**Technical Paper**

https://doi.org/10.7733/jnfcwt.2024.021

# Conceptual Designs and Evaluation of the Treatment Process of Square and Cylindrical Concrete Re-Package Drums

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(Received June 3, 2024 / Revised June 11, 2024 / Approved June 17, 2024)

After the permanent shut down of Kori Unit 1, various decommissioning activities will be implemented, including decontamination, segmentation, waste management, and site restoration. During the decommissioning period, waste management is among the most important activities to ensure that the process proceeds smoothly and within the expected timeframe. Furthermore, the radioactive waste generated during the operation should be sent to a disposal facility to complete the decommissioning project. Square and cylindrical concrete re-package drums were generated during the 1980s and 1990s. The square, containing boron concentrates, and cylindrical, containing spent resin, concrete re-package drums have been stored in a radioactive waste storage building. Homogeneous radioactive waste, including boron concentrates, spent resin, and sludge, should be solidified or packaged in high-integrity containers (HICs). This study investigates the sequential segmentation process for the separation of contaminated and non-contaminated regions, the re-packaging process of segmented or crushed cement-solidified boron concentrate, and re-packaging in HICs. The conceptual design evaluates the re-packaging plan for the segmented and crushed cement-solidified waste using HICs, which is acceptable in a disposal facility, and the quantity of generated HICs from the treatment process.

Keywords: Boron concentrates, Spent resin, Large concrete drum, High-integrity container, Low level waste

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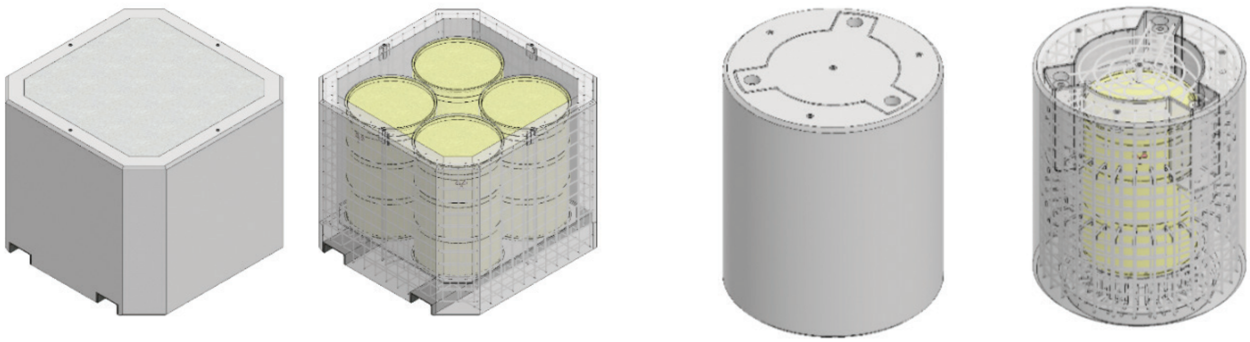


(a) (b)

Fig. 1. Schematic figure for (a) square concrete re-package drums and (b) cylindrical re-package drums.

## 1. Introduction

Various types of solid waste are generated during nuclear power plant (NPP) operation, including dry active waste (DAW), boron concentrates, spent resin, and spent filters [1-3]. DAW is generally compacted in 200 L drums and disposed of in a disposal facility. Boron concentrates are a result of evaporation of liquid waste from the primary circuit [4]. Diverse treatment technologies have been applied to boron concentrates in Korea, such as cement solidification, paraffin solidification, and polymer solidification [5-7]. Currently, boron concentrates are treated using a concentrated waste drying system (CWDS) and stored in NPPs. In accordance with the requirements for a high-integrity container (HIC), it is expected that low-level and very-low level boron concentrates will be packaged in 860 L polymer concrete high-integrity containers (PC-HIC) and disposed in disposal facility [8].

Homogeneous radioactive waste, including boron concentrates, spent resin, and sludge, should be solidified or packaged in HIC [9]. The waste acceptance criteria (WAC) of the Korean radioactive waste agency (KORAD) disposal facility defines the required characteristics of the solidified form in terms of compressive strength, radiation exposure stability, thermal cycle stability, and sufficient leachability index [9, 10]. The measurement results of previous characteristics should be identified clearly to satisfy the WAC. General requirements should also be satisfied, such as identification of radioactive nuclides in the waste, free-standing water content, and surface dose rate.

