ANF-18/MOX:
A Modular Transport System for Fresh PWR MOX Fuel Assemblies

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Introduction

For the shipment of non-irradiated PWR mixed oxide (MOX) fuel assemblies from the fabrication facility to the power plant, the new ANF-18/MOX transport system has been designed on the basis of the recently developed ANF-18 shipping container for non-irradiated Uranium fuel assemblies [1]. The ANF-18/MOX transport system fully meets the requirements of the IAEA Safety Standard Series No. TS-R-1 (ST-1, Revised) [2] for the transportation by road, rail and sea.

The ANF-18/MOX transport system has a capacity of two PWR fuel assemblies of type 15x15, 16x16 and 18x18 with a maximum Pu-fiss content of 7 %. All relevant safety analyses have been performed and it is expected that the container will go into services during the course of 2002. The safety analyses take credit from tests and calculation results of the ANF-18 shipping container for Uranium fuel assemblies. The allowable number will be "N" = 2 with regard to criticality safety index (CSI = 25).

Safety Requirements

The ANF-18/MOX transport system will be licensed as a Type B (M) package for fissile radioactive materials according to the IAEA requirements [2] and the corresponding international regulations ADR, RID and IMDG-Code.

The main safety requirements for the transport of MOX fuel assemblies are to ensure that the containment system is capable to withstand effects arising from normal conditions of transport and accidental conditions without loosing its tightness and to prevent configurations of the fuel assemblies which will result in an unacceptable K_{eff} value in criticality safety.

Since the containment system is provided in the present case by the fuel rods it has to be demonstrated that the rods will remain leak tight under normal conditions of transport and accidental conditions. Concerning criticality safety, the main aspect is to prevent unacceptable widening of the fuel rod array.

ANF-18/MOX Transport System

The ANF-18/MOX transport system with a total gross weight of 7.7 tons and the main dimensions of 6002 mm x 1485 mm x 1050 mm consists of an outer protective packaging and an inner ANF-18/MOX container (Fig. 1).

The outer protective packaging which provides additional protection against mechanical and thermal impacts under accident conditions for the inner container and additional shielding consists of a rigid rectangular steel box with 8 mm wall thickness which is closed on top by a lid fixed with 30 screws. The steel box is clad inside with at least a 30 mm thick layer of spruce wood. In addition, the outer protective packaging is equipped on the inside with shock absorbing structures made of balsa wood which limit the impacts resulting from accidental conditions.

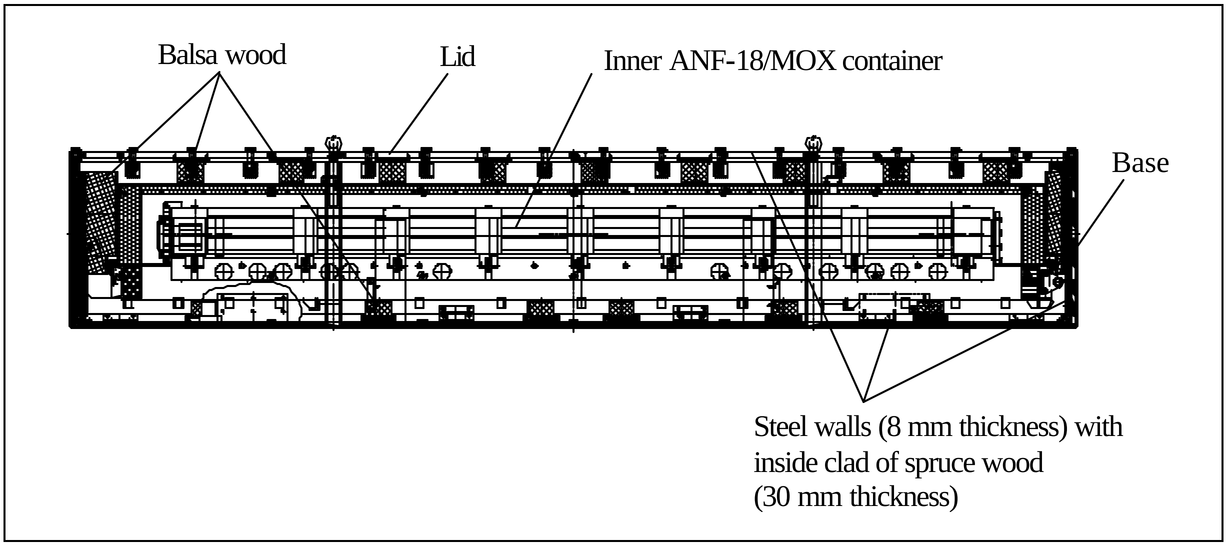

Fig. 1 ANF-18/MOX Transport System: Outer Protective Packaging and Inner ANF-18/MOX Container

