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Developing an Integrated Nuclear Waste Management Strategy on Aggregate Orphan Source Radioactive Materials in the Oil and Gas Sector.

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ABSTRACT

Orphan sourced radioactive waste materials associated with oil and gas exploration, exploitation and production have been identified as causal factors in environmental health risks of operation personnel and the host communities in the Niger Delta. These Technologically Enhanced Radionuclides such as ^{14}C, ^{40}K, ^{87}Rb, ^{232}Th, ^{288}U and some low frequency radioactive heavy metals constitute potential dangers to environmental health assay. Highly Sensitive Radiation Detection Tracers (HSRDT) were deployed for tracking and analysis of ionized leakages in the coastal marine offshore and shallow offshore areas in in a typical deltaic region. The inverse determination technique of the generalized half-life period was integrated into the model equations 1 – 12. Table 1 is a survey from 1992 t0 2015, showing that some identified radionuclides are reactive and contaminants to the surrounding environment from oil and gas processes. However, inadequate strategic decommissioning activities are responsible for severe occupational and environmental hazards to flora and fauna. This paper is fundamental to developing an integrated orphan waste management system as remedial techniques to minimize radiation waste burns and other harmful environmental effects on personnel and the environment. Its application is useful for decision-making on radioactive waste material management strategy. Furthermore, possible conceptual legal framework and standards for the disposal system of orphan sourced radionuclides in the petroleum sector could be explored.

Keywords: Radioactive Waste Materials; Aggregate Orphan–Sourced Radionuclides; Environment Management; Waste Disposal Systems; Oil and Gas Sector etc.

1.0 INTRODUCTION.

An integrated nuclear waste management strategy is an attempt to provide multi-dimensional framework necessary to reduce the risk effect of orphan radionuclides abandoned in facilities and activities undertaking in the petroleum sector. The integrated nuclear waste management strategy would be an efficient and veritable tool in the assessment, regulation, and management of orphan sourced nuclear materials in a typical marine ecosystem in the Niger Delta. The International Atomic Energy Agency (IAEA) has specifically stipulated in the publication of GSR, part 2, that nuclear materials (including used and not used nuclear radiation materials) should have established standards for implementation, assessment, continual improvement and management of nuclear facilities and activities globally. The assertion of the nuclear watchdog is to ensure safety, security, health, environment and economic enhancement for the citizenry. The global aim is to minimize the hazards and risk impacts on both personnel and the environment for improved productivity. However, the gross negligence and carelessness of human activities aside from natural occurrences in the hydrocarbon and other related industries have grown tremendously over the years with attendant proportional increase in environmental impact resulting in radiation related burns, pollution and outright degradation of both flora and fauna. To a large extent, industrialization and industrial activities in the ever-increasing petroleum exploration, production and distribution subsectors enhanced rapid deterioration of the environment, which is the consequence of accelerated nuclear waste generation without corresponding integrated nuclear waste management strategies (Innocent et al, 2016). Most important to the oil and gas sector is the issue of waste contamination and crude oil polluted marine environment, an integral of rapid waste discharge either as a result of operational mishap or sabotage of natural tendencies (Neeka, Jack and Chris, 2008). Accordingly, nuclear waste characterization and classification largely depend on the management strategies in the petroleum sector for sustainable development. However, the question that is practically fundamental in this paper is “how can orphan sourced nuclear waste be managed” to minimize health risks on the environment and enhance optimal development in the petroleum sector.

1.10 WHAT IS ORPHAN SOURCED NUCLEAR WASTE.

Remnants of used radioactive materials, when not properly disposed, constitute orphan sourced radionuclides with potential danger and risk of contamination or radiation pollution to the environment. This classification in general terms and in accordance with Chris

Maduabuchi (2005), define nuclear waste as anything from radioactive materials arising as a result of human and animal activities that are discarded as useless or unwanted". Proper de-concentration through back tracking mechanisms and disposal strategies, are essentially linked to the collaborating activities of the operators and regulators alike in the oil and gas sector, to regulate and control potential nuclear waste harmful effects on the environment.

