ENCAPSULATION OF FUEL RODS FOR TRANSPORT

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ABSTRACT

The package NCS 45 is licensed for the transport of fuel rods with a burn-up of up to 120 GWd/MgU. Fuel rods with a burn-up of more than 62 GWd/MgU must be encapsulated, with even more stringent requirements in USA. The cans must not contain free water and must be sealed by welding or an adequate method.
The production of welded cans in Hot Cells is standard practice. However, the encapsulation of fuel rods in a fuel assembly pool was not possible in the past. For this problem NCS developed a solution (pat. pend.) comprising an encapsulation device, cans and a proper process to produce sealed and dry cans containing fuel rods under water. In this NCS process a brazing method is used to seal the cans.
A trial installation has been built and test cans were produced to validate the encapsulation process including drying and leak-testing. A qualification program was established and carried out successfully and at the time of PATRAM the production installation is being manufactured.

INTRODUCTION

Due to a lack in benchmarks, currently used computer codes for fuel depletion and decay are not validated for very high burn-up values. Furthermore, there is no sufficient information about the mechanical properties of cladding and fuel available to assess the behavior of fuel rods with very high burn-up under normal and accident conditions of transport. Therefore, for modern designs of packages encapsulation of fuel rods with a very high burn-up as well as for damaged fuel rods is required by the competent authorities. On the other hand, utilities, fuel manufacturers and plant operators have a high demand to transport fuel rods with these very high burn-up values for post irradiation and failure mode investigations.
The transport of fuel rods with a burn-up of more than 62 GWd/MgU is possible with the NCS 45 package if the rods are enclosed in sealed cans. The production of welded cans inside Hot Cells is common practice but there is no comparable method for fuel rods stored under water, where welding is not applicable.
In order to overcome this problem, NCS developed a process suitable to encapsulate fuel rods under water. The following presentation will provide first an overview about the requirements for the can and the process, present then the technical solution and will conclude with the description and the results of the qualification process.

REQUIREMENTS FOR THE CAN AND THE ENCAPSULATION PROCESS

Requirements for the can

The following requirements apply for the can:

- designed to withstand normal conditions of transport as specified in the Regulations,
- provide a leak tight barrier for the fuel under normal conditions of transport,
- corrosion resistance under the conditions to be expected in the reactor pool,
- no free water in the cavity of the can,
- cavity of the can filled with inert gas (e.g. Helium),
- designed to be handled in NPPs and Hot Cells (e.g. German KTA requirements).

Requirements for the encapsulation process

The encapsulation process must meet the following requirements:

- the production installation must be designed to be operated in the fuel assembly pool,
- easy and safe loading of cans and fuel under a sufficient head of water,
- remote controlled brazing,
- high quality process control,
- documentation of process parameters,
- provide sufficient performance.

DESIGN OF THE CAN AND THE ENCAPSUALTION DEVICE

Design of the NCS can

The design of the NCS can is shown in Figure 1. The main body is a tube (1) made of stainless steel. On the top side the tube has two holes (10) which allow safe handling of the empty tube under water. On the bottom side the tube has two slits (5) through which the water is drained after the fuel rod was loaded.

The tube is closed on both sides with two plugs which are connected to the tube by brazing. The bottom plug (3) is preassembled with the tube. In the “loading” position the bottom plug allows draining of the water through a filter (4) in the plug and the corresponding slits in the bottom part of the tube. In order to reach the “brazing” position the bottom plug is pushed axially into the tube and comes to rest above the slits. The top plug (2) is inserted after loading of the fuel rod into the can and is positioned by a circular stop (6). The outer shape (7) of the top plug can be adapted to the requirements of the nuclear site to allow handling with existing tools.

Both plugs are made of stainless steel. The brazing solder is fixed to the plugs in a deposit (8) which is applied by using the “cold gas spray” technology. During the brazing operation the brazing solder becomes liquid and flows into the narrow gap (9) between the tube and the plugs and seals these connections.

The wall thickness of the tube as well as the dimensions of the brazing gap are designed to withstand normal conditions of transport but would even withstand accident conditions of transport. Leak-tightness is assured under normal conditions of transport. The tube and the plugs consist of standard high quality stainless steel and the brazing material consists of a nickel alloy thus providing sufficient corrosion resistance.

