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Okinoshima site study

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Abstract. The Okinoshima Islands are located on an off-axis of 0.76 degree (almost on-axis) with the same neutrino beam setting as T2K (2.5 degree off- axis to Kamioka). The distance of Okinoshima from the neutrino source, KEK/J-PARC, is 658 km. This configuration enables to conduct precision measurement of the 1st and 2nd neutrino oscillation maxima of the appearance electron neutrino energy spectrum. We have made studies of the Okinoshima Island site from the geological, geographic and infrastructure points of view to investigate the possibility of building a large underground cavern there to install a 100 kton class Giant Liquid Argon Time Projection Chamber (TPC) detector for a neutrino oscillation and proton decay experiment. We have found that the Okinoshima Island site is a good candidate site for such an observatory.

1. General outline of Okinoshima

The Okinoshima Islands are located on an off-axis of 0.76 degree (almost on-axis) with the same neutrino beam setting as T2K (2.5 degree off- axis to Kamioka) and the distance of Okinoshima from the neutrino source, KEK/J-PARC, is 658 km as is shown in Figure.1. This configuration enables to conduct precision measurement of the 1st and 2nd neutrino oscillation maxima of the appearance electron neutrino energy spectrum [1]. Okinoshima mainly consists of Dogo Island and the Dozen group of islands. Of all the Okinoshima islands, the biggest is Dogo. The islands in the group were born as volcanic islands about 5~6 million years ago, and Dogo still has some of the original stable homogeneous bedrock, Oki-gneiss, in which a large underground cavern could be excavated.

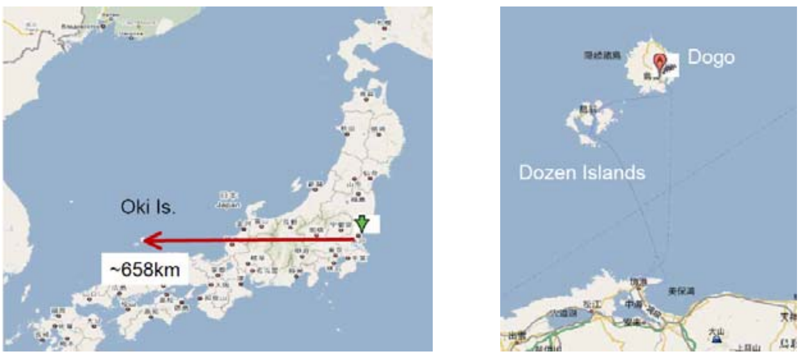

Figure1. Location of the Okinoshima Islands (http://maps.google.co.jp/maps).

Dogo is almost circular with a diameter of about 16 km and the center is mountainous with a 500 m altitude, this is where we would look for a candidate site for the underground neutrino observatory. The circumference of Dogo is 151 km and the area is 243 km^2. The distance between the main island of Honshu and Okinoshima is about 80 km and all of the Okinoshima islands belong to the Shimane prefecture. The seashore has been designated the Daisen-Oki National Park. Therefore, any developments there would be covered by various laws and regulations. The central mountainous region is, however, excluded from these restrictions. These islands are historically important as a place of exile for various unfortunate nobles between the 9th to 14 th centuries. At present about 16000 people live there and the economy mainly depends on the fishery and tourist business.

2. Site selection: Geology and geography

The bedrock under Okinoshima was originally formed from metamorphic rocks, which were extruded when the Pacific and Eurasian plates collided. This rock is called Oki-Gneiss and is one of the oldest rocks in Japan. Following that, during volcanic activities between 5~6 million years ago, Igneous rock intruded into the most of the area of these Islands. But a circular wall of Oki-Gneiss remained at Dogo as shown in Figure 2. Geographical features along sections A-B and C-D lines are also shown in the same figure. The Igneous rock areas include not only lava but also pyroclastic material and underground water. Therefore, they would not be suitable for making an underground cavern. On the other hand, the remaining Oki-Gneiss is very stable and in general there are only a few cracks, dislocations or active faults. Typical specific gravity and axial strength of the Oki-Gneiss is 27 kN/m^3 and 79 MPa, respectively.

