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Borehole disposal concept for radioactive waste disposal-the GAEC project

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ABSTRACT

The most likely process that can lead to the release of radionuclides from a repository to the geosphere is transport by groundwater. Hence, waste disposal-related safety analyses must assess the possibility of the migration of radionuclides in the conservative assumption of leaching by groundwater after the destruction of the engineered barriers. The need to protect groundwater from possible radioactive contamination and the need to investigate radionuclide migration through soils and rocks of the zone of aeration into groundwater has become very urgent at a time when geological disposal of radioactive waste is being considered. This is why the Borehole Disposal Concept (BDC) is being implemented to address the problem. The BDC involve the conditioning and emplacement of disused sealed radioactive sources in an engineered facility of a relatively narrow diameter borehole (0.26 m). This concept is inherent with physical and chemical characteristics such as intrusion barriers, casing, lining materials, back-filling materials and stainless steel waste containers that prevent or delay the movement of radionuclides between components and inadvertent access to humans, animals and plants.

Introduction

The fundamental requirement that must be followed in a radioactive waste management programme is to ensure the protection of human health and the environment both now and in the future from a radiological accident or incident. A long term management of radioactive waste requires the disposal of the waste in a system that will prevent all forms of contamination and access to human. Such is the Borehole Disposal Concept (BDC). The concept was first developed by the Nuclear Energy Corporation of South Africa (NECSA), and has been accepted and developed further by the IAEA as a safe and secure disposal option.

The Ghana Atomic Energy Commission (GAEC) in collaboration with the International Atomic Energy Agency (IAEA) intends to implement the BDC in Ghana. When the project is completed and facility becomes operational, Ghana would be the first country to implement this concept for the disposal of radioactive waste generated in Ghana.

The BDC involve the conditioning and emplacement of disused sealed radioactive sources in an engineered facility of a relatively narrow diameter borehole (0.26 m). This disposal option uses the multiple concepts based on a system of several passive barriers which consist of the conditioned and packaged waste, repository lining, back-filling and other engineered barriers within the borehole repository [1, 2, 3]. The Borehole Casing stabilizes the borehole; it keeps the repository dry during the operational period while acting as additional barrier to transport of the radionuclides. Backfilling materials will add an additional barrier between the containers and aggressive chemicals, prominently chloride that might initiate corrosion of the stainless steel capsule [4]. The sorptivity nature of the backfilling material makes it act as a chemical buffer to intrinsically limit or reduce the release of radionuclides to the geosphere; it will also form a physical and a hydrological barrier through which leached radionuclides must pass before they are released into the immediate surroundings [4, 5].

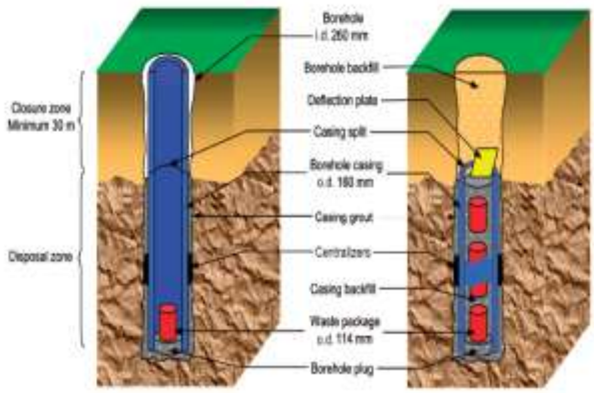

Figure (1): borehole disposal facility; showing emplaced radioactive waste and engineered barriers.

Site Location and Description:

The site for the facility is located at the Ghana Atomic Energy Commission's site at Kwabenya; in the Ga East District of the Greater Accra region. The area lies within latitudes $5^{0}6'7"$N to 5^{0} $6'9"$N and longitudes 0^{0} 21' W to 0^{0} 26' W at elevation of 64 m. The major geological formations in the area comprise of the Togo series and the Dahomeyan system [6]. The Togo consists of phyllite, schist and quartzite. The Dahomeyan system comprises schist, gneisses, and migmatites. The Togo occupies the north-western section of GAEC and occupies the highland areas whereas the Dahomeyan-outcrop in the low-lying areas [6, 7].