Following from the above, nuclear waste could be any nuclear materials that is no longer needed by the primary source (original user) which is either discarded or abandoned." In 2009, regulators in England and Wales managed a total of around 134Million tonnes of radioactive waste materials: 46.5Mtons were land sourced for land filled; 41.9Mtons were transferred, before final disposal or recovery; 24.4Mtons were treated and de-concentrated; 13.2 were handled through metal recycling facilities; 5.4Mtons were incinerated" (Environmental Agency, 2010). Similarly, soil and marine waters contain about 8ppm of Thorium alone described as the highest sources of nuclear energy, even more reactive than Uranium, (Balogun, 2015). According to the World facilities Nuclear Association, 2014, most developed economies have experience using Thorium as nuclear fuel and in oil and gas exploitation. It is a naturally occurring nuclides with high potential to radiate emissions, when uncovered and or abandoned in its natural habitat. It is worthy of note here that what 'A' would regard as waste could as well be useful start- up material for 'B' hence the need for waste management. To take this discussion further, we will critically look at the various technologies/ techniques available to properly manage nuclear waste so that the society will be more environmentally friendly and a safe place to live.

2.0 WASTE MINIMIZATION TECHNIQUES

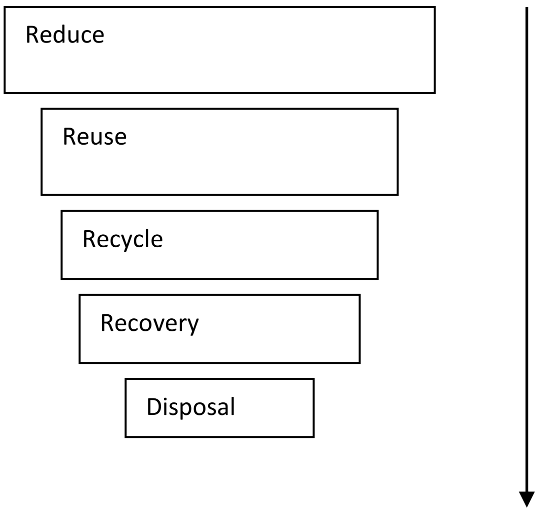

Fig 1: Waste minimization techniques in descending order

2.10 Reduction

This approach requires a control use of the initial start-up material so that the left-over could be minimal. It entails generating less waste through more efficient practices; the entire production process should be looked into to find out if there are other ways to produce the same product with minimal waste (material purification) or look at changing the raw material (feed); modifying the production facility (equipment, piping, layout changes, provide additional automation); observe changes in operational settings, material handling improvement and production scheduling; ordering of chemicals in bulk to reduce the number of containers requiring disposal. The above considerations should be made based on the "Best Available Techniques Not Entailing Excessive Cost" (BATNEEC).

2.20 Reuse:

Depending on the type of waste in general and nuclear waste under reference, this can be done on site or off site. Basically, most Industrial waste can be reused on site. This is achieved by returning it to the original process or making it a substitute for another process. An example is "chemical container buy-back option" rather than disposing the container it could be bought back and reused. The residue from the atmospheric distillation unit (ATU) in a crude oil refining process is not discarded but taken to the Vacuum distillation unit (VDU) and then to Fluid Catalytic Cracking Unit (FCCU) and Pyrolysis unit. You can decide to reuse your water bottle rather than discard it. However, the potency to reuse orphan sourced nuclear waste appear not to be an on-site success. It will require an automated cycle in a nuclear plant.

2.30 Recycle:

Nuclear waste could be processed for resource recovery or taken back into the production facility and processed as a by-product. This is done based on the "Best Practicable Environmental Option" (BPEO). Recycling entails converting waste back into suitable and usable materials. Examples include recycling of old metals or plastic products; paper into toilet rolls etc. This is the recommended back tracking process for radioactive materials used for various oil and gas facilities and activities.

2.40 Recovery:

Extracting energy or material from waste for other uses; waste can be burnt in an incinerator to produce heat and steam which can be converted to electricity. An example is the Sheffield waste incinerator used for the generation of electricity. "About 70 percent of the components that comprise solid waste are organic; the potential for the recovery of energy is high" (Peavy et al, 1985).

2.50 Disposal:

The least desirable option for waste minimization is disposal. This option ranks at the far bottom of the chart in figure 1. It is still an option because modern day science and technology have not found a way to eliminate waste. Waste disposal is accomplished through land filing. Land filing entails the controlled disposal of waste beneath the earth's surface, usually carried out on a selected site that has undergone environmental impact assessment test. Before the final disposal, waste is usually collected into different containers. Here in Sheffield, different containers have been provided to separate waste. This is then transferred from smaller collection vehicle to larger vehicle; the process is called transfer and transport. The waste is taken to processing facility to improve upon it making it less toxic and recovery of conversion products and energy before the final disposal.

