A Well Established System For The Dry Storage Of Spent Fuel

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ABSTRACT

The German company GNS Gesellschaft für Nuklear-Service mbH today looks back on more than 30 years of operational experience with dual-purpose casks. Following customer demands, GNS developed two different cask types for SNF – the CASTOR® and the CONSTOR® cask type. While the CASTOR® type is optimized for high thermal loads – which allows loading after extremely short cooling times and/or high burn-up of the SNF – the CONSTOR® type is cost-optimized for the cost-efficient storage of large quantities of cooler SNF.

By now almost 1,300 GNS-casks are in operation worldwide. In Germany alone, more than 1000 CASTOR® casks are stored with individual storage periods of up to 30 years. Taking into account the additional casks that have to be manufactured, loaded and stored during the final years of the German Nuclear Phase-Out, there will be 2000 casks by GNS in operation worldwide.

The presentation will give an overview over several national and international projects and show the bandwidth of customized solutions by GNS.

1. INTRODUCTION

For several decades in the use of nuclear energy the common solution for the interim storage of spent nuclear fuel (SNF) have been spent fuel pools. As integral part of the plants the fuel pools were designed to accommodate – at the most - all the spent nuclear fuel assemblies accumulated during the originally intended plant life time.

While internationally there still are no final repositories for high-level waste in operation or at least in construction, many plants are reaching the end of their originally intended life time as well as capacity limits of their fuel pools. A prerequisite for the in many cases aspired plant life extensions is a feasible way for removing the fuel assemblies from the pools to additional storage facilities. In addition to these rather practical and economical issues, the interim storage in spent fuel pools has undergone a substantial re-evaluation as a consequence of the Fukushima Accident. Therefore systems for dry interim storage in dual-purpose casks become increasingly important.

2. THE ROLE AND EXPERIENCE OF GNS IN GERMANY

GNS is fully owned by the German utilities, the percentage of their shares roughly oriented on their individual number of NPPs. For more than 25 years, GNS has been responsible for the management of all the radioactive waste and the SNF resulting from the operation of the German NPPs. Its products and services comprise the design and manufacturing of casks and containers for ILW and HLW, the construction of equipment for the conditioning and packaging of wastes as well as the operation of conditioning and interim storage facilities.

The complete life cycle of the spent fuel casks is covered by GNS, since it is not only the designer and manufacturer of the casks, but is also responsible for the loading, transport and storage of the casks within the NPPs. Operational experiences gained during several hundred loadings mostly carried out by GNS' own staff result in a cask design which offers easy handling and guarantees minimum turnaround times within the reactor unit.

Fig. 1. Loading of a CASTOR® V/19 for PWR-FA

3. HISTORY OF INTERIM STORAGE IN GERMANY

In contrast to most other countries using nuclear energy, Germany's nuclear industry pursued already in the 1970s feasible ways for dry interim storage in dual-purpose casks.

3.1 THE FIRST DUAL-PURPOSE CASK

Already in the mid 1970s German utilities commissioned a small German company called "GNT Gesellschaft für Nuklear-Transporte mbH" which was just about to be renamed to "GNS Gesellschaft für Nuklear-Service mbH" with the development of a – back then – revolutionary concept: a dual-purpose cask for both transport and long-term dry interim storage of spent fuel.

Based on the design features necessary to meet all the intended protection goals of the casks, GNS' developers decided to use cast iron as the material for the cask body. First prototypes were developed and as early as 1978 the very first drop tests was performed. A series of tests proved the safety and robustness of the cask even under severe accident conditions. About the same time the name CASTOR® was established and has been GNS' unique trademark ever since.

