GNS IQ –
The Integrated Quiver System for Damaged Fuel

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Abstract.
Complete removal of fuel from a NPP is a prerequisite for decommissioning and dismantling. In particular the defueling of damaged spent fuel and the following dry storage remains a challenge. Here we describe the development of the Integrated Quiver System and present the handling of damaged fuel rods and the dispatch of Quivers for the dry storage and transportation of damage spent fuel.

Keywords: Damaged spent fuel, Integrated Quiver System

BACKGROUND

Dry interim storage systems for spent fuel assemblies have been in use worldwide for more than three decades by now. Starting with the first CASTOR® dry storage systems by GNS in the early 80s, this proven and reliable technology has enhanced the safe storage of spent fuel in countless NPP worldwide. However, there has been no proven dry storage method for damaged fuel rods in Germany so far. Damaged fuel rods have been collected during the NPPs lifetime in the spent fuel pools. Complementing the dry storage technology for intact fuel assemblies a comprehensive solution for damaged fuel rods comprising concepts for transport as well as for storage had to be developed and implemented. This challenge becomes even more provoking, since the first high-capacity NPP have to be dismantled in short term and complete defueling of the corresponding pools becomes a requisite. In 2011, GNS was commissioned to find a solution on how to dispose of damaged fuel rods. GNS proposed to use the established GNS-casks equipped with an additional integrated Quiver system.

For that purpose, GNS designed two Quivers for damaged fuel rods to fit into the basket slots of the CASTOR® V/19 (PWR) and the CASTOR® V/52 (BWR) respectively. The customizable internal baskets of the Quivers facilitate the disposal of a large variety of nuclear inventory. Furthermore, the Quiver features a robust design and a welded closure system. This design has been affirmed by a series of tests and qualification processes, supervised by the German authorities. This first of its kind solution ensures the dry interim storage of all the damaged fuel rods from the German NPPs. The package design approval for the Quiver for CASTOR® V/19 was authorized in 2017 and for CASTOR® V/52 of the end of April 2018.

This work focuses on the robust design of the Quivers in combination with the main disposal concept, based on the CASTOR® V casks. We show the components of the Quiver and explain their mechanical characteristics during accident conditions of transport. Here we describe the handling of damaged fuel rods and the dispatch of Quivers for the dry storage and transportation of damage fuel rods in CASTOR® V cask.

It is the aim of the Quiver project to develop a one-fits-it-all solution for all different kinds of damaged fuel rods and to develop in addition comprehensive handling equipment to ensure a thoroughly dispatch of the damaged fuel rods inside the Quiver.

The Quiver project is divided into three subprojects. The first subproject [1] is the development and manufacturing of the first Quiver specimen as well as obtaining the package design approval for transportation and creation of application documents for obtaining the storage licences for interim dry storage facilities (In Germany the storage licensee holders are the utilities rather than the provider of the casks). The second subproject [2] is the development and manufacture of equipment for delivery, handling and dispatch of Quivers and the creation of supporting documents for the loading campaigns in the NPPs. The third subproject is the development and manufacture of equipment for handling and preparation of damaged fuel rods for the loading into the Quivers and into the Casks.

FIRST STEP: DESIGN OF THE INTEGRATED QUIVER SYSTEM

The Quiver for damaged fuel rods has been designed to be accommodated by the basket of the CASTOR® V/19 or CASTOR® V/52 using the same outer geometries as a standard FA. The overall length of the base body of the Quiver including head and foot pieces corresponds to the maximum approved total length of a PWR- or BWR-FA. The overall length of PWR-Quiver is 4950 mm with cross section 230 mm. The length of BWR-Quiver is 4460 mm with cross section 146 mm. All components of the Quiver are made of austenitic stainless steel.
The base of the Quiver consists of a monolithic body, an internal basket, a lid as well as a head and a foot piece (Figure 1). The components of the Quiver are manufactured according to the highest quality standards.