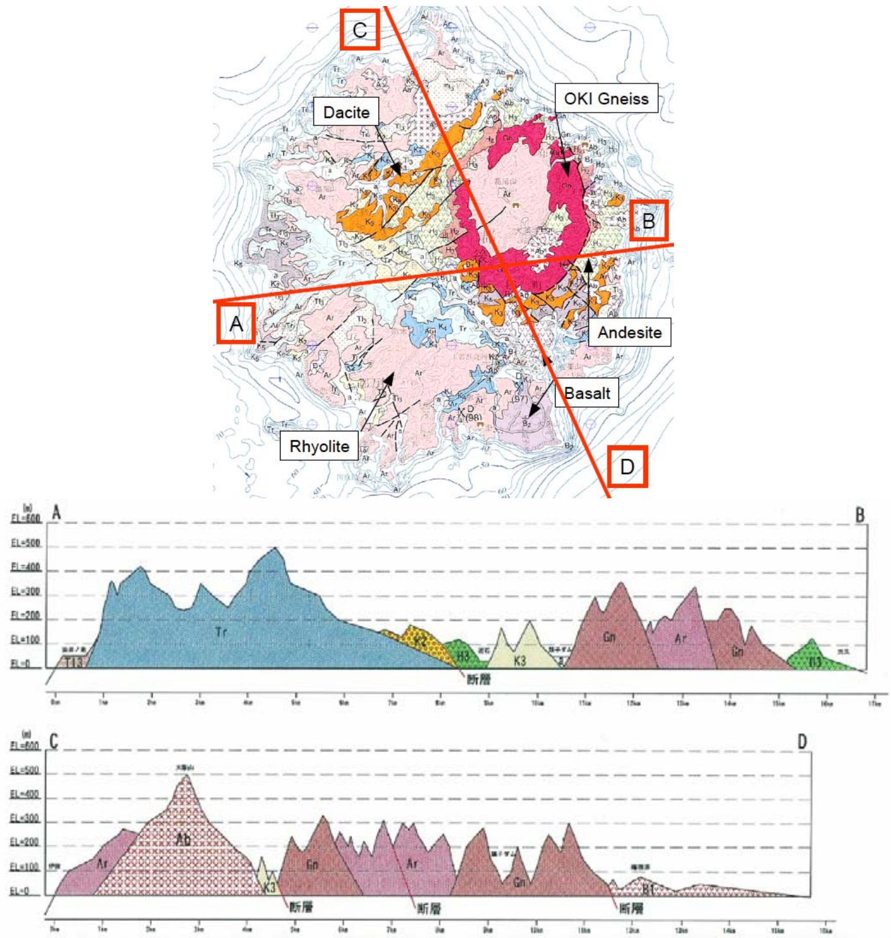

Figure2. The geology and geography of the biggest Island, Dogo.

Since the characteristics of the Oki-Gneiss are so good several quarries on Dogo provided crushed rock for the foundations of the Shimane Nuclear Power Plant. One of such quarry is shown in Figure 3.

Figure3. One of the quarries in Dogo.

A flood-control dam, the Choshi Dam (see Figure 4) was constructed in 2000, adjacent to the quarry in Figure 3 in the Oki-Gneiss area. The coefficient of water permeability was carefully examined and confirmed to be smaller than 10^{-7} m/s (Lugeon coefficient) in the Oki-Gneiss area.

