Planning and concept of borehole disposal technology for disposal of disused sealed radiation sources from using in health and industry

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Abstract. Disused sealed radiation sources (DSRS) that have been stored in the Interim Storage 1 and 2 (IS-1 and IS-2), and High Activity Waste Storage (PSLAT) mainly consist of Co-60, Cs-137 and Ra-226. The DSRS is the most suitable to be disposed of in borehole disposal after conditioned and stored. The difficulties faced on storage and disposal are reasoned by long half-life, high gamma-photon radiation, not established disposal system, expensiveness of disposal facility, difficulties on the option to re-export of the DSRS and the activity exceed for near-surface disposal. For that reason, the disposal system for DSRS must be developed with the small scale national facility having some advances as well as costly cheaper, fulfill the safety standard, and could avoid the possibility of human intrusion. The answer to this problem is the borehole disposal concept. By using this concept can be hoped that the problems of DSRS disposal can be handled well, based on DSRS capsule packaged design, site characterization, borehole technology, repository facility, and safety assessment. The selection of borehole disposal technology for DSRS has been made. The selection was made descriptively, involve technological concept and site. One concept of the borehole has been obtained and recommended by the International Atomic Energy Agency (IAEA,) applicable and suitable with the waste and site condition. The concept is Borehole Disposal with unsaturated, very low permeability and high sorption (e.g. clay) host-rock or environments.

1. Introduction
Various field activities using radiation sources (RS) in the field of health and industry in Indonesia are radiotherapy, calibration, gauging, irradiator, logging, storage, products and standardization. The inventory of the RS which is still used (∓ 6,424 sources) [1]. After the level of radiation of RS decreased until not enough to be used anymore, the RS will be declared as a disused sealed radiation source (DSRS). There are about 3,031 pieces of DSRS Category 3-5 at the Center for Radioactive Waste Technology (CRWT) BATAN [2]. Some of them are contained neutron emitter radionuclide (Cf-252, Am-241 Be, Po-210 Be) stored in the Bunker of the Interim Storage for High Radiation Waste (PSLAT). DSRS contains Co-60, Cs-137, Sr-90, Am-241, Kr-85, etc. are stored in the 350 concrete shells, placed in Interim Storage 1 and 2. DSRS Category 1 – 2 (34 Units), the sources still in the cylinder head, stored in the racks, placed at the Interim Storage which equipped with CCTV and electronic access control.

DSRS contains Ir-192 (T½ : 74 days), from radiography and industry, stored for decay in the specific container. DSRS contains Ra-226 (radium needles from the hospital, protector), encapsulated
in the stainless steel capsule, weld leak test the capsule (using desiccator + ethylene glycol), stored in the long term storage shield (LTSS), and placed in the 200 L concrete shell drum.

The amount of DSRS Cat 3 – 5 that had been dismantled and encapsulated in the SS Capsule can be seen in figure 1 and table 1 [2].

![Figure 1. Dismantling and encapsulation of DSRS Category 3-5 (a. process of dismantling, b. the 200 L concrete shell drum, and c. stainless steel capsule)](image)

| No | Radionuclide | Amount of capsules | Amount of sources |
|----|--------------|--------------------|-------------------|
| 1  | Co-60        | 4                  | 176               |
| 2  | Cs-137       | 4                  | 101               |
| 3  | Am-241 Be    | 1                  | 10                |
| 4  | Am-241       | 1                  | 20                |
| 5  | Ra-226       | 156                | 531               |
| **Total**: | 166            | **838**            |                   |

The processes of dismantling and encapsulation of DSRS Category 3-5 have been supported by IAEA until now. The effort to dismantle and encapsulate DSRS Category 1-2 still in progress under the support of IAEA also.

Temporary and sustainable storage of DSRS still faces many difficulties for several reasons, among others because they are long half-life long sources, high levels of gamma-photon radiation, storage systems have not been established, expensive disposal facilities, difficult options to be returned to the country of manufacture, the activity exceeds the limit for near-surface disposal [3-5]. For this reason, it is necessary to develop a sustainable disposal system for DSRS with small-scale national facilities that are inexpensive, meet safety standards for workers, public and the environment, and prevent the possibility of intrusion by unwanted parties. The answer to this problem is with the concept of sustainable disposal in borehole disposal [3-5]. With the borehole disposal concept, it is expected that DSRS storage problems can be handled properly, which is based on site characterization, drilling techniques, DSRS capsule package design, repository facilities and adequate safety assessment. Finally after being found, the optimal concept will be applied in the future, to support national nuclear programs that can be accepted by the public.

