

EXPERIMENTAL DATABASE OF E110 CLADDINGS UNDER ACCIDENT CONDITIONS

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1. INTRODUCTION

The zirconium-steam reaction under accident conditions results in the oxidation of the fuel cladding and hydrogen production as an accompaniment. The oxidation causes mechanical deterioration and embrittlement of the cladding. The formed hydrogen is partly absorbed by the Zr alloy and it contributes to the cladding brittleness, which can lead to the fragmentation of the fuel rods under thermal and mechanical loads.

Since the beginning of the 90s', several experimental series have been performed at the AEKI with Zr1%Nb (E110) and Zircaloy claddings. The aims of these experiments were to study and to compare the mechanical properties of the cladding materials in the temperature range of 20-1200 °C and to investigate the effect of oxidation and hydrogen uptake on the mechanical performance of the claddings. The objectives have been achieved through separate effect tests with well defined conditions.

Due to the Zr-steam reaction, in accidental conditions a hydrogen-rich steam atmosphere may evolve, as well. In 2004 a new experimental programme (COHYRA) started at the AEKI in order to investigate the combined effects of steam and H-contents on the mechanical properties of the VVER fuel cladding.

This report gives an overview of the experiments involved in the database, the test facilities and conditions. It presents the most important results and consequences.

2. CONTENTS OF THE DATABASE

The *Experimental Database of E110 Claddings under Accident Conditions* involves the data of oxidation and mechanical tests performed at the AEKI with E110 claddings, the results of post-test investigations, photos, figures, information concerning the test conditions and the corresponding English-language publications.

The experimental database contains the results of some tests performed at the AEKI (from 1994 to 2004) with Zircaloy-4 claddings, as well.

The involved separate effect tests were grouped as follows:

1. Cladding ballooning tests

- 7-rod bundle tests to investigate the hazard of coolant flow blockage
- isothermal burst tests with as-received and pre-oxidized Zr1%Nb tube specimens
- isothermal burst tests with as-received Zircaloy-4 tube specimens
- isothermal burst tests with Zr1%Nb tube specimens to investigate the effect of pressurization rate
- burst tests on pre-pressurized Zr1%Nb rods with linear temperature increase
- Isothermal burst tests with as-received and pre-oxidized Zr1%Nb tube specimens in argon atmosphere
- Isothermal burst tests with as-received Zr1%Nb tubes in argon-hydrogen atmosphere

2. Tensile tests

- tests with Zr1%Nb sheet specimens
- tests with Zr1%Nb tube specimens
- tests with Zircaly-4 sheet specimens
- tests with Zircaloy-4 tube specimens
- tests with pre-oxidized Zr1%Nb rings specimens

3. Oxidation tests

- one-side steam oxidation of Zr1%Nb tubes at 900 °C (Pre-oxidation for ballooning tests in 1995)
- double-side steam oxidation of Zr1%Nb rings at 900 1200 °C (PECO Project 1995)
- double-side steam oxidation of Zr1%Nb rings at 500 900 °C (IAEA CRP 1995)
- double-side steam oxidation of Zr1%Nb and Zircaloy-4 rings at 900-1200 °C (1997)
- double-side steam oxidation of Zr1%Nb rings at 800 1100 °C (2000)
- double-side steam oxidation of Zr1%Nb rings at 1010 °C (OMFB 1994)
- double-side oxidation of Zr1%Nb rings in hydrogen-steam mixture at 900 1100 °C (pre-oxidation for ring compression tests)
- double-side oxidation of Zr1%Nb rings in hydrogen-steam mixture at 900 1100 °C (pre-oxidation for ring tensile tests)
- one-side oxidation of Zr1%Nb tubes in hydrogen-steam mixture at 900 1100 °C (preoxidation for first test series ballooning tests)

4. Ring compression tests

- tests with Zr1%Nb tube specimens
- tests with Zircaloy-4 tube specimens
- tests with pre-oxidized Zr1%Nb rings specimens to study ductile-brittle transition

5. Post-test investigations

- visual observations
- metallographic analysis
- SEM analysis

3. BALLOONING TESTS

Cladding ballooning tests at the AEKI comprised both single rod and rod bundle experiments to evaluate the strength and deformation of the VVER fuel rods as well as the hazard of coolant flow blockage under LOCA conditions. The pressure histories and the residual deformations of more than 170 rods are available in the database.

3.1. 7-rod bundle tests

To investigate cladding tube deformation and flow blockage phenomenon in VVER bundle were the main objectives of the test. The experiments were performed in a domestic project supported by the National Committee for Technological Development (OMFB) [2].

3.1.1. Description of the tests

This test series was performed with short (150 mm) 7-rod bundles in order to investigate the possible flow blockage rate in a VVER core under LOCA conditions. The experimental facility contained a high temperature furnace with temperature control system, a steam generator with a super heater, a pre-pressurization system to set the initial pressure of the rods and a computerized measurement and data acquisition system. (Figure 1).



Figure 1. Schematic view of the test facility for bundle blockage tests

Each test bundle contained seven Zr1%Nb cladding tubes arranged in hexagonal geometry with the pitch of 12.2 mm characterizing the VVER-440 reactor core. The lower and upper grid plates were prepared from Zr2%Nb plates with 2 mm thickness. The cladding tubes were connected to the pre-pressurization system mounted with check valves and pressure transducers. On the other end the tubes were closed with Zr2%Nb plugs. The test assembly was placed in an Al_2O_3 ceramic tube with hexagonal inner hole. (Test characteristics are summarized below.)

