# REMOTE HANDLING OPERATION TECHNIQUE FOR HIGH-LEVEL RADIOACTIVE WASTE REPOSITORY INVESTIGATION AND PERFORMANCE TEST FOR SEVERAL DIFFERENT EMPLACEMENT CONCEPTS

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## ABSTRACT

During the operation of repository of high-level radioactive waste, waste package and engineered barrier will be transported from aboveground facility to underground facility, then be emplaced at a certain place of the repository. From the view point of operation safety and radiation safety through this process, technical feasibility for a variety of options for remote handling and remote emplacement of the waste package and engineered barrier must be provided at this moment in our repository program in Japan. In this study, several EBS concepts, especially for different types of buffer material – block, monolith, in-situ compaction, pellet, and pre-assemble (pre-fabrication) – were combined with two emplacement concepts –vertical and horizontal-. Then key technical issues of these different remote operation methods from aboveground facility to underground facility were classified into hard- and soft-ware element.

According to the key technical issues, priority and methodology of investigation and performance test for remote handling and remote emplacement were settled. In this paper the following two concepts were mainly discussed. For the block type buffer material, forming method and condition were investigated. Through a thick/ near full-scaled bentonite block forming test, a relationship between compaction pressure and density distribution of bentonite was confirmed, and a scale effect of full scale block forming was discussed. A vacuum suction cup was applied to lift the formed block, and several lifting properties and condition were evaluated. Degradation phenomena of formed bentonite block were also investigated under exposure condition of high-temperature with high humidity air, and relation between water content ratio and degradation phenomena was discussed. For the pre-assembled EBS concept, an air pressure used mechanism was investigated the applicability and property to lift and to transport in the underground drift for the heavily assembled module.

## INTRODUCTION

Geological repository programs are conducting in many countries as a final disposal for spent nuclear fuel and vitrified waste which are generated while nuclear power plant operation and reprocessing of spent nuclear fuel. Geological disposal basically involves manufacturing, transportation and emplacement of sealed waste container and engineering barrier from aboveground facility to deep under ground facility. In generally, using a multi-barrier system consisting of the engineering barrier system(EBS) including waste container and buffer material, and the natural barrier formed by bedrock, isolation of radionuclides from biosphere for a long time is a basic concept of geological repository[1][2][3][4]. And from view points of operation safety and radiation safety, transportation, handling and emplacement techniques of waste package and engineered barriers are desirable to be conducted by remotely controlled system from aboveground facility to underground facility. In order to realize the concept, remote handling and remote operation techniques of radioactive wastes and EBS materials at above- and underground facility are identified as key technology.

In Japan, HLW final disposal project is on the process of open solicitation for preliminary survey conducted by NUMO(Nuclear Waste Management Organization of Japan), which was established in October, 2000 as an implementing entity of Japan. Along to the NUMO’s activities, RWMC is conducting a R&D program of Remote Handling Operation Technique for HLW Repository. On the process of early stage of site selection and site investigation, now we are just facing, providing a technical feasibility, applicability and achieved performance of repository operation technologies is a key issue. Especially, variety of technologies for manufacturing, transportation and construction of EBS with required quality should be provided as technical option. In this study, remote operation technologies of overpack and buffer materials were investigated and evaluated for several EBS concepts, especially for different types of buffer material – block, monolith, in-situ compaction(powder), pellet[5][6][7], and pre-assemble (pre-fabrication) – , which were combined with two emplacement concepts –vertical and horizontal-. Along with these wide-variety performance test, system design of remote handling and emplacement technology was also studied. Influence factors which are related to operation process and repository elements were extracted and categorized each other. Then relationship between influence factors and operation system for each remote handling methods (bentonite block, monolith, in–situ compaction, pellet and pre-assembled package) are also categorized.

This R&D study had started at FY 2000 as five (5)-years program as identified the following three(3) phases;

Phase I FY2000-Conceptual Design & Extraction of Key Technical Issues
Phase II FY2001-2003 Component Test & Study on System Design
Phase III FY2003-2004 Component Test(Continued) & Remote Handling System Design

In Phase I, conceptual design for full-scale remote handling and emplacement equipment was performed. Concept and basic specification of remote operation machines for overpack and buffer materials, which were correspond to each repository concept consists of four(4) different types of bentonite –block, monolith, in-situ-compaction and pellet-with two(2) different emplacement methods –vertical and horizontal-, and two(2) additional option for horizontal emplacement, including a pre-assembled package, were settled(Fig.1), and key technical issues were extracted for each handling/emplacement concept.

Based on the first year’s results, several component tests were begun at FY2001 to examine and to evaluate component performance, which are key technical issues for each remote handling/emplacement concept, as Phase II. Also in this phase, the key technical issues were listed into several software items which were related to remote handling system design, remote handling operation influence factors, operation safety and EBS quality control. In Phase III, more rational remote handling system will be identified, then wide variety of technical option shall be completed under combination with component tests result and system design study at the end of FY2004.After completion this wide variety of technical option, some large scale or near full-scale demonstration and validation tests at aboveground and URL shall be desirable for more practical solution of remote operation concepts.

Current results from component tests and system design for each remote handling/emplacement technologies are shown in Table I. The component tests are focused on remote handling and remote transportation technologies of waste packages and buffer materials. And System design study items are categorized into each item of system design technique, quality control and operation safety. Along with our situation that no specific geological formation and specific repository concept have not yet selected, more flexible study condition shall be applied to the component tests and system design, respectively.

In this paper, component tests of remote handling and remote emplacement of bentonite blocks and pre-assemble package are mainly discussed. Furthermore, the basic specification of EBS concepts were based on the results of JNC's H12 Report(Table II,[8]).