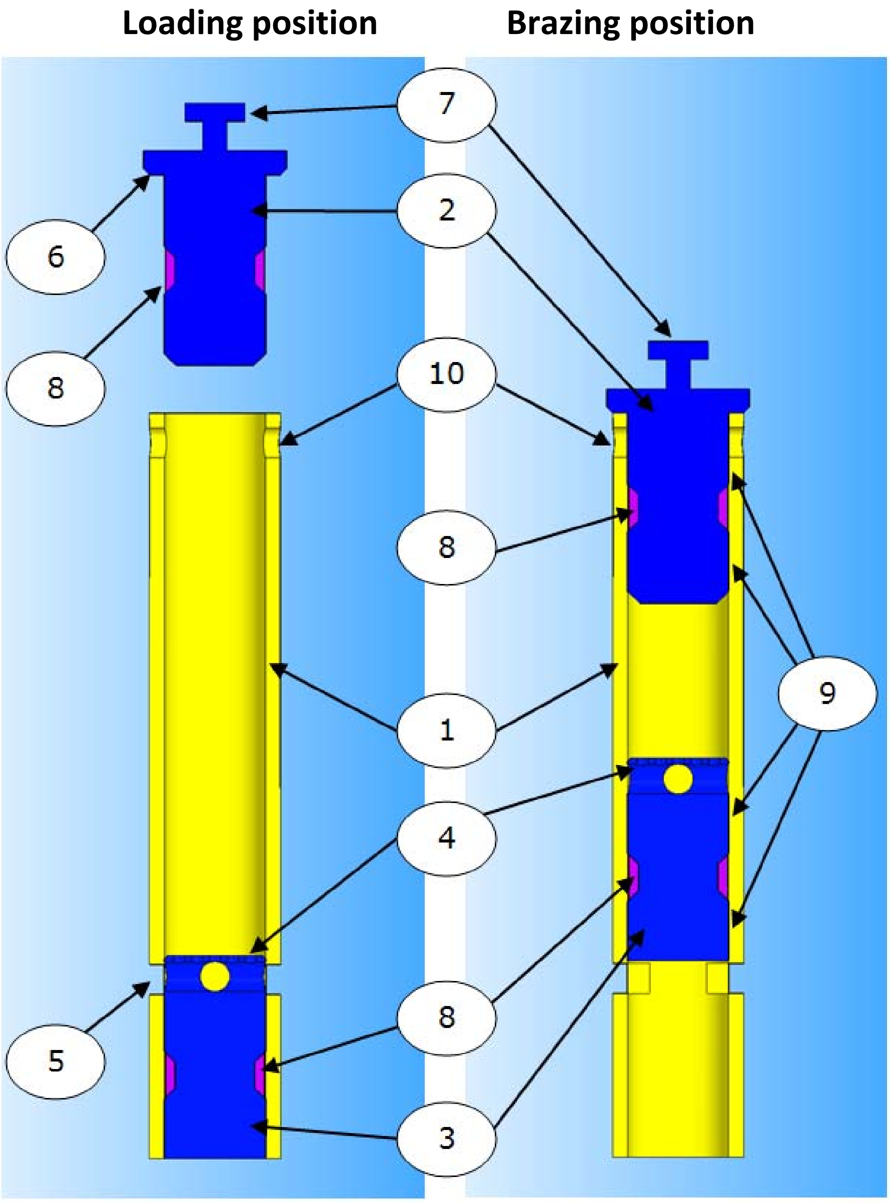

Figure 1: Section of the can

Encapsulation device

The encapsulation device shown in Figure 2 consists of an upper (A) and lower (B) brazing station which are connected by a tube (H). Each station includes an inductor (C) and a pyrometer (D). The inductors are connected to the control unit by electrical wires (E) which are guided and enclosed by flexible hoses (not pictured). The pyrometers are connected to the control unit by fiber optics (F). Each of the stations has a connector (G) to attach a tube for draining, evacuation, filling with inert gas and leak-testing.

The upper station has a lid (I) which is open for loading and closed and sealed during the whole encapsulation process. The lower station is equipped with a remotely operated lift (J) to raise the can up to the brazing position.

The encapsulation device is designed in a rather robust manner taking into account high safety margins against the forces to be expected during its operation in a fuel assembly pool. All materials in direct contact with the borated pool water are made of corrosion resistant stainless steel.
The control unit positioned at the side of the pool allows a completely remote controlled process. All relevant parameters are kept in the unit's memory and can be accessed by standard data transfer like a USB-connection.

