

Risk Assessment of Abandoned Radioactive Logging Sources in Oil Wells in Nigeria

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Abstract
An integrated model for the risk assessment is developed for abandoned radioactive logging sources (Am-241 and Cs-137) in oil wells. The model is composed of four components: Source term, Barrier failure model, a geosphere model, a biosphere model, and finally a dose and health effect model to analyse the radionuclide dispersion phenomenon from the abandoned source term to the risk of serious health effects on members of the public (cancer death). In addition to time-dependent annual release rate and dose rate for each radionuclide, the ultimate risk in terms of cancer death rate is estimated. The results show that the highest value of the annual dose for the abandoned radioactive logging sources is less than the individual dose limit to the human body, and the calculated highest cancer death rate is much lower than that of background radiation but higher than that of low-level waste repository. Subsequently, an abandonment procedure was developed in an effort to manage the risk and reduce it to the barest minimum. It is concluded that the use of simplified mathematical modelling for the risk assessment of abandoned radioactive sources in oil wells could be an effective tool for development of efficient and acceptable abandonment procedure.

Keywords: risk assessment, geosphere model, dose, cancer death, logging sources, low-level repository, radionuclide, abandonment procedure

1. Introduction

The average number of radioactive sources abandoned in oil wells in Nigeria between 2001 and 2007 is greater than the worldwide average. Most of these radioactive sources are high risk with considerable long half lives which can pose danger to human health and the environment. In general these radioactive sources were abandoned deep in the ground as a result of well logging activities. The nature of the containment as well as the location of the abandonment is such that, radionuclide release to the environment could occur after a period of time thereby contaminating the environment.

Worldwide data on abandoned radioactive sources were available for 18 years. Data on loss of control of radioactive sources in oil wells which pose the threat of actual or potential release of radioactive materials to the environment were obtained from IAEA TECDOCS 588(1991), 1105(1999) and 1242(2001) as compiled by Bello (2007). The reported cases of abandonment of radioactive sources in some of the oil producing countries between 1983 and 2001 are shown in Fig 1 with USA having the highest number of cases.

There is no data on stuck and abandoned radioactive sources in oil wells in Nigeria prior to 2001. The respective numbers of abandonment of radioactive sources in wells by well-owners are depicted by Fig 2.

Since 2001, there has been at least one recorded case of abandonment of radioactive sources in oil wells in Nigeria. The highest numbers of reported cases were obtained in 2006 and this called for concern by both the well owners and the regulatory authority. The numbers of reported cases of radioactive sources abandonment in Nigeria for every year from 2001 to 2007 are clearly shown in Fig 3.

Among the radioactive sources abandoned in Nigeria (2001-2007) there were 17 Cs-137 (30yrs) and 17 Am-Be (433yrs). Therefore, number of incidents recorded in Nigeria between 2001 and 2007 (6 years) is greater than the worldwide average as shown in Fig 4

