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ENUN CASK – A success history

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ABSTRACT

The purpose of this paper is to explain the history of the ENUN dual-purpose bare-fuel type cask series from the conception until the first recent loadings, together with an update on the current design status and manufacturing process improvements.

After the design of the former ENSA-DPT cask in the 90's and the HI-EN collaborative cask design, Ensa started a new cask project to improve the performance and reduce the production costs of the casks, in order to provide Spanish NPPs with an improved and customized solution adapted to the country's actual spent fuel management strategy: the ENUN cask series. New materials, state-of-the-art calculation methodologies and improved manufacturing processes were studied in order to increase the competitiveness of the cask. This design process led to the submittal of the first revisions of the Safety Analysis Reports of the ENUN 32P to the Spanish nuclear authority in 2011. Shortly after, a smaller and customized BWR version of the ENUN cask was designed for Santa María de Garoña NPP, whose license was obtained in November 2014 for Storage and in June 2015 for Transportation. In parallel, a Chinese transportation modified version of the ENUN 32P cask was designed for the Chinese market and licensed both in Spain and China in July 2017 and in April 2018 respectively.

After years of work, finally three ENUN 32P casks have been successfully loaded in Trillo and Almaraz NPP's in Spain in December 2018. Lessons learned directly related with these loadings include the composition of the anticorrosion protective coating in the inner surface of the casks and an update of the pressure transducer design for higher temperatures.

Currently, Ensa is also involved in design modifications to increase the capabilities of the ENUN casks, new materials and manufacturing processes, so that the overall production process can be improved in terms of time and cost. Also, ENSA is now implementing the Building Information Modeling methodology to study the manufacturing flow (4D planning) for expected large series of new units of ENUN casks needed from the NPPs and the potential collisions with other large nuclear component being manufactured at ENSA's facility.

INTRODUCTION

The ENUN cask is today a successful cask for use in 5 nuclear power plants throughout the world, allowing the storage and transportation of spent fuel. This cask however has not been the first involvement of the company Equipos Nucleares S.A., S.M.E. (Ensa) in the world of the transportation and storage of spent fuel. Before the ENUN cask existed, Ensa has manufactured casks of other designers, and manufactured and developed other proprietary cask designs, including loading campaigns in Spain. Gaining the required experience in the manufacturing and loading of casks Ensa decided to develop its own cask designs, of which the ENUN cask represent today the culmination.

HISTORY

The following is a summary of Ensa history in the field of spent fuel cask design and fabrication. Ensa, as a renowned company in the field of manufacturing of main nuclear components, has experience in cask manufacturing since 1985.

DPT Cask. In the 1991 Ensa developed the dual-purpose cask, the DPT deployed at Trillo NPP in Spain, based on an existing design of Nuclear Assurance Comp. Intl. (NAC) of the U.S.A. This existing design, the STC-26, was already approved by the Nuclear Regulatory Commission in U.S.A. after an order was received by NAC-Ensa from Enresa in 1988 for Almaraz NPP. The design of the DPT was adjusted from the STC-26 design, to accommodate the fuel of Trillo NPP and the specific plant requirements. In addition, some changes were made to the original design of STC-26, such as fewer basket positions: 21 PWR positions vs. 26 positions and changes in the materials in the basket.

The project was led by Enresa (public company responsible of nuclear waste management in Spain), acting as licensee and owner of the cask. Ensa was responsible for the design, calculations, scale model tests, thermal load test, manufacturing and loading on site. The design was led by Ensa with the collaboration of NAC regarding nuclear calculations, reviewing and licensing support. This cask has been loaded by Ensa staff in Trillo NPP from 2002 until 2017, with a total of 32 casks successfully loaded and transferred to the ISFSI (storage building).

HI-EN69 cask. Similarly, in the late 90’s (1998), a conceptual design was developed for Hitachi Ltd., a new dual-purpose cask for BWR fuel with maximum capacity and competitive cost for the Japanese market, mainly intended for the Mustu large storage site. Ensa worked on conceptual design, feasibility studies, manufacturability, structural calculations, thermal, material evaluation, design criteria and shared responsibility in the implementation and subsequent evaluation of the drop tests on a 1/3 scale model. Ensa manufactured the 1/3 scale prototype to demonstrate the manufacturability to the final client and to the Japanese regulatory authorities. Furthermore, Ensa was responsible for conducting the thermal test in the first unit manufactured of this design. In Japan, Hitachi received an initial order for 50 units. Currently, there are 17 casks loaded at Fukushima Daiichi Nuclear Power Station.