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Figure 2. Geological Map of Accra showing the study site and surrounding towns

Requirements for the BDC

The Borehole Disposal Concept involves series of radioactive waste management activities; administrative and technical, from pre-disposal to disposal and post-closure controls. The BDC design appears to be quite robust in terms of limiting releases to acceptable levels. This was found to be true for disposal in both saturated and unsaturated conditions, although unsaturated conditions appear to be preferred [16].In addition, the system exhibits superior hydraulic performance in unsaturated soils [16]. The requirements for the BDC are:

Planning Phase

- Source/Waste Inventory:

Source inventory is a key feature of the BDC. It is a pre-requisite developed at the conceptual stage. A country needs to prepare an inventory of all the disused sealed radioactive sources earmarked for disposal. The inventory will include the locations where the sources are kept, and detailed information regarding their number, activity, physical dimensions, identification numbers, and their actual physical conditions.

- **Public participation:**

Public participation may be required during the site selection and preliminary design phase of the project. The public participation process will depend on the approval requirements of a particular country with regard to environmental impact assessment (EIA) and or licensing of the concept [8, 9]. The main purpose of the public participation process is to raise the concerns and issues of the public and to get public approval for the implementation of the concept at a specific site. The public may also be invited or reach out to for sensitization on nuclear safety and security and other nuclear issues of public concerns.

- **Legal framework**:

Besides requiring the development of the necessary technical and operational capability, safe management of radioactive waste is also promoted by the existence of an appropriate legal infrastructure. The development of a borehole disposal facility should therefore be carried out in compliance with any relevant national regulations. Ideally, there should be an appropriate national legal and organizational framework, within which responsibilities should be clearly allocated, including those regulating activities such as the development, operation and closure of a disposal facility [10, 11]. Such a framework, including any regulations, should be appropriate to the scale and potential hazard of the proposed facility.

- **Regulatory Approval:**

Regulatory approval processes differ from country to country. In some countries a "license to construct" will first be issued followed by a license for "disposal" [12]. In other countries however, the approval process may be consolidated into one single approval. Notwithstanding the respective licensing regimes, an eventual license is required before disposal of disused sealed radioactive sources in the borehole could take place. In most countries, an Environmental Impact Assessment (EIA) will be required as part of the regulatory approval process. Part of this will entail a public participation process [10, 12].

Site Selection and Characterization:

Selection of site must be informed and favoured by the following factors which are considered in the designing phase:

- Geology: the topographical and lithological forms of the site and its environs to provide the frame for site investigation. The suitability of the site will be informed by the geological data.
- Hydrogeology: the nature of the groundwater flow system at the site and its spatial variation, the nature of flow between different hydrogeological units, the surface water hydrology and the nature of near-surface hydrology in the form of recharge and discharge areas are of utmost consideration [13, 14].
- Geochemistry: to identify the presence of anthropogenic influence on groundwater composition, to detect the presence and identity of different groundwater bodies; their distribution and extent to which mixing is occurring or has occurred, the chemical conditions that may affect the integrity of the engineered barriers of the borehole disposal facility [13, 14].
- Geomorphology: to aid the interpretation of the surficial distribution of the geological materials present at the site. The proposed site and disposal borehole need to be characterized. The information gathered during the characterization exercise will be used as input to the preliminary design, site-specific safety assessment and will serve as baseline for any future monitoring [13, 14].
- Characterization of waste involves determination of the physical, chemical and radiological properties of the waste to establish the need for further adjustment, treatment, conditioning, or its suitability for further handling, processing, storage or disposal [15].

Design:

All new equipment will be designed according to the design requirements [3] and will be qualified and tested to verify that the design requirements are met. Where possible, existing design information will be used. Existing equipment and processes used, for example in the conditioning of radium needles will not be redesigned [8]. The existing process and equipment will be qualified with the new process.

Construction Phase:

Construction of the borehole repository can only start after regulatory authorization has been issued. This usually requires the review of the safety case documentation. The construction includes activities such as drilling of the borehole, insertion of the casing, grouting of the casing and plugging of the bottom of the casing. The qualification is done to verify that the borehole is constructed in accordance with the approved design.

Manufacturing and Qualification:

Manufacturing is done according to the detailed design and all equipment with safety significance needs to be tested and qualified (engineering substantiation) to verify that it is manufactured in accordance with the approved design, relevant safety and quality control requirements.

