Identification of Sandstone Layer beneath the Demonstration Disposal Site at Nuclear Serpong Area Using Resistivity Geo-electrical Method

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Abstract. The depth, thickness and expanse of sandstones or sandy material in site candidate of the disposal demo in Serpong nuclear area (SNA) need to be identified. This is considered because sandstones as ground water aquifers will potentially serve as a medium for transporting radionuclides from waste to biosphere. For design optimization and safety assessment of radioactive waste disposal facility so as not to endanger the public and environment, it is necessary to identify the sandstone layer data. This study was conducted with primary data at SNA using the Wenner configuration of resistivity geoelectricity method on five lines. Data processing and modeling is done through RES2DINV software to obtain the resistivity value of rocks that represent sandstone beneath the surface. In the line 1, the sandstone is at a depth of 6 m and 10 m with a resistivity value of 2.13 – 9.40 Ωm. In the line 2, the sandstone is at a depth of 12.5 m and 17.5 m with a resistivity value of 0.51 – 1.43 Ωm. In the line 3, the sandstone is at a depth of 18 m with a resistivity value of 0.70 – 3.28 Ωm. In the line 4, the sandstone is at a depth of 30 m with a resistivity value of 3.97 – 8.48 Ωm and in the line 5, sandstone is at a depth of 16 m with a resistivity value of 1.12 Ωm. Based on the results of the assessment, all the lines meet the safety requirements of radioactive waste disposal because there is a sufficient barrier zone between the base of the repository and the sandstone as groundwater aquifer, line 1 has a thickness of 4 m and 8 m, line 2 has a thickness of 10.5 m and 15.5 m, line 3 has a thickness of 16 m, line 4 has a thickness of 28 m and line 5 has a thickness of 14 m.

Keywords: identification, sandstone layer, disposal site, resistivity, geo-electrical

1. Introduction
To anticipate the need for radioactive waste disposal from research, medical and industrial, a near surface disposal facility (NSD) should be prepared, as well as complementary national facilities for radioactive waste management services in Indonesia. The facility is also designed to be used as a demonstration plant to show the performance of the disposal system. The provision of NSD facility shall take into account the public and environmental aspects of safety [1]. The basic principle of disposal is how the facility is placed, designed, built, operated, closed and decommissioned in such a way that
workers, communities and the environment are protected from the risk of radioactive release. The land for the disposal site is selected that meets the safety criteria so that it can confine the radionuclides in the waste, capable of holding the release of the radionuclides into the biosphere and capable of supporting the load of the repository and its waste [2]. One potential area for the disposal site of radioactive waste is at the Serpong Nuclear Area (SNA) as showed in Figure 1.

Figure 1. Map of research location [3].

In the disposal site selection, one of the safety considerations that the International Atomic Energy Agency (IAEA) needs to address is that there is a minimum of 4 m barrier between the bottom of the repository and the groundwater [4]. The purpose of the research is to make reconstruction of underground layers that have potential as aquifer. For the interpretation of the existence of aquifer, it is necessary to research the existence of sandstone beneath the surface because sandstone is a type of rock that has porosity and a relatively large permeability in absorbing, storing and releasing groundwater (as aquifer).

One geophysical method that can identify sandstone layers is the geo-electrical method. The geo-electrical method is familiarly used for the exploration of subsurface natural resources to study the nature of electric current in the subsurface rocks.

In principle, the geo-electrical measurement is to inject electrical current into the earth and measure the magnitude of the electric potential due to the flow of electric current [5]. From the measured potential difference, it can be calculated the resistivity value of rocks found beneath the earth's surface.

In this research, Wenner configuration of geo-electrical resistivity method is a geophysical method by utilizing electrical properties from earth layer through data retrieval by mapping (horizontal). Through the Wenner configuration it can be known that the resistivity value of the sandstone is potential as a groundwater aquifer.

2. Theory
2.1. Sandstone
Sandstones or sandy materials are sedimentary rocks composed mainly of minerals or grains of sand-sized rock (0.05 - 2 millimetres). Most sandstones are formed by quartz or feldspar because they are the most abundant in the earth's crust [6]. The types of sandstones, among others, are:

a. Quartz sandstone is a 90% grain sandstone composed of quartz. Quartz grains have good sorting and round grain shape because it is transported to a great distance.

b. Greywacke is a sandstone that is 15% or more composite is a clay-sized matrix, resulting in poor sorting and the colour of rocks are dark gray or greenish.

c. Arkose is a sandstone containing feldspar> 25% in addition to quartz minerals.

d. Lithic arenite is a sandstone that contains many rock grains.
2.2. Aquifer

Aquifer is a saturated and permeable geological formation, containing and flowing ground water so as to provide the volume of ground water as an adequate source of water. If the rock formations are only capable of producing a volume of groundwater less than the aquifer, then the rock formation is called aquitard. Whereas if the movement of ground water in the rock formations is so slow that it can be said no longer produce the volume of groundwater, then the rock formation is called aquiclude \[7\].