Figure 1. The DPT and HI-EN 69 casks

ENUN cask. Due to the evolution of the market and the new requirements of the nuclear power plants to load spent fuel with improved parameters, Ensa continued during the 2000s the research on new materials, calculation methodologies, etc. to apply to a new design of metal cask more competitive than the DPT cask. From this research, different R&D projects were initiated, culminating in a redesigned dual-purpose metal cask called ENUN (ENsa UNiversal). The R&D projects were aimed to develop a PWR fuel cask and also a BWR cask for all existing nuclear power plants in Spain, including a new design for impact limiters with new materials (other than wood). In these projects, Ensa has been the only responsible and has acted both as designer and as licensee. Ensa is responsible for all design, calculations, manufacturability study, analysis and evaluation of materials, model tests, regarding the regulatory requirements and licensing activities of the ENUN.

In 2013 Ensa was awarded a contract to develop a cask for the transportation of the Spent Fuel in P. R. China. For this project Ensa customized the design of the existing ENUN 32P cask according the requirements of the Chinese customer and developed the ENUN 24P cask. The adaptations considered for the ENUN 24P included the development of female trunnions, increasing of basket plates thicknesses and modification of the impact limiter design for the reduction of the outer diameter. Although the ENUN 24P has been designed for storage and transportation, the customer required only the transportation license that included high burnup fuel.

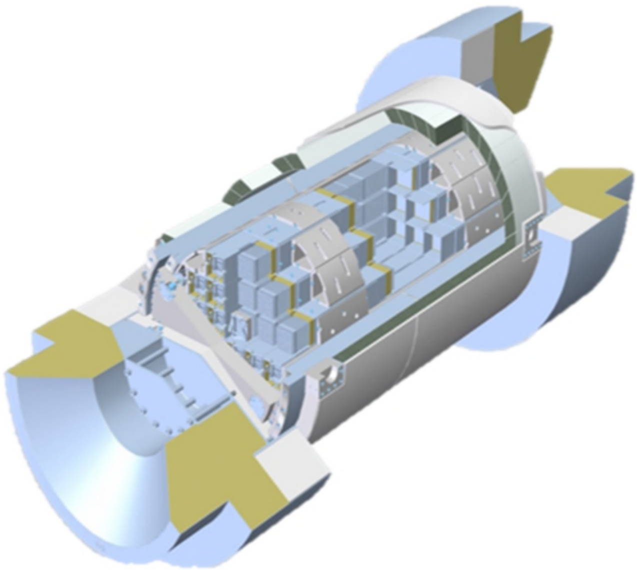

Figure 2. The ENUN 24P cask

The main specifications of the casks mentioned above are summarized in the following table:

Attribute	HIEN 69	DPT 21	ENUN 32P	ENUN 52B	ENUN 24P
Purpose	Storage / Transport	Storage / Transport	Storage / Transport	Storage / Transport	Transport
Capacity (FA)	69	21	32	52	24
Fuel Types	BWR	PWR	PWR + NFH	BWR	PWR
Loaded Weight - Storage Condition (Tons)	121	105	120	72	-
Overall Length - Storage Condition (m)	5.3	5	5	4.8	-
Overall Cross Section - Storage Condition (m)	2.5	2.4	2.7	2.1	-
Distance between Trunnions (m)	2.8	2.4	2.8	2.2	2.5
Loaded Weight w/Impact Limiters - Transport Condition (Tons)	132	113	137	82	121
Overall Length w/Impact Limiters - Transport Condition (m)	6.8	6.7	8.3	7.6	7.9
Overall Cross Section w/Imact Limiters - Transport Condition (m)	3.6	3.2	3.8	3.2	3.3
Heat Rejection (kW)	12.1	27.3	40.1	13	39.3
Maximum Burnup (GWd/MTU)	40	49	58.5	37.5	57
Maximum Enrichment U-235 (%)	3.1	3.7	4.9	3	5
Minimum Cooling Time (years)	18	9	7	22	3
Body Material	CS	SS/Lead/SS	CS	CS	CS
Basket Material	BSS+Al	SS + Al + +MMC	SS + Al + MMC	SS + Al + MMC	SS + Al + MMC
Gamma and Neutron Shield	CS+ Resin	SS/Lead/SS + Resin	CS+ Resin	CS+ Resin	CS+ Resin
Lids	Triple Lid (CS)	Double Lid (SS3)	Double Lid (SS)	Double Lid (SS)	Double Lid (SS)
Cask Sealing	Double Metallic O-rings in lids	Double Metallic O-rings in lids	Double Metallic O-rings in lids	Double Metallic O-rings in lids	Double Metallic O-rings in lids

