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CASTOR® and CONSTOR® A well established system for the dry storage of spent fuel and high level waste

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Kurzfassung

CASTOR® und CONSTOR® Ein bewährtes System für die trockene Zwischenlagerung bestrahlter Brennelemente und hochradiaktiver Abfälle

Die deutsche Firma GNS Gesellschaft für Nuklear-Service mbH blickt mittlerweile auf mehr als 30 Jahre Erfahrung in der Herstellung und der Verwendung von Großbehältern für den Transport und die Zwischenlagerung bestrahlter Brennelemente aus dem Betrieb von Kernkraftwerken und hochradioaktiver Abfälle (HAW) aus der Wiederaufarbeitung zurück.

Dem Bedarf ihrer Kunden entsprechend entwickelte GNS zwei unterschiedliche Behältertypen für bestrahlte Brennelemente – die CASTOR®- und die CONSTOR®-Bauarten. Während die CASTOR®-Behälter für hohe Wärmelasten optimiert sind – was eine Beladung bereits nach extrem kurzen Abklingzeiten und/oder hohen Abbrand der Brennelemente erlaubt – sind die CONSTOR®-Behälter für eine kosteneffiziente Lagerung großer Mengen kühlerer bestrahlter Brennelemente optimiert.

Während GNS-Behälter ein geeignetes und bewährtes Mittel sind, um Brennelementen vom Kraftwerk selbst in ein trockenes Zwischenlager einzulagern, hat der deutsche Ausstieg aus der Nutzung der Kernenergie zusätzlich den Bedarf nach einer Entsorgungslösung für Sonderbrennstäbe ausgelöst, die normalerweise bis zum Betriebsende im Brennelementbecken gesammelt werden. Zur Etablierung eines Entsorgungskonzeptes entsprechend dem Bedarf deutscher Betreiber hat GNS ein weltweit einmaliges Köchersystem für Sonderbrennstäbe entwickelt.

Bis heute sind bereits an die 1.300 GNS-Großbehälter im Einsatz, davon alleine in Deutschland mehr als 1.000 CASTOR®-Behälter mit Lagerzeiträumen von bis zu 30 Jahren. Unter Berücksichtigung der weiteren Behälter, die im Rahmen des deutschen Atomausstiegs noch gefertigt, beladen und eingelagert werden müssen, ist bis zum Ende des nächsten Jahrzehnts weltweit mit rund 2.000 eingesetzten GNS-Großbehältern zu rechnen.

Der vorliegende Beitrag bietet einen Überblick über zahlreiche nationale und internationale Projekte und zeigt die Bandbreite der kundenspezifischen Entsorgungslösungen der GNS.

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Introduction

For several decades the common solution for the interim storage of spent nuclear fuel (SNF) has been "wet" storage in 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 are still no final repositories for high-level waste in operation or at least under construction, many nuclear power plants are reaching the end of their originally intended life time, as well as the capacity limits of their fuel pools. A prerequisite for – in many cases – aspired plant life extensions is a feasible way for removing the fuel assemblies from the pools to external storage facilities. In addition to these rather practical and economical issues, the interim storage in spent fuel pools has undergone a substantial reevaluation as a consequence of the Fukushima accident. Therefore, systems for dry interim storage in dual-purpose casks have become increasingly important.

The role and experience of GNS in Germany

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

GNS offers all services around the complete life cycle of the spent fuel casks, since it is not only designer and manufacturer of the casks, but is also responsible for dispatching prior to transport and storage of the casks within the NPPs. Today, 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 (Figure 1).

History of interim storage in Germany

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

The first dual-purpose cask

Already in the mid-1970ies German utilities commissioned a small 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.

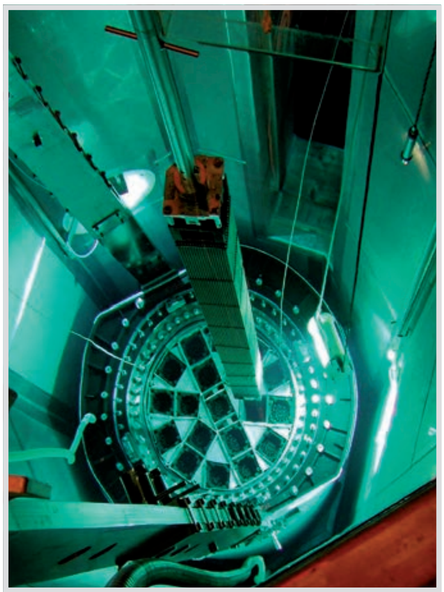

Fig. 1. Loading of a CASTOR® V/19 for PWR fuel assemblies.

