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Development of Ductile Cast Iron Packaging Container for Low- and Intermediate-Level Radioactive Wastes

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1. Introduction

As of the end of December 2020, low- and intermediate-level radioactive waste (LILW) generated in Korea is a total of 149,077 drums based on 200L drums, of which 27,735 drums are being managed by KORAD (Korea Radioactive Waste Agency), the radioactive waste management agency, and 121,342 drums are being stored by waste generators (mainly Korea Hydro & Nuclear Power) in 12 temporary storage facilities within NPP site (see Table 1). Looking at the future generation of radioactive waste, the total is 738,000 drums based on 200L drums by 2095 when NPP decommissioning is completed (see Table 2).

Table 1 Status of radioactive waste generation (source: KORAD)

Management Agency (KORAD)			Waste Generators			
Wolsong Disposal Center	Daejeon RI Mgmt. Facility	Sub total	KHNP	KAERI	KNF	Sub total
27,339	396	27,735	27,735	90,040	9,270	121,342

Accordingly, the government is reviewing the near surface disposal method as the second-stage disposal method as long-term disposal scenarios for LILW after the first-stage silo disposal method, and preparing a facility with a total capacity of 125,000 drums [1].

The waste packaging containers to be used in this near surface disposal facility are thought to be drums. In the case of actual cylindrical drums, however, it is very difficult to directly stack them. Therefore KORAD is considering a plan to construct concrete floor for each layer of the drums in order to stack the drums [1]. This plan not only requires additional concrete pouring work, but also causes a loss in stacking stories.

In this study, a box-type LILW packaging container is developed to resolve the difficulties. The box-type container can not only increase the volume inside the container for the improved storage efficiency, but also allow the container to be directly stacked without concrete floors. In addition, the box-type container is made by a one-body casting of ductile cast iron without any welding, so that the structural integrity is greatly improved.

Table 2 Prospects for generating radioactive waste (until 2095) (source: KORAD)

	NPP			Non-NPP	Total
	Operating	Decomm.	Subtotal		
Intermediate-Level	7,393	18,274	25,667	2,554	28,767
	4.4%	4.2%	4.3%	2.1%	3.9%
Low-Level	139,543	124,823	264,366	69,555	333,921
	77.4%	28.7%	43.0%	58.5%	45.5%
Very Low-Level	32,788	291,903	324,691	46,790	371,481
	18.2%	67.1	52.8%	39.4%	50.6%
Total	180,270	435,000	615,270	118,899	734,169
	100%	100%	100%	100%	100%

2. Development of box-type ductile cast iron packaging containers

This study aims to develop a box-type ductile cast iron packaging container for solid LILW that improves packaging efficiency by more than 20% compared to a 200L drum (see Table 3 attached).

2.1. Structural design of container

As shown in Fig. 1, the container in this study has a box-shaped structure with an open top, and the outer dimensions are designed to be the same as those of a 200L cylindrical drum. The body is a one-body casting and the material is ductile cast iron. The thickness of the container is 20mm, the lid is fastened to the body with bolts, and an O-ring is installed for sealing. In addition, a hole like ISO-1161 design is prepared in the upper shoulder of the container to accept lifting lugs when handling the container and bottom legs of the upper container to be stacked. The inside of the container has reinforcements at eight corner to minimize deformation when dropped.

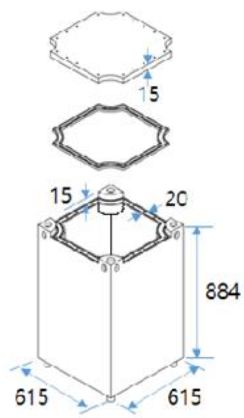


Fig. 1 Packaging container shape

2.2. Container material development

In this study, a material of ductile cast iron [2] was developed to satisfy the design requirements for radioactive waste packaging containers, such as the structural integrity, corrosion resistance, and impact resistance. As the performance requirements, we aimed for world-class quality with tensile strength of 390MPa or more, elongation of 18% or more, spheroidalization rate of 90%, ferrite rate of 95%, etc., and the test results showed that all requirements were satisfied (see Fig. 2 and 3).