**BENTONITE-BLOCK CONCEPT**

**Concept**

Piling the bentonite blocks was recognized as one of the most typical construction technique to place EBS at disposal pit (vertical) and/or drift (horizontal) in our study. Manufacturing the blocks at the aboveground facility is the most advantage for this method, because required process and treatment on the blocks can be done at the facility, which will be able to maintain high quality control for each block. It means that a high-performance and a high-quality EBS system can be realized at the repository if such highly controlled bentonite blocks are used to the repository. Furthermore, bentonite block fabrication technology is recognized as basic and common, which means validation test to form full-scale bentonite blocks can be done based on current industrial technology. And this concept gives a flexibility to the system design of remote handling and remote emplacement of EBS, because of its flexibility of block's shape, dimension and dividing. Which means that a numbers of block piling is one option to construct EBS at the repository, on the other hand, place a bentonite monolith, formed by CIP(Cold Isostatic Pressing), at one time at the repository is another advanced option.

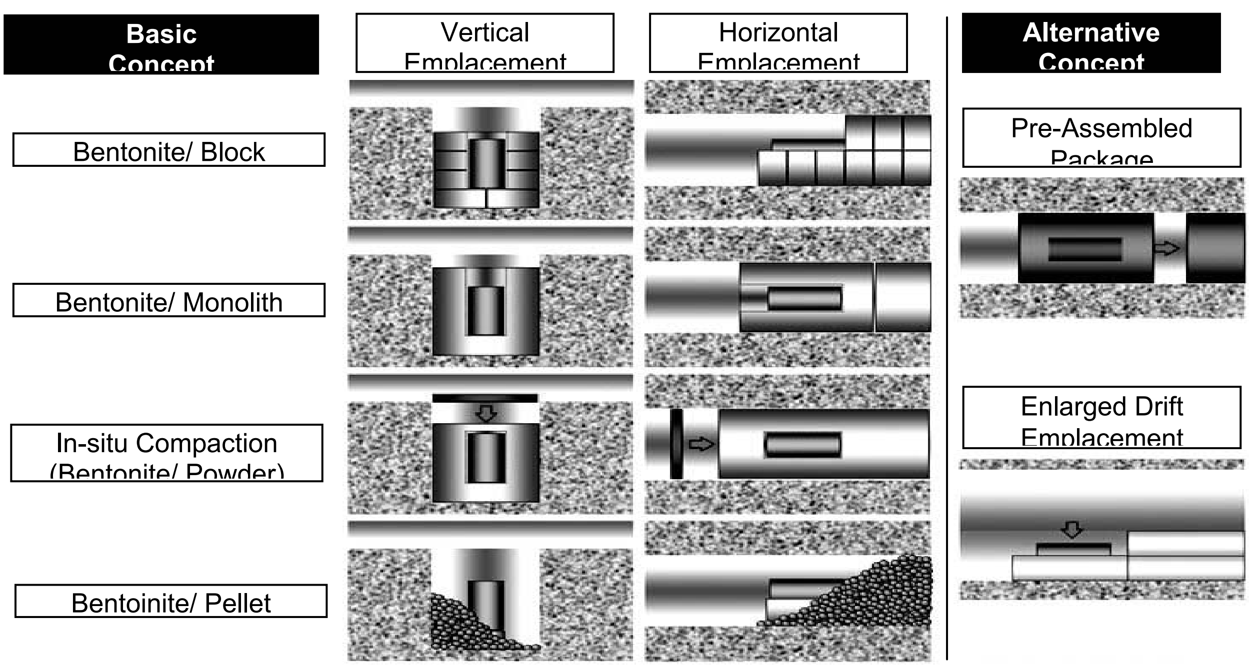


Fig. 1 Repository concepts based on several different EBS emplacement techniques

One of the key technical issues in this concept were lack of manufacturing experiences for full-scale bentonite block. An applicable forming condition of the large size block must been obtained, however, It has not been obtained yet, because neither experimental study nor demonstration to fabricate full-scale bentonite block had been performed. And degradation process and phenomena of formed bentonite block under atmospheric condition with relatively high-temperature and high-humidity in repository drift, is another concern to apply this concept to the repository operation. Addition to these issues, confirmation of remote handling operability of bentonite block also must be obtained to realize the block emplacement technique.

Through these consideration, the following three(3) items were identified as key technical issues for this bentonite block concept;

- Bentonite Block Manufacturing Technique
- Bentonite Block Remote Handling Technique
- Degradation Control of Bentonite Block

**Bentonite Block Manufacturing Technique**

The concept of bentonite block consists of two different types of block of circle block and one-eighth (1/8) dividing block, which is divided into a several portion from whole circle. And both type of blocks were examined in this study.

Table I RWMC's R&D performance & results for remote handling operation techniques for HLW repository

| Category | | Key Technology | RWMC's R&D Performance & Results | Emplacement Concept |
|---|---|---|---|---|
| Component Performance | Manufacturing of Buffer Materials | Static Compaction | ●Single Axis Compaction Property of Bentonite<br>●Manufacturing Technique of Full-scale Block (Φ2260mm x 300mmH)<br>○Forming Technique of 1/8 Dividing / Full-Scale Block<br>○1/8 Dividing Block Assembling Technique to Full-Scale / Circle Block | Block (V,H) |
| | | Dynamic Compaction | ●In-situ Compaction Property of Bentonite Powder<br>○Numerical Analysis Method of Destructive Evaluation of Host Rock and Waste Package<br>○Impact Energy Absorbing Property of Bentonite | Powder (V) |
| | | Bentonite Pellet Manufacturing | ●Bentonite Pellet Manufacturing Techniques and Physical Property<br>○Bentonite Pellet and Powder Mixture Technique<br>○Bentonite Pellet and Water Injection Technique | Pellet (V,H)<br>Gap Filling |
| | Remote Handling and Remote Emplacement of Waste Package and Buffer Materials | Bentonite Block | ○Block Performance Test (Mechanical Strength, Surface Friction Coefficient)<br>●Vacuum Suction Cup Gripping Performance (Static and Dynamic)<br>●Degradation Control of Bentonite Block | Block (V,H) |
| | | In-situ Compaction | ●Development of Inner Mold Type Compaction Method | Powder (V) |
| | | Bentonite Pellet | ○Homogeneous Mixing of Bentonite Powder and Pellet<br>○Water Injection Method for Filled Bentonite Pellet | Pellet (V,H) |
| | | Pre-Assembled Package | ○Applicability of Air Pallet for Surface Unevenness and Gap of Drift<br>○Development of Air Pallet System for Drift Transfer (Curved Surface with Gap) | Pre-Assembled |
| | | Overpack | ●Option for Overpack Gripping Mechanisms | All Types |
| | | Positioning/ Sensor | ●Research of Position Detector/Sensor (Mechanism, Accuracy, etc) | All Types |
| System Design | Process, System and Remote Operation | Process and System | ●Extraction of Influence Factors & Correlation between the factors and operation system<br>●Methodology of System Design | All Types |
| | | Design of Remote Operation System and Mechanism | ○EBS Construction Method and System Design for Different Emplacement Concepts | All Types |
| | Operation Safety and Quality Control | Operation Safety | ●Philosophy and Application for Operation Safety<br>●Study on Accident Evaluation Method | All Types |
| | | Quality Control | ●Quality Control and Quality Management Methods of EBS<br>●Study on Quality Control Items and Techniques | All Types |
| Others | Disposal Pit and Drift Excavation | | ○Excavation Accuracy and Quality of Disposal Pit and Drift | All Types |
| | Bentonite Pellet Performance Test | | ○Data Collection of Density, Permeability, Swelling Property, Thermal Conductivity, etc. of Bentonite Pellet (Bulk Data) | Pellet (V,H)<br>Gap Filling |