Characterization of the test

• Cladding tube:	
alloy:	Zr1%Nb
geometry:	Ø9.1 x 0.65 length=150 mm
end plugs:	Zr2%Nb
ZrO ₂ layer:	0-200 μm
Pressurization tube:	
alloy:	Zry-4
geometry:	Ø 6.0 x 1.0
• Grid plates:	
alloy:	Zr2%Nb
geometry:	hexagonal (plate distance=34 mm, pitch=12.2 mm)
number:	two (150 mm distance between the spacers)
 Test pressure: 	60 bar
• Instrumentation:	pressure transducer for each tube
	thermocouples at three axial locations (middle \pm 70 mm)
 Temperature range: 	20-1300°C
• Temp. increase rate:	1 K/s
Pressure range:	7-55 bar (maximum pressure in cold state)
• Atmosphere:	argon / steam
 Data acquisition: 	1 record/s
• Number of specimens	9 x 7 rods

There were nine successful experiments performed at linear temperature increase of 1K/s. The initial pressure of the rods varied between 3 and 30 bars. The individual pressure history of each rod was measured on-line and the temperature was detected in three different axial positions. The data acquisition frequency was 1 record/s. Tests in argon (bundles 1-5) and steam atmosphere (bundles 6-9) were compared to investigate the effect of cladding oxidation on flow blockage.

The main steps of the experiments were as follows:

- 1. pre-pressurization of the test tubes (3-30 bar)
- 2. activating Ar or steam injection into the furnace
- 3. heat-up of the furnace (1 K/s)
- 4. on-line detection of the pressure and temperature histories
- 5. stop of the experiment after the burst of all the seven rods of the bundle

Post-test examinations

In order to measure the deformations and the flow blockage rate after the test the bundles were filled with epoxy and horizontal cuts were prepared at different elevations. (Photos of the cuts are involved in file '*cuts.pdf*'). The elevations of the cuts corresponded to 0, ± 10 and ± 20 mm measured from the axial position of the bursts. (The axial location of the claddings' blow was identical in the bundle and generally corresponded to the hottest point.) The flow blockage rate was calculated on the basis of the measured total cross section area of the deformed rods. The considered flow channel is represented in Figure 2. The ZrO₂ layer thicknesses were measured, as well.





3.1.2. Test results and conclusions

The performed tests represented the ballooning of the cladding tubes, and the measured parameters provided adequate information for comparative analyses. The most important experimental data are summarized in Table 1 (See Appendix 1, too). The measured pressure and temperature histories for all the 9 bundles are figured in file 'graphs.pdf'. (Figure 3 represents the data of test bundle 5). The data files of the histories are stored in separated files for all the nine experiments ('test01.prn' – 'test09.prn')

No.	Atmos-	Initial	Max.	Temperature at the	Max.	Blockage
	phere	pressure	pressure	failure of the 1st rod	temperature	rate
1	Argon	10 bar	23 bar	800 °C	1000 °C	72 %
2	Argon	3 bar	7.5 bar	1100 °C	1200 °C	57 %
3	Argon	20 bar	35 bar	900 °C	900 °C	59 %
4	Argon	30 bar	46 bar	800 °C	900 °C	-
5	Argon	30 bar	53 bar	800 °C	900 °C	76 %
6	Steam	30 bar	55 bar	900 °C	900 °C	43 %
7	Steam	20 bar	36 bar	800 °C	900 °C	55 %
8	Steam	10 bar	20 bar	900 °C	900 °C	57 %
9	Steam	3 bar	7 bar	-	1300 °C	34 %

Table 1. Summary of 7-rod ballooning test parameters [3]

Figures of the measured cross section areas are presented in file '*csa.pdf*'. The data are printed in Appendix 1. On the basis of the measured data the following conclusions were drawn:

- Lower initial pressure resulted in higher failure temperature.
- Ballooning always occurred at the elevation of the maximum temperature.
- Each rod of the test bundle burst at the same axial elevation.
- Oxidation due to steam atmosphere resulted in smaller deformation.
- High initial pressure resulted in larger crack.
- The typical blockage rate was 40-50%.
- The maximum blockage rate was below 80%. The largest cladding deformation was observed in test 5. The temperature and pressure histories of this bundle are presented in Figure 3. The measured cross section areas and the flow blockage rate are presented in Figures 4 and 5, respectively.



Figure 3. Measured temperature and pressure histories of test bundle 5



Figure 4. Rod cross section areas in test bundle 5 after the ballooning experiment



Figure 5. Flow blockage rate in test bundle 5 as a function of the axial elevation measured from the cracked part

3.2. Single rod ballooning tests

3.2.1. Test series in steam atmosphere

Altogether three test series were performed to investigate the mechanical behaviour and strength of VVER cladding tubes and to provide adequate data for model validation. The effects of temperature, pressurization rate oxidation and iodine absorption produced on the deformation and the burst pressure were investigated in more than 100 biaxial tests [4, 5].

3.2.1.1. Description of the tests

Test series PUKI

The first test series (experiments PUKI) was initiated in 1995 under the support of the National Committee for Technological Development (OMFB). Fifty-four short Zr1%Nb tube samples were investigated in a resistance furnace providing isothermal conditions in the temperature range of 650-1200 °C. The inner pressure of the test tube was increased linearly until the burst of the sample. The pressure history was monitored on-line by a computerized data acquisition system. The residual deformation of the samples was measured after the test.

The schematic view of the test facility is presented in Figure 6. The specimen was placed in a quartz test tube filled with inert gas (Ar), and heated up in an electrical furnace. The pressure of the inert gas in the quartz tube was kept at constant 1 bar by means of a buffer volume. After an approximately 1000 s heat-up period the sample was pressurized with argon gas at a constant pressure gradient provided by choking with a capillary tube. Different pressurization rates between 0.01-0.1 bar/s could be achieved by using capillary tubes with different diameters. The temperature in the furnace and the cladding inner pressure were recorded by a PC with the data acquisition frequency of 10 records/s.

The specimens were 50 mm long pieces of original VVER claddings with the inner / outer diameters of 7.8 / 9.1 mm respectively. The samples were closed with Zircaloy endplugs welded to the cladding in argon atmosphere. The pressurization was performed through a Zircaloy-4 pipe (\emptyset 2.15 x 0.25) attached to one end of the specimen. (Figure 7) In order to investigate the effect of corrosion on the mechanical strength of Zr1%Nb some samples were treated in steam or iodine atmosphere before the ballooning tests. Pre-oxidation was performed in steam at 900 °C for different time periods between 50 and 3600 s. Iodine treatment was carried out for 1200 s at 700 °C in special argon-filled ampoules containing iodine in the concentration of 10 mg/cm³. These treatments issued in samples with outer oxide layer of 14-57 μ m or iodine concentration of 1.7-2.6 mg/cm².

