

A DEVICE TO TEST THE LONG-TERM CREEP BEHAVIOUR OF CLADDING FROM HIGH BURNUP SPENT FUEL

W. Goll*, H. Kostecka^o and E.H.Toscano^o

^o European Commission, JRC-Karlsruhe, Institute for Transuranium Elements, PO Box 2340, 76125 Karlsruhe, Germany.

* Siemens Nuclear Power GmbH, P.O.Box 3220, 91050 Erlangen., Germany.

ABSTRACT¹

In the last years the discharge burnup of fuel in Light Water Reactors (LWR) has been increased by introducing, e.g., high corrosion resistant materials and advanced reshuffling schemes. For the fuel rod, high burnup means increased neutron fluence and hydrogen content in the cladding and increased rod inner gas pressure due to a higher fractional fission gas release.

Dry cask storage, which is used for the interim storage of spent fuel, has to consider this changing burnup situation including provisions for future burnup perspectives. Unlike earlier experiments, where materials with enveloping creep behaviour were tested under short-time conditions, commercial cladding shall be tested under experimental conditions as realistic as possible.

Therefore, a device for long-term (≥ 1 year) creep testing of irradiated cladding materials from high burnup spent fuel has been developed at the Institute for Transuranium Elements. In the paper the experimental setup as well as the sample preparation steps will be described. Experimental results concerning non-irradiated samples, tested to check the apparatus performance, will be presented.

¹ To be presented to the European Working Group "Hot Laboratories and Remote Handling", to be held from 27th to 29th September, 2000, at Paul Scherrer Institute, Villigen, Switzerland.

INTRODUCTION

In the last years the discharge burnup of fuel in Light Water Reactors (LWR) has been increased by introducing, e.g., high corrosion resistant materials and advanced reshuffling schemes. For the fuel rod, high burnup means increased neutron fluence and hydrogen content in the cladding and increased rod inner gas pressure due to a higher fractional fission gas release. This affects cladding stress and strain, which are important to assess the long-term integrity during interim dry storage.

The purpose of these experiments is to provide data to support the licensing of the dry storage of spent fuel assemblies for further increased burnup. Unlike earlier experiments /1/, where materials with enveloping creep behaviour were tested under short-time conditions, commercial cladding shall be tested under experimental conditions as realistic as possible.

Therefore, a creep-testing device had to be developed at the ITU with the following features:

- Long-term operation (> 1year) of gas filled samples (up to 20 MPa and 400 °C)
- Long-term temperature scenario with low axial variations
- Statistically relevant number of re-fabricated samples from fuel rods operated in commercial power plants
- Measurement of the cladding diameter during the experiment with high accuracy

1. EQUIPMENT DESIGN

The system is based on the internal pressurization of a tubular sample by using a gas (He). To reach this goal, the absolute tightness of the samples is essential. In this context, the sample preparation plays a very important role and forms the basis for the success of the tests.

After cutting and de-fueling (see Sample Preparation) end caps are welded to the samples, then the specimens are pressurize (see Filling Device), introduced in an appropriated furnace and kept at the desired temperature for the desired time. After different heating-periods, the samples are taken out of the furnace to measure the diameter as a function of the time (see Measuring Device).

1.1. Furnace:

To have a representative response from the material, one of the important boundary conditions is the uniformity of the temperature along the whole length of the samples. To this goal, a furnace based on an electrical heating with a double-wall tube containing a low melting point metal was selected.

The furnace is divided into two parts (Fig 1), namely two half cylinders. Only one half of the furnace is heated: the lower part. The uniformity of the temperature is obtained through the double-wall tube containing cesium. In fact, in the tube the

temperature gradient is minimized by the principle of the transportation of the evaporation heat in hermetically closed containers. This is achieved through a continual evaporation/condensation process (see below for experimental results concerning the temperature uniformity).