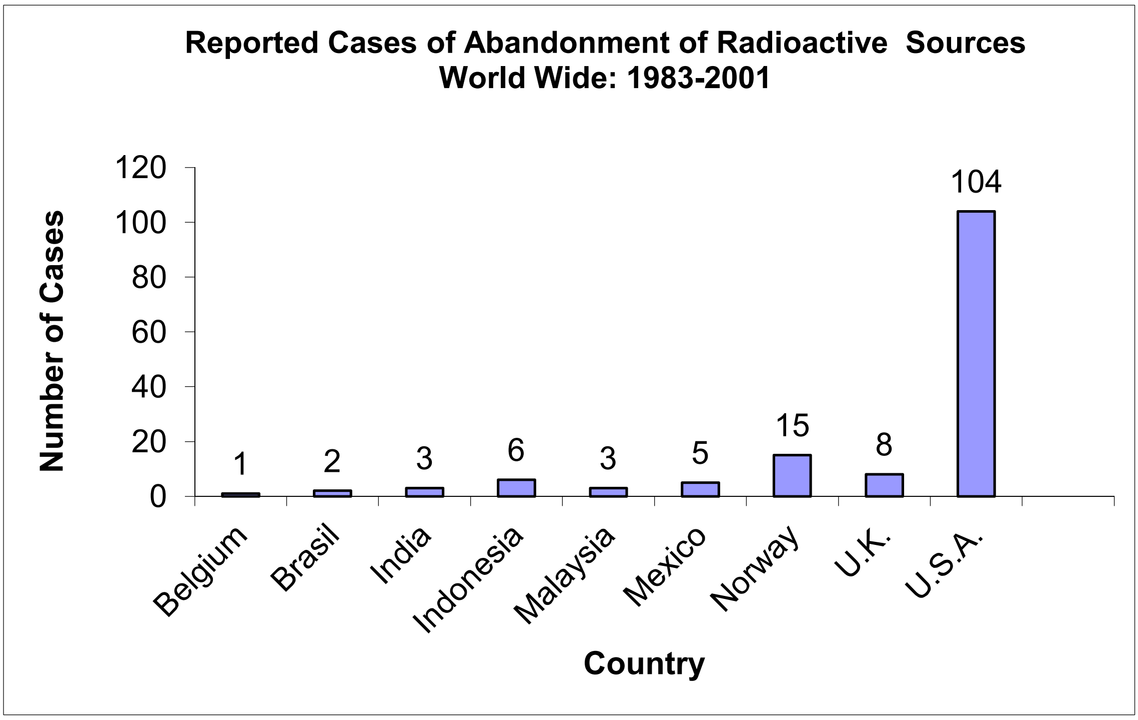

Fig 1: Reported Cases of Abandoned Radioactive Sources World Wide

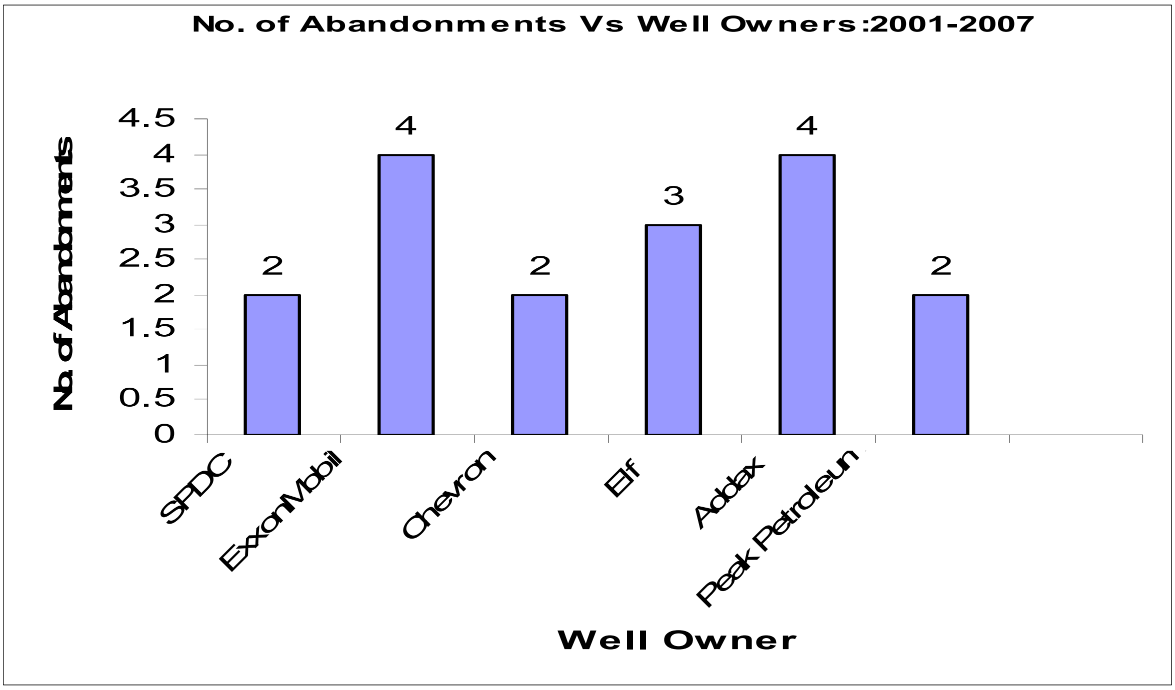

Fig 2: Number of Abandoned Radioactive Sources by Well Owners in Nigeria

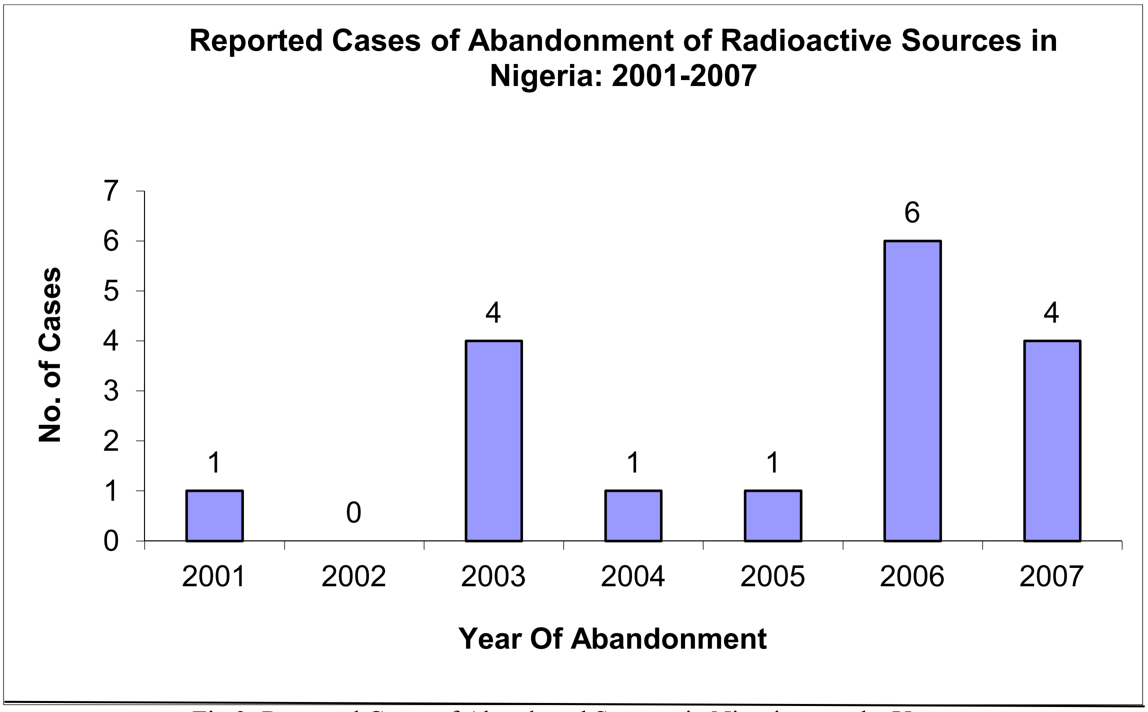

Fig 3: Reported Cases of Abandoned Sources in Nigeria over the Years

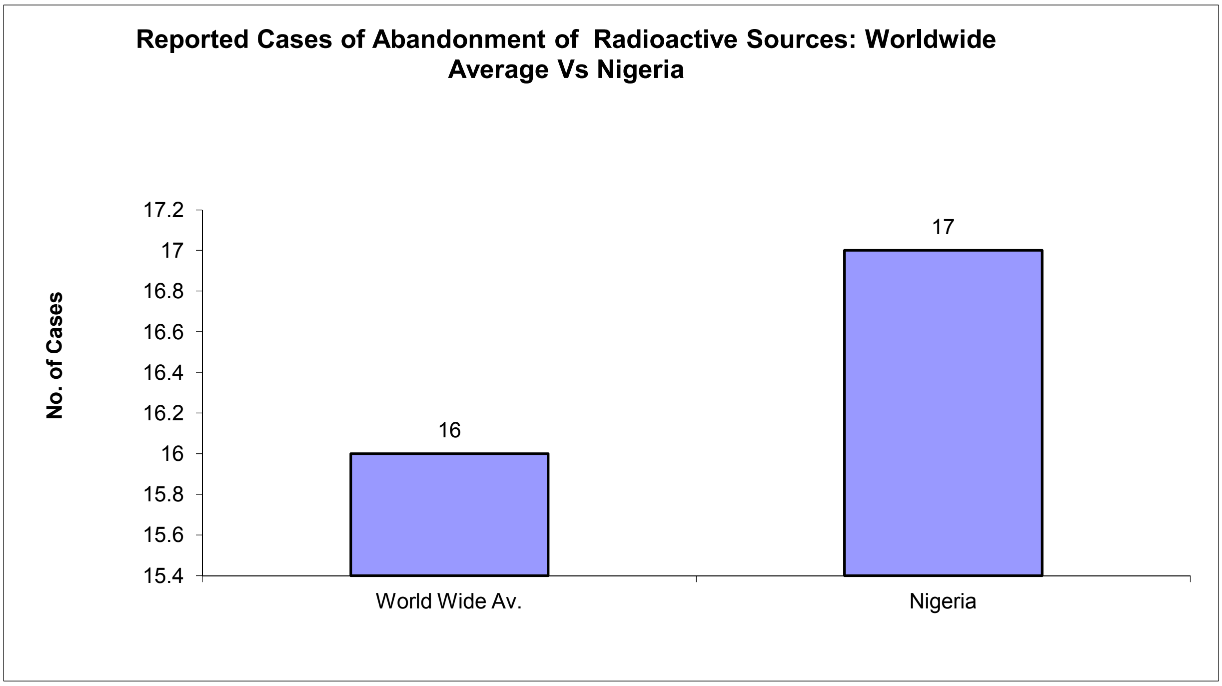

Fig 4: Comparison of Average Number of Abandoned Sources in Nigeria with World Wide Average

