CUSTOMIZATION OF ENUN 24P CASK FOR TRANSPORT OF HIGH BURNUP SPENT FUEL IN CHINA

ENSA has designed a cask for the transportation of spent fuel in China. The ENUN 24P is a cask based on the design of double-purpose metal casks ENUN, composed of a carbon steel forging body, double bolted lids, a neutron shield perimeter and a fuel basket. The design of the ENUN 24P cask includes the necessary modifications to meet demanding conditions, such as admitting high burnup and low cooling time fuel, or reducing the diameter of the impact limiters for the transportation.

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PERSONALIZACIÓN DEL CONTENEDOR ENUN 24P PARA EL TRANSPORTE DE COMBUSTIBLE GASTADO DE ALTO QUEMADO EN CHINA

Ensa ha diseñado un contenedor para el transporte de combustible gastado en China. Dicho contenedor, el ENUN 24P, es un contendor basado en el diseño de contenedores de combustible metálicos de doble propósito ENUN, compuestos de un cuerpo de forja de acero al carbono, doble tapa empernada, un blindaje neutrónico perimetral y un bastidor para alojar los combustibles. El diseño del contenedor ENUN 24P incluye las modificaciones necesarias para cumplir con exigentes condiciones, tales como admitir combustibles con alto grado de quemado y bajo tiempo de enfriamiento, o la reducción de diámetro de los limitadores de impacto.

INTRODUCTION

The ENUN 24P dual-purpose metal cask has been adapted from the ENUN cask series concept developed by Ensa, to fulfil specific spent fuel transport requirements across People's Republic of China. Among those, it is designed to allow the transportation of spent nuclear fuel from Ling Ao and Daya Bay Nuclear Power Plants (NPPs) located in south-east China, to Lanzhou storage facility crossing China in different regions and climate conditions through road & rail transportation.

People's Republic of China has not already established a unified and definitive strategy for the spent fuel definitive management. For any fuel cycle option and waste management strategies, transportation of the spent fuel is considered a critical step in the back end of the Chinese nuclear fuel cycle, with the particularity that distances between the different facilities are usually huge (several thousands of kilometers).

In 2013 CGNPC Uranium Resources Company Co., Ltd. studied the necessity to request an improved and cheaper solution for the transportation of spent fuel between Daya Bay NPP and Lanzhou. This solution should allow the possibility to transport high burnup spent fuel (BU > 45 GWd/tU) in a package with limited outer dimensions, and also with a more competitive cost in comparison with that of previous casks manufactured in 2003 for the same purpose. In addition, the cask had to be designed for intermodal transportation, by road and by rail.

Figure 1. Transportation of Spent Nuclear Fuel across People's Republic of China.

By the end of 2013 ENSA was awarded with a contract to supply initially one ENUN 24P cask, the ancillary equipment and training services to the operating personnel at Daya Bay and Ling Ao NPPs. ENSA started the detailed design of the cask and some months later the purchase of material for the manufacturing. All the equipment was completed and shipped from Santander to China in May 2017. In September of the same year, ENSA obtained the Certificate of Compliance (CoC) as a Type B(U) cask for high burnup nuclear spent fuel from the Spanish Safety Council. 7 months later, in April 2018 ENSA obtained the validation of that CoC by the Chinese nuclear authority (NNSA), finishing a successful design and licensing process of the ENUN 24P cask.

INITIAL DESIGN

The New Ensa ENUN Spent Fuel Cask Series

The ENUN 24P design was adapted by Ensa from the reference ENUN 32P dual-purpose cask (Figure 2), already licensed in Spain and in use in Trillo and Almaraz NPP's, but including some technical modifications. All systems from the new ENUN spent

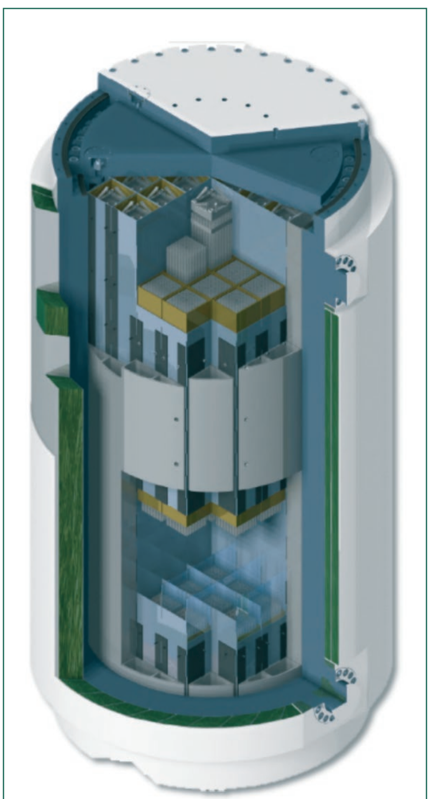

Figure 2. The Reference Cask: the ENUN 32P Dual-Purpose Cask.

