Onyema Nwabuoku[2*], Famous Akpojotor[3], Ehis Edwin Amiegbereta[4]

[1,2,4]Department of Physics, Dennis Osadebay University, Asaba, Delta State, Nigeria

[3]Department of Physics, University of Benin, Benin City, Nigeria

DOI: https://dx.doi.org/10.51244/IJRSI.2026.13010110

Received: 21 January 2026; Accepted: 27 January 2026; Published: 05 February 2026

ABSTRACT

This baseline survey assesses TENORM/NORM and background ionizing radiation at Seplat Energy facilities in Nigeria. Soil activity concentrations of ^{238}U, ^{266}Ra, ^{238}U and ^{40}K in Seplat West often exceeded UNSCEAR (2000) world averages (35 $BqKg^{-1}$ for ^{238}U and ^{226}Ra, 30 $BqKg^{-1}$ for ^{232}Th, 400 $BqKg^{-1}$ for ^{40}K), with ranges including 3.30±0.2 to 61.03±3.08 $BqKg^{-1}$ for ^{238}U, 7.62±0.45 to 80.25±3.41 $BqKg^{-1}$ for ^{226}Ra, 0.28±0.03 to 92.07±4.59 $BqKg^{-1}$ for ^{232}Th and BDL to 1772.8±91.3 $BqKg^{-1}$ for ^{40}K. In Seplat East, ^{238}U, ^{226}Ra and ^{232}Th were slightly above averages, while ^{40}K was below. Absorbed dose rates exceeded the world average of 59 $nGyh^{-1}$ except for SOM at Oben and SJWL/S at Jisike. Annual effective doses exceeded 0.07 $mSvy^{-1}$ except at SOM and SOHSP. Radium equivalent (Ra_{eq}) values were below 370 $BqKg^{-1}$, and external, internal, and gamma indices were all less than unity. Excess lifetime cancer risk (ELCR) values exceeded the world average of 0.29×10^{-3} (UNSCEAR, 2000).

Keywords: TENORM/NORM, Radionuclide, Ionizing Radiation, Effective dose

INTRODUCTION

Radiation is present everywhere in our environment and we are constantly and continuously exposed to it, either from the air we breathe in, the water we drink, the food we eat or the soil around us (Ademola, 2008; Agbalagba et al., 2013; Mokobia et al., 2020; Ijabor et al., 2023).

In Nigeria, crude oil is the major source of its economic sustenance and this fact cannot be undermined. However, the method(s) of exploration by crude oil companies results in enhanced ionizing radiation which has several negative environmental impacts and these consequences cannot be ignored. Crude oil exploration and exploitation in commercial quantity from its deposits causes radionuclides trapped within the earth's crust to be exposed to the environment which is as a result of materials used during the exploration process (Laogun et al., 2006; Chad-Umoren, 2012; Anekwe and Enyinna, 2017).

Naturally Occurring Radioactive Materials (NORMs) in the environment has garnered significant attention due to its potential health risks and implications for public safety. NORMs are those materials that contain radionuclides from known natural sources (DHS, 1996). NORM includes radioactive isotopes such as uranium (^{238}U), radium (^{226}Ra), thorium (^{232}Th), and potassium (^{40}K), and their radioactive decay products (USEPA, 2025). They can be found in various geological formations and can accumulate in industrial processes, particularly in the oil and gas sector (UNSCEAR, 2000). The exploration and processing of fossil fuels may introduce high levels of these radionuclides into the surrounding environment, necessitating the need for a radiological assessment to better understand their concentration and associated risks (IAEA, 2003).

More recently, the baseline survey of Technologically Enhanced Naturally Occurring Radioactive Material (TENORM) has become a crucial aspect of environmental monitoring. TENORM refers to the increased concentration of natural radionuclides due to human activities, which may lead to enhanced exposure levels than naturally occurring (NCRP, 2009).

For instance, several studies have documented the prevalence of TENORM in oil and gas facilities, highlighting the need for regular monitoring and evaluation (Elena and Gracea, 2004; Hilal et al., 2014; Kumar et al., 2015; Alnabhani et al., 2018; Ali et al., 2019).

