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RADIOLOGICAL IMPACTS ANALYSIS WITH USE OF NEW ENDPOINT AS COMPLEMENTARY SAFETY INDICATORS

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ABSTRACT

The paper shows the new safety indicators on risk assessment (safety assessment) to radioactive waste environmental management implementation (concentrations and fluxes of naturally occurring radioactive materials (NORM)). The endpoint obtained, allow the best analysis of the radiological impact associated to radioactive waste isolation system. The common safety indicators for safety assessment purpose, dose and risk, are very time dependent, increasing the uncertainties in the results for long term assessment. The complementary and new proposed endpoints are more stable and they are not affected by changes in the critical group, pathways, etc.. The NORM values on facility site were obtained as result of national surveys, the natural concentrations of U, Ra, Th, K has been associated with the variation of the lithologies in 3 geographical areas of the Country (Occidental, Central and Oriental). The results obtained are related with the safety assessment topics and allowed to apply the new complementary safety indicators, by comparisons between the natural concentrations and fluxes on site and its calculated values for the conceptual repository design. In order to normalize the concentration results, the analysis was realized adopting the criteria of the Repository Equivalent Rock Volume (RERV). The preliminary comparison showed that the calculated concentrations and fluxes in the Cuban conceptual radioactive waste repository are not higher than the natural values in the host rock. According to the application of new safety indicators, the reference disposal facility does not increase the natural activity concentration and fluxes in the environment. In order to implement these new safety indicator it has been used the current ^{226}Ra inventory of the Repository and the ^{226}Ra as natural concentration on the site.

1. INTRODUCTION

Cuba has been committed to the peaceful use of ionizing radiation in order to achieve social-economic development in diverse sectors. Consequently, the use of radioactive materials and radiation sources and the production of radioisotopes may generate radioactive wastes, which require a safe and proper management.

The Center for Radiation Protection and Hygiene (CPHR) is responsible for developing and implementing a national strategy about the management and safety assessment of radioactive wastes. The current approach is to disposal those wastes in two near surface repositories, a vault concept for low and intermediate radioactive waste and a borehole for the spent sources. Into the SA, of safety indicators are the endpoints, which are measures of the capacity of isolation system for the environment and human, from the risk associated for a radiological or nuclear practice. These safety indicators allow to comparing the obtained result with the national and international standards and regulations to estimate the possible impact in the human and the environment for a practice [1, 2, 3, 9, 10].

In the radiation protection field, the common safety indicators are the dose and risk, which are not suitable for all nuclear practice, they can be affected for different assumptions about

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the critical group, assessment period and parameter uncertainties for long term safety assessment for radioactive waste disposal. Our practice experience in this thematic [4, 6, 8, 9, 10] showed the necessity of new safety indicators complementary to dose and risk, which would be less influenced for element such as: critical group, consumption habits, pathways and so on, those element are very difficult to predict their behaviour for long time scales and the complementary endpoints may facilitate the defence of the safety assessment results, according the radiation protection principles.

The natural concentrations of radionuclides (NORM) can provide an indication of the potential effect on humans and their environment, this parameter is quite stable in the time and also, is easy to implement in the safety assessment methodology. For this study we use the NORM concentrations and the natural fluxes of radionuclides as a safety indicators, for the first one a wide database was created, where this indicator are associated to the different lithologies in the Country.

2. OBTAINING OF THE NATURAL RADIOACTIVE CONCENTRATION LIKE SAFETY INDICATOR

2.1. Investigations carried out for data collection

2.1.1. Source of Data collection of natural radionuclides concentrations.

In these moments a homogeneous map of the natural elements distribution radioelement (geochemistry maps) and the Iγ, U(Ra), Th and K doesn't exist in the Republic of Cuba. The information contained in each one of the elements gamma spectrometric airborne, carried out for the flat and mountainous regions, have not become unified, disabling for this reason, to conform an unique map of the natural radioelement distribution.