2. Description of Hypothetical Source Abandonment Site

The hypothetical logging source abandonment site considered in this study is a typical bottom hole source abandonment containing Caesium (^{137}Cs) and Americium-Beryllium (^{241}Am-Be) sources which is illustrated in Fig. 5

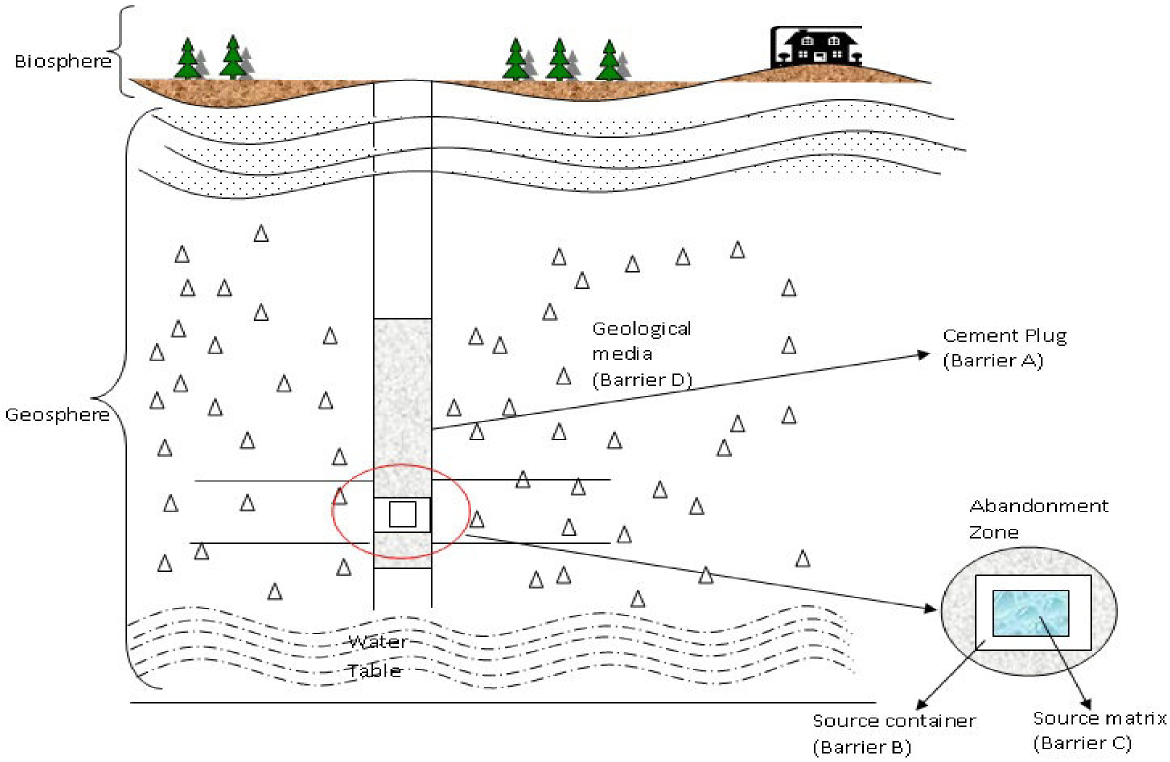

Fig 5: Schematic Diagram of a Multi-Barrier System for Radioactive Sources Abandonment in Oil Wells

The ^{137}Cs is contained in glass or ceramic matrix before being doubly encapsulated with carbon steel while ^{241}Am-Be is a mixture of Americium oxide powder and Beryllium oxide powder contained in a pressurized carbon steel container. The multi-barrier system includes the engineered barriers such as the cement plug and the source container. The natural barrier is the undisturbed geological formation between the abandoned logging source and the biosphere.

3. Models and Calculation

3.1 Abandoned Logging Source Term Model

The most common chemical sources used in petrophysical measurements are ^{137}Cs (Caesium) which provides gamma rays used in formation density logging and a mixture of ^{241}Am (Americium) and Be (Beryllium) which provides neutrons for neutron porosity logging.

From the half-life and the initial activity, the time dependent activity, $A_k(t)$, of the radioactive nuclide i is obtained:

$$A_i(t) = A_0^i e^{-\lambda_i t} \qquad 1$$

Where A_0^i is the initial activity, and λ_i is the decay constant of nuclide i. The half-life and initial activity for relevant radionuclide are given in Table 1

Table 1: Relevant Radionuclide Used in Neutron-Density Logging Tool

Nuclide	Half-life (yr)	Initial Activity (Ci)
Cs-137	30.2	1.7
Am-241	433	8.0
Np-237	2 million	0.0

3.2 Barrier Failure Model

The failure of a logging source abandonment system means that all the unit components (barriers) have failed and the radionuclides are released into the biosphere. Then the failure probability of the abandonment system can be expressesed, according to Kim et al (1993), by the following integral.

$$f_S^i(t) = \int_0^t f_A^i(t_A) \int_{t_A}^t f_B^i(t_B - t_A) \int_{t_B}^t f_C^i(t_C - t_B) \times f_D^i(t - t_C) dt_C dt_B dt_A \qquad 2$$

$$= \prod_{k=A}^{D} \lambda_k e^{-\lambda_i} \sum_{k=A}^{D} \frac{e^{-(\lambda_i+\lambda_k)t}}{\prod_{j\neq k}(\lambda_j-\lambda_k)} \qquad 3$$

Where

λ_i = decay constant of the radionuclide i

λ_k = failure rate of the barrier k, k = A, B, C, and D

The survival probability density function of radionuclide i is $f_s^i(t)$ at time t when barrier C has failed at $t_C \leq t$, the barrier B has failed at $t_B \leq t_C$ and barrier A has failed at $t_A \leq t_B$.

Here $f_A^i(t)$, $f_B^i(t)$, $f_C^i(t)$, and $f_D^i(t)$ are the survival probability density functions of the radionuclide i, for the single barriers A, B, C, and D, respectively.

The time dependent annual release rate, $R_i(t)$, of the radioactive nuclide i to the environment is then obtained as:

$$R_i(t) = A_0^i \cdot f_s^i(t) \qquad 4$$

The amount of radioactivity released to the geosphere is calculated on the basis of sequential failure of each barrier due to corrosion (resulting from water infiltration) or human intrusion such as drilling operation. The failure scenario for each barrier is summarized in Table 2 along with assumed Mean Time to Failure.

Table 2: Representation of Barrier Failure Scenarios

No	Barrier	Failure Scenario	Range of MTTF[a] (year)	Reference Value (year)
A	Cement Plug	Degradation of the cement plug due to water infiltration from rain fall or failure resulting from drilling activities.	300-4000	300
B	Source Container	Corrosion of the carbon steel container due to water infiltration or outright damage by drilling operations	750-1000	750
C	Source Matrix	Leaching or dispersion of source nuclide into water	5-900	6
D	Geological Structure	Radioactivity release to environment by ground water. Mobility of radionuclide is based on retardation factor (R_d) and water travel time (T_w)	R_dT_w	R_dT_w

[a]These values are assigned on the basis of Kim et al (1993) and Cho et al (1992)

3.3 Geoshpere Model

The geosphere model is used to translate the radioactivity release rate into radionuclide concentration dispersion across the geological structure by ground water.