Kori Unit 1 was permanently shut down on June 18, 2017. After an expected transient period, decommissioning processes will be implemented. The primary decommissioning activities are decontamination, segmentation, waste management, and site restoration [11]. During the decommissioning period, waste management is one of the most important activities to ensure that the process proceeds smoothly and within the expected timeframe. In addition, the treatment of long-term temporary storage radioactive waste is important for safe operation of NPPs.

Square and cylindrical concrete re-package drums were generated during the 1980s and 1990s. These drums have been stored in a radioactive waste storage building. They have inner drums that have been re-packaged into steel reinforced concrete re-package drums, as shown in Fig. 1. It is expected that the primary purposes of the re-packaging process in the 1980s and 1990s were to reinforce the safety of inner waste, reduce worker radiation exposure for long-term storage, and improve radioactive waste management efficiency.

In this paper, the treatment process of square and cylindrical concrete re-package drums is studied, including the conceptual design of shielding house preparation, pre-treatment, and HIC packaging of square and cylindrical concrete re-package drums, to satisfy the WAC.

## 2. General Description of Square and Cylindrical Concrete Re-Package Drums

### 2.1 Square Concrete Re-Package Drums

Square concrete re-package drums were produced in the 1980s and 1990s and stored in a radioactive waste storage building in the NPP site.

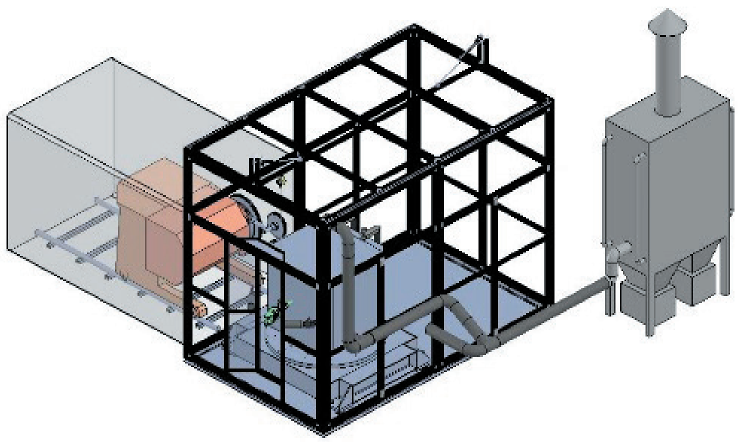
A square concrete re-package drum contains 4 boron concentrate cement-solidified inner drums. According to documents, the inner drums were solidified using cement before the introduction of the concentrated waste drying system (CWDS) while they are currently treated using CWDS and stored in 200 L drums. It was found that 3 types of solidification processes were adopted for the solidification of boron concentrates: in-situ injection, in-drum cement solidification, and out-drum cement solidification [12]. In-situ injection is the process of injecting boron concentrates using injection pipes into a 200 L drum filled with cement solidification material in advance. In-drum cement solidification is the process of filling cement and boron concentrates into 200 L drums, stirring them, and then curing them. In this process, there is a possibility of producing a non-homogeneous solidified form, depending on the stirring method. Consequently, there is a possibility of local agglomeration of free-standing water. Out-drum cement solidification is the process of filling pre-treated solidified materials in 200 L drums. The pre-treated solidified material is a mixture of cement and boron concentrates with optimal composition. Out-drum cement solidification produces a homogeneous solidified form and decreases the free-standing water. However, there is a possibility that a small amount of free-standing water may aggregate on the outer surface of the solidified form. All of the mentioned processes have the potential to generate free-standing water in the drums, and there is a possibility that moisture may coagulate during long-term storage. It is also speculated that the free-standing water may potentially be removed by evaporation or absorption into a solidification medium, but it has the potential to cause corrosion and damage in some drums.