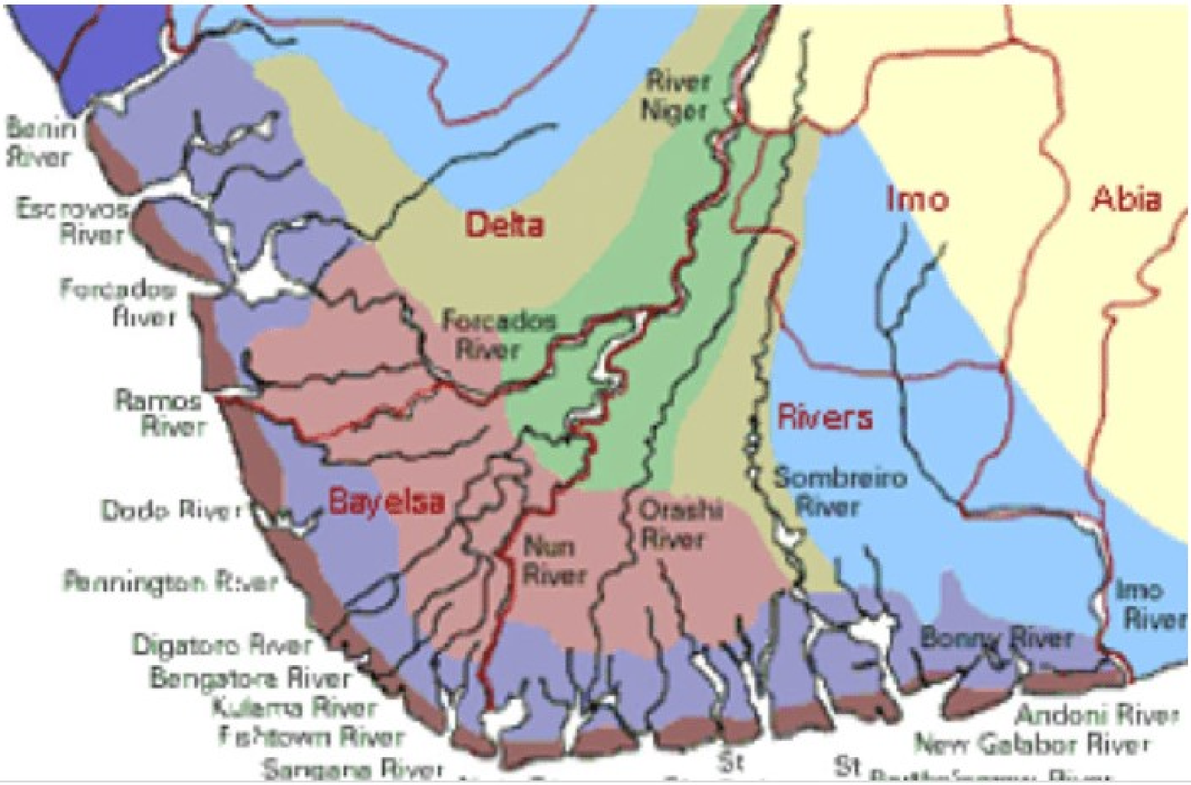

Fig 2: Niger Delta Map Showing Marine Ecosystems; Google Search 18th Jan. 20.

3.0: REGIONAL OUTLOOK AND CAPACITY BUILDING MODEL

Although a national outlook of radiation waste management system covers both inland and offshore territorial integrity of the country, the typical deltaic region indicated gross shift in concentration of nuclear radiation in areas of industrial utilization for oil and gas activities. Fundamental to the spread is the available marine ecosystem covering about twenty-eight rivers from Benin to Imo, Fig 2. The Marine ecosystem therefore influenced and enhanced the nucleotides wavelength spread and migration by diffusion in the water body (Balogun, 2015). The highly reactive radionuclides of orphan sourced origin are detrimental to the environment. The deployment of this model would be useful in the control, monitoring and evaluation processes with the determination to forecast the future effects on man and materials. Naturally, the marine ecosystem is the habitat for all marine lives and constitute sources of food, health, wealth, comfort and aesthetics to human being within its territorial existence. Marine ecosystem in the typical Niger Delta region form the original living pattern and standards of the people but, gradual degradation, pollution, depletion and extinction of those natural marine lives, affects the living standards of the people as a whole. Nuclear radiation from orphan sourced radioactive material is one major sources of marine pollution and grossly enhance the depletion of notable aquatic lives within the area. The economic and health risks associated with nuclear radiation on man and materials could be catastrophic and ultimately need to be seriously put under strategic control by regulators and operators alike.