The inner ANF-18/MOX container (Fig. 2) consists of a two-section enclosure (base and cover) and a rigid fuel assembly support (cradle), complete with L-shaped doors to protect the fuel assemblies against the effects of accidents. The cradle is suspended in the base by means of rubber shock absorbers. The cover and base are bolted together. The design of the inner ANF-18/MOX container is essentially based on the design of the ANF-18 container with additional material considerations due to the higher temperatures in case of the MOX fuel.

The inner ANF-18/MOX container can be loaded with two PWR fuel assemblies of type 15x15, 16x16, and 18x18. Differences in the fuel assembly length can be compensated by front adapters. In case of the 15x15 fuel assemblies which have a smaller cross section than the other assembly types, the L-shaped angle doors are adjusted to these dimensions. A more detailed description of the ANF-18 container is given in [1].

Transport and Handling

Two packages of the ANF-18/MOX transport system can be stacked on one another and transported in the German security vehicle owned by the Nuclear Cargo + Service GmbH company. Load securing within the security vehicle is provided by means of holding frames with are screwed to welded plates on the outside of the protective packaging.

At the power plant the package is unloaded from the security vehicle and after opening of the outer protective packaging only the inner ANF-18/MOX container is transferred to the containment area of the power plant. Therefore, the load attaching points of the inner ANF-18/MOX container are designed in accordance with the German KTA standard 3905 [3] for increased requirements.

Because the inner ANF-18/MOX container is nearly identical to the ANF-18 shipping container, the reactor operator has the primary advantage that the handling is very much the same for both container types and therefore the reactor personnel are already familiar with the handling procedures and no additional installations or handling equipment is required.