● : **Completed** (In FY2002) ○ : **Under Performing** (Until FY2004) **V**: Vertical **H**:Horizontal

| EBS | Item | Specification | Remarks |
|---|---|---|---|
| Overpack | material | Carbon Steel | - |
| | Dimension | Φ820mm x 1730mmH<br>Thickness 190mm | - |
| | Weight | 6.1t | Incld. Vitrified Waste |
| Buffer Material | Material | Bentonite and Silica Mixture Material<br>(Bentonite 70wt% + Silica 30wt%) | - |
| | Dimension | Φ2260mm x 3260mmH<br>Thickness 700mm | - |
| | Dry Density | 1.6Mg/m$^3$ | - |

Table III Bentonite Block Manufacturing Test: Dimension of Formed Blocks

| Height / Diameter | Diameter 50 | Diameter 300 | Diameter 700 |
|---|---|---|---|
| H/D=1.00 | H=50 | H=300 | — |
| H/D=0.64 | H=32 | — | H=450 |
| H/D=0.43 | H=21 | H=129 | H=300 |
| H/D=0.13 | H=6.6 | H=40 | H=93 |

(unit :mm)

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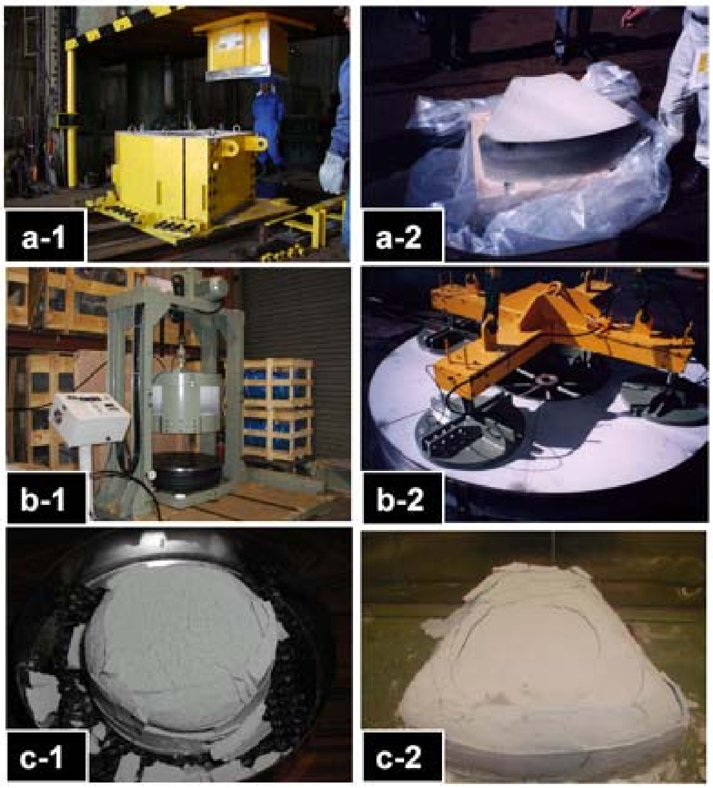
(unit :mm)

For the circle block, 2260mm diameter and 300mm thickness with dry density 1.9Mg/m$^3$, was chosen to our basic specification for vertical emplacement concept. Bentonite block manufacturing test was performed to form several bentonite blocks with 50~700mm diameter, 6.6~450mm thickness, as parameters of silica sand content ratio, water content ratio, by single-axis, static pressing machine, and forming pressure, density distribution of formed blocks and size precision was observed as show in Table III and Table IV.

Through these tests, required forming pressure to obtain adequate dry density around 1.9Mg/m$^3$ was increased as the ratio of H/D(Height/Diameter of formed bentonite block) increased. This means that increasing the H/D ratio induced more friction generation between the inside wall of metal mold and bentonite powder during the compression process. From this result, an appropriate compressing pressure can be introduced with depending on the dimension ratio H/D above. In our case, manufacturing of full-circle/disc type block of 2,260mm diameter with 300mm thickness was estimated to be completed under compressing pressure 20~30MPa. And this compressing pressure is equivalent to the capacity of 100~200kN as an industrial scale press machine. Before conducting this bentonite block manufacturing test, about 200~300kN capacity was estimated to be needed to form the full-circle bentonite block, however, from the result of H/D ratio consideration, it can be reduced to about one-half capacity for full-scale bentonite block forming. Dry density distribution was examined to small blocks, 50x30x30mm, divided from large blocks, and it showed that the value of dry density was quite depending on the thickness of the block. That means almost similar dry density distribution could be obtained if the thickness is same, even if the diameter is different between different blocks. In the case of 300mm thickness block, dry density distribution was almost homogeneous, excluding upper and lower part of circumference of the block. From these results, it is expected that a circle block of 2,260mm diameter with 300mm thickness can be formed with adequate dry density distribution.