The IAEA together with the South African countries has developed the borehole disposal method, the BOSS concept, for solving DSRS problems in African countries [3]. The BOSS concept has advantages, namely design and dimensions that are more adequate and complete with descriptions such as printed on table 1. For its application in Indonesia, it only requires a little adjustment or modification in accordance with the selected site conditions and existing DSRS waste.

The IAEA has conducted a review of the performance of the BOSS concept with 3 different types of site geological environmental models that have been designed differently, namely: 1) Non-saturated
and non-sulfate environments; 2) Saturated, non-sulfate, non-clay, medium-high permeability environments; and 3) Saturated environment, very low permeability and high sorption properties. Ideally the selected site has all the advantages or at least meets the established criteria, namely an unsaturated environment, very low permeability and high sorption properties. However, it is relatively impossible to get the ideal site, for this reason it is necessary to compensate for technology to cover site deficiencies.

### Table 2. General description of borehole disposal design facility [4]

| No. | Component                        | Specification                                      |
|-----|----------------------------------|----------------------------------------------------|
| 1.  | Depth                            | Minimum 30 m                                       |
| 2.  | The inner diameter of the borehole | 260 mm                                             |
| 3.  | Waste package configuration       | Space between waste container 0.1 to 1 m with backfill as separator |
| 4.  | Waste type                       | The capsule of DSRS with short to the long half-life |
| 5.  | Container for disposal           | Welded stainless steel with outer diameter 114.3 mm, length 250 mm. |
| 6.  | Borehole casing                  | The pipe from carbon steel, stainless or PVC from the base of the borehole to 1 m at the top of the waste zone |
| 7.  | Bottom plug                      | The base of the borehole to 0.5 m filled with backfill |

### 2. Theory

#### 2.1. Management of disused sealed radiation sources

Ideally, the management of DSRS consists of 9 steps [6]: 1) collecting and storing sources in the containers, 2) sorting the sources and removing sources from the containers, 3) encapsulating the sources in stainless steel capsule, 4) welding and leak testing the capsule, 5) re-encapsulating leaked capsule, 6) interim storage of capsule, 7) placing capsule in the disposal container filled with cement, 8) welding disposal container and transfer into the borehole, and 9) emplacing disposal container into borehole and do backfill.

Until now, in Indonesia, the management of DSRS reaches step number 6, interim storage of capsule, especially for an amount of DSRS Category 3-5 (figure 2). Dismantling and encapsulation of DSRS Category 1-2 will be conducted under the supervision of IAEA experts, after the hot cell facility at CRWT has been modified and improved properly to handle the process safely.

Step numbers 7 to 9 will be performed while conducting site selection, site evaluation, site characterization and safety assessment.

#### 2.2. Borehole Disposal Concept

The borehole disposal concept is the placement of solid radioactive waste in a specially engineered facility in the form of a relatively narrow diameter drill hole and its operation directly from the surface of the earth. The depth of borehole discharges varies from several meters to hundreds of meters, with borehole diameters ranging from several tens of centimeters to more than one meter [7]. The borehole can be cased, used source waste should be confined in a safe container, and its placement in the borehole is isolated with backfill materials. The disposal facility can consist of a single or double drill hole in which its location does not have to be within a certain nuclear area.

The borehole disposal facility has a number of interesting characteristics that can potentially provide several advantages in terms of safety and economy, namely: 1) Providing long-term protection to humans and the environment from a small amount of radioactive waste that has high specific activity in high integrity packaging; 2) Providing easy direct access and cost savings in placement on the appropriate geological horizon; 3) Only requiring limited land and infrastructure; 4) Only requiring a short time for construction, operation and closure; 5) Can be developed as soon as needed, i.e. if the amount of waste has fulfilled; 6) having a small probability of human intrusion and the danger of...
damage due to the small package of facilities and the safe depth of waste placement; and 7) Only requiring minimal control at the post-closing stage.