Parameter	ENUN 24P
Fuel design	AFA 2G, AFA 3G, AFA 3GAA
Maximum burnup	Up to 57000 MWd/tU
Minimum cooling time	Up to 3 years
Maximum initial enrichment	Up to 4.5 % wt U-235
Type of loading	Uniform
Burnup credit	No

Table 1. ENUN 24P Design Fuel Basis Bounding Parameters.

fuel casks series developed by Ensa share the same concept design of 'bare-fuel' type dual-purpose metal casks, but each one includes specific features depending on the customer specific requirements.

Origin of the ENUN 24P

The ENUN 24P has been specifically designed for transportation of high burnup PWR type spent nuclear fuel of the following designs: AFA 2G, AFA 3G and AFA 3GAA. It fulfills all the specific requirements of a Type B(U) package indicated in the international transport regulation IAEA No. SSR-6 [1] for the safe transport of radioactive material[1].

The ENUN 24P is designed for a uniform fuel loading strategy, where any authorized fuel assembly can be loaded in any of the 24 basket cells positions. The design basis fuel bounding parameters of the authorized content that can be transported in the ENUN 24P cask are indicated in Table 1. ENUN 24P Design Fuel Basis Bounding Parameters.. These parameters comply with the most limiting of the spent fuel intended to be transported from Daya Bay and Ling Ao NPPs.

The principal design change introduced for the development of the ENUN 24P project has been the maximum capacity of the cask. Since the Chinese client and nuclear authority did not initially allow the application of the burnup credit methodology, for the ENUN 24P cask Ensa decided to include a "flux trap" concept in the basket layout to increase the gap between adjacent fuel cell positions, and assure the subcritical condition of the spent fuel considering it as fresh fuel for the criticality evaluations. Consequently, the maximum capacity of the cask had to be reduced from 32 to 24 fuel positions.

[1]Additionally, the ENUN 24P is perfectly suitable for dry storage of spent fuel, since it has been designed as a dual-purpose cask.

This reduction gave Ensa the possibility of slightly reduce the inner cavity diameter of the ENUN 24P respect to the reference ENUN 32P, from 1866 mm to 1669 mm but maintaining the inner shell thickness that provides the majority shielding against the radial gamma radiations. Therefore, the weight of the cask was reduced. The maximum loaded cask weight was another limitation imposed by the Chinese customer, since the maximum lifting capacity of the cranes in all fuel buildings was limited to 110 tons.

A second important design modification was in the shielding capabilities of the cask. The design basis fuel parameters, specifically the high burnup and the very short cooling time detailed in Table 1. ENUN 24P Design Fuel Basis Bounding Parameters., produced very high gamma and neutron fluxes and elevated decay heat that the cask had to dissipate. Furthermore, the Chinese client imposed another challenging requisite to the Ensa team. The maximum dose rates in the package surface had to be conservatively reduced to 2 mSv/h. This additional demand forced Ensa engineers to increase the gamma and the neutron shielding capabilities of the cask, but without penalizing in excess the overall weight. The following technical solutions were adopted by the Ensa team:

- Increase the thickness of the aluminium profiles in the basket.
- Weld a set of stainless steel plates in the periphery of the basket.
- Triplicate the thickness of the outer shell.
- Increase the inner volume of the aluminium fins.
- Add discs of solid neutron shielding material at the centre of both impact limiters.

All these new features proposed by Ensa during the pre-design phase of the ENUN 24P project finally convinced the client with the enhanced cask design. The tight schedule agreed in the contract to comply with the established date for the first fuel loading and transportation campaigns from Daya Bay NPP, obligated Ensa to start the fabrication activities in parallel with the completion of the detailed design evaluation and the issuance of the licensing documentation, in Spain and in China.

Cask Design Changes Due to Client Additional Requirements

However, once the pre-design phase had been completed and the start of the elaboration of the manufacturing documentation had been approved, the client requested Ensa to perform additional design modifications in the cask. There were principally two important issues that had to be addressed and solved by Ensa engineers within a very short time, in order to not affect the licensing, manufacturing and fuel loading schedules:

I. The client wanted to reduce the maximum diameter of the transportation package, limiting it to 3300 mm. due to geometrical restrictions.

II. An anti-corrosion coating should be applied to the inner metal surfaces of cask that were going to be in contact with water from the spent fuel pools. An agreement was achieved to apply an aluminum based anti-corrosion treatment to the inner cavity and the inner lid, to mitigate any potential risk of corrosion since the cask was going to be used for several transportation campaigns per year.

