NATURALLY OCCURING RADIOACTIVE MATERIALS AND THEIR EFFECTS IN THE ENVIRONMENT - A REVIEW.

[1]Naziru Imam, [2] Umar Mansir, [3]Anyiam Ngozi D., [4]Muhammad Bashir R.

[1,2,3]Mr.

[1]Department of Pure and Industrial Chemistry, Faculty of Natural and Applied Sciences
Umaru Musa Yar'adua University, Katsina, Nigeria.

Abstract *: Naturally occurring radioactive materials (NORMs) is a term given to elements that are naturally radioactive and radiologically hazardous to mankind and environment. This paper reviewed the chemistry of NORMs and their effects on the environment. The study showed that naturally Occurring Radioactive Materials are hazardous, and the long-term health implications on living things and the environment at large is reported. This calls for appropriate care by all, in order to ensure that healthy environment is maintained. The ways by which these NORMs's hazardous effects on the environment can be minimized or controlled are also briefly highlighted.*

IndexTerms- **Radioactive; Harzadous; NORMs; Implications; Environment.**

INTRODUCTION

The security of the citizenry and the health rating must be put into consideration in evaluating the national development and standard of living of any nation. Our environment is associated with number of components among which are, soil, rocks and trees. Soil and groundwater contamination is a common concern in many countries. A wealth of studies describes methods and technologies used for remediating contaminated environments[3]. This literature has traditionally been dominated by studies based on a narrow range of remediation benefits. They often involve cost benefit analysis, and the best-value remedial design is defined as the one which involves the lowest cost for an effective remedy over the lifetime of the remedy, whilst maximizing other key factors such as land value [6].

Over time, the scope of remediation practice has extended to include the "lost" costs and benefits of remediation, or what welfare economists call the "positive and negative externalities" [5] associated with contaminants [17]. Consideration of externalities has led to more comprehensive appraisals of the impacts of remediation decisions upon the total Environment [14]. These appraisals have involved engagement with a multitude of participants ranging from representatives of major multinational corporations to local neighbours, and they have been influenced by an increased focus on sustainability across diverse international jurisdictions. This has acted as a driver in remediation processes [2]; [15].

All radioactive elements or substance emit radiation, especially those that are found in nature. Since all materials contain radio nuclides of natural origin it was emphasized by several speakers that there is need to distinguish between the few that require regulatory attention and the vast majority that do not. The fact that NORMs is an acronym for naturally occurring radioactive materials, had led to a tendency in some quarters for all minerals to be regarded as NORMs, with erroneous implication that they were therefore all radiologically hazardous and in need of regulatory control.

One attempt to distinguish those materials that need to be regulated had been to introduce the term TENORM an acronym for technically enhanced NORM, but it was pointed out that this did not solve the problem and was potentially confusing, because there was no direct correlation between the need for regulation and the application of any industrial process [10].

All minerals and raw materials contain radio nuclides of natural origin, of which the most of exposure to these radio nuclides are not significantly greater than normal background levels. Important for the purposes of radiation protection are the radio nuclides in the ^{238}U and ^{232}Th Decay series and ^{40}K. For most human activities involving minerals and raw materials, the levels such exposures, while having been the subject of much research, are not of concern for radiation protection. However, certain work activities can give rise to significantly enhanced exposures that may need to be controlled by regulation. Material giving rise to these enhanced exposures has become known as naturally occurring radioactive material (NORM) [10].

Radioactive materials, sealed sources and radiation generators are used extensively by the oil and gas industry, and various solid and liquid wastes containing naturally occurring radioactive materials (NORMs) are produced. The presence of these radioactive materials and radiation generators results in the need to control occupational and public exposures to ionizing radiation.

Various radioactive wastes are produced in the oil and gas industry, including the following:

a) Discrete sealed sources, e.g., spent and disused sealed sources;

b) Unsealed sources, e.g., tracers;

c) Contaminated items;

d) Wastes arising from decontamination activities, e.g., scales and sludge [11].

NATURALLY OCCURING RADIOACTIVE MATERIALS (NORMs)

Opinion differs on what exactly is meant by the term NORMs. Reports of the occurrence of significant concentrations of radio nuclides of natural origin in the oil and gas industry go back to 1904 and it seems that the term NORMs was first coined by this industry when referring to radium rich scales deposited inside well tubular, surface piping, vessels pumps and other production and processing equipment. Since then the term NORMs has become widely adopted beyond oil and gas industry and now tend to be associated with almost any type of mineral processing activity where the presence of radio nuclides of natural origin is of interest [18].