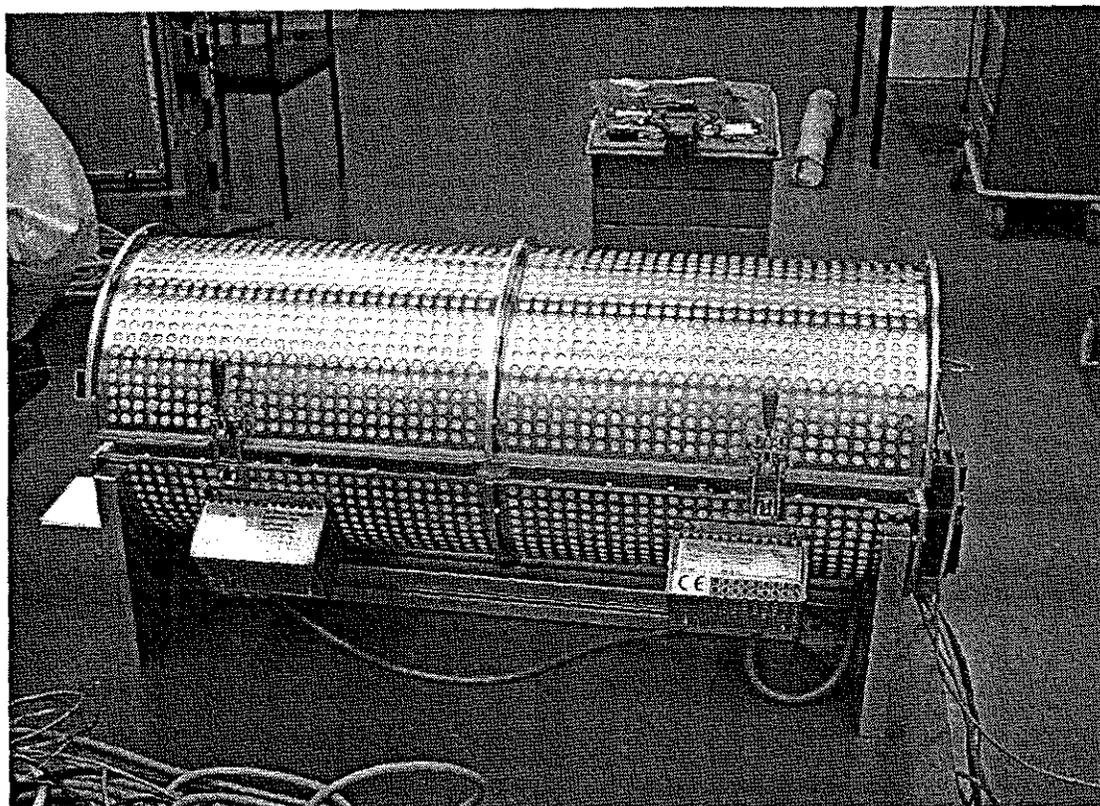


Fig. 1a): Electrical furnace (closed).

In total 16 samples can be tested at the same time.