In 2004 in Bacau and Braila districts, Elena and Gracea carried out environmental radioactivity monitoring of environs of six oil fields and their findings was no radiological challenge; however, they reported that high ^{226}Ra content of oil field formation waters could lead to environmental pollution (Elena and Gracea, 2004).

Enyinna et al., (2017) in their analysis of ingested water from Estuaries within the Coastal Area of Akwa Ibom State, Nigeria, revealed that majority of the radiation risk parameters computed were above world permissible limits and attributed their findings to oil production activities within the area Enyinna and Uboh, (2017).

Similar results have also been reported in Rivers State of Nigeria with results above standard limits of radiation exposure set by the US Nuclear Regulatory Commission and International Commission on Radiological Protection (ICRP). They also attributed their findings to oil exploration and production activities going on within the surveyed areas (Anekwe and Enyinna, 2017).

This study aims to conduct a baseline TENORM/NORM survey to determine radionuclide concentrations and evaluate the effective dose levels of Background Ionizing Radiation (BIR) at Seplat Energy facilities in the West and East regions of Nigeria. Understanding these levels is essential for assessing compliance with international safety standards, particularly those set by organizations such as the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (UNSCEAR, 2000) and the International Atomic Energy Agency (IAEA) (IAEA, 1999). By comparing measured radionuclide concentrations against global averages, this research will provide insights into the radiological hazards present in the Seplat Energy facilities and contribute to the broader discourse on environmental health and safety in the oil and gas sector.

MATERIALS AND METHOD

Study Area

This study was conducted at Seplat Energy facilities in Nigeria's western and eastern regions. These include Amukpe, Oben, Sapele, Orogho, Okporhuru, and Ovhor, all in the Seplat West region; Jisike and Ohaji both in the Seplat East. The facilities under evaluation included various operational zones such as oil and gas processing areas, storage facilities, and other relevant infrastructure. Coordinates of the specific locations were documented to ensure precise geospatial referencing of the survey points using a Garmin GPS etrex 10 GPS Meter.

The main geological components of the sampled area, at depths reaching thousands of meters, are the Benin formation, followed by the Agbada formation and then the Akata formation with the former being the youngest and the later the oldest (Doust and Omatsola, 1990; Agbalagba et al., 2013).

Sample collection and preparation

Soil, water and sediment samples were collected and an in-situ background dosecrates were measured using two well-calibrated Radalert 100 and Digilert 200 counters with Caesium-137 probes, with a capability of measuring alpha, beta, gamma and x-ray radiation in mRh^{-1} within the temperature range of 10-50 °C. Detectors were placed 1.0 m above ground, 2 m from structures, facing potential sources. Readings were converted to absorbed dose rate ($nGyh^{-1}$) (Agbalagba et al., 2013).

Soil samples weighing 250 g were collected at 0-5 cm and 5-10 cm depths using clean hand auger, sealed in a radiation-proof polyethene bags and sent to the laboratory for analysis.

Soil samples were analyzed for ^{238}U, ^{226}Ra, ^{232}Th and ^{40}K using a high purity germanium (HPGe) detector gamma spectrometry system. Readings were obtained between the hours of 13:00 and 16:00 since the meter exposure rate has a maximum response to environmental radiation within these hours. Samples were air dried, sieved and sealed in airtight containers for a period of 28 days to achieve secular equilibrium between ^{226}Ra and ^{232}Th and progeny. Energy calibration used standard sources like ^{137}Cs. Efficiency calibration employed certified reference materials. The counting time was typically 36,000 s. Also spectra were analyzed for characteristics photopeaks (Laogun et al., 2006; Avwiri et al., 2007a; Agbalagba et al., 2013). Minimum detectable activity (MDA) was calculated using Currie's method.

RESULTS AND DISCUSSION

The tables presented in this study provide critical insights into the radionuclide concentrations and background ionizing radiation levels at Seplat Energy western and eastern facilities. The findings reveal significant variations in effective dose equivalents and activity concentrations across the different facilities, highlighting potential radiological hazards associated with oil and gas operations.

Activity concentrations varied across facilities, many in Seplat West exceeding UNSCEAR averages. Absorbed dose rate from in situ measurements and annual effective doses generally exceeded world averages (59 $nGyh^{-1}$ and 0.07 $mSvy^{-1}$).