The experimental data involved in the summary file '*pukizrnb.prn*' are tabulated in Appendix 2, as well.

Characterization of the test:

٠	Cladding tube:	
	alloy:	Zr1%Nb
	geometry:	Ø9.1 x 0.65 length=50 mm
	end plugs:	Zircaloy-4
	ZrO ₂ layer:	0-57µm
•	Pressurization tube:	
	alloy:	Zry-4
	geometry:	Ø 2.15 x 0.25
•	Instrumentation:	pressure sensor
		temperature sensor
•	Temperature range:	650-1200°C
•	Temperature	
	increase rate:	isothermal tests
•	Pressure range:	0-140 bar
•	Pressurization rate:	0.007-0.17 bar/s
•	Atmosphere:	argon
•	Data acquisition:	10 records/s
•	Number of specimens	
	tested successfully:	54





Figure 6. Schematic view of the test facility for single rod ballooning test



Figure 7. Drawing of the Zr1%Nb tube specimen for ballooning test

Test series PUZRY

The second test series (experiments PUZRY) was performed in the same test facility with thirty-one Zircaloy-4 tube specimens in order to provide data for comparative analyses too [4, 5]. The specimens' inner / outer diameters of 9.3 / 10.75 mm corresponded to the parameters of PWR fuel claddings. The test conditions were very similar to that of the first test series: linear pressure increase under isothermal conditions in the range of 700-1200 °C. The effect of corrosion on the mechanical performance of Zircaloy-4 cladding was not investigated. (The experimental data can be found in Appendix 3.)

Characterization of the test:

- Isothermal tests with linear pressure increase
- Cladding tube:

	alloy:	Zircaloy-4
	geometry:	Ø10.75 x 0.725 length=50 mm
	end plugs:	Zircaloy-4
	ZrO ₂ layer:	0 μm
•	Pressurization tube:	
	alloy:	Zry-4
	geometry:	Ø 2.15 x 0.25
•	Instrumentation:	pressure sensor
		temperature sensor
•	Temperature range:	700-1200°C
•	Temperature	
	increase rate:	isothermal tests
•	Pressure range:	0-106 bar
•	Pressurization rate:	0.007-0.26 bar/s
•	Atmosphere:	argon
•	Data acquisition:	10 records/s
•	Number of specimens	
	tested successfully:	31

Test series BALL

The third test series (experiments BALL) was performed in 2000 in order to investigate the effect of pressurization and temperature increase rate produced on the burst pressure of Zr1%Nb cladding tubes. Twenty-five experiments in two groups were performed in an interim project of the AEKI. New test facility was constructed to provide higher pressurization rates and steam atmosphere, as well.

In the first group of this test series 150 mm long, pre-pressurized Zr1%Nb tube samples were investigated at linear temperature increase. The initial pressure of the samples and the temperature increase rate were varied between 10-40 bars and 6.4-13.5 K/s, respectively.

In the second group of the test series the Zr1%Nb tube samples were investigated at different linear pressure increase rates (0.6-6.6 bar/s) under isothermal conditions in the temperature range of 800-1200 $^{\circ}$ C.

Appendix 4 contains the summary of the experimental data.

Characterization of the test:

•	Cladding tube:	
	alloy:	Zr1%Nb
	geometry:	\emptyset 9.1 x 0.65 length=150 mm
	end plugs:	Zircaloy-4
	ZrO ₂ layer:	0
•	Instrumentation:	pressure sensor
		thermocouples at three different elevations
•	Temperature range:	800-1200°C
•	Temperature	
	increase rate:	6.4-13.5 K/s
•	Pressure range:	10-40 bar
•	Pressurization rate:	0.6-6.6 bar/s
•	Atmosphere:	argon / steam
•	Data acquisition:	2 records/s
•	Number of specimens	
	tested successfully:	25

3.2.1.2. Test results and conclusions

On the basis of the ballooning tests, performed with 110 (79 Zr1%Nb + 31 Zircaloy-4) cladding tube samples the following main conclusions were drawn:

1. The mechanical behaviour of the PWR and VVER claddings are similar. However, the experiments revealed that in the temperature range of 800-1000 °C the mechanical strength of the Zr-1%Nb cladding is lower than that of the Zircaloy-4 tube, since the α - β phase transition temperature is different for Zr1%Nb and Zircaloy-4 (Figure 8).

- 2. The coolant side oxidation had a significant effect on the mechanical strength of the cladding. The strength of Zr-1%Nb increased up to 10 μ m oxide layer thickness, but decreased with further oxidation (Figure 9). Decreasing deformation with an increasing ZrO₂ layer was also observed. At the oxide layer thickness of 10-40 μ m the tangential strain decreased to the 40-30% of the oxide-free samples' strain.
- 3. The iodine treatment did not influence the mechanical behaviour significantly: only a small increase of the Zr1%Nb cladding's high temperature strength and a small decrease of deformation were observed.
- 4. Larger pressure increase rate resulted in higher burst pressure (Figure 10). On the other hand, no influence of the temperature increase rate was experienced.