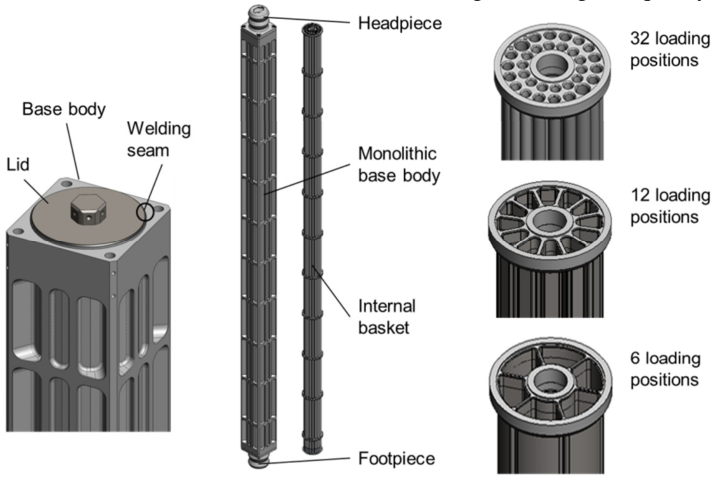

Figure 1: PWR-Quiver for damaged fuel rods: Sealing system (left), Head- and Foot piece mounted to the Base body and internal basket (middle) and exemplary configurations of internal baskets (right).

The base body of the Quiver is made by forging and then mechanically processed (Figure 2). This proves great advantage compared to a welded construction, since high mechanic loads must be coped with during accident conditions of transport as well as thermal stresses. Recesses are cut into the outer profile of the base body.

Figure 2: Manufacturing process of the PWR-Quiver base body.

The internal basket accommodates the damaged fuel rods. Various different diameters for loading positions have been defined. As a matter of principle, other configurations of the internal basket are also possible (Figure 1 right). The internal basket can be easily modified according to customer specifications and adapted to the required geometries and the amount of the damaged fuel rods available in the NPP. Thus, an optimization in terms of loading capacity is provided. If necessary, the internal basket can be taken off and unloaded from the Quiver.
The base body and the lid ensure the gas-tightness of the Quiver. The lid is screwed in and then welded, providing the leak-tightness of the Quiver. This has significant advantages compared to screwed connections in conjunction with gaskets, since relaxation effects in a screwed connection may be observed during dry storage, compromising the leak-tightness of the Quiver over the time. Because additional monitoring is not necessary, there are no significant follow-up costs. If required, the weld can be opened, allowing the retrievability of the damaged fuel rods.

SECOND STEP: LOADING OF DAMAGED FUEL RODS INTO THE QUIVER

German NPPs are equipped with several under water facilities and tools for the repair of fuel assemblies and the dismantling of fuel rods. During the repair process of fuel assemblies with damaged fuel rods, these rods were dismantled from the fuel assemblies and collected in receptacles inside the spent fuel pool for temporary storage. These under water tools can also be used for the unloading of the receptacles. This process is schematically shown in Figure 3:

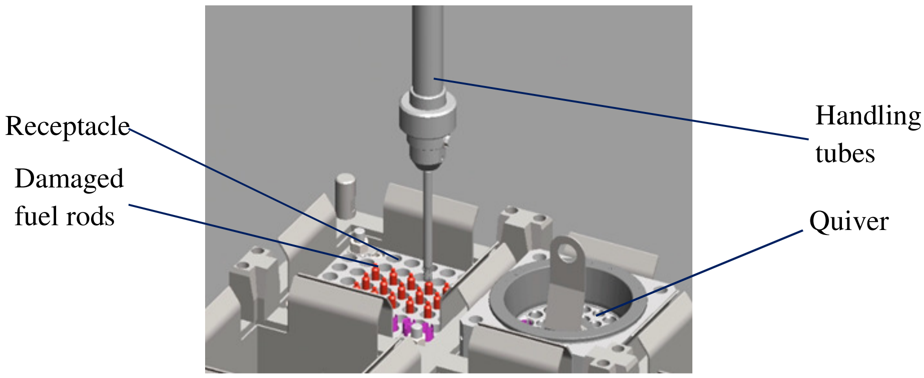

Figure 3: Damaged fuel rods and handling tubes with fuel rod sections are placed in a receptacle. The receptacle is positioned in the fuel assembly storage rack (left). Next to the receptacle the Quiver, also placed in the fuel assembly storage rack, is waiting for the loading (right).

