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Bolt Breakage Incident for Low-Level Radioactive Waste Container（1）
—Investigation into Cause and Measures—

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Abstract

The Nuclear Fuel Transport Co., Ltd. (“NFT”) found that lid anchor bolts (“lid bolts”) on Low-Level Radioactive Waste (“LLW”) containers failed during inspection and/or maintenance. LLW transport was suspended temporarily to verify LLW container safety after this incident.

First, NFT went immediately to work to determine the cause and formulate measures to prevent any such recurrence. As a result, the cause was identified as “delayed fracture.” In addition, as for the recurrence prevention measures, we made the assessment that changing to a lower strength class of lid bolt would be effective. NFT resumed LLW transport using LLW containers for which recurrence prevention measures had been adopted.

Introduction

NFT owns over 3,000 LLW containers and has safely transported these for 25 years. An LLW container can be loaded with eight LLW drums (Fig.1). LLW is loaded into an LLW container, which is transported by the dedicated ship from a nuclear power station in Japan to Mutsu-Ogawara Port at Rokkasho Village. Then, it is transported by the LLW truck from the Mutsu-Ogawara Port to the disposal center. After the LLW is unloaded from the drum, the empty LLW container is returned to NFT’s LLW center where it is stored outside the center (Fig.2).

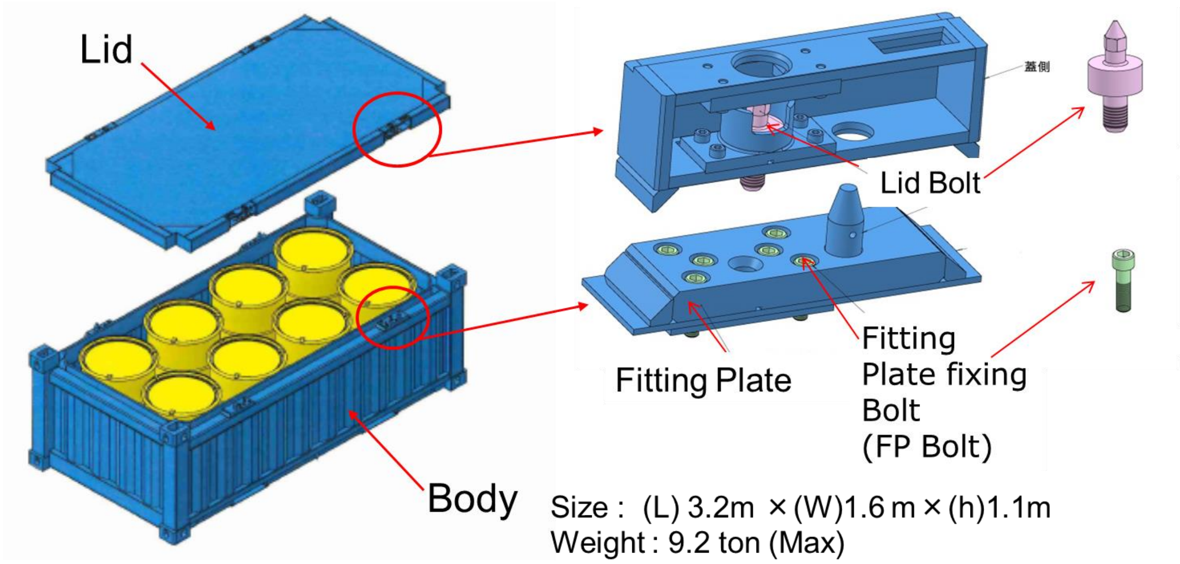

Fig.1 LLW container, fitting plate and lid bolts

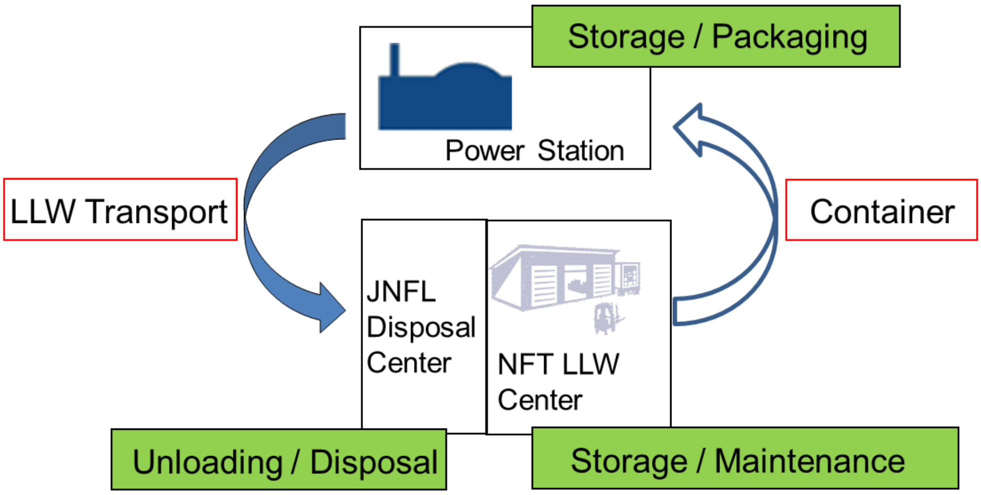

Fig.2 Cycle of LLW transport

Photo 1 shows a fractured lid bolt. A delayed fracture occurs without any sign under specific conditions. Accordingly, if such conditions are satisfied, all kinds of bolts may experience delayed fractures. Here, NFT presents a warning about delayed fractures and information about prevention measures.