Absorbed dose rate (DR): The radiation dose absorbed in air at 1.0 m above the ground level is estimated in units of $nGyh^{-1}$ ^{238}U, ^{232}Th and ^{40}K, using a conversion factors of 0.462, 0.604 and 0.0417 respectively (Beretka and Mathew, 1985; UNSCEAR, 2000) are as in Equation 1:

$$D_R = 0.462 A_U + 0.604 A_{Th} + 0.0417 A_K \quad (1)$$

Where D_R is the absorbed dose rate in air in $nGyh^{-1}$, 8760 is the total hours in a year; 0.7 $SvGy^{-1}$ is the dose conversion factor from absorbed dose in air to the effective dose and 0.2 is the occupancy factor for outdoor exposure as recommended by UNSCEAR (2000).

$$AEDE = D_R \times 8760 \times 0.2 \times 0.7 SvGy^{-1} \times 10^{-6} \quad (2)$$

Excess Lifetime Cancer Risk (ELCR): The excess lifetime cancer risk is used in radiation therapy to estimate a person's lifetime risk of developing cancer due to low radiation exposure ELCR was estimated using Equation 3 by calculating annual doses (Ugbede and Akpolile, 2019; Mokobia *et al.*, 2020).

$$ELCR = AEDE \times DL \times RF \quad (3)$$

Table 1. Mean Values of Effective Dose Equivalents Measured at Oben Gas Plant

Location Coordinate	**Effective Dose Equivalent (μSvh^{-1})**
N06˚00.821' E005˚52.116	0.121
N06˚00.821' E005˚52.106	0.284
N06˚00.832' E005˚52.082	0.199

N06˚00.811’ E005˚52.083	0.153
N06˚00.782’ E005˚52.056	0.405
N06˚00.763’ E005˚52.042’	0.289
Average	**0.346**

Table 2. Mean Values of Effective Dose Equivalents Measured at Oben Flow Station

Location Coordinate	Effective Dose Equivalent (μSvh^{-1})
N06˚00.706’ E005˚52.026’	0.229
N06˚00.714’ E005˚52.007’	0.090
N06˚00.729’ E005˚52.999’	0.157
N06˚00.718’ E005˚52.046’	0.613
Average	**0.272**

Table 3. Mean Values of Effective Dose Equivalents Measured at Orogho Manifold

Location Coordinate	Effective Dose Equivalent (μSvh^{-1})
N05˚50.556’ E005˚55.229’	0.143
N05˚50.538’ E005˚55.236’	0.163
Average	**0.153**

Table 4. Mean Values of Effective Dose Equivalents Measured at Okporhoro Manifold

Location Coordinate	Effective Dose Equivalent (μSvh^{-1})
N05˚53.887’	0.169

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue I January 2026

E005˚50.267’	
N05˚53.879’ E005˚50.261’	0.175
N05˚53.858’ E005˚50.260’	0.260
Average	**0.201**

Table 5. Mean Values of Effective Dose Equivalents Measured at Ovhor

Location Coordinate	Effective Dose Equivalent (μSvh^{-1})
N05˚48.992’ E005˚39.883’	0.158
N05˚48.997’ E005˚39.882’	0.235
N05˚48.996’ E005˚39.875’	0.250
N05˚49.001’ E005˚39.903’	0.179
Average	**0.206**

Table 6. Mean Values of Effective Dose Equivalents Measured at Sapele Flow Station, Seplat facility

Location Coordinate	Effective Dose Equivalent (μSvh^{-1})
N05˚53.857’ E005˚34.952’	0.166
N05˚53.892’ E005˚34.882’	0.258
N05˚53.844’ E005˚34.958’	0.256
N05˚53.843’ E005˚34.951’	0.375
Average	**0.264**

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue I January 2026

Table 7. Mean Values of Effective Dose Equivalents Measured at Amukpe Seplat Facility

Location Coordinate	Effective Dose Equivalent (μSvh^{-1})
N05˚51.810’ E005˚41.511’	0.555
N05˚51.809’ E005˚41.514’	1.110
N05˚51.8788’ E005˚41.499’	0.244
N05˚51.760’ E005˚41.467’	0.585
N05˚51.768’ E005˚41.467’	0.260
N05˚51.797’ E005˚41.484’	0.257
N05˚51.677’ E005˚41.411’	0.160
N05˚51.598’ E005˚41.093’	0.454
N05˚51.571’ E005˚41.136’	0.263
N05˚51.487’ E005˚41.207’	0.216
N05˚51.458’ E005˚41.216’	0.195
Average	**0.391**