Therefore, the CPHR have the information of the anomalies gamma spectrometric airborne contained in each one of the reconnaissance carried out in the country and data of the radioactive anomalies detected in surface and wells. The information is given by the different carried out geologic reconnaissance and the same one is in database form. Data of flights don't exist in the county of Havana City, (we are working in it). Thus, we have done a content initial data on Cuba wide U, Ra, Th, K distributions and Iγ, which to characterize the values of the mentioned elements, giving the minimum, maximum values and the average of the total anomalies measured in each one counties that conform the Republic of Cuba, we also show the quantity and the type of measured anomalies. The maximum and minimum values have been referential to terrestrial and longing well anomalies. The minimum values of Iγ (they correspond with the values of the normal bottom for each county, taken directly of measurement carried out in different field itineraries (measures with a scintilometer) [9]. According to obtain safety indicators, only a few information are available about concentration of elemental and naturally occurrence radionuclide NORM in our repository site, therefore we use for some studies cases data from international references taking into account our specifics characteristics.

2.1.2. Geologic Cuban aspect into account in the investigations

The Cuban geology is very complex, due their physical form and geographical position, an island is considered. For this reasons, we have divide the Country in 3 regions (see figure 1).

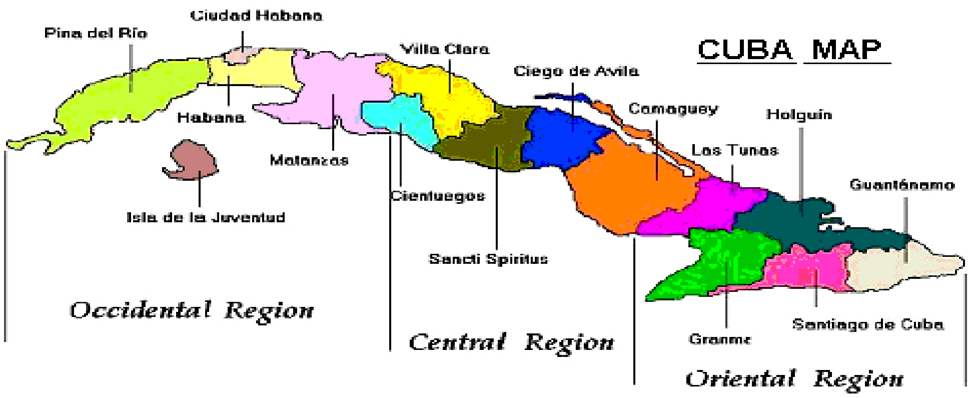

Figure 1. Geographical areas of Cuba associated with the lithologies variation

West region: This region has been created by the provinces of: Pinar del Río, Havana City and Matanzas. The mentioned area is geologically conformed by Limestone, Sandstone, Schist and Lutites.
Central region: This region includes the provinces of: Villa Clara, Sancti Spiritus, Ciego de Avila and Camaguey. This area is geologically conformed by Limestone, Serpentine, Skarn, Granite, Tuff, and Schist.
East region: This region includes the provinces of Holguín, Gramma, Guantánamo, and Santiago de Cuba. This area is geologically conformed by Limestone, Schist, Tuff, Granite and Serpentine.

The table 1, show the Oriental region, with the highest contributions associated to the sedimentary rocks. In other regions of the Country also differ in the results, (e.g. U and Ra, the highest values correspond to the Occidental and Central region, associates fundamentally to the limestone and skarn respectively. In the Th and the K, there are not important variations in the data of the 3 regions; these results show the geologies behaviour in the different areas. As result of the carried out investigation, was obtained the distribution of the concentration for the natural radioactive elements, associated to the lithology and the fundamental geological environment. The variation of the concentrations is associated to the changes lithologies, to the genesis of the geological formations, geographical position, etc.

Table 1. Distribution of anomalies (Iγ, U, Ra, Th and K) in the surface, wells, trenches and flights aero-gamma spectrometric.

