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MUTUAL IMPACT ASSESSMENT ON TRANSPORT AND STORAGE OF DUAL PURPOSE METAL CASK

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ABSTRACT

Spent fuel was assumed to be stored at away from reactor by dual purpose metal casks. These casks will be transported from nuclear power plants to a storage facility. After several tens of years these casks will be transported to a reprocessing plant. Under this scenario, mutual impact assessment of transport and storage of the cask were carried out. From nuclear power station to storage facility, casks with metal gaskets in the lids will receive mechanical vibration in transport. Influence of the mechanical vibration in transport on the metal gasket was experimentally investigated on the containment performance in storage. As the results, we found that required containment performance in storage was secured. During a long-term storage, the metal gasket will be subjected to a high temperature due to decay heat of spent fuel. This will cause creep deformation and corresponding relaxation of the gasket. The containment performance of the metal gasket was analyzed by a finite element method code (ABAQUS). As the results, we found that the required containment performance of the gaskets in transport was secured. For post-storage transportation, the integrity of the spent fuel in the metal casks should have been confirmed firstly at the time of installation into the metal casks. The spent fuel should have been properly installed in the metal casks and transported from the power plants to the storage facility. In the storage facility, there should have been no abnormality for the pressure between the cask lids, for the cask surface temperature, and no external force acted on the casks. Based on these conditions, we could evaluate that the metal casks can be safely transported after storage without opening the cask lids for visual inspection.

INTRODUCTION

Spent fuel was assumed to be stored at away from reactor by dual purpose metal cask. These casks will be transported from nuclear power plants to a storage facility. After several tens of years these casks will be transported to a reprocessing plant. From nuclear power station to storage facility, casks with metal gaskets in the lids will receive mechanical vibration in transport. Influence of the mechanical vibration in transport on the metal gasket has not been understood quantitatively. This study experimentally investigated on the containment performance in storage. As the results, we found that required containment performance in storage was secured. During a long-term storage, the metal gasket will be subjected to a high temperature due to decay heat of spent fuel. This will cause creep deformation and corresponding relaxation of the gasket. The containment performance of the metal gasket after storage has not been understood quantitatively. We analyzed the creep effect by a finite element method code (ABAQUS). As the results, we found that the required containment performance of the gaskets in transport was secured. For post-storage transportation, the dual purpose metal cask may not be open for visual inspection of the cask basket and spent fuel. With information from the records on inspection at nuclear power plant, during transportation from the power plant to the storage facility, and during storage, we could evaluate the integrity of the cask basket and spent fuel in the casks. Thus, without opening the casks, we could obtain the same information that would be obtained by visual inspection. These knowledges have been summarized in a book “Basis of Spent Nuclear Fuel Storage” published by CRIEPI[1).

INFLUENCE OF MECHANICAL VIBRATION IN TRANSPORT ON CONTAINMENT PERFORMANCE OF METAL GASKET IN STORAGE

Transport casks of spent nuclear fuel will receive mechanical vibration during transport. It has been known that the containment performance of metal gaskets is influenced by large external load or displacement. Quantitative influence of such vibration during transport on the containment performance of the metal gasket has not been known, but is crucial information particularly if the cask is stored as it is after the transport. The standard for safety design by Atomic Energy Society of Japan[2) stipulates that the dual purpose metal cask shall not lose its containment function for the successive storage by vibration and external force in the normal transport. The purpose of this section is to find experimentally the influence of mechanical vibration during transport of transport/storage cask with metal gasket on the performance during storage. For the experimental conditions, acceleration values measured in an actual sea transport of transport cask employed. More detailed information is found in the literature[3].

Experimental apparatus and specimen

In order to obtain a relationship between the amount of lateral sliding (displacement) of the lid and the leak rate, a 1/10-scale model of a lid structure of metal cask with a metal gasket of double O-ring type was fabricated and assembled as shown in Fig. 1. The gasket had a diameter of 10 mm and was coated with aluminum sheet. The scale model consists of three flanges bolted together and helium gas was installed in a groove of one of the outer flanges.