3.01: CAPACITY BUILDING MODEL

Constant review of capacity building and competency development programmes and the activities that actuate capabilities are imperative for a regulator in the determination of the areas of isolated orphan source radioactive materials in the country. In the context of this paper, capacity building models are multi-phased covering various areas of administrative indicators for the effective regulation of radioactive materials in the industry. For instance, planning strategy is envisaged to address the potency of authorization before use from operators through standard regulation policy. Regular inspections and enforcement criteria are fundamental to the assessment and quantification of available sites of that captures the actual statistics on orphan sourced radionuclides Figures 3 and 4 are typical administrative model for building capacity for a structured regulatory authority, (NNRA, 2015). Essentially, capacity building models must include the safety culture that takes cognizance of radiation risk awareness and hazards related to the work place and working environment. Safety and safety standards form the crucibles of radiation waste management in the oil and gas sector. Furthermore, safety culture must avoid safety degradation, support and encourage communication in reportage of operational deficiencies, system incompetence and technical ineffectiveness in the conduct of facilities and activities relating to nuclear waste management. Interestingly, capacity building models integrate leadership component as core in the actualization of the mandate of regulatory control of nuclear materials, globally. Therefore, capacity building culture must provide leadership with purpose, vision and core-values in the handling of and management of nuclear wastes in the oil and gas industry. Such leadership structure will undertake activities in operational demands that stipulate health, safety and protection guidelines, regulatory control regimes for all activities involving ionizing radiation in a typical marine ecosystem. Global best practices position capacity building models to be sensitive to rational decision making. Accordingly, radiation control design is expected to prepare leaders to make objective and informed decisions through professionalism, consistent regulatory processes and legislative framework that bench-mark international standards of experience organizations and individuals. It must take note of the need to collaborate with local and foreign regulators, laboratory operators, management professionals etc. in the area of nuclear radiation remediation to foster exchange of knowledge, transfer of technology and building of skills for incubation in-country. There are fundamentally three strategic components of the capacity building model that enhances strong management of radioactive materials in the industry. These include: measurement, assessment and improvement processes based on sourced information. Capacity building programme is naturally design to measure closely associated demand-supply relationship between operators and regulators in specific operational territory. In the context of this paper, a typical marine ecosystem is identified to curb abuse, neglect, and nuclear material diversion for destructive purposes. The measuring method is based on IAEA established standards. Evaluation are periodically carried out to ensure conformity with international best practices. Evaluation are predicated on set out targets and defined key performance indicators. Most assessment in capacity building programme are contracted for external assessors, and in some cases, carried out internally. Surveillance and on-the-job monitoring could also equip personnel in the competency training and in developing achievable goals in regulatory activities in the oil and gas sector. Finally, reviews are carried out to maintain safety standards and reduce risk to man and material, thereby improving productivity through effective performance.