For the unloading of the fuel rods with minor damages (e.g. gastight with reduced cladding thickness or gastight with deformations) from the receptacles, the fuel rod is gripped at its upper pin by means of a plier. The operator lifts the tool with the crane and moves the attached fuel rod above the Quiver. Subsequently, the fuel rod is lowered into a free loading position of the internal basket of the Quiver.

Before loading into the Quiver, heavily damaged fuel rods, fuel rod sections down to the size of pellets, are placed in small handling tubes. The handling tubes are handled by another type of gripper (Figure 4). However, the loading process of the handling tubes into the internal basket of the Quiver remains unchanged with respect to the fuel rods with minor damages which are directly loaded into the Quiver.

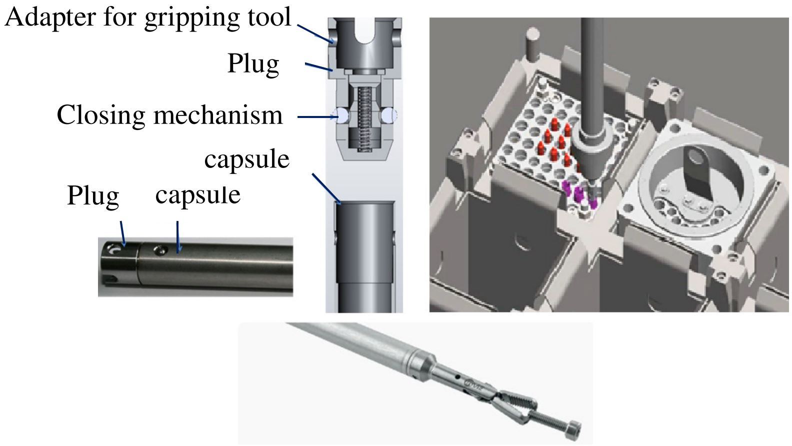

Figure 4: *left:* Handling tube for the collection of heavily damaged fuel rods. These handling tubes are also capable to take up smaller sections of fuel rods or even broken peaces down to the size of pellets. *right:* In analogy to the loading of fuel rods with an intact upper pin, the handling tubes are placed in the internal basket of the Quiver. *Bottom:* Example for a gripper to collect fuel debris for placement in catridges befor loading into the Quiver.

After retrieval of all damaged fuel rods from the receptacle in the spent fuel pool, its interior will be checked with an endoscope camera. If fuel debris is found, which cannot be gripped with e.g. a tweezers gripper (Figure 4 *bottom*), a suction tool is used to recover and deposit all particles within a small stainless steel filter cartridge. The filter cartridge is placed in a handling tube or directly into the internal basket of the Quiver. In worst case, the receptacle in the spent fuel pool has to be rotated to reach the remaining fuel debris.

THIRD STEP: DISPATCH OF INTEGRATED QUIVER SYSTEM

In contrast to the regular dispatch of spent fuel assemblies under water in the spent fuel pool, the dispatch of the Quiver is performed outside the spent fuel pool on the reactor floor. This approach is motivated by the use of a much simpler technology, that would be required if processing is done under water in the spent fuel pool. This also yields an increase in process stability. However, this approach requires some additional equipment especially in terms of shielding.

After loading of the Quiver with damaged fuel rods as described in the section “first step” a transfer-head piece is attached to the top of the Quiver for handling purposes. This transfer-head piece allows handling of the Quiver with a gripper like a standard fuel assembly. Then the Quiver is lifted out of the storage rack and is (still under water) placed into a shielding basket. The shielding basket is the primary shielding (Figure 5a right) of the Quiver during handling outside of the spent fuel pool and is positioned in a loading station (Figure 5) waiting to take up the Quiver. As shown in Figure 5 the loading station is located at the position in the spent fuel pool, where the CASTOR® V casks are usually loaded during a standard defueling campaign and consists of a stable base plate with welded lateral guide and support elements for the shielding basket. The loading station and the shielding basket are handled with the same crane system of the respective NPP.