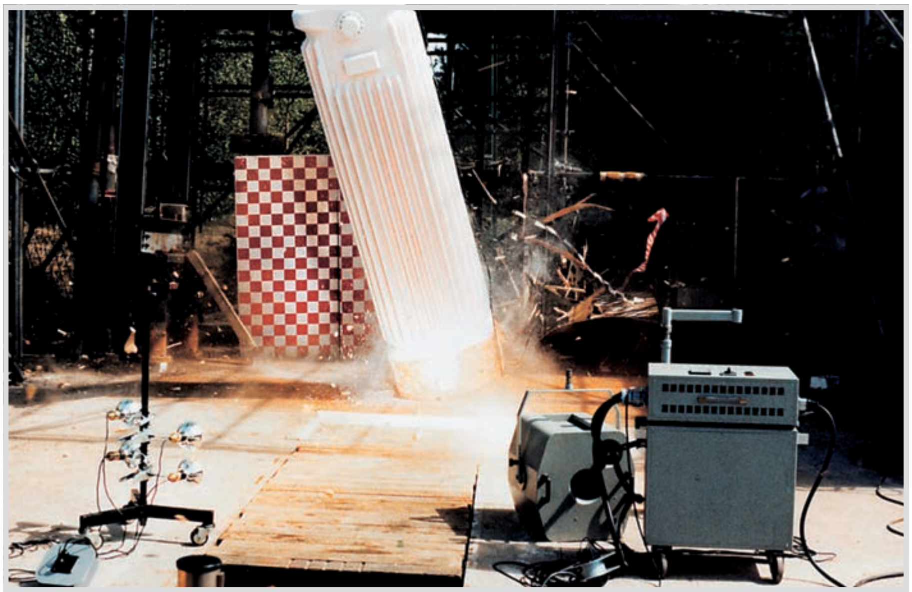

Fig. 2. Drop test of CASTOR® IA.

Based on the design features necessary to meet all the intended protection goals of the casks, GNS' developers decided to use cast iron as material for the cask body. First prototypes were developed and as early as 1978 the very first drop tests were 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 (Figure 2).

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 radioactive material, the cooling fins for steady heat removal and the deep boreholes inside the cask's wall, filled with moderator material to slow down fast neutrons.

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

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 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.

Political decision against reprocessing

Also starting at the end of the 1970ies, the German utilities contracted reprocessing services in France and the UK to reprocess German SNF, intended for a period as long as the then-projected domestic reprocessing plant Wackersdorf was not yet available.

Since these plans to establish an own reprocessing plant in Germany had to be stopped due to lacking public and political acceptance, SNF from German NPPs was shipped for many years 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 on the sites of operating NPP's for interim storage of the SNF assemblies until a final repository would be available. 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.

Germany's nuclear phase-out and current GNS capacities

Germany's post-Fukushima decision of 2011 to totally phase out nuclear energy by end-2022 defined the number of SNF casks that will still have to be loaded with SNF until all the German NPPs will be free from nuclear fuel, which is a prerequisite for decommissioning. Counting from the phase-out decision in 2011, there will be a total demand of about 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 its manufacturing capacity to 80 casks per year.

Taking into account all the GNS casks that were already loaded and in interim storage facilities worldwide, as well as the additional casks that will have to be manufactured, loaded and stored during the final years of the German nuclear phase-out, there will be a total of 2,000 GNS casks for dry interim storage in operation by the end of the next decade.

Protection goals and technical concept

The main design idea of the dual-purpose GNS casks 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 therefore 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 safety distances for the public further.

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 gauge which is integrated in the secondary lid.

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.

Dissipation of the decay heat from the radioactive material

On the outside wall of the cask body, cooling fins dissipate the heat load from the cask's inventory to the environment. From the second cask generation until today, these fins are radially machined into the cask body, extending the surface of the cask by a factor of about three.

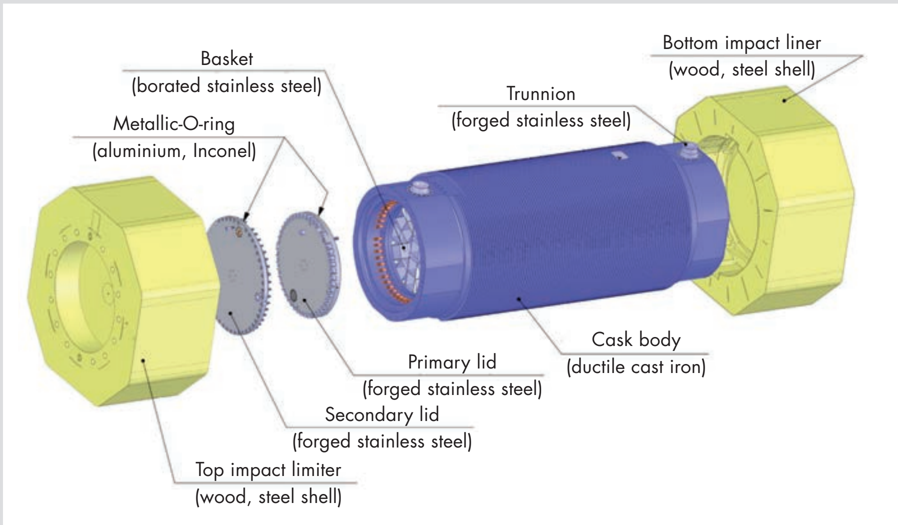

Fig. 3. CASTOR® V/19 in transport configuration (with impact limiters).