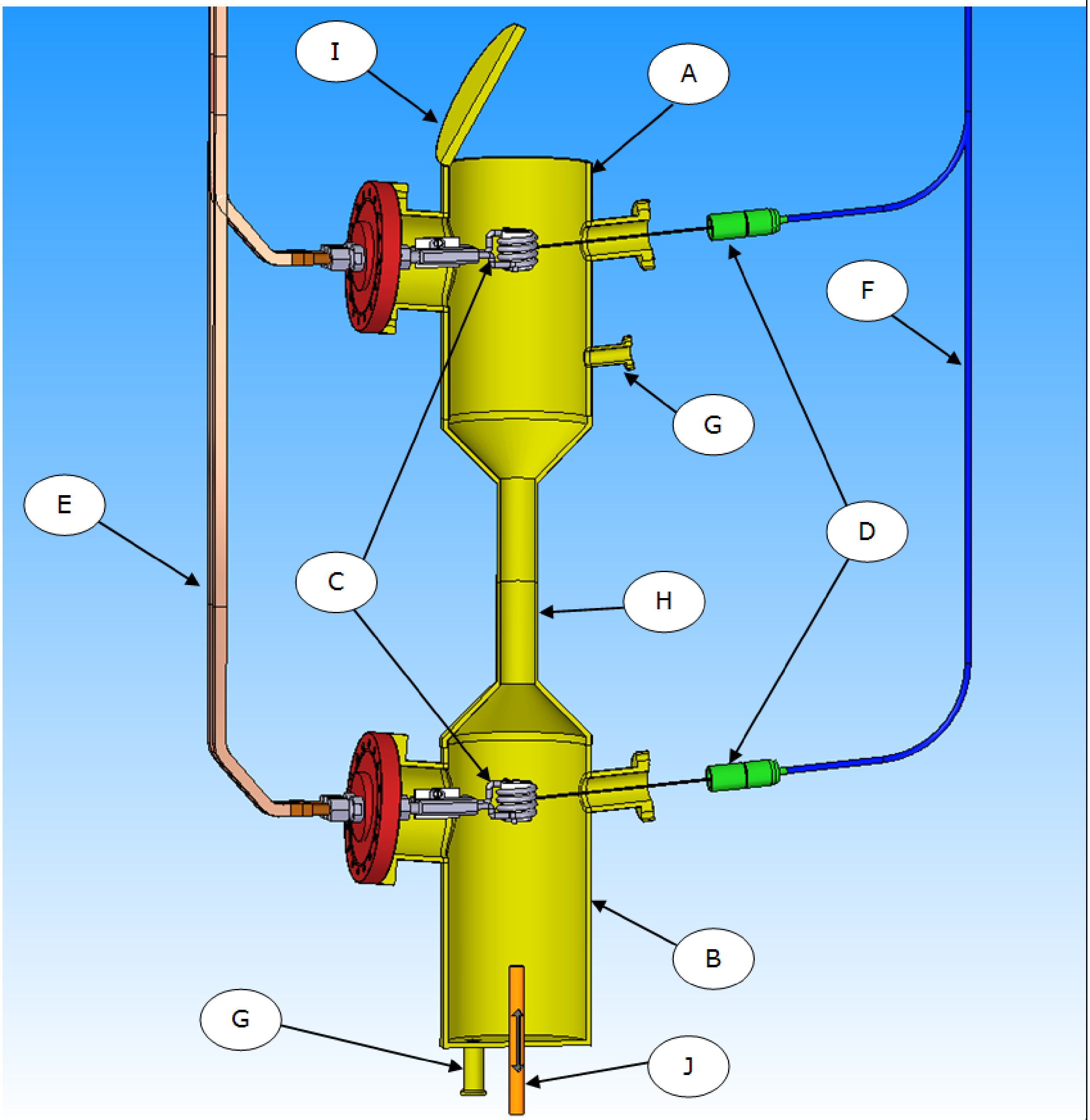

Figure 2: Encapsulation device

ENCAPSULATION PROCESS

The encapsulation process consists of following general steps:

- loading of the empty can with the preassembled bottom plug into the encapsulation device
- loading of the fuel rod into the can
- inserting the top plug into the device and closing of encapsulation device
- draining and drying
- filling with inert gas
- brazing
- leak test
- flooding of the encapsulation device and removal of the sealed can

Loading of can and fuel rod, closing of the encapsulation device

Prior to loading, the lid (I) of the encapsulation device is opened. The empty can with preassembled bottom plug is attached to the handling tool and lowered into the device. Then the fuel rod is inserted into the empty can by using the fuel rod handling tool of the nuclear site. Finally, the lid of the encapsulation device is closed and secured.