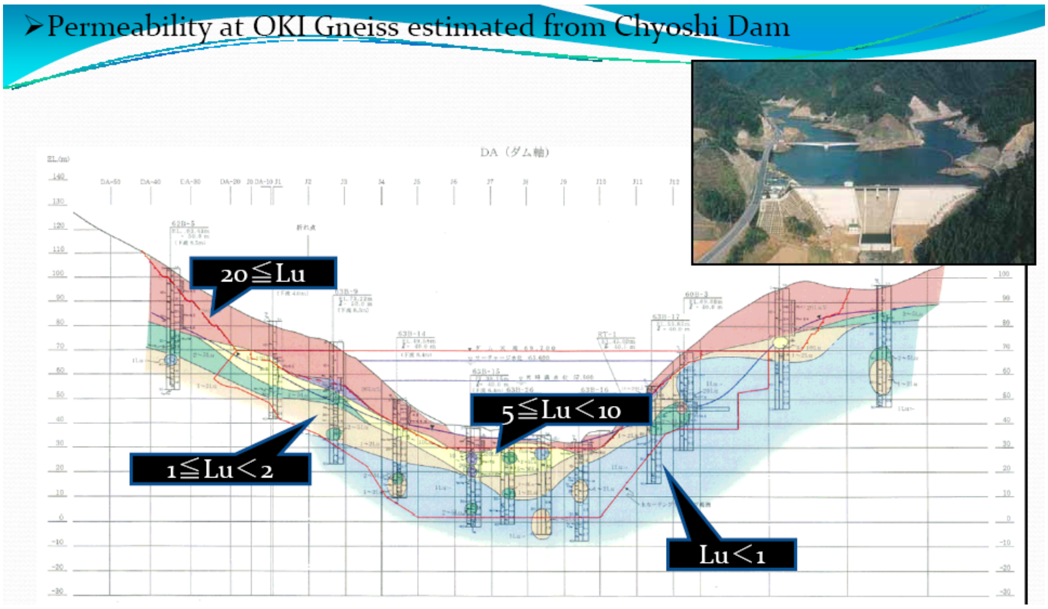

Figure4. Lugeon coefficient of Choshi Dam.

From the conservative civil engineering and safety point of view, the best location for the underground cavern is the quarries as shown in Figure 3. This is based on the following considerations:

- The location of the cavern should be in an Oki-Gneiss area and have enough distance from the igneous rocks to avoid rock brake down and degradation by the thermal effect of hot igneous rock intrusions during volcanic episodes.
- Fault zones should be avoided.
- Existing infrastructure, e.g., access to roads, sea port, etc., should be utilized as much as possible.
- Minimization of damage to the natural environment.
- The site should not be inside of the national park area.

3. Conceptual design of the cavern

Figure 5 shows a cross-sectional drawing of the potential location of the cavern in the Oki-Gneiss area, where the nearest distance from the Rhyolite area is larger than 500 m. The elevation at the bottom of the cavern would be 63 m and the earth covering between the top of the cavern and the mountain top is 252 m. The bottom of the cavern could be lowered, for instance by another 100 m if necessary. In such a case, the access tunnel from the ground surface would have to be inclined down to the cavern floor.

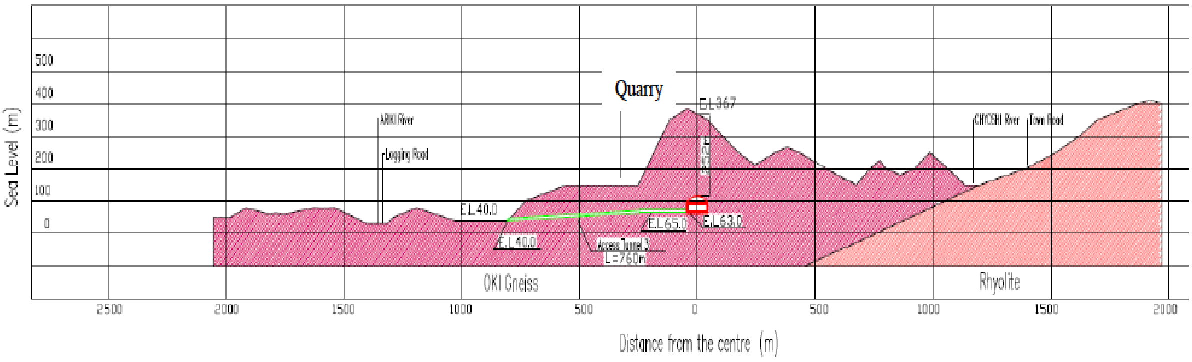

Figure5. Geological profile at the location of the cavern.

A conceptual design of the cavern has been carried out and is shown in Figure 6. In order to contain a cylindrical 100 kton Liquid Ar TPC detector with a base diameter of 80 m and a height of 20 m, the inner dimensions of the cylindrical cavern should provide a base diameter of 91 m, a height of 20 m and a spherical cap of 20 m in height.

