Implementation of the Borehole Disposal System for safe and secure management of Disused Radioactive Sources in Ghana.

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Abstract

Radioactive materials mainly in the form of Sealed Radioactive Sources (SRS) have been in use in Ghana for more than six decades in numerous applications for sustainable development. The disused sealed radioactive sources (DSRS) generated from the applications of SRS may still be highly radioactive. They can therefore pose a safety and security threat and thus require proper management to prevent any hazard to human health and the environment. Storage is an important radioactive waste management step, but long-term storage is not considered sustainable as it may represent a high-risk situation with regard to both the health hazard and security. DSRS need to be managed and disposed of carefully and in a safe and secure manner. The Borehole Disposal System (BDS) is a specially designed engineered borehole disposal facility for disposal of DSRS. The BDS has been extensively studied and developed over the last two decades. It provides a cost effective, safe and secure disposal option, particularly for countries with small DSRS inventories, limited radioactive waste disposal capabilities and infrastructural constraints. A project on the borehole disposal of DSRS is on-going in Ghana. Although the project has made good progress and moved the concept forward to a solution that is close to being implemented, it has demonstrated the challenges that developing a borehole disposal solution present.

1.0.Introduction

Radioactive materials have been in use in Ghana for more than six decades, mostly in the form of Sealed Radioactive Sources (SRS) for diagnostic and therapeutic procedures in medicine, measurement and processing techniques in industry, irradiation techniques for food preservation, sterilization of medical products, research and teaching. These sources are sealed and are typically a few centimeters in size and suitably housed in materials made of, with very few exceptions, of stainless-steel, platinum, titanium or other inert metals (Fig.1).

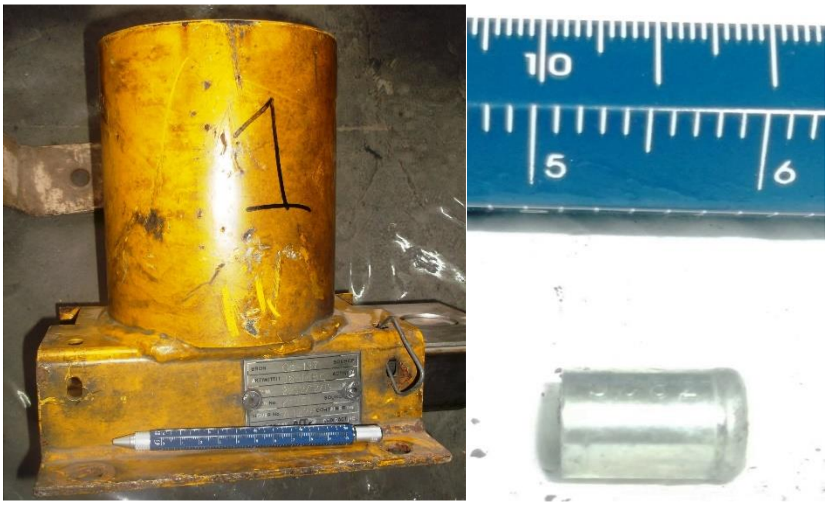

Figure 1. (a) Cs-137 Nuclear gauge (b) Cs sources removed from the gauge

These SRS, when they are no longer powerful enough for their intended purpose or when they fall out of use due to obsolescence of equipment or techniques, they are termed Disused Sealed Radioactive Sources (DSRS). A DSRS may still be highly radioactive and potentially hazardous to human health and the environment. It thus requires proper management to prevent any hazard to human health and the environment. Improper management of these beneficial devices have contributed to several incidents around the world that have resulted in serious injuries, death and extensive contamination of the environment. An example is the accident involving DSRS which occurred in Goiânia (Brazil) in 1987 [1] It resulted in four (4) fatalities, injuries and extensive damage to the environment. Accidents with DSRS also results in great economic cost, as demonstrated by an accident in a scrapyard in Spain. In 1998 a cesium-137 source was accidently melted in a scrap metal furnace and its radioactive material was released [2]. The clean-up costs and economic losses due to the interruption of the factory activities, however, were estimated at around 26 million US dollars.

DSRS also present security concerns as the sources can be stolen and their radioactive materials used in radiological dispersion devices (RDD). An RDD is designed to disseminate radioactive material without a nuclear detonation, thereby killing people or causing disruption. The consequences of an RDD attack in a population center could be very costly, considering the emergency response, the evacuation, the medical response, the radiological assessment, the decontamination or demolishment of facilities and lands, the radioactive waste management and disposal, rebuilding, and the loss-of-use [3,4].