Draining and drying, filling with Helium

The water inside the cavity of the encapsulation device and the can is drained via the connections (G). The water inside the can drains through the filter (4) in the bottom plug and the slits (5) in the tube. Then, the cavity of the encapsulation device and the cavity of the can are dried by means of vacuum drying. After reaching the drying criterion, the cavity of the encapsulation device together with the cavity of the can are filled with Helium.

Figure 3: Test stand

Brazing

Before brazing starts, the bottom plug (3) and the tube (1) are lifted by using the remote controlled lift (J) into the brazing position. The brazing solder (8) is then heated up by inductive heating until it becomes fluid and flows into the gap between tube and plug.

Leak test

After brazing is finished and the brazing areas have cooled off the encapsulation device is rinsed with dry Nitrogen to remove the Helium inside the cavity of the encapsulation device. The encapsulation device is then evacuated again and a leak test carried out.

Flooding of the device and removal of the sealed can

Before the sealed can is removed all parameters are double checked to verify proper operation of the device. The encapsulation device is then flooded with water via the connectors (G), opened and the sealed can is removed with the handling tool.

TEST STAND AND PROCESS QUALIFICATION

For the development of the brazing process a small test stand shown in Figure 3 was designed and manufactured. With this test stand cans with a length of approximately 750 mm could be produced which however, complied in the top and bottom parts with the production version cans.

The first tests showed that the correct parameters are absolutely essential to receive good and repeatable brazing results. Several adjustments were performed to optimize the device so that finally the process qualification could be performed witnessed by the German Competent Authority (BAM).

The process qualification comprised the entire process from loading, draining, drying and brazing to the leak test. In the following, some of the important findings during the development of the process and the process qualification are presented.

Brazing temperature profile

For the brazing temperature profile the following parameters are essential:

- heating gradient
- holding time

Various combinations of these parameters were tested. It became apparent that neither a very steep nor a very flat gradient would be the optimal heating gradient. For a steep gradient a certain overheating of some areas occurred because the power control of the generator could not follow the pyrometers. For a very flat gradient the properties of the material might be affected.

Figure 4 shows schematically the optimal temperature profile. In the detailed view, a step in the heating curve can be seen which indicates the beginning of the brazing solder´s flow.

Leak test

The leakage rates of the cans produced during the process qualification were all in the range of $1x10^{-8}$ Pa m³/s or better.

Pressure test

To prove the mechanical properties of the brazed connections a pressure test was carried out with a pressure of 7 MPa according to the standard DIN EN 10217-7:2005. No leakage or mechanical deviations were detected.

Metallographic analysis

A metallographic analysis was carried out to investigate the influence of the heating on the structural properties of the base material. The results of this investigation were satisfying as the heating and cooling down of the can did not have any effect on the structure of the material.

Wetted area

Figure 5 shows a close-up of a brazed plug. It is visible that the brazing solder has flown out of its depot into the gap between tube and plug to the bottom and to the top.

To determine a quantitative result for the wetted area two methods were used:

- x-ray analysis
- mechanical cuts and counting

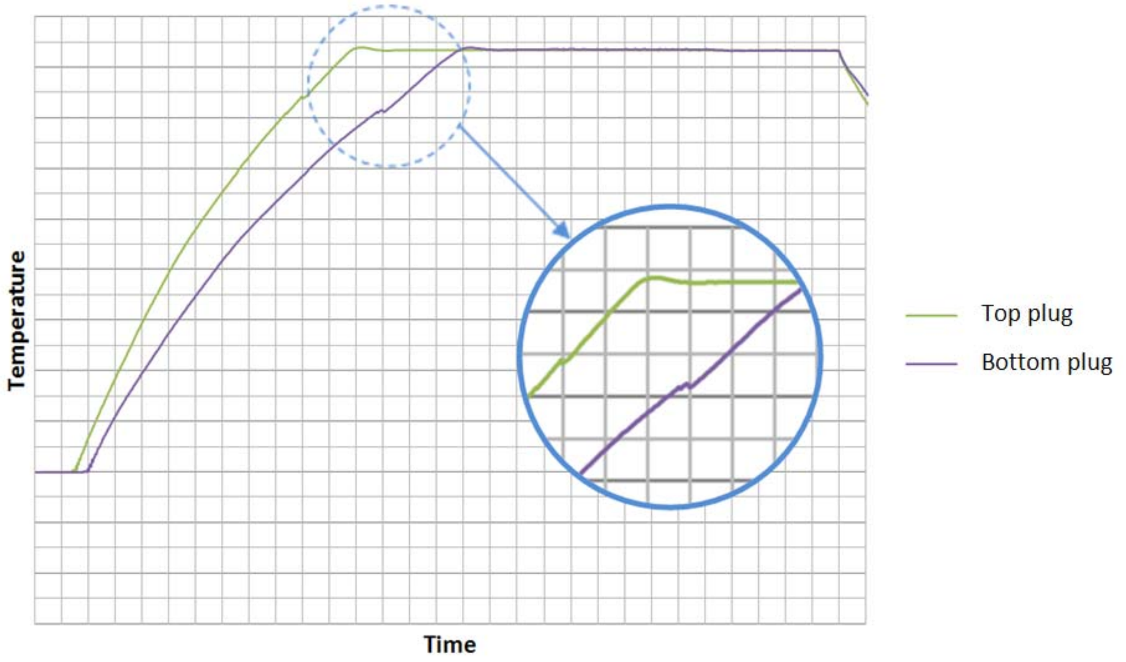

Figure 4: Temperature profile for brazing operation

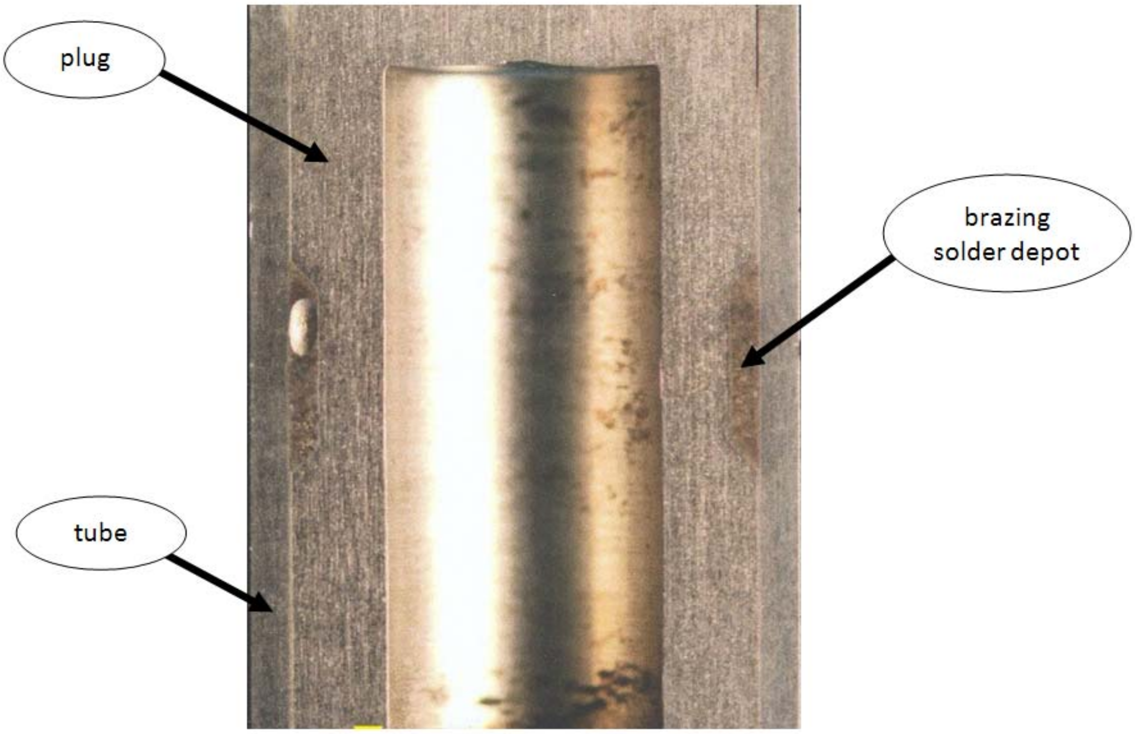

Figure 5: Close-up of brazing plug in tube

CONCLUSIONS

The encapsulation process developed by NCS is a new development which is suitable for the encapsulation of fuel rods under water. It was initially developed for the preparation of fuel rods with a high burn-up or damaged fuel rods for the transport in the package NCS 45 but also other applications are possible which require long term stable and sealed cans. The current application requires cans which could withstand normal conditions of transport but the safe design of the cans is also sufficient to withstand accident conditions of transport.

The encapsulation process comprising cans, the encapsulation device and proper procedures was qualified in a test stand producing short test cans. The results of the qualification were as expected; the produced cans fulfilled all applicable requirements. The manufacturing of the production installation is on the way and the first hot application of the process is planned for the next few months.