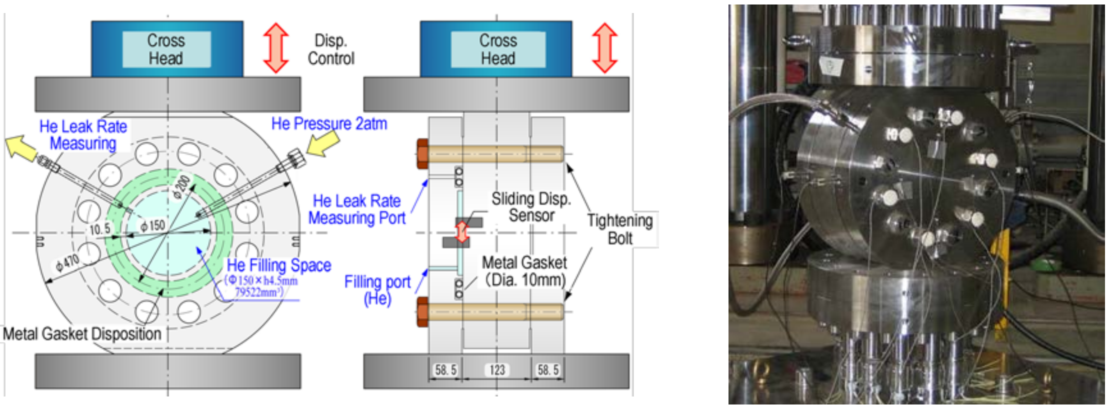


Fig. 1 Scale model (1/10) of a lid structure of metal cask with a metal gasket

Eddy current displacement sensors (accuracy of ±0.01 mm) were used to measure displacement of the flanges. Sliding load and relative displacements were applied to the middle flange using loading test equipment. In order to simulate the thermal ageing effect of the metal gasket due to the heat from spent fuel loaded inside the cask, the flanges with the metal gasket were heated for 20 hours at 180 ℃ inside an oven prior to the tests. The temperature and the time conditions were assumed to simulate the heat history of the gasket after spent fuel loading before transport, with the aid of Larson Miller Parameter equation.

Experimental conditions

Acceleration wave in transport was assumed by the time history of acceleration measured at a truunion supports of the spent fuel shipping cask transport frame as shown in Fig. 2[4]. For analysis, a dynamic analysis code LS-DYNA was employed for the dual purpose cask shown in Fig. 3 (storing 21 PWR spent fuel assemblies) designed by JNES[5]. Using the time history of the acceleration, we calculated the time history of a lateral sliding of the secondary lid. As the results, the maximum sliding displacement was found in the vicinity of the trunnion, of which the amplitude was approximately 0.014 mm at maximum.

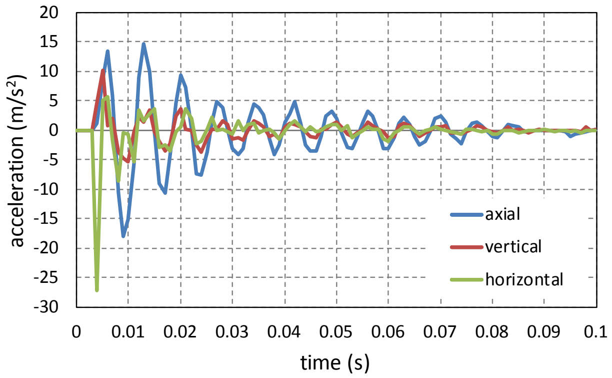


Fig. 2 Time history of acceleration measured at a trunnion supports of the cask transport frame