Natural concentrations		REGIONS					
		Occidental		Central		Oriental	
		Aerial	*Terrestrial*	Aerial	*Terrestrial*	Aerial	*Terrestrial*
Iγ (μR/h)	Mínimum	0.66	5	0.54	4.6	0.60	5.75
	Máximum	5.25	643.3	3.31	268.00	5.59	11.25
U (ppm)	Mínimum	0.73	0	1.40	1.00	0.93	1.25
	Máximum	9.6	1182	9.70	428.2	15.89	72.5

	Fondo	4.30	80.88	3.51	92.1	0.91	15.95
Ra (ppm)	Mínimum	-	22	-	2.00	-	2.00
	Máximum	-	1067	-	917.00	-	87.5
	Background	-	71.53	-	191.53	-	13.89
Th (ppm)	Mínimum	0.96	0	0.78	0	0.37	1.91
	Máximum	19.1	29.50	7.70	47.5	61.98	41.00
	Background	6.86	8.37	2.27	8.95	9.65	13.83
K (%)	Mínimum	0.26	0	0.28	0.05	0.31	0.1
	Máximum	2.03	3.75	2.51	3.42	5.17	5.3
	Background	0.50	0.99	0.54	1.48	1.13	2.23
Main lithologies		*Limestone, sandy, schist and lutite*		*Limestone, serpentine, skarn, granite, tuff and schist*		*Limestone, schist, tuff, granite and serpentine*	

2.1.3. Data collected about de indicator obtained (natural radioactive concentration).

In the first stage, the maximum and minimum values of U, Ra, Th, K (ppm and %) distributions and Iγ (μR/h), have been referred to terrestrial, longing well, samples and anomalies gamma spectrometric airborne, carried out in the different region of the Republic of Cuba (West, Central and East) [9]. The table 2 shows the main results, which are sorted according to different types of lithologies in the country and the variation ranges of the concentration for each element. The concentrations obtained characterise in the regions country, the main rock associate to this indicator, which are the main existent types in the Cuban geology. In the west region, the biggest contribution is associated to the sedimentary rocks. Also, the different regions country differ in their results (Uranium and Ra, of the West and Central region had the highest values in the country, quite differentiated from the values of the East region, associates fundamentally to the limestone and skarn respectively). For the Th and K there are not important variations data of the 3 regions, those results are an image of the different geology in the areas. In the whole country, the concentration distribution for natural radioactive elements was obtained, associated to the main present lithologies.

Table 2. Natural radionuclide's concentration for rocks type

Radioactive element		**Main lithologies (Regions)**								
		West			**Central**			**East**		
		Limestone	***Lutite***	***Schist***	***Skarn***	***Limestone***	***Schist***	***Granite***	***Limestone***	***Tuff***
U (ppm)	*Min.*	1	33	5	2	8	0.50	5	2	5
	Max	673	488	229	3450	160	63	29	14	184
Ra (ppm)	*Min.*	5	32	5	7	6	26	2	*	2
	Max	577	490	134	2500	50	628	22	*	129
Th (ppm)	*Min.*	0	1	0.14	0.30	0	2.5	5	0.13	2
	Max	20	20	28	150	150	16	48	202	202
K (%)	*Min.*	0	0.10	0.10	0	0	0.50	0.30	0	0.2
	Max	4	2	3.50	5	5	4	8.40	1.5	13.8

* not available concentrations in this rock.
Min.= Minimum ; Max.= Maximum

According the Cuban geology where the sedimentary rocks are majority, the limestone is included in the 3 regions, in the West it possesses the maximum concentration values for U and Ra; for Th and K the relative peaks are located in the East and Central respectively. All these variations respond to the different geologic histories of the evaluated regions. For the igneous rocks, the granites possess relatively low values of natural radioelement concentration; the tuffs have interesting maximal values for Th and K. The metamorphic rocks included the Skarn. The skarn rock has the higher concentration of U and Ra of natural occurrence in Cuba, which are associated to an anomalous area of the Central of the country (taking account this U concentration high values, have been done 10 new assessment in order to prove it and the result was the same, see table 3). The schist, in the West and Central regions has important values of concentration in Ra and U.

Table 3. New assessment about higher values

Sample number	*U Concentration (ppm)*	*Standard deviation*	*Confidence interval*
1	3390.00	112.00	4.00
2	3560.00		
3	3280.00		
4	3260.00		
5	3600.00		
6	3460.00		
7	3530.00		
8	3450.00		
9	3420.00		
10	3500.00		
Average 3445.00			

The obtained indicator will be incorporated inside the methodology of the SA, in the evaluation stage of the results as comparison measure to evaluate the possible impact of a nuclear practice. These indicators will establish the limits (concentration) of the natural occurrence of radioelement for different rock types; which should be fulfilled to guarantee that the nuclear practice has not negative impact in the environment and the man.