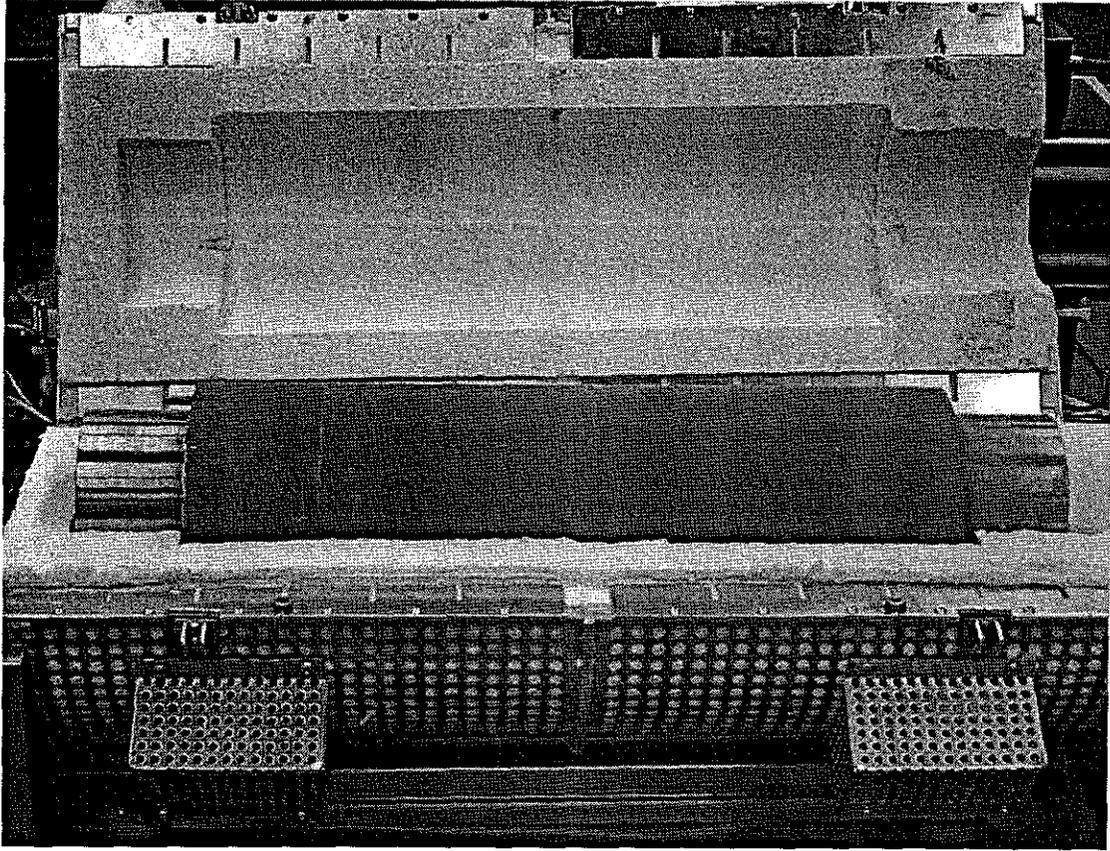


Fig.1b): Electrical furnace (open) showing the double-wall tube.

To test the temperature uniformity, an aluminum cylinder about 50 mm in length and having a diameter slightly inferior as the internal diameter of the double-wall tube, was heated positioned in different axial positions of the furnace. A thermocouple permitted the measurement of the temperature, also in different azimuthal positions.

In Fig. 2 the experimental result is shown. As can be seen, the thermal gradient over 450 mm is less than 0.2 °C, assuring the sample temperature uniformity along the whole length, except for the region near to the furnace entrance. This allows that two rows of samples, 8 specimens each, can be tested simultaneously (16 samples in total). No differences could be detected concerning the azimuthal positions.

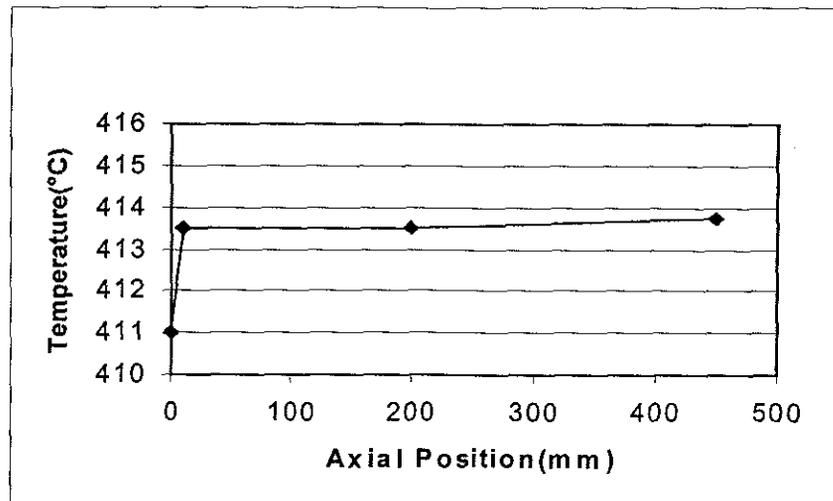


Fig.2: Measured temperature gradient in the furnace.