CS: Carbon Steel;
SS: Stainless Steel;
BSS: Borated Stainless Steel;
MMC: Metal Matrix Composite;
NFH: Non fuel hardware;

Table 1. Ensa's casks main parameters

ENUN CASK GENERAL DESCRIPTION

The ENUN cask concept is constituted by a single inner shell made of forging material. A flat forging plate of the same material is welded to the lower part of the shell constituting the bottom of the cask. The upper part of the inner shell is mechanized, to allow the attachment of the inner and outer bolted lids. It performs the following three main functions: structural, containment and shielding, mainly against gamma radiation. The shell and bottom can be comprised of two or three pieces of forging that are joined by means of a circumferential full penetration weld. The contact surfaces of the upper section of the inner shell with the inner and outer lids are protected with an austenitic stainless weld cladding around the metallic gaskets area.

A set of aluminum fins (aluminium extruded profiles) is radially disposed around the inner shell, to help extracting the decay heat of the fuel from the inner cavity outside of the cask, in a passive way. Poured inside the Aluminium fins is the neutron shielding material, a solid synthetic polymer with boron carbide, performing shielding against the neutron radiation. Confining the aluminum fins and the neutron shielding material there is the outer shell, made of a rolled plate with upper and lower closing rings. It constitutes the outermost radial surface of the cask. Within this outer shell are placed the relief valves that limit the pressure in the space between the inner and the outer shell, where the aluminum fins and the neutron shielding material are placed.

A set of four trunnions made of high resistance steel are bolted to the inner shell. There are two upper ones to lift the cask, and two lower ones to help in the cask hadling operations. A draining tube made of stainless steel placed in the inner cavity conducts the water during draining operation and the helium during the further drying operation, to the draining penetration lid embedded in the inner lid. The draining tube is attached to the anti-rotation bar which is welded to the inner cavity. It maintains the basket relative position and avoids its rotation in relation with the cask body.

The cask closure system is constituted by two lid that can be bolted to the cask body. A Helium pressurized gap exists between both lids. The inner lid is part of the containment barrier while the outer lid constitutes a redundant protection barrier against any kind of impacts. The inner lid includes two penetrations embedded with their corresponding bolted lids, for draining and drying operation (drain and vent penetrations). The outer lid includes one single embedded penetration to check the pressure in the space between the lids, and control that any hypothetical leak from the containment boundary is produced (control pressure penetration). All penetrations include fast connection plugs for all loading, unloading and pressure monitoring operations.

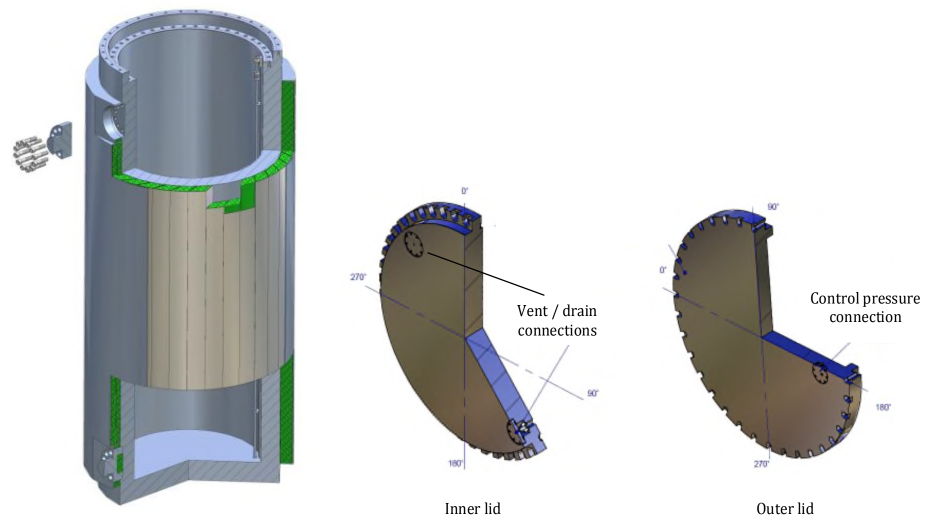

Figure 3. ENUN cask body and lids

The basket is constituted by a grid of stainless steel plates arranged in an "egg-crate" type structure, constituted by multiple cells. The basket rails are aluminum profiles bolted to the periphery of the stainless steel structure. They contribute to the decay heat dissipation and give a rounded shape to the entire basket structure to better fit inside the inner cavity of the cask. Inside the cells are inserted the fuel tubes. They are square prisms made of welded plates of neutron absorber material: a metal matrix composite (MMC) constituted by an aluminum matrix with boron carbide added (B_4C).

