SAFETY ASPECTS OF FUEL BEHAVIOUR IN OFF-NORMAL AND ACCIDENT CONDITIONS

CONSIDÉRATIONS DE SÛRETÉ DU COMPORTEMENT DU COMBUSTIBLE DANS DES CONDITIONS ANORMALES ET D'ACCIDENT

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INFLUENCE OF A COLD CONTROL ROD GUIDE THIMBLE ON THE BALLOONING BEHAVIOUR OF ZIRCALOY CLADDINGS IN A LOCA

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ABSTRACT

In the REBEKA program a fuel rod bundle is simulated by electrically heated fuel rod simulators in a 5x5 array of full length. One part of this program is the investigation of the influence of a control rod guide tube (CRGT) on the cladding deformation during the refill- and reflood-phases of a loss of coolant accident (LOCA).

A cold CRGT generated a pronounced azimuthal temperature difference on the adjacent claddings. In contrast to the general expectation the Zircaloy tubes show a relatively high circumferential burst strain. A mechanical and thermohydraulic interaction with the cold CRGT resulted in a decrease of the clad heating rate on the hot side and a reduction of the azimuthal cladding temperature differences. Both effects lead to higher burst strains.

The ballooning problem of Zircaloy claddings during a loss-of-coolant accident and the REBEKA-program is described in /1/. One part of this program is the investigation of the influence of control rod guide thimbles on cladding deformation during the refill- and reflood-phases of a LOCA.

EXPERIMENT

The bundle consists of electrically heated fuel rod simulators in a 5x5 array with true KWU-PWR-dimensions and spacer grids. The cold guide tube is located in the centre of the bundle. The outer ring of 16 fuel rod simulators does not deform during the test and serves to simulate the thermal surroundings. Fig. 1 shows the bundle layout.

TEST PROCEDURE

Fig. 2 shows the test data and the test procedure. The initial conditions for the test were the following: Power is off, the cladding temperatures at axial midplane of the bundle are about 550 °C, the internal rod pressure has reached a value of 70 bar (7 MPa) and the pressure supply valve is closed. Test starts with a heat-up-ramp of 7 K/s, corresponding to a specific rod power of 20 W/cm. During heat-up a heat transfer of about 30 W/m^2K is realised by a steam flow downwards through the test rig. At a cladding temperature of about 780 °C flooding water enters the test bundle with a cold flooding rate of 3 cm/s with a water inlet temperature of 130 °C. The system pressure is 4 bar. During the whole test the temperature of the control rod guide tube is 130 °C constant over the axial length of the tube because the flooding water is introduced at the top of the test rig into the guide tube and flows downwards through it to the lower plenum of the test rig.

DEFORMATION MECHANISM

It has been found in previous tests, that the burst strain depends on the load, heating rate and the azimuthal temperature distribution during ballooning. It was found that the azimuthal temperature distribution is one of the most important factors /2/. Small azimuthal differences in temperature result in high circumferential burst strains, large azimuthal differences in temperature result in low burst strains (Fig.3).

It has been observed that Zircaloy claddings deformed under azimuthal temperature differences result in a tube bending with the consequence that the gap between pellets and cladding is closed on the hot side and opened at the opposite cold side.

In REBEKA-test 4 a cold control rod guide tube (CRGT) generated a pronounced azimuthal temperature difference on the adjacent claddings and was therefore expected to limit the circumferential burst strain /3/.

Fig. 4 represents the circumferential strains of the 8 Zircaloy claddings and the coolant channel blockage versus the heated length of the fuel rod simulators.

In contrast to the general expectation the Zircaloy tubes show a relatively high deformation, not smaller than in bundle test 3 performed under identical thermohydraulic conditions, but without a cold control rod guide thimble.

Fig. 5 shows temperature histories at the axial midplane of the guide tube, of the Zircaloy cladding at the inner and outer side and of the Inconel cladded fuel rod simulator, as well as the internal pressure history. Two things can be seen from the figure:

- the development of the azimuthal temperature difference starts during heat-up.
- plastic deformation starts also during heat-up indicated by the decrease of the internal pressure before start of flooding.

The consequence is the bending of the Zircaloy claddings with a non symmetric balloning.

Fig. 6.1 represents schematically a guide tube, a Zircaloy cladded rod and a rod of the next row. The cold side of the Zircaloy cladding starts to balloon non symmetrically as predicted towards the cold guide tube (Fig.6.2). If the distance to the cold CRGT would be large enough, the deformation would continue to go into the same direction and the Zircaloy cladding would have burst as predicted with a small circumferential strain.