Source Conditioning for Storage:

Conditioning of sources involves characterization of the sources, the transferring of the sources from a storage container to the capsule, the closure and leak testing of the capsule. The capsules will be stored in a shielded container until the conditioning for disposal starts [8, 9].

Conditioning for Disposal:

The conditioning for disposal means the transfer of a source capsule to the waste disposal container, the backfilling of the container, and the closure of the disposal container.

Disposal Process:

The disposal process includes the following:

- Transferring of a disposal container from the conditioning facility to the borehole.
- Emplacement of the disposal container.
- Backfilling of the borehole.
- Sealing of the borehole.

Closure, Decommissioning and Rehabilitation:

Closure, decommissioning (of the conditioning facility) and rehabilitation of the repository will take place after the receipt of waste ceases and waste emplacement operations have been completed [10]. Engineered barriers, in particular the final cover, are emplaced to ensure the integrity of the repository and minimize ingress of infiltrating water to the waste, thereby limiting radionuclide releases, and also to reduce the likelihood of disturbance by human activities. The closure can include the physical marking of the borehole, if required.

Post Closure Phase:

The post-closure activities of the borehole disposal system should include a period of monitoring known as the active institutional control period and a passive controls period. The safety during the post-closure period will be shown by means of a Radiological Post-closure Safety Assessment. The institutional monitoring will be done according to formally approved (IAEA) methods. Controls maintained over a repository after closure are designed to enhance its safety, in particular, by preventing intrusion into the disposal units. [11]

Work-done & Methodology

- Development of waste/source inventory: the waste inventory dubbed the National Radioactive Waste Inventory is under development. It captures all characterized disused sealed radioactive sources (dsrs) and waste forms.
- Development of Technical Specification; with exploitation of geo-techniques for site investigations based on:

✓The nature, distribution and properties of the sedimentary cover rocks present at and around the site;

✓The nature and characteristics of the structural geological features present at the site including folds, faults, bedding planes, joints, etc.;

✓An evaluation of the geological history of the site, including an evaluation of the manner in which it is anticipated that the geology could continue to change in the future; and

✓The nature, extent of distribution and history of exploitation of mineral deposits within the area and an assessment of the potential for future exploitation.

✓The topographic form of the site and its environs to provide the framework within which the investigations and the disposal facility are located;

✓The geomorphology of the site and its environs as an aid to interpreting the surficial distribution of the geological materials present at a regional scale and at the site and also for evaluating the presence of lithological boundaries and/or structural features;

✓The nature and distribution of the soils and rocks at the site presented as a geological map, a geological succession and geological cross sections

- Geophysical Investigations:

Two surface geophysical surveys; resistivity and seismic were undertaken to:

(i) Provide data and information on the nature of the sub-surface environment in terms of lithological contrasts, structural features and depth to groundwater (in 2D and possibly 3D); and

(ii) Identify prospective locations for siting exploration and then disposal boreholes.

- Radioactive Waste Management (RWM) Regulation was drafted whilst the RWM policy and strategy were developed.
- Human resource development- Scientists and Technologists have had training on the following key features of the BDC:

✓Waste acceptance criteria (WAC)

✓Conditioning for storage

✓Conditioning for disposal

✓Waste packaging, containerization and emplacement

✓Development of safety assessment manual

✓Disposal, closure and post-closure controls

Work to be done:

- Detail site characterization including drilling boreholes, testing, logging, geochemistry; hydrogeology and geomorphology studies.
- Perform safety and environmental impact assessment studies
- Develop site-specific safety case (on-going)
- Review quality manual for pre-disposal management of DSRS
- Draft and review waste acceptance criteria
- Development of the engineered design of the facility including waste package components
- Development of quality management manual for construction of the facility including processes and procedures

Results/Outcome:

(I) National Radioactive Waste Inventory was developed through the characterization of the sources. Data obtained include radionuclide type, activity, form, quantity at storage and country of origin. Below is the national inventory showing some features of the radioactive sources.