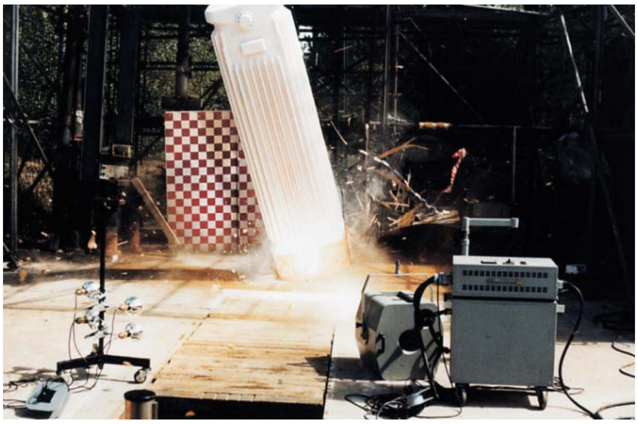

Fig. 2. Drop test of CASTOR® Ia

Even back then the CASTOR® casks already had the same basic safety features to fulfil all the necessary protection goals, such as the double-lid system for safe enclosure of the radioactive material, the cooling fins for steady heat removal and the deep boreholes inside the casks wall filled with moderator material for neutron moderation.

Based on this original cask design the first casks were manufactured and – starting with the very first cask at Paul-Scherrer-Institut in 1983 – loaded with spent fuel and put into interim storage.

3.2 CONSTRUCTION OF THE FIRST INTERIM STORAGE FACILITIES

In the early 1980ies the German utilities decided to build two large central interim storage facilities, one at Ahaus, the other one at Gorleben, for SNF and later also for the residues from reprocessing of German SNF. Each of these storage buildings offers 420 storage positions for dual-purpose casks. In 1989 these two facilities were taken over by GNS and have since then been part of its operations.

3.3 POLITICAL DECISION AGAINST REPROCESSING

Also starting at the end of the 1970ies, the German utilities contracted reprocessing plants in France and the UK to reprocess German SNF as long as the projected German reprocessing plant was not available.

Since these plans to establish an own reprocessing plant in Germany had to be stopped due to the lack of public and political acceptance, for many years SNF from the German NPPs was shipped to La Hague and Sellafield for reprocessing. Only the residues from reprocessing had to be taken back to Germany and, also safely stored in CASTOR® casks, were brought to the Gorleben interim storage facility.

With the political decision of the year 2000 to quit reprocessing by banning transports of SNF, a total of twelve on-site interim storage facilities had to be erected at all the NPP's sites for the interim storage of the SNF assemblies until the availability of a final repository. With this paradigm shift, the demand for GNS SNF casks now necessary for holding all the spent FA instead of only the residues from reprocessing rose to unprecedented numbers.

3.4 GERMANY'S NUCLEAR PHASE-OUT AND CURRENT GNS CAPACITIES

Germany's decision of 2011 to totally phase out of nuclear energy by 2022 defined the number of SNF casks that still have to be loaded with SNF until all the German NPPs will be free from nuclear fuel and are thus ready for decommissioning. Counting from the phase out decision in 2011, there is a total demand of about another 800 dual-purpose casks for SNF and HLW from reprocessing within the next 15 years. To be able to reliably serve that demand as well as the additional demand from foreign customers, GNS has increased the manufacturing capacity to 80 casks per year.

Taking into account both all the casks by GNS that are already loaded and in interim storage facilities worldwide as well as the additional casks that have to be manufactured, loaded and stored during the final years of the German Nuclear Phase-Out, there will be total of 2000 GNS casks for dry interim storage in operation by the end of the next decade.

4. PROTECTION GOALS AND TECHNICAL CONCEPT

The main idea of the dual-purpose casks by GNS is, that all the protection goals that have to be fulfilled during transport as well as for decades of dry interim storage are covered by the cask itself.

The four protection goals are:
Safe enclosure of the radioactive contents
Shielding of radiation
Dissipation of the decay heat from the radioactive material
Guarantee of subcriticality

The GNS casks can be stored with or without storage buildings depending on national regulations and local conditions. For heat removal from the storage buildings, a passive cooling system by natural convection is sufficient and well established in all of the German interim storage facilities. This makes the interim storage of the casks a completely passive system. Storage buildings may provide additional protection from environmental influences and reduce radiation exposure to the public.

4.1 SAFE ENCLOSURE OF THE RADIOACTIVE CONTENTS

To guarantee the safe enclosure of the radioactive contents, the casks are equipped with a double-barrier system made of forged stainless steel lids with metal seals. During interim storage the lid system consisting of the two barriers is permanently monitored for leak-tightness. Monitoring is performed by a pressure switch which is integrated in the secondary lid.