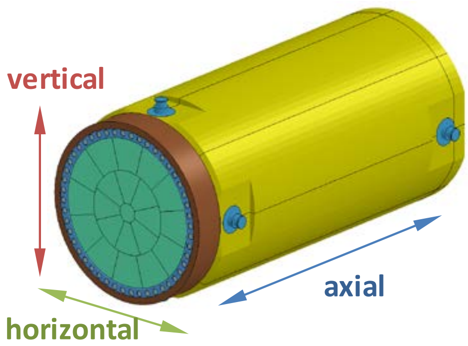


Fig. 3 Cask model for the analysis

<u>Experimental result</u>

The frequency of the cyclic displacement experiment was 0.125 Hz and the nominal displacement was ± 0.02 mm. Fig. 4 shows a representative result showing leak rate and displacement as a function of time. The initial leak rate was 1×10^{-10} Pam^3/sec. The leakage started when the radial displacement exceeded ± 0.022 mm and increased as the displacement increased. When the cyclic displacement stopped, the leak rate recovered until the initial leak rate if the cyclic displacement was less than ± 0.025 mm. The leak rate did not recover to the initial leak rate if the cyclic displacement was more than ± 0.035 mm. Nevertheless, the leak rate is still less than 1×10^{-8} Pam^3/sec. Corresponding leak rate of a full-scale cask lid model would be less than 1×10^{-7} Pam^3/sec taking account of the scale factor[6)].

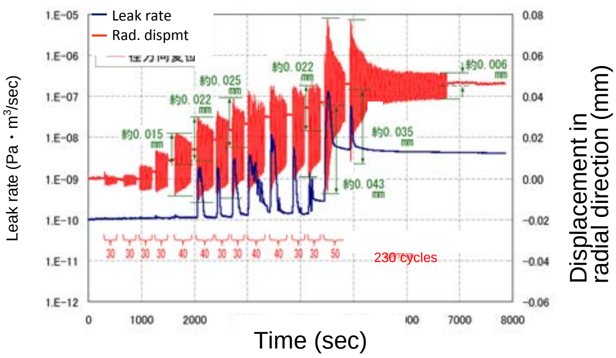


Fig.4 Measurements of leak rate and radial displacement with elapsed time under cyclic loading

EVALUATION OF CONTAINMENT PERFORMANCE OF METAL GASKET IN TRANSPORT BY AGEING OF THE METAL GASKET UNDER LONG-TERM STORAGE

Transport and storage dual purpose metal casks of spent nuclear fuel used in nuclear power plants will be stored in interim storage facilities for 40 to 60 years. The casks usually use metal gaskets for safety and steady containment performance for the long term as shown in Fig. 5. Metal gaskets generally consist of helical metal spring, inner and outer metal jackets. The outer jacket is made of flexible metal material, such as aluminum or silver, and aluminum has been adapted to outer jackets for adhesion between the gasket and lids or cask body surface in Japan. As high temperature due to decay heat of spent nuclear fuel will impose to the seal area of cask lid systems during storage, the high temperature can accelerate ageing, such as creep deformation of the outer jacket and corresponding relaxation of the linear load of the gasket complex[7]. Therefore, when the cask and the heated gasket received the vibration force during normal transport operation on land or sea after storage, the containment performance of metal gaskets might be affected.

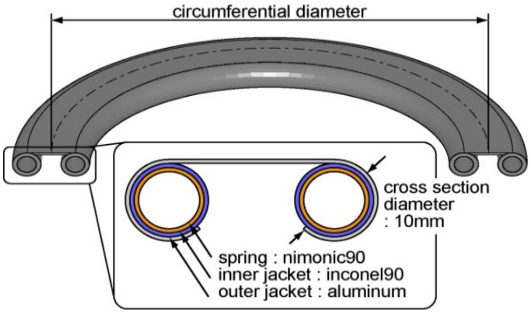


Fig. 5 Overview of a metal gasket

To evaluate the containment performance of the metal gasket used for long term at high temperature, it is important to comprehend creep characteristics of aluminum at high temperature under compressive loading. In this section, the compressive creep characteristics were obtained by compressive creep tests using aluminum. In order to establish the numerical methodology of the ageing phenomena on containment performance of the metal gasket over the long term, the compressive creep characteristics of the aluminum were introduced in the Finite Element Method code (ABAQUS). More detailed information is found in the literature[8].