Therefore, radioactive materials which occur naturally and expose people to radiation occur widely, and are known by the acronym 'NORM' [11]. Also Naturally Occurring Radioactive Materials (NORMs) are defined as radioactive substances that exist in all natural media: soils, rocks, water, and even air [16].

Similarly NORMs are materials that can be found in many geological formations and may be brought to the surface during oil/gas drilling and abstraction. Once at the surface it may accumulate in scales and sludge on and within drilling and processing equipment. It may also accumulate in brines and sediments within holding tanks or ponds [4].

According to Friedlander [8] NORMs are elements found in natural material sources with atomic number greater than 83 (Bismuth).

TECHNICALLY ENHANCED NATURALLY OCCURING RADIOACTIVE MATERIALS (TENORMS)

TENORMs is an acronym for solid materials containing human made elevated concentrations of naturally occurring radioactive elements [12]. The exploitation of crude oil and natural gas are very often connected with strong enhancement of radium isotopes, ^{210}Pb and ^{228}Th. Generally, TENORMs are radioactive materials brought onto the earth surface by human made activities, such as mining, exploitation of crude oil and other natural underground resources. In order to remediate, minimise and control NORMs and TENORMs in the environment, the search of literature on their sources, chemistry and health implications is significant and is indeed a good starting point.

NORMs IN GENERAL.

The international atomic energy agency (IAEA) establishes principles, requirement and guidance with respect to radiation protection and safety in its Safety Standard Series publications, comprising Safety Fundamentals, Safety Requirements and Safety Guides. The Safety Guide on Occupational Radiation Protection provides general guidance on the control of occupational exposure.This guidance is based on the requirements contained in the International Basic Safety Standards for Protection against Ionizing Radiation and the Safety of Radiation Sources (BSS). The objectives, concepts and principles of radioactive waste management are presented in the Safety Fundamentals publication on The Principles of Radioactive Waste Management. [11]

The NORM occurs reservoir rock contains small amounts of natural uranium and thorium and their radioactive daughters. One daughter, radium, is water soluble and dissolves in reservoir water. Radium can precipitate with the barium and calcium ions to make any scales slightly radioactive. Clay and fine particles can absorb the radium from the formation water. The radionuclides identified in oil and gas streams belong to the decay chains of the naturally occurring primordial radio nuclides ^{238}U and ^{232}Th. The presence in subsurface formations from which hydrocarbon are produced, these parent radionuclides have very long half-lives and are ubiquitous in the earth's crust with activity concentrations that depend on the type of rock. Radioactive decay of ^{238}U and ^{232}Th produces several series of daughter radioisotopes of different elements and of different physical characteristics with respect to their half-lives, modes of decay, and types and energies of emitted radiation [11].

Some elements have isotopes, which exist when a chemical element has the same number of protons (atomic number) as another, but a different number of neutrons, and thus a different mass. Radioisotopes are isotopes with an unbalanced number of protons and neutrons. This result in an unstable nucleus which undergoes radioactive decay until it is stable. For example, uranium-238 (^{238}U) and ^{235}U have similar chemical behavior, but have different atomic masses, and thus different physical and radioactive properties. Primordial radioisotopes, such as ^{238}U, and thorium-232 (^{232}Th), are those that originated from the fusion of multiple elemental nuclei during one or more supernovae (star collapse) over 6 billion years ago. These isotopes have not all decayed because their half-lives (the amount of time it takes for half of a quantity of a given radioactive element to decay) are so long that there are still many atoms left to decay. Nearly all rocks and soil contain some levels of uranium & thorium, their daughter products, and 40K. The concentrations of these isotopes vary based on the type of rock [16].

In the absence of suitable radiation protection measures, NORM in the oil and gas industry could cause external exposure during production owing to accumulations of gamma emitting radio-nuclides and internal exposures of workers and other persons. Particularly during maintenance, the transport of waste and contaminated equipment, the decontamination of equipment, and the processing and disposal of waste. Exposures of a similar nature may also arise during the decommissioning of oil and gas production facilities and their associated waste management facilities [11].