In general, the aquifer is divided into 3 types namely \[7\]:

a. **Unconfined aquifer.**

Also called phreatic or water table aquifer. The upper limit of the free aquifer water level is the water table, ie the surface in the free aquifer saturation zones that are at atmospheric pressure, generally occurring at relatively shallow depths above the waterproof layer.

b. **Confined or artesian aquifer.**

The water body on confined aquifer lies between two impermeable layers. Water in a confined aquifer is called confined water or artesian water.

c. **Semi confined or leaky aquifer.**

The semi-confined aquifer occurs when a fully water-saturated aquifer lies above the water-resistant layer and is topped by a semi-pervious layer, a layer whose permeability is lower than the permeability of the aquifer.

2.3. Radioactive Waste Disposal

Disposal is a facility used to store radioactive waste in a sustainable manner. In Serpong Nuclear Area, this facility will be built and operated as an experiments, demonstrations and disposal facilities for radioactive waste \[8\].

There are several disposal methods for confining radioactive waste, such as near surface disposal (NSD) which is the most common choice used in some countries, including those to be built in the Serpong Nuclear Area, BATAN. The near surface disposal (NSD) facility is located at or below ground level with a thickness of several meters. The facility is intended for radioactive waste with low and medium activity with little or no long-lived radionuclides.

All disposal types generally have the same purpose, which distinguishes them from the containment capacity of the radioactive waste they receive. In general, the disposal objectives are as follows \[9\]:

1. Accommodates radioactive waste.
2. Isolating radioactive waste from the biosphere, including reducing the possibility of human intrusion into radioactive waste disposal facilities.
3. Obstruct, reduce, slow down and / or close the potential for radionuclide migration to the biosphere.
4. To ensure that radionuclides that may migrate from the disposal facility to the biosphere are within the limits that meet the safety requirements.

For safety purposes, disposal facilities need to be provided with barrier to prevent water entering the repository and to retain the release of radionuclides into the biosphere. The system in a disposal should also ensure the function of the barrier to retain the movement of rainwater that infiltrate below the surface. One way to achieve that goal is to pay attention to the presence of sandstone layers. Sandstone layer should be identified to anticipate the flowing of groundwater which maybe transport the radionuclide and move to the environment.

2.4. Resistivity Geo-electrical Method

Geo-electric is one of the methods in geophysics that study the nature of the flow of electricity in the earth by directing DC current (Direct Current) which has high voltage into the ground. The working principle of the resistivity geo-electric method is to pass an electric current into the earth through two current electrodes, then its potential difference is measured by two potential electrodes, so that its resistivity value can be calculated \[10\]. Figure 2 show the electrical current lines and potential fields arising from the presence of two current sources.
Resistivity geo-electrical method is based on Ohm's law which aims to know the type of rock layers based on the distribution of resistivity value in each layer. In this method it is assumed that the earth is homogeneous isotropic, where the measured resistivity value is not an actual price but is a false resistivity of magnitude:

$$\rho_a = K \frac{\Delta V}{I}$$  \hspace{1cm} (1)

with:

- $\rho_a =$ False resistivity ($\Omega$m)
- $K =$ Geometrical factor
- $\Delta V =$ Potential difference (V)
- $I =$ Electric current (A)

K value (geometrical factor) depends on the order of electrodes (configuration). The value of K can be calculated by the equation:

$$K = \frac{2\pi}{\frac{1}{r_1} - \frac{1}{r_2}} \frac{\Delta V}{I}$$  \hspace{1cm} (2)

2.5. Electrode configuration

The electrode configuration used in this research is the Wenner configuration because of the good enough resolution both vertically and horizontally and deep penetration depth. The advantage of the Wenner configuration is the accuracy of the voltage reading at a better potential electrode with a relatively large number because of the potential electrode relatively close to the current electrode [12]. The schematic diagram of the Wenner configuration can be seen at Figure 3.
In this configuration, AM = MN = NB = a, the Wenner configuration geometry factor is as follows:

\[
K = \frac{2\pi}{\left(\frac{1}{AM} - \frac{1}{BM}\right) - \left(\frac{1}{AN} - \frac{1}{BN}\right)}
\]

\[
= \frac{2\pi}{\left(\frac{1}{a} - \frac{1}{2a}\right) - \left(\frac{1}{2a} - \frac{1}{a}\right)}
\]

\[
= 2\pi a
\]

Where \(a\) represents the distance between the two current electrodes and the potential electrode.