However at a strain of 19 % the Zircaloy cladding touches the cold CRGT and as a consequence (Fig.6.3) the cladding is forced to balloon on its opposite hotter side. The hot gap opens and decreases the gap conductance which results in a decrease of the clad heating rate on the hot side and a reduction of the azimuthal temperature difference during ballooning. Both effects i.e. the lower heating rate and the smaller azimuthal temperature difference lead to higher burst strains.

A third information can be taken from Fig.5. At start of flooding the thermocouple (TC) which faces the outher cooling channels compared with the TC facing the CRGT shows a higher decrease in cladding temperature. This effect can be found on all Zircaloy claddings. This means that at start of flooding there was a higher heat transfer in the outer cooling channels than in the central cooling channels e.g. as a consequence of a higher blockage of the central cooling channels and/or a reduction of the quantity of water droplets in the two phase flow mixture resulting from deentrainement by the cold CRGT in the central cooling channels.

This thermohydraulic phenomenon leads also to a lower heating rate at the hot side and to smaller azimuthal cladding temperature differences and therefore to higher burst strains. Cross sections through the bundle (Fig.7) show that direct adjacent Zircaloy claddings touch the control rod guide tube in the planes of burst with a wall thickness nearly of the initial size in this region.

Fig. 8 gives information about the burst strain, the burst position, the time at burst and the quench time at axial midplane.

A detailed evaluation of bundle test 3 and 4 gave first hints on a possible interaction between neighboring rods with the consequence of a failure propagation. It could be shown that a local sudden increase of the temperature of the Zircaloy cladding was initiated by the burst of the neighboring rod as a consequence of a gas jet after burst (Fig.9). At burst of the neighboring rod the situation was the following: a Zircaloy cladding which had lifted from its heat source, a temperature difference between pellets and Zircaloy cladding of about 100 K (Fig. 10) and a two phase flow cooling with a heat transfer coefficient of about 130 W/m^2K. An increase of the cladding temperature of 25 K with a gradient of 40 K/s over a time period of 8 seconds (see Fig.9) was measured. This is the result of the reduction of the heat flux from the cladding to the two phase cooling due to the mixing with the hot helium gas and the resulting higher local fluid temperature.

It has to be analysed in more detail whether the relatively large circumferential burst strain of 79 % is the result of this temperature increase.

CONCULSION

A cold control rod guide thimble in a bundle produced relatively high azimuthal differences in temperature, but it did not restrict the circumferential burst strains in the predicted way under the conditions simulated in REBEKA test 4 because of mechanical and thermohydraulic interactions.

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Influence of Thermohydraulics on Fuel Rod Behaviour in a LOCA. CNSI-Specialist Meeting, Espoo, Finland/Sept. 1-4, 1980