Table 8. Mean Values of Effective Dose Equivalents Measured at Jisike

Location Coordinate	Effective Dose Equivalent (μSvh^{-1})
N05˚37.049’	

E006˚48.965’	0.151
N05˚37.047’ E006˚48.957’	0.137
N05˚37.056’ E006˚48.962’	0.189
N05˚37.061’ E006˚48.965’	0.147
N05˚37.087’ E006˚48.975’	0.097
N05˚37.089’ E006˚48.969’	0.151
N05˚37.089’ E006˚48.974’	0.118
N05˚36.759’ E006˚50.146’	0.161
N05˚36.749’ E006˚50.144’	0.118
N05˚37.088’ E006˚51.302’	0.176
N05˚37.088’ E006˚51.302’	0.135
N05˚37.088’ E006˚51.302’	0.127
Average	**0.148**

Table 9. Mean Values of Effective Dose Equivalents Measured at Ohaji South

Location Coordinate	Effective Dose Equivalent (μSvh^{-1})
N05˚21.222’ E006˚50.487’	0.169

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue I January 2026

N05˚21.227’ E006˚50.491’	0.076
N05˚21.227’ E006˚50.488’	0.096
N05˚21.233’ E006˚50.489’	0.121
N05˚21.118’ E006˚50.731’	0.144
N05˚21.’125 E006˚50.731’	0.242
N05˚21.237’ E006˚50.489’	0.118
N05˚21.206’ E006˚50.488’	0.156
N05˚27.166’ E006˚50.802’	0.212
N05˚27.810’ E006˚50.092’	0.157
N05˚27.833’ E006˚50.097’	0.178
N05˚27.833’ E006˚50.097’	0.181
Average	**0.154**

Table 10. The summary of Average Mean and Annual Effective dose rates at the various facilities

Location	Mean Effective Dose Equivalent (μSvhr^{-1})	AEDE (mSvy^{-1})
Oben Gas Plant	0.346	3.031
Oben Flow Station	0.272	2.383
Orogho Manifold	0.153	1.340

Okporhoro Manifold	0.201	1.760
Ovhor Facility	0.206	1.804
Sapele Flow Station	0.264	2.281
Amukpe Facility	0.391	3.425
Jisike Facility	0.148	1.296
Ohaji South Facility	0.154	1.349

AEDE: Annual Effective Dose Equivalent

Table11. Activity Concentration of Radionuclides for Seplat West

Sample Location	Sample code	Coordinates	^{238}U	**^{232}Th**	**^{40}k**	**Remarks**
Seplat Amukpe Facility	SAF	N05˚51.760’ E005˚41.467’	56.37±3.08	63.90±3.76	448.99±23.6	Soil mixed with sluges
Seplat Amukpe Facility1	SAF1	N05˚51.809’ E005˚41.514’	61.03±3.08	87.56±4.25	1728.37±85.2	Soil
Seplat Amukpe Facility 2	SAF2	N05˚51.810’ E005˚41.511’	59.80±3.11	76.32±3.71	1683.19±79.4	Soil
Seplat Oben Gas Facility	SOGF	N06˚00.782’ E005˚52.056	58.77±3.13	88.35±5.88	1701.0±90.0	Soil
Seplat Oben Manifold	SOM	N05˚50.538’ E005˚55.236’	3.97±0.25	0.28±0.03	BDL	Water
Seplat Sapele West	SSW	N05˚53.843’ E005˚34.951’	30.77±1.60	27.96±1.60	71.20±3.77	Soil
Seplat Oben Flowline	SOBF 1	N06˚00.706’ E005˚52.026’	60.86±3.42	92.07±4.59	1772.8±91.3	Soil
Seplat Oben Flowline	SOBF 2	N06˚00.718’ E005˚52.046’	45.82±3.22	59.48±2.99	387.54±25.0	Soil
Sapele Orogho Facility 1	S0F 1	N05˚50.538’ E005˚55.236’	33.14±1.94	24.95±1.97	76.38±4.05	Soil
Seplat Okporhuru	SOF 2	N05˚53.858’	29.14±2.59	24.79±0.97	68.41±2.93	Soil

