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DEVELOPING A SPECIFIC CRITERIA FOR CATEGORIZATION OF RADIOACTIVE WASTE CLASSIFICATION SYSTEM FOR UGANDA USING THE RESRAD COMPUTER CODE.

Abdul Byamukama[a], Haiyong Jung[b]
[a]*Nuclear and Quantum Engineering Department, Korea Advanced Institute of Science and Technology, Daejeon, Republic of Korea*
[b]*Korea Institute of Nuclear Safety, Daejeon, Republic of Korea*
Corresponding author: abdul.byamukama@kaist.ac.kr

Abstract

Radioactive materials are utilized in industries, agriculture and research, medical facilities and academic institutions for numerous purposes that are useful in the daily life of mankind. After the useful period of radioactive materials, they should be effectively managed as radioactive waste since they contain varying levels of radioactivity. Whereas storage facilities can be used as a temporary measure for isolating radioactive waste from the biosphere, the ultimate solution is to dispose them of to prevent undue burdens to the future generation with the major objective of long-term protection of the public and the environment from the dangers resulting from ionizing radiation. To effectively manage the radioactive waste and selecting appropriate disposal schemes, it is imperative to have a specific criteria for allocating radioactive waste to a particular waste class. Uganda has a radioactive waste classification scheme based on activity concentration and half-life albeit in qualitative terms as documented in the Uganda Atomic Energy Regulations 2012. There is no clear boundary between the different waste classes and hence difficult to; suggest disposal options, make decisions and enforcing compliance, communicate with stakeholders effectively among others. To overcome the challenges, the RESRAD computer code was used to derive a specific criteria for classifying between the different waste categories for Uganda basing on the activity concentration of radionuclides. The results were compared with that of Australia and were found to correlate given the differences in site parameters and consumption habits of the residents in the two countries.

1.0 Introduction

In Uganda, there is neither an operating nuclear power plant (NPP) nor research reactor and so no HLW is generated as a result. The major sources of radioactive waste are; medical and industrial facilities, research and academic institutes and mining and mineral processing industries. These facilities utilize radioactive sources (sealed and none sealed) for different purposes such as; well-logging, brachytherapy, radiotherapy, food irradiation, radiography among others. After a specified period of use, these sources are regarded as “radioactive waste” (disused sources) since they can no longer perform their intended functions [1]. Most of the waste produced in Uganda fall into LLW and ILW classes respectively which can further be separated depending on their activity concentration and half-life of the individual radionuclides.

The generated waste has to be managed effectively to ensure the protection of the public and environment from harmful effects of ionizing radiation while not compromising the safety and security of radioactive waste thus, the waste management must be compatible with the international standards ands and principles. Most of the waste generated in Uganda is inform of disused sealed sources and bulk waste from mining and mineral extraction. Disused radioactive sources contain varying levels of concentrations of radionuclides that may not be suitable for either surface landfill or near surface disposal irrespective of half-life [2][1][3] hence a need for a criteria to qualify the waste to a particular disposal stream [4],[5].

For effective radioactive waste management in Uganda, there is a need to ratify laws and regulations, codes of practice and safety guides stipulating the specific requirements for disposal or storage of spent/disused radioactive waste. According to the IAEA basic safety standards (IAEA, BSS GSR 3), the fundamental safety objectives that apply for all facilities utilizing and/or emitting ionizing radiation should apply to activities in radioactive management including the disposal of radioactive waste [6], [7].

Uganda has a classification system based on the international recommendation [8] documented in the Atomic Energy Regulations 2012 considering both the longevity of the individual radionuclides and the radiological hazard albeit in a qualitative way. However, this classification does not provide a quantitative criteria to distinguish between the different waste classes and neither does it provide specific options regarding waste disposal. Additionally, the criteria does not describe the real Ugandan scenario in terms of the nature and types of radioactive waste generated and hard to implement within the available regulatory and legal infrastructure unless major reviews are made and other supporting legal documents developed. This implies the need to develop a specific criteria for radioactive waste classification that suits the Ugandan scenario and regulatory capabilities to facilitate the; development of relevant legislations, establishment of relevant regulatory requirements and criteria, strengthening of communication with the relevant stakeholders and interested parties including the public and improvements in record keeping [9][10][11].