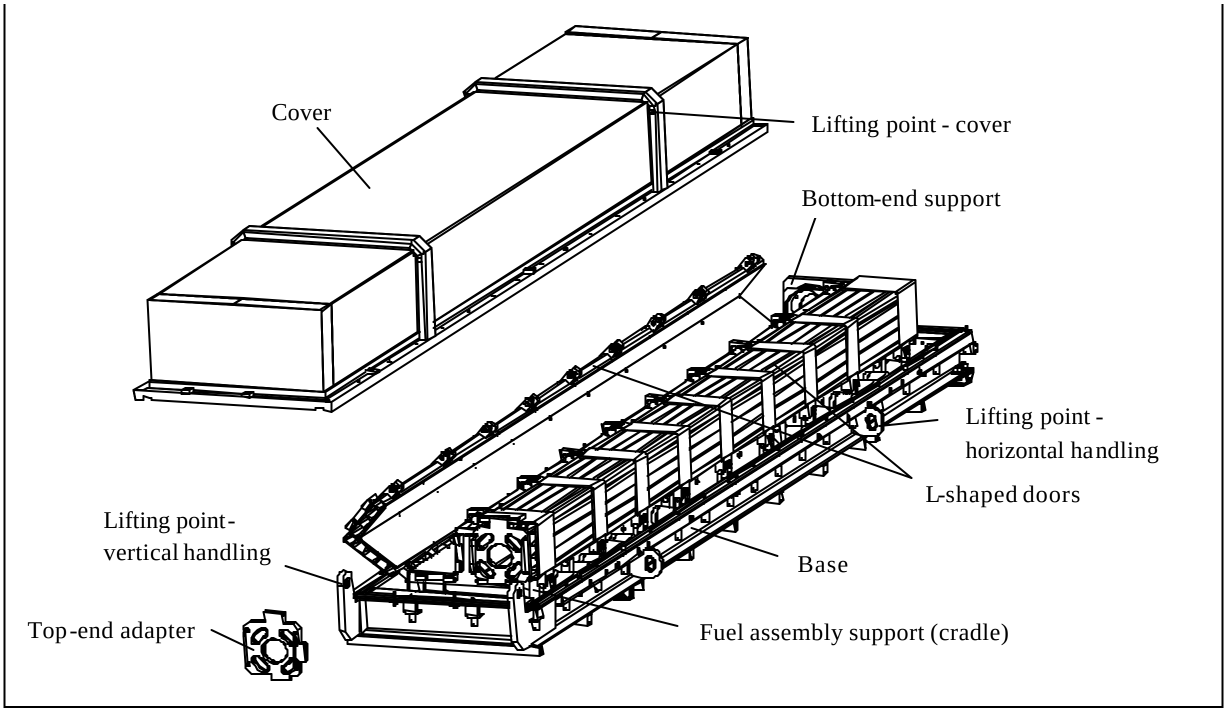

Fig. 2 ANF-18 Shipping Container

IAEA Tests and Results

- **Mechanical tests**

Concerning the mechanical aspects, safety analyses of the behavior of the package and the fuel rods under normal conditions of transport and accidental conditions is mostly based on analytical calculations and tests performed with the ANF-18 shipping container.

Following structural dynamic investigations using the DYNA-3D FEM code [4] to identify and substantiate the "most damaging position" required by the IAEA regulations for the drop tests, a 9 m drop test with the ANF-18 prototype container was performed at the test site of the Federal Institute for Materials Research and Testing (BAM) in Lehre, Germany. As the most severe drop orientation, especially for the fuel assemblies, a drop onto the side wall with a longitudinal inclination of 15^{o} was performed (Fig. 3).

The 9 m drop test was followed by two drop tests onto the bar on the pre-damaged side wall and the bottom of the ANF-18. The drops were performed with an inclination of 25^{o} and 20^{o}, respectively.

For these tests, the ANF-18 prototype container was loaded with two dummy assemblies (one 16x16 and one 18x18 rod array) which were identical to the standard fuel assemblies with the exception of the pellets (uranium dioxide was substituted with lead).

After these tests, the ANF-18 prototype container and the dummy assemblies were inspected for damages. The prototype container exhibited local deformations at the point of impact from the 9 m drop test and local deformations at the side wall and penetrations at the bottom caused by the drop tests onto the bar. The dummy rods and the spacers of the dummy assemblies exhibited some deformation but spacer strips were not fractured (Fig. 4). The cross sectional area of the dummy assemblies was not enlarged. The leak tightness of the dummy rods was verified by drilling holes into all cladding tubes of the pre-pressurized rods.

Fig. 3 9 m Drop Test with the ANF-18 Container

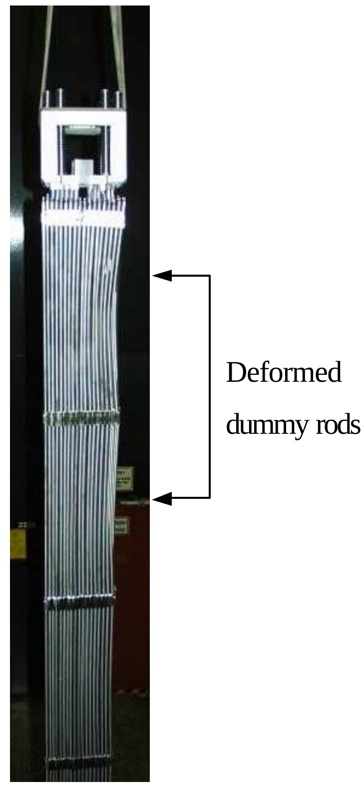

Fig. 4 Dummy Assembly of Type 18x18, Deformation at the Slap Down End

Drop tests onto the bar were conducted with a 1:2 scaled model of the outer protective packaging. The packaging wall was not penetrated during the horizontal impact. With a longitudinal inclination of 25° as the most severe drop orientation, the packaging wall was only partly penetrated by the bar. The plate representing the boundary of the inner container was not affected (Fig. 5).

Taking into account the additional protection supplied by the outer protective packaging with its additional balsa wood shock absorbers and its ability to prevent damages from the bar drop test (Fig. 5) it is ensured that the fuel rods will remain leak tight after the mechanical tests for accidental conditions and no widening of the fuel rod array will occur which would cause criticality concerns.

- **Thermal tests**

To evaluate the temperature distribution within the ANF-18/MOX transport system under normal conditions of transport a heating test was performed with a shortened model of the outer and inner packaging loaded with two dummy assemblies. The dummy assemblies were equipped with a heating applicator to simulate the heat rate of the MOX fuel assemblies. With the applied heat rate (conservatively representing a heat rate of 1100 W per original MOX fuel assembly), a maximum temperature of 190° C of the fuel rods was evaluated taking into account an ambient temperature of 38° C with insulation. Results showed that no unacceptable temperatures occurred for the container materials.