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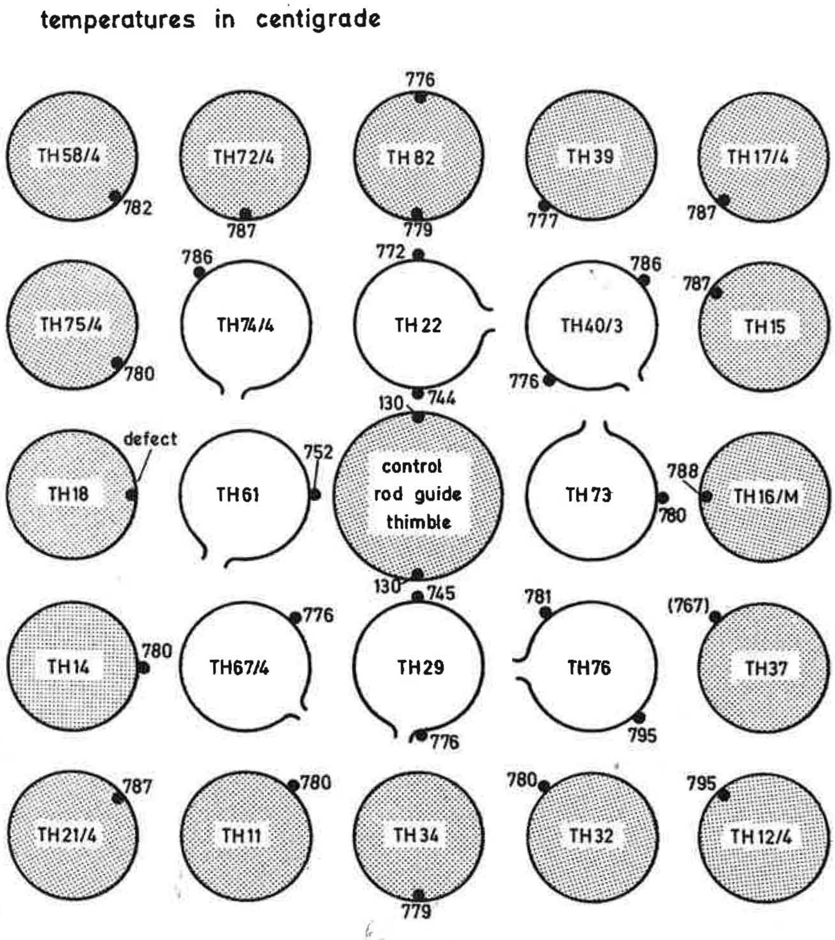
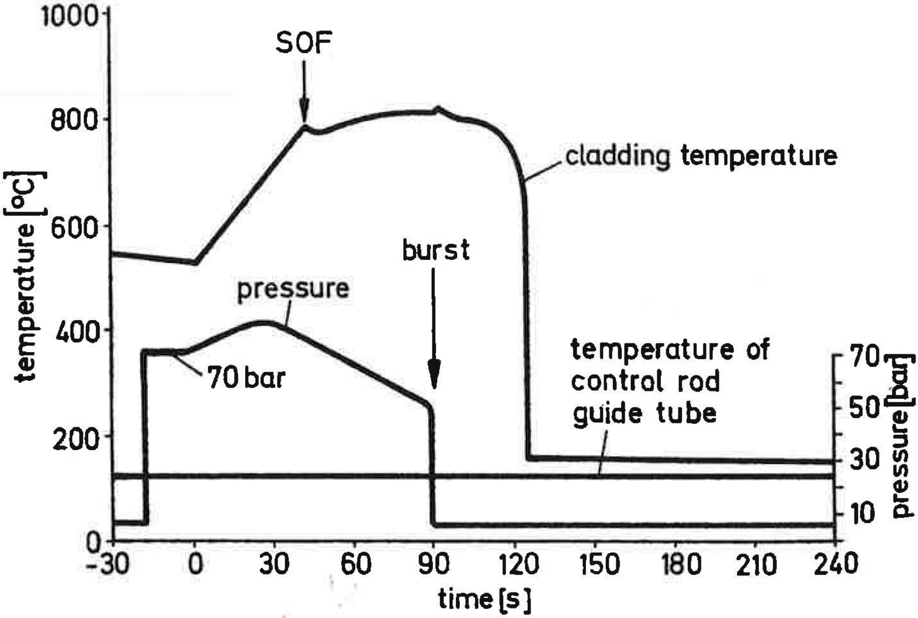


REBEKA 4

cladding temperatures in axial midplane at start of flooding

Fig. 1

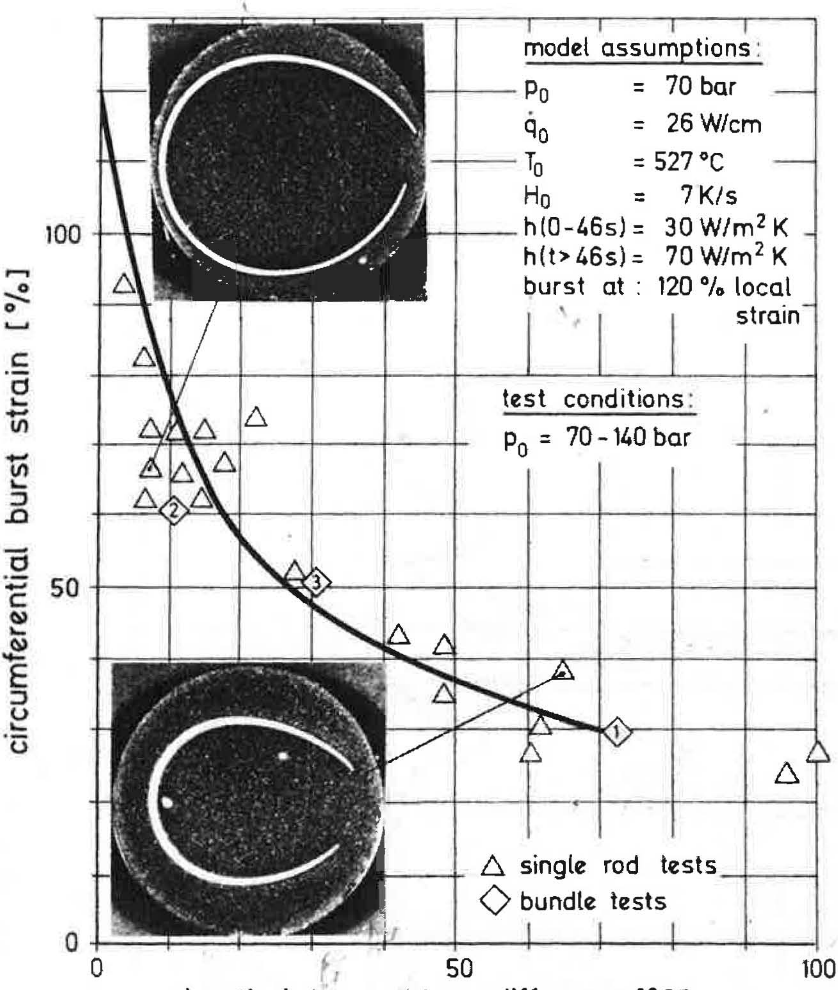
internal rod pressure	70 bar
decay heat rating at midpoint	20 W/cm
heat transfer by steam in heat-up phase	30 W/m^2K
cladding temperature at start of flooding (SOF)	≈780 °C
flooding rate, cold	3 cm/s
flood water temperature	130 °C
system pressure	4 bar
temperature of control rod guide tube	120 °C