1.2. Measuring Device:

The measuring device, based on a linear-variable-differential transducer (LVDT), is shown in **Fig. 3**. The device permits the measurement of the diameter with a precision of $\pm 0.1 \mu\text{m}$. The apparatus also performs the measurement of the axial displacement ($\pm 0.01 \text{ mm}$), allowing the correlation of the diameter measurement to the axial position on the sample. More details concerning this apparatus are given elsewhere^[1].

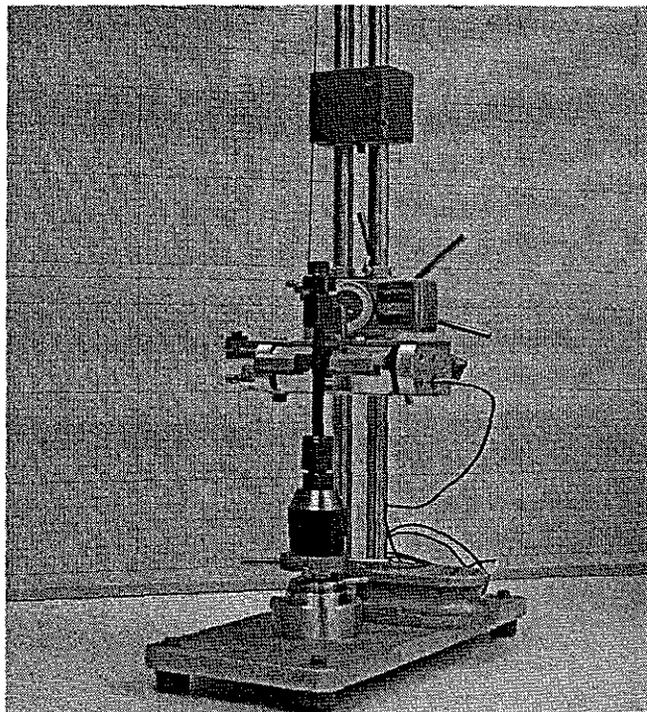


Fig.3: Measuring device.