**Figure 2.** Flowchart of the existing management of DSRS at CRWT – BATAN Indonesia [6]

In terms of safety, borehole disposal has no different concepts with near-surface disposal and geological disposal. To ensure disposal safety, a combination of natural barriers and the engineered barrier is required, accompanied by institutional control until the time of radionuclide decays to the extent that the radiation is no longer significant for human and environmental safety.

Borehole disposal does not only mean to improve the safety of the DSRS, but also to increase its security from the threat of terrorists or criminals to access it and use it for the benefit of terrorism or other crimes.

2.3. Technical Aspect
Proper and acceptable management or long-term disposal options depend mainly on time needed for radionuclides to decay to a safe level. This again depends on the initial activity and the half-life.

Radionuclide categories with a half-life of more than 30 years in many cases are not acceptable in near-surface disposal. The DSRS must be disposed of in a repository facility that is able to protect and isolate from the environment for thousands of years such as deep-geological disposal if available. As an alternative of disposal for DSRS is borehole disposal with sufficient depth in the appropriate geological environment.

Programs for site selection and characterization, design, construction, operations, closure and post-closure activities need to be developed and implemented. This program includes safety assessment activities to assess the long-term performance of the borehole disposal system.

Key factors that must be considered in the long-term safety performance of the disposal system are the waste inventory, the level of confinement and isolation required, the depth of placement of waste, natural characteristics and engineered barriers, the potential for human intrusion, and the period of institutional control [3].

2.4. Safety Aspect
The fundamental requirements for all disposal types are that they must meet the IAEA principles in managing radioactive waste [3,4], namely 1) Protection of human health; 2) Protection of the environment; 3) Protection against influences out of national borders; 4) Protection of future generations; 5) Does not cause a burden for future generations; 6) In the legal aspect of the national aspect; 7) Control of the growth of radioactive waste; 8) Interdependence between the growth of radioactive waste and its management; and 9) Safety of facilities.

General safety requirements that can be applied to borehole disposal are as follows [3,4]: 1) Fulfilling radiological protection requirements for disposal, as stated in the IAEA Safety Standard; 2) Carrying out double safety functions which include natural and engineered barriers, as well as institutional controls; 3) Using engineering that is good for all phases of design and development; 4) Minimizing potential damage due to natural and human influences, with the right selection of sites and designs; 5) Carrying out adequate control over the activities of design, construction, operation, closure of borehole facilities, and specifically fulfill the criteria for receiving waste; 6) Maintaining of waste information and inventory, so that it can still be used by future generations in making decisions about facility safety.

Borehole facilities need to be designed and implemented so that human and environmental safety is protected from radiological hazards, both for the present and in the future. The International Commission on Radiological Protection (ICRP) has developed a radiological protection system from radiation exposure for all sources as adopted by the IAEA Basic Safety Standard [8]. ICRP has outlined the application of the system to radioactive waste disposal in ICRP Publication No. 77 [9] and 81 [10]. Radiation protection applied in this case includes safety during the operation phase, with an effective dose limit for workers ≤ 20 mSv/year on average in 5 years, and ≤ 50 mSv/year for each year. Dosage for people outside the background dose should not exceed 1 mSv/year and the dose constraint is no more than 0.3 mSv/year. Radiation protection applied for long-term safety, effective dose for the community is 1 mSv/year, and the dose constraint is no more than 0.3 mSv/year.

The safety approach includes the development of a phased disposal facility, passive safety, adequate understanding and confidence in safety, and optimization of protection. Safety functions include confinement, isolation and multiple safety functions.

2.5. Development of Borehole Disposal Facility
The IAEA provides practical guidance on activities and decisions that must be made in the development of DSRS borehole disposal facilities. The following list of activities is made assuming that the regulatory framework has been established and the criteria for waste acceptance have been established [4], namely: 1) Collection, characterization and prioritization of DSRS and other wastes; 2) Identification of appropriate disposal sites; 3) Environmental characterization of disposal sites; 4) Design of disposal facilities; 5) Evaluation of safety and environmental impact assessment; 6) Conditioning and packaging of waste for disposal; 7) Operation and closure of disposal facilities; and 8) Post closure.

3. Method
The study of borehole disposal was carried out with a descriptive method with a scope covering literature study, preparation of site criteria and disposal design, technological aspects, environmental safety, and analysis of the results of studies.