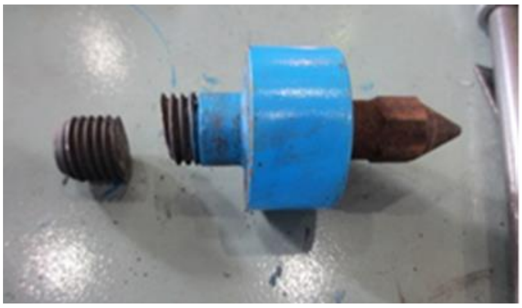

Photo 1 Fractured lid bolt

Lid Bolt Structure

The following is an overview of the lid bolt structure and conditions during transport and storage. Under normal use conditions, an excessive load is not placed on the lid bolts. However, when stored outside, water (ex. rainwater) can easily enter a tightened lid bolt.

1. Use conditions

   Lid bolts are stored tightened onto all LLW containers at a torque of 147N-m ± 20%. An LLW container is used over a cycle of approximately one year. However, there are also containers that are not used for transport, but stored outside for one to two years.

2. Storage environment

   In the case of outdoor storage, lid bolts are directly exposed to wind and rain (Photo 2). The arrows indicate the water intrusion route to a lid bolt.

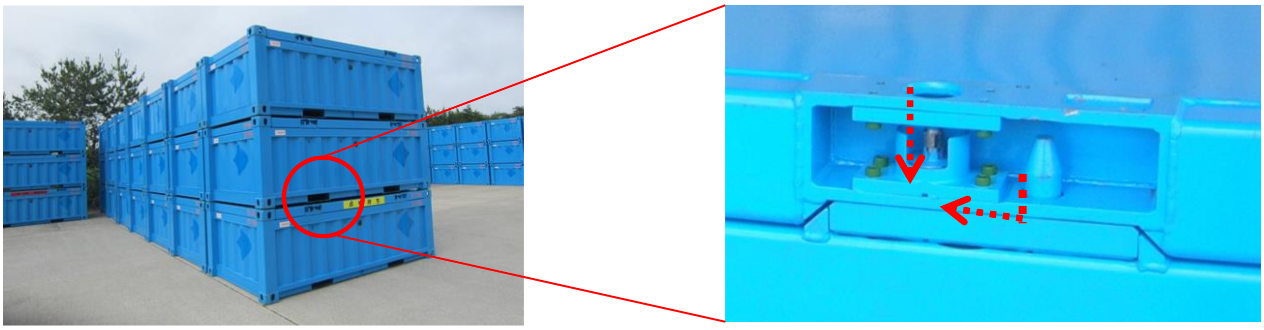

Photo 2　Transport containers stored outside at NFT LLW Center

3. Handling

A forklift and crane are used to move LLW containers. The corner posts are holded with the cell guides for transport by the dedicated ship. For LLW truck transport, the frame couples tightly to four mounting lugs on the bottom corners.

Bolt Breakage Incident for LLW Container

The first bolt breakage was conformed in February 2015. To date, a total of 16 fractured bolts have been confirmed. The characteristics of the containers on which bolts failed are as follows.

- Lid bolt strength class: 12.9 (equivalent tensile strength 1200MPa class).
- Lid bolts were tightened during transport/storage containers to the predetermined torque value.
- Some containers have never been used for transport.

Investigation into Cause

1. Fault tree analysis (FTA)

FTA of the lid bolt breakage was constructed using six factors: production, maintenance, operations, human factor, design and environment. The outcomes are shown in Table 1.