For the separate type block manufacturing, one-eighth(1/8) dividing block forming was performed by using capacity of 20kN of single-axis press machine, as show in Fig.2(a). The 1/8-dividing block was compacted under 20~30MPa of forming pressure, which achieved dry density of 1.97~1.98Mg/$m^3$ with considering about 5vol% gain caused by release of elastic deformation. Formed bentonite blocks showed slight dimension differences as planed block about -4~+3mm in thickness and 1~4mm in radius direction, respectively. The formed blocks were divided into small blocks to examine dry density distribution, just as same as full-circle block, and relatively lower density (1.7Mg/$m^3$) at the part of lower corner and relatively higher density(2.0Mg/$m^3$) at the upper corner were observed in general trend. Then eight(8) 1/8-dividing blocks were bundled into one full-scale/circle block with two steel bands and inner steel support. This bundled one full-scale block was served to our remote handling test shown in below.




**(a)Block Manufacturing Technique**

**a-1** Piston , Mold , and 200kN Press

**a-2** Manufactured Block (Full Scale 1/8 Dividing Block)

**(b)Bentonite Block Remote Handling by Vacuum Suction Cup**

**b-1** Vacuum Suction Cup Performance Test

**b-2** Gripping by Vacuum Suction Cup (Full Scale Circle Block)

**(c)Bentonite Block Degradation Phenomena**

**c-1** Degradation Phenomena of Small-Scale Bentonite Block

**c-2** Degradation Phenomena of Large-Scale Bentonite Block

For our component test of remote handling and remote emplacement technique of bentonite blocks to vertical emplacement concept, rubber pad/vacuum suction cup was selected, which can avoid direct mechanical impact on the surface of the block, and mechanical grip and mechanical-vacuum suction combined method were also selected for horizontal emplacement concept, then the following test were performed.

- Vacuum Suction Cup Performance Test
- Vacuum Suction Cup Application Test for Full-Scale Circle Block
- Study on Horizontal Emplacement Technique

Vacuum suction cup performance test was conducted to identify static gripping capability and dynamic gripping performance, which foresee several operation modes expected in repository operation, as show in Fig.2(b)b-1 and Table V, and the specification of tested bentonite block and vacuum suction cup are shown in Table VI. In static test, detachment force was gradually added to vacuum gripped bentonite block, then limitation of gripping capability of vacuum cup was examined and the relationship between the gripping capacity and vacuum pressure (negative pressure) was identified as show in Table VII. For example, gripping capacity of 19.5kN can be obtained by vacuum pressure (negative pressure) at 100kPa toward a bentonite block with 30wt% of silica sand mixture. This phenomena was evaluated as equivalent to a hoisting capacity towards steel plate, that means almost no air leakage occurred during the process of vacuum suction gripping of this bentonite block. However, for the bentonite block with 70wt% of silica sand mixture, vacuum pressure was observed 30% less than that of the bentonite block with 30wt% silica sand mixture, so that an apparent descending of gripping capacity was observed since lack of negative pressure caused by added silica sand mixture. Through these performance tests, bentonite block gripping capacity equivalent to that of steel plate can be obtained at up to 50% of silica sand mixture.

Table V Vacuum suction cup performance test - Test condition -

| Vacuum Grip Performance Test Item | Test Parameter |
|---|---|
| Static Grip Performance | Buffer Specification |
| | Repetition |
| | Slant |
| | Bending Moment |
| | Shearing |
| Dynamic Grip Performance | Move Acceleration |

Table VI vacuum suction cup performance test - Specification of tested bentonite block and suction cup -

| | | | Specification |
|---|---|---|---|
| Bentonite Block | Material | Bentonite | Kunigel-V1 |
| | | Sand Mixture | Silica Sand |
| | Dry Density | | $1.9 Mg/m^3$ |
| | Sand Mixture Content | | 0~50% |
| | Water Content | | 4.9~9.0% |
| | Dimension | | Φ700mm x 300mmH |
| | Compaction Method | | Single Axis |
| Vacuum Suction Cup | Material | | Rubber + Steel |
| | Dimension | | Φ500mm |
| | Negative Pressure | | 100kPa (Max) |

Table VII Results of vacuum suction cup performance test

| Material | Sand Mixture Content | Water Content | Negative Pressure (kPa) | Number of Test | Results: Negative Pressure [Measured] (kPa) | Results: Static Gripping Performance (kN) |
|---|---|---|---|---|---|---|
| Bentonite + Silica Sand | 30% | 9% | 100 | 1 | 98.1 | **19.5** |
| | | | | 2 | 98.4 | **19.5** |
| | | | | 3 | 98.1 | **19.5** |
| | | | 80 | 1 | 79.5 | **15.8** |
| | | | | 2 | 79.7 | **15.9** |
| | | | | 3 | 79.7 | **15.8** |
| | | | 60 | 1 | 60.6 | **12.0** |
| | | | | 2 | 60.3 | **12.0** |
| | | | | 3 | 60.5 | **12.0** |
| | 50% | 7% | 100 | 1 | 99.3 | **19.4** |
| | 70% | 10% | 60 | 1 | 42.1 | **8.2** |
| | | | | 2 | 42.0 | **8.1** |
| | | | | 3 | 42.2 | **8.2** |
| Steel Plate | | | 100 | 1 | 99.8 | **19.4** |
| | | | | 2 | 99.4 | **19.6** |
| | | | | 3 | 99.5 | **19.6** |
| | | | 80 | 1 | 80.1 | **15.8** |
| | | | | 2 | 80.1 | **15.8** |
| | | | | 3 | 80.2 | **15.8** |
| | | | 60 | 1 | 60.3 | **11.9** |
| | | | | 2 | 60.4 | **12.0** |
| | | | | 3 | 60.1 | **11.8** |

eight(8) 1/8-divide blocks. In this test four(4) vacuum cups were assembled into one hoisting mechanism , then the cups was attached to four(4) each block already bundled, as show in Fig.2(b)b-2.