Depending on the specific design of each ENUN model, the fuel tubes can also be simplified as plates, which avoid the need of welding the tubes. Additionally, in some cases due to customer requirements, a double stainless-steel plate basket is needed to create a "flux-trap" (such as the case of the ENUN 24P cask).

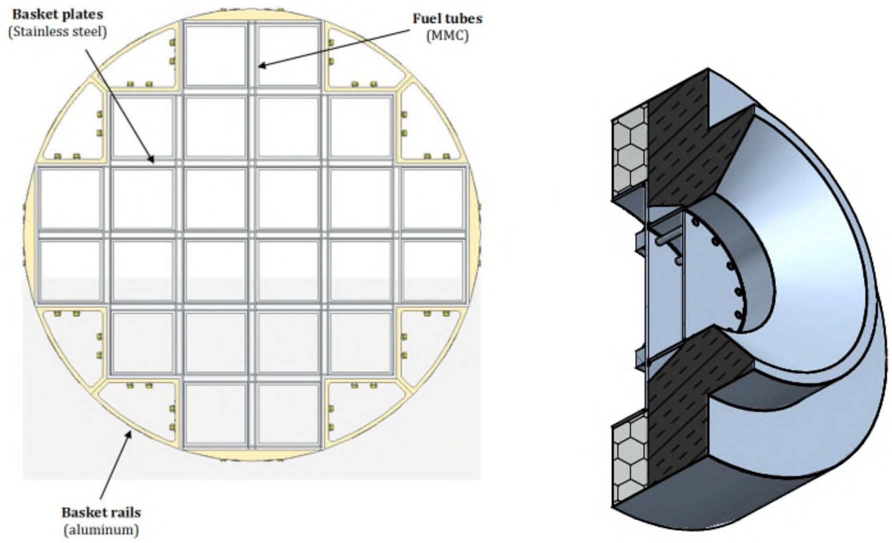

Figure 4 Basket Layout of the ENUN 24P Cask and Impact Limiter section

A set of stainless steel plates are located surrounding the basket plates and welded to the plates of the basket structure. They strengthen the whole assembly and the connection of the basket guides by means of welded threaded rods attached with nuts and washers. They also provide shielding against gamma radiation. Extruded Aluminium profiles that hold the fuel cells and constitute the transition between the polygonal periphery of the cells and the rounded shape of the cask body. They contribute to the removal of heat from the inner cavity.

The outer surface of the cask body is painted with a protective epoxy-based coating, while the inner cavity surface is protected with an anti-corrosion coating.

The impact limiters are constituted by a stainless steel envelope, a set of steel inner and outer reinforcement discs, polyurethane foam poured inside the envelope and a ring of aluminum honeycomb blocks surrounding the outer surface of the cask. Sixteen stainless steel bolts pass through a set of rounded tubes that connect inner and outer discs, to attach the impact limiters top the cask. The polyurethane foam is the material used to absorb the impact forces. In addition, several blocks of aluminum honeycomb placed around the outer surface of the cask contribute to the energy absorption. Furthermore, due to high thermal conductivity of the aluminum, they also enhance the heat extraction.

The impact limiters of the ENUN casks have been designed and developed by Ensa in collaboration with SANDIA National Laboratories, USA.

Latest developments in design

The ENUN cask is constantly under the process of improvement. Not only major design adaptations can be performed to customize the cask design for new customers (new fuel types, specific power plant restrictions, different crane capacities, etc.) but there have been some generic design improvements that are applicable to all the ENUN cask range, some of which are still under way. Some of these generic design improvements have been developed in the last months after the first loading campaigns of the ENUN 32P, such as the protective anticorrosion coating applied in the inner wall of the cask cavity, and the pressure transducer adaptation.

During the cold tests of the ENUN 32P cask in the first unit of Almaraz NPP, before the first loading campaign took place in December, it was observed that the water of the cask cavity in the power plant gradually lost its transparency. It was soon perceived that the specific chemistry of the power plant pool water was affecting the carbon steel forging through some corrosion mechanism. Ensa then initiated a series of tests to thoroughly study an characterize this corrosion mechanism to better adapt the ENUN cask to the chemistry of the power plant water.