The design and steps carried out through the following stages: 1) Site criteria and disposal design are determined and prepared based on IAEA provisions and expert opinions; 2) Data and information about aspects of DSRS, site, technology, safety of borehole disposal traced and collected from various literature; 3) The data and information in number 2 are evaluated and used as the basis for the assessment.

As a guideline for site selection, site criteria for borehole disposal have been compiled, namely: 1) Permanent unsaturated rock environment or at least saturated environment with low permeability; 2) Low hydraulic gradient; 3) Little or no water and mineral resources found; 4) Low erosion rates and no potential for flooding, heavy rain and land instability; 5) Stable tectonically and far from the
active fault zone; 6) Geological structure and simple hydro-geological systems; and 7) It should also be noted about accessibility, land ownership, infrastructure, social aspects and planning factors.

The basic aspects considered in borehole facility design are [4-5]: 1) Borehole dimensions must be sufficient for DSRS disposal in appropriate packaging; 2) Borehole designs must pay attention to operational requirements, such as for DSRS placement in boreholes during the operating period; 3) Design must minimize active maintenance needs after site closure and adjust to the natural characteristics of the site to reduce environmental impacts; and 4) Intrusion by humans must be complicated.

4. Results and Discussion

4.1. Planning on borehole disposal development

Management of DSRS in Indonesia can be mentioned that has been begun since 2012 with some activities such as revision of Government Regulation (GR) Number 27/2002 and launching of GR Number 61/2013 on Radioactive Waste Management in 2013. Some activities have been conducted in continuing the DSRS management, started with inventory, dismantling, repatriation, reuse-recycle, encapsulation, conditioning and storage. In order to avoid burden for the next generation and protect the environment, the management of DSRS must be finished with the disposal. The most suitable and economist disposal option for DSRS is borehole disposal. Based on the proposed milestone of DSRS management in Indonesia as shown at figure 3, planning and concept of borehole disposal has been initiated in 2018-2019, and should be continued with site selection, site characterization, designing, safety assessment, safety analyses report, environmental impact analyses report and licensing for duration from 2019 to year N-1. After all the requirements are completed than finished with the construction, operation, closure and monitoring in year N to N+.

4.2. Disused sealed radiation sources (DSRS)

Disused sealed radioactive sources (DSRS) that are still stored in Interim Storage 1 and 2 (IS-1 and IS-2) or the High Activity Waste Storage (PSLAT) Center for Radioactive Waste Technology (PTLR) is quite a number and kind, such as Ra-226 (as a source in the medical field) as many as 1019 needles (stems), Cs-137 (as irradiators) as many as 142 pieces, Co-60 (as irradiators) as many as 67 pieces, Sr-90 (as thickness gauge) as many as 51, Am-Be (as a neutron source) as many as 34 pieces, Kr-85 (as thickness gauge) as many as 12 pieces, Pm-147 (as sources as standards in instruments) 5 units, Ir-192 (as Industrial radiotherapy) as many as 4, Cf-252 (for calibration) of 3 pieces, as well as X-ray and U sources 1 each [2].

From DSRS data in PTLR as mentioned above, Co-60, Cs-137 and Ra-226 is the most urgent DSRS and is ready to be stored in borehole disposal in accordance with the BOSS concept, because a part of the DSRS has been conditioned in a stainless steel capsule container as shown in figure 1.

4.3. Container concept
DSRS in the form of Co-60, Cs-137 and Ra-226 which have been confined in large capsules and in small capsules. Each capsule is then contained in SS 304 containers with a diameter of 150 mm and a length of 200 mm, which is given a hook at the top or end that functions in handling the DSRS package. The remaining space between the capsule and the container is filled with cement concrete as one part of the engineered barrier. A schematic description of the confinement or storage system can be seen in figure 4.

![Figure 4. Containment of DSRS [5]](image)

4.4. Emplacement of containers in the borehole
Container, which is 150 mm in diameter and 200 mm high, so that all of them can be put in one drill hole with a diameter of 165 mm with a casing. To maintain the strength of the placement and for safety purposes between a container with a container below and or above it needs to be given a distance of 10 cm filled with cement concrete. The total thickness of the container stack along with the total cement concrete from the bottom to the bulkhead is 52.00 m, so that if the drill hole is 100 m deep then the depth of the top container is 48.00 m.