The safe management of DSRS depends on the source strength (as indicated by its Category) and the half-life of the radionuclide that it contains [5]. Very short-lived DSRS, i.e. those with half-lives of less than about one year, can usually be “decay stored” i.e. kept in storage for up to ten years until their activity has reached exemption levels when that can be disposed or recycled as non-radioactive waste. Long-lived DSRS with very low activity (e.g. domestic fire detectors) may be also be classed as exempt and similarly treated. More powerful, longer lived DSRS will not be exempt and here an option may be to return the DSRS to the manufacturer as envisaged by the IAEA Code of Conduct on Safety and Security of Radioactive Sources [6]. More often, practical difficulties, such as the absence of an agreement with the manufacturer, the original supplier is unknown, untraceable or no longer exists, expired source certificate, or lack of funds, intervene.

DSRS that cannot be returned to the supplier, reused or recycled and that cannot be stored until they decay to clearance levels, are being storage. Storage for an extended period of time, for periods running into many years, requires ongoing regulatory control and associated resources (financial and technical) to support active management. This cannot be ensured indefinitely and the disposal of those DSRS should be considered instead of their long-term storage.

Countries with a nuclear power program, may have the option to co-dispose their DSRS in a near-surface or geological disposal facility although some DSRS may not comply with the waste acceptance criteria set up for the near-surface disposal facility. The Borehole Disposal System (BDS) for Disposal of Disused Sealed Radioactive Sources (DSRS) developed by the Nuclear Energy Corporation of South Africa (NECSA) under an International Atomic Energy Agency (IAEA) Technical Cooperation (TC) project as part of an AFRA Regional Project, offers a solution for the final management of long lived and high activity DSRSs for countries with limited volume of radioactive waste, mainly or only DSRSs, limited radioactive waste disposal capabilities, and infrastructural constraints [7]. The BDS is a multi-barrier disposal system for DSRS that uses stainless steel capsules, containers and cement barriers to contain and isolate the wastes from the biosphere, with disposal in a borehole at depths greater than 30 m to greatly reduce the likelihood of both inadvertent and deliberate human intrusion. Generic safety assessments have been performed for the BDS and have been peer reviewed by international experts.

The Government of Ghana, through Ghana Atomic Energy Commission (GAEC) is implementing the Borehole Disposal System (BDS) for disposal of Disused Sealed Radioactive Sources

(DSRS). The paper discusses the BDS and its implementation in Ghana. It also highlights the challenges in the implementation of the BDS in Ghana to date and how the challenges are being addressed.

2.0. The Borehole Disposal System

The borehole disposal system (BDS), i.e. the disposal facility and the environment in which it is sited, entails the emplacement of conditioned disused sealed radioactive sources (DSRS) in a relatively narrow diameter engineered borehole facility (shown schematically in Fig.2). The disposal borehole is closed by backfilling it with a cementitious backfill material.