2.6. Resistivity of rock

Resistivity is a specific characteristic of a material, namely the degree of ability of a material in inhibiting the electric current expressed in units \(\Omega m\). It is noted that the value of resistivity depends on the type of material. To determine the rock formations as well as the mineral content contained in an area can be done by interpreting the data obtained in the field with a resistivity value referring to the existing reference. Table 1 and Table 2 show the resistivity value of various materials on earth.

| Material          | Resistivity (\(\Omega m\)) | Material          | Resistivity (\(\Omega m\)) |
|-------------------|-----------------------------|-------------------|-----------------------------|
| Sulphides         | 1.2x10^{-5} – 3x10^{-1}     | Sandstone         | 1 – 7.4x10^8                |
| Chalcopyrite      | 2.9x10^{-5} – 1.5           | Limestone         | 50 – 10^7                   |
| Pyrite            | 7.5x10^{-6} – 1^{-2}        | Clay              | 1 – 100                     |
| Pyrohotite        |                             | Sand              | 1 - 1000                    |
| Oxides            |                             | Alluvium and sand | 10 - 800                    |
| Hematite          | 3.5x10^{-3} - 10^7          | Soil (40% clay)   | 8                           |
| Limonite          | 10^{-1} - 10^7              | Soil (20% clay)   | 33                          |
| Magnetite         | 5x10^{-6} – 5.7x10^{3}      | Very dry clay     | 50 – 150                    |
| Quartz            | 300 - 10^6                  | Dry gravel        | 1400                        |
| Rock salt         | 30 - 10^{13}                | Saturated gravel  | 100                         |
| Granite (fresh)   | 300 – 1.3x10^6              | Sand clay/clayey sand | 30 – 215                |
| Granite (weathered)| 300 - 500                  | Sand and gravel   | 30 – 225                    |
| Basalt            | 10 – 1.3x10^7               | Andesite          | 1.7x10^2 – 4.5x10^4        |
| Conglomerate      | 2x10^3 – 10^4               | Groundwater       | 0.5 - 300                   |

| Material          | Resistivity (\(\Omega m\)) |
|-------------------|-----------------------------|
| Clayey soil       | 0.5 – 300                   |
| Silty clay and wet silty soil | 3 -15                |
| Silty, sandy soil | 15 – 150                    |
| Jointly bedrock filled with saturated soil | 150 – 300              |
| Sand-gravel-silt mixture | ± 300                  |
| Sand-gravel with silt layer | 300 – 2400              |
| Jointly bedrock filled with dry soil | 300 – 2400            |
| Gravelly sand deposit coarse grain | 2400                  |
| Weathered bedrock | 2400                        |
| Fresh water       | 20 – 60                     |
| Marine water      | 0.8 – 0.24                  |
| Groundwater       | 0.5 - 300                   |
3. Method
The study was conducted for 4 (four) months starting from March to June 2017 with primary data in Serpong Nuclear Area using the Wenner configuration geo-electrical resistivity method for 5 (five) trajectories. Each trajectory has different length and spacing of electrodes. The tracks 1 and 5 have a trajectory length of 155 m with a spacing of 5 m electrodes. The tracks 2 and 4 have a track length of 217 m with a spacing of 7 m electrodes. While trajectory 3 has a path length of 133.3 m with a spacing of 4.3 m electrodes. For data processing used RES2DINV software which is a software used to invert the underground surface in 2-D. Results of data processing in the form of 2-D modelling which can then be determined resistivity value in each soil layer. Thus it can be seen the resistivity value of sandstones as ground water aquifers which become the reference for safety assessment of radioactive waste disposal.

4. Result and Discussion
4.1. 2D Modelling Results
4.1.1. Trajectory 1.
Results of 2-D modelling of trajectory 1 shows a percentage error of 19.5%. Surface topography on this track is relatively flat with elevation 55 - 85 m above sea level and resistivity value ranged from 2.13 - 385 Ωm. In this path, there are two points of sandstone layer as groundwater aquifer which has resistivity value between 2.13 - 9.40 Ωm. The 2D modelling result of path 1 can be seen at Figure 4.

