Classification of the Inventory of Spent Sealed Sources at INSHAS Storage Facility

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ABSTRACT

The Egyptian Atomic Energy Authority (EAEA) is responsible for the recovery, transportation, conditioning, storage and disposal of all unwanted spent sealed radioactive sources (SSSs) in Egypt. Because of radioactive decay, damage, misuse or changing technical conditions, approximately 600 unwanted SSSs are now in storage at the EAEA's Hot-Laboratories Center in INSHAS.

For the safe recovery, transportation, conditioning and storage of these unwanted SSSs the EAEA uses an International Atomic Energy Agency's (IAEA's) categorization system. The IAEA system classifies sealed radioactive sources (SRSs) into five categories based on potential risks to current workers and the public. This IAEA system allows Member States like Egypt to apply a graded approach to the management of SRSs and SSSs. With over 600 unwanted SSSs already in storage, the EAEA is planned to dispose unwanted SSSs in near surface vault structures with solidified low- and intermediate-level radioactive wastes. The IAEA's categorization system is not designed to protect future populations from the possible long-term migration of radioactive wastes from a disposal system.

This paper presents the basis of a second categorization system, designed to protect the public in Egypt from radioactive wastes that may migrate from a near-surface disposal facility. Assuming a release of radionuclides from the near-surface vaults 150 years after disposal and consumption of contaminated groundwater at the 150 m fence-line, this classification systems ranks SSSs into two groups: Those appropriate for near-surface disposal and those SSSs requiring greater isolation. Intermediate depth borehole disposal is proposed for those SSSs requiring greater isolation.

Assistance with intermediate-depth borehole disposal is being provided by the Integrated Management Program for Radioactive Sealed Sources (IMPRSS) and by the IAEA through a Technical Cooperation Project. IMPRSS is a joint Egyptian / U.S. program that is greatly improving the cradle-to-grave management of SRSs and SSSs in Egypt. As a component of IMPRSS, Sandia National Laboratories is transferring knowledge to the Egyptian counterparts from implementation of the Greater Confinement Disposal boreholes in the U.S.

INTRODUCTION

Various types of sealed radioactive sources (SRSs) are widely used in Egypt for many applications; oil exploration, industry, agriculture, and medical applications. Spent sources (decayed, damaged and/or orphan) are stored in prepared storage rooms in Hot-laboratories center at INSHAS site. The Hot-laboratories are the responsible center for the management of low and intermediate radioactive wastes generated from all nuclear activities in Egypt. Long-term storage of hundreds of SSSs is undesirable for economical, safety, security reasons. Therefore, the Hot-Laboratories planned to dispose these sources with the low and intermediate radioactive wastes in near surface disposal vaults. These vault structures are under operation licensing procedures.

However, the management of spent sealed sources has been related accidents documented in the literature. The IAEA has published information concerning accidents that have occurred over the past few decades (Mexico, China, Algeria, Morocco, Italy, Brazil and Egypt). All of these events resulted in exposure to high amounts of radiation, and some of them caused deaths in one or a few individual. Reported accidents with spent radiation sources have caused the death of more than 9 persons since 1960. In more than 100 registered accidents with sealed radiation sources, about 700 persons have been exposed to a whole-body dose larger than 0.25 Sv or to a local skin dose above 6 Sv. In addition there have been accidents which were not reported, the number of which probably is equally large[1, 2]. Consequently, based on their deterministic health effects, IAEA developed a simple logical system for ranking radioactive sources into discrete categories to establishing safety measures during their management.

This categorization considers the use of source, place of use, exposure scenarios that may arise, accident history, and the considerations present when it becomes spent. These factors are important to the establishment of suitable ranking system. Each radionuclide source type contributes in every category since all parameters taken in this classification is based on the potential of radioactive sources to cause deterministic health effects during the transportation, treatment and handling conditions. According to this classification, the sources are ranked onto five categories depending on the level of dangerous source “A/D value”. The A value represents the activity of the source and D is the dangerous value lead to deterministic effects that has been calculated by given exposure scenarios and given dose criteria[3, 4].