Implications of the Reduction of the Outer Diameter of the Package

The transportation package of the ENUN 24P (Figure 3) is constituted by the cask and the impact limiters attached to the outer lid and the bottom of the cask. The outer dimension of the protective barrier is limited by the outer diameter of the impact limiters.

Therefore, in order to reduce the outer diameter of the package, Ensa had to reduce the diameter of the impact limiters. The impact limiters were tested in Sandia National Laboratories (see Figure 4) using a mock-up of the ENUN 32P cask from 9 m free drop and 1 m puncture impact tests, in 'cold' and 'hot' testing conditions and different cask orientations as required by IAEA SSR-6 [1]. After that, they were validated through detailed finite element analysis, and adapted to fit other casks designs from the ENUN series.

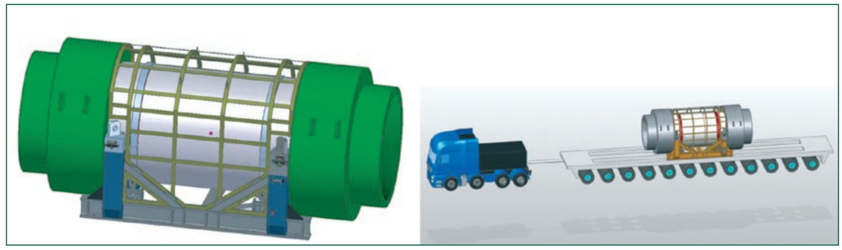

Figure 3. Transportation Package of the ENUN 24P.

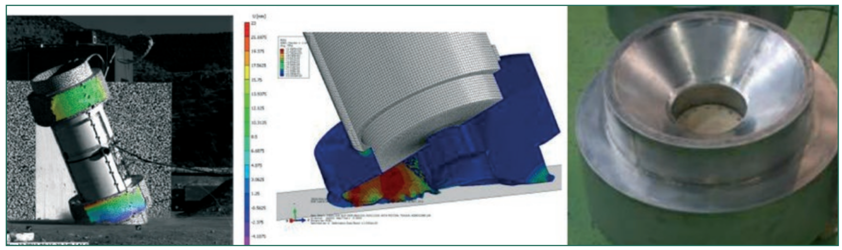

Figure 4. Impact Limiters, Drop Tests and Component Validation of the ENUN Casks.

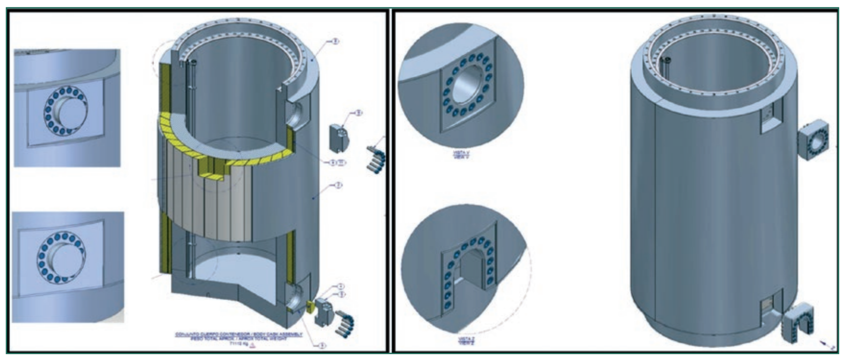

Figure 5. Modification of the Trunnions in the ENUN 24P: From 'Male' to 'Female' Concept.

The first set of drop analyses performed on the ENUN 24P cask using impact limiters with reduced diameter (3300 mm) led to accelerations in the center of gravity of the package in the 'cold test condition' over the 60 G design limit, and in the 'hot test condition' would cause a very hard impact between the cask trunnions and the flat surface due to the depletion of the energy absorbing material.

At this critical point of the development, Ensa started a close working relationship with Sandia National Laboratories and the supplier of the aluminum honeycomb energy absorbing material, in order to search and test enhanced properties materials to absorb more impact energy and redistribute it. Several scoping analyses were performed with the cask and the impact limiters that covered a complete range of the parameters, but assuring any impact on the validated methodology for the ENUN casks drop tests:

- Cask orientations: horizontal, vertical, slap-down, etc.;
- Cask temperature:
- Impact limiter honeycomb absorbing material crush strength;

Ensa finally decided to maintain the same type of honeycomb absorbing material used in the rest of impact limiters of all ENUN cask. However, a slight modification was performed in the geometry of the internal structure of the impact limiters that allowed the installation of higher volume of honeycomb absorbing material, thereby reducing the maximum acceleration of the cask centre of gravity within the design limits. Additionally an innovative technical solution was proposed by Ensa: substituting the traditional trunnion concept protruding out of the outer surface of the cask (commonly named as 'trunnion male concept') by drilling an inner cavity in the trunnion block (Figure 5). This has named by Ensa team as 'trunnion female concept'.