REBEKA 4

test data and test procedure

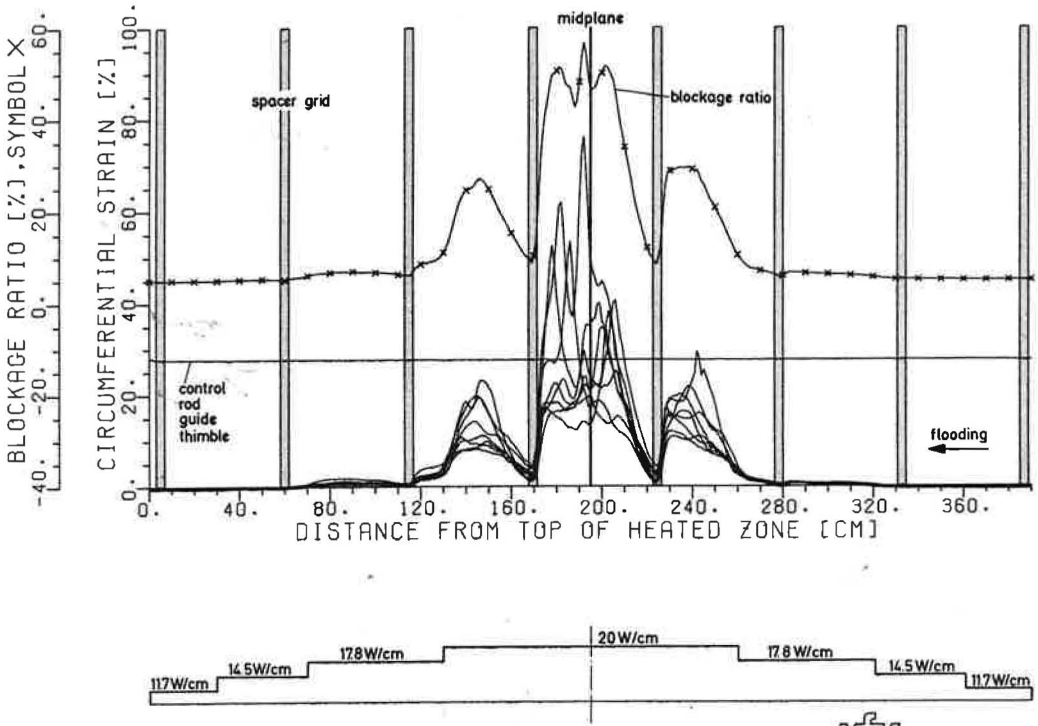
Fig. 2



Burst strain vs. temperature difference

(SSYST / AZI - prediction and test results)