Figure 8. Comparison of the failure pressures measured in biaxial tests for Zr1%Nb and Zircaloy-4 cladding specimens



Figure 9. Measured time to burst at constant pressurization rate in biaxial tests as a function of the ZrO₂ layer thickness on pre-oxidized Zr1%Nb cladding samples



Figure 10. Burst pressure of Zr1%Nb tube specimens as a function of the pressurization rate

Evaluation of high temperature cladding creep

Considering the Norton creep equation as

$$\dot{\varepsilon} = k \cdot \sigma^n \tag{1}$$

where:

 $\dot{\varepsilon}$ hoop strain rate σ hoop stress k $A \cdot \exp(-Q/RT)$ A constant Q heat production rate T cladding temperature n stress exponent, metallurgy parameter

k and n parameters were derived on the basis of the first and second test series' data following the methodology below [4]:

Since hoop stress can be calculated as

$$\sigma = p \cdot \frac{r}{s} = \frac{p}{p_0} \sigma_0 (1 + \varepsilon)^2$$
⁽²⁾

where

p over pressure; linear function of the time (*t*):

$$p(t) = b \cdot t \tag{3}$$

- s cladding wall thickness
- p_0 over pressure at $t=t_0$
- σ_0 hoop stress at $t=t_0$;
- ε hoop strain

The Norton equation can be integrated as follows:

$$\int_{0}^{\varepsilon_{R}} \frac{d\varepsilon}{\left(1+\varepsilon\right)^{2n}} = \int_{0}^{t_{R}} k \cdot \left(\frac{\sigma_{0}}{p_{0}}\right)^{n} p(t)^{n} dt \tag{4}$$

Where:

 ε_R hoop strain at rupture

 t_R time to rupture

Considering two different pressurization rates $(b_1 \text{ and } b_2)$ resulting in different rupture pressures $(p_{R1} \text{ and } p_{R2})$ parameters *n* and *k* can be easily derived after performing the integration of the equation above:

$$n = \frac{\ln \frac{t_{R2}}{t_{R1}}}{\ln \frac{p_{R1}}{p_{R2}}}$$
(5)

In view of n and using the relation

$$\frac{\sigma_0}{p_0} = \frac{r_0}{s_0} \tag{6}$$

$$k = \left(1 - \frac{1}{\left(1 + \varepsilon_{R1}\right)^{2n-1}}\right) \frac{n+1}{2n-1} \left(\frac{s_0}{r_0}\right)^n \frac{1}{p_{R1}^{\ n} t_{R1}}$$
(7)

The calculated *n* and *k* parameters for Zr1%Nb and Zircaloy-4 are presented in Tables 2 - 4 and Figures 11 and 12.

	Oxide			
TEST	layer	Temp.	п	k
	μm	°C		1/(sMPa^n)
puki-46	0.0	650	6.1	2.95E-15
puki-47	0.0	650	6.1	2.99E-15
puki-27	0.0	700	4.2	2.45E-11
puki-28	0.0	700	4.2	6.79E-11
puki-53	0.0	700	4.2	3.79E-11
puki-44	0.0	750	3.8	4.10E-10
puki-45	0.0	750	3.8	4.12E-10
puki-18	0.0	800	2.7	2.62E-07
puki-8	0.0	800	2.7	2.48E-07
puki-2	0.0	850	3.0	7.06E-07
puki-6	0.0	850	3.0	1.14E-06
puki-9	0.0	900	4.3	2.43E-06
puki-10	0.0	900	4.3	2.22E-06
puki-17	0.0	900	4.3	1.93E-06
puki-11	0.0	950	6.7	3.88E-08
puki-25	0.0	950	6.7	3.96E-08
puki-24	0.0	1000	10.4	3.30E-10
puki-12	0.0	1000	10.4	3.69E-10
puki-26	0.0	1000	10.4	4.06E-10
puki-13	0.0	1050	10.4	1.01E-09
puki-23	0.0	1050	10.4	1.48E-10
puki-14	0.0	1100	8.2	4.73E-08
puki-21	0.0	1100	8.2	3.94E-08
puki-22	0.0	1100	8.2	5.75E-08
puki-15	0.0	1150	12.0	6.65E-10
puki-20	0.0	1150	12.0	6.75E-10
puki-19	0.0	1200	7.3	7.52E-07
puki-16	0.0	1200	7.3	7.57E-07

Table 2. Parameters of the Norton eq. for oxide-free Zr1%Nb specimens

	Oxide			
TEST	layer	Temp.	п	k
	μm	°C		$1/(sMPa^n)$
puki-48	6.3	700	4.2	7.92E-12
puki-54	6.9	700	4.2	1.16E-11
puki-29	13.9	700	4.2	1.27E-11
puki-30	20.0	700	4.2	1.23E-11
puki-55	22.3	700	4.2	4.19E-11
puki-32	41.4	700	4.2	1.83E-10
puki-31	56.7	700	4.2	1.23E-10
puki-49	6.5	800	2.7	5.39E-08
puki-36	14.3	800	2.7	2.31E-08
puki-33	20.2	800	2.7	5.7E-08
puki-34	28.3	800	2.7	1.45E-07
puki-50	6.8	900	4.3	4.77E-08
puki-37	14.6	900	4.3	3.9E-08
puki-35	19.4	900	4.3	1.41E-07
puki-38	22.8	900	4.3	4.18E-08
puki-51	7.1	1000	10.4	1.61E-11
puki-40	15.1	1000	10.4	4.17E-11
puki-39	22.2	1000	10.4	1.45E-13
puki-52	7.5	1100	8.2	2.68E-08
puki-42	22.8	1100	8.2	5.67E-09
puki-43	24.2	1200	7.3	2.63E-07

Table 3. Parameters of the Norton eq. for pre-oxidized Zr1%Nb specimens

	Oxide			
TEST	layer	Temp.	п	k
	μm	°C		1/(sMPa^n)
puzry-26	0.0	700	6.2	3.08E-15
puzry-16	0.0	750	5.8	1.03E-13
puzry-30	0.0	800	4.9	1.7E-11
puzry-17	0.0	850	3.3	4.5E-08
puzry-18	0.0	900	3.8	5.39E-08
puzry-7	0.0	950	3.6	7.59E-07
puzry-8	0.0	1000	3.4	1.75E-05
puzry-9	0.0	1050	3.6	2.5E-05
puzry-10	0.0	1100	3.5	4.91E-05
puzry-11	0.0	1150	3.9	4.21E-05
puzry-12	0.0	1200	3.6	8.11E-05

Table 4. Parameters of the Norton eq. for oxide-free Zircaloy-4 specimens



Figure 11. *n* and *k* parameters of the Norton equation for Zr1%Nb on the basis of tube ballooning tests





3.2.2. Test series in hydrogen rich steam atmosphere

The ballooning experiments aimed to provide information about the effect of hydrogen rich steam oxidation and the effect of the hydrogen content on the cladding strength and deformation under simulated LOCA conditions. So far two test series were performed.