Source of Data collection of fluxes

There are a national database about the fluxes data, which take account the river flow rates and the aquifer underground fluxes. The National research Institute of Water resource operates a comprehensive monitoring system for both flow and water quality using a network of over 73 gauging stations. This fluxes data, together with information from other sources, is held in the National Office for mineral resource, which storage all information about the geology and hydrology investigation. The archive contains a broad range about this important information in order to can obtain relevant evaluation of the fluxes. There are some lack of information for certain elemental and specific site parameters, in this case, we used data from international references, previous a technical review.

We have not specific investigations about erosion rate in granodiorite in Cuba, therefore we use international associated with national data. According our geology, the climate and the topographical aspects we can assume an average erosion rate of 5 m/My. For 80 km^2 of exposure rock, we can define that the total mass of material eroded is 1.06×10^{12} kg/year, that means a flux due erosion of 1.325×10^4 $kg/km^2/year$. The main fluxes associated to rock erosion are summarized in the table 4.

Table 4. Fluxes associated to rock erosion

Species	*Mass flux for total granodiorite kg/yr*	*Specific mass flux $kg/km^2/yr$*	*Activity flux for total granodiorite Bq/yr*	*Sppecific activity flux $Bq/km^2/yr$*
U	3.71	0.05	-	-
Th	16.9	0.21	-	-
K	2120	26.6	-	-
U chain	-	-	4.6×10^7	5.75×10^5
Th chain	-	-	8.6×10^5	1.0710^4
^{40}K	-	-	6.67×10^5	8.3×10^3

The other important natural process causing elemental fluxes that we taking into account is the groundwater flow, according the site-specific data and some parameters from international references we defined the typical hydraulic parameters, see table 5.

Table 5. Hydraulic typical parameters

Rock	**Hydraulic conductivity (m/s)**	**Porosity**	**Gradient**	**Groundwater flux ($l/m^2/yr$)**	**Groundwater velocity (m/yr)**
Granodiorite	1.1×10^{-7}	0.1	0.02	4.1×10^{-4}	7.2

The elemental concentrations in the groundwater in the site are: Uranium 3 mg/l; Thorium 2.1 mg/l; Potassium 4 mg/l. The specific groundwater fluxes are: Uranium 1.23×10^{-3} $kg/km^2/yr$; Thorium 8.61×10^{-4} $kg/km^2/yr$; Potassium 1.64×10^{-3} $kg/km^2/yr$. The activity flux from groundwater discharge is: Uranium 15.25×10^3 $Bq/km^2/yr$; Thorium 14.12x103 $Bq/km^2/yr$; Potassium 34.28×10^4 $Bq/km^2/yr$.

3. APPLICATION OF NEW SAFETY INDICATORS. CUBAN RADIOACTIVE WASTE REPOSITORY.

3.1. Assessment using radionuclides concentrations.

The host rock is a massif granodiorite in the central part of the country in the province of Cienfuegos, all relevant information about the geosphere was obtained during the site selection process [10]. We carried out geologic, hydro geologic and geophysical investigation in order to obtain the most important parameter associate to the characteristics of the host medium. Those studies started from early 90 and were concluded in the stage of the site characterization and all they are mentioned in the document references. The site is located in the Manicaragua granodiorite belt, in relation with sedimentary and other volcanic rocks, its surface area is about 225 Km^2 and some regional studies suggest a depth of around 5 Km, therefore taking into account a square shape the total volume of Manicaragua granodiorite is the order of 1125 Km^3 and according its average density of 2650 kg/m^3 the total mass is the 2.98 x 10^{15} kg, these data were used in the calculation.

Preliminarily, for the repository radionuclide inventory, were used the data from a reference repository for high level waste [1, 4, 5], because, according our nuclear policy, we will not disposal high level waste in Cuba at the moment. Have been used only the data for Uranium Thorium and Potassium radioelement according its amount, activities and hazards, the inventory were defined as: ^{238}U 3x10^{13} Bq; ^{235}U 1.1x10^{11} Bq; ^{232}Th 1.2x10^{10} Bq; ^{40}K 2.3x10^{8} Bq. According the repository volume, the radionuclide activities are: ^{238}U 3.38x10^{8} Bq/m^3; ^{235}U 2.86x10^{5} Bq/m^3; ^{232}Th 3.10x10^{4} Bq/m^3; ^{40}K 5.97x10^{2} Bq/m^3.