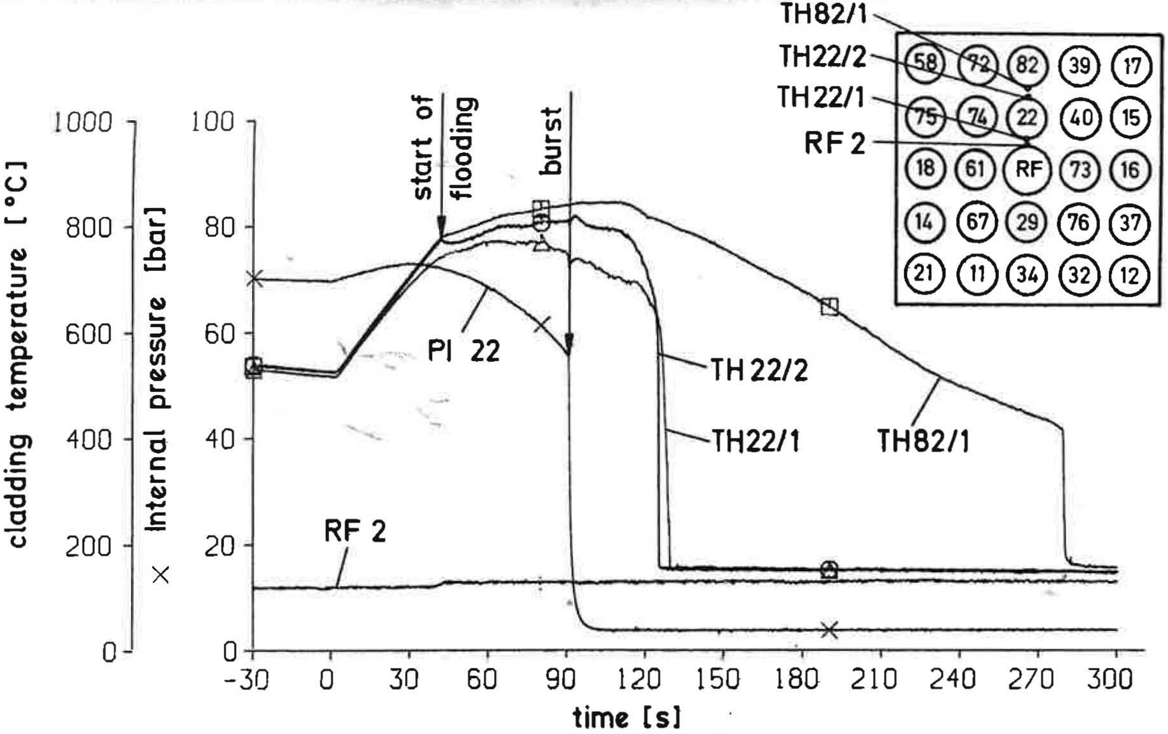
Fig.3



REBEKA 4

circumferential strain of the 8 Zircaloy claddings and coolant channel blockage

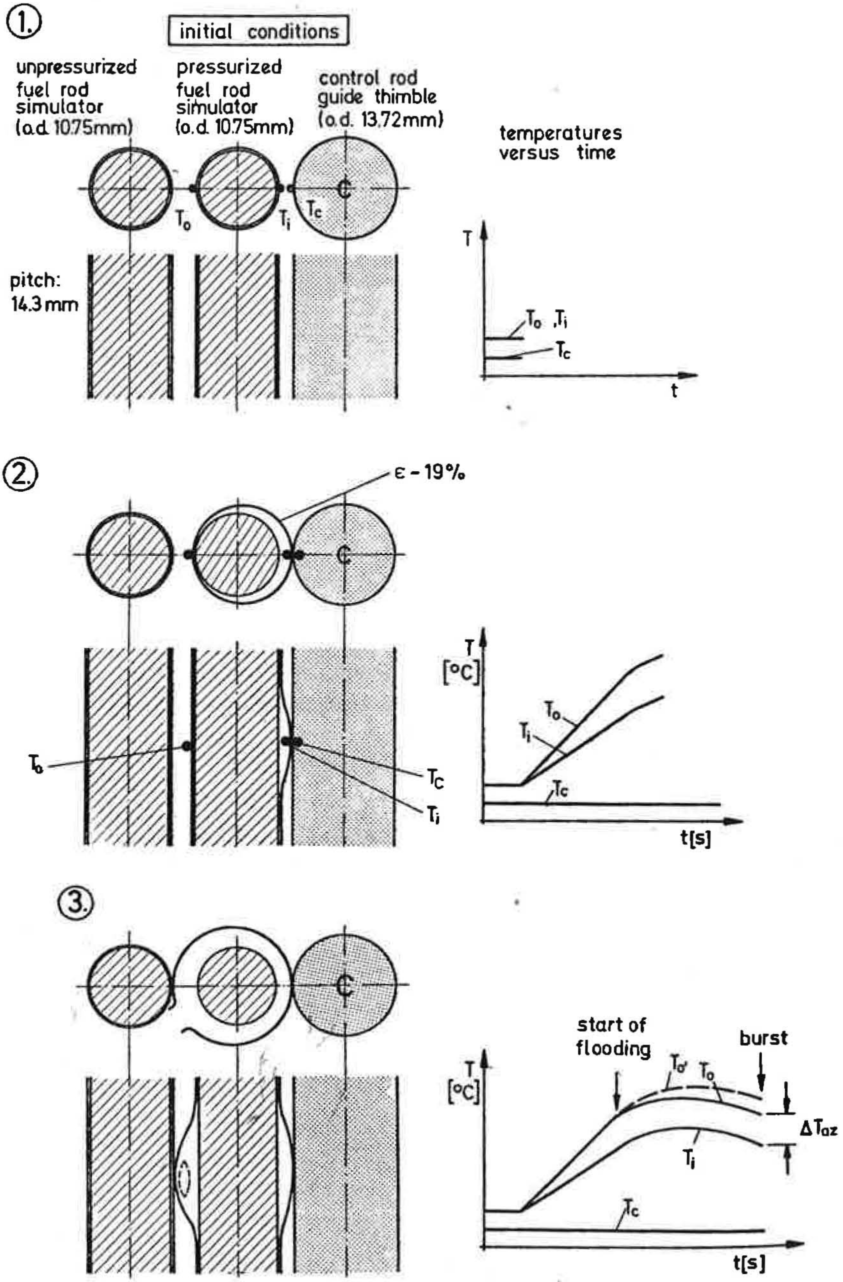
Fig. 4



REBEKA 4