The total weight of up to 2300kg, include eight(8) divided block 266kg each, and two steel bands and an inner steel support 135kg, was hoisted, horizontally moved, then down to the floor. During this process, bundled block could be hoisted by assembled vacuum cup mechanism securely, no negative incidents were observed. Through this test, four(4)-vacuum cup assembling device was evaluated that it has sufficient capability to handle a full-scale bentonite block.

According to the results from above tests, a prospect to realize vertical emplacement of bentonite block should be done by this vacuum suction cup hoisting device. Study on horizontal emplacement technique is now just performing.

**Degradation Control of Bentonite Block**

During the process of remote handling and remote emplacement of bentonite block in repository drift, degradation of bentonite block induced by atmospheric condition of high temperature and high humidity is concerned to maintain the block’s quality. In order to examine such degradation process and countermeasure, formed bentonite blocks, whose specification are shown in Table VIII, were exposed to high temperature with high humidity air for 48 hours, which simulated that of repository drift, as show in Table IX., and dependence of degradation process, like some changes in size, weight and surface degradation, upon time were observed. One example of observed degradation phenomena are summarized in Table X. Swelling and crack were induced on many test samples, however, such degradation phenomena were typically occurred for relatively lower water content of bentonite block as shown in Fig.2(c)c-1 . On the other hand, bentonite block having a relatively high water content showed a resistivity against such atmospheric condition, and degradation process was slower than that of low water content blocks even if under high temperature and high humidity air condition. This is because of small difference of water potential between bentonite itself and surrounding air, absorbing water amount and water absorbing velocity of bentonite block supposed to be small.

Table VIII Specification of bentonite block tested under high temp. and high hum. air condition

| | | Specification |
|---|---|---|
| Material | Bentonite | ・Kunigel-V1 Powder / Granulate<br>・MX-80 |
| | Sand Mixture | Silica Sand |
| Dry Density | | 1.6~1.9Mg/m$^3$ |
| Sand Mixture Content | | 0~30% |
| Water Content | | 6~20% |
| Dimension | | Φ50mm x 20mmH |
| Compaction Method | | Single Axis |

Table IX Exposure condition of bentonite block

| Case | Temp. (°C) | Hum.(%RH) | Exposure Time(h) | Remarks |
|---|---|---|---|---|
| 1 | 30 | 80 | 48 | Simulated Ventilation Condition |
| 2 | 30 | 95 | 48 | |
| 3 | 45 | 95 | 48 | |

Table X Degradation phenomena of small-scale bentonite block

| Temp. (°C) | Hum. (%) | Bentonite Materials | Sand Mixture Content | Water Content | Dry Density ($Mg/m^3$) | Exposure Time (h) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1 | 3 | 5 | 8 | 12 | 24 | 48 |
| 30 | 80 | K-V1 | 0% | 10% | 1.6 | ○ | ○ | ● | ● | × | × | × |
| | | K-V1 | 0% | 10% | 1.8 | ○ | ○ | ○ | ○ | ○ | ○ | ● |
| | | K-V1 | 30% | 10% | 1.6 | ○ | ○ | ○ | ○ | ○ | ● | ● |
| | | K-V1 | 30% | 10% | 1.8 | ○ | ○ | ○ | ○ | ○ | × | × |
| | | K-V1 | 0% | 6% | 1.6 | ○ | ○ | ● | × | ○ | × | × |
| | | K-V1 | 30% | 6% | 1.6 | ○ | ○ | ○ | ○ | ○ | ○ | ● |
| 30 | 95 | K-V1 | 0% | 10% | 1.6 | × | ● | ● | × | × | × | × |
| | | K-V1 | 0% | 10% | 1.8 | × | × | × | × | × | × | × |
| | | K-V1 | 0% | 10% | 1.9 | ● | × | × | × | × | × | × |
| | | K-V1 | 30% | 10% | 1.6 | ○ | ● | ● | × | × | × | × |
| | | K-V1 | 30% | 10% | 1.8 | ○ | ○ | ● | ● | × | × | × |
| | | K-V1 | 30% | 10% | 1.9 | ● | ● | ● | ● | × | × | × |
| | | K-V1 | 0% | 18% | 1.6 | ● | ● | ● | × | ● | × | ● |
| | | K-V1 | 30% | 18% | 1.6 | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| | | MX-80 | 0% | 18% | 1.6 | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| | | MX-80 | 0% | 10% | 1.6 | × | × | × | × | × | × | × |
| 45 | 95 | K-V1 | 0% | 10% | 1.6 | × | × | × | × | × | × | × |
| | | K-V1 | 0% | 10% | 1.8 | × | × | × | × | × | × | × |
| | | K-V1 | 30% | 10% | 1.6 | × | × | × | × | × | × | × |
| | | K-V1 | 30% | 10% | 1.8 | × | × | × | × | × | × | × |
| | | K-V1 | 0% | 6% | 1.6 | × | × | × | × | × | × | × |
| | | K-V1 | 30% | 6% | 1.6 | × | × | × | × | × | × | × |
| | | K-V1 | 0% | 20% | 1.6 | ○ | ● | ● | - | - | ● | - |
| | | K-V1G | 0% | 18% | 1.6 | ○ | ● | ● | - | - | ● | - |
| | | MX-80 | 0% | 18% | 1.6 | ● | - | - | - | - | ● | - |
| | | MX-80 | 0% | 18% | 1.8 | ● | - | - | - | - | ● | - |

**Introductory notes:** **K-V1**:KunigelV1-Powder **K-V1G**:KunigelV1-Granulate **MX-80**:MX-80
**Degradation Bentenite Block** / ○:No Degradation ●:Surface Crack ×:Crack/Degradation

In order to confirm a water content which can be equilibrated with atmospheric temperature and humidity, bentonite blocks with water content 0~20%, 2% changed to each block, were exposed to the air, conditioned at 45°C with relative humidity of 95% for 18 hours, then water content of the bentonite block were observed. The water content, initially different between the tested blocks , were observed as converging on a certain value, as shown in Table X.