4.5. Borehole facility for DSRS disposal
The borehole disposal concept consists of a standard hole (diameter 165 mm) with a depth of 100 m (figure 5). Depending on site conditions, depth can be more or less than 100 m. One hundred fifty millimeter (150 mm) casing diameter is installed to limit disposal volume. The bottom hole plug is installed to ensure disposal remains dry during operation. The tread area needs to be equipped with a fence to prevent access to the disposal environment, and a temporary office should also be provided.

A reference design has been proposed, which includes stainless steel containers, cemented waste and enclosed sources in capsules. Waste packages are placed in wet concrete in a borehole. The special concrete mixture is then poured over and around the container. The DSRS package is then placed into the hole and the process is repeated as before. DSRS placement is continued until the limit of waste acceptance criteria or the depth limit is reached (full).
Figure 5. Borehole disposal concept [5]

The rest of the borehole room is sealed / filled with concrete. The provision of means for retrieval has not been considered in the borehole disposal concept. The footprint can be marked or not, but a small footprint or footprint of the borehole must be observed. It is also necessary to make a cap that is resistant to intrusion at shallow depths and then camouflaged so that the presence of the drill hole is not conspicuous.

4.6. Site selection, potential site and site characteristic

Site selection must be based on the site selection criteria described earlier which concern the method. An appropriate site can be selected either from the process of downsizing candidates from a number of prospective sites, or by objectively evaluating a proposed site as a potential site. The two methods are not essential for choosing the best site, but the important thing is to guarantee a waste disposal system that can be seen by its ability to answer safety, technical and environmental requirements. Specific sites may be proposed for consideration by a local or national authority. Existing nuclear facilities or land around existing nuclear facilities can be specified as a special consideration because of the potential benefits in terms of co-location, especially in relation to reduced potential burdens in terms of public acceptance and DSRS waste transportation.

There are some potential sites that can be co-located to potential site for near-surface disposal at Serpong Nuclear Area, Karawang, Sumedang, Serang, Jasinga, Bangka Barat and Bangka Selatan [11], [12], [13], [14], [15], [16], [17]. Potential host rock for borehole disposal at Serpong and Jasinga are clay-siltstone from Bojongmanik Formation [11], [12], [13], [14], Karawang and Sumedang are claystone from Subang Formation [15], Serang is andesite [15] and Bangka Barat and Bangka Selatan are granite from Granit Klubat [16], [17].

4.7. Optimization of borehole disposal model at Serpong Nuclear Area

Based on the principle of co-location, the site can be selected in the area around the demo disposal site in front of IS-2 which has environmental characteristics as shown in table 3. Drilling data up to a depth of 100 meters has been obtained by drilling conducted in 2010, so that hope to get adequate host rock, namely clay-siltstone with low permeability and high adsorption, with unsaturated environmental conditions can be obtained.

Data of borehole DH-2 at Serpong Nuclear Area which the depth is 100 m, consist of three main stratigraphy unit, residual soil at top (0 m to 8.8 m), Serpong Formation (8.8 m to 24.8 m) and Bojongmanik Formation (24.8 m to 100 m or more) as are shown on figure 6.
### Table 3. Characteristics of the geological and non-geological environment of the potential site for borehole disposal at Serpong Nuclear Area [11-14]