Influence of control rod guide thimble on cladding temperatures

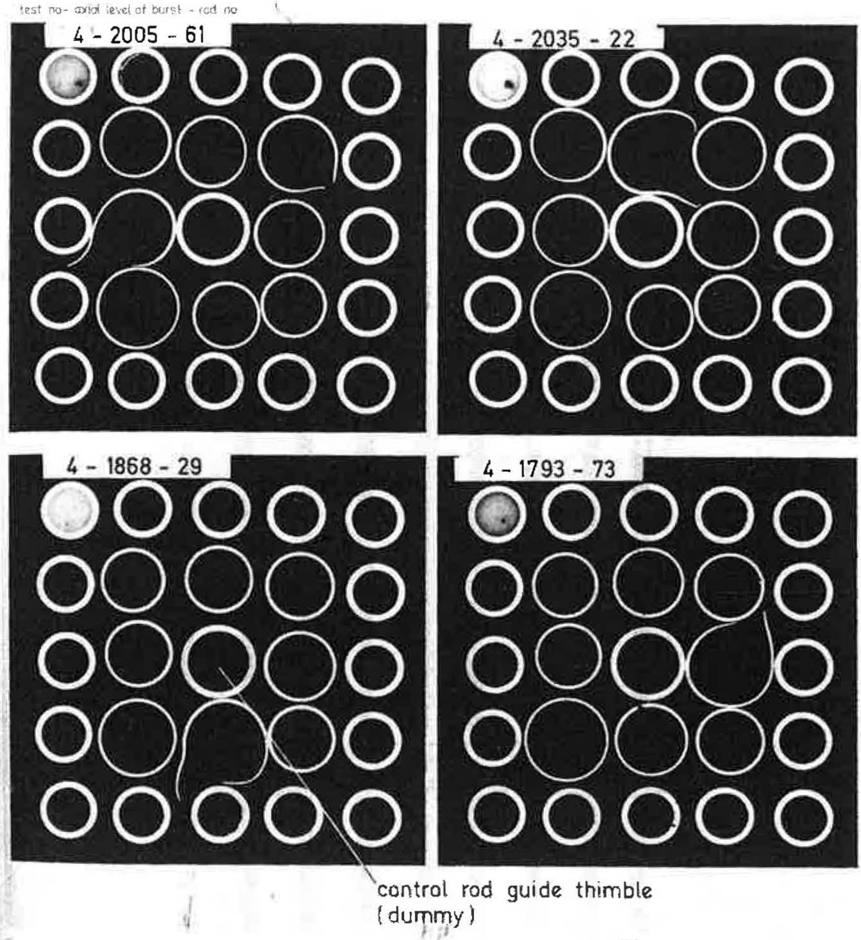
Fig. 5



REBEKA 4

Cladding deformation mechanism under the influence of a cold control rod guide tube (schematic)