RADIONUCLIDE	NO. OF SOURCE	TOTAL ACTIVITY (Bq)	APPLICATION	FORM
Cs-137	30	5.66E+12	Level gauges	Sealed
	2	4.90E+05	-	Sealed
	3	3.70E+11	-	Sealed
	1	3.00E+07	Nuclear gauge	Sealed
Co-60	2	1.75E+06	NDT	Sealed
	2	4.90E+05	-	Sealed
	1	2.78E+14	Gamma Cell-research	Sealed
	1	1.85E+14	Teletherapy	Sealed
	1	2.22E+14	Food Irradiator	Sealed
Am-241	3	1.85E+12	-	Sealed
	1	1.80E+09	Nuclear gauge	Sealed
	105	3.50E+07	Smoke Detectors	Sealed
	1	1.67E+09	Nuclear gauge	Sealed

Sr-90	33	1.25E+10	Thickness Gauges	Sealed
Ir-192	1	2.26E+12	NDT	Sealed
Cd-109	6	6.66E+08	Research	Sealed
I-131	2	6.21E+09		Unsealed
Cf-252	2	2.22E+10		Sealed
Ra-226	19	7.03E+09		Sealed
H-3	2750L	3.70E+07		Unsealed (Liquid)
Fe-59	2	2.22E+10		Sealed
Co-57	3	1.11E+08		Sealed
Zn-65	1	3.70E+08		Sealed
Sr-89	1	4.77E+09		Sealed
Tl-204	2	7.40E+05		Sealed
P-32	4	1.18E+09	Research	Unsealed
S-35	5	925/ml		Unsealed
Ca-45	3	1.85E+08		Unsealed
Na-22	4	3.70E+06		Unsealed
In-113m	12	2.22E+09		Unsealed

Table 1. Radioactive Waste Inventory (NRWMC-Ghana)

(II) Geophysical Investigation:

The preliminary resistivity profiling survey conducted showed some zones of low resistivities at specific stations on all four survey lines which implies discontinuities in the rock formation and which also suggests the presence of geological contact. The seismic surveys revealed weak zones at stations close to the stations of the resistivity surveys. These weak zones suspected to be as a result of faults or fractures have been mapped in figure (3). With the aid of the resistivity sounding data and that of the seismic refraction, the site was thus characterized as a four layer formation with geological contacts at certain points.

Mapped weak zones

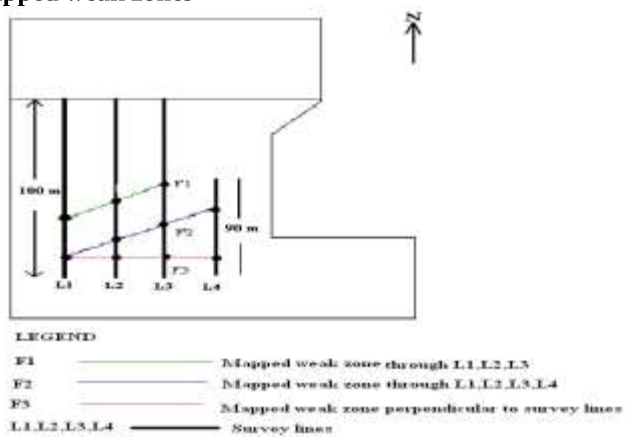

Figure 3. Mapped weak zones of project site

(III) Tender document as well as technical specification document has been drafted for award of contract. The documents clearly define all the requirements for the construction of the facility as well as roles and responsibilities.

Conclusion:

Preliminary work including desk study (of existing information), geophysical investigation, and site selection have all been done for the borehole disposal facility. Data obtained were subjected to analysis and interpretation to aid decision making for further works.

Legislative framework (regulations and strategy) to legalize the activities of the Radioactive Waste Management Centre who are the main operator/implementer of the BDC and to clearly define and allocate roles and responsibilities with regards to the operation, closure and post-closure activities of the facility have been drafted for parliamentary approval.

Human resource development is on-going. Five (5) Junior Scientists and a Technologist have had some training through workshops organized collaboratively by IAEA, NECSA and GAEC. Similar workshops and Fellowships are expected in the 2012/13 TC Project Plan for Ghana.

Recommendation:

- Site-specific Safety Case and Safety Assessment for the Borehole Disposal Concept should be completed.
- As part of the requirements to award post-graduate degree, some graduate students should be tasked to undertake comprehensive studies on the geochemistry, geomorphology and hydrogeology of the area to generate a comprehensive surface and subsurface information of the site.
- Human resource training should continue to refresh and enhance expertise and skills.

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