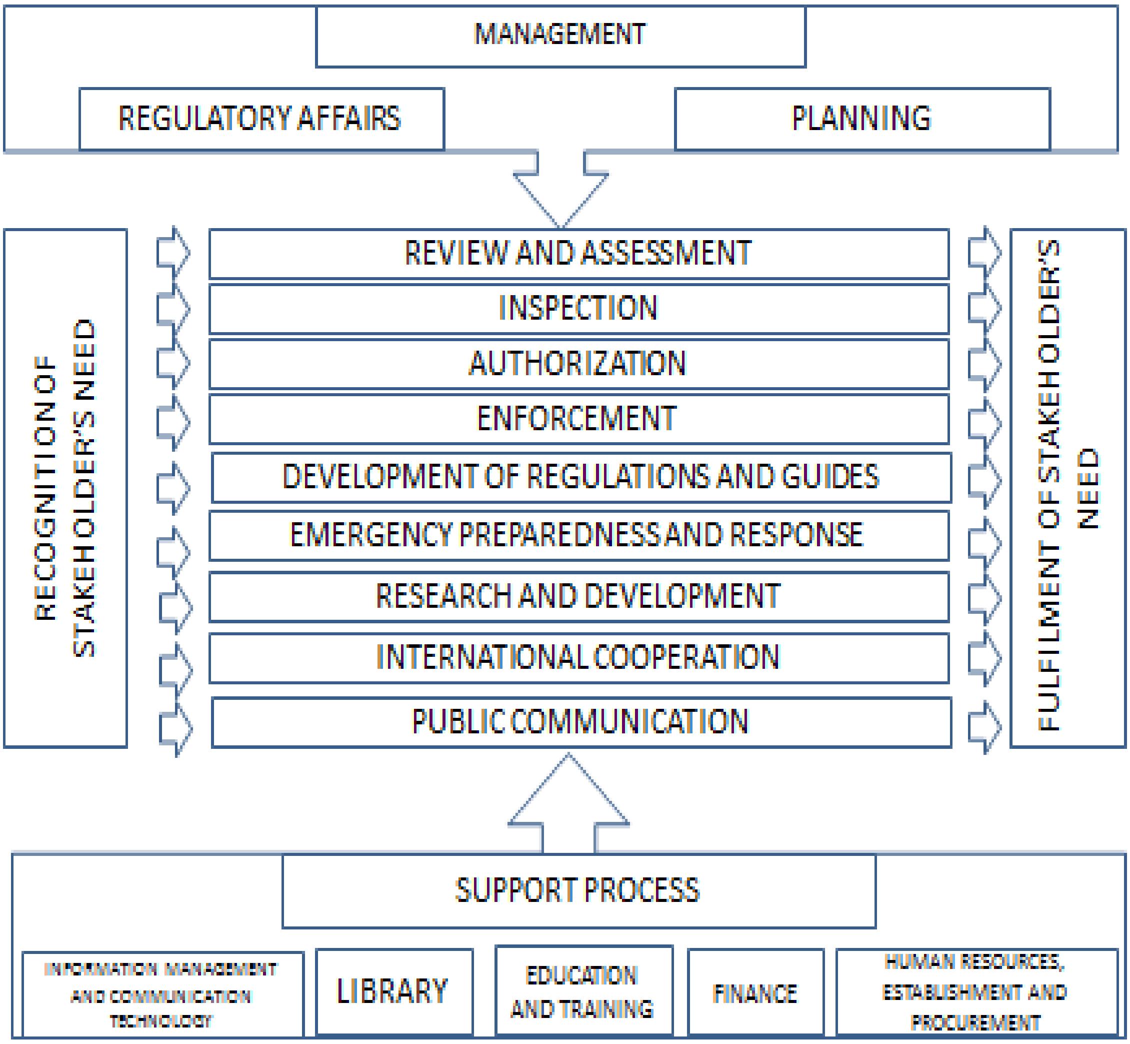

Fig 3: Strategic Personnel Nuclear Waste Management Structure, NNRA 2019.

3.10: MATERIALS AND METHODS

A review of existing data from the documented Department of Petroleum Resources (DPR, report 2016) indicated that radiotracers and electron beam treatment devices were deployed to monitor seepage leakages for back tracking orphan sourced radioactive materials in various fields in the typical Niger Delta Offshore ecosystem. Several types of radioactive sourced materials that were used in prospecting, mining and production processes either in well logging, seismic interpretation, surface gauging, scanning, NDT testing, X-ray diffractions, density analysis, drilling and instrumentation activities etc. abounds. For efficient monitoring, portable dosimeters and contamination monitors carefully calibrated were deployed for rapid collection, analysis and de-concentration of the ionize particles within the mapped out identified marine environment. Both electron beam and radiation wavelength tracers could track the seepage intensity of radionuclides and synchronize it to give the potency of radiation control. They also indicate the quantum of radiation for proper optimization of exposure against doses for health, safety and security of personnel and the environment. A mathematical model on radiation dispersion in marine ecosystem was also used as tool for monitoring and evaluation of polluted marine environment and distortion to oil and gas platforms aesthetic quality. Tests and experiment results were compared with the recommendation of Federal Environmental Protection Agency (FEPA) 1991 as cited in Department of Petroleum Resources (DPR) (2009). The initial random survey carried out by the DPR is presented in Table 1. Finally, a simplified model to predict the extent of dispersion of radionuclide spread in water from the deep offshore operation was introduced to monitor the rate and recovery time respectively. Critical administrative analysis of all results from the established research path in Table 1, form the compass on the various remedial measures on nuclear waste management, waste control and waste monitoring as discussed in this paper.