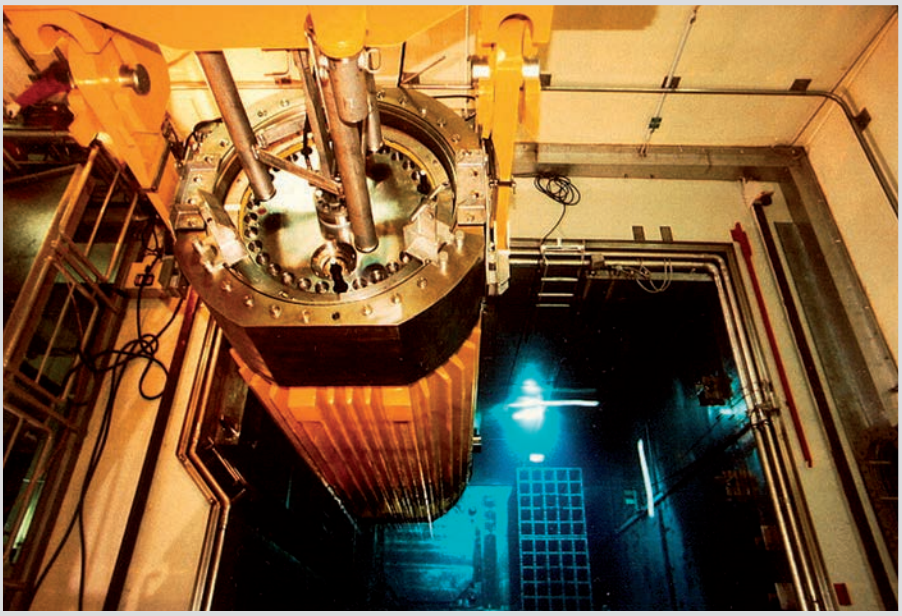

Fig. 4 CASTOR® Ib after loading.

Fig. 5. CASTOR® V/21 casks at Surry nuclear power station, Virginia/USA.

Guarantee of subcriticality

The design of the cask and its components guarantees subcriticality under standard as well as accident conditions (Figure 3).

Cask evolution, national and international projects

The first generation

The CASTOR® Ia prototype (used for the first drop tests) was already featuring the original dimensions: weighing approximately 70 tonnes, 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 approximately one year cooling time after discharge from the reactor, and had capacities of 4 PWR or 16 BWR fuel assemblies (Figure 4).

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.

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 technologies such as computerised numerical control (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/ USA. 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 (Figure 5).

For SNF from the German NPPs, 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 also designed wholly new casks for SNF and HLW (Figure 6).

The latest member of the CASTOR® family is the 1000/19, which was designed to accommodate 19 PWR fuel assemblies from the Temelin NPP in the Czech Republic (Figure 7).

An alternative cask design for different demands

As an alternative to the CASTOR®, GNS has also developed and delivered another line

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

of casks, called CONSTOR®. Its cask body consists of a hybrid structure, having an inner liner and an outer liner made of steel. The space between the liners is filled with CONSTORIT, a heavy concrete with special shielding characteristics, developed by GNS. Due to the properties of these materials, casks of this type cannot handle as much decay heat as ductile cast iron casks, but still fulfil the same safety functions as the CASTOR® while the construction is much easier and less costly (Figure 8).

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

International experience

From the beginning of the very first cask projects, dry interim storage systems were also of great interest 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 ongoing projects. Due to local requirements and legislation, not all of these casks had to be licensed also for transport purposes (Table 1).

Tab. 1. GNS casks in storage as of December 2014.

Country	Location	Number
Germany	16 sites	1,012
Lithuania	Ignalina	118
Czech Republic	Dukovany, Temelin	103
USA	Surry, Hanford, Idaho Falls	35
Switzerland	Würenlingen	8
Belgium	Mol	7
Bulgaria	Kozloduy	6
South Africa	Koeberg	4

In addition to these casks used for dry interim storage purposes, there are also CASTOR® casks exclusively used for transport of SNF, such as the CASTOR® KN12 in Korea or the CASTOR® TVO in Finland.

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 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 local legislation requirements including geological needs?

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

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

– 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 construction 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 lasts.