### 2.2 Cylindrical Concrete Re-Package Drums

Cylindrical concrete re-package drums were produced in the 1990s and stored in a radioactive waste storage building in the NPP site. The inner drums contain spent resin. It is speculated that most of them were simply dewatered and dried, but some of them are thought to have been solidified using the out-drum process. Prior to introduction of the waste spent resin drying system (SRDS), spent resin was generally filled into drums in a slurry form and subjected to dewatering and natural drying while they are currently treated using SRDS and stored in HICs. According to process book records, it is speculated that free-standing water does not exist inside the inner drum. However, there is a possibility that moisture contained inside the spent resin could have escaped during long-term storage and leaked into the inner surface of the drums. It is expected that the generated moisture might have been removed by evaporation or absorption into the concrete lining. It that case, the spent resin would be partially stuck due to the free-standing water.

## 3. Result and Discussion

The treatment process to satisfy the WAC for square and cylindrical concrete re-package drums consists of pre-treatment and re-packaging processes. Since these involve inner drums being re-packaged into steel reinforced concrete re-package containers, the inner drum should be disposed in a disposal facility or free-released. For implementation of the



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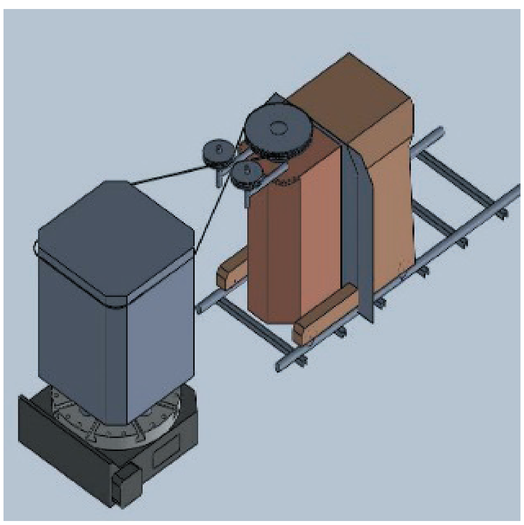

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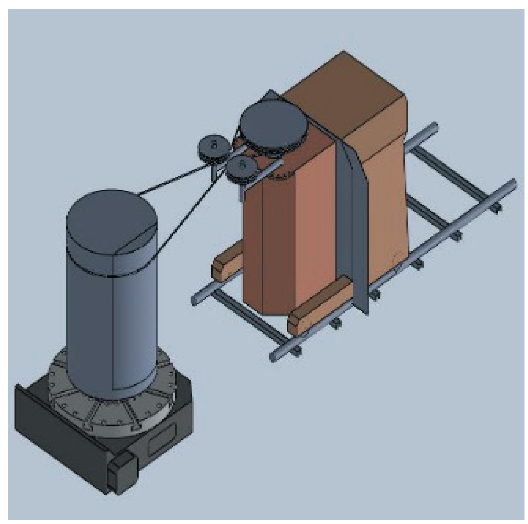


(c)

Fig. 2. Conceptual design for (a) shielding house and equipment and top region segmentation of (b) square, and (c) cylindrical concrete re-package drums.

clearance process, a detailed characterization of the radioactive waste and evaluation of radiation exposure is necessary. However, it is unlikely that the outer steel reinforced concrete re-package container is contaminated.

### 3.1 Pre-Treatment of Square and Cylindrical Concrete Re-Package Drums

Conceptual design of a shielding house is conducted for safe treatment of square and cylindrical concrete re-package drums, as shown in Fig. 2. Various processes will be implemented in the shielding house, including pre-treatment, separation of inner drums, and HIC repackaging.

The shielding house, consisting of a wire saw, chipping tool, turnable table, local ventilation system, and dust separation tent, enables the remote process and results in the reduction of radiation exposure. The dry cutting method is installed to offer precise segmentation and reduce the generation of liquid radioactive waste. The