Meanwhile, the IAEA defines the short-lived waste, for the disposal phase, as radioactive waste that will decay to an acceptably low activity level from a radiological viewpoint within a time during which administrative controls can be expected to last. Concerning the long–lived waste, they will not decay to an acceptable activity level during the time which administrative controls can be expected to last. The boundary activity concentration between short and long-lived disposed in near surface disposal in various countries is limited to 4000 Bq/g of long-lived alpha emitters in individual radioactive waste packages[5, 6]. For that reason, the long-lived spent sources cannot be disposed in near surface structure as vault. Therefore, the IAEA categorization of sources is not meeting the requirements of the radioactive waste acceptance criteria for the disposal. Consequently, the spent sources should reclassify according to the potential hazard of short and long-lived radioactive sources during the administrative controls of disposal phase.

Accordingly, vault structures at INSHAS site is often represent a safe option for the disposal of the spent sources of activity relatively low and half-lives less than about thirty years, and the long-lived sources should disposed in intermediate deep boreholes[7]. Therefore, through a joint project of the Egyptian government, in coordination with Sandia National Laboratories and the U.S. Agency for International Development that has initiated the Integrated Management Program for Radioactive Sealed Sources (IMPRSS) to greatly improve the "cradle to grave" management of RSSs in Egypt “IMPRSS” is currently addressing all nine elements of the infrastructure necessary to safely manage SRSs. The nine elements of IMPRSS are: tracking, awareness, regulatory reform, security, recovery, conditioning and storage, recycling, disposal and emergency preparedness.

The IMPRSS disposal task focuses on the development of intermediate-depth borehole disposal facility for long-lived sealed radioactive sources based on the U.S. experience with Greater Confinement

Disposal (GCD). Shallow land burial of short-lived sealed radioactive sources at INSHAS has not been the focus of IMPRSS, and shallow land burial work has been funded direct.

Criteria and Methodology of IAEA classification
This categorization depends on the sealed source type according to their radioactive content, radiological properties and form of material. Additionally, the use of source, place of use, exposure scenarios that may arise, accident history and the causes that lead the source to become spent are factors contribute to the establishment of suitable ranking system[4, 9]. Depending on these parameters, the types of sources can be grouped to:

Group I consists of industrial Radiography, teletherapy, and irradiators. The sources in this category present significant hazards, and high degree of safety and security measures.

Group II consists of HDR Brachtherapy, fixed industrial gauges involving high activity sources, well logging and LDR Brachtherapy. These sources may present significant hazards that require the surveillance of regulatory authority.

Group III consists of fixed industrial gauges involving lower activity sources, which require less safety and security measures.

According to these three groups and by using basic scenarios, IAEA categorization divides sources into five categories according to their potential to cause harmful health effects, which is indicated by the dangerous value D. A dangerous source is defined: "a source that is could, if not under control, give rise to exposure sufficient to cause deterministic effects[8]. Each source activity A was divided by the corresponding D value to give the dimensionless ratio A/D that denoted the category level of the source. That is resulted five category levels[4]:

Category 1 (A/D>10000): Sources in this category are considered extremely dangerous (class I)

Category 2 (1000>A/D>10): Sources considered also dangerous if not safely managed or securely protected (class II).

Category 3 (10>A/D>1): Sources considered dangerous. If dispersed, it cannot threat health (class III).

Category 4 (1>A/D>0.01): Sources are unlikely to be dangerous; if dispersed, it could permanently injure persons (class III).

Category 5 (0.01>A/D>exempt/D)
Sources are not considered dangerous. If dispersed, it could not permanently injure persons (class III).

Categorization of spent sealed sources at INSHAS site.
There are about 595 spent sealed sources at INSHAS site in the storage rooms. The inventory of spent sealed sources contains 10 different sources Co-60, Cs-137, Ir-192, Sr-90, Am/Be, Ra-226, Am-241, Cd-109, Fe-55 and Kr-85. These 595 sources are classified according to IAEA categorization into the five categories as shown in Table I.

From this table it is clear that: most of the sealed sources are classified in category 3 and 4. There are 10 spent sources in the category 1, which includes two Cs-137, seven Co-60 sources and one unknown telethrapy machine. Only one spent source in category 2 (Ir-192), while 68 sources in category 3 (16 Am-Be and 52 Cs-137). Category 4 includes 222 sources (188 Cs137, 18 Am-Be, 8 Co-60, 5 Am-Cs and 1 Ir-192). There are 48 sources in category 5 (38 Ir-192, 9 Kr-85 and 1 Sr-90). As seen in this table most of the spent sources are in category three and four. The remaining other sources are in between unknown number, unknown activity and unknown number and activity.