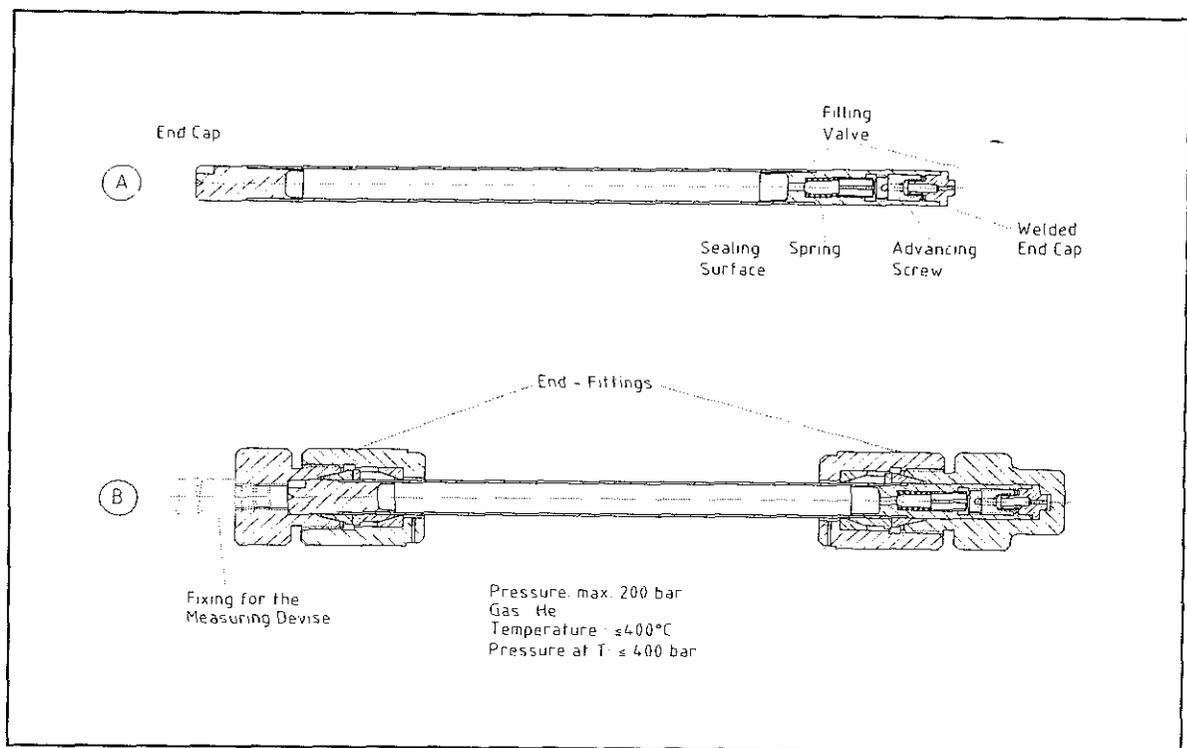


Fig. 4: Scheme of the sample preparation showing the details of the filling valve (A) and the end-fittings (B).

2. SAMPLE PREPARATION

2.1. De-fueling:

Samples for the future active tests were already prepared. The specimens were taken from fuel rods irradiated in LWR. After cutting to the appropriate length, the fuel was removed using the method described elsewhere^[1]. In order to remove the remained fuel at both ends, the samples were introduced in a HNO₃-bath at 90 °C for several hours. After that the samples were mechanically reamed to obtain a well-finished surface in the zone of the end caps (about 25 mm in length).

2.2. Filling valve:

To introduce the filling gas a special valve was modified for hot cell application.

In Fig. 4 A) a sample with the end cap and the filling valve is shown. Both end caps are welded to the de-fueled sample by means of a TIG orbital welding system.

The filling valve consists of a short cylinder, fitting closely to the housing, can be moved by the advancing screw. A spring holds the cylinder in the open position to allow the gas to ingress into the sample. Once the desired pressure is achieved (see below, Filling Device), the advancing screw can be tightened moving it towards the sealing surface. Finally, to warranty the absolute tightness of the sample, an end cap is welded over the valve.

2.3. End fittings:

As mentioned before, after gas filling the sample is welded tight by using an orbital TIG-welding system in order to assure the absolute tightness of the samples during the test. This procedure causes in the samples a heat-affected zone which, free from the radiation damage, can basically creep with a higher creep-rate. In order to avoid this problem end-fittings were fixed to the samples as shown in **Fig. 4 B**). An especial device, described elsewhere^[1], was used in order to tighten the end-fittings.

2.4. Filling Device

To fill the samples with the He-gas a device had to be developed. The equipment is shown in **Fig. 5**. The concept is based on a quick-connector and a pressure gage. The massive platform provides the necessary stability to allow the closing of the filling valve. The equipment was designed for a maximum pressure of 250 bar.