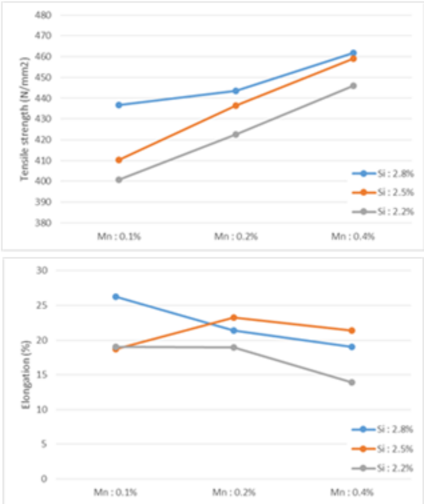


Fig. 2 Changes in tensile strength and elongation according to elemental composition

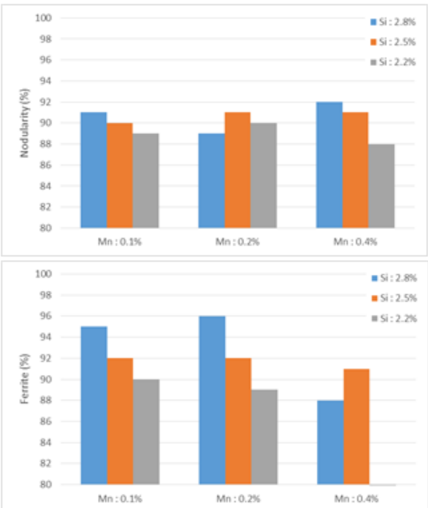
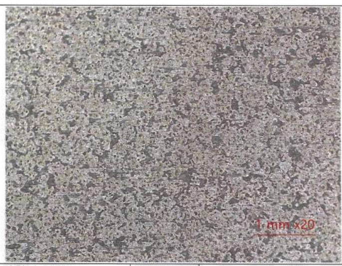


Fig. 3 Changes in spheroidalization rate and ferrite rate according to elemental composition

The durability of the developed ductile cast iron packaging container was confirmed by a corrosion test [2]. When accelerated corrosion was performed in a 3.5% NaCl aqueous solution at 22°C for 7 days, the corrosion rate was found to be 14.3mdd(mg/dm^2·days). Compared to the corrosion rate of 19.1mdd of the existing carbon steel base material or 20.6mdd of the welding material, the corrosion resistance of the developed ductile cast iron was excellent (see Fig. 4). It can be said that the corrosion life of the packaging container with a thickness of 20 mm was found to be more than 300 years.

In addition, the impact resistance of the developed packaging container was confirmed by the Charpy impact test (standard: KS B0810-2003).



시험 시료	시험편 크기, mm			총 면적 (dm^2)	질량			¹mdd
	두께	폭	길이		시험 전 g	시험 후 g	질량 손실 mg	
Y블록 시험편	6.04	24.45	50.02	0.33	51.278 3	51.244 9	33.4	14.3

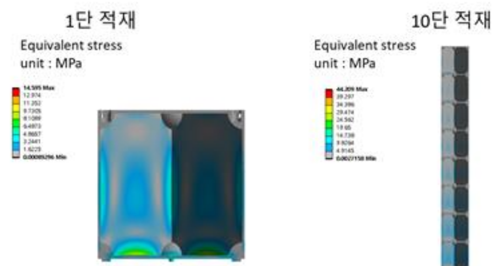
- 용액 : NaCl + H_2O (3.5 % NaCl 수용액), 시간 (h) : 168 (7일), 배율 : × 20, 온도 (℃) : 22
- 각주 1. = 질량 손실(mg) / (dm^2 × 시간 (days))

Fig. 4 Corrosion test result

2.3. Evaluation of structural integrity of containers

The cylindrical drum currently used is made of steel plate by rolling and welding. Thus structural integrity degradation and corrosion resistance deterioration could be occurred due to the existence of weldments. The ductile cast iron packaging container developed in this study is made of one-body casting. Since there is no weldments, the problem above mentioned is fundamentally blocked.

As for the performance requirements of this LILW container, it must withstand an internal pressure of 2 atm. and maintain its structural integrity even when loaded in 10 stories. As a result of the structural integrity evaluation, as shown in Fig. 5, the maximum stress calculated was 44.21MPa even when loaded in 10 stories. Compared to the yield strength (250MPa) for the material, the safety factor is 5.7 meaning no problem in structural integrity. In addition, there was no leakage and no deformation of the container in the drop test [5] from a height of 1.2m (see Fig. 6).



	1단	10단
최대응력(MPa)	14.6	44.21

Fig. 5 Stress analysis result

Fig. 6 Drop test

2.4. Shielding performance of container

It is required to limit the dose rate outside the packaging container to protect workers in packaging LILW containers [3]. The dose rate limit on the surface is 2mSv/h or less, and the dose rate at 1m from the surface is 0.1mSv/h or less. Table 4 (attached) shows the equivalent evaluation of the amount of radiation source in the container that satisfies this with a Co-60 source [4].

2.5. How to handle containers

The container is lifted by a crane with the eye bolts fastened to the ISO-1161 holes at the upper shoulder of the container as shown in Fig. 7. When stacked with the leg fitted into the holes of lower container, the eye bolts are removed.