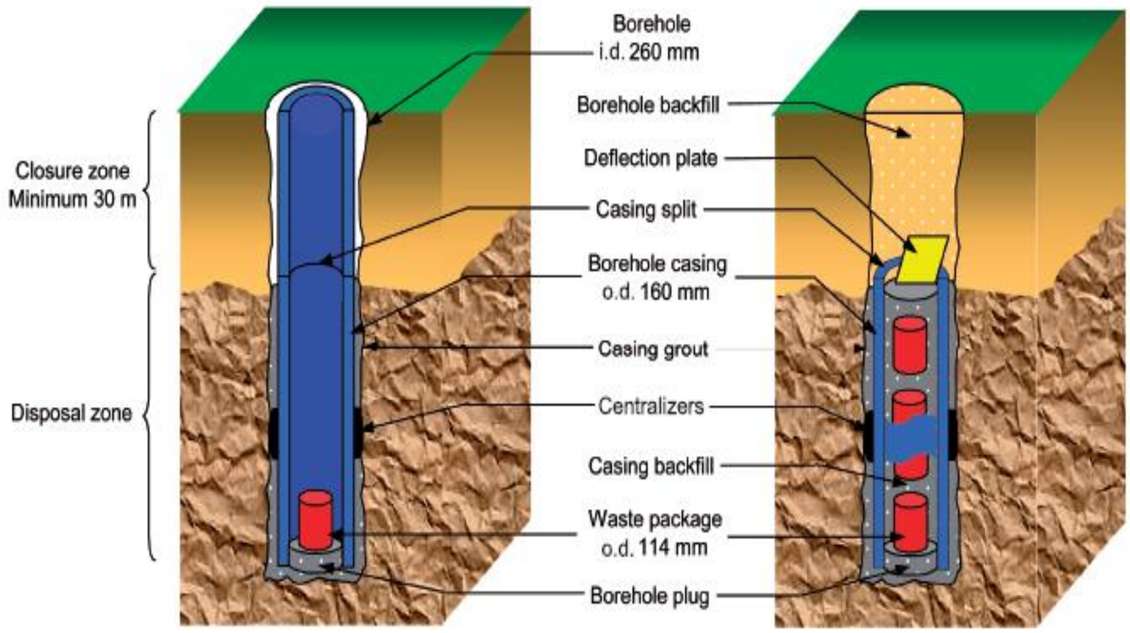

Figure 2: Graphical representation of the repository of the borehole disposal concept, showing the position of the waste packages (Not to scale). The left-hand diagram shows the borehole after the first waste package has been lowered into position. The right-hand diagram shows the completed borehole.

The DSRS are first encapsulated in high integrity three millimetre (3mm) thick 316L welded stainless steel capsules. The capsules have an outer diameter of 65 mm and a set of fixed lengths, the shortest being 135 mm long and the longest 485 mm. A set of wider capsules, with an inner diameter of 66 mm, also exist to enable re-encapsulation of a regular capsule. The sealed capsule with DSRS is then placed in a six millimetre (6mm) thick 316L stainless steel container having a concrete grout lining (here called the containment barrier) (Fig.3). A set of fixed container lengths exists with the shortest one being 250 mm long and the longest 600 mm. The containers all have a fixed outer diameter of 115 mm.

The capsule lids have a lifting pin enabling its handling. The container lids have grooves onto which a grabber can be hooked to lift and handling the container. The combination of capsule, container and grout is termed a waste package. Leak testing of both the capsule and container guarantees that the radionuclides are safely contained.

Figure 3. (a) Stainless-steel capsule; (b) cement-based containment barrier inside the stainless-steel disposal containers

The borehole has a standard diameter of 260 mm (10”). The minimum depth of the disposal zone needs to be sufficient to provide adequate isolation and not be susceptible to human intrusion. It is determined primarily by considerations of safety, including the need for suitable geology, hydrogeology and geochemistry. The borehole is cased to keep the borehole stable and to prevent water entering the hole during waste emplacement. The reference design has a 10 mm thick high-density polyethylene (HDPE) casing with an internal diameter of 141 m. This is enough to accommodate the 115 mm wide disposal containers. The casing is made watertight at the bottom by putting a cement-based plug or a casing closed at the bottom.

Figure 4: Cement Dumping Container (Hooper) and Pneumatic Grabber

The waste package is lowered using a grabber attached to winch and lifting equipment. There is a groove in the container lid that allows the grabber to attach itself to the waste package. Before the emplacement of the waste package, an amount of backfill (about 375 mm in depth), enough to envelop the waste package is poured to the base of the borehole using a cement dumping container (hooper) (Fig. 4). The waste package is then lowered slowly down the borehole at a preset speed, so that the waste package sinks through the fresh grout. After having completed each waste package and backfill emplacement operation, the backfill is left to harden for 24 hours or, at least until the backfill would not be displaced by emplacement of the next waste package. The process is repeated until the required number of waste package has been emplaced. A single waste package and it backfill of cement grout will occupy length of 1 m in the borehole. The grabber and hopper are operated pneumatically.

After all waste package are emplaced, the top part of the casing is removed to avoid the formation of a preferential pathway for radionuclide migration from the borehole up to the surface. The top few meters of the borehole are filled with native or crushed soil contributing to the borehole isolation.