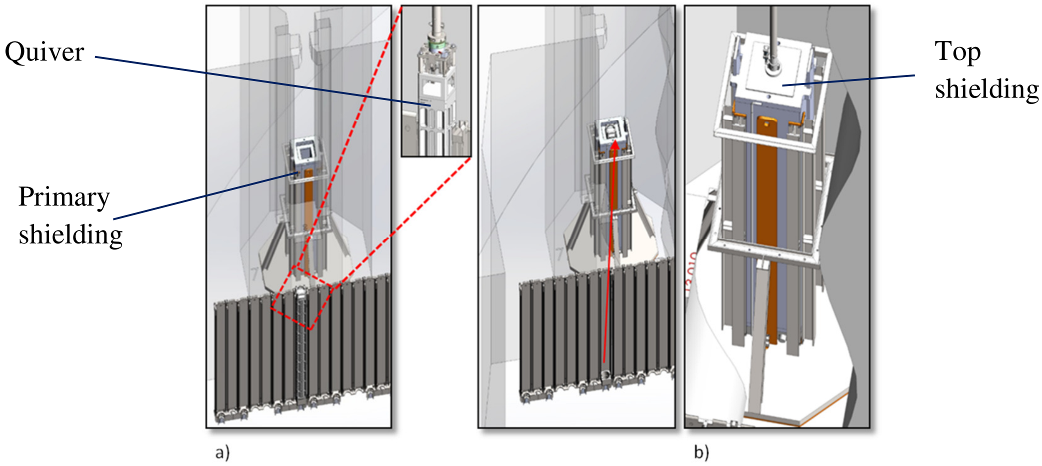

Figure 5: *a) left:* The Quiver is still placed in the fuel-assembly rack with the attached transfer-head piece. The primary shielding is already inside the loading station at the usual loading position of the CASTOR® V cask. *a) right*: The Quiver is positioned inside the primary shielding. *b):* After removal of the transfer-head piece the primary shielding is closed with a top shielding. Now the shielding basket is ready to be leveled up on to the reactor floor.

After transferring the Quiver into the shielding basket the transfer-head piece is removed and a top shielding, closing the shielding basket from the top is attached to the primary shielding (Figure 5). The shielding basket including the Quiver is now leveled up to the reactor floor and positioned into a handling station (Figure 6).

The handling station is the location where the actual dispatch of the Quiver takes place. It consists of a secondary shielding system, a mobile operating platform and a simplified hot cell, which is operated by a remote control. The shielding block as the secondary shielding system for the Quiver consists of a sandwich structure of polyethylene and stainless steel. One side is designed as a door for setting the shielding basket with the traverse into the shielding block. The mobile operation platform is fitted to the shielding block, enabling access to the upper part of the shielding block and for inspection works. Inside the simplified hot cell (Figure 6) of the handling station the drying and welding of the Quiver is performed. The simplified hot cell creates a barrier between the damaged fuel rods in the Quiver and the atmosphere of the controlled area in the NPP, retaining particles etc. The atmosphere inside the simplified hot cell is controlled and gives the possibility to replace the air inside the simplified hot cell by an inert gas atmosphere. The exhaust line from the simplified hot cell is connected to the building ventilation system via a particle filter, providing further contamination control.

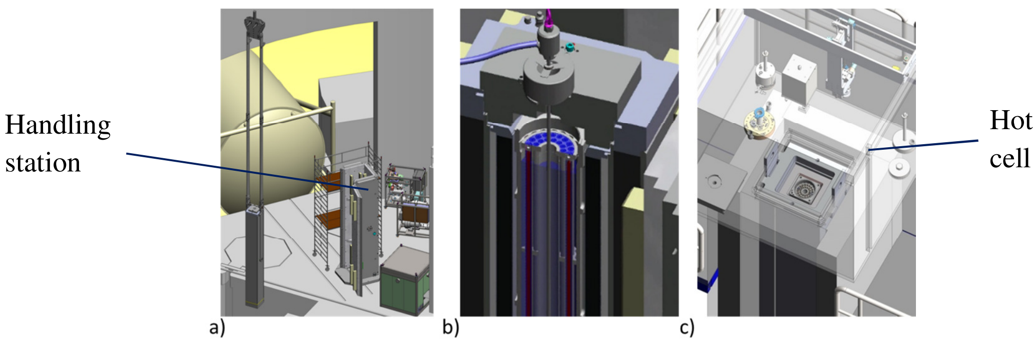

Figure 6 *a):* The Quiver inside the primary shielding is lifted out of the pool into the handling station on the reactor floor. *b)* Dewatering of the Quiver inside the handling station. *c)* View inside the simplified hot cell on top of the handling station.