3.20: MATHEMATICAL MODEL EQUATIONS

Fundamentally, all radioactive nucleus decay with the passage of time, depending on the nature and composition of the state of the radionuclides. The basic law of radioactive nuclide decomposition states that if *N* at time *t* decays, and if no new nuclei are introduced (orphan source) into the environment, then *dN* decaying in time t is directly proportional to *N,* the number of radio nuclides at time *t*., Maduabuchi (2005);

It implies that;

$$\frac{dN}{dt} \ @\ N \text{ -------------------- } (1)$$

$$-\frac{dN}{dt} = \lambda Ndt \text{ --------------- } (2)$$

Where λ is the decay constant of the identified radionuclide over time, t

$$dN = -\lambda Ndt \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots...\ (3)$$

$$\frac{dN}{N} = -\lambda dt \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (4)$$

Integrating both side of the equation and rearranging with respect to N, yield;

$$N_{(t)} = N^{e-\lambda t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (5)$$

It follows therefore that;

$$t_{1/2} = \frac{In2}{\lambda} \ \ldots\ldots\ldots\ldots\ldots\ldots\ (6)$$

Equation 6 is the half-life of the radionuclide, which when determined, could be used to estimate the duration of the radioactive efficacy of the nuclear materials in the environment. The inverse of the half-life is the lifetime duration of existence of the radiation from the nuclear materials, and should be estimated to give the lifetime that the nucleus will survive before the actual decay is completed in the field.

Furthermore, for a single-phase oil activity model involving well logging or seismic testing of hydrocarbon in a marine environment, the equation of radiation wave flux is given as:

$$\lambda = 21 \times a + 0.03 \times b^2 + 1300 \times c^3 \qquad (7)$$

Where λ = radiation wave flux as pollutant concentration, a = CH_4, b^2 = NOx, C^3 = Sox, principal components of a typical hydrocarbon source.

$$\lambda = f\prod \Sigma F \upsilon i \qquad (8)$$

The pollutant concentration is defined with respect to the decay element and dispersion period within the tidal wave frequency. This is the element of the radionuclides needed for seismic and well logging signals in the industry.

$$\lambda = K^1 \prod \Sigma F \upsilon_i \qquad (9)$$

And K^1 is the dispersion value index factor. ΣF is the sum of the constant and υ_i is the sum of the independent variables.

$$\text{Recall that } \tau = f(T) \qquad (10)$$

Where T is time of dispersal of the decayed pollutant as a fraction of the lifetime of the radionuclide of the radioactive material and τ is the quantity of the nuclides in the marine environment determined per time, T.

$$\text{Hence, } T = K'' \tau \qquad (11)$$

If we assume that K' = K", then substitute equation (9) into (11) and rearranged yield:

$$\tau = \frac{K'' \Sigma F \upsilon_i}{\lambda K' T} \qquad (12)$$

Equation 12 is the decay radionuclide pollution concentration value index in a typical marine environment. This is the actual causal factor for radiation burns and environmental contaminations experienced from orphan sourced radioactive materials in the oil and gas sector.

4.0: RESULTS AND DISCUSSIONS

The techniques in nuclear waste measurement, monitoring and control and the various models elaborated above would help to reduce the inherent danger posed by the huge amount of orphan sourced nuclear waste generated daily through man-made activities in the oil and gas industry. For instance, Table 1 represent speculative survey data. Multi-dimensional evaluation of various activities in the upstream, mid and downstream operations respectively. The data covers an extended period from 1992 to 2016 activities. The total dissolved solids (TDS), Total Suspended Solids (TSS), cations and anions are sources of concern to human and the marine environment, especially oil platforms. Strong ionize radiation are indication of particulate pollutants which spread from excited nuclear waste and constitute environmental hazards (Hester et al 2002). Figures 1 represent industry-based optimization models suitable for waste minimization. Waste minimization techniques are control indices from a seemingly non-avoidable scenario in the hydrocarbon sector (Ataikiru, 2005). The improvement in technology and advances in science and engineering has made it increasingly possible for wastes to be converted into wealth in the waste recovery approach. Process and produced wastewater could be re-injected into the wells and flow systems (Ajayi et al, 1981). Figure 2 is a typical regional outlook of the marine ecosystem with high concentration of oil and gas exploration activities. The increase in available orphan sourced radioactive materials is a direct consequence of hydrocarbon prospecting (exploitation, exploration, production) concentrated within the region. These highly concentrated radiation saturates the body of waters in the Niger Delta, (Neeka et al, 2008). Qualitative analysis indicated that these components are lost into the marine environment during pollution and rapidly enhanced degradations and in extreme cases depletion of the marine lives. The effect of tidal waves and solubility could also increase the dispersion rate and the concentration level of pollutant will be high to impact other marine platforms, engineering structures and the environment (Neeka et al, 2004).