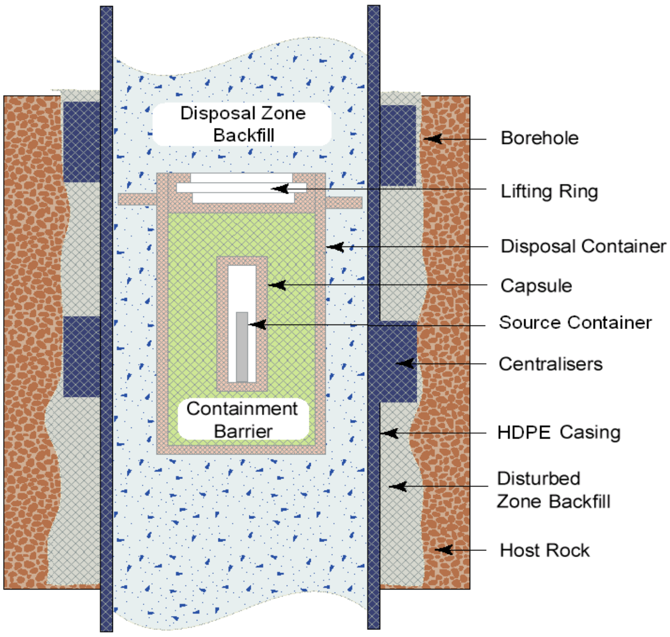

Figure 5: Schematic illustration of possible components of a borehole disposal system

2.1.Safety and Security Features

The safety and protection of human health and the environment, is achieved through the containment and isolation of the radionuclides in the DSRS. Containment refers primarily to the radionuclides in the waste, isolation is more concerned with the waste itself and the need to keep this potentially dangerous material away from the human environment for as long as it remains a significant hazard.

The combination of corrosion-resistant stainless-steel components embedded in a cement-based material, surrounding the disposal containers with cement-based backfill material in the borehole, ensure slow corrosion of the capsules and containers. Isolation is primarily achieved through disposal at depth supported by suitable host rock properties such as the absence of exploitable resources that might encourage digging or drilling, a low rate of erosion and the absence of other processes that might expose the waste packages. The small footprint of the borehole and disposal depth which removes the DSRS the accessible environment, supports the realisation of the isolation safety and security function.

3.0.Disused Sealed Radioactive Source management in Ghana

Peaceful application of radioactive materials began in 1952 in the University College of Gold Coast (now University of Ghana). Most of these radioactive materials are in the form of SRS. Before the establishment of Radiation Protection Body (RPB) in 1993 by PNDC Law 308 and empowered with the Legislative Instrument (LI) 1559, there was no control over the use of radioactive materials in Ghana. The establishment of RPB instituted a regime of licensing, registration, and inspection of all radioactive materials and facilities in Ghana. In 1995 the Radioactive Waste Management Centre (RWMC) was established to carry out safe and secure management of radioactive waste materials in Ghana. In 1998, the RWMC in collaboration with the RPB, began retrieval of disused radioactive materials from users for management at the Centralised Radioactive Waste Management facility at Ghana Atomic Energy Commission (GAEC) premises.

Majority of the disused radioactive materials retrieved were nuclear gauges used in the mining, tobacco, road construction industries. They contain radionuclides such as cobalt-60 (Co-60), strontium-90 (Sr-90), cesium-137 (Cs-137), americium-241(Am-241) and also americium in association with beryllium (Am/BE). Radium 226 needles used for brachytherapy and cobalt -60 sources used for teletherapy were also retrieved.

A Nuclear Regulatory Authority Act, 2015 ACT 895, was promulgated by the Parliament of Ghana in 2015. The Act established a nuclear regulatory board independent GAEC, the Nuclear Regulatory Authority (NRA) in 2016 with the mandate to carry out nuclear regulatory functions. The Nuclear Regulatory Authority is developing an effective national legislative and regulatory system for the management and protection of radioactive sources.

The draft National Radioactive Management Policy and Strategy is in the process of undergoing stakeholder review. The draft national policy for radioactive waste management defines the objectives that will ensure that management of radioactive waste, DSRS and spent nuclear fuel in the Republic of Ghana are performed to national and internationally-recognized standards of safety and security.

According to the draft Policy, the Government of Ghana recognizes two management options for radioactive wastes that will remain hazardous for many years and cannot be decay stored to exemption/ clearance levels. The first option, which is preferred, entails repatriation of the waste to the country of origin. This option is practicable for DSRSs and spent research reactor fuel. The second option is storage in a licensed facility followed by permanent disposal in a suitably designed licensed disposal facility. The radioactive waste management system practiced in Ghana is storage.

4.0.Implementing the borehole disposal System

The choice of the BDS was made taking into account the DSRSs inventory in storage as well as anticipated DSRSs, extent of containment and isolation needed, depth of waste emplacement, the characteristics of the engineered and natural barriers, likelihood of human intrusion, and the length of the assumed institutional control period. RWMC currently stores an inventory of 256 DSRSs with a total activity of 900 Ci or 33 TBq.. The source with the highest activity is a 22 TBq Co-60 source.