Now the dewatering and drying of the Quiver can take place. While the dewatering is performed by sucking of the water (Figure 6) the drying process is more sophisticated. Figure 6 shows the principles drying process. The Quiver is heated to temperatures above the boiling point of water by hot air from a heating unit. A vacuum drying device with a special throughput of hot air as well as humidity sensors is used to monitor the residual moisture in the

Quiver and its inventory. The applied vacuum assists the drying process to remove water from inside the damaged fuel rods through existing holes and cracks in their cladding, even if they are not permeable for water under normal conditions in the spent fuel pool. During the drying process, a controlled retention of nuclear particles and gases is put in place. The drying process is therefore designed with different drying steps as shown in Figure 7. After drying, the pressure build-up is measured. The drying process is finished, when a pressure build-up criterion is reached.

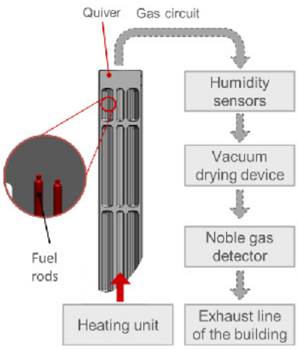

Figure 7: Sketch of the priciple drying process.

The removal of the residual water from the damaged fuel rods has been approved in tests with German authorities.

After drying, the Quiver is filled with helium providing inert conditions inside the Quiver. The lid of the Quiver is screwed in using remote manipulation tools. In order to provide the gas tightness of the Quiver, a welding seam is produced by means of a remote welding machine. The welding process was also qualified with the German authorities and it was shown that the automated process with the welding machine produces a gastight welding seam fulfilling the design specifications. Finally, after the welding a leak tightness test of the welding seam is performed inside the simplified hot cell.

As mentioned above all the operations inside the simplified hot cell are performed by remote control and are monitored by video. This significantly reduces dose rate uptake of the personnel. Figure 8 shows the manipulation device and one of the six cameras inside the simplified hot cell. The remote control station is positioned beside the handling station and is connected to the simplified hot cell.

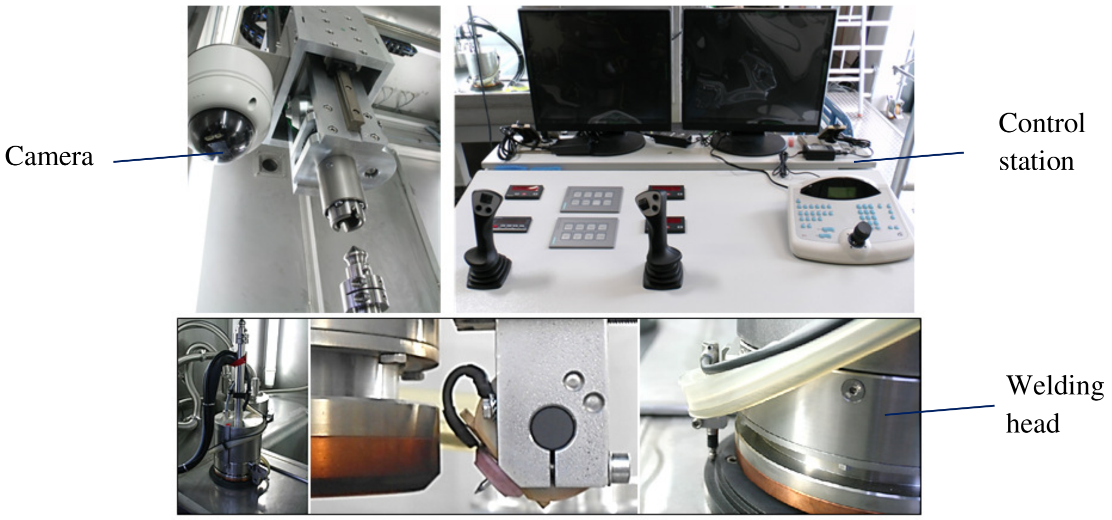

Figure 8 *left*: Photo of the actual remote controlled handling device inside the simplified hot cell with one of the six cameras inside the cell. *right*: Photo of the actual remote controll terminal with is placed next to the handling station *bottom:* Photo of the actual remote controlled automatic welding device.