Table 1　Fault tree analysis results

Factor	Point of view	Affairs / situation	Outcome
Production	Manufacture, manufacturing lot	Passed inspection, no bias in the lot	N
Maintenance	Inspection, maintenance, repair	Performed as specified in manual	N
Operations	Handling, fitting, impact load, vibration during transport and handling	Torque value setting, no excessive load or vibration sustained	N
Human factors	During manufacture, storage and handling	Passed inspection, stored in a restricted access area	N
Design	Shape, material, corrosion resistance	Structure does not preclude contact with rainwater or other liquids, only strength class 12.9 bolts failed	Y

Environment	Outdoor storage, salt damage	Outdoor storage, structure does not preclude contact with rainwater or other liquids	Y

2. Fracture surface observation

We examined the fracture surface of 16 broken lid bolts by the electron microscope. 15 lid bolts had an intergranular fracture that showed embrittlement.

Identification into Cause

Design and environment were specified as the causes of the breakages. For this reason, FTA was performed that was specific to the fracture mode of the lid bolts. As a result, the breakage was identified as due to delayed fracture (Table 2).

Table 2 Fracture mode review results

Fracture mode	Occurrence factor	Bolt and container conditions	Outcome
Static fracture	①Excessive torque setting	①Continuous 147N-m ± 20% (during storage and transport)	N
	②Insufficient bolt strength	②Lid bolt is high-strength class (12.9)	N
Fatigue fracture	①Vibration	①Some containers have not been used for transport.	N
	②Fracture surface of the shell pattern	②Shell pattern was not confirmed	N
Low-temperature brittleness	①Environmental temperature and usable temperature of material	①Environmental temperature: -5 ℃ practicable temperature of material: -20℃	N
	②Impact load	②No impact damage to containers	N
Stress corrosion cracking	①Stress always applied	①Continuous 147N-m ± 20% (during storage and transport)	Y
	②Localized corrosion	②Ordinary rainwater does not result in stress corrosion cracking of carbon steel	N
Delayed fracture	①High-strength bolts	①Lid bolt used is high-strength class (12.9)	Y
	②Water infiltration, embrittlement	②Water enters the structure	Y
	③Load continually applied	③Continuous 147N-m ± 20% (during storage and transport)	Y

Review of Delayed Fracture Countermeasures

Delayed fracture is caused by a confluence of three elements (material strength, use environment and stress conditions). Accordingly, NFT measured the sensitivity to the amount of hydrogen in accordance with the strength class. From the results, we confirmed that the bolt breakage was caused by delayed fracture, and the effectiveness of the preventive measures (Fig.3). The strength class of the bolts was 12.9, which is close to the risky zone. Strength class 9.8 bolts are close to the safety zone and delayed fracture does not occur so easily. Therefore, it was concluded to be the adequate measure would be to lower the strength class of the material (12.9 ⇒ 9.8).