3.2.2.1. Description of the tests

The tests were carried out with 100 mm long tube specimens cut from original VVER claddings. The samples were closed with end-plugs. The pressurization was performed through a pipe attached to one end of the specimen. The tests were carried out under isothermal conditions in the temperature range of $900 - 1000^{\circ}$ C. The inner pressure of the test tube was increased linearly until the burst of the sample. The pressure history was monitored on-line. After the burst tests, the residual deformation of the specimens was measured. Afterwards two ring pieces were cut from all tubes (not far from the burst) for determination of absorbed hydrogen.

First test series

The ballooning experiments with oxidized and as-received samples were performed in argon atmosphere.

The experimental data are summarised in the data file '*cohyra_balloon.prn*' and printed in Appendix 18. The measured temperature and pressure histories are stored in separated files for all experiments '*cohyra_balloon_history1.prn* - *cohyra_balloon_history8.prn*'.

Second test series

In order to investigate the effect of the hydrogen content on the mechanical strength and deformation, some as-received samples were treated in hydrogen-rich atmosphere during the ballooning tests. Different hydrogen partial pressures could be achieved by using different hydrogen-argon flow rates.

The experimental data are compiled in the summary file 'cohyra_balloon2.prn' and printed in Appendix 19. The measured temperature and pressure histories are stored in separated files for all experiments 'cohyra_balloon2_history1.prn - cohyra_balloon2_history6.prn'.

After the ballooning test some broken pieces of the cladding (at the burst) were used for determination of the hydrogen, as well. The measured data are in the summary file 'cohyra_balloon2.prn'.

3.2.2.2. Results and conclusions

First test series

On the basis of the measured data the conclusions are the followings:

- The burst pressure of the pre-oxidized samples was higher than that of the as-received specimen.
- At low oxidation ratio the strength of the cladding increased and the cladding deformation decreased.
- The effect of hydrogen uptake is not obvious. The measurements of the hydrogen contents of the specimens carried out after the burst tests have indicated that most of the hydrogen absorbed in the pre-oxidized specimens was released during the high temperature burst tests.

Second test series

- The burst of the hydrided specimens occurred at higher pressure than the burst of the as-received sample.
- The measured hydrogen concentration around the burst was not different from the concentration at the burst.
- On the basis of the second test series we could not observe relationship between the hydrogen content and the cladding strength.
- The few performed tests did not make possible the comparison of the effect of different hydrogen content.

4. TENSILE TESTS

4.1. Test series in steam atmosphere

Beyond ballooning experiments tensile tests have been performed at the AEKI since 1989 in order to investigate the mechanical strength of VVER fuel cladding under reactor and temporary storage conditions. The tests were carried out with tube and sheet specimens in different projects partly supported by the National Committee for Technological Development [2, 6].

To investigate the effect of temperature and oxidation on the strength of Zr1%Nb alloy was the primary objective of the tensile tests. The temperature range of the tests was generally 20-350°C but a limited number of experiments were performed at higher temperatures, to 600°C, as well. The effect of oxidation on the mechanical strength was studied through the testing of pre-oxidized specimens. The maximum equivalent oxidation (ECR - Equivalent Cladding Reacted) of the specimens was 35%. In order to provide data for comparison, Zircaloy-4 specimens were tested, as well.

4.1.1. Description of the tests

The experiments were performed by a universal tensile-testing machine Instron 1195 according to the Hungarian Standard MSZ EN 10002-5. The crosshead speed was 1-2 mm/min. Digital data acquisition provided the recording of the force-displacement curves for the latter tests. Consequently, beyond the engineering stress-strain relations, the true stress-strain curves can be derived, as well. For early measurements only the data of the tensile strength, yield strength, strain and contraction are available.

There were specimens with two different geometries tested:

- 1. tube specimens (\emptyset 9.1 x 0.65) with the gauge length of 25 mm and
- 2. sheet specimens tooled at the workshop of the AEKI from original cladding tubes (Figure 13).

Both geometries supported the measurement of longitudinal strength parameters. (A new test series with ring specimens to investigate the claddings' strength in transversal direction is under preparation.) The applied E110 cladding tubes were received from two different deliveries in 1989 and in 1999.

Specimens with and without annealing as well as with and without pre-oxidation, were compared. The annealing of the specimens was performed at 580 $^{\circ}$ C or 700 $^{\circ}$ C for several hours.



Figure 13. Drawing of the sheet specimen for tensile test

Pre-oxidation of the specimens was performed in steam atmosphere at 900 °C for different time intervals between 100 and 1600 s. Both the temperature and the steam flow rate were constant during the oxidation. Since the ends of the tube specimens were plugged only the outer surfaces were oxidized. The equivalent oxidation was calculated on the basis of the measured mass gain of the specimens. The oxide layer thickness on the specimens was also evaluated as follows:

Indicating the unknown ZrO_2 thickness with x we can write the following simple relation for the ZrO_2 mass in unit length:

$$\left[d_{o}^{2} - (d_{o} - 2x)^{2}\right]\frac{\pi}{4}\rho_{ZrO_{2}} = \Delta m \frac{M_{ZrO_{2}}}{M_{O_{2}}}$$
(8)

Where:

 Δm

mass gain due to the oxidation for unit length

$$\Delta m = \frac{ECR}{100} \Delta m_{tot} \tag{9}$$

 Δm_{tot}

theoretical maximum of the mass gain for unit length

$$\Delta m_{tot} = \frac{M_{O_2}}{M_{Zr}} \frac{\pi}{4} \pi (d_o^2 - d_i^2) \rho_{Zr}$$
(10)