In the first study stage, only was evaluated the use of the NOR for comparison purpose therefore all calculation are associated to the Uranium (total activity), Th^{232} and K^{40}, other elemental or radionuclide data will be used in next stages. According to national investigations the average elemental concentrations in granodiorite rock are: Uranium 17 mg/kg; Thorium 26.5 mg/kg; Potassium 500 mg/kg. Taking into account the previous information, the total mass for each element in the granodiorite rock is: Uranium 5.07x10^{10} kg; Thorium 7.89x10^{10} kg; Potassium 1.49x10^{12} kg. According to these data the most important amount is the Potassium element, wish is included as associated minerals to the granodiorite rock.

The next stage was, to obtain the activities for the radionuclides in the selected environment; we used the data, showed in the table 6. For the selected radionuclides the specific activities and the isotopic abundance are:

Table 6. Radioelement characteristics.

Radionuclide	*Isotopic abundance*	*Specific activity (Bq/kg)*
^{238}U	0.9927	1.24x10^{7}
^{235}U	0.000056	7.11x10^{7}
^{234}U	0.0072	2.30x10^{11}
^{232}Th	1 *	4.1x10^{6}
^{40}K	0.000118	2.09x10^{8}

* All Th is assumed to be ^{232}Th

According to this information, the activity in the granodiorite massif is: $^{(238+235+234)}$U 624 Bq/Kg; ^{232}Th 432.9 Bq/kg; ^{40}K 18.8 Bq/kg. An useful alternative approach in order to avoid inappropriate comparison is to evaluate the total activity contained in a uniform volume of rock, the repository equivalent rock volume (RERV), according to our repository conceptual design we can consider a RERV with dimensions of 544m x 118m x 6m for a total volume of

385152 m^3. For this equivalent rock volume, we also make calculations of activities. The total mass for each element in the RERV in the granodiorite massive is: Uranium 1.74×10^4 kg; Thorium 2.70×10^4 kg; Potassium 5.10×10^5 kg, and the specific activity in the RERV is: $^{(238+235+234)}U$ 1.63×10^3 Bq/Kg; ^{232}Th 434 Bq/kg; ^{40}K 12.35 Bq/kg. The total activity in the RERV is: $^{(238+235+234)}U$ 1.66×10^{12} Bq; ^{232}Th 4.43×10^{11} Bq; ^{40}K 1.26×10^{10} Bq.

3.2. Assessment using radionuclides flux.

For calculation of the flux data from the Repository, we carried out a safety assessment for our radioactive waste disposal system following the ISAM methodology [5]. According the assessment context, we have defined a normal scenario (release scenario), which takes into account only the natural occurrence process in the disposal system, corrosion, degradation, infiltration and so on. For calculation, we use a compartments model in order to simulate the complete radioactive waste disposal system; the software was the Model Maker [13], software from Cherwell Scientific Ltd, UK. This code is quite useful for modeling environmental problems, including the release, transport and final incorporation of the radioactive contaminants to the environment. The final objective was to obtain the specific activity flux from the repository for each radionuclides, allowing a preliminary release comparisons against the natural-occurring species.

The Model Maker [5, 7] simulate the reality using compartment or box models, and the system to be modeled is divided into suitable compartments and is possible to define between which compartments the transport occurs. This tool is useful for modeling the diffusion and advection transport of radionuclides, which are very important events in the repository performance. We have divided the Repository in different box, according the waste packages, the disposal container and the possible occurrence of flow and transport of material between the compartments. In the near field, we identified as compartment the waste form and the different engineer and finally we modeled the geosphere taking into account the possible relevant process (advection, dispersion, radecay, etc). Some parameter data used, are site specific and other more generic according our possibility, we carried out several model runs in order to improve the model and verify the results. The evaluated time was 1×10^{12} years, from the closure of the Repository and the endpoint was the specific activity flux (see table 6)

Table 6. Specific activity flux.