Fig.6

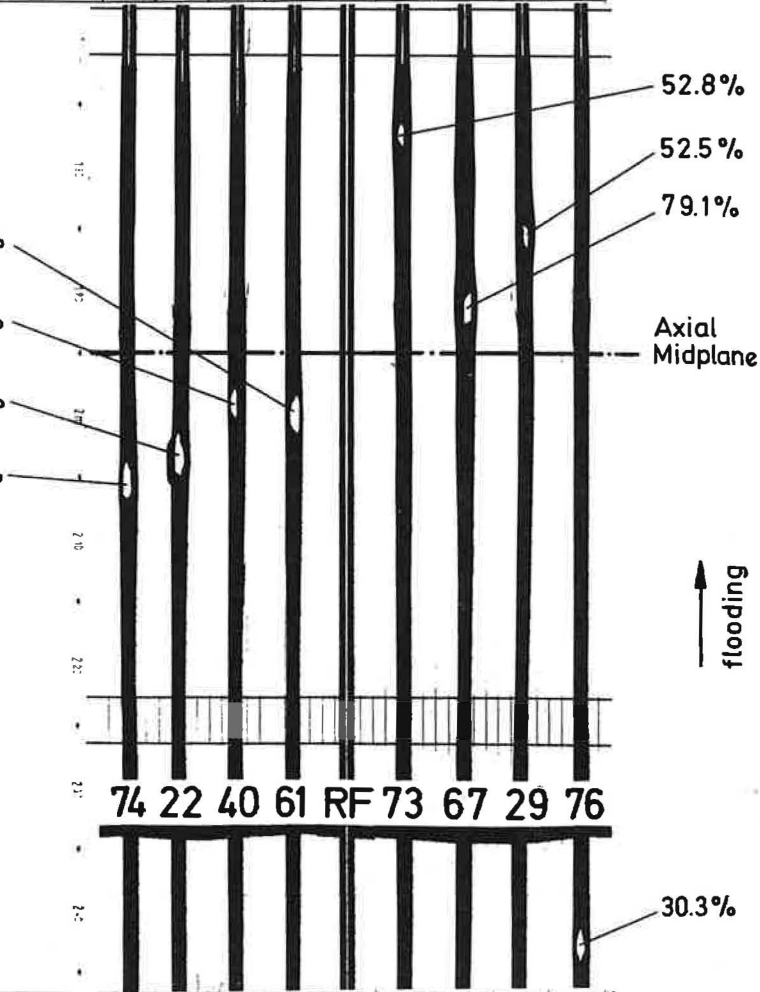


REBEKA 4

bundle cross-sections in the burst planes of claddings normally adjacent to the control rod guide thimble

Fig.7

Burst Time [s]	74	91	89	82	-	111	91	85	82
Burst Sequence	1	6	5	2	-	8	7	4	3



Strain [%]	13	21	35	20	-	24	51	17	20
Quench Time [s]	144	127	162	127	-	191	117	114	189
Quench Sequence	5	4	6	3	-	8	2	1	7

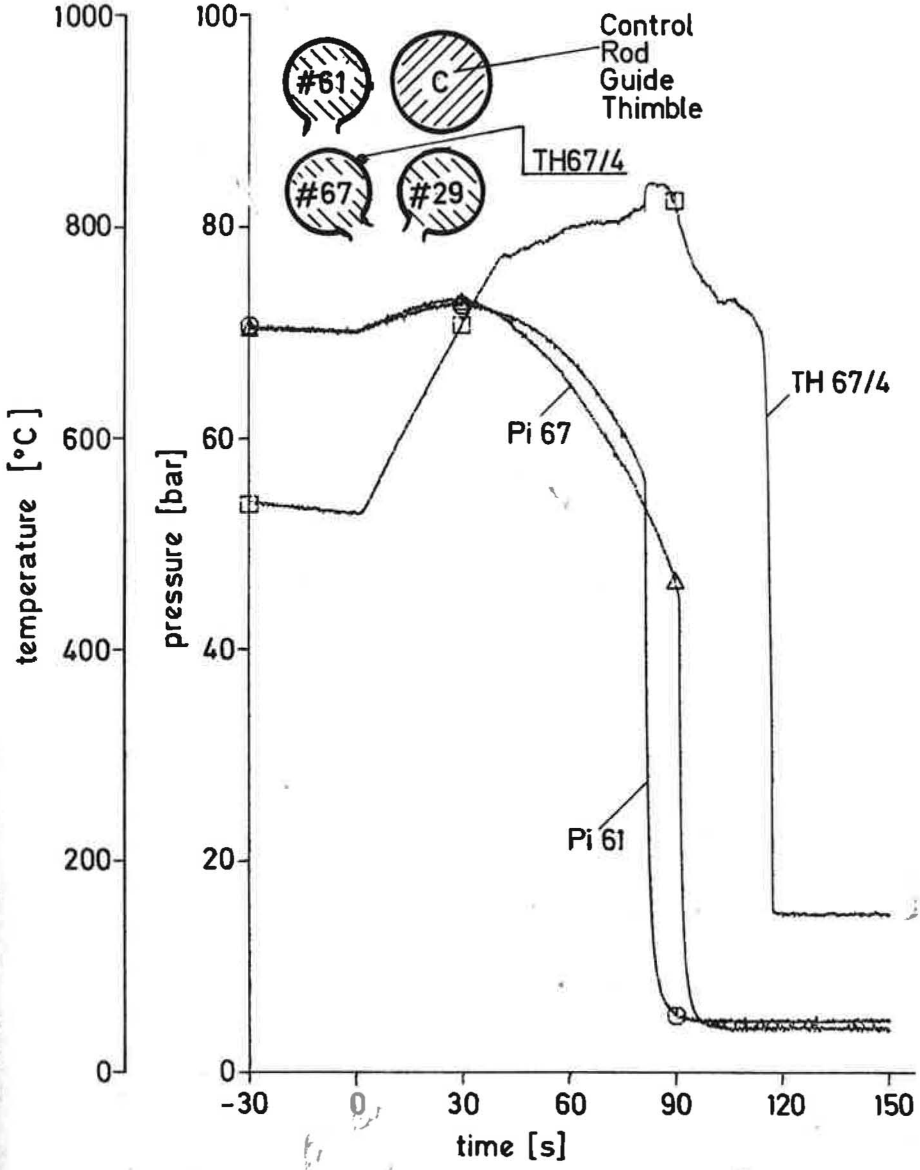
(Strain, Quench Time and Quench Sequence: Axial Midplane)