ECR	equivalent oxidation in %
M_{O_2}	molecular weight of oxygen (32)
M_{Zr}	molecular weight of zirconium (91.2)
M_{ZrO_2}	molecular weight of zirconium-dioxide (123.2)
d_{o}	cladding outer diameter (measured after the oxidation)
d_i	cladding inner diameter
$ ho_{Zr}$	density of zirconium (6490 kg/m ³)
$ ho_{\it ZrO_2}$	density of zirconium-dioxide (5820 kg/m ³)

Substituting equations (9) and (10) into (8) the following relationship can be derived between the equivalent oxidation (*ECR*) and the ZrO_2 layer thickness:

$$x = \frac{d_o}{2} \left(1 - \sqrt{1 - \frac{ECR}{100} \left(\frac{d_o^2 - d_i^2}{d_o^2} \right) \frac{\rho_{Zr}}{\rho_{ZrO_2}} \frac{M_{ZrO_2}}{M_{Zr}}} \right)$$
(11)

$$x = \frac{d_o}{2} \left(1 - \sqrt{1 - \frac{ECR}{100} \frac{\left(d_o^2 - d_i^2\right)}{d_o^2} 1.5064} \right)$$
(12)

4.1.2. Results and conclusions

Experimental data have been summarised separately for Zr1%Nb and Zircaloy-4 sheet and tube specimens. The summary files are printed in Appendix 5.

The measured VVER cladding strength parameters corresponded to the data in international publications. The annealing did not influence the strength and the strain of the specimens considerably. Differences in tensile strength and elongation of the samples from the two different deliveries were in the range of the measurements' uncertainty.

On the other hand the pre-oxidation of the specimens in steam atmosphere resulted in relevant influences. Tensile test and ballooning experiments indicated analogous effects of the oxidation on cladding strength and deformation. Below the ECR of about 5% the tensile strength increases with the oxidation up to a definite maximum and decreases with further oxidation. This phenomenon is clearly indicated in Figure 14 representing the test data at three different temperatures as 20 °C, 150 °C and 300 °C. The measured strains of the specimens sharply decrease with the oxidation already at a low level of ECR (Figure 15). Tensile testing of deeply oxidized Zr1%Nb came up against technical difficulties due to the unstable fixing of the embrittled specimens.





Figure 14. Tensile strength of Zr1%Nb tube as a function of the ECR and the temperature. AEKI tensile test data



Figure 15. Strain of Zr1%Nb tube as a function of the ECR and the temperature. AEKI tensile test data

4.2. Test series in hydrogen rich steam atmosphere

The main objective of the tensile tests was to investigate the effect of hydrogen rich steam oxidation and the effect of the hydrogen content on the strength of E110 alloy.

4.2.1. Description of the tests

The tensile tests of cladding rings with 2 mm length were carried out at room temperature using INSTRON 1195 universal testing machine. The velocity of the crosshead moving was 0.5 mm/min. Digital data acquisition provided the recording of the load – displacement curves. The extent of the equivalent oxidation was lower than 6 % in the performed experiments.

The experimental data are compiled in the summary files 'cohyra_tensile.prn and cohyra_tensile_curves.pdf', and printed in Appendix 17.

4.2.2. Results and conclusions

Figure 16 represents the measured tensile strength of the E110 specimens versus the ECR. The effect of the oxidation was consistent with the results of earlier tensile tests with cladding specimens pre-oxidized in pure steam at 900° C [18]. Below the equivalent oxidation of about 3 % the tensile strength increases with the oxidation up to a definite maximum and decreases with further oxidation. However, the tensile strength is slightly lower in steam-hydrogen mixture than in pure steam. It means that the fuel cladding is less loadable probably due to the higher hydrogen content of the cladding oxidized in hydrogen-rich steam.



Figure 16. Tensile strength of E110 as a function of the oxidation

Figure 17 illustrates the tensile strength as a function of the hydrogen content of the specimens.



Figure 17. Tensile strength of E110 as a function of the hydrogen content.

On the basis of the COHYRA experiments the mechanical deterioration of the fuel cladding was observed above 600 wppm hydrogen content. The hydrogen content was not measured after the earlier tensile tests.

5. OXIDATION EXPERIMENTS

5.1. Test series in steam atmosphere

Data of seven different series of oxidation experiments were involved in the database. All the seven experiments aimed at the investigation of Zr1%Nb claddings' high temperature oxidation in steam atmosphere. The kinetics of the oxidation was studied at constant steam flow in the temperature range of 500-1200 °C. Some of the experiments were initiated to provide pre-oxidized samples for mechanical tests. Beyond this report, ref. [7] also summarizes information about the cladding corrosion tests performed at the AEKI.

5.1.1. Experiments 'PUKOX'

This series of experiments was performed in 1995 in order to provide pre-oxidized specimens for the ballooning tests 'PUKI' (described in chapter 3.2) [4]. The 50 mm long Zr1%Nb tube specimens were oxidized at 900 °C in constant steam flow. The time of oxidation varied between 50 - 3600 s resulting in the equivalent oxidation (ECR) of 0.6 - 6%. Only the outer surface of the specimens was oxidized, since both ends of the tubes were plugged. The weight of every specimen was measured before as well as after the oxidation. The equivalent oxidation and the ZrO₂ thickness were calculated on the basis of the measured mass gain. The achieved 0.6 - 6% of ECR corresponded to the ZrO₂ thickness of $6 - 60 \mu$ m. The oxidation rate constant was also tabulated for each specimen.

The measured data are tabulated in the data file 'pukox.prn' and printed in Appendix 6.

5.1.2. Experiments 'EU-PECO'

This EU supported project initiated in 1995 aimed at the study of Zr1%Nb oxidation and hydriding phenomena in the temperature range of 900-1200 °C. The rate of mass gain and the formation of zirconium oxide layers were determined in high temperature steam oxidation tests performed with original VVER cladding tube specimens (\emptyset 9.14 x 0.70, length=40 mm).

The cladding specimens were tested under isothermal conditions in constant steam flow. The rate of oxidation was characterized by the mass gain measured by analytical balance. Metallographic tests were used to determine the thickness of the reaction layers. Hydrogen contents of the specimens were measured after the oxidation tests by means of hot extraction method.