The convection-diffusion equation (CDE) is a classic model for radionuclide dispersion in the soil profile. For instance, ^{137}Cs can be adsorbed onto soil particles and transported into the soil profile by infiltration and bulk-mixing processes (i.e. wetting/drying and freeze/thaw cycles, and bioturbation). The CDE model does not represent these processes explicitly, but instead treats soil-transport processes as analogous to the hydrodynamic dispersion of a passive tracer, or to the Brownian motion of molecules in a liquid.

$$\frac{\partial C}{\partial t} = \nabla.(D\nabla C) - \nabla.(vC) + R \qquad 5$$

C is the radionuclide concentration, v is the velocity and R is the sink.

Assumptions: It is assumed that the convective component of transport is negligible and that the diffusion coefficient is constant and there are no sinks

The solution of equation (5) for a unit instantaneous release of radioactivity taking into account the infiltration by groundwater is given by:

$$C(z,t) = \frac{1}{\sqrt{4\pi Dt}} e^{-\frac{z^2}{4Dt}} \qquad 6$$

The equation (6) which describes the evolution of radionuclide concentration C by diffusive processes is the solution to the diffusion equation in a semi-infinite medium with no-flux boundary condition at the surface and a unit instantaneous release at z = 0 and t=0, z is depth in the soil profile, D is the diffusivity or dispersion coefficient, and t is time following abandonment.

3.4 Biosphere Model

The biosphere model is used to calculate the rate at which human ingests, through the biosphere pathways, the radionuclides which emerge from the geosphere. There are many identified pathways of the radionuclide to man such as drinking contaminated surface water, ingestion of milk, meat, fish, green and root vegetables, inhalation of dust resuspended from a irrigated soil, and direct irradiation from the contaminated field. These pathways are shown in Fig 6. However, owing to insufficiency of site-specific data, this study considered generic pathways of drinking contaminated surface water. The surface water will be rivers, wells, lakes, reservoirs, and so on. In order to obtain a more precise estimation of the amount of radionuclide which reaches man, the site-specific biosphere model should be established. The annual ingestion rate to an individual through the drinking of contaminated water pathway is given by:

$$IS_i(t) = \frac{R_i(t)}{V} IR_{i,w} \qquad 7$$

Where

$IS_i\,(t) =$ Annual ingestion rate of an individual for radionuclide i from the abandonment zone through the pathway of drinking contaminated surface water (Ci/yr)

$V =$ Volume flow rate (VOLFLOW) of the surface water (m^3/yr)

$IR_{i,w} =$ Annual individual ingestion rate with the unit concentration (1 Ci/m^3) of radionuclide i in the surface water through the pathway of drinking contaminated surface water (Ci/yr per Ci/m^3)

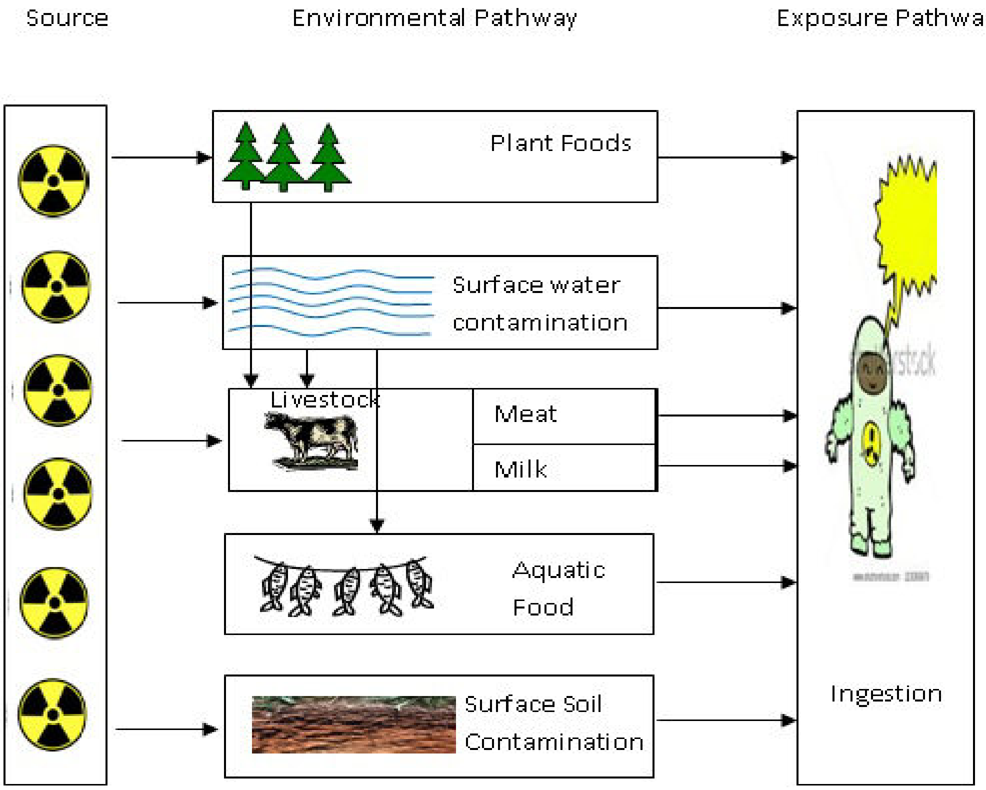

Fig 6: Identified Pathways for Biosphere Model

3.5 Dose and Health Risk Model

This model evaluates doses to an exposed individual at any time after the abandonment and health effects due to ingestion of radioactivities. The time dependent annual dose rate (Sv/yr) to an individual is obtained from multiplying the annual ingestion rate, $IS_i(t)$, by a dose conversion factor for each nuclide i:

$$\dot{D}_i(t) = 3.7 \times 10^{10} \cdot IS_i(t) \cdot DCF_{ing} \qquad 8$$

Where

$\dot{D}_i(t) =$ annual dose rate to an individual for radionuclide i from the source abandonment zone through the pathway of drinking contaminated surface water.