5.0 CONCLUSIONS AND RECOMMENDATIONS

There is urgent need to combat nuclear waste and orphan sourced abandoned radioactive materials through waste reduction, reuse, recycle, recovery, and disposal techniques as minimization strategies as optimal tool for effective waste management in the petroleum industry. Regular inspections of industrial sites and operating environments by waste management experts are critical to cost reduction or reuse of wastes generated. Moreover, pollution management strategy of industry operators should be regulated by Government

Agencies such as the Federal Environmental Protection Agency (FEPA, 1991)[15], Department of Petroleum Resources (DPR) and the Federal Ministry of Environment in Nigeria as it is done in the United Kingdom. Difficult marine ecosystems could be monitored by simulation using mathematical models as indicated in equations 1-12. Designs and industrial control indices should be based on functional waste management models as shown in figures 1 and 2. Thus simplified integrated approach discussed in this paper appeared to be the solutions to waste problems in the developing economy. Accordingly, the submission in this paper is a companion to administrators and decision makers in understanding the dynamics in waste management and thus would know what to do with waste for the overall benefits of society. This will in no doubt make the environment safer and a better place to live. Waste collection containers should be strategically positioned on the streets and major roads and stiff penalties should apply should anybody be found littering. Nuclear waste disposal and proper decommissioning should be given attention and feasibility studies carried out. Adequate regulatory and legal frameworks must be put in place to serve the purpose of implementation. More advocacy campaign should be carried out to create the much-needed awareness of the inherent dangers of scattering waste on the streets of Nigeria.

6.0: ACKNOWLEDGEMENT

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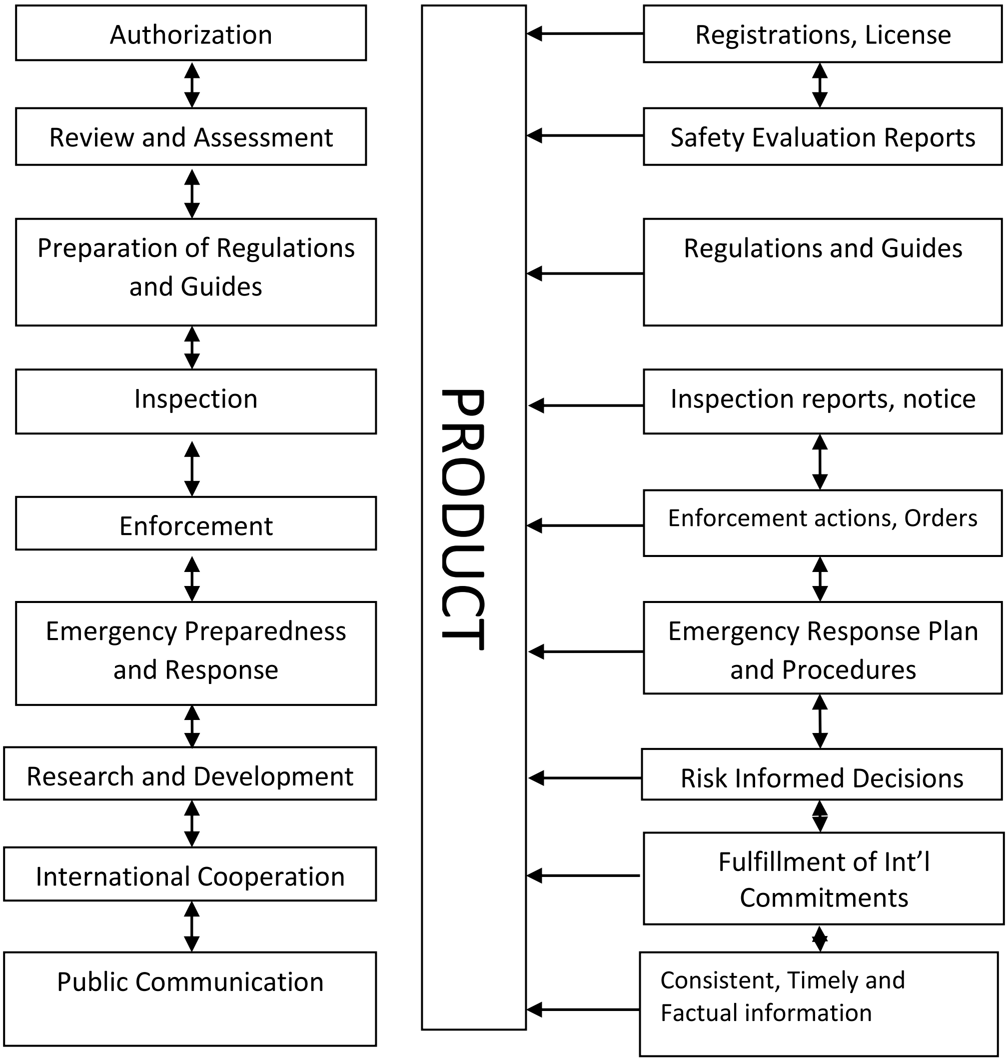
SPECULATIVE SURVEY DATA STATUS