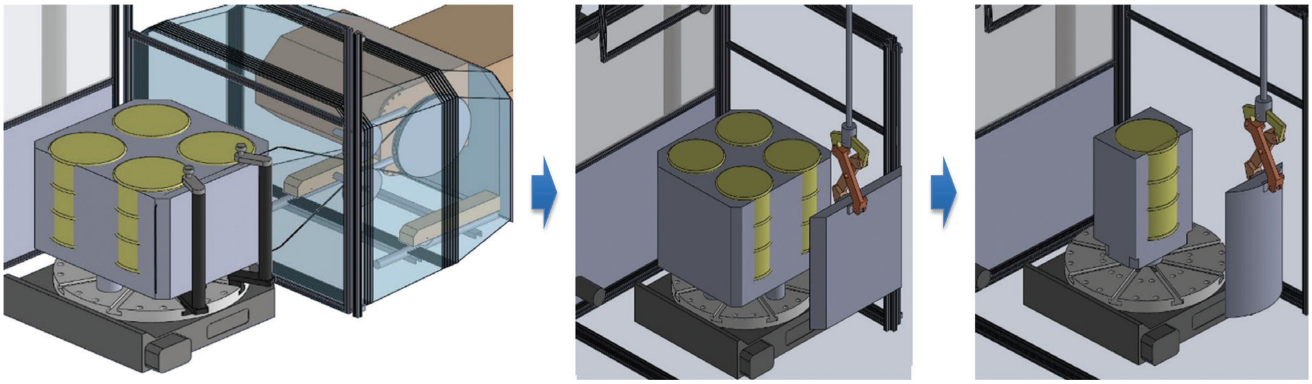
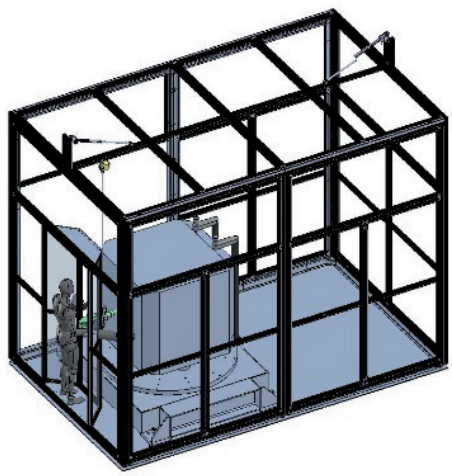


Fig. 3. Conceptual design for the segmentation process of square concrete re-package drums.



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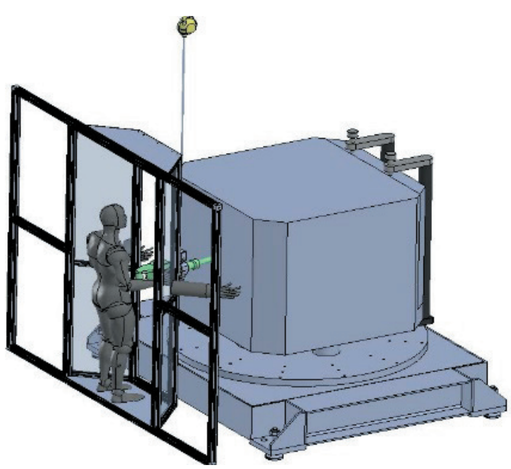

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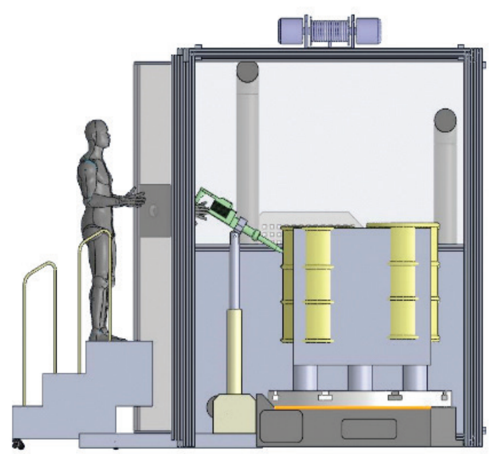

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Fig. 4. Conceptual design for the chipping process: (a) worker, target, chipping equipment preparation (b) arrangement of worker and equipment, and (c) chipping process of segmented inner drum pieces.