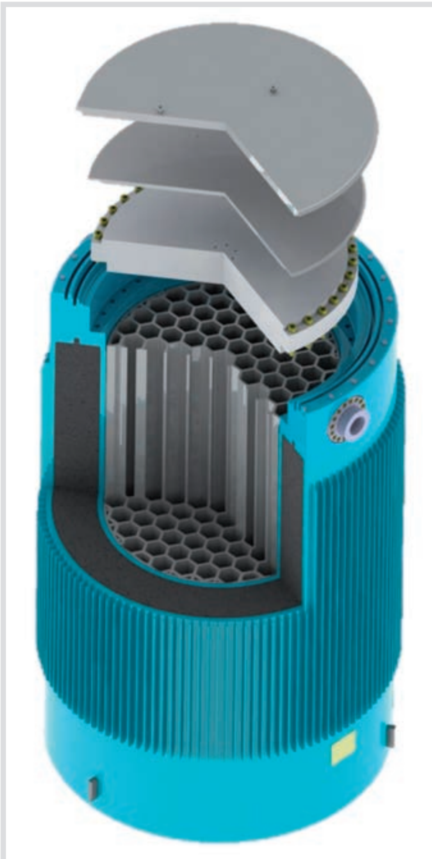

Fig. 8. Schematic diagram of a CONSTOR® cask for hexagonal fuel assemblies.

Quiver-system for the disposal of special fuel rods in CASTOR® casks

Special fuel rods (SFR) are fuel rods that had to be removed from fuel assemblies mainly due to their special condition, e.g. damaged cladding of the fuel rods which may have occurred during reactor operations. SFR are usually stored in the spent fuel pond after they have been removed from the fuel assembly until the final shutdown of the NPP. This makes removal of the SFR a prerequisite for achieving the status "free from nuclear fuel", an essential milestone to start decommissioning and dismantling of shutdown NPPs.

In order to establish a disposal concept suitable for the needs of German utilities, GNS developed a first-of-a-kind solution. Pursuing a combined approach to prepare and package SFR prior to dispatch and to its transport to the interim dry storage facility, GNS designed a quiver system. The overall concept encompasses the disposal of SFRs via CASTOR® V-casks. The quiver features a robust yet simple design, with high mechanical stability, reliable leak-tightness and large safety margins for future requirements from safety analyses.

Applications for use of the quivers in the transport and storage casks CASTOR® V/19 and CASTOR® V/52 have been submitted to the German regulators in accordance with transport regulations and nuclear law for interim dry storage. The examination and accompanying tests as well as the necessary qualification procedures are currently ongoing. The production of the quivers has started.

The quivers for special fuel rods can easily be adapted to a large variety of different fuel rod damages and be tailored to the specific needs of the customer. It is adaptable e.g. in length and diameter for use in other types of transport and storage casks and is applicable in other countries as well (Figure 9).

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 1,200 casks are stored at 26 storage facilities in eight countries. According to current plans, there will be a total of 2,000 GNS casks in dry interim storage facilities by the end of the next decade. In combination with the quiver system for special fuel rods, GNS offers a comprehensive solution for the complete removal of all fuel from ponds of operating as well as shutdown NPPs.

Based on this unique experience, GNS is one of the world's leading industry partners for realising dry interim storage solutions.

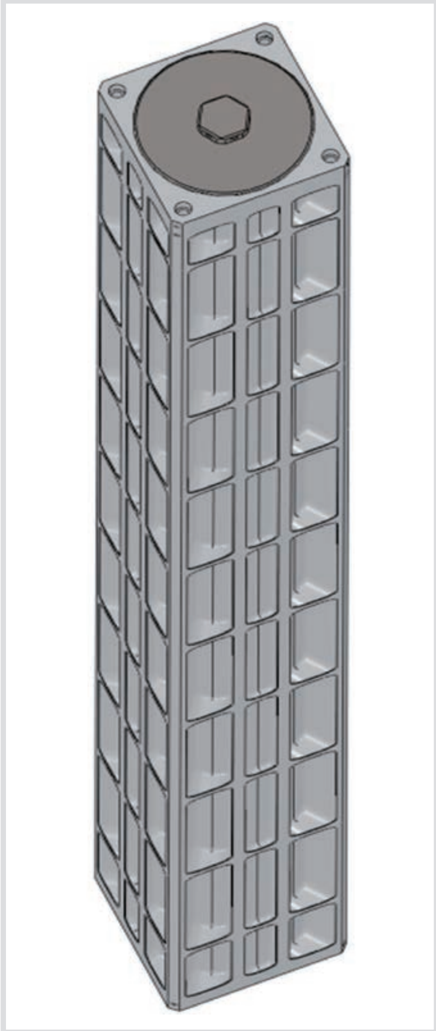

Fig. 9. Quiver for special fuel rods (schematic illustration).