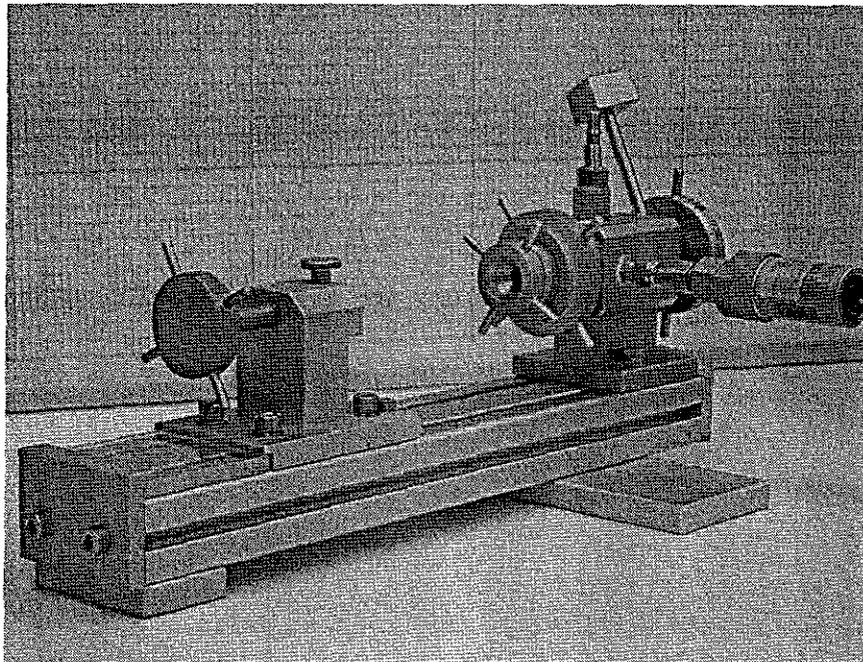


Fig. 5: He-filling device.

3. COLD-TESTING OF THE CREEP DEVICE

In order to test the whole method (filling device, welding procedure and end-fittings mechanical stability) two non-active samples were prepared and tested at 350 °C and 410 °C respectively.

3.1. Material

For the cold tests a cladding material with high creep strength was chosen to obtain strains comparable to the expected strains of the future irradiated samples. Especially, to test the end-fitting stability under conditions as realistic as possible.

3.2. Creep tests

The two samples were filled with He at 200 bar (350 °C) and 100 bar (410 °C). This pressure is measured at room temperature and has to be corrected for the corresponding test temperature. The results are presented in Fig 6.

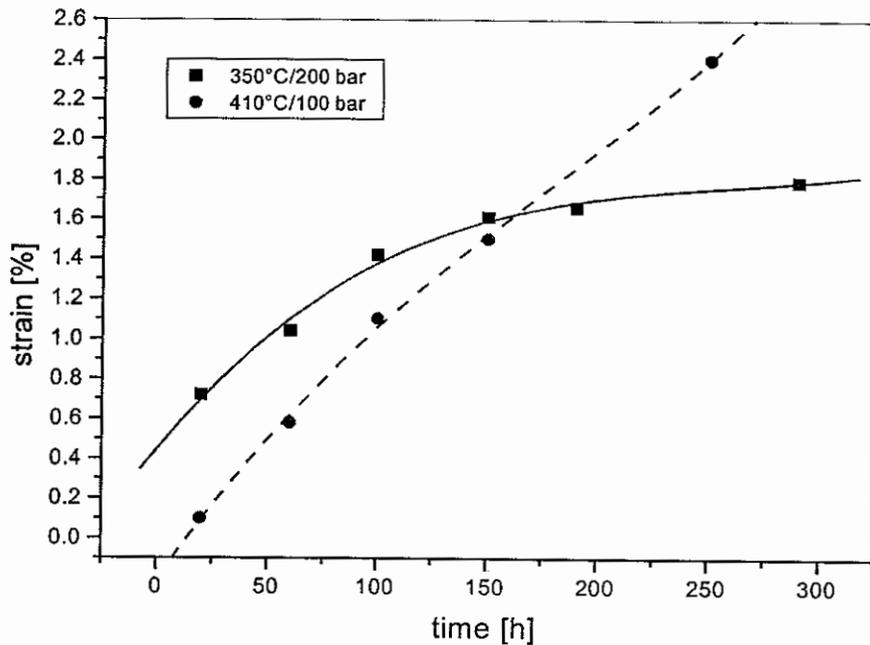


Fig. 6: Cold tests. Creep-strain as a function of time.

Possible axial displacements of the end-fittings were followed after each heating period by measuring the free length of the sample. No displacement could be detected.

CONCLUSIONS

A creep test device was developed to test the long-term creep behaviour of irradiated samples. The device was successfully tested under cold conditions. The apparatus will be introduced in a hot cell and samples obtained from LWR-fuel rods will be tested.

REFERENCES:

1. Short-Time Creep and Rupture Tests on High Burnup Fuel Rod Cladding
W. Goll, H. Spilker, E. Toscano.
KTG-Meeting „Verifikation des Brennelementverhaltens durch Nachbestrahlungsuntersuchungen und Experimente“, 29.Februar/1.März 2000, Karlsruhe