Disposal of damaged fuel

Christoph Rirschl and **Hagen Höfer** introduce a new concept for disposal of damaged fuel rods in dual purpose casks

Christoph Rirschl

Head of Cask Loading Services
GNS Gesellschaft für Nuklear-Service mbH

Hagen Höfer

Managing Director
Höfer & Bechtel GmbH

IN GERMANY TODAY, B(U)F-package transport and storage casks of the CASTOR® family engineered and delivered by GNS Gesellschaft für Nuklear-Service mbH are used for the transport and dry storage of entire spent nuclear fuel assemblies from the German nuclear plants. More than 1300 of these casks have already been loaded and are stored in interim dry storage facilities worldwide.

While GNS casks of the CASTOR® family are a suitable means to transfer fuel assemblies from the plant to an interim dry storage site, Germany's phase-out of nuclear energy has triggered the demand for an additional solution to dispose of damaged fuel rods, usually remaining in the fuel pond until the final plant shutdown.

In order to establish a disposal concept suitable for the needs of the German utilities, GNS developed the GNS IQ Integrated Quiver System for damaged fuel rods from pressurised water reactors and boiling water reactors, the PWR- and the BWR-Quiver, which are specifically designed to fit into the basket slots of CASTOR® casks.

Inventory of the Quiver

The Quiver was designed and developed by GNS to accommodate a large variety of different damaged fuel rod types, such as:

- Irradiated or unirradiated nuclear fuel in the form of fuel rods or fuel rod sections,
- Leak-tight and dry fuel rods with potential damage, eg reduced cladding thickness or deformed fuel rods,
- Leaking fuel rods, starting with pin hole defects and hairline cracks up to exposed nuclear fuel, eg fragments, loose pellets, broken fuel rods or debris,
- Fuel rods in capsules or cartridges,
- Test rods from irradiation experiments,
- Irradiated rods, such as dummy rods or control rod fingers (which may also be used for filling any existing free slots of the Quiver),
- Equipment for core instrumentations such as self-powered-neutron detectors.

Given the large variety of damaged fuel rods, special attention has to be attributed to those that are leaking. In these cases, it has to be assumed that water has leaked into the cladding during reactor operations or wet storage. This may result in a significant amount of water per damaged fuel rod, which may be released during transport or dry storage, causing pressure buildup and corrosion.

Disposal concept

GNS has shown that the CASTOR® V cask and intact fuel assemblies meet both the safety objectives and specified parameters for transport, as well as the nuclear law for dry interim storage in Germany. This has to be verified for casks loaded with Quivers for damaged fuel rods.

The overall concept for the packaging and the Quiver for damaged fuel rods was developed on the basis of these requirements. GNS verified all safety objectives, such as criticality safety, shielding, heat dissipation and activity release.

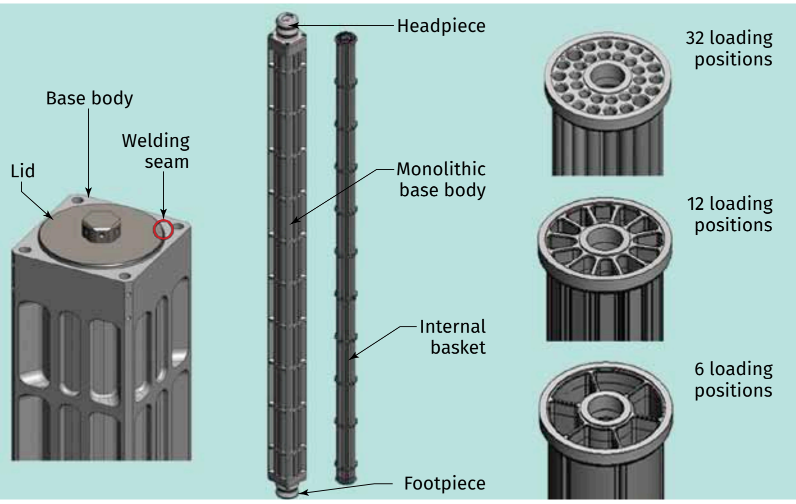

Figure 1: **PWR-Quiver for damaged fuel rods: Sealing system (left), head- and foot piece mounted to the base body and internal basket (middle) and example configurations of internal baskets (right)**

Design of the Quiver

The base of the Quiver has a monolithic body, an internal basket and a lid, as well as a head and a foot piece (see Figure 1). The components of the Quiver are manufactured according to the highest quality standards, like those for the CASTOR® casks.

The base body of the Quiver is made of forged stainless steel and then mechanically processed. This is better than a welded construction, since it must cope with high mechanical loads during accident conditions as well as thermal stresses.

The internal basket accommodates the damaged fuel rods. Various different diameters for loading positions have already been defined. Other configurations of the internal basket are also possible.

The base body and the lid ensure the Quiver is gas-tight, and it is further leak-tight because the lid is screwed in and then welded.