Multi-Client Data Projects Status as at December 2016					
S/No	Company	Area of Survey/Block	Type of Survey/Project	Quantum of Survey	Year of Survey/Project
1	Mabon Limited/TGSI	AR2	2D Seismic & Geochemistry	24,400.00km Regional/ Infill	1992
2	Mabon Limited/TGSI	AR3 Shelf Survey	2D Seismic & Interpretation Biostat	6,990.40km Seismic / 6,990.40 Interp/Biostat	1994
3	Mabon Limited/TGSI	NDRDC	Niger Delta Regional Date Compilation / Well Logging	7,600.3km / 216 wells	1996
4	Mabon Limited/TGSI	AR3 (ABCD)	2D Seismic and Gravity Mag.	6,373.3km Seismic / 20,260 Sq. km Grav. Mag.	1994
5	Mabon Limited/TGSI	AR3 Infill/AR3F	2D Seismic	10,899.50km Seismic	1997
6	Mabon Limited/TGSI	Phase AR6 Very Deep Offshore	2D seismic Very Deep Off-shore	7,012.70km Seismic	2005
7	Mabon /GXT	Nigeria Spam I	2D Seismic Regional Survey	4,844.0km Seismic Data	2006
8	Mabon /GXT	Nigeria Span II	2D Seismic Regional Survey	7,350km Seismic Data	2011
9	TGS-Petrodata JV Offshore Services Ltd	Nigeria Offshore	2D Seismic	17,000km	2000
10	TGS-Petrodata JV Offshore Services Ltd	OPLs 257, 227,471, OMLs 79,83,85,86,88	2D Seismic	2,000km	2001
11	PGS Geophysical Nigeria Limited	OPL 214/213	3D Seismic	2814 Sq. km	2003
12	PGS Geophysical Nigeria Limited	OPL 244	3D Seismic	1700 Sq. km	2002
13	PGS Geophysical Nigeria Limited	OPL 245	3D Seismic	2247 Sq. km	2002
14	PGS Geophysical Nigeria Limited	OPL 248	3D Seismic	1940 Sq. km	1999
15	PGS Geophysical Nigeria Limited	OPL 249	3D Seismic	1954 Sq. km	1999
16	PGS Geophysical Nigeria Limited	OPL 250	3D Seismic	1265 Sq. km	2003

SPECULATIVE SURVEY DATA STATUS					
Multi-Client Data Projects Status as at December 2016 Contd.					
17	PGS Geophysical Nigeria Limited	OPL 256	3D Seismic	2655 Sq. km	2003
18	PGS Geophysical Nigeria Limited	OPL 257	3D Seismic	538 Sq. km	2004
19	PGS Geophysical Nigeria Limited	OPL 314	3D Seismic	1252 Sq. km	2004
20	PGS Geophysical Nigeria Limited	OPL 315	3D Seismic	1718 Sq. km	2010
21	PGS Geophysical Nigeria Limited	OPLs 312,313,314	3D Seismic	2845 Sq. km	ongoing
22	PGS Geophysical Nigeria Limited	Offshore Niger Delta	3D Mega Survey	17,000km / 75,000 Sq. km	2014
23	Sonar/Ikon Science	Onshore & Offshore Niger Delta	Geo-pressure survey	Report	2005
24	TDI-Brooks	Offshore Niger Delta	Surface Geochemical Exploration and Heat Flow Study	Report	2005
25	Acorn Geophysical	Offshore Niger Delta	CSEM Imaging	OPL 351, 323,321,325,327 &257	2005
26	Polarcus/ Ashbert Limited	VERNG-99,VERNG-02, VERNG-03, VERNG-04	3D Seismic	9,308 Sq. km	1999-2004
27	Bilview Energy Services	Offshore Niger Delta	Wells log scanning, digitizing and marketing	Over 6,000 Digitized Well Logs	2015


Authorization
Review and Assessment
Preparation of Regulations and Guides
Inspection
Enforcement
Emergency Preparedness and Response
Research and Development
International Cooperation
Public Communication
PRODUCT
Registrations, License
Safety Evaluation Reports
Regulations and Guides
Inspection reports, notice
Enforcement actions, Orders
Emergency Response Plan and Procedures
Risk Informed Decisions
Fulfillment of Int'l Commitments
Consistent, Timely and Factual information