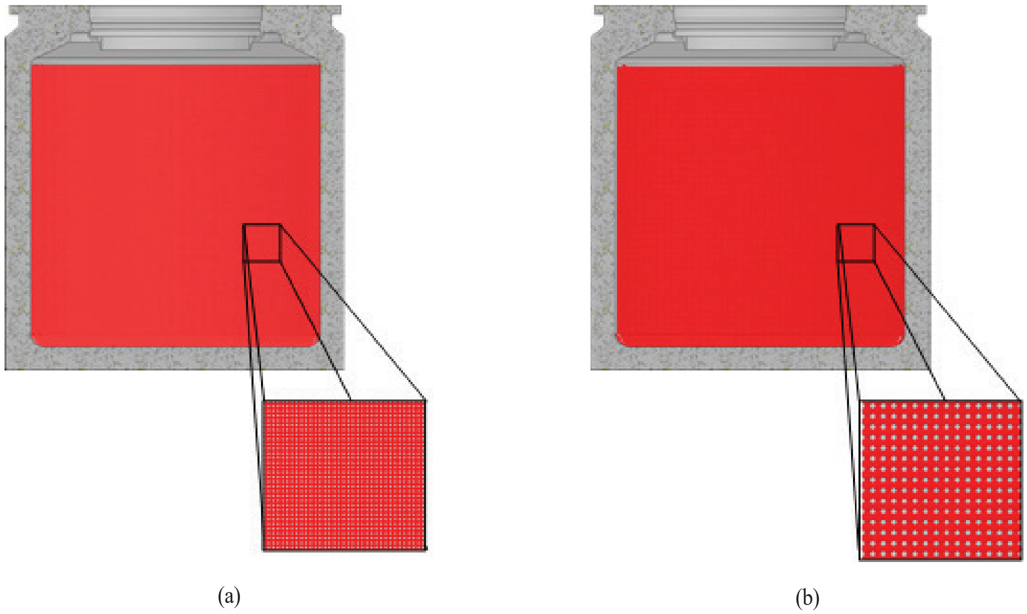


Fig. 5. Schematic images of (a) 1 mm diameter and (b) 10 mm diameter crushed boron concentrate solidified form packaged in 860 L PC-HIC.

local ventilation system consists of a HEPA filter, cartridge filter, and dust hopper. It offers effective separation of fine particulates and prevents secondary contamination. The large concrete drums are placed in the shielding house via its openable upper part. The transparent window and internal monitoring device enables effective management of the pre-treatment process and improves process accuracy. The rail-based approach and fine roller system also enhances precision of the segmentation process and transportation.

Sequential segmentation to lateral parts of the square concrete re-package drums separates the contaminated and non-contaminated regions, as shown in Fig. 3. The turnable offers sufficient integrity to support massive large concrete re-package drums. The outer fixing tool supports the lateral segments. The segments are transported using a gripper and sent to a surface dose rate measurement unit.

Chipping equipment offers effective separation of residual grouting material, as shown in Fig. 4. After segmentation of lateral parts, the chipping process follows to remove the attached grouting materials on the inner surface of the 200 L drums. The chipping equipment provides mechanical vibration to the drum surface and effectively removes attached materials. During the chipping process, a protective package is placed to separate coarse and fine particulates from equipment and thus prevent cross-contamination.

### 3.2 Packaging of Radioactive Waste Inner Drums in HIC

According to the waste acceptance criteria (WAC) of KORAD, boron concentrates and spent resin should be solidified with adequate material or packaged in an approved HIC. It is expected that cutting and/or crushing of solidified boron concentrates and re-packaging in HIC will be a reasonable process that satisfies the WAC.

The conceptual design of the crushing and re-packaging process was investigated, as shown in Fig. 5. To evaluate the applicability of the crushing process of the fabricated cement-solidified form, the crushing process was applied to a mock-up of the cement-solidified boron concentrate using