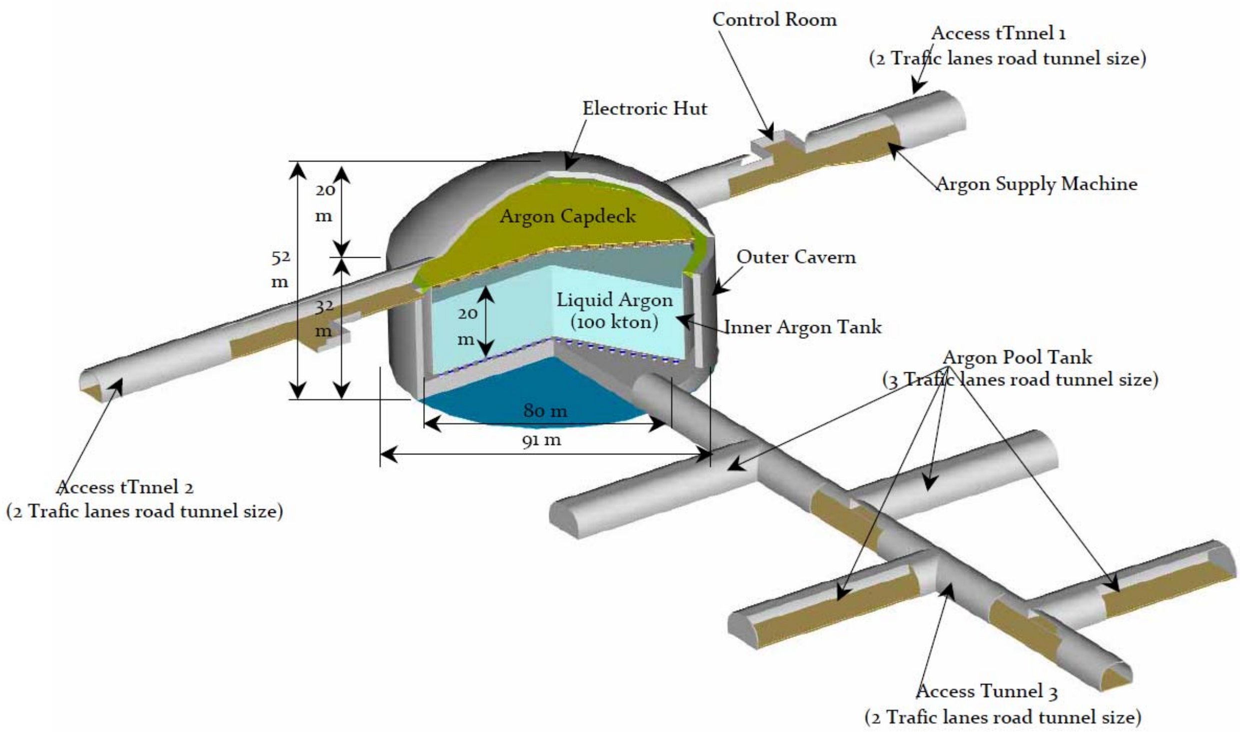

Figure6. A conceptual design of the cavern.

It should be mentioned that the biggest deep underground cavern existing in Japan now is the Kan-na-gawa underground power plant of Tokyo Electric Power Company shown in Figure 7. The present proposed cavern would have a similar volume.

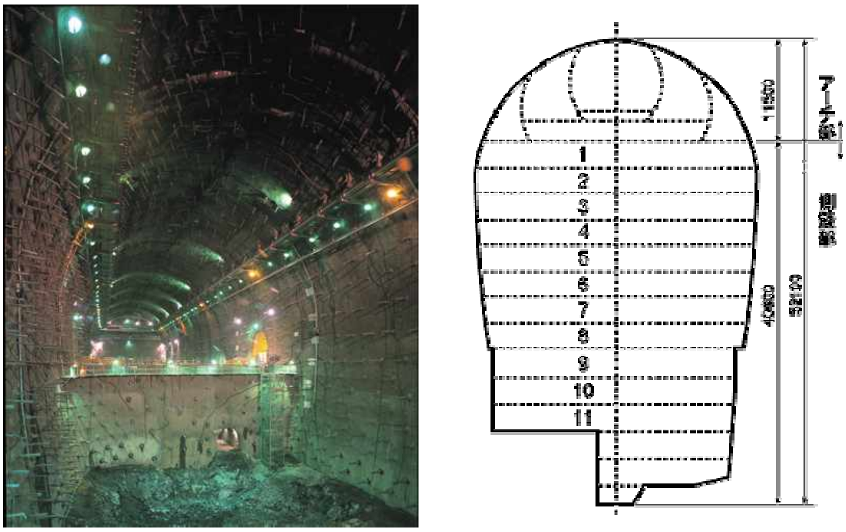

Figure7. The cavern of the Kan-na-gawa underground power plant.
(http://www.kajima.co.jp/news/digest/aug_2000/tokushu/toku03.htm)