4.2 SHIELDING OF RADIATION

The cask consists of a thick-walled (about 40 cm) monolithic body made of ductile cast iron. The cask body together with the lids is responsible for the shielding of Alpha-, Beta and Gamma-radiation. For neutron moderation, axial boreholes are drilled into the cask wall and filled with polyethylene moderator rods. In addition, there are plates of polyethylene at the bottom end and on the underside of the secondary lid.

4.3 DISSIPATION OF THE DECAY HEAT FROM THE RADIOACTIVE MATERIAL

On the outside wall of the cask body, cooling fins are integrated depending on the heat load from the casks inventory. From the second cask generation until today these fins radially machined into the cask body. This enlarges the surface of the cask by a factor of about 3.

4.4 GUARANTEE OF SUBCRITICALITY

The design of the cask and its components guarantees subcriticality under standard as well as accident conditions.

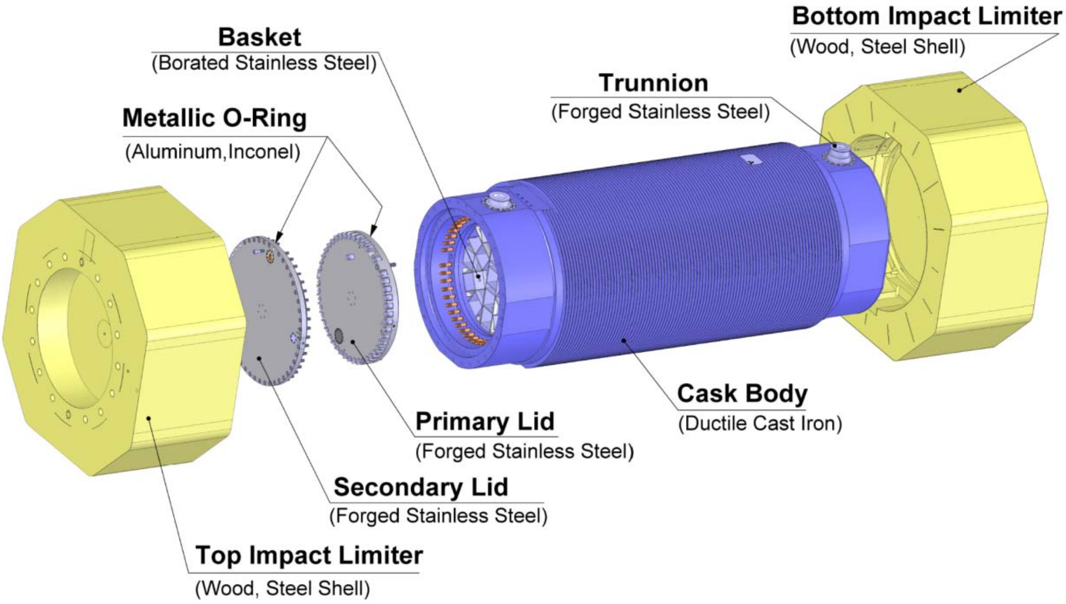

Fig. 3. CASTOR® V/19 in transport configuration (with impact limiters)

5. CASK EVOLUTION, NATIONAL AND INTERNATIONAL PROJECTS

5.1 THE FIRST GENERATION

The CASTOR® Ia prototype used for the first drop tests was already featuring the original dimensions: weighing approx. 70 tons, it was six meters long, and nearly two meters in diameter.

The initial designs for the first CASTOR® casks included the Ia, Ib and Ic casks, which were designed to accommodate spent fuel with approx. one year cooling time after discharge from the reactor, and had capacities of 4 PWR or 16 BWR fuel assemblies.