$3.7 \times 10^{10} =$ activity conversion factor (Bq/Ci)

$DCF_{ing} =$ dose conversion factor for ingestion (Sv/Bq)

The dose conversion factors for each nuclide are listed in Table 3

Table 3: Dose Converstion Factor for Radionuclides

Nuclide	DCF_{ing} (Sv/Bq)
Cs-137	1.30×10^{-8}
Am-241	1.10×10^{-7}
Np-237	2.0×10^{-7}

The total annual dose, $\dot{D}_T(t)$, from all the radionuclides considered is obtained by taking the sum of dose, $\dot{D}_i(t)$, for each radionuclide:

$$\dot{D}_T(t) = \sum_i \dot{D}_i(t) \qquad 9$$

Radiological dose can be converted to carcinogenic risk using radionuclide-specific risk coefficients (also called slope factor) developed by US EPA. Often the risk is calculated by applying a dose-to-risk (DTR) conversion factor to the effective dose (the whole body dose). Radionuclide slope factors are age-averaged by calculating doses to each target organ or tissue, apply age- and gender-specific risk factors, and integrate over a lifetime.

- External (uniform whole body) irradiation is 8 x 10^{-7} radiogenic cancers (incidence)/millirem.
- For intakes, dose to risk conversion is radionuclide-dependent and varies between 1 x 10^{-7} and 3 x 10^{-6} per millirem

However BEIR – V estimated 5.0×10^{-2} (fatal cancer probability coefficient per unit Sv) for low-level doses as a risk conversion factor, where only stochastic effects (fatal cancer) are considered.

$$Risk\ (of\ Cancer\ Mortality) = Dose\ (Sv/yr) \times DTR\ Conversion\ Factor\ \ (per\ person - Sv) \qquad 10$$

4.0 Results and Discussions

The risks evaluation carried out for a Logging While Drilling (LWD) tool which contains ^{137}Cs source and Am-Be neutron source abandoned in oil well using the integrated model with the associated input parameters. With the input parameters shown in Table 4, the integrated models developed were evaluated using MATLAB R2009a codes developed and The calculated annual release rates, annual ingestion rates, annual individual dose rates and annual risk rates of the two nuclides (Cs and Am) are shown in the Table 5 and Table 6

The data contained in Table 5 and Table 6 for Cs nuclides and Am nuclides respectively were used to make plots of annual nuclide release rate, annual dose rate, and individual risk rate as shown in Fig 7, Fig 8 and Fig 9.

Table 4: Integrated Models Input Parameters

INPUT PARAMETERS	**VALUES**
Depth of Abandoned Source	15000ft
Initial Activity of Cs	2.0Ci
Initial Activity of Am	23Ci
Half-Life of Cs	30.2yrs
Half-Life of Am	433yrs
MTTF of Cement Plug	300yrs
MTTF of Source Container	750yrs
MTTF of Source Matrix	6yrs
MTTF of Geosphere	400yrs
Water consumption rate	4L/day
Volume Flow rate of S/W	10^{10} m^3/yr

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Table 5: Risk Evaluation Parameters for Cs-137 Radionulide

Time (yr)	Annual Release Rate (Ci/yr)	Annual Dose Rate (Sv/yr)	Annual Risk Rate (/yr)
10	2.675410E-09	7.039190E-09	3.519600E-10
50	9.665980E-10	2.543190E-09	1.271590E-10
100	2.707480E-10	7.123570E-10	3.561780E-11
200	2.124240E-11	5.589020E-11	2.794510E-12
400	1.307620E-13	3.440430E-13	1.720210E-14
500	1.025930E-14	2.699300E-14	1.349650E-15
800	4.954880E-18	1.303660E-17	6.518320E-19
900	3.887510E-19	1.022830E-18	5.114160E-20
1000	3.050070E-20	8.024950E-20	4.012470E-21

Table 6: Risk Evaluation Parameters for Am-241 Radionuclides

Time (yr)	Annual Release Rate (Ci/yr)	Annual Dose Rate (Sv/yr)	Annual Risk Rate (/yr)
10	1.430730E-08	3.186030E-07	1.593010E-08
50	1.212260E-08	2.704030E-07	1.352010E-08
100	9.854660E-09	2.202740E-07	1.101370E-08
200	6.512300E-09	1.461730E-07	7.308660E-09
400	2.843930E-09	6.436900E-08	3.218450E-09
500	1.879360E-09	4.271510E-08	2.135750E-09
800	5.423600E-10	1.248230E-08	6.241150E-10
900	3.584100E-10	8.283210E-09	4.141610E-10
1000	2.368490E-10	5.496720E-09	2.748360E-10

It could be observed that the annual dose rate from Am nuclides is relatively constant over a long period of time. This is because of the high half-life time of the nuclide which is 433 years. This implies that it will take about 1000 years for the dose rate form Am nuclide to reduce by one-fourth.
However, the annual dose rate from Cs nuclides drops off drastically after like 120 years of abandonment in the oil well. The reason for this is that the half-life of Cs nuclide is 30.2 years which is relatively low. Therefore, after a period of about 500 years, the dose rate from Cs should have gone down to a safe level.