Relaxation test of metal gasket

The CRIEPI carried out relaxation tests using the metal gasket with aluminum outer jacket in a 1/10-scale flange model. As a result, the residual linear load decreased to 212 N/mm from 350 N/mm due to the relaxation of heated gasket complex. Measurements of the residual linear load corresponding to leak rate over 10 $^{-8}$ Pa・m^3/s (Y_1) and

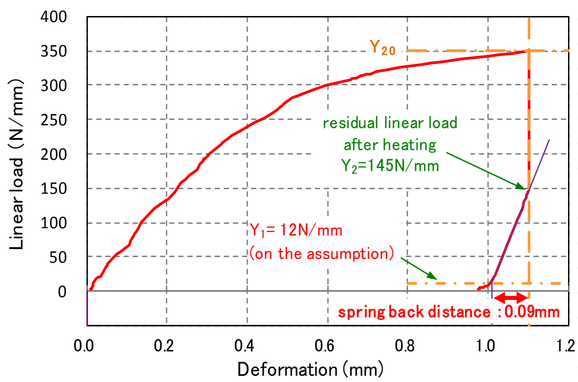


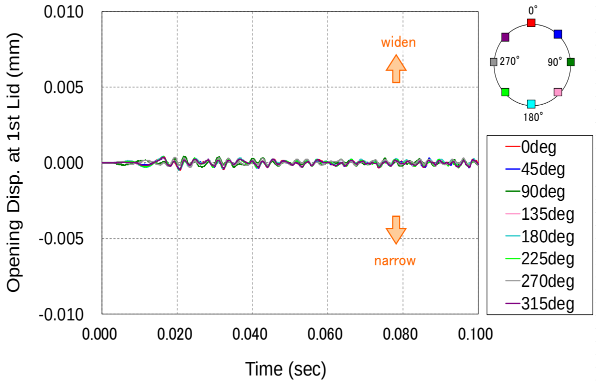
Fig. 6 Relationship between deformation and linear load (analytical result)

the effective spring back distance (r_u) were 12N/mm and 0.12mm, respectively. Thus, the threshold value of residual linear load Y_1 to maintain containment performance was determined to 12N/mm. For this experiment, the analytical method showed a good agreement. Using this analytical method, we calculated the residual linear load and effective spring back distance of a metal gasket used for storage of 60 years. Fig. 6 shows a result of the analytical result. The external load would not affect the containment performance if vertical displacement of gasket due to an external load is smaller than the spring back distance, r_u=0.09mm.

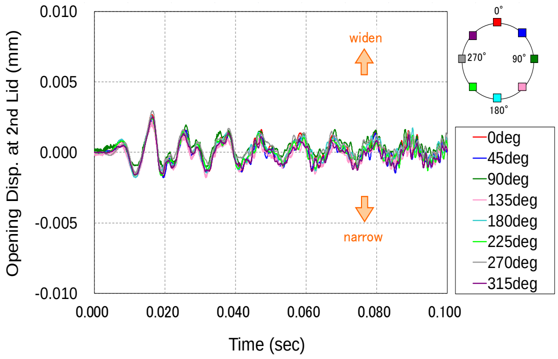
Effect of vibration in sea transport on the aged metal gasket