| No  | Environmental Aspect | Parameter | Field Characteristic |
|-----|----------------------|-----------|----------------------|
| 1.  | Geomorphology        | Landform  | Undulating plains (56-76 m) |
|     |                      | Slope     | 0 to 7.41°           |
|     |                      | Process   | Weathering, erosion  |
|     |                      | Depth     | 8.8 m                |
|     |                      | Permeability | 1.826E10⁻⁶ m/s to 9.717E10⁻⁸ m/s |
| 2.  | Rock & Stratigraphy  | Strength  | 62 kPa (surface) to 761 kPa (depth 100 m) |
|     |                      | Stratification | Horizontal layers/lamination |
| 3.  | Structure            | Structure condition | Undetected structure |
|     |                      | Run-off   | No data              |
| 4.  | Hydrology & Hydrogeology | Distance to river | 160 m |
|     |                      | Depth of groundwater | 7.91-11.35 m (DH-5) |
|     |                      | Groundwater flow pattern | Sub-parallel |
|     |                      | Earthquake | Low (MMI scale<IV), 0.15g |
|     |                      | Volcanic   | Dust fall out from Salak volcano |
|     |                      | Rock mass movement | None |
|     |                      | Flooding   | None |
|     |                      | Rainfall   | 1.710 –2.677 mm/year |
| 5.  | Geological hazard    | Temperature | 20.8° – 35.0° (average 25.4° - 27.5°) |
|     |                      | Atmosphere cond. | Neutral to stabile |
| 6.  | Climate              | Mineral    | None |
|     |                      | Groundwater | ± 0.22 l/s |
|     |                      | Land       | High value |
|     |                      | Position   | Close to Radioactive Waste |
| 7.  | Landuse              | Installation | |
| 8.  | Mineral resources    | Groundwater | ± 0.22 l/s |
|     |                      | Land       | High value |
|     |                      | Position   | Installation |
|     |                      | Accessibility | Easy, road |
|     |                      | Position   | North and east |
| 9.  | Position, dimension and accessibility | Dimension | ± 1 Ha |
|     |                      | Accessibility | Easy, road |
|     |                      | Position   | North and east |
| 10. | Position and distance to settlement | Distance | 500 m |
|     |                      | Population | ± 5,424 person |
|     |                      | Density    | D= 1,726 person/km |
|     |                      | Ownership  | 100% government (PUSPIP-TEK & BATAN) |

Residual topsoil consists of clay, silt and sand, as A and B soil horizon. Serpong Formation is composed of sandy-gravelly silt. Bojongmanik Formation is composed of siltstone intercalated with sandstone and limestone, and at the depth 70 to 80 m found a layer consists of limy-siltstone and limestone, which intercalated with siltstone and claystone.

Borehole disposal zone (BDZ) can be considered at the depth between 24.8 m to 100 m (Bojongmanik Formation, thickness more than 75.2 m) which have suitable characteristics as the host rock for disposal function. Not all of the BDZ zone can be used for emplacement the container of...
DSRS, a part of them must be allocated for the bottom plug (1 m), cover plug (1 m) and cover zone (30 m) as a safety purpose. The top of the borehole disposal is considered to be at the same level as the deepest valley near the site.

![Stratigraphic column of DH-2 borehole](image)

**Figure 6.** Stratigraphic column of DH-2 borehole [11]

From the topographic map can be interpreted that the depth of the valley is 18 m (73 m - 56 m). Based on the calculation, the effective BDZ will be about 51 m (100 m – 17 m – 30 m - 2 m). So that, the maximum capacity of the BDZ zone will be 170 containers (51 m : (20 cm + 10 cm)), which 20 cm is the length of the container, and 10 cm is the thickness of cement concrete backfill between containers). Of course, there is a need for a safety assessment to optimize how many containers can be placed at the BDZ, and also how many boreholes can be constructed on the site. Figure 7 shows the distribution of cover zone, containers zone, backfill zone et cetera, based on borehole optimization.
5. Conclusion

Indonesia still faces problems with DSRS which has been partially encapsulated, conditioned and stored in Interim Storage 1 and 2 (IS-1 and IS-2), as well as Temporary Storage of High Activity Waste (PSLAT). Each capsule is packed in SS 304 containers with a diameter of 15 cm and a length of 20 cm.

Planning and concept of borehole disposal system should be initiated immediately. Planning of borehole disposal was integrated into the DSRS management.

The concept of borehole disposal is started with all containers are stored in a drill hole with a diameter of 16.5 cm, so that the height of the pile plus the space between containers whose thickness is 10 cm is 5,100 cm or 51 m, so if the drill hole is as deep as 100 m the depth of the top container is 48 m.

Based on the principle of co-location the site can be selected on the land around the demo disposal site which is in front of IS-2 with sufficient environmental characteristics.

Borehole data up to a depth of 100 meters had been obtained by conducting exploration drilling, so that adequate host rock as expected is found, siltstone-claystone with low permeability and high adsorption in unsaturated groundwater environments.

The next stage that needs to be done is the preparation of conceptual designs and safety assessments using software suitable for borehole disposal facilities.

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