The tests involved the use of the 1/3 scale mockup of the ENUN 32P cask, and some mockups of lids and metal cylinders that represented the basket (Aluminium and Stainless Steel and inner shell (carbon steel forging). Tests were conducted at different temperatures of the water (30-60ºC) by electric heating means, and with different types of anti-corrosion layers (various degrees of Zn-Al mixing, HVOF Inconel and SS coating) and different surface treatments such as shoot peening. The objective of the tests was to identify solutions that did not affect significantly the chemistry and that did not create turbidity in the pool water.

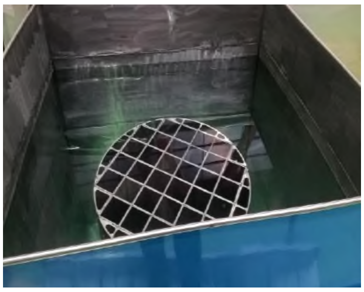

Figure 5. 1/3 scale basket in corrosion test pool

After the tests performed the main corrosion mechanisms identified were areas that suffered general corrosion and areas that suffered galvanic corrosion. To avoid these, Ensa has decided to apply thermal spray anti-corrosion coatings in the inner cavities of the different casks, as the most convenient solution for the borated water of the PWR pools and the deionized water of the BWR pools.

Another design improvement of the ENUN cask involves the update of the pressure transducer design. During the first loadings of the ENUN 32P it has been used the same pressure transducer than the ones used in the DPT cask. However a new pressure transducer have been adapted in collaboration with the supplier in order to achieve resistance to higher temperatures when loading spent fuel with higher thermal loads.

LICENSING AND MANUFACTURING STATUS

In 2015, Ensa was awarded by Enresa an order for 10 units of the ENUN 32P cask for the Almaraz and Trillo plants. The ENUN 32P has been the first ENUN cask whose license was requested by Ensa in 2012 and achieved in September 2015 (Storage). The ENUN 32P is currently licensed by the Spanish nuclear authority (CSN) for storage and transportation of the nuclear spent fuel of the 6 existing PWR type NPPs in Spain (NPPs: Almaraz I and II, Trillo, Vandellós II, Ascó I and II). Additionally, Ensa has requested approval to include in the license, damaged and high-burnup fuel. Currently, 3 ENUN 32P casks have been loaded in Trillo and Almaraz and more are expected to be loaded in 2019.

The ENUN 24P is a cask specifically developed for the Chinese fuel transport market. Although it is designed for storage and transportation, it has been licensed only for transportation in Spain (July 2017) and P.R.China (April 2018), including high-burnup fuel. In 2018, one unit was delivered to P. R. China. This cask has a somewhat lower capacity (24 PWR type elements compared to 32 of the ENUN 32P) since the Chinese regulator does not allow to apply credit to the burnup in the criticality evaluations, and it is necessary to allow separation between adjacent fuel assemblies.

Regarding BWR fuel, Ensa received in 2011 an award for 5 units of the ENUN 52B for Santa María de Garoña NPP. These units have been manufactured and are already licensed for storage and transportation since November 2014 and June 2015 respectively. Ensa is currently working on the update of the license documents of the ENUN 52B cask to allow the loading of all the spent fuel inventory of Santa María de Garoña NPP in case new contracts are awarded to the company.

All Ensa ENUN casks are licensed as Type B(M)F or B(U)F casks according to IAEA Safety Requirements No. SSR-6 (Ed. 2012)

As part of its continuous improvement endeavors, Ensa has recently performed a deep study of the manufacturing means needed in order to supply large number of casks in short periods of time. As a result of this study, Ensa has currently identified all investments and changes necessary to implement in case a large order of casks is received. With the needed workshop adaptation Ensa would be able to supply one fully manufactured cask every week without major impact in the other manufacturing lines.

OTHER RELATED ACTIVITIES

Ensa has recently participated with Sandia National Laboratories in different tests involving the use of the ENUN cask, or ENUN cask components. These tests include the multi-modal transportation test using an ENUN 32P cask, the 30cm drop test using the 1/3 scale mock-up of the ENUN 32P cask, and the dummy fuel drop using an MMC tube from the ENUN 32P basket and full-scale dummy fuel assembly specifically manufactured by Ensa.

CONCLUSIONS

After involvement in different cask designs Ensa has finally developed and loaded its ENUN cask, the first cask entirely designed and licensed by the Spanish company. This cask represents the success of the company in the field of the spent fuel storage and transportation solutions. The ENUN cask has been recently used in different research tests conducted by Sandia National Laboratories.

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