PWR Fresh Fuel Shipping Package Development

Dae-woon Choi, Su-pil Ryu, Hak-in Lee, Ju-hong Chun, Dong-geun Ha, Yoon-ho Kim*
KEPCO Nuclear Fuel, 242, Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon, Republic of Korea

**Corresponding author: dwchoi@knfc.co.kr*

Keywords : Fresh fuel, Shipping package, IAEA SSR-6, USNRC 10CFR71, NSSC notice 2019-7

1. Introduction

PIONEER G was developed to satisfy the international regulation including IAEA SSR-6[1], USNRC 10CFR71[2] and Nuclear Safety and Security Commission (NSSC) notice 2019-7[3] with MPR Associates, Inc. The PIONEER G is designed to transport up to two (2) un-irradiated uranium dioxide PWR fuel assemblies enriched in U-235 up to a maximum of 5.0 weight percent (w/o). The PIONEER G is designed to be licensed as a type "AF" radioactive material shipping container. Three or four packages can be shipped on one conveyance in a two-by-two square array or a two-and-one triangular package array. The PIONEER G includes two configurations: the longer PIONEER G -L, with lengths appropriate for Korea Standard Nuclear Plant (KSNP) type fuel assemblies; and the shorter PIONEER G-S, with lengths appropriate for Westinghouse-type fuel assemblies. PIONEER G shipping package was initially developed to facilitate the export of the nuclear fuel to the United States, with its design also considering future exports to advanced nuclear markets, including those in Europe.

2. PIONEER G Configuration

The PIONEER G -L and PIONEER G -S packages are right circular cylinders with an outer diameter of approximately 1 meter and lengths of approximately 5.5 and 5 meters, respectively. For licensing purposes, the maximum bounding design weight is 3,743 kg for the PIONEER G -L and 3,650 kg for the PIONEER G -S, which includes the weight of two fuel assemblies. The PIONEER G packaging structural components are fabricated from austenitic stainless steel and consist of four major components: an upper shell, a lower shell, an internal cradle assembly, and a T-frame assembly. The PIONEER G is illustrated in Figure 1, with a cross-sectional view and inner configuration.

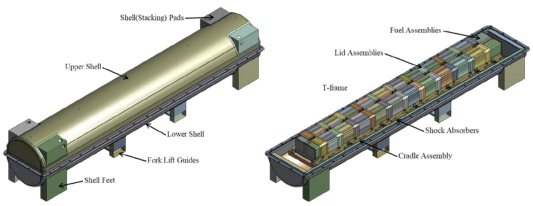
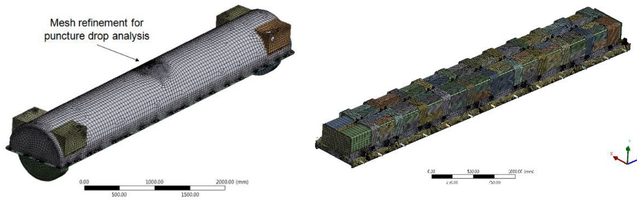


Fig.1 Configuration of PIONEER G shipping package

3. PIONEER G Evaluation

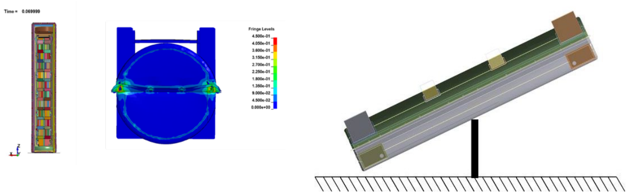
3.1 Structural Evaluation

Structural integrity of the package under normal conditions of transport (NCT) has been performed by hand calculation and computational analysis by ANSYS. And the evaluations for hypothetical accident condition (HAC) have been performed by using the LS dyna. The analysis model is illustrated in Fig.2. The most important consideration in the structural evaluation was to find the most conservative drop test conditions for 9m free drop. The evaluation results are illustrated in Fig.3.