The experimental facility consisted of a tube furnace, a steam generator, a super-heater, a quartz tube and a condenser (Figure 18.). The steam flow rate was about 7.5 mg/s, the super-heating temperature was 350 °C. The temperature of the furnace was controlled between 900 and 1200 °C with the accuracy of $\pm 1^{\circ}$ C. The exposure time intervals varied between 5-166 minutes at 900 °C and 1-8 minutes at 1200 °C.



Figure 18. Schematic view of the test facility for cladding oxidation tests

The extent of oxidation did not exceed 20% ECR in the performed experiments. The kinetics of the oxidation was evaluated through the mass gain and the zirconium oxide layer growth. The measured data proved the square root relationship between the oxidation rate and the time indicating diffusion-controlled process. The rate constants calculated at different temperatures for the mass gain and the ZrO_2 layer growth are presented in Figures 19 and 20, respectively.

Multi-layer structure of the ZrO_2 was observed if the oxidation had been performed below 1100 °C. (See more in Chapter 5.1.4). Compact oxide layer formed at higher temperatures (1100-1200 °C).

Hot extraction methods indicated 10 - 40% uptake of the formed hydrogen. It was concluded that the kinetics of the hydrogen uptake strongly depends on the oxide layer structure. During steam exposure under 1050 °C the hydrogen uptake was nearly proportional to the mass gain. But, the compact oxide layer at higher temperatures impeded the hydrogen uptake.

Comparison of the experimental records with literature data indicated similar mass gain rates but different oxide layer morphologies for Zr1%Nb and Zircaloy-4 alloys. The hydrogen uptake of Zr1%Nb is more intensive than that of the Zircaloy.

Detailed description of the experiments and the comparison with literature data can be seen in reference [8]. The experimental data are tabulated in Appendix 7.



Figure 19. Temperature dependence of the mass gain on the basis of Zr1%Nb oxidation tests in steam between 900 - 1200 °C.

Figure 20. Temperature dependence of oxide layers' formation on the basis of Zr1%Nb oxidation tests in steam between 900 - 1200 °C.

5.1.3. Experiments 'IAEA-CRP'

The oxidation experiments were performed in the IAEA co-ordinated research programme in 1997 in order to investigate the oxygen uptake, ZrO_2 and α -Zr(O) layers' formation and hydrogen absorption of Zr1%Nb alloy in steam atmosphere in the temperature range of 500-900 °C [9].

The specimens were 5 mm long slices of VVER fuel cladding tubes (\emptyset 9.1 x 0.7). The total surface (inner and outer) area of the specimen was 3 cm². The experimental facility was similar to that of the former oxidation tests. The set-up involved a tube furnace with temperature control system and a steam generator with superheater to provide constant steam flow. The specimens and a thermocouple were located in a quartz tube passing through the furnace. Six specimens were oxidized simultaneously. The temperature control system provided isothermal conditions with the accuracy of $\pm 1^{\circ}$ C. The oxidation time varied from 30 s to 180 h, depending on the temperature of the test.

Mass gain due to the oxidation was derived by means of microbalance measurements before and after the test. The hydrogen content of the specimens was determined by post-test hot extraction method; i.e. the specimens were heated and flushed with argon gas and the released hydrogen was detected by means of gas chromatography. ZrO_2 and α -Zr(O) layers' thicknesses were measured as well (Appendix 8).

The oxidation rate constants were derived on the basis of the measured data. Figures 21 and 22 present the temperature dependencies of the rate constants for the mass gain, and the zirconium oxide layer formation, respectively. The relations fitted to the measured data are summarised below:

Mass gain rate (mg·cm⁻²·s^{-1/2}):

$$k_{\Delta m} = 284.1 \cdot \exp(-79274/RT) \tag{13}$$

Where:

R

Т

- 8.314 J/(mol.K)

- temperature in *K* [773; 1173]
- ZrO_2 formation rate (cm·s^{-1/2}):

$$k_{ZrO_2} = 2.88 \cdot \exp(-86468 / RT) \tag{14}$$

$$\alpha$$
-Zr(O) formation rate (cm·s^{-1/2})
 $k_{\alpha Zr(O)} = 18.0 \cdot \exp(-129419 / RT)$ (15)





Figure 22. Temperature dependence of oxide layers' formation on the basis of oxidation tests in steam

5.1.4. Experiments 'OAH-ABA'

An experimental project supported by the Hungarian Atomic Energy Authority (HAEA) was initiated in 2000 in order to compare the oxidation and hydrogen uptake kinetics of Zr1%Nb and Zircaloy-4 cladding alloys [10, 11, 12].



Figure 23. Test facility for steam oxidation of cladding specimens

The experimental set-up for the oxidation tests contained a steam generator, a tube furnace with precise temperature control system, a quartz tube as the reaction volume and a condenser (Figure 23). The H₂ formation was monitored on-line by gas thermal conductivity measurement: argon as carrier gas was fed to the steam flow in the concentration of 12 v%. (Experiments indicated that this amount of Ar gas does not influence the kinetics of the oxidation.) After condensing the steam at the outlet of the test tube the Ar-H gas mixture was monitored by a thermal conductivity detector (TCD). The signal of the detector was proportional to the H₂ concentration in the gas mixture.

Ring specimens of original cladding tubes (Zr1%Nb: \emptyset 9.1 x 0.7, Zircaloy: \emptyset 10.74 x 0.73) with the identical length of 8 mm were oxidized in steam under isothermal conditions at 900, 1000, 1100, and 1200 °C. The steam flow rate was 8.5-11 cm/s. Due to different oxidation temperatures and time intervals the ECR varied between 1 and 40%. The mass gain of the samples was measured by analytical balance with the accuracy of \pm 1 mg.

Post-test investigations involved mechanical compression tests on tensile machine to analyse the embrittlement of the oxidized samples and also the hot extraction of absorbed hydrogen.