After the dispatch of the Quiver, it is transferred back to the storage rack in the spent fuel pool. The Quiver remains inside the spent fuel pool until being loaded into the CASTOR® cask. The procedure described above for dispatching a Quiver is assumed to last not longer than one week and results in a collective dose of less than 3,7 mSV including independent inspectors.

For the handling and dispatch of the Quiver all tools and devices as well as shielding systems were designed, manufactured and already tested by the German authorities. The first hot trial of a Quiver in a PWR NPP is realized in early 2018. The entire equipment will be brought into the reactor building and erected within two weeks.

Subsequently to the loading of the Quiver with damaged fuel rods and mounting of the head piece for internal transfer, the dewatering procedure starts using a pressure cushion. The Quiver is not dried and water remains in the loading positions of the Quiver and on the ground of the base body. The amount of remaining water highly depends on the number of not loaded tubes. This amount has to be considered, amongst others, for the evidences of leak tightness, material compatibility, safety evaluation for thermal and criticality and with respect to the duration of the internal transfer. Furthermore, although a leak tightness test is performed before loading the Quiver into the CASTOR® V cask for the internal transfer, the impacts on the material behavior of the cask because of intruding water, which originates from the Quiver in the cask cavity, have been evaluated. This assessment was done taking into account the leakage rate of the elastomeric ring.

The first internal transfer was realized to take place at the end of 2016 in an NPP in Germany that is no longer under operation. The NPP has two Units (A and B), and it was planned to get Unit A defueled as soon as possible.

FINAL STEP: LOADING OF INTEGRATED QUIVER SYSTEM INTO THE CASK

The loading of Quivers into the CASTOR® V cask is carried out similar to a standard loading campaign with intact fuel assemblies. Therefore the loading and dispatch of CASTOR® V cask with Quivers requires no additional equipment.

With respect to fast licensing processes, mixed loading of Quivers with intact fuel in the CASTOR® V casks are not implemented in the transport and storage licensee applications. This provides additional safety margins. However, for international campaigns no technology boundaries are visible that prevent mixed loadings of Quivers and intact fuel assemblies.

The storage of casks with Quivers follows immediately after the dispatch due to the German decentralized, on-site storage policy.

CONCLUSIONS

In combination with the Quiver, GNS casks offer a comprehensive solution for the complete disposal of the spent nuclear fuel stored in the spent fuel pools in German NPPs.

The Integrated Quiver System for damaged fuel rods features a robust design with a high mechanical stability, a reliable leak-tightness and large safety margins. It can be easily adapted to a large variety of fuel rod damages and tailored to the specific need of the customer.

The Integrated Quiver System 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.

The overall concept presented here is a first of its kind solution for the disposal of damaged fuel rods via CASTOR® V casks. This provides an important precondition in achieving the status “free from nuclear fuel” within the shut down process of German NPPs.

The type B(U)F-packages transport and storage cask CASTOR® V/19 and CASTOR® V/52 have been licensed for loading with The Quiver in Germany in accordance with transport regulations. In addition storage licence for two German PWR NPP’s are already issued in accordance with nuclear law for interim dry storage. The cold commissioning for both Quiver types already succeeded. The loading of the first twelve PWR-Quivers in two different German NPP's has been completed. The complete dispatch is currently ongoing. The Loading into the CASTOR® V casks will start subsequently. The GNS Integrated Quiver System has now become a well established solution for the treatment of damaged fuel rods and has so far been ordered by eleven of twelve German NPP's.

ACKNOWLEDGMENTS

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