(a) Upper Shell (b) T-frame & Lid Ass'y

Fig.2 Structural analyses model of PIONEER G



(a) 9m free drop (b) 1m puncture drop

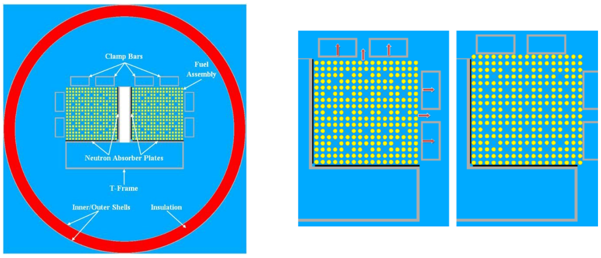
Fig.3 Structural analyses for HAC

3.2 Thermal Evaluation

All of the safety related structural components of the Pioneer G package are designed to withstand exposure to the hypothetical fire accident conditions (30 minutes at 800ºC) without degradation. The fuel assemblies themselves can also withstand exposure to such conditions. As a result, normal conditions of transport and hypothetical accident thermal conditions will not affect the performance of the Pioneer G shipping package.

3.3 Criticality Evaluation

Criticality analysis was performed by using SCALE code based on very conservative assumptions regarding the deformation of the shipping package structure and nuclear fuel that would occur during drop tests. after conducting the demonstration test, the observed deformation that occurred in the test was compared with the assumed deformation. The criticality analysis model of PIONEER G for HAC is illustrated in Fig.4.



(a)Criticality Model for HAC (b) Fuel deformation model
Fig.4 Criticality analysis model of PIONEER G

3.4 Demonstration Tests

Two full-size PIONEER G-L test articles were subjected to drop testing. The longer and heavier PIONEER G-L was judged to be limiting for structural testing because of its greater mass. Drop testing was conducted on two test articles, which each held two mock fuel assemblies. The mock fuel assemblies used surrogate pellets to replace and simulate the weight distribution and hardness of the uranium dioxide fuel pellets used in real fuel. Each test article contained one mock fuel assembly with lead pellets and one mock fuel assembly with tungsten pellets.

The five drop tests listed in Table 1 were required to be performed for the PIONEER G demonstration test series. The NCT tests were required in order to evaluate the package according to the more stringent NCT acceptance criteria, and the HAC tests were chosen to maximize damage in the more severe accident conditions. Two 9 m free drops were required in order to fully test key safety features of the packaging. The end drop was required to test the resistance of the fuel to buckling and subsequent lattice expansion after impacting the foam damper at the end of the package. The slap-down drop was required to test the structural integrity of the packaging and its ability to retain the fuel in the confinement geometry as this drop orientation resulted in the highest g-forces on package internals. The puncture drop was required to test the ability of the packaging to resist penetration by a puncture spike after accumulating damage from previous drop tests. The deformation did not exceed the assumed deformation in the criticality analysis during the drop tests. The drop tests configuration is illustrated in Fig. 5.

Table 1. List of PIONEER G demonstration test

Test	Test Detail
1.2 m drop	drop onto the upper shell with 10°
1.2 m drop	drop onto the flange with 10°
9 m drop	drop onto the upper with 10°
9 m drop	drop with vertical axis
1m Puncture drop	drop onto the upper shell with 25°

(a) 9m-10° drop (b) 9m-90° drop (c) 1m-Puncture
Fig.5 Configuration of PIONEER G HAC drop tests

4. Conclusions

In conclusion, through structural, thermal and criticality evaluations, PIONEER G shipping packages were proved to meet the regulatory requirements. There was no crack and damage on the fuel rods after performing drop tests. Therefore, Uranium would not leak out of the fuel rod. PIONEER G could meet the thermal requirements because all of material can maintain its integrity under 800 ℃. Criticality analyses were performed by reflecting all predictable deformations, and the conservatism of this approach was confirmed through demonstration test results. The criticality evaluation results show that the calculated final effective multiplication factor(k_{eff}) is less than Upper Subcriticality Limit(USL). PIONEER G meets all regulatory requirement of fresh fuel shipping packages. Therefore, it can be used to transport nuclear fuel overseas and also apply i-SMR fuel transportation.

ACKNOWKEDGEMENT

This work was supported by the Innovative Small Modular Reactor Development Agency grant funded by the Korea Government (MOTIE) (No. RS-2023-00259032).

REFERENCES

[1] International Atomic Energy Agency (IAEA) Safety Requirement No. SSR-6, Regulations for the Safe Transport of Radioactive Material, 2012 Edition.
[2] Title 10, Code of Federal Regulations, Part 71, Packaging and Transportation of Radioactive Material.
[3] Nuclear Safety and Security Commission (NSSC) Notice No. 2019-7, Regulations for the Packing and Transport of Radioactive Materials, etc.
[4] PIONEER G Safety Analysis Report (SAR) Rev.4, KNF, April, 2021.