This technical solution implied also the modification of the ancillary equipment for the fuel loading and unloading operations of the cask, principally the lifting yoke

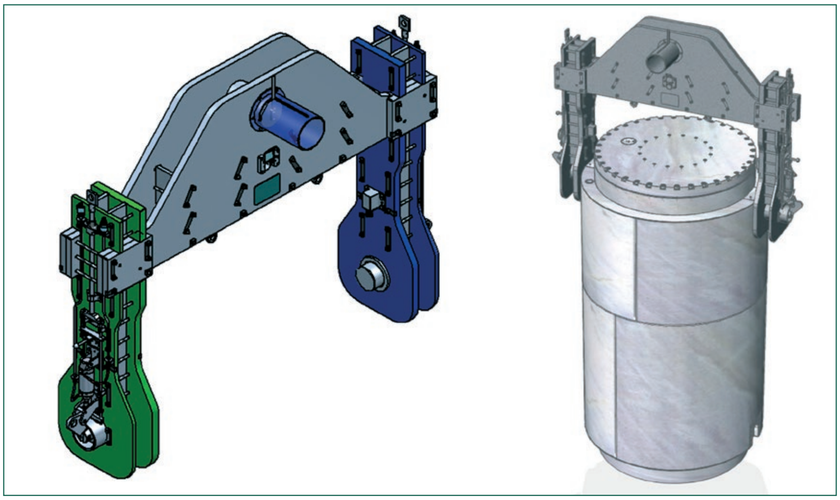

Figure 6. Specific Lifting Yoke Developed for the ENUN 24P.

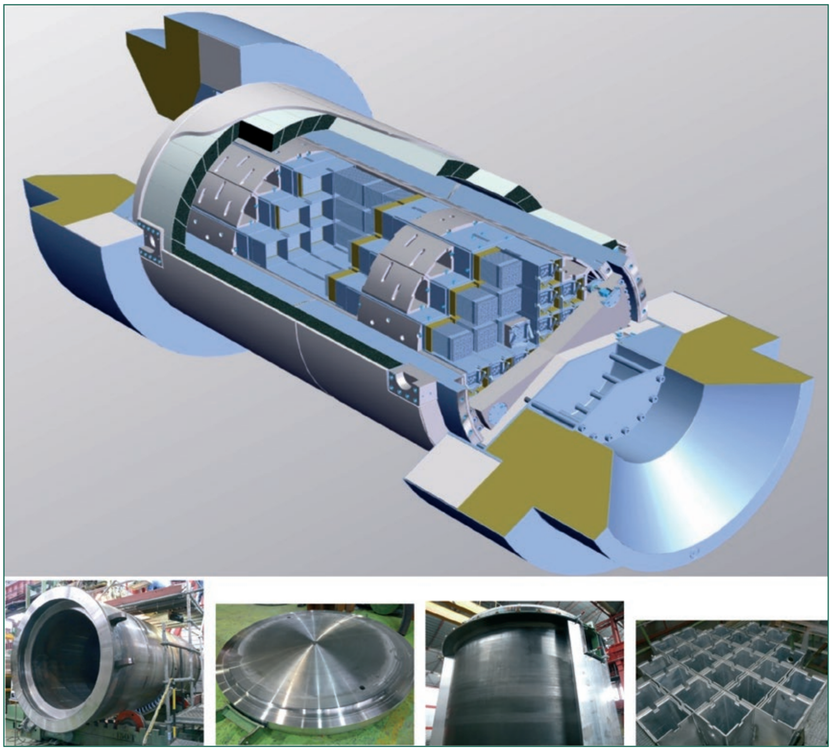

Figure 7. Final Design and Manufacturing Sequences of the ENUN 24P.

and the transport skid. Ensa has developed a sophisticated device driven by a pneumatic actuator system (but including also an additional countermeasure actioned manually in case of off-normal or accident conditions) and a double blade system to reinforce the structural behaviour of the lifting yoke (Figure 6).

This innovative 'female trunnion concept' has allowed Ensa to remove any protruding from the outer surface of the cask and avoid the harsh impact with the flat surface. The complete depletion of the energy absorbing material during any cask orientation in 9 m free drop tests was completely avoided and the successful performance of the impact limiters was validated at any postulated accident condition, according to IAEA SSR-6 [1].■

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