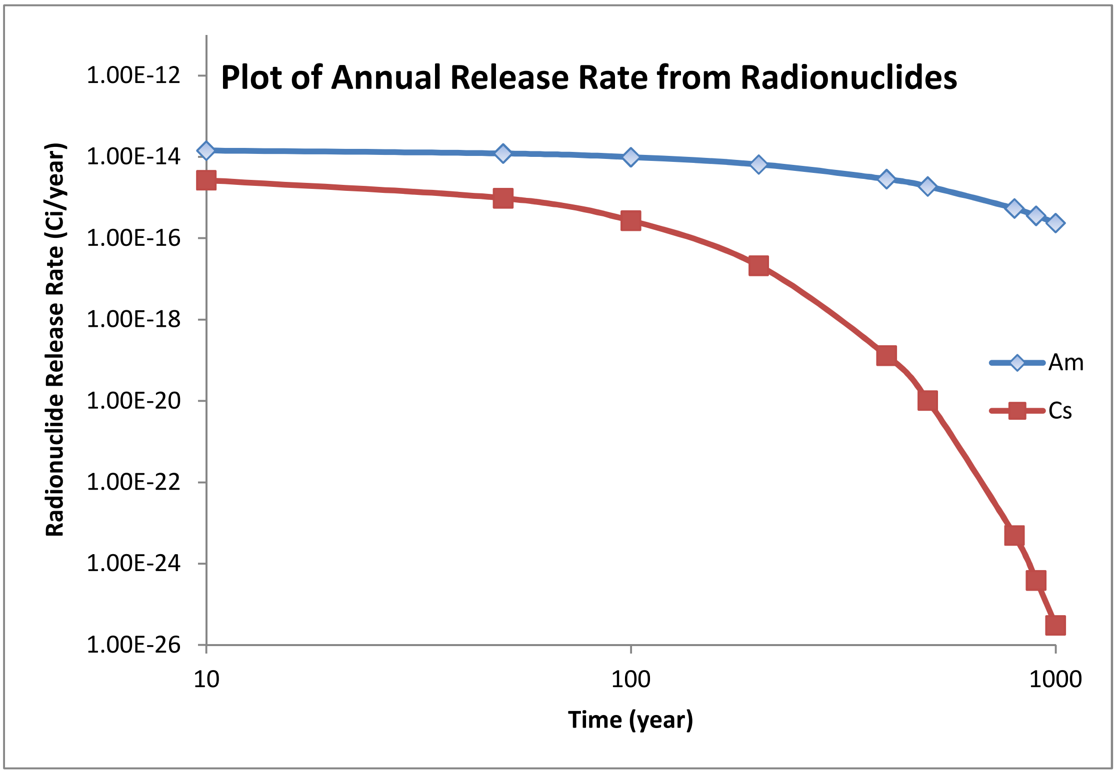

Fig 7: Annual Release Rate of Radionulides

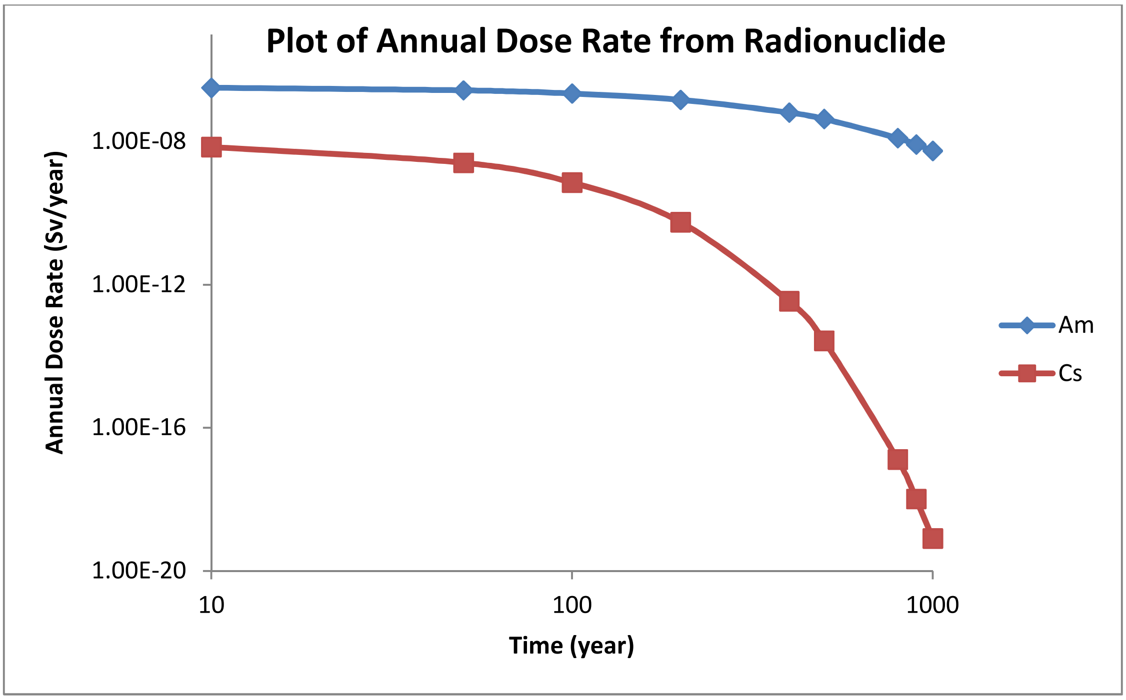

Fig 8: Annual Dose Rate from Radionuclides

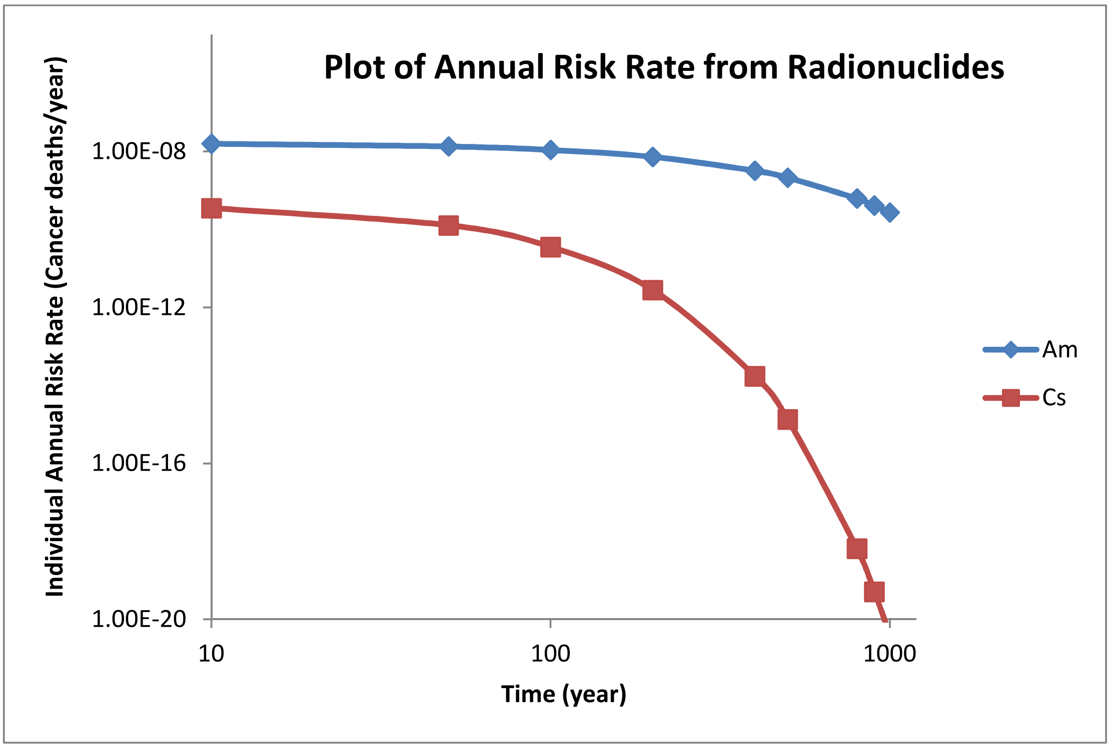

Fig 9: Annual Individual Risk Rate from the Radionuclides

The average of the risk obtainable from the abandonment of radioactive logging sources in oil wells (due to Cs and Am) was obtained from the Fig 5 to be 8.141×10^{-9} cancer deaths/year and this can be compared to normal annual risk of mortality from other sources of risk. This is clearly shown in Table 7.

Table 7: Normal Annual Risk of Mortality[*]

Sources of Risk	Annual Risk Rate (Death Rate)
Smoking cigarettes	1.739×10^{-3}
Natural Background Radiation	1.087×10^{-5}
Drowning	2.696×10^{-5}
Air Travel	6.522×10^{-6}
Lightning	3.826×10^{-7}
Nuclear Fuel Cycle[a]	1.305×10^{-8}
Low-Level Waste Repository[a]	3.695×10^{-9}
Abandoned Logging Sources[b]	8.141×10^{-9}

[*]Estimated from E.L. Etnier and C.C. Travist, (1993)
[a]Obtained from Kim et al (1993)
[b]Obtained in this Study

The annual risk rate (8.141×10^{-9} cancer deaths/year) from abandoned logging sources in oil wells is slightly higher than the annual risk rate (3.695×10^{-9} cancer deaths/year) from Low-Level Waste Repository. The reason being that the site of low-level wastes repository is carefully selected and sufficient engineered barriers are put in place to shield the biosphere from the effects of the wastes. Whereas logging sources are abandoned in an unplanned site and efforts are just being made to contain the sources from contaminating the environment. The implication of this is that 8 people out of 10^9 people that were exposed to these radionuclides would die of radiation-induced cancer.