In the case of unknown number and activity, the spent sealed sources are classified according to the first three groups defined by the IAEA that based on the type of the source. For example, teletherapy machine of unknown activity and unknown radionuclide is considered as a category one.

Near surface disposal at INSHAS site

The burial facility for low and intermediate level radioactive waste at INSHAS site consists of four reinforced concrete vaults. The four vaults structure units cover an area of 4000 m^2. The capacity of the disposal area is about 600 concrete containers. The facility currently has sufficient capacity to dispose of all the low and intermediate level radioactive waste that will be generated in Egypt until the year 2020 [10].

Table I. Classification of Spent Sealed Sources at INSHAS Site According to IAEA Categorization

Source Type	Category					Unknown number	Unknown activity	Unknown Number And activity
	1	2	3	4	5			
Am-Be			16	18			7	
Am-241				2			2	
Ra-226								1 (set of needles) 2
Ir-192		1		1 NDT	38	2	23 1 NDT	2
Cs-137	2		52	188		1 (category 4) 1	3 NDT 35	1
Cd-105							1	
Kr-85					9		4	
Sr-90					1	1		
Co-60	7			8			50 normal dimension 79 small discs 1 set of discs	2
Fe-55							1	
Cs-Co							25 calibrators	
Am-Cs				5				
Unknown Tele-therapy source	1							

RECLASSIFICATION OF RADIOACTIVE SOURCES FOR DISPOSAL PHASE

The rational of any categorization method should be based on the cause of its need. In other word, each phase of waste management system should have its specific categorization according to the regulations, security and safety measures requirements during this phase.

The IAEA categorization system is based on the potential of radioactive source to cause deterministic health effect, which may be occurred during handling, transportation, and storage phases and not during the disposal phase. Therefore, the concept of the reclassification are based on the deterministic health effect that may initiate during the post-disposal of radioactive sources through suitable scenario reflects the incidents during the post-closure phase of disposal.
The estimation of the waste release to the near field water flow is an important scenario [11]. This scenario is considered the drinking dose of an individual from a constructed domestic well far from the vaults design 150 m (out of fencing of INSHAS area). Since these vaults are prepared initially for the conditioning liquid or solid radioactive waste that collected from all nuclear activities in Egypt and not only for the radioactive spent sources, the deterministic scenario developed is described the health effects of the disposal only of these sources. Therefore, assumptions used should be conservative to some extent. It is important to note that the inadvertent human intruder scenario is an important scenario, which should consider. However, this scenario required specific detailed information which not available; therefore, it is not addressed in the paper.

The conservative scenario considered the release of radionuclides from the vaults from failed containers after 150 years from disposal to a drinking well. The resulting is a downward piston flow of dissolved radionuclides, which migrates through unsaturated zone (13 m) and saturated zone (150 m). Dilution and chemical reaction of radionuclides flow until reach domestic well are not considered.

The vault is treated as localized point source. Under steady flow conditions, assuming linear reversible adsorption in both unsaturated and saturated zones, the point source can be approximated as a pulse of duration T_u and T_s to reach the well [12]. One flow direction is undertaken vertical downward in the unsaturated zone and horizontal direction in the saturated zone.

Knowing that:
The velocity of flow in the unsaturated zone (v) is 0.0039 m/day, moisture content of the sand soil (Ə) is 0.25 in unsaturated zone and 0.3 in saturated zone, density of the sand soil (ρ) 2.6 g/cm3, and velocity in the aquifer is 0.04 m/day [13, 14], the travel duration in second for both zones are calculated from (Eq. 1) and (Eq. 2) as follows:

$$T_u = 13 * 0.25 \frac{\left[0.25 + \left(2600 * K_d\right)\right]}{0.0039} \quad \text{(Eq. 1)}$$

$$T_s = 150 * 0.3 \frac{\left[0.3 + \left(2600 * K_d\right)\right]}{0.04} \quad \text{(Eq. 2)}$$

Where: K_d is the adsorption coefficient of radionuclides on soil

The drinking dose received by the individual is calculated by (Eq. 3):

$$\frac{I * 0.73 * DCF}{\left(N * V\right)} \quad \text{(Eq. 3)}$$

Where:
I is the inventory calculated after the decay time $T_u + T_s$, 0.73 m^3/y as a standard drinking water quantity (2 liters/year). DCF is the ingestion dose conversion factor. N is the number of the vault cell. V is volume of the cell (length L= 10m, width W= 5m, Height H= 3m)

During the calculation, the half-life of the combined source as Am-Be is considered for the americium half-life. Concerning the adsorption coefficient of this source an average value is assumed. Additionally the other combined sources such as Co-Cs and Am-Cs, the activity of each element is added to its similar separately source.
Table II presents the different parameters for the calculations of the annual dose of each radionuclide considered in the scenario.