Integrity of the sealing system

The integrity of the sealing system was experimentally

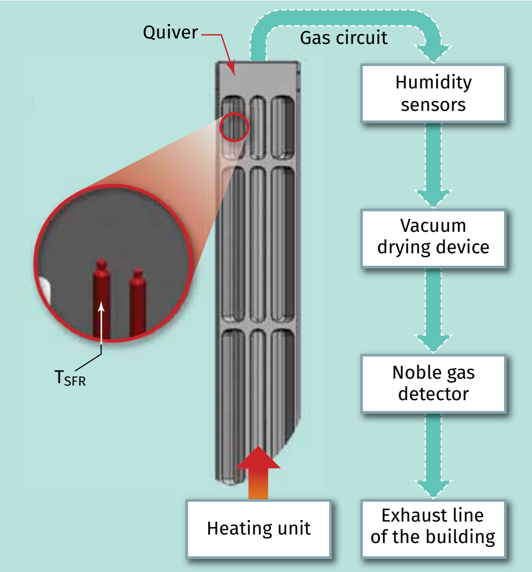

Figure 2: **Drying process for the Quiver (schematically)**

proved for any load that may occur if there is an accident during a transport, especially for the lid of the Quiver. Experiments showed that under a static force the functionality of the lid is not compromised and the lid of the Quiver stays intact. Theoretical calculations of the lid thread dimensions were confirmed. The Quiver is much more rigid than a fuel assembly. In order to adapt the rigid Quiver to the mechanical behaviour of fuel assemblies in a transport cask under accident conditions, the head and the foot piece are designed to act as a shock absorber to limit impacts between the Quiver and the cask.

Drop test

Unlike a fuel assembly, which bends under mechanical loads, the Quiver is a much more rigid structure and this will stress the lid system much more than a fuel assembly if there is a transport accident. The interaction of the cask with its contents leads to stress peaks in the cask's components. This happens for every cask design and must be taken into account in the Safety Analysis Report. The Quiver has been designed to cope with this effect.

The effectiveness of these measures has been proven in drop-tests conducted in coordination with German authorities and using original Quiver components.

Welding

To make sure the Quiver is gas-tight the lid is welded using a remote welding machine. The weld thickness is dimensioned based on the results of a mechanical assessment. The requirements from the mechanical analysis were balanced with the requirements from process stability and from robust fabrication of the welding seam, in order to avoid failures during welding. The welding process was qualified with the German authorities.

Drying

It is important that the Quiver system complies with the design criterion for residual water. A drying and moisture measuring procedure that ensures the minimum residual moisture measured inside of the Quiver was developed and certified by German authorities. The moisture is measured using a tuneable laser absorption spectroscopy monitor (TLASM). These measures limit pressure buildup and improve the long-term stability of the Quiver. The drying process is shown in the diagram.

The TLASM had to be proven to work under these ambient conditions. The TLASM was validated while drying CASTOR® V casks during campaigns in German plants. Figure 3 shows that there was a very good accordance with other moisture gauges like the chilled mirror hygrometer and the capacitive pressure gauge. These two technologies were approved by German authorities and have been used since the early nineties for drying and moisture measuring in CASTOR® cask inner cavities.

First cold trial test

In February and March 2017, a cold trial test of all handling equipment of the Quiver for damaged fuel rods was performed at Biblis A, which had been shut down in March 2011. The cold trial comprised all handling and dispatch steps, except loading it with real fuel rods. It showed that the handling and dispatch equipment can be used at the reactor floor of a typical German PWR and that a quiver loaded under water with boric acid in a spent fuel pool can be dried and welded without problems. The cold trial test was supervised by the independent expert organisation TÜV Süd.

Even before the cold trial, three quivers had been used to transfer real damaged fuel rods from Biblis A to Biblis B. Since all intact spent fuel had been removed using CASTOR® V/19 casks, Biblis A is empty of nuclear fuel, which is an important decommissioning milestone. These three quivers are stored in the spent fuel pool of Biblis B and will be loaded with more fuel rods later.

Outlook

GNS has received licence approval for the CASTOR® V/19 cask, including the PWR-Quiver. Licence approval for the BWR-cask, including the BWR-Quiver, is expected in the first quarter of 2018.

Handling and dispatch of all Quivers at Biblis is scheduled for 2018. Based on the experience from the transfer of Quivers between the two units and from the cold trial at Biblis A, the complete handling and dispatch of about ten Quivers will be performed in 2018. We will report on the experiences of this first hot handling and dispatch at a later date. ■

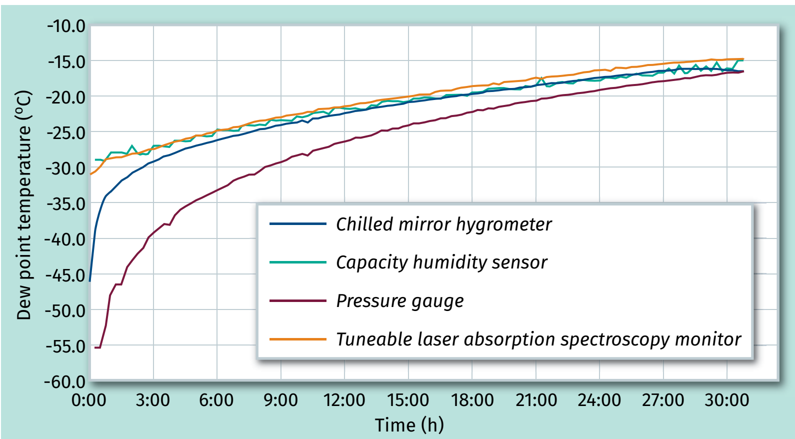

Figure 3: **Validation of the Tuneable Laser Absorption Spectroscopy Monitor**