These water content values are the point of equilibrium between the water potential of surrounding air and bentonite. So that if bentonite block is conditioned to this water content, the water absorbing shall be restrained, and then degradation process shall be controlled even if the bentonite block is handled and placed under high temperature and high humidity air condition.

Then large-scale bentonite block exposure test was conducted to confirm degradation phenomena and the water absorbing suppression effect based on the above mentioned water potential equilibrium. In this test, two types of bentonite blocks, a cylindrical block with 700mm diameter and 300mm thickness and full-scaled 1/8-divide block, were placed in a homoiothermy room controlled at 45°C, and relative humidity 95%. The test result was shown in Table XII. In general, degradation, mostly detachment, occurred typically on the sidewall of these blocks.

Table XI Converged water content ratio

| Temperature | Humidity | Bentonite Materials | Sand Mixture Content | Converged Water Content |
|---|---|---|---|---|
| 45°C | 95%RH | MX-80 | 0% | 20% |
| | | Kunigel-V1 | 0% | 16% |
| | | | 30% | 11% |
| | | | 50% | 8% |

Table XII Large-scale bentonite block degradation phenomena

| Atomos -phere | Bento -nite Material | Block Type | Sand Mixture Content | Water Content | Degradation Surface | Exposure Time (h) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 0 | 6 | 24 | 30 | 48 |
| Temp. 45°C Hum. 95RH% | Kunigel -V1 | Full -Circle Φ700mm x 300mmH | 70% | 14% | Upper Surface | ○ | ○ | ○ | ○ | ● |
| | | | | | Side Walls | ○ | ○ | ○ | ○ | ○ |
| | | | 70% | 9% | Upper Surface | ○ | ○ | ○ | ○ | ○ |
| | | | | | Side Walls | ■ | ■ | ■ | ■ | ■ |
| | | | 50% | 7% | Upper Surface | ○ | ○ | ○ | ○ | ● |
| | | | | | Side Walls | ○ | ○ | ○ | ○ | ○ |
| | | Full-Scale 1/8 Dividing Block | 70% | 14% | Upper Surface | ○ | ○ | ○ | ● | ● |
| | | | | | Side Walls | ○ | ■ | ■ | ■ | ■ |
| | | | | | Outside Wall | ○ | ○ | ■ | ■ | ■ |
| | | | | | Inside Wall | ○ | ○ | ○ | ● | ● |
| | | | 70% | 9% | Upper Surface | ○ | ○ | ● | ● | ● |
| | | | | | Side Walls | ○ | ○ | ● | ● | ● |
| | | | | | Outside Wall | ○ | ○ | ● | ● | ● |
| | | | | | Inside Wall | ○ | ● | ● | ● | ● |
| | | | 70% | 4% | Upper Surface | ○ | ● | ● | ● | ● |
| | | | | | Side Walls | ○ | ● | ● | ● | ● |
| | | | | | Outside Wall | ○ | ● | ● | ● | ● |
| | | | | | Inside Wall | ○ | ● | ● | ● | ● |
| | | | 50% | 7% | Upper Surface | ○ | ○ | ○ | ○ | ○ |
| | | | | | Side Walls | ○ | ○ | ○ | ○ | ○ |
| | | | | | Outside Wall | ○ | ○ | ● | ● | ● |
| | | | | | Inside Wall | ○ | ○ | ○ | ○ | ○ |

○:No Degradation ●:Crack ■:Detachment

That supposed the macrostructure of the sidewall must be disturbed by friction force affected by a mold which used during the process of block forming. And in the case of 1/8-dividing block, around the corners were typically degraded, since unevenness of density distribution around here was relatively large (Fig.2(c)c-2). From the results of this large-scale block exposure test summarized in Table XII, in the case of high water content blocks, it took longer time until crack and detachment induced. Therefore, degradation process supposed to be able to restrain and/or to retard through taking a balance between the water contents of bentonite block and surrounding air conditions. Moreover, providing a highly water contained bentonite block at aboveground facility which adjusted to a repository drift air condition of relatively high temperature and high humidity, contraction of drying and crack generation of formed bentonite block will be arisen as another concern for maintaining of bentonite block quality control. So that bentonite block handling system must be considered a water content balance between bentonite block and surrounding environment in repository drift, including effects of air conditioning and ventilation system, etc.

## PRE-ASSEMBLED PACKAGE CONCEPT

### Concept

Pre-assembled Package Concept, in which overpack and buffer material are assembled into one package at the aboveground facility, then it will be transferred to the underground repository and be emplaced at a certain place of disposal drift. Through these streamlined process, operation of the package transfer and emplacement inside the drift with very limited workspace and capacity is desirable to be done with more simple movement and procedure. And because of the casing, which hold the waste package and EBS inside, degradation process on buffer materials by humid atmosphere inside a repository tunnel shall be relieved. These advantages, especially that of workability caused by one assembled package, should be attracted to realize horizontal emplacement concept to the repository drift.

### System Design

Through the system design of pre-assembled package concept, transportation and emplacement mechanism was examined. Assuming the total weight of the package as up to 30 tons, which equivalents to one unit of vitrified waste (canister), overpack and buffer materials with steel casing, loading mechanism and transfer mechanism were extracted as shown in Table XIII and Table XIV. For the load bearing mechanism, air pressure technique was evaluated as a more practical method for its compact size and its workability under limited space of drift. And for the transfer mechanism, wheel and crawler were identified as more reliable method, then crawler was selected for further examination. Then by using these two mechanisms, transportation and emplacement system of pre-assembled package was studied as shown in Fig.3. In this concept, air pallet system was selected to lift the heavy load as an application of air pressure, and air jack system was also selected to support lifting capability of air pallet under uneven drift surface condition.