The classification criteria will also help the facility operators to design appropriate waste packages, carry out appropriate segregation and management of waste as required by the classification criteria. Given that short-lived radionuclide can cause similar health effects albeit for a shorter period than the latter, activity concentration should be used in developing the specific classification criteria.

The lack of a specific radioactive waste classification criteria has led to delayed decision making regarding radioactive waste management and inadequate communication between the regulatory body and the concerned parties. Consequently, most waste generated is stored at the producers' site in temporary storage (bunkers) with no specific guidelines and codes of practice that merit the standards of the storage facilities which compromises the security of the radioactive waste and the safety of workers and the public.

Table 1. List of radionuclides in the national (Uganda's) inventory.

#	Nuclide	Half-life
1	Cs-137	30.1a
2	Am-241-Be	432a
3	Am-241	432a
4	Ni-63	100a
5	H-3	12.3a
6	Ra-226	1,600a
7	C0-57	271d
8	Co-60	5.3a
9	Tc-99m	6.1h
10	I-131	8d
11	Ir-192	74d
12	I-125	60d
13	Sr-90	28.8a

Source: Uganda Atomic Energy Council (AEC) annual report 2012/13

The IAEA recommends a generic classification criteria for classifying disused sealed radioactive sources based on the activity and longevity of the radionuclides with a view of qualifying the waste for particular disposal schemes [7]. The radionuclide with activity; < 10 GBq is regarded as weak, 10 GBq - 10 TBq is regarded as medium risk and > 10 TBq is high risk and the respective recommended disposal schemes [1]. The waste disposal options also imply the classes within which the radioactive waste fall.

Australia has an already established classification system for disused sealed sources and other radioactive waste in general based on activity concentration with a view to qualify the waste for near surface disposal [13]. Since the Australian situation is more or less similar to that of Uganda, it will serve as a guideline for comparison of practice. The derived criteria is anticipated to not to change the classification system for Uganda but rather make it more meaningful by suggesting recommendations for amendments.

The RESRAD V.7.0 computer code [14], [15] was used to derive boundaries between the two categories of radioactive waste i.e. LLW and ILW retaining the boundary between ILW and HLW as heat generation of $2kW/m^3$. The RESRAD code was preferred for this study since it is; user friendly, considers all the exposure pathways with flexible site specific input parameters that can be adjusted depending on the site characteristics and takes into account future land use considering different exposure scenarios. Given that the objective of the study was to establish a radioactive waste classification criteria based on activity concentration (reverse dose assessment), the RESRAD computer code calculates homogeneous soil guidelines for single user specified radionuclide for the applicable exposure pathways for which the basic dose limit will not be exceeded over a given time period after disposal of the waste and hence provides a greater degree of reliability.

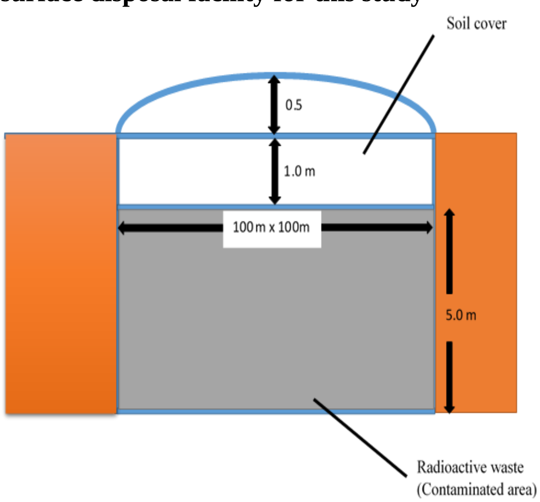
2.0 Materials and methodology

During the study, the radioactive waste management situation for Uganda was assessed and the most likely exposure scenario was identified. This formed a basis for selection of a tool or model to derive the concentration limits to distinguish between LLW and ILW with an aim of allocating the different waste classes to different disposal streams.