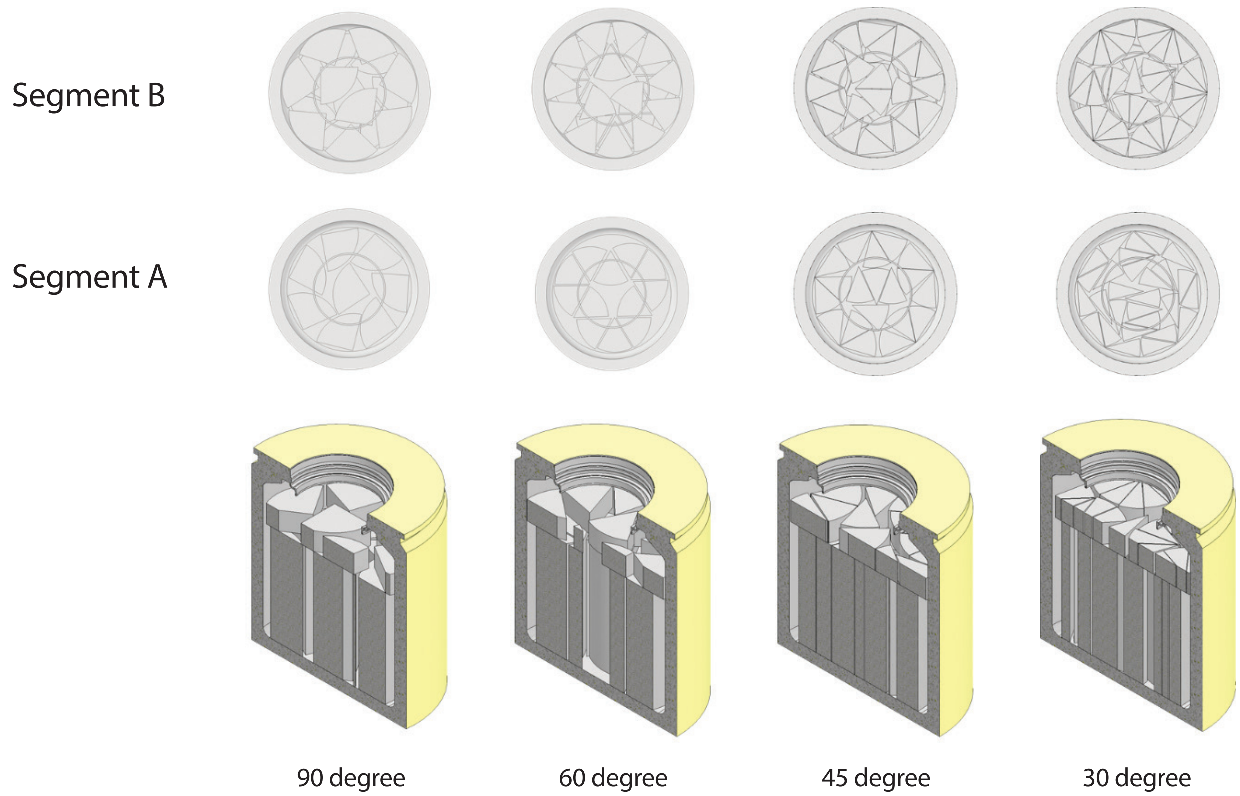


Fig. 6. Conceptual design for 860 L PC-HIC repackaging from segmented boron concentrate solidified form: Cutting angles of 90 degrees, 60 degrees, 45 degrees, and 30 degrees.

a jaw/blade crusher. As shown in Fig. 5, it was found that crushed waste cement-solidified powder with a diameter of 10 mm or 1 mm was produced effectively depending on each process condition. The WAC states that the dispersible waste, radioactive waste containing particulates with a diameter of 0.01 mm or less and accounting for more than 1% of the weight of the waste, or that particulates with a diameter of 0.2 mm or less and accounting for more than 15% of the weight of the waste, should be properly treated to be non-dispersible [9]. Considering the particulate diameter and filling ratio, the feasibility study of their packaging in an HIC and disposal safety was followed. The filling ratio of 95% and crushing diameter of 10 mm and 1 mm were considered in this conceptual design. The generic vacancy percentages of 10 mm and 1 mm were 26 and 40%, respectively [13, 14]. Since the diameter of particulates related to the vacancy, the actual quantity of required packages could vary with respect to process optimization and its accuracy. The fill ratio of 860 L PC-HIC was assumed to be 95% and the crushing diameter of the inner solidified drums was 10 mm and 1 mm. The conceptual design indicated that each 860 L PC-HIC had the potential to contain ~2.58 ea (200 L drum) of 10 mm and ~3.18 ea (200 L drum) of 1 mm diameter crushed cement-solidified form.