### Package Design

In the package design, casing material and assembling method were supposed to be key issues. Metal, ceramics cement and glass were selected as candidate materials for the casing and organic materials was eliminated by concerning its effect on performance assessment of repository system. Then ceramics and glass were eliminated by their manufacturability, and mechanical property of their brittleness. And cement has disadvantages, especially for its chemical property of high-pH effects on the repository system for long-term prospect. So the metal was selected to the most adequate casing material of our pre-assembled package, because of its manufacturability and mechanical property so far. Casing concepts were listed into four(4) different types of no-casing, half-cover, tube and full-cover, respectively, as show in Table XV, and the full-caver type was supposed to be the most practical for our pre-assembled package concept.

Table XIII Loading mechanisms for pre-assembled package

| Mechanisms | | Load Bearing | Uneven Surface | Size | Remote Operability |
|---|---|---|---|---|---|
| Floating | Magnetic | A | B | B | B |
| | Air Pressure | A | B | A | B |
| Wheel Drive | | A | B | B | B |
| Crawler Drive | | A | B | B | B |
| Walking Robot | | B | B | B | B |
| Pushing Mechanism | | A | C | A | B |

**A**: Good **B**: Satisfied **C**: Unsatisfied

Table XIV Transfer mechanisms for pre-assembled package

| Mechanisms | | Dynamic Transmission | Uneven Surface | Size | Remote Operability |
|---|---|---|---|---|---|
| Non-Contact Movement | Magnetic | B | B | B | B |
| | Air Pressure | C | B | A | B |
| Wheel Drive | | A | B | B | B |
| Crawler Drive | | A | B | B | B |
| Walking Robot | | B | B | B | B |
| Pushing Mechanism | | A | C | A | B |

**A**: Good **B**: Satisfied **C**: Unsatisfied

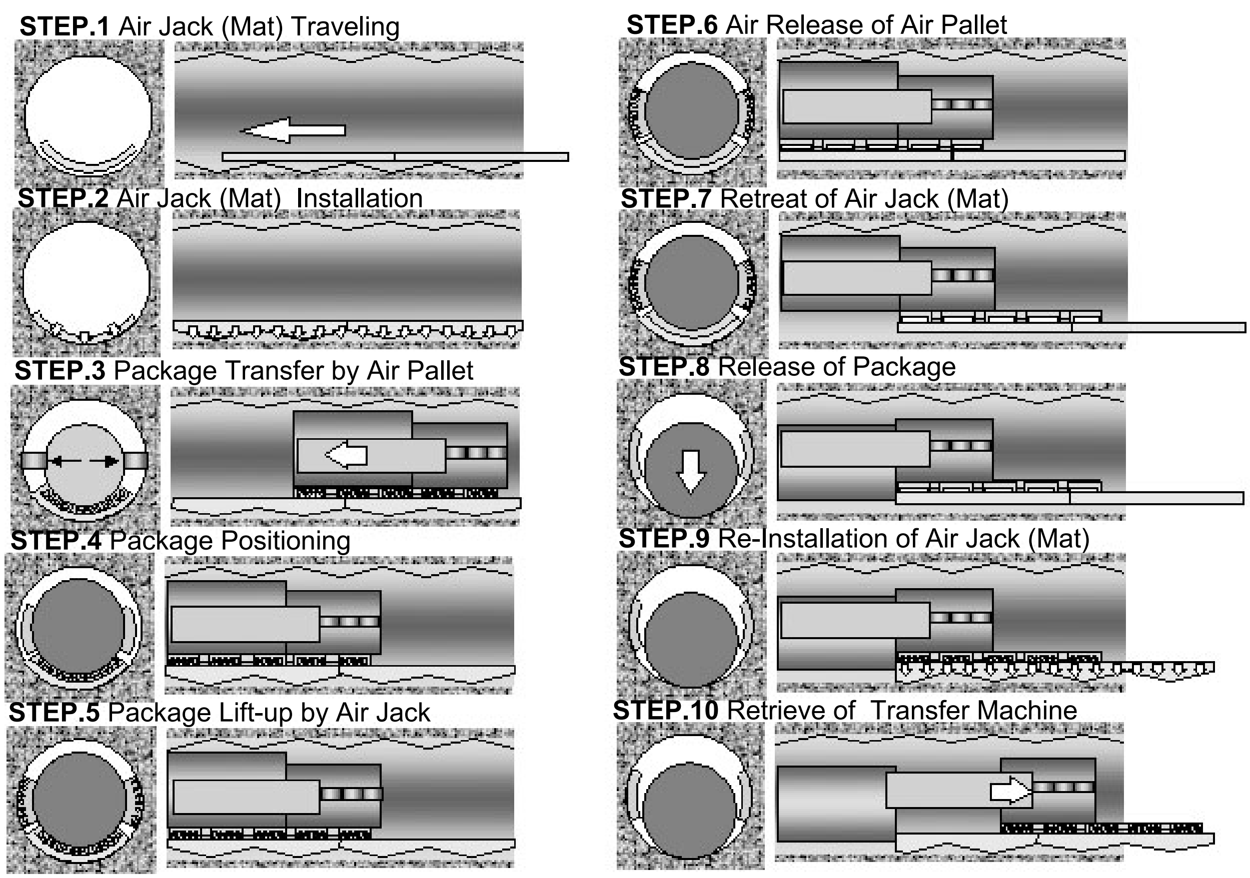



Fig. 3 Pre-assembled package operation procedure

Table XV Casing concepts for pre-assembled package

| Casing Type | Casing Manufactur-ability | Remote Assembling Workability | Remote Emplacement Workability | Applicability to Types of Buffer Materials | Radiation Shield |
|---|---|---|---|---|---|
| No Casing | - | C | C | C | - |
| Half Cover | B | B | B | C | C |
| Tube | B | B | B | B | C |
| Full Cover | B | B | A | A | B |

**A**: Excellent **B**: Good **C**: Insufficient

**Air Pallet System**

As shown in Fig.3, air pallet lift system of heavy-loaded pre-assembled package was built with combination of air pallet and air jack. Key technical issues are focused on load bearing capability of air pallet and emplacement procedure by air jack for up to 30tons of package, respectively. As show in Fig.4, air pallet component itself has already been applied to commercial use, in which friction force between the loading module and ground surface can be reduced to less than 1/1000 through the air supplying process in principle. However, gap and uneven on the ground surface will be affected as obstacle to its movement, so that more smoothly processed surface, just like a factory, should be more practical for this system. Furthermore, circular surface of drift tunnel may also be difficulty to this method. Through these considerations, component performance must be tested to evaluate the applicability of air pallet and air jack to the drift condition with uneven surface and circular surface with heavy load capacity. In our study, such an evaluation will be done in our performance of Phase III.