The Ghana Borehole system consist of a single borehole, two hundred and sixty millimeters (260mm) in diameter, drilled to a depth of one hundred and fifty meters (150m) and operated directly from the surface. The sources will be conditioned in 13 disposal containers and disposed of at a depth between 137 m and 150 m. The disposal site is located within the premises of GAEC and is a secured site. The site has been characterized in an iterative manner so as to provide adequate scientific understanding of the aspects critical to BDS safety and to enable the BDS design to be optimized in conformance with the ALARA approach. The host rock is dominated by quartzite, phyllite and schist.

The groundwater is a few meters deep. It is neutral (pH ~7) with a high chloride content (~ 770 ppm). The presence of pyrite infers reducing groundwater conditions. The highest hydraulic conductivity measured was in the order of 10^{-7} m/s.

According to the Nuclear Regulatory Act, Act 895, 2015 compliance with the long-term safety of a disposal facility should be demonstrated by means of a safety and security case. The draft National Radioactive Waste Management Regulations, (RWMR) require the safety and security case to demonstrate the level of protection of people and the environment and also provide assurance to the Nuclear Regulatory Authority and other State Regulatory Agencies that the safety, security and safeguards (where applicable) requirements have been met.

The development of the safety case involved an iterative process that has evolved with the implementation of the BDS. The step by step approach encouraged the various iterations of the site characterization, post closure safety assessment and engineering design to be progressively developed. These allowed for the identification of issues that required further attention to be addressed in order to improve the understanding of aspects influencing the safety of the disposal system and reduce uncertainties by appropriate design choices.

At the commencement of the site characterization program, the amount of information on the site was limited and restricted to existing information available from sources such as published materials and information on the site documented in the Ghana Research Reactor -1 (GHARR-1) Safety Analyses report. The first iteration Post Closure Safety Assessment (PCSA) of the BDS was developed in 2012 to assess the possibility of using the narrow borehole disposal system for the long-term management of DSRSs in Ghana. It was a generic assessment. It was followed with site characterization which involved geological, geochemical, geophysical and hydrogeological investigations. It was facilitated by the drilling of two test bores on the site to depths of 150m each. Since then the PCSA has gone through three iterations, taking into account the inventory of DSRSs for disposal and site-specific data on geology, geochemistry, hydrology and hydrogeology obtained from two test boreholes drilled at the site. The PCSA have been reviewed by IAEA experts in August 2017 and May 2019. Decisions on the final design and operation adopted are justified from the safety assessment and demonstration of compliance with safety requirements and criteria.

A safety case has been developed to demonstrate that the long-term safety and security in the management of DSRSs complies with the requirement in the Nuclear Regulatory Authority Act, Act 895, 2015 and the draft radioactive waste management regulations. The safety case includes all the aspects or arguments that ensure the safety of all management activities relating to the development of the BDS in Ghana. It presents the arguments for the long-term radiological safety of the BDS. Consideration has been given to uncertainties and the establishment of limits controls and conditions based on the assessment so as to assure safety. The safety case was reviewed twice by a team of IAEA experts in August 2017 and May 2019.

The safety case and associated safety assessment document will be submitted to the Nuclear Regulatory Authority (NRA) in support of an application for a license to develop the BDS based on the current Nuclear Regulatory Authority Act 895 of 2015, the draft NRWMR and recommendations in the international safety standards.

5.0.Challenges and Lessons Learnt

Like any radioactive waste disposal project, the borehole disposal project in Ghana contains a broad range of activities: a disposal policy and regulations need to be established, the disposal site and its future evolution needs to be characterized and assessed, the facility needs to be designed and constructed, a license application, including a safety case, needs to be developed and evaluated.

The DSRS borehole disposal projects are under way in Ghana and Malaysia and are being considered in several other countries. Although the projects have made good progress and moved the concept forward to a solution that is close to being implemented, it has demonstrated the challenges that developing a borehole disposal solution present.

One of the lessons learned from implementing the project is that developing the technical documentation and license application can be challenging. The narrow borehole disposal option is new and most of the technical documents available are based on generic data. In order to overcome this challenge and make the borehole disposal solution more readily implementable, the IAEA is developing a standardized framework for DSRS borehole disposal. This will reduce the need for other interested countries from developing all materials from first principles in order to implement the system.