![Figure 4. 2D modeling result of path 1](image)

The first point lies in the measuring point 25 - 59 m which is at a depth of 10 m with a layer thickness of 14 m. The second point lies in the measuring point 78 - 135 m which is at a depth of 6 m with a layer thickness of 13 m.

4.1.2. Trajectory 2.
The 2-D model 2nd trajectory shows the percentage of error of 29.7%. Surface conditions on this trajectory are relatively undulating with elevations of 40-80 meters above sea level and resistivity values range from 0.18 to 252 Ωm. It is seen that the sandstone layer as aquifer of groundwater has a resistivity value ranging from 0.51 - 1.43 μm which is divided into two points. The 2D modelling results of path 2 can be seen at Figure 5.

![Figure 5. 2D modeling result of path 2](image)
The first point lies in the 92 - 125 m measuring point at a depth of 17.5 m with a layer thickness of 15 m. The second point lies in the measuring point 149 - 161 m which is at a depth of 12.5 m with a layer thickness of 7.5 m.

4.1.3. Trajectory 3.
The 2-D model of path 3 shows the percentage of error of 9.7%. The surface topography on the track is relatively flat, only slightly wavy at the measuring point 21.5 - 43 m with elevation of 45 - 75 m above sea level and resistivity value ranges from 0.70 to 156 Ωm. In this path only visible a small part of sandstone layer due to the length of the track that is not too far away and the result depth is not too deep. The sandstone layer as a groundwater aquifer in path 3 has a resistivity value between 0.70 - 3.28 Ωm located at the measuring point 79.55 - 90.2 m and is at a depth of 18 m with a layer thickness of 4 m. The 2D modelling results of path 3 can be seen at Figure 6.

4.1.4. Trajectory 4.
The 2-D model of path 4 shows the percentage error of 10%. The surface conditions on this trajectory are surging with elevation of 50 - 90 m above mean sea level and the resistivity value is between 3.97 - 56.5 Ωm. In this trajectory the sandstone layer as groundwater aquifer has resistivity value between 3.97 - 8.48 Ωm located at the measuring point 73.6 - 149 m and is at a depth of 30 m with a layer thickness of 7.5 m. The 2D modelling result of path 4 can be seen at Figure 7.

4.1.5. Trajectory 5.
The 2-D model of path 5 shows the percentage error of 19.8%. The surface conditions on this trajectory are undulating with elevation of 55-85 m above mean sea level and the resistivity value ranges from 0.15 - 178 Ωm. In this trajectory only a small fraction of the sandstone layer as a groundwater aquifer has a resistivity value of 1.12 Ωm which is suspected to extend from a 50 to 105 m measuring point. The sandstone layer on track 5 is located at a depth of 16 m with a layer thickness of 8 m. The 2D modelling result of path 5 can be seen at Figure 8.
4.2. Discussion

Based on the results of the analysis and interpretation using the software 2-D modeling, sandstones as groundwater aquifers identified on tracks 1, 2, 3 and 5 are at depths of 6-18 m which can be used for disposal of NSD model (near surface disposal). As for track 4, sandstones as groundwater aquifers are at a depth of 30 m. Based on these results and with the correlation using the borehole data in Figure 9, there is obtained a corresponding result between the two data showing that the sandstone layer as groundwater aquifer in the study area is at a depth of 10 meters below the surface.

![Figure 8. 2D modeling result of path 5](image)

![Figure 9. Hydrogeological data of borehole disposal site](image)

Based on the IAEA recommendation in ensuring the safety of the disposal system, there must be a barrier zone between the bottom of the repository with the sandstones as a groundwater aquifer of at least 4 meters thick. This barrier zone has function that if in case of isolation failure in the repository, radionuclides in the waste will still fall within the clay barrier, thus indirectly migrating to the biosphere and not endangering the community and the environment. The disposal facility is placed at or below the soil surface with a thickness of several meters of cover as shown at Figure 10 below.