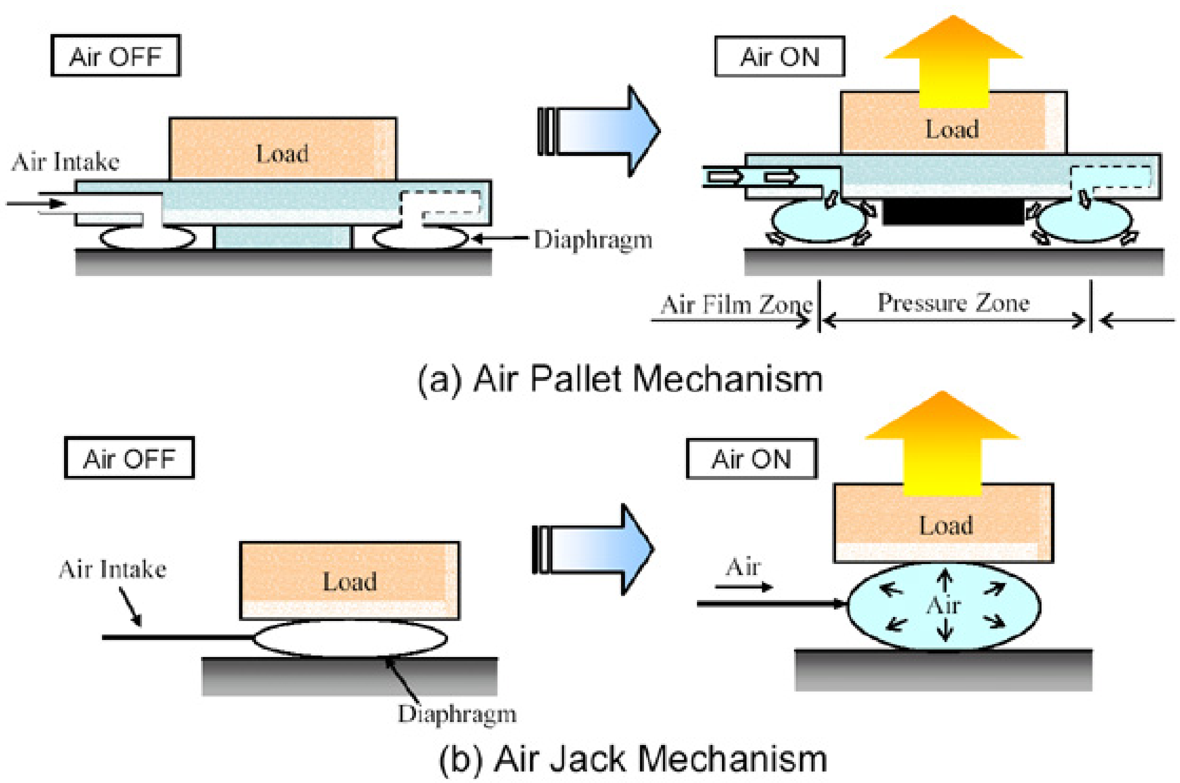



Fig. 4 Principle of air pallet and air jack for pre-assembled package

## OTHER TECHNOLOGIES

Besides the above two examinations, the following studies are carrying out for another remote handling concepts, One of them is an in-situ compaction technique of bentonite powder at vertical disposal pit, which has an advantage of no necessity to transport brittle bentonite block in repository tunnel. Through near full-scale in-situ compaction test, the compaction performance was confirmed as a compacted bentonite with more than 1.6Mg/m$^3$ of dry density could be obtained under compaction energy of 0.15Ec per impact (Ec : Compactive Effort(Standard Proctor), 1Ec=5.51x10$^2$ kJ/m$^3$) to the bentonite powder. Along to this dynamic test, numerical analysis method of destructive evaluation to host rock and waste package was developed with concerning an effect and damage on host rock and waste package caused by impact energy, and a threshold energy of compaction work coincide with geological formation properties were examined.

Bentonite pellet filling technique was also evaluated for its manufacturability, thermal conductivity, water permeability, gap-filling technique, etc, for four (4) types of bentonite, granulate(crushed ore), tablet , chunk(crushed formed block) and ball (highly compacted bentonite ball). Our results showed that bentonite pellet filled buffer material has sufficient water permeability even if relatively low dry density, however has less than adequate thermal conductivity as a buffer material, so that some improvement to the pellet should be necessary was suggested.

## CONCLUSION

In this paper, R&D results of remote handling and remote emplacement technology for HLW repository operation were introduced and discussed with mainly focused on two basic concepts of bentonite block and pre-assembled package. For the bentonite block concept, block manufacturing techniques for full-circle block and 1/8-divided block, block remote handling technique by vacuum suction cup, and block protection technique against degradation process under repository atmospheric conditions were examined and discussed. And at least such manufacturing, remote handling and remote operation technologies were suggested that they can be applied to vertical emplacement concept. And for the pre-assembled package concept, remote operation system combined with air pallet, air jack and crawler was recommended for the horizontal emplacement concept, and an integrated system operation technology was discussed. Besides these examinations, another candidate remote operation technologies were also surveyed and discussed.
Through these studies, eventually more flexible technical options, which can prove the technical feasibility of remote handling and remote emplacement for the waste package and the buffer material at HLW repository, and also which comprehend more variety potential techniques for both basic repository concepts of vertical and horizontal emplacement, shall be completed in the end of next fiscal year of 2004.

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