It has been known that the containment performance of a metal gasket is influenced by external load or displacement. Especially, the aged gasket with reduced residual linear load and spring back distance subjected to vibration force during transportation is concerned. In this section, in order to evaluate the influence of vibration during normal transportation on containment performance of the gasket, the opening displacement perpendicular to the flange surface of the gasket during normal transportation was compared with the spring back distance r_u of the gasket used for 60 years. The displacement of the gasket due to vibration force was calculated by dynamic analysis using Finite Element Method code LS-DYNA. The cask used in dynamic analysis is a full scale transport and storage dual purpose metal cask as shown in Fig.3. Time history of acceleration employed in the analytical model was the measurement by gauges set on support frame of cask during actual marine transportation. The measured accelerations as shown in Fig. 2 were of three directions including axial, horizontal and vertical directions. The duration of accelerations used in the dynamic analysis was 10ms comprising maximum accelerations of about 3G in the horizontal direction.

The input data was the measurement without wave filter processing. In the dynamic analysis, the accelerations were input at the trunnion of the cask model and the gravity acted on over-all analytical model. Fig. 7 shows time history of opening displacement at primary and secondary lid. In primary lid, the peak displacement was very small, less than 0.001mm. In secondary lid, the peak displacement was about 0.003mm and the amplitude of the displacement gradually decreased. The results revealed the displacements were much smaller than the spring back distance. Therefore, the containment performance will not be lost during the sea transportation within the acceleration measured.



(a) Primary lid



(b) Secondary lid

Fig 7 Dynamic analysis result on lid opening displacement

HOLISTIC APPROACH FOR SAFETY EVALUATION OF POST-STORAGE TRANSPORTATION

The metallic casks are to be shipped to the reprocessing facilities, etc. after storage in the interim storage facilities. Spent fuels, contained in the shipped metallic casks, is the ones whose integrity as spent fuel assemblies at the time of being placed into the metallic casks is confirmed, which is properly contained in the metallic casks and properly transported from the power plants to the interim storage facilities. In addition, in the interim storage facilities, the fuel is stored in the environment which is designed in such a manner that safety for long-term storage is sufficiently considered, and it is confirmed that there is no abnormality in the pressure between the lids, surface temperature, and external force. Therefore, shipment from the interim storage facilities to the reprocessing facilities was studied and summarized in a report by the government (NISA)[10). Fig. 8 shows an example of management of licensing and inspection in spent fuel transport and storage[11). In order to confirm safety of transportation at the end of storage, integrity of the metallic casks and contents should be checked, for example, by visual check of the condition of the contents and baskets by opening the lid of the metallic casks, or by inspecting atmosphere inside the metallic casks before shipment in the interim storage facilities. On the other hand, following facts should be considered; ①interim storage facilities are very stable and static, and ②radioactivity of spent fuel contained in the metallic casks gradually decays by releasing heat, and ③just for visual check21. it is required to break the containment boundary of the metallic casks. This action is undesirable not only from the viewpoint of reduction of workers' exposure or leak prevention of radioactive materials, but also that it may cause another accident, and would rather increase risks.