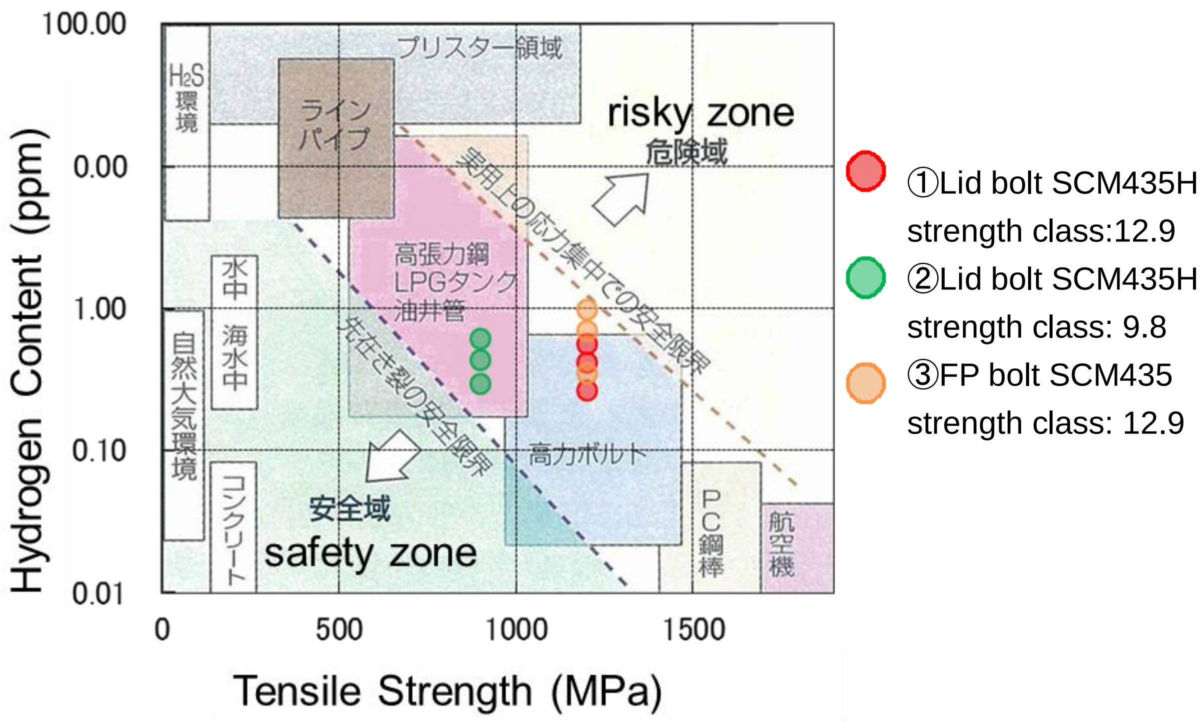

Fig.3 Plotted results of dissipative hydrogen content measurements (Plotted on references[3])

Recurrence Prevention Measures

From the above results, the opinions of the taskforce and literature investigation, NFT concluded that changing of intensity classification would be a sufficient countermeasure. We implemented the following improvement measure to prevent any recurrence of this breakage.

・Modification of lid bolt material

Tensile stress class 12.9 ⇒ 9.8

・Lateral implementation

High tensile materials used for lid tightening were changed to a lower stress class.

FP-bolt material tensile stress class: 12.9 ⇒ 9.8 (Fig 4)

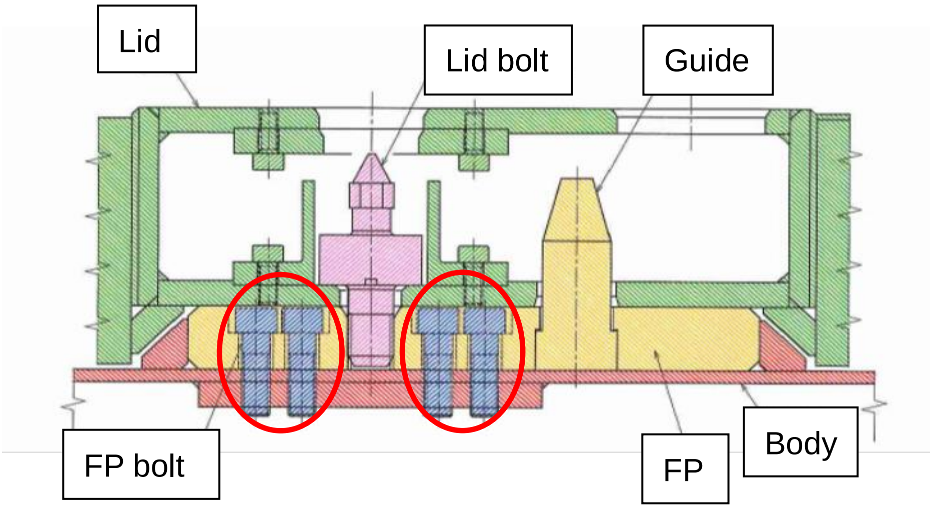

Fig 4 Overview of FP bolt

Conclusions

- ✓ Bolt breakages occurred due to “delayed fracture” which tends to happen to high-tension materials.
- ✓ NFT implemented the following improvement measures so that such breakages do not recur.
  - Modification of lid bolt material
    Tensile stress class 12.9 ⇒ 9.8
  - Lateral implementation
    FP- bolt material tensile stress class: 12.9 ⇒ 9.8
- ✓ NFT replaced the lid bolts and FP bolts at power plants and the LLW center in September 2015. We resumed transported using a transport vessel for which the measures were applied. No new bolts have failed, and the LLW containers have been safely transported.

References

(1) Japan Society of Steel Construction, “Guidebook for Assessing the Characteristics of Delayed Fracture in High-Strength Bolts.”
(2) Tanaka, Kazuaki, “Encyclopedia for Understanding the Fundamentals of the Latest Metals,” Shuwa System.
(3) Matsuyama, Shinsaku, “Delayed Fracture,” Nikkan Kogyo Shimbun (1989).