A hypothetical near surface disposal facility was assumed as shown in figure 1 and a human intrusion scenario assumed to occur after the loss of the passive institutional control of 300years and a residential house was assumed to be built directly on top of the waste as shown in figure 2. The soil cover, rocks and the waste itself are regarded as porous materials and the resident is assumed to drain water for household use, drinking and irrigation from the well situated at the downstream of the waste.

The radionuclides used in the simulation were selected from the national inventory [table 1] that are commonly utilized in Uganda i.e.; Cs-137 used in industrial applications for radiography, gauging devices and food irradiation; Co-60 used for the same purpose as Cs-137 as well as in medical applications for tele-therapy, brachytherapy, blood irradiator, etc. The other sources applied in medical and industrial applications include H-3, Ra-226 and Sr-90.

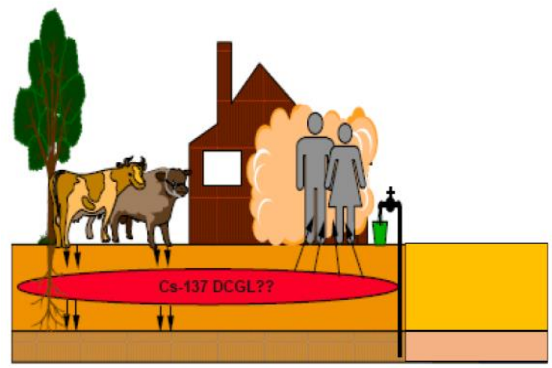
Figure 1: A hypothetical representation of a near-surface disposal facility for this study



Source: Individual study

The radioactive waste was assumed to be of area 10,000 m^2 to cater for faming activities and residence, 5 m thick and covered with soil of thickness 1.5 m. The 0.5 m soil cover is assumed to be eroded by the surface water at the end active institutional period (300 years), also the source containers and waste packages are conservatively assumed to have degraded by corrosion. The intruder is assumed to excavate the surface of the disposal site for construction and drilling of a well hence bringing the contaminated soil to the surface. Due to degradation of the waste packages and source containers, it is also assumed that the intruder cannot distinguish between the radioactive waste material and soil.

Figure 2: A conceptual model for human intrusion scenario for the calculation of the single radionuclide soil guideline



Source: Edited from user manual for RESRAD V.6.5

The human intrusion scenario was assumed to occur as a result of loss of passive institutional control with the intruder assumed to be a resident on site practicing subsistence agriculture and rearing some animals. A conservative dose limit to the intruder of 1 mSv/yr was assumed in excess of the background radiation to derive the upper limits of concentration suitable for near surface disposal hence the lower limits for intermediate radioactive waste. The site specific parameters considered in the model include;

- Physical parameters (size, depth, density, porosity, diffusion coefficient)
- Hydrological parameters (conductivity, gradient, water table depth)
- Geochemical parameters (distribution coefficient, leach rate, solubility)
- Meteorological parameters (precipitation, evapotranspiration, erosion, runoff, mass loading)
- Usage and consumption parameters (inhalation, irrigation, ingestion, occupancy)

To ensure a conservative analysis, the modeled waste was assumed to contain a mixture of long-lived and short-lived radionuclides mixed homogenously with equal distribution of radionuclide and is assumed to satisfying the inequality;

$$M(t) = \sum \frac{S_i(0)}{G_i(t)} \leq 1 \quad \text{for } t_r \leq t \leq t_h \qquad (4)$$

Where; $M(t)$ is fraction of dose limit received by the intruder at time t after radiation survey, $S_i(0)$ is initial concentration of the ith principal radionuclide in a uniformly contaminated zone at t=0 and $G_i(t)$ is the single radionuclide concentration guideline for the ith principal radionuclide in a uniformly contaminated zone at time t, t_r is the time from which the radioactive waste is disposed of in a repository while t_h is the time horizon. The radiation survey is assumed to have been carried out from the time of disposal.

The pathways considered for the modelling include;

- External exposure from gamma radiation
- Dust inhalation, radon inhalation assumed not to result from radioactive waste disposal and so left out of scope.
- Ingestion of contaminated meat, soil, milk, surface water, ground water, grains, vegetable and fruits
- Use of contaminated water for irrigation of crops and stock

Default dose conversion factors for external exposure and radionuclide intake by ingestion and inhalation were used. Qualitative literature review was conducted for selection of input values and defining exposure pathway parameters basing on the food consumption habits and lifestyle of Ugandans.