5.0 Management of Risk: Development of Logging Sources Abandonment Procedure

The template for radioactive logging sources plugging and abandonment procedures was developed using the common requirements of Industry Standard, Regulatory Authority and Operator Best Practices as shown in Fig 10. The template has two sections which are Pre-abandonemt, and Abandonment sections.

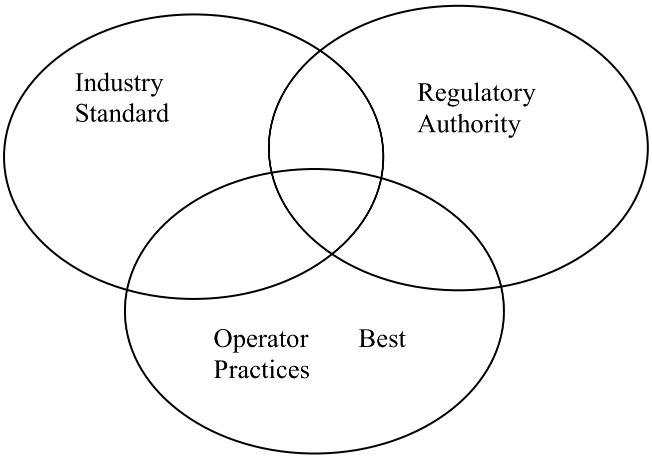

Figure 10: Common Requirement for Abandonment Template

5.1 Pre-Abandonme

Whenever a sealed radioactive logging source gets lodged downhole, the licensee should be required by regulation to do the following forthwith.

1. Notify the Regulatory Authority
2. Monitor the presence of radioactive contamination at the surface with survey meter and if there is a detection of radioactive contamination, the Regulatory Authority should be notified immediately.
3. In a case where the lodged sealed source is still intact, then several attempts must be made to recover it using different fishing methods. The recovery operation must be done in such a way that the sealed source is not damaged in the process.
4. When it becomes apparent that efforts to recover the radioactive source will not be successful, then abandonment procedure plan should be developed based on the following highlighted information about the well: Date of occurrence, Type of sealed source (Cs or Am) and activity level, Depth of well, Depth of lodged radioactive source, Surface location and identification of the well, Water Depth, Hole conditions, Hole and Casing sizes

5.2 Abandonment Phase

If, after making all reasonable attempts to recover a tool containing a radioactive source without a success, the source shall be classified as irretrievable. Then, abandonment plans should be drawn up following guidelines stated below but subject to the approval of appropriate regulatory agency before its implementation.

STEP 1: Leaving Minimum of 100ft drillpipe above the Source

In implementing the abandonment procedure, the standard practices with most operators is to leave about 100ft to 200ft of drill pipe above the sources to act as a layer of defence against inadvertent intrusion or influx of corrosive element into the sources. Afterwards, the radioactive source shall be immobilized and sealed in place inside the drill pipe using cement slurries of specifications stated in STEP 2. The cement slurry should cover the 100-foot drillpipe which houses the radioactive source.

STEP 2: Immobilization and Sealing in Place of Radioactive Source with Cement Plug

In this study, the cement slurry design uses modified class G/H cement (based on API cement classification) for the immobilization and sealing in place of the lodged sources. The modification done to the class G/H cement is the addition of 1% nanosilica. The nanosilica is added to achieve the following advantages over ordinary class G/H cement Ershadi et al (2011)

- It increases the Compressive Strength to 3023 psi at 158^0F and P = 3000psi.
- It reduces the permeability by 99% and reduces the porosity by 33.3%

The other features of the cement slurry are given as shown in Table 8.

Table 8: Features of Cement Slurry

Cement Class	Water/Cement (W/C) ratio (gal/sk)	Slurry Density (lb/gal)
Class G + 1% nanosilica	5.0	15.8
Class H+1% nanosilica	4.3	16.4

STEP 3: Plugging of the Well

The common lodged sources scenarios and their plugging methods are enumerated in Table 9 for the vertical wells.

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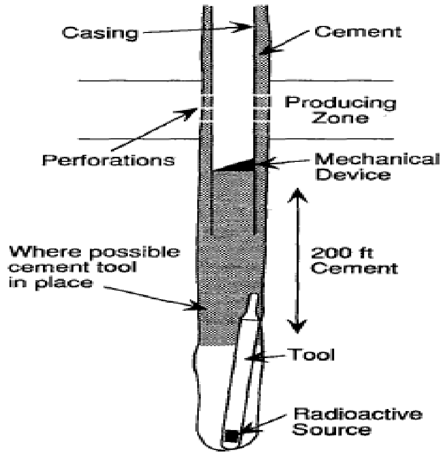
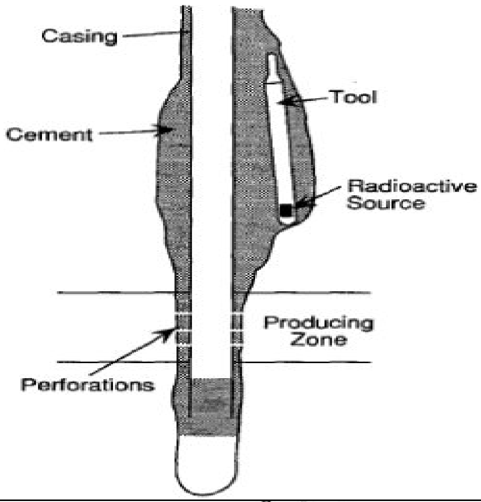
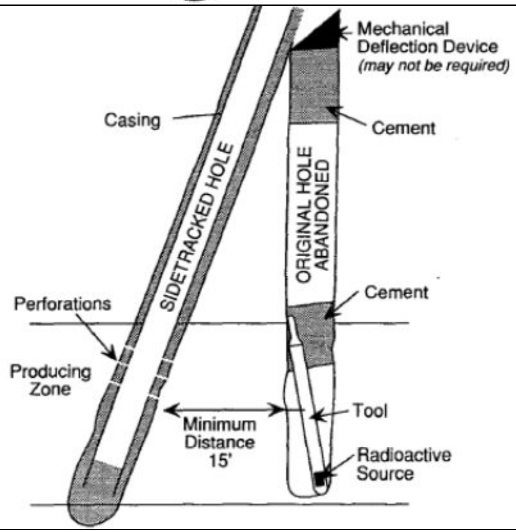
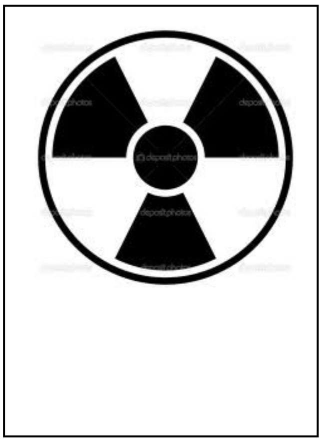
Table 9: Plugging of Wells Containing Radioactive Sources