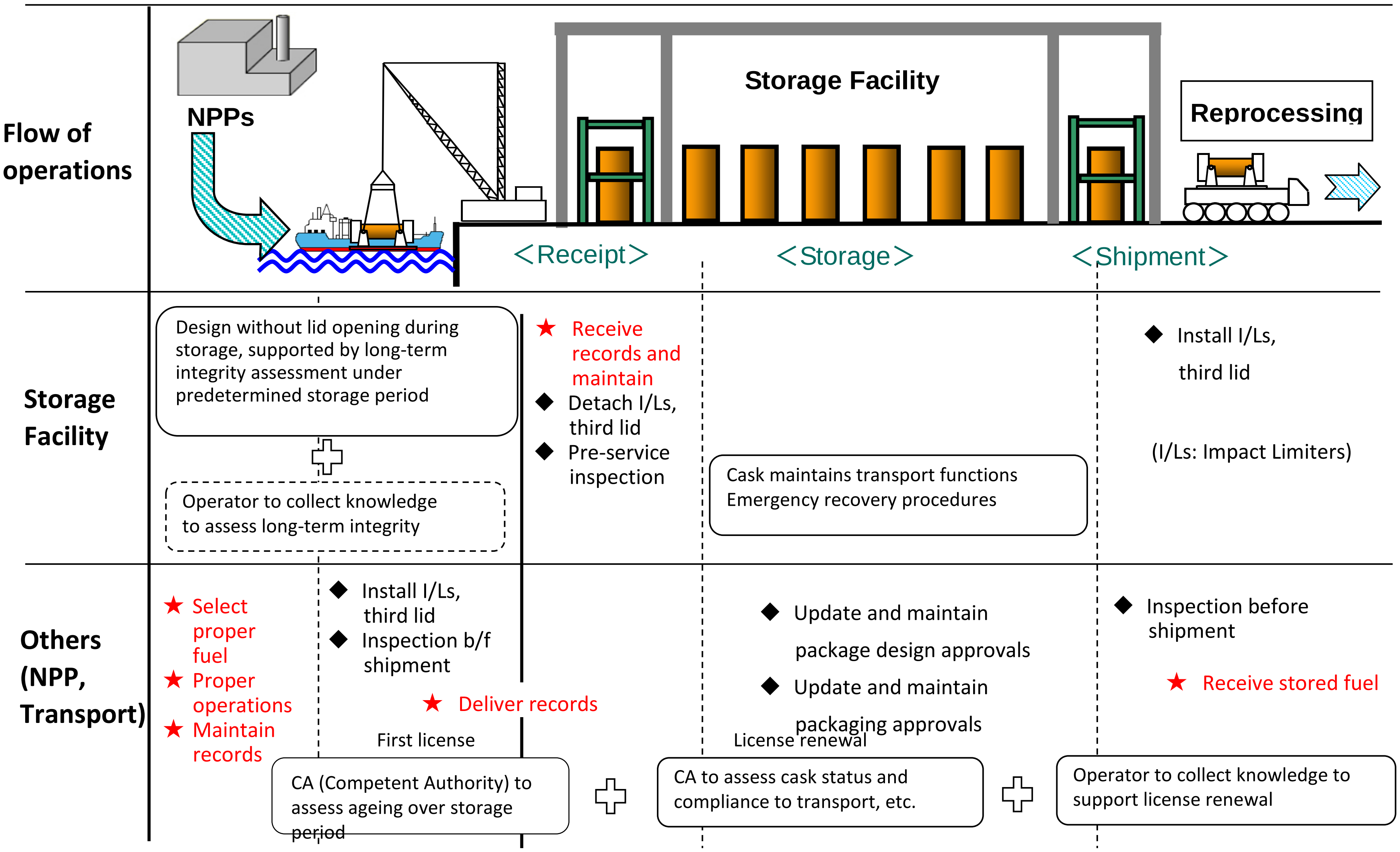


Fig. 8 Example of management of licensing and inspections in spent fuel transport and storage[11)]

(At the end of storage, if it is decided to actually measure the pressure in the atmosphere inside the metallic cask, a vent valve installed in the primary lid must be opened after opening the secondary lid. This action is regarded as an operation to break the containment boundary of the cask, just like opening of the primary lid.) Consequently, when the same level of safety can be assured as visual check, it is more desirable to perform inspections based on alternative approaches. Fig.9 shows an example of the above-mentioned inspections[12)].