At the commencement of the site characterization programme, the amount of information on the site was limited and restricted to existing information available from sources such as published materials and information on the site documented in the Ghana Research Reactor -1 (GHARR-1) Safety Analyses report. There was the need for site specific data and the need for expertise in designing the site characterization program. With the assistance from the IAEA through expert missions the following Technical Specification document for Site characterisation were developed; Technical specification Existing Data, Technical specification for data acquisition, Technical specification for interpretation. The technical documents were used in the design of the site characterization activities. The document was also in the engagement of contractors to carry out various tasks.

Although the BDS employs readily available constructional techniques and limited infrastructure as compared to near surface disposal facility, it requires expertise with good knowledge in radioactive waste disposal. The site characterization activities for the BDS is the first radioactive waste disposal project in the country and the contractors to be engaged have little experience in radioactive waste disposal activities. The contractors thus need guidance in order to produces the required results. This challenge was resolved with the development of contractual agreement, technical specifications and appointment of a project manager with adequate knowledge in the investigations to be carried out to ensure that the Contractor(s) fully understand and address the requirements for the task they are undertaking.

Development of the safety case and associated safety assessment including developing site characterization report requires some expertise and software tools. The RWMC lacked the needed expertise in developing the various document. To overcome this challenge, the IAEA organised a national training course on the use of the AMBER software for development of safety assessment for a borehole disposal facility. The training course was followed up with a six weeks fellowship programme for a staff of the RWMC to Quintessa,UK Staff of both the RWMC and the NRA have participated in Regional workshops and meetings organised by the IAEA on use of the AMBER software for development of safety assessment and safe case for borehole disposal facility. In framing these documents, considerable support has been received from IAEA in the form of document templates that allow the drafting to follow best international practice.

A generic safety assessment (GSA) published by the IAEA 2004 [8,9] and updated in 2017 [10] was used in the development of the Ghana PCSA for the BDS. The scenarios identified in the IAEA Generic Safety Assessment (GSA) were reviewed and modified to produce site-specific scenarios

Ghana intends disposing her Category 2 Co-60 radiotherapy sources in the Borehole disposal facility. For high activity sources there is a risk of localized corrosion due to the elevated temperatures and gamma radiation field during the initial phase. This only applies to the container as capsule corrosion can only start after the container is breached. By that time the temperature and gamma dose rates have sufficiently decreased. This was evaluated by the IAEA and more corrosion-resistant superaustenitic or super-duplex stainless-steel was proposed as container material for high-activity sources. This container is being assessed in the PCSA being carried out.

The expert reviews of the safety documentation are helping the development of an acceptable document for licensing the BDS in Ghana. Financial resources have also been a challenge, but thanks to IAEA donor partners (Canadian Government) for providing resources for the expert missions.

6.0 Conclusion

The borehole disposal system (BDS) potentially provides a cost effective, safe and secure disposal option, particularly for countries with small DSRS inventories, limited radioactive waste disposal capabilities, and infrastructural constraints. The BDS is a multi-barrier disposal system for DSRSs that uses stainless steel capsules, containers and cement barriers to contain and isolate the wastes from the biosphere, with disposal in a borehole at depths greater than 30 m to greatly reduce the likelihood of both inadvertent and deliberate human intrusion. The BDS enables the disposal containers to be placed in an underground environment where they are isolated from humans and the accessible environment. The concept also reduces the security threat posed by the DSRSs. Once the DSRSs are disposed of in the borehole and the borehole is sealed, the security threat is eliminated. To determine whether a site is suitable for a borehole disposal facility it will always be necessary to characterize the site, undertake a site-specific safety assessment and develop a safety case.

The borehole disposal projects in Ghana and Malaysia have catalyzed interest in other countries. Although the projects have made good progress and moved the concept forward to a solution that is close to being implemented, it has demonstrated the challenges that developing a borehole disposal solution present. To facilitate possible future borehole disposal projects, the IAEA plans to develop a standardized framework for borehole disposal. This will comprise of a comprehensive and consistent set of specifications, procedures, guidance and training material addressing the technology aspects of all stages in developing and implementing a borehole disposal system. This will reduce the need for those countries to develop all materials from first principles and will make the concept more readily implementable.

In progressing the implementation of the BDS in Ghana, RWMC has received considerable support from IAEA in the form of expert missions. These have covered the full range of issues addressed by the safety case including waste characterization and update of waste inventory, site characterization, post-closure safety and safety case development. These missions have helped resolved some of the challenges in implementing the project in Ghana.

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