Radionuclides	***Specific activity flux (Bq/km^2/yr)***
^{238}U	0.9×10^5
^{235}U	4.8×10^2
^{234}U	43.0
^{232}Th	38.60
^{40}K	5.60×10^{-2}

3.3. Interpretation of the concentration and flux data as safety indicator (endpoint).

We have been the simple comparison of mass and activities for the rock and the repository and the same for the flux associated to natural process in the granodiorite and the normal release scenario in the repository, see table 7.

Table 7. Comparison between mass rock and activity flux.

Radionuclides	*Total activity RERV (granodiorite) (Bq)*	*Total activity Repository (Bq)*
U chain	$1.66x10^{12}$	$1.30x10^{10}$
^{232}Th	$4.43x10^{11}$	$1.20x10^{10}$
^{40}K	$1.26x10^{10}$	$2.3x10^{8}$

The simple activity comparison between the granodiorite and the Repository, taking into account the RERV, showed that the total activities in the Repository are lower than the granodiorite activities. The main reason of this slight difference is associated fundamentally to the designed Cuban Repository, which is for low and intermediate radioactive waste level and therefore the total waste volume are very lower than the reference disposal facility used for define the radioactive waste inventory (high level radioactive waste). Next stages, we will carry out an assessment with more realistic inventories according the repository size.

The comparison between activity flux from granodiorite and the repository flux, the last one was obtained by calculations of the model for normal release scenarios, which only included natural process relevant for the repository performance; the table 8 summarized the results.

Table 8. Comparison between activity flux from granodiorite and the repository flux.

Species	*Activity flux for granodiorite (Bq/yr)*	*Activity flux for Repository (Bq/yr)*	*Specific activity flux Granodiorite ($Bq/km^2/yr$)*	*Specific activity flux Repository ($Bq/km^2/yr$)*
U chain	$4.6x10^{7}$	$1.1x10^{-1}$	$5.75x10^{5}$	$0.9x10^{5}$
Th chain	$8.6x10^{5}$	$4.15x10^{-5}$	1.0710^{4}	38.60
^{40}K	$6.67x10^{5}$	$4.8x10^{-8}$	$8.3x10^{3}$	$5.60x10^{-2}$

The comparison showed that the values of activity fluxes from the repository are lower than the flux from the host rock. In this case, there is a main difference in relations with the former case (activity comparison), the repository barrier play an important role as a flux controller, despite, our disposal concept is not designed for high level waste. The waste form, the engineer barriers and the important role of the rock (granodiorite) with poor hydrogeology conditions, water movement associated to fracture and faults, was the principal reason of these results. The preliminary results showed the possibility to use other safety indicator to support the safety assessment activities, these complementary endpoints are useful for long term assessment and are less influenced by human factors. In next stages, we will evaluate other elements and radionuclides present in our inventories, we will carry out more specific site investigation in order to reduce the data uncertainty and we use the safety assessment methodology with dose and other safety indicators to derive acceptance disposal criteria.

4. CONCLUSIONS

1. A wide databases was obtained in 3 Cuban regions, which characterise the natural elemental radioactive concentration and the variation range for the lithologic types studied in order to use it in the safety assessment.
2. The concentrations of U vary in a wide range from 0.5 to 3445 ppm, the Ra from 2 to 2500 ppm, the Th from 0 to 203 ppm and the K from 0 to 14%. For all regions, the Central region has the rock (skarn) with the higher values in concentration of U and Ra.
3. The studies allowed to evaluate, for first time in Cuba, the concentrations and fluxes as a safety indicators for safety assessment of radioactive waste disposal facilities.
4. According to the new safety indicators (endpoint), the activity concentration and fluxes for the Cuban repository are lower than to the environment values for the granodiorite rock (the disposal facility does not increase the background levels).
5. The activity flux of the repository are several order smaller than the granodiorite rock due the different engineer barriers used and the favourable site begin to play their useful role, which allows to reduce the radionuclides discharges from the repository.

It is recommedable do not replace dose and risk with natural safety indicators. Instead, natural safety indicators are considered to be complementary to dose and risk. In next stages, to evaluate other elements and radionuclides present in the Cuban inventories and carry out more specific site investigation in order to reduce the data uncertainty and to use the safety assessment methodology with dose and other safety indicators to derive acceptance criteria.

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