Facility 2		E005˚50.260’				
Seplat Ovhor Gas Flow Station	SOVF	N05˚48.996’ E005˚39.875’	36.37±3.25	28.35±2.06	83.13±4.79	Soil

^{238}U (Uranium – 238), ^{232}Th (Thorium – 232), ^{40}K (Potassium – 40), BDL: Below Detection Limit

Table 12. Radiological Hazard Indices for Seplat West Samples

S/N	Sample Location	Sample Code	Absorb Dose Rate (nGyh $^{-1}$)	AEDE (mSvy^{-1})	$ELCR \times 10^{-3}$
1	Seplat Amukpe Facility	SAF	158.1	0.775	2.713
2	Seplat Amukpe Facility1	SAF 1	290.77	1.426	4.991
3	Seplat Amukpe Facility2	SAF 2	273.62	1.342	4.697
4	Seplat Oben Gas Facility	SOGF	287.33	1.410	4.935
5	Seplat Oben Manifold	SOM	3.960	0.019	0.665
6	Seplat Sapele West	SOBF 1	299.1	1.467	5.135
7	Seplat Oben Flowline	SOBF 2	138.6	0.680	2.380
8	Seplat Oben Flowline	SSW	64.76	0.318	1.113
9	Sapele Orogho Facility1	SOF 1	64.04	0.314	1.099
10	Seplat Okporhuru Facility2	SOF 2	59.55	0.292	1.022
11	Seplat Ovhor Gas Flow Station	SOVF	71.30	0.350	1.225
	World Average	**W/A**	**59.0**	**0.07**	**0.29**

Table 13. Activity Concentration of Radionuclides for Seplat East

Sample Location	**Sample code**	**Sample Code**	**Activity Concentration (BqKg $^{-1}$)**			**Sample Type**
			^{238}U	^{232}Th	^{40}k	
Seplat Jisike Test Seperator	SJTS	N05˚37.088’ E006˚51.302’7	41.28±3.25	32.09±2.78	88.97±5.31	Soil
Seplat Jisike Well L/S	SJW L/S	N05˚37.056’ E006˚48.962’	9.69±0.53	6.83±0.37	190.31±10.1	Soil
Seplat Ohaji Schema Pit	SOHSP	N05˚27.166’	3.30±0.22	0.69±0.05	BDL	water

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue I January 2026

		E006˚50.802’				
Seplat Ohaji Facility 3	SOHF3	N05˚21.’125 E006˚50.731’	33.95±2.22	26.11±2.00	79.82±5.31	Soil

^{238}U (Uranium – 238), ^{232}Th (Thorium – 232), ^{40}K (Potassium – 40), BDL: Below Detection Limit

Table 14. Radiological Hazard Indices for Seplat East Samples

S/N	Sample Location	Sample Code	Absorb Dose Rate (nGyh $^{-1}$)	AEDE (mSvy^{-1})	$ELCR \times 10^{-3}$
1	Seplat Jisike Test Seperator	SJTS	80.39	0.394	1.379
2	Seplat Jisike Well L/S	SJW L/S	31.65	0.155	0.543
3	Seplat Ohaji Schema Pit	SHOF 3	66.34	0.325	1.138
4	Seplat Ohaji Facility 3	SOHSP	3.960	0.019	0.665
	World Average	**W/A**	**59.0**	**0.07**	**0.29**

Table 1 shows the effective dose equivalents measured at various coordinates within the Oben Gas Plant. The values range between 0.121 µSvh^{-1} to 0.405 µSvh^{-1}, with an average of 0.346 µSvh^{-1}. This average is above the world average of 0.273 µSvh^{-1} for background radiation, suggesting a heightened level of exposure due to nearby oil and gas activities. The highest recorded value may indicate localized sources of radiation, necessitating further investigation.

Similar to Table 1, Table 2 shows effective dose equivalents at the Oben Flow Station, with values ranging from 0.090 µSvh^{-1} to 0.613 µSvh^{-1}and an average of 0.272 µSvh^{-1}. Although the average is slightly lower than at the gas plant, it still exceeds global averages, indicating that operations in this area may also contribute to increased radiation exposure.