The performed experiments proved that the mass gain due to oxidation is linearly proportional to the square root of the exposure time. The mass gain for unit surface area can be described as follows:

$$\frac{\Delta m}{F} = A \cdot \exp(\frac{-Q}{RT}) \cdot t^{1/2} \tag{16}$$

Where:
- Q activation energy (J)
- R gas constant = 8.314 J/(mol·K)
- T temperature (K)
- t time of steam exposure (s)

 $k = A \cdot \exp(\frac{-Q}{RT})$ is called to the reaction rate constant. On the basis of the mass gain data measured for Zr1%Nb and Zircaloy-4 the following relations were derived for the oxidation

rate constants versus temperature (Figure 24):

$$k_{Zr1\%Nb} = 288.6 \cdot \exp\left(\frac{-77576}{R \cdot T}\right)$$
(17)

$$k_{Zircaloy} = 3273 \cdot \exp\left(\frac{-103667}{R \cdot T}\right) \tag{18}$$



Figure 24. Oxidation rate constants for Zr1%Nb and Zircaloy-4 as a function of the temperature on the basis of experimental mass gain data

As it was observed on Zr1%Nb specimens during the oxidation at 900-1000 °C, the ZrO₂ layer periodically breaks away at the thickness of 8-14 μ m. After the break-away phenomenon the oxidation and also the H₂ absorption accelerate. Consequently equation 17 is valid till the first break away of the ZrO₂ layer (at the thickness of about 10 μ m). On the other hand, compact oxide layer formed if the oxidation temperature exceeded 1000 °C. At 1100 and 1200 °C there was no spalling of ZrO₂ observed and the on-line H₂ detection proved the validity of the square root relationship between the reaction rate and the time during the total oxidation period. Hot extraction method confirmed that the H₂ absorption was also limited by the compact ZrO₂ layer (Figure 25).



Figure 25. H/Zr ratio measured by hot extraction method in Zr1%Nb specimens oxidized to the ECR of 35% at different temperatures.

Oxidation of Zircaloy-4 specimens indicated more compact oxide layer formation and very limited H₂ absorption. Oxide spalling and measurable H₂ up-take occurred only at 1000 $^{\circ}$ C at a considerably thick ZrO₂ layer (> 60 µm) formed during a 40-minute steam exposure.

Ring compression tests pointed out that due to intensive H₂ absorption the Zr1%Nb cladding embrittles more widely during steam oxidation than the Zircaloy-4 tube.

Experimental data of Zr1%Nb and Zircaloy-4 specimens have been tabulated in files 'OAHzrnb.prn' and 'OAHzry.prn' (Appendix 9), respectively. More information concerning experimental results can be found in ref. [11].

5.1.5. Experiments 'HTARTOX'

Oxidation experiments performed with as-received and hydrided Zr1%Nb and Zircaloy-4 ring specimens in order to study the effect of the cladding's hydrogen content on the oxidation rate and the emission of hydrogen during the late phase of the steam oxidation [12, 13]. The experimental facility for steam oxidation is presented in chapter 5.4. The kinetics of the oxidation and the hydrogen emission were analysed on the basis of TCD signals proportional to the H₂ content of the exhaust gas mixture. Mass gain of the specimens was measured by analytical balance, too. Data evaluation indicated, that the oxidation rate of hydrided specimens was lower than that of the as-received samples. On the other hand, the hydriding of the specimens did not influence considerably the hydrogen emission during the late phase of the oxidation.

The database contains the geometry, the mass gain data and the resulted oxidation rate of only the as-received specimens (file *'htartox.prn'*, Appendix 10).

5.1.6. Experiments 'OMFB-94'

One of the first oxidation tests performed in 1994 at the AEKI in the framework of a comprehensive project to study fuel rod performance. The project was supported by the National Committee for Technological Development (OMFB).

Zr1%Nb tube specimens were oxidized in steam at 1010 °C in order to check the square root relationship between the oxidation rate and the time for the VVER cladding alloy and to compare the reaction rate with published data. The time of oxidation varied from 500 s to 4000 s. Measured mass gain data and the derived oxidation rate constants are tabulated in file 'omfb-94.prn'.

The experiments nicely reproduced the reaction rate constants measured by other institutions (e.g. FZK, Karlsruhe – Figure 26) at the same temperature.



Figure 26. Comparison of mass gain rate constants derived from AEKI and FZK oxidation tests performed with Zr1%Nb alloy at 1010 °C.

5.2. Test series in hydrogen rich steam atmosphere

Data of four different series of oxidation experiments were involved in the database. The experiments were performed in order to provide pre-oxidized samples for ring compression, tensile and ballooning tests and to study the effect of the presence of hydrogen in steam atmosphere on the oxidation kinetics.

5.2.1. Description of the tests

Un-irradiated, original VVER cladding specimens (outer diameter: 9.14 mm) were oxidized in a controlled, mixed steam-hydrogen atmosphere under isothermal conditions between 900 and 1100 °C. Two test series (first and fourth series) were carried out for ring compression tests. In the first test series the hydrogen content in the steam was fixed between 0 and 36 vol. %. During the fourth series the experiments were performed in extended range (the H-content was 5 and 65% in the steam). The second and third oxidation series were performed in 20 – 36 vol. % hydrogen-steam mixture for ring tensile and ballooning tests. After steam exposure for different time periods the samples were characterized by their oxygen content. The oxygen content was defined as oxidation ratio. The extent of the oxidation was measured through the weight gain of the specimens. Prior to testing, the specimens were degreased in acetone.

A high temperature tube furnace was used for the oxidation of the samples. The experimental set-up consisted of a steam generator, a three-zone furnace and a condensing system (Figure 27). The outlet hydrogen flow rate was measured by calibrated Soap Bubble Gas Flow Meter, the steam flow was evaluated through the measured weight of the condensed water. When the temperature of the furnace and the steam + hydrogen flow became stabilized, the sample in a quartz boat was pushed to the centre of the furnace. At the end of oxidation the sample was withdrawn to the cold part of the quartz tube.



Figure 27. Scheme of the experimental set-up for oxidation