Table II. Different Parameters for the Annual Dose Calculation of Radionuclides

Source Type	**Half-life (Years)**	**Activity (Ci)**	**Distribution Coefficient (K_d) (L/Kg)***	**Total Travel time In both zones (Years)**
Am-Be	432	23	1900- 250 (1075)	6.28E+02
Am-241	432	23.26	1900	1.11E+03
Ra-226	1599	1	500	2.92E+02
Cs-137	30.1	251.4	280	1.64E+02
Cd-105	1.27	1	80	4.67E+01
Sr-90	28.5	1.1	15	8.76E+00
Co-60	5.27	5508.6	60	3.50E+01
Fe-55	2.73	1	220	1.28E+02

*[15]

The value of the drinking annual dose obtained from the calculations is the critical parameter, on which the classification of the sources is based. The dose calculated for each radioactive source is presented in Table III. The short-lived radionuclides with half-lives less than 30 years as will have decayed significantly before they can migrate to the aquifer such as Cd-105, Co-60 and Fe-55, causes a low drinking annual dose which is meet the Egyptian regulations. The safety requirement of a near surface disposal is based on the dose limit of 1 mSv per year [Egyptian regulations], On the other hands, the other long–lived sources such as Am-Be, Am-241, Ra-226, Cs-137, and Sr-90 show very higher dose than Egyptian regulations [16].

From the above results the reclassification for disposal of the sources, which is ranked the sources into two only categories according to the suitable disposal option that are based on their deterministic health effect during the post-closure phase, is shown in Table IV. Consequently, near surface disposal (vaults structure) at INSHAS is not considered as a safety decision for the burial of the long-lived radionuclides.

Table III. Annual Dose Calculation of Radionuclides

Source Type	**Half-life (Years)**	**Inventory calculated After total Travel time (Ci)**	**DCF (mSv/Bq)**	**Dose (mSv/Year)**
Am-Be	432	6.60E+00	5.70E-07	1.7E+05
Am-241	432	3.08E+00	5.70E-07	7.95E+04
Ra-226	1599	8.26E-01	2.20E-07	8.2E+03
Cs-137	30.1	1.84E-01	1.30E-08	2.2E+01
Cd-105	1.27	2.35E-47	2.00E-09	0.2E-40
Sr-90	28.5	2.31E-02	2.80E-08	3E+01
Co-60	5.27	1.48E-07	1.01E-07	6E-04
Fe-55	2.73	1.96E-31	4.00E-10	3.5E-26

Table IV. Categorization of Spent Sources According to the Disposal Option

Disposal Option	**Intermediate Bore-hole Disposal**	**Near Surface Disposal**
	1	**2**
Category	**Am-Be** **Am-241** **Ra-226** **Cs-137** **Sr-90**	**Cd-105** **Co-60** **Fe-55**

CONCLUSIONS

To insure the safe and secure recovery, transportation, conditioning and storage of unwanted SSSs the EAEA uses an IAEA's categorization system. The IAEA system classifies sealed radioactive sources into five categories based on potential risks to current workers and the public. The EAEA has undertaken a study of the possible long-term health effects of disposal of all unwanted SSSs in near-surface disposal vaults and determined that some SSSs, which have been classified as relatively safe categories (3 to 5), may present a long-term hazard to the public.

An Egyptian classification system, which is based on the assessment of radiological doses calculated from a drinking water exposure scenario, ranks the SSSs into two groups, those appropriate for near-surface disposal and those SSSs requiring greater isolation. This second classification system concludes that the near surface disposal (vault structures) at INSHAS provides long-term protection of the public from SSSs containing radionuclides with half-lives less than 29 years. An intermediate-depth borehole disposal system is proposed as a safe design for the SSSs containing radionuclides with half-lives of 29 years or greater.

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