![Figure 10. Design conceptual of radioactive waste disposal facility in NSD model](image)
Based on the analysis and interpretation of 2-D modeling, on track 1 there is a barrier zone as thick as 4 m and 8 m. On track 2 there is a 10.5 m and 15.5 m barrier zone. On track 3 there is a 16 m barrier zone. On track 4 there is a 28 m barrier zone and on track 5 there is a 14 m. The result of this investigation can be compared to another results with same region but different in objective and method. As an example, this result can be compared to result of identification of fault using pole-dipole configuration at Serpong area [16].

5. Conclusion
Based on the results of analysis and interpretation through 2-D modeling, sandstone as groundwater aquifers for safety assessment of radioactive waste disposal, the following conclusions are obtained:

Trajectory 1 has a resistivity value of the sandstone layer as a groundwater aquifer of $2.13 - 9.40 \, \Omega m$ which is divided into two points with a depth of 10 m and a thickness of 14 m and a depth of 6 m and a thickness of 13 m. Path 2 has a resistivity value of sandstone layer as ground water aquifer of $0.51 - 1.43 \, \Omega m$ which is divided into two points with a depth of 17.5 m and a thickness of 15 m and a depth of 12.5 m and a thickness of 7.5 m. Path 3 has a resistivity value of sandstone layer as aquifer of $0.70 - 3.28 \, \Omega m$ with a depth of 18 m and a thickness of 4 m. Path 4 has a resistivity value of the sandstone layer as a groundwater aquifer of $3.97 - 8.48 \, \Omega m$ with a depth of 30 m and a thickness of 7.5 m and path 5 has a resistivity value of the sandstone layer as a groundwater aquifer of $1.12 \, \Omega m$ with a depth of 16 m and a thickness of 8 m. Based on the results of the assessment, the five trajectories meet the safety requirements for radioactive waste disposal because there is an adequate barrier zone between the bottom of the repository and the sandstones as a groundwater aquifer under it.

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7. References
[1] Sucipta dan Risdiyana Setiawan 2016 *Eksplorium* Vol. 37 no. 2 (Jakarta: PTBGN BATAN) p. 115-124.
[2] Sucipta 2014 *Jurnal Teknologi Pengelolaan Limbah* Vol. 17 no. 2 (Serpong: PTLR BATAN) p. 31-43.
[3] Syaeful H, Sucipta dan I.A. Sadisun 2014 *Eksplorium* Vol. 35 No. 1 (Jakarta: PTBGN BATAN) p. 13-28.
[4] IAEA 1985 *Operational Experience in Shallow Land Disposal of Radioactive Wastes* TRS 253 (Vienna: IAEA).
[5] Loke M H 2004 *Electrical Imaging Surveys for Environmental and Engineering Studies*, *Tutorial 2-D and 3-D Electrical Imaging Surveys* (Malaysia: Geotomo Software).
[6] Dahlan B M 2015 *Geologi untuk Pertambangan Umum* (Yogyakarta: Graha Ilmu) p. 71.
[7] Soewarno 2015 *Analisis Data Hidrologi Menggunakan Metode Statistika dan Stokastik*; *Seri Hidrologi*. (Yogyakarta: Graha Ilmu) p. 363-368.
[8] Sucipta 2013 *Jurnal Teknologi Pengelolaan Limbah* Vol. 16 No. 2 (Serpong: PTLR BATAN) p. 47-64.
[9] IAEA 2011 *Disposal of Radioactive Waste* SSR 5. (Vienna: IAEA).
[10] Wahyuningrum R R, Budi L dan Darsono 2013 *Jurnal Teori dan Aplikasi Fisika* Vol. 01 no. 02 (Lampung: FMIPA UNILA) p. 199-205.
[11] Reynold J M 1997 *An Introduction to Applied and Environmental Geophysics* (New York: John Wiley and Sons Ltd).
[12] Pryambodo D G, Pihantono J, Troa R A dan Triarso E 2016 *Eksplorium* Vol. 37 no. 1 (Jakarta: PTBGN BATAN) p. 51-61.
[13] Milsom J 2003 *Field Geophysics 3rd ed.* (England: John Wiley & Sons Ltd)
[14] Muharis C dan Riswandi 2010 *Jurnal Rekayasa Sipil* Vol. VI no. 2 (Padang: Polteknik Negeri Padang) p.106-113.
[15] Pusat Pengembangan Geologi Nuklir (PPGN)-BATAN 2010 *Pemboran Inti dan Diagrafi Nuklir*. (Serpong: PTLR BATAN).
[16] Suntoko H 2017 *Jurnal Pengembangan Energi Nuklir* Vol 19 no 2 (Jakarta: PKSEN BATAN) p. 81-88.