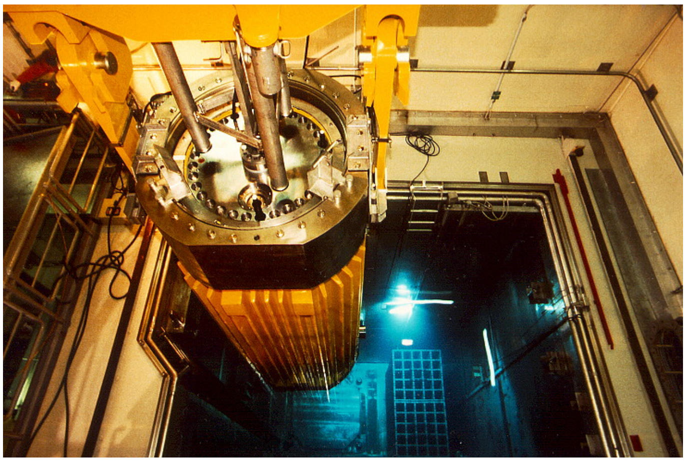

Fig. 4. CASTOR® Ib after loading

One version of the CASTOR® Ic was modified to hold fuel from the Diorit reactor at the Paul Scherrer Institute (PSI) in Switzerland. The loading of this cask in 1983 was in fact the very first loading of a CASTOR®. The fuel is still stored in the cask in Switzerland today, more than thirty years after its loading.

5.2 THE SECOND GENERATION

Beginning in 1984, a completely new generation of casks was designed for larger capacities and longer cooling times of the fuel using advanced engineering and production technology such as CNC machining.

Based on a cooling period of five years in the SNF pool, a new cask family was introduced called CASTOR® V. It included the CASTOR® V/21, which holds 21 PWR assemblies of the Westinghouse type. This cask type was first loaded at the Surry Power Station in Virginia. A total of 25 of these casks have been kept in an open-air interim storage facility on the site for more than a quarter of a century now.

Fig. 5. CASTOR® V/21 casks at Surry Powerstation, Virginia/USA

For SNF from the German NPP, two similar casks have been designed, licensed and delivered: for PWR fuel the CASTOR® V/19, and the CASTOR® V/52 for BWR fuel. Today already more than 350 of these casks have been loaded and are stored in German interim storage facilities. Following demand from various customers GNS modified existing casks and designed wholly new casks for SNF and HLW.

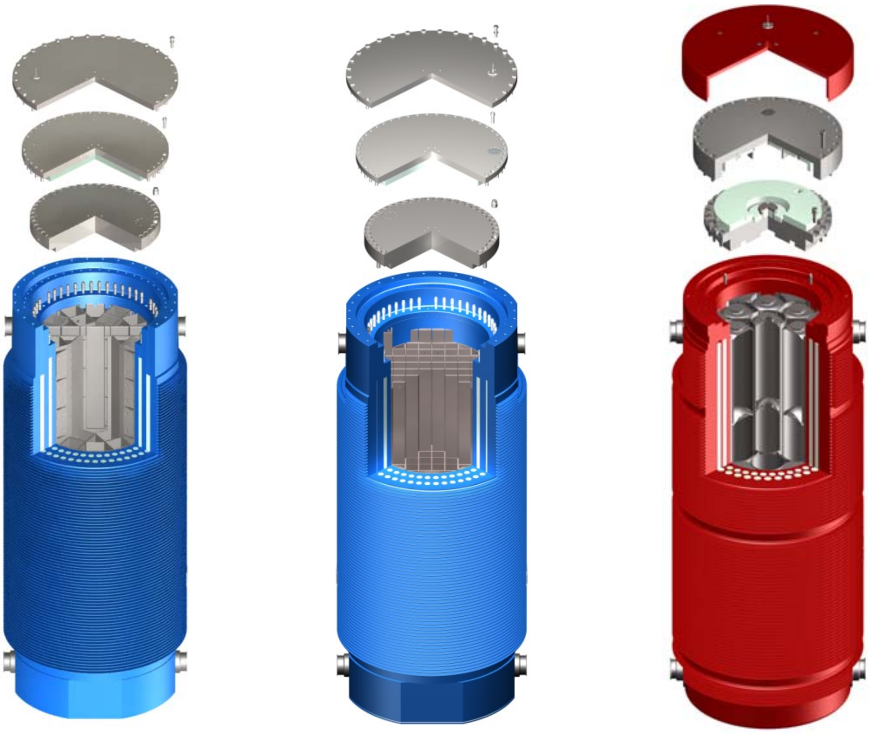

Fig. 6. CASTOR® V/19 (PWR), V/52 (BWR), HAW28M (HLW)

The newest member of the CASTOR® family is the 1000/19, which was designed to accommodate 19 PWR-FA from Temelin NPP.