KfK

REBEKA 4

strain at axial midplane, burst strain time to burst, time to quench

Fig.8



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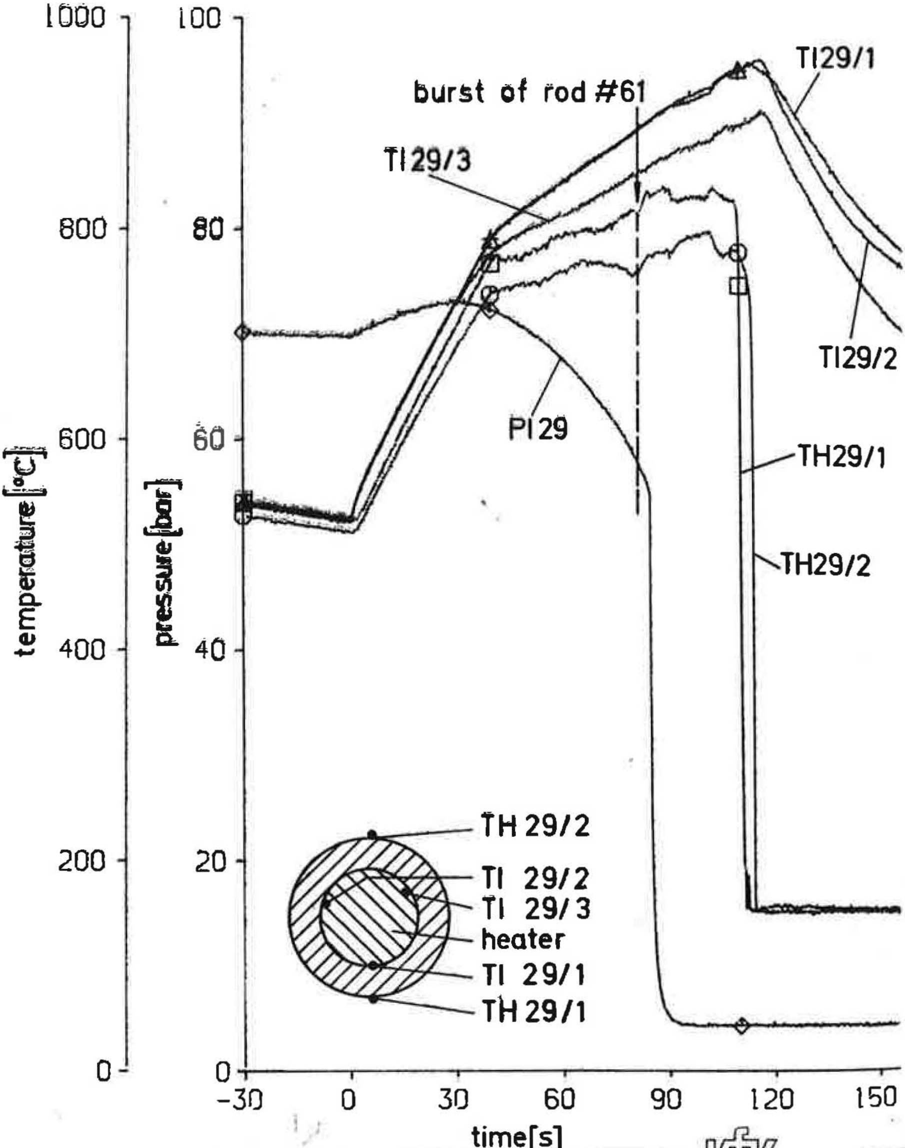
REBEKA4

Zircaloy cladding temperature response to the burst of an adjacent cladding

Fig.9



KfK

REBEKA 4
cladding temperature and pressure histories of rod#29

Fig.10