The conceptual design of the cutting and re-packaging process was investigated, as shown in Fig. 6. A process for packaging the 860 L polymer concrete high-integrity container (PC-HIC) was developed. The 860 L PC-HIC was developed and approved for packaging and disposal of low-level and very low-level radioactive spent resin and boron concentrates. The cutting angles of cement-solidified boron concentrates were 30 degrees, 45 degrees, 60 degrees, and

Table 1. Estimated segment quantity and re-packaging ratio according to treatment process conditions

| Category I | Category II | Re-packaging segments[1)] | | Ratio[2)] |
|---|---|---|---|---|
| | | Seg_A | Seg_B | |
| Segmentation | 90 degree | 8 | 9 | 2.45 |
| | 60 degree | 12 | 14 | 2.47 |
| | 45 degree | 19 | 23 | 2.95 |
| | 30 degree | 28 | 37 | 2.95 |
| Crushing | 10 mm | - | - | 2.58 |
| | 1 mm | - | - | 3.18 |

1) Quantity of segments re-packaged in 860 L PC-HIC
2) Ratio of cement solidified form in 200 L drum and 860 L PC-HIC from optimized re-packaging plan

90 degrees. The assumed height of cement-solidified boron concentrates in a 200 L drum was ~745 mm, considering a filling ratio of 90%, as shown in Fig. 6. Since the assumed height of 860 L PC-HIC was ~1,000 mm, additional vertical cutting was also considered in order to increase packaging efficiency. The cement-solidified boron concentrates in 200 L were vertically and horizontally segmented in this conceptual study.

The vertical cutting generated two different parts: Seg_A and Seg_B. The respective heights of Seg_A and Seg_B were ~745 and ~139 mm. The wire saw segmentation kerf width was roughly 12.5 mm. Horizontal cutting was applied to Seg_A and Seg_B with the desired angles. In the case of cutting 90-degree angles, 8 Seg_A and 9 Seg_B were re-packaged in 860 L PC-HIC. It was found that 860 L PC-HIC had the potential to contain ~2.45 ea (200 L drum) of cement-solidified form (90-degree segmented). In the case of cutting 60-degree angles, 12 Seg_A and 14 Seg_B were re-packaged in 860 L PC-HIC. It was found that 860 L PC-HIC had the potential to contain ~2.47 ea (200 L drum) of cement-solidified form (60-degree segmented). In the case of cutting 45-degree angles, 19 Seg_A and 23 Seg_B were re-packaged in 860 L PC-HIC. It was found that 860 L PC-HIC had the potential to contain ~2.95 ea (200 L drum) of cement-solidified form (45-degree segmented). In the case of cutting 30-degree angles, 28 Seg_A and 37 Seg_B were re-packaged in 860 L PC-HIC. It was found that 860 L PC-HIC had the potential to contain ~2.95 ea (200 L drum) of cement-solidified form (30-degree segmented).

The re-packaging plan with 860 L PC-HIC generating from segmented and/or crushed cement-solidified form is summarized in Table 1. In order to ensure process efficiency and reduce worker exposure, a process of guiding and packaging using a jig was suggested. The conceptual design indicated that a cutting angle of 45 degrees would generate the minimum quantity of 860 L PC-HIC.

Considering cutting line tolerance and loading efficiency of the segmentation process in practical applications, the occurrence of some empty space between segments and packages is inevitable. It seems that a process of filling crushed cement-solidified boron concentrates or secondary dust into the gap between segments and packages will be considered for practical application to increase the filling ratio and efficiency.

## 4. Conclusion

Square and cylindrical concrete re-package drums were generated during the 1980s and 1990s. The generated square, containing boron concentrates, and cylindrical, containing spent resin, concrete re-package drums have been stored in a radioactive waste storage building. The conceptual design of a shielding house, segmentation process of square and cylindrical re-package drums, and re-packaging of crushed and/or segmented inner cement-solidified forms was conducted. A crushing diameter of 10 mm and 1 mm was considered, and it was found that 860 L PC-HIC could contain 2.58 ea of 10 mm crushed and 3.18 ea of 1 mm crushed cement-solidified form in a 200 L drum. Segmentation angles of 90 degrees, 60 degrees, 45 degrees, and 30 degrees were investigated, and it was found that 860 L PC-HIC could contain 2.45 ea of 90-degree segmented, 2.47 ea of 60-degree segmented, 2.95 ea of 45-degree segmented, and 2.95 ea of 30-degree segmented cement-solidified form in a 200 L drum.

## Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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