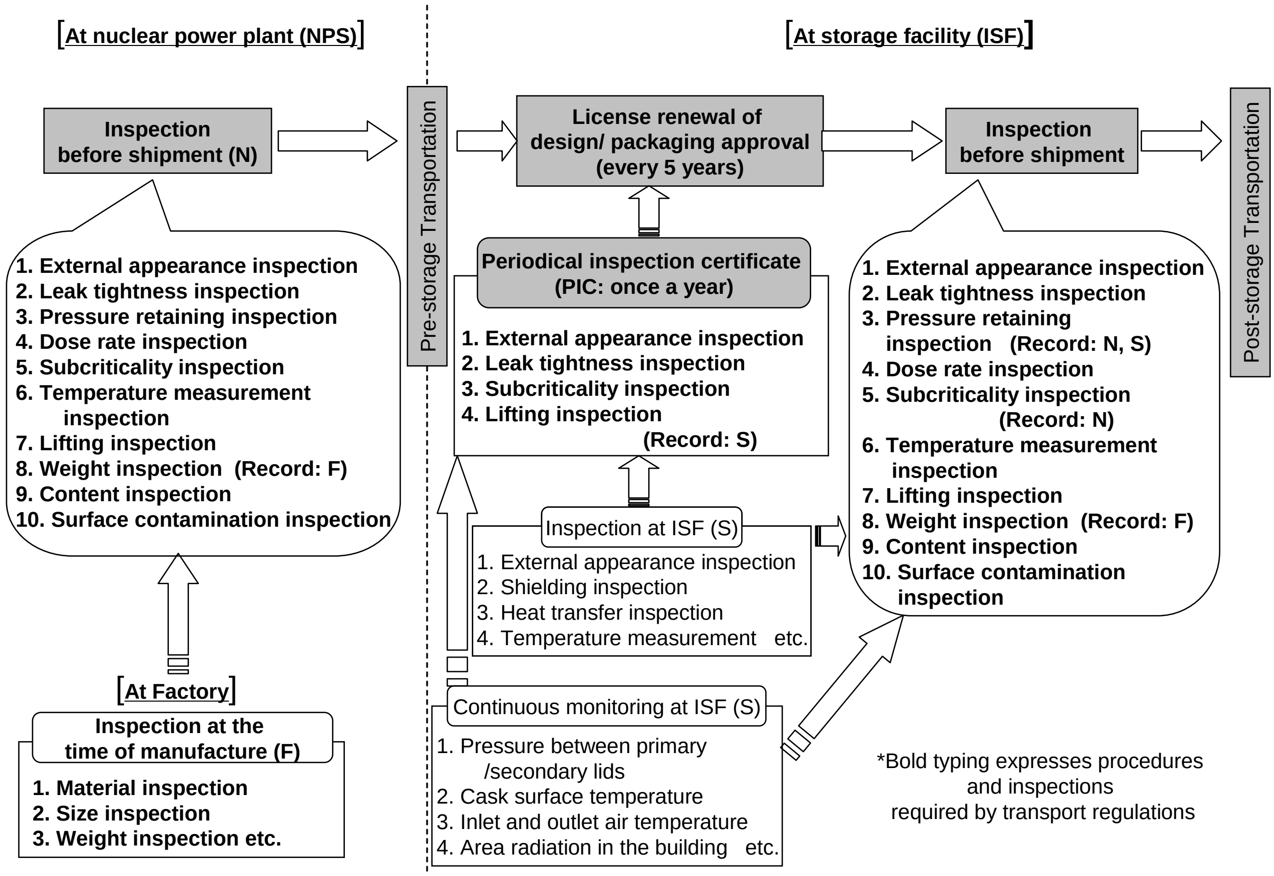


Fig. 9 Example of schematic diagram of a series of investigations required for dual-purpose casks (from the viewpoint of transportation)
(Provided by Tokyo Electric Power Co, Inc.)

CONCLUSION

1. Experiments using a scale model of a cask lid with a metal gasket showed that mechanical vibration during transport would not interfere the containment performance of the metal gasket of the cask in storage.
2. Creep experiments of the metal gasket simulating a storage condition and analysis on the cask lid opening by mechanical vibration simulating an acceleration in transport showed that the metal gasket would not lose the containment performance

in transport.

3. Holistic approach would ensure post-storage transportability without opening the cask, based on records of safe operations of the cask before transport and assessment thereof.

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