Fig. 7. CASTOR® 1000/19 in the interim storage facility at Temelin/Czech Republic

5.3 CASTOR® KN-12 – A SLIGHTLY DIFFERENT DESIGN FOR A SLIGHTLY DIFFERENT PURPOSE

Based on the wide experience of designing casks for different customers and purposes, GNS signed a joint venture with DOOSAN in 2000. The aim was the development, design and the manufacturing of a forged steel cask for the Kori Nuclear Power Plant for the wet transfer of spent fuels between the units. While GNS was responsible for the design and licensing of the cask, the manufacturing was done by DOOSAN. The CASTOR® KN-12 has been designed to accommodate 12 PWR-FA. Two CASTOR® KN-12 have been used since 2002, while three additional casks have been manufactured and delivered in 2007.


Fig. 8. CASTOR® KN-12 for the wet transfer of spent fuel at Kori /S. Korea

5.4 AN ALTERNATIVE CASK DESIGN FOR DIFFERENT DEMANDS

As an alternative to the CASTOR®, GNS has also developed and delivered another line of casks, called the CONSTOR®. Its cask body consists of a hybrid structure, having an inner liner and an outer liner made of steel, with heavy concrete in between. Due to the properties of these materials, casks of this type can not handle as much decay heat as ductile cast iron casks, while the construction is much easier and not as costly.

Fig. 9. Schematic diagram of a CONSTOR® cask for hexagonal FA

Today a total of 104 CONSTOR® casks are in use at the Ignalina and Kozloduy NPPs.

5.5 INTERNATIONAL EXPERIENCE

From the beginning of the very first cask projects, the realization of dry interim storage systems were of great interest also to foreign customers. Today already a total of 281 GNS-casks for SNF and HLW are stored in ten interim storage facilities in seven countries outside of Germany, and this number is still increasing with the ongoing projects. Due to local requirements and legislation, not all of these casks have to be licensed for transport while in interim storage.

Table I: GNS casks in storage as of December 2014

Country	**Location**	**Number**
Germany	16 sites	1012
Lithuania	Ignalina	118
Czech Republic	Dukovany, Temelin	103
USA	Surry, Hanford, Idaho Falls	35
Belgium	Mol	7
Switzerland	Wuerenlingen	8
Bulgaria	Kozloduy	6
South Africa	Koeberg	4

5.6 VERSATILITY, FLEXIBILITY AND ECONOMIC ASPECTS

The casks of the CASTOR® and the CONSTOR® family are the basis of a well established system for the dry interim storage of SNF and HLW. Depending on the properties of the radioactive materials as well as local legislation, GNS offers adequate and economic solutions adaptable for manifold kinds of SNF and HLW from commercial and research reactors. The total costs of interim storage projects differ very much depending on the special requirements of every single project: Does the heat generation of the SNF require CASTOR® casks or might a CONSTOR® be the appropriate package? What kind of storage building is necessary to meet the local legislator and geological needs?

In general the following can be stated in comparison to long term storage in pools:

Since the main protective goals are already covered by the casks, the additional infrastructure and storage facilities are by far less expensive than for wet storage.

The main investment for wet storage accrues at the start of the project for the erection of the building, while the casks for dry storage can be purchased as they are actually needed.

Obviously the operational costs of a wet storage system are significantly higher than those of a dry storage facility. With the availability of potential final repositories still in the remote future, dry storage becomes economically more attractive the longer the interim storage periods last.

6. CONCLUSIONS AND OUTLOOK

GNS casks for the dry interim storage of SNF and HLW have been in use for over three decades. Today more than 1200 casks are stored at 26 storage facilities in eight countries.

According to current plans there will be a total of 2000 GNS casks in dry interim storage facilities by the end of the next decade. Based on this unique experience GNS is one of the world's leading industry partners for the realization of dry interim storage solutions.