As is shown in Figure 7, the cavern has an egg shaped cross-section provide for good stability against the strong underground pressures. Many rock bolts and pre-stressed rock anchors were used to achieve enough inner surface stability. For the neutrino observatory, detailed design of the cavern shape and the arrangement of rock bolts and rock anchors should be carried out based on multiple pilot surveys before and during the excavation work. The excavation volume of the cavern for the Liquid Ar TPC detector (Figure 6) is slightly less than that of Kan-na-gawa underground power plant (Figure 7). The shape of this cavern would be, however, different from the underground power plant case. As a consequence, careful studies of the construction methods and supporting arrangement of the rock bolts and anchors are necessary. Figure 8 shows one of the examples from our preliminary studies.

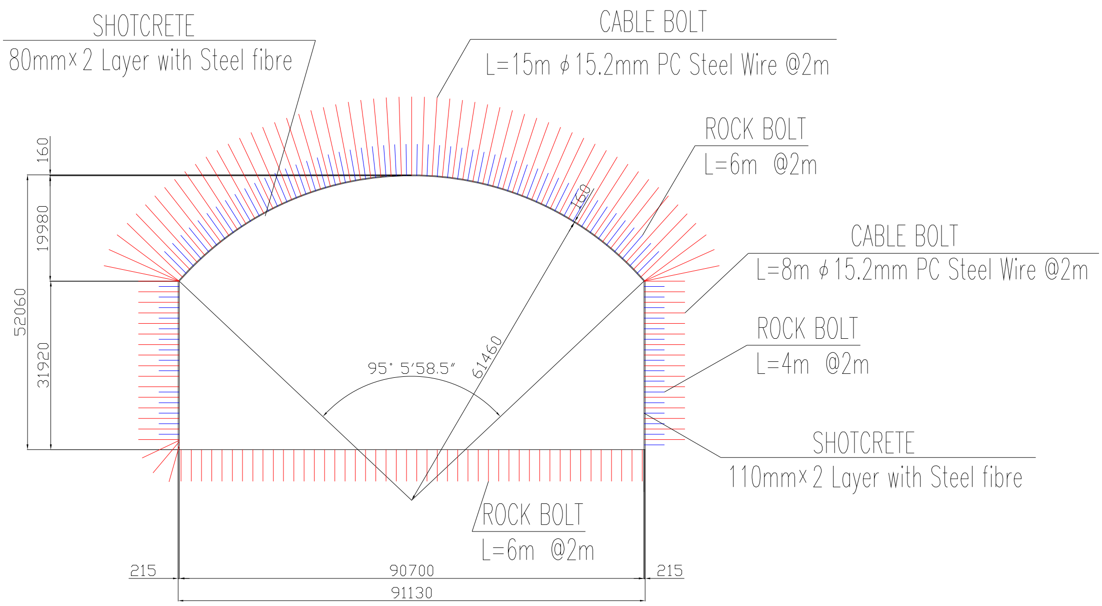

Figure8. An example of the cavern shape reinforcement study.

In order to excavate the cavern, access tunnel-1 should be constructed first. Access tunnel-2 is necessary for emergency escape, but would also be useful for the observatory operation, maintenance and so on. Access tunnels-1 and -2 come in at the top of the cavern. The main excavation starts from the top (the arch) and then proceeds to dig down to the bottom. Access tunnel-3 is mainly for the Liquid Ar pool and the construction of the main body and detector vessel, it should be constructed as early as possible. Four Liquid Ar tanks are shown in Figure 6, but the necessary number of tanks and their volumes would be determined by the means of procuring 100 kton of Liquid Ar . This will be discussed later. The size of these access tunnels should be about twice the standard single-lane road traffic tunnel size. The overall construction schedule is shown in Figure 9.