Vertical Wells	
1. Bottom Hole Abandonment: Sources abandoned in the bottom of the hole shall be covered with a (100-200)-foot standard color-dye cement plug on top of which a mechanical stop or deflector shall be set. The dye shall contrast with the color of the formation to alert a re-entry operator prior to encountering the source	
2. Abandonment behind Casing String: In a well where a logging source has been cemented in place behind a casing string and above total depth, upon plugging the well, a (100-200)-foot color-dyed cement plug shall be placed opposite the abandoned source inside the well bore and a mechanical stop or deflector shall be placed on top of the plug.	
3. Producing Zone Abandonment: If a well is to be deviated or sidetracked around a lost radioactive source, then a (100-200)-foot standard color-dyed cement plug (dyed with red iron oxide) shall be placed above the abandoned source, and an approved deflection device shall be placed on top of the plug. The sidetrack requirement shall be a horizontal distance of (15-20)-foot from the lost radioactive source.	

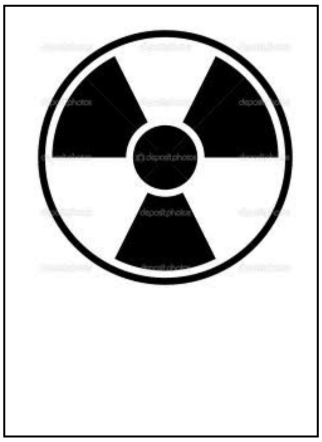
STEP 4: Mechanical Stop or Deflection Device
A well in which a radioactive source has been abandoned shall be mechanically equipped and plugged so as to prevent either accidental or intentional mechanical disintegration of the radioactive source. An example of such mechanical deflection device is whipstock.
STEP 5: Placement of Identification Plaque (if practical)
Upon plugging a well in which a radioactive source is left in the hole, the operator shall place a permanent

plaque by welding or bolting or cementing it to the top of the well in a manner approved by the Regulatory Authority such that re-entry cannot be accomplished without disturbing the plaque. The plaque shall serve as a visual warning to a person re-entering the hole that a radioactive source has been abandoned in-place in the well. The plaque shall depict the trefoil radiation symbol with the words ''Caution, Radioactive Material'' and shall be constructed of a long-lasting material such as monel, stainless steel, bronze or brass. A typical plaque is shown in Fig 11. The marker shall bear the following information:The words "CAUTION, RADIOACTIVE MATERIALS", Radiation symbol without the conventional color requirement, Date of abandonment, Name of the Well Operator or Well Owner, Well name and well identification number, The sealed sources by radionuclides and by activity level, The source depth and the depth to the top of the plug.

COMPANY NAME: W & T Offshore, Inc. Port Harcourt, Nigeria
WELL: OCS-G - 26168 A-6 STOO BP03 API 17-724-40942-00
LOCATION: MAIN PASS BLOCK 279 OFFSHORE GOM



CAUTION



ONE 1.7 CU E CS-137 AND ONE 8.0 CURIE AM-24lBE
RADIOACTIVE SEALED SOURCES ABANDONED ON
6 December 2008 @ 5004 FT MD (4580 FT TVD)
PLUGBACK DEPT 4700 FT MD (4336 FT TVD)

DO NOT RE-ENTER THIS WELL
BEFORE CONTACTING
NIGERIA NUCLEAR REGULATORY
AUTHORITY

Fig 11: Typical Identification Plaque

6.0 Conclusions

The annual risk rate (8.141×10^{-9} cancer deaths/yeeary) from abandoned logging sources in oil wells is slightly higher than the annual risk rate (3.695×10^{-9} cancer deaths/year) from Low-Level Waste Repository. The reason being that the site of low-level wastes repository is carefully selected and sufficient engineered barriers are put in place to shield the biosphere from the effects of the wastes. Whereas logging sources are abandoned in an unplanned site and efforts are just being made to contain the sources from contaminating the environment. The possibility of damaging the encapsulation of abandoned sealed source through human intrusion and natural disruptive processes could be high. This could lead to the release of radionuclide into the environment.

However, the safety of the abandoned sources can be assured if dispersion of the radionuclide into the biosphere, driven by natural processes, is retarded until they have decayed to a safe level and if human intrusion into the source is unlikely. In order to achieve this, modified class G/H cement with the addition of 1% nanosilica has been found to provide substantial standard cement slurry in terms of compressive strength, permeability and porosity. This kind of cement slurry, when used for plugging and abandonment of radioactive sources, will greatly retard the dispersion of radionuclide through the geopshere to the biosphere.

Subsequently, a template for abandonment procedure of radioactive logging source in oil well was developed based on the requirements of Industry Standards, Regulatory Authority and Operator Best Practices. This template should be adopted as a basis for development of abandonment plan, however, if hole conditions make it impossible to abandon source as prescribed in the template, then alternate abandonment procedures should be developed which should be subjected to the approval of the regulatory authority before implementation.

References

*Bello, N.A (2007) "*Regulatory Framework for Safety and Security of Radioactive Sources used in Nuclear Well Logging", presented at the 1-day Technical Meeting on the Abandonment of Radioactive Sources Stuck in Oil Wells.

Kim, Y.N., Kim, J.K. and Kim, T.W. (1993):"Risk assessment for shallow land burial of low-level radioactive waste" Waste Management 13 (8), 589–598.

Cho, W.J., Chang, S.H. and Park, H.H. (1992): "Uncertainty analysis of safety assessment for high-level radioactive waste repository", Waste Management 12 (1), 45–54.

Etnier, E.L. and Travist, C.C. (1993): "Risk of EnergyTechnologies", Nuclear Safety, 24:671.

Ershadi, V., Ebadi, T., Rabani, A.R, Ershadi, L., Soltanian, H. (2011): "The Effect of Nanosilica on Cement Matrix Permeability in Oil Well to Decrease the Pollution of Receptive Environment", International Journal of Environmental Science and Development, Vol 2., No. 2, April 2012

International Atomic Energy Agency (1991):"Inventory of Radioactive Material Entering the Marine Environment: Sea Disposal of Radioactive Waste", TECDOC 588, IAEA, Vienna.

International Atomic Energy Agency (1999):"Inventory of Radioactive Waste Disposal at Sea", TECDOC 1105, IAEA, Vienna.

International Atomic Energy Agency (2001):"Inventory of Accidents and Loses at Sea Involving Radioactive Material", TECDOC 1242, IAEA, Vienna.