The RESRAD code was iterated for 1,000 years to establish the potential effects of the repository on the life time of the intruder and the future generation since the exposure from some radionuclides reaches maximum value at the beginning of 1,000 year. For long-lived radionuclides with decay progenies, the parent nuclide are assumed to be in secular equilibrium with their daughter nuclides.

3.0 RESRAD Result and analysis

The purpose of modelling the individual radionuclide soil guidelines was to develop a classification criteria for distinguishing between LLW and ILW for Uganda. The derived values represent the upper limit for LLW for which a dose to the reference person cannot exceed 1mSv/yr from an individual radionuclide at t = 0.

The derived result are conservative due to the conservative but realistic assumptions and will further facilitate in selection of appropriate disposal schemes and in the development of relevant laws and regulations.

Table 2: RESRAD output results for the single radionuclide concentration in the soil for 1mSv/yr dose limit.

Single Radionuclide Soil Guidelines G(i,t) in Bq/g

Basic Radiation Dose Limit = 1.000E+00 mSv/yr

Nuclide (i)	t= 0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02	3.000E+02	1.000E+03
Co-60	2.660E+04	3.002E+04	3.821E+04	8.896E+04	9.948E+05	4.257E+09	*4.118E+13	*4.118E+13
Cs-137	1.797E+06	1.814E+06	1.849E+06	1.975E+06	2.384E+06	3.285E+05	7.128E+04	1.763E+10
H-3	*3.560E+14	1.637E+02	2.665E+01	1.383E+02	2.164E+05	*3.560E+14	*3.560E+14	*3.560E+14
Ra-226	3.446E+04	3.415E+04	3.352E+04	3.141E+04	2.610E+04	1.632E+03	5.469E+00	5.663E-02
Sr-90	4.442E+09	4.486E+09	4.576E+09	4.906E+09	5.986E+09	4.371E+04	6.994E+03	1.120E+11

*At specific activity limit

The results are comparable to the maximum concentration limits for class C category of Australia albeit calculated for 200 yr ICP. There is a slight agreement in the derived criteria and the Australian classification criteria. The variations are a result of differences in the input parameters e.g. site specific parameters, consumption habits, assumptions, among others.

Table 3: Comparison between derived criteria and the Australian criteria for high activity limits for LLW.

Radionuclide	Derived criteria (Bq/g) (300 yr ICP)	Australian criteria (Bq/g) (200 yr ICP)
H-3	3.56E+14	1.00E+09
Sr-90	4.44E+06	5.00E+06
Cs-137	1.79E+06	5.00E+06
Co-60	2.66E+04	5.00E+06
Ra-226	3.45E+04	5.00E+03

There is a slight agreement in the derived criteria and the Australian classification criteria. The variations are a result of differences in the input parameters e.g. site specific parameters, consumption habits, assumptions, among others. Any radioactive waste with radionuclide of activity concentration in excess of the derived values belongs to the ILW hence classifying the radioactive waste. This criteria thus helps to allocate the particular wastes to appropriate disposal schemes by virtue of their waste classes.

4.0 Recommendations and conclusion

The results of this study should serve as a basis for developing a comprehensive radioactive waste classification criteria for Uganda to distinguish between different waste categories. The classification criteria will further help in;

- selecting appropriate disposal scheme; Actually, the derived criteria can also serve as a radioactive waste acceptance criteria for near surface disposal
- developing appropriate legal documents such as; safety guides, codes of practice, radioactive waste management policies, etc. that will help in enforcing compliance, decision making processes and setting standards
- effective communication between producers, regulatory body and the public
- selecting appropriate means for handling, transporting and packaging, among others.

Further studies should be carried out in future using specific data particularly; hydrological, geochemical and metrological data and compare with the results of this study.

Since a conservative dose limit of 1mSv/yr was used in the derivation of the criteria, a dose constraint should be establish to ensure that the dose to the member of the public should not exceed 1 mSv/yr. The ALARA principle should be applied considering the social and economic factors and future use of the land.

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