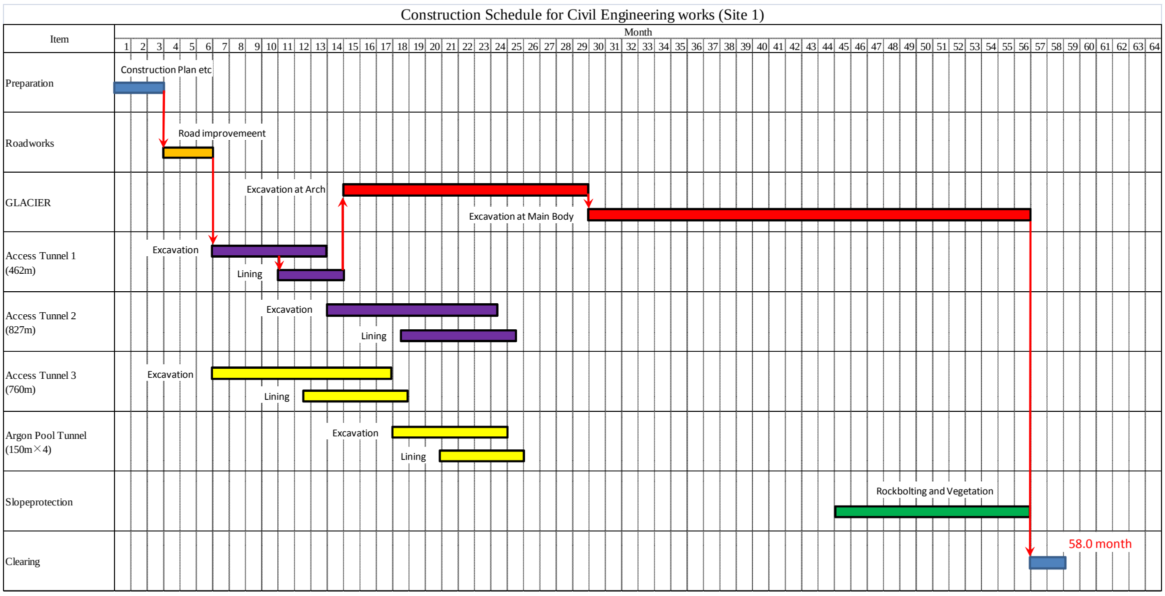

Figure9. Overall construction schedule.

In the present study, 58 months are necessary to complete the reference design construction in total. We would need more studies and necessary pilot surveys, including the construction of the pilot tunnels, boring studies, and other geotechnical investigations.

4. Infrastructure

Since there are regular daily commercial connecting flights and ferry services between Honshu and Dogo, we would have no transportation problem. The most important harbour is the Saigou port, which is close to the location of the candidate site. The existing access traffic situation from Saigou port to the site is almost adequate for carrying the heavy equipment needed for the civil engineering work, the large amount of Liquid Ar, and for the construction of the detector system. Only a short access road would need to be constructed for the final approach to the site.

The Chugoku Electric Power Company provides electricity for the Okinoshima Islands. The existing total electricity capacity is 32 MW and may be enough for the construction and operation of the observatory, but the adequacy depends on the status of industry and population of these islands.

5. Procurement of Liquid Ar

We have considered various case studies as to how to procure 100 kton of Liquid Ar over a 5 year period considering the need to minimize the cost. A solution could be as simple as the following;

- Buy Liquid Ar from several large-scale manufacturing plants having large production capacities. Many such plants are located in Japan. There are 5 candidate plants at this moment in the west side of Japan near Okinoshima, and we would contract to buy 10~15 % of their annual production capacity.

- Hire 4 tanker trucks dedicated for the Liquid Ar ground transportation, both in Honshu and Okinoshima for 5 years.
- Hire 1 barge dedicated for the marine transportation between Honshu and Okinoshima for 5 years.

We have studied other cases. For example:

- Construct an on-site production plant: But the cost for the initial construction would be very expensive and enough electricity for its operation would not be available in Dogo.
- Use an LNG carrier: We would have to solve the technical and legal problems in converting an LNG carrier to Liquid Ar. Further, the cost of hiring such a ship for 5 years would be expensive.
- Use regular commercial ferry transport: Currently they are not legally allowed to carry tanker trucks.

Therefore the present proposed solution is very simple and we would not need to solve any technical and legal problems. The cost of contracting for trucks and a barge for 5 years is not the major part of the total cost for the Liquid Ar.

6. Acknowledgement

Mr. Seishiro Yoshioka of OSAKA GAS CO., LTD. is the key person who provided us valuable information about the means of procuring 100 kton of Liquid Ar. He also introduced us Mr. Masataka Ito of NIPPON STEEL ENGINEERING CO., LTD. and Mr. Hiroshi Terai of AIR WATER INC.. We could not have arrived at the present solution without their help. The authors are very grateful for their assistance.

Reference

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