Table 3 to Table 9 present effective dose equivalents at several other facilities, including Orogho Manifold, Okporhoro Manifold, Ovhor, Sapele Flow Station, Amukpe, Jisike, and Ohaji South. The values range from 0.143 µSvh^{-1} at Orogho to 0.555 µSvh^{-1} at Amukpe, with several locations having average values above 0.3 µSvh^{-1}. The maximum value of 1.110 µSvh^{-1} at Amukpe is concerning, as it is well above typical background levels, indicating a significant radiological risk.

The average effective dose rates across these facilities are consistently higher than the world average of 0.273 µSvh^{-1}, suggesting that personnel and nearby residents may be subjected to elevated radiation levels, raising public health concerns.

Table 10 consolidates the average effective dose equivalents and annual effective dose rates (AEDE) across the studied locations. The AEDE values vary from 1.296 mSvy^{-1} at Jisike to 3.425 mSvy^{-1} at Amukpe. All observed AEDE values exceed the UNSCEAR and IAEA recommended public dose limit of 1 mSvy^{-1}, indicating that safety measures may need to be reassessed at these facilities (UNSCEAR, 2000; IAEA, 1999).

The excess lifetime cancer risk (ELCR) values are concerning, as they exceed the world average, highlighting the long-term health implications of exposure to these radiation levels.

Table 11 to Table 14 shows the activity concentrations of radionuclides (^{238}U, ^{226}Ra, ^{232}Th, and ^{40}K) across various locations. For Seplat West, concentrations of ^{238}U range from 3.30 to 61.03 BqKg^{-1}, while ^{226}Ra concentrations vary from 7.62 to 80.25 $BqKg^{-1}$. Most of these values exceed global averages, indicating significant radionuclide presence due to oil and gas activities.

In Seplat East, the activity concentrations of ^{238}U, ^{226}Ra, and ^{232}Th are slightly above the world average, with all values for ^{40}K below average. This suggests that while there are concerns, the levels may be less severe than those found in Seplat West, suggesting increased monitoring in these locations.

The values of the absorbed dose rate at the various facilities are all higher than the world average of 59 $nGyh^{-1}$ (UNSCEAR, 2000) except SOM at Seplat West as well as SJW L/S and SOHSP both at Seplat East. The annual effective dose rates are all higher than the world average of 0.07 $mSvy^{-1}$ (UNSCEAR, 2000) except SOM at Seplat West and SOHSP at Seplat East. The radium equivalent (Rq_{eq}) calculated within the Seplat West and East facilities are all lesser than the world average of 370 $BqKg^{-1}$ (UNSCEAR, 1988). The external, internal and gamma index are less than unity. The excess life cancer risk (ELCR) values are all higher than the world average of 0.29×10^{-3} (UNSCEAR, 2000). ELCR is additional risk of a person developing cancer over the cause of a lifetime. These are compared with the hazard indices of the world average recommended safety limit values and the requisite prevailing safety standard values of Nigeria Upstream Petroleum Regulatory Commission (NUPRC) and Nigerian Nuclear Regulatory Authority (NNRA).

CONCLUSION

The radiological impact of oil and gas activities on field workers and residents of host community was investigated in this study. The findings are in agreement with similar studies in the Niger-Delta region and around the world. The elevated radiation levels reported in this study is evidence that both Seplat workers and indigenes of host communities are exposed to radiation risks, necessitating the need for continuous monitoring and potential remediation efforts to mitigate the risks associated with elevated radiation levels and also ensure compliance with local and international standards aimed at protecting both workers and local populace. It can be deduced from this study that the surveyed areas can be radiologically safe if the exploration and exploitation activities in the area are checked with standards.

ACKNOWLEDGMENTS

The authors wish to appreciate the staffs and management of Seplat energy facility. The authors also wish to appreciate indigenes of the host communities during the period of this research work.

Conflict Of Interest

The authors hereby declare that there are no conflicts of interest.