Fig. 5 Model of the Outer Protective Packaging, Results from 1 m Oblique Drop Test onto the Bar

Following the heating test for normal conditions of transport, a thermal test according to the IAEA requirements was performed with the model at the fire test facility of the BAM in Lehre. A circular disc was cut out of the side wall of the outer protective packaging as a result of the oblique drop test onto the bar (see also Fig. 5). Before the thermal test the model was heated up until the dummy rods reached the temperatures evaluated for normal conditions of transport. Figure 6 shows the test segment after the thermal test.

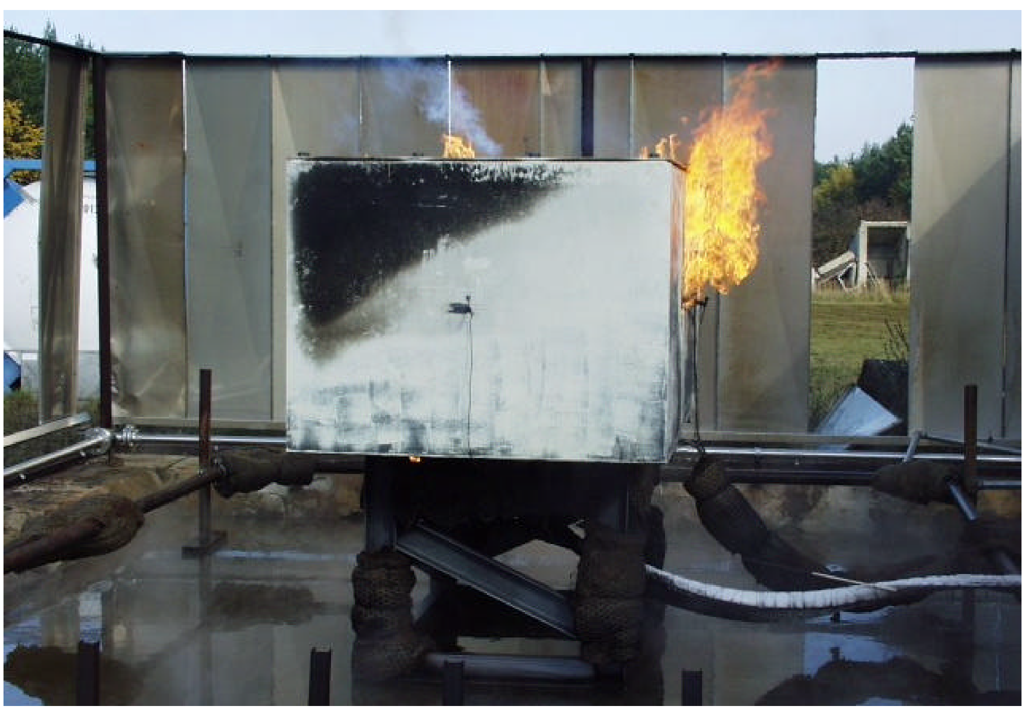

Fig. 6 Test Segment of the Outer Protective Packaging After the Thermal Test

Inspection after the thermal test showed no significant mechanical damage of the ANF-18/MOX transport system besides the fact that the wood cladding of the outer protective packaging was partly charred and the rubber round bearings suspending the cradle of the inner container were sheared off. The maximum temperature of the dummy rods was measured as 213° C. The cradle, L-shaped doors and dummy rods exhibited no visual damage. A tightness check of the dummy rods demonstrated that they remained leak tight.

Criticality Safety

Criticality safety was demonstrated for the ANF-18/MOX transport system using the program system SCALE-4.4 a [5] and taking into account the IAEA requirements [2] with a conservative model which assumes that the outer protective packaging is not present and conservative assumptions concerning the deformation of the inner container geometry and the widening of the fuel rod array the results show that even for a maximum Pu-fiss content of 10 % the design limit of $K_{eff} \leq 0.95$ is fully met.

References

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[2] Regulations for the Safe Transport of Radioactive Material, 1996 Edition (Revised)
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[4] DYNA-3D: A Nonlinear, Explicit, Three-Dimensional Finite Element Code for Solid and Structural Mechanics - User Manual, University of California, Lawrence Livermore National Laboratory, UCID Report, UCRL-MA-107254 Rev. 1, 1993

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