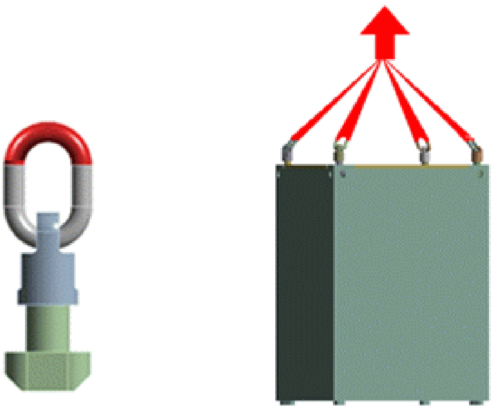


Fig. 7 Container lifting method

2.6. Economic review of containers

The box-type container developed in this study has an internal volume that is about 24% larger than that of a 200L cylindrical drum. In addition, the box type ductile cast iron container can be directly stacked on the top of another container, while the cylindrical drum cannot. Compared to drums that must need concrete floor (thickness of 100 mm) for stacking, one more story can be stacked when considering the facility space (10m high) of the currently planned near surface disposal site. It is possible to store LILW much more economically (see Table 5).

Table 5 Stacking Economics in Near Surface Storage Facility

	Drum height (884mm) Concrete floor (100mm)	Box height (884mm)
Height of storage facility (10m)	884×9 story+100×8 floors =8756mm	884×10 story =8840mm

3. Conclusion

The characteristics of the LILW packaging containers developed in this study are as follows.

- As made in a box type, the internal storage volume is improved by more than 20% compared to a cylindrical drum.
- As made in one-body of ductile cast iron, structural integrity is improved by eliminating weldment, and corrosion resistance and impact resistance are equivalent to world-class standards.
- Radiation shielding performance can also satisfy the limits.
- When stacking in a near surface disposal facility, stacking economics is excellent as the containers can be directly stacked without constructing any concrete floor.

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[2] ASTM G3-72(2004): Standard Practice for Laboratory Immersion Corrosion Testing of Metals

[3] Nuclear Safety and Security Commission Rules, 'Rules on Technical Standards for Radiation Safety Management,' etc.

[4] Radcore Co., Ltd., RC-LSC-001 Low- and Intermediate-Level Waste Packaging Container Dose Evaluation, 2021.6

[5] Bukuk Metal Co., Ltd., Free fall test method for packaging prototypes, 2021.10

Acknowledgement

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Table 3 Comparison between the box-type structure of this study and the current drum-type packaging

Shape	Box Type Container				Drum Type Container (200L)
Outer Size(mm)	615×615×884				Φ 615×884
Material	Ductile Cast Iron (Spheroidal cast iron)				Steel
Loadability	✓ As it is a box type, there is no need for a secondary concrete disposal container. ✓ Box can be directly stacked without constructing any concrete floors.				✓ For silo disposal, 16 drums are loaded in a secondary concrete disposal container. ✓ For near surface disposal, concrete floor is needed for stacking of drums.
Resistence to earthquake	By designing the ISO-1611 design on the box shoulder, it is possible to support each other between containers and improve earthquake resistance.				Cylindrical drums cannot support each other in the event of an earthquake.
Internal volume	Thickness (mm)	Weight (kg)	Internal volume (L)	Volume improve-ment (%)	211(L)
	10	208	288	36.4	
	15	307	275	30.3	
	20	404	262	24.1	

Table 4 Results of dose evaluation according to packaging container thickness

용기 두께	5mm		10mm		15mm		20mm	
잡고체 밀도 (g/cm^3)	0.087	1.6735	0.087	1.6735	0.087	1.6735	0.087	1.6735
용기내부 부피 (cm^3)	3.81E+05	3.81E+05	3.65E+05	3.65E+05	3.50E+05	3.50E+05	3.35E+05	3.35E+05
표면선량 (mSv/hr/Bq)	1.46E-09	5.45E-10	1.27E-09	4.51E-10	1.09E-09	3.77E-10	9.42E-10	3.19E-10
1m 선량 (mSv/hr/Bq)	1.74E-10	6.12E-11	1.58E-10	5.40E-11	1.42E-10	4.75E-11	1.26E-10	4.17E-11
표면선량 기준 허용가능 Co-60 방사능 (Bq)	1.37E+09	3.67E+09	1.58E+09	4.43E+09	1.83E+09	5.30E+09	2.12E+09	6.27E+09
1m 선량 기준 허용가능 Co-60 방사능 (Bq)	5.74E+08	1.63E+09	6.32E+08	1.85E+09	7.06E+08	2.10E+09	7.96E+08	2.40E+09