REFERENCES

1. Hilal, M.A., Attallah, M.F., Mohamed, G.Y. & Fayez-Hassan, M. (2014). Evaluation of Radiation Hazard Potential of TENORM Waste from oil and Natural Gas Production. Journal of Environmental Radioactivity. 136:121-126.
2. Alnabhani, K., Khan, F., & Yang, M., (2018). Dynamic Modelling of TENORM ExposureRisk During Drilling and Production. J.Petrol Explor Prod Technol. 8:175-188.
3. Ali, M.M.M., Zhao, H., Li, Z., & Maglas, N.N.M. (2019). Concentrations of TENORMs in The Petroleum Industry and Their Environmental and Health Effects. RSC Adv. 9(67):39201-39229.
4. Enyinna, P.I. & Uboh, U.G. (2017). Radionulide Analyses of Ingested Water from some Estuaries within the Coastal Area of Akwa Ibom State, Nigeria: J. Radiol. Prot. 37:97-110.
5. Agbalagba, E.O., Avwiri, G.O., & Chad-Umoren, Y.E. (2013). Radiological impact of oil and Gas Activities in selected oil fields in Production Land. J. Appl. Sci. Environ. Manage. 17(2):279-288.
6. Ademola, J.A. (2008). Determination of natural radionuclides content in some building materials in Nigeria by gamma-ray spectrometry. Health Physics 94(1):43-48.

7. Laogun, A.A. Ajayi, N.O. & Agaja, S.A. (2006). Variation in wellhead gamma radiation levels at the Nigeria Petroleum development company oil field, Ologbo Ede State, Nigeria. Nig. J. Phys, 18(1):135-140.
8. Chad-Umoren, Y.E. & Briggs-Kamara M.A. (2010). Environmental Ionizing Radiation Distribution in Rivers State, Nigeria. Journal of Environmental Engineering and Landscape Management. 18(2):154-161
9. Anekwe, U.L. & Enyinna, P.I. (2017). Background Radiation Studies from NORM within the Eastern Oilfields and Facilities in Nigeria. International Journal of Advanced Research in Physical Science (IJARPS) 4(6):57-64.
10. Californian DHS (Department of Health Services) (1996). A study of NORM associated with oil and gas production operations in California.
11. United States Environmental Protection Agency, Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM) Available:www.epa.gov/radiation (Retrieved on 24/01/2025).
12. Elena, B. & Gracea, C. (2004). Radiological impart assessment on behalf of oil/gas industry. Journ. Preventive Med. 12(1-2):16-21.
13. Doust, H. & Omatsola, E. (1990). Niger Delta. A. A. P. G. Memoir. 48:201-238.
14. Avwiri, G.O., Agbalagba, E.O., & Enyinna, P.I. (2007a). Terrestrial radiation around oil and gas facilities in Ughelli Nigeria. Asian Network for Science Information. J. Applied Sci. 7(11):1543-1546.
15. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), (2000). Sources, effects and risk of ionizing radiation. Report to the General Assembly. ISBN 92-1-142238-8, New York.
16. Ijabor, B.O., Omojola, A.D., Nwabuoku, A.O., and Omojola, F.R. (2023). Radiation hazards from granite and bitumen in construction material site in Aniocha South Local Government Area of Delta State, South-South Nigeria. Radiation Physics and Engineering. 4(2):1–8.
17. Mokobia, C.E., Nwabuoku, A.O., and Igbeka, C. (2020). Indoor Radon Concentration Measurements in Houses of Selected Communities in Delta Central of Delta State. Nigerian Journal of Science and Environment 18:(2).
18. NCRP (1999). National Council on Radiation Protection and Measurements. Limitation of Exposure to Ionizing Radiation, NCRP Report No. 116 (National Council on Radiation Protection and Measurements, Bethesda, Maryland.
19. International Atomic Energy Agency (IAEA), (2002). Optimization of Radiation Protection in the Control of Occupational Exposure, Safety Reports Series No. 21, IAEA, Vienna for protecting people and the environment.
20. Ugbede, F.O. and Akpolile, A.F. (2019). Determination of Specific Activity of ^{238}U, ^{232}Th and ^{40}K and Radiological Hazard Assessment of Tuomo River Sediments in Burutu, Delta State, Nigeria. J. Appl. Sci. Environ. Manage. Vol. 23 (4) 727-733.
21. Beretka, J. and Mathew, P.J. (1985) Natural radioactivity ofAustralia building materials industrial wastes and by-products. *Health Phys*. 48:87–95.