SOURCES OF NORMS

Naturally occurring radioactive materials can be obtained mostly form the following main sources;

1. Naturally Occurring Radioactive Sources (Isotopes)

Sixty-five naturally occurring radioactive isotopes are currently known. In the chart of nuclides, these naturally occurring radioactive nuclides are highlighted either by a black band at the top of the square or, for nuclides forming the naturally-occurring radioactive decay chains, a smaller black rectangular area near the top of the square in which the symbol corresponding to the historic name of the nuclide is given [8].

These isotopes generally belong to one of three classes:

A. Cosmogenically produced nuclides present in the atmosphere

This class of naturally-occurring radioactive materials includes ^{3}H, ^{7}Be, and ^{14}C. These isotopes are all formed in the atmosphere at concentrations greater than 0.01 picocuries per kilogram of air by reactions initiated by cosmic rays. Both ^{3}H and ^{14}C decay by β^- emission and have half-lives of 12.32 and 5715 years, respectively. Both have been used to determine the ages of objects that contain them. ^{7}Be decays by electron capture and has a half-life of 53.3 days. Filters through which air has passed are radioactive due to both ^{7}Be and radon chain products, which deposit on dust and airborne particles.

B. Unstable nuclides having lifetimes sufficiently long to have survived from the time the elements were formed

Materials belonging to this class, along with their half-lives (in years) and abundances are listed in Table 1. These isotopes decay by β^+, ε, β^-, or decay and, with the exception of ^{232}Th, ^{235}U, and ^{238}U, form stable products. The three nuclides, ^{232}Th, ^{235}U, and ^{238}U are the parents of naturally-occurring radioactive decay series and are discussed below. As can be seen in the Table, in addition to the very long half-lives, many materials in this group have very low abundances resulting in low activities and making them difficult to detect. A few nuclides, for example, ^{82}Se, ^{116}Cd, and ^{130}Te, have been found to decay by $\beta^-\beta^-$ emission with half-lives greater than 10^{19} years. Because of the unusual type of decay and extremely low activities, these nuclides were not given much consideration.

Table 1: Long-Lived Naturally-Occurring Radioactive Isotopes

Isotope	Decay	Half-life (yr)	Abund (%)	Decay Products
^{40}K	β^- β^+	1.27E09	0.0117	^{40}Ca, ^{40}Ar
^{50}V	ε, β^-	1.40E17	0.250	^{50}Ti, ^{50}Cr
^{87}Rb	β^-	4.88E10	27.83	^{87}Sr
^{113}Cd	β^-	7.70E15	12.22	^{113}In
^{115}In	β^-	4.40E14	95.71	^{115}Sn
^{123}Te	ε	6.00E14	0.89	^{123}Sb
^{138}La	ε, β^-	1.05E11	0.090	^{138}Ba, ^{138}Ce
^{144}Nd	α	2.38E152	3.80	^{140}Ce
^{147}Sm	α	1.06E11	14.99	^{143}Nd
^{148}Sm	α	7.E15	11.24	^{144}Nd
^{152}Gd	α	1.1E14	0.20	^{148}Sm
^{176}Lu	β^-	3.75E10	2.59	^{176}Hf
^{174}Hf	α	2.0E15	0.16	^{170}Yb
^{180m}Ta	ε, β^+	>1.2E15	0.012	^{180}Hf
^{187}Re	β^-	4.12E10	62.60	^{187}Os

^{186}Os	α	2.E15	1.59	^{182}W
^{190}Pt	α	6.5E11	0.014	^{186}Os
^{232}Th	α	1.40E10	100	^{208}Pb
^{235}U	α	7.04E08	0.720	^{207}Pb
^{238}U	α	7.47E09	99.2745	^{206}Pb

C. Naturally-occurring radioactive decay chains

This class is made up of three most important nuclides which are U, Th, and Ac. All decay to shorter-lived radioactive daughters forming long chains or radioactive series. Because the parents are found in nature, their daughters achieve a significant equilibrium concentration where the parent activity is found [8].

NORMS DECAY SERIES

Naturally occurring radioactive decay series generally consist of three major Nuclides (radioactive nuclides) of which their concentration is of significant consideration. These includes;

1. The first series, known as the Thorium Series, consist of a group of radio nuclides related through decay in which all the mass numbers are evenly divisible by four (the 4n series). The series has its origin in the radionuclide ^{232}Th (abundance x=100 %, specific activity S =2.4 x 10^5 χ dpm g^{-1}) which undergoes α-decay with a half-life of 1.41 x 10^{10} years. The terminal nuclide in this decay series is the stable species ^{208}Pb which is also known as ThD. The transformation from the original parent, ^{232}Th to the final product ^{208}Pb requires 6α and 4 β-decays. The longest-lived intermediate is 6.7y ^{228}Ra. [8].

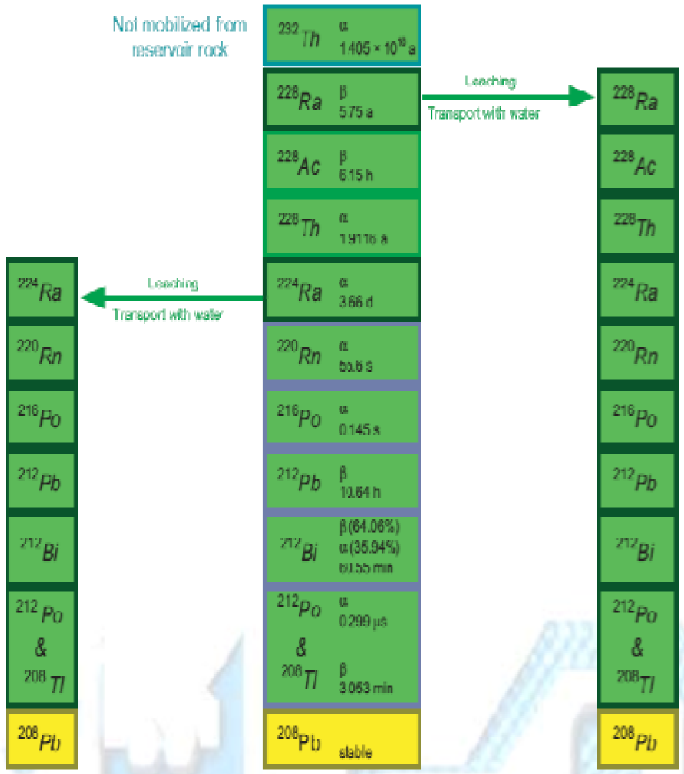

Fig: 1.1 **^{232}Th decay series** [11]

2. The second series is Uranium series (also known as 2n + 4 series); it commences with the parent element uranium-238 (^{238}U) and terminates with the stable element lead-206 (^{206}Pb). The transition from Uranium-238 to lead-206 requires 8 α-and 6 β-decay steps. The series derive its name from uranium-238 which is the prominent member of the series and has the longest half-life [1].

3. Actinium series is the third series which start with the radioactive element Uranium-235. The end product is the stable element lead-207. This series derived its name from the prominent member actinuim-227 [1]. The series is also known as 4n + 3 series, which means the various masses of the daughter nuclides are divisible by 4 with reminder of 3. The stable end product of the series is ^{207}Pb, which is formed after 7α and 4 β-decays. The actinium series includes the most important isotopes of the elements protactinium, actinium, francium, and astatine. Inasmuch as ^{235}U is a component of natural uranium, these elements can be isolated in the processing of uranium minerals [8].

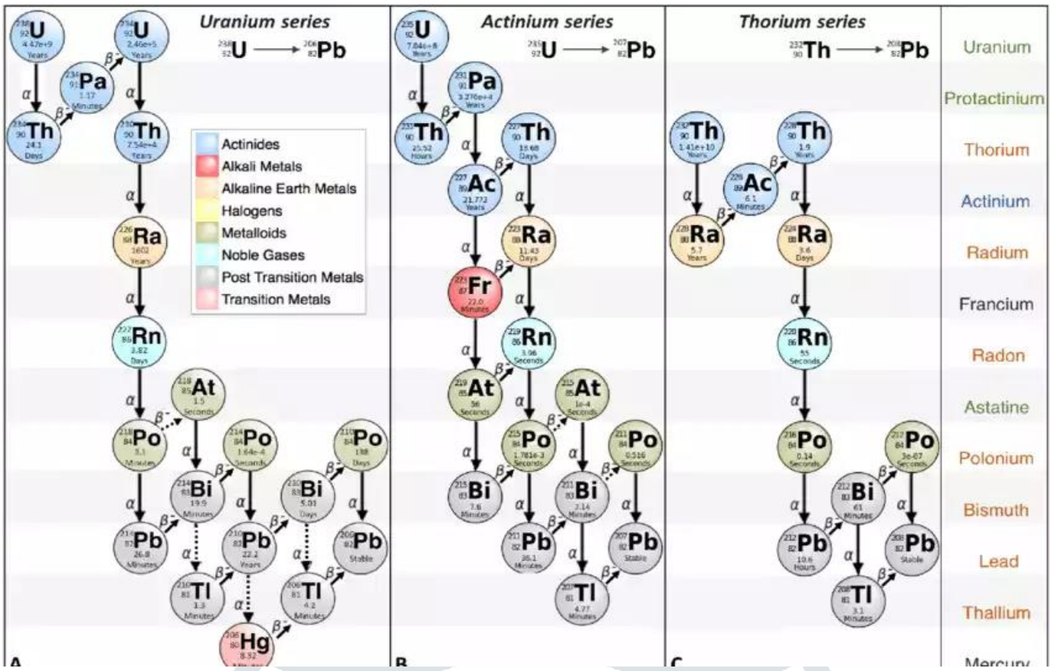

Fig. 1.3: Actinium Decay Series

4. This last series consists of a group of radio nuclides whose mass number when divided by 4 has a remainder of 1 (the 4n + 1 series). This series is known as the Neptunium series since the longest-lived and therefore parent, species is ^{237}Np which undergoes α-decay with a half-life of 2.1 x 10^6 y. In as much as this half-life is considerably shorter than the age of the Earth, ^{237}Np can no longer exist on Earth, and, therefore, the Neptunium series is not found as a natural occurrence. However, it has been discovered in the spectra of some stars. ^{237}Np is formed in nuclear reactors from uranium by thermal neutrons. ^{235}U(n,γ) ^{236}U(n,γ) ^{237}U and by fast neutrons ^{238}U(n,2n)^{237}U

The end product of the Neptunium series is ^{209}Bi, which is the only stable isotope of bismuth. Seven α-decays and 4 β-decays are required in the sequence from the parent ^{237}Np to ^{209}Bi. An important nuclide in the Np decay series is the Uranium isotope ^{233}U, which has a half-life of 1.8x 10^5y (the most stable intermediate) and like ^{235}U, is fissionable by slow neutrons [8].

HAZARDS OF NATURALLY OCCURING RADIOACTIVE MATERIALS

All radioactive materials weather natural or artificial emits radiation of different types, depending on the nature of the material. These radiations include alpha, beta and gamma.

The energy being emitted by gamma specifically is more powerful than that emitted by alpha and beta, and hence it is more hazardous.

NORMs generally, are radioactive and the radiation being emitted is hazardous to some extent, depending on the exposure, strength and nature of the energy being emitted.

Some of the hazardous effect of NORMs are as follows:

The hazardous elements found in NORMs are Radium 226, 228, and Radon 222 and also daughter products of these nuclides. These elements are referred to as “bone seekers” which when inside the body migrate to the bone tissue and concentrate. This exposure can cause bone cancers and other bone abnormalities.

Radium nuclides emit alpha and beta particles as well as gamma rays. The radiation emitted by radium 226 atom is 96% alpha particles and 4% gamma rays. The alpha particle is not the most dangerous associated with NORMs. Alpha particles are helium nuclei. Alpha particles travel short distance in air, only 2-3cm, and cannot penetrate through a dead layer of skin on the human body. However some radium alpha particles emitters are “bone seekers” due to radium possessing a high affinity for chloride ions. In the case that radium atoms are not expelled from the body, they concentrate in areas where chloride ions are prevalent, such as bone tissue [13].

SOLUTIONS TO THE HAZARDS OF RADIOACTIVE MATERIALS

1. Decontamination of Plant and Equipment

The removal of NORM containing scales and sludge from plant and equipment, whether for production and safety reasons or during decommission needs to be carried out with adequate radiation protection measures having been taken and with due regard for other relevant safety waste management and environmental aspect. In addition to the obvious industrial and fire hazards, the presence of other contaminants such as hydrogen sulphide, mercury and hydrocarbons (including benzene) may necessitate the introduction of supplementary safety measures on-site decontamination is the method preferred by operators when the accumulation of scales and sludge interferes with the rate and safety of oil and gas production, especially when the components cannot be reasonably removed and replaced or when they need no other treatment before continued use.

It will necessitate arrangements, such as the construction of temporary habitats, being made to contain any spillage of hazardous materials and to prevent the spread of contamination from the area designated for the decontamination work. Decontamination work has to be performed off the site where:

a) On-site decontamination cannot be performed effectively and/or in a radiologically safe manner;

b) The plant or equipment has to be refurbished by specialists prior to reinstallation;

c) The plant or equipment needs to be decontaminated to allow clearance from regulatory control for purposes of reuse, recycling or disposal as normal waste.

Service companies hired to perform decontamination work need to be made fully aware of the potential hazards and the rationale behind the necessary precautions, and may need to be supervised by a qualified person. Personal protective measures will comprise protective clothing and in the case of handling dry scale, respiratory protection as well. The regulatory body needs to set down conditions for the:

a) Protection of workers, the public and the environment;

b) Safe disposal of solid wastes;

c) Discharge of contaminated water;

d) Conditional or unconditional release of the decontaminated components [8].

2. PRACTICAL RADIATION PROTECTION MEASURES

The requirements for radiation protection and safety established in the BSS apply to NORM associated with installations in the oil and gas industry. The common goal in all situations is to keep radiation doses as low as reasonably achievable, economic and social factors being taken into account (ALARA), and below the regulatory dose limits for workers . The practical measures that need to be taken in order to reach these goals differ principally for the two types of radiation exposure: through external radiation and internal contamination [11].

3. MEASURES AGAINST EXTERNAL EXPOSURE

The presence of NORM in installations is unlikely to cause external exposures approaching or exceeding annual dose limits for workers. External dose rates from NORM encountered in practice are usually so low that protective measures are not needed. In exceptional cases where there are significant but localized dose rates, the following basic rules can be applied to minimize any external exposure and its contribution to total dose:

a) Minimizing the duration of any necessary external exposure;

b) Ensuring that optimum distances be maintained between any accumulation of NORM (installation part) and potentially exposed people;

c) Maintaining shielding material between the NORM and potentially exposed people.

4. MEASURES AGAINST INTERNAL EXPOSURE

In the absence of suitable control measures, internal exposure may result from the ingestion or inhalation of NORM while working with uncontained material or as a consequence of the uncontrolled dispersal of radioactive contamination. The risk of ingest-ing or inhaling any radioactive contamination present is minimized by complying with the following basic rules whereby workers:

a) Use protective clothing in the correct manner to reduce the risk of transferring contamination.

b) Refrain from smoking, drinking, eating, chewing (e.g. gum), applying cosmetics (including medical or barrier creams, etc.), licking labels, or any other actions that increase the risk of transferring radioactive materials to the face during work;

c) Use suitable respiratory protective equipment as appropriate to prevent inhalation of any likely airborne radioactive contamination

d) Apply, where practicable, only those work methods that keep NORM contamination wet or that confine it to prevent airborne contamination;

e) Implement good housekeeping practices to prevent the spread of NORM contamination

f) Observe industrial hygiene rules such as careful washing of protective clothing and hands after finishing the work [11].

CONCLUSION

All minerals and raw materials contain radionuclides of natural origin, these minerals are important for exploration. Notwithstanding, NORMs are materials that are naturally radioactive and so the chemistry of NORMs is important from the mineral and health perspectives. It has long been recognized that large doses of ionizing radiation can damage human tissue. Over the years, as more was learned, scientist became increasingly concerned about the potentially damaging effects of exposure to large doses of radiation. The need to regulate exposure to radiations prompted the attention of scientist on what to do to tackle the problem and hence hazardous effect of these radiations. We all face risk in life and it is not possible to get rid of them all, but it is possible to reduce the risk to its minimal level.

The use of coal, oil and gas for example as source of electricity has to do with some risk associated with NORMs. These materials are very radioactive, and so have tremendous effect, to our environment and particularly human beings. Although no standard measure of controlling of all these radiation, precautionary measures must be put in place to prevent, internal or external exposure.

RECOMMENDATIONS

The following are hereby recommended based on the foreseen effects of NORMs:

a) Federal government of all nationals must enforce laws on the proper disposal of radiological waste either by the mining industries or co-operate bodies.

b) A mapping of each expected residential area should be given before people start settling so that if such naturally occurring radioactive materials exist, people can easily vacate the site before exposing themselves to these hazardous radiation.

c) Adequate precautionary measures must be put in place by all mining and exploration industries.

d) Proper ventilation should be ensured in area expected or confirmed to have these naturally occurring radioactive materials.

e) Subsequent researchers should dig deeper and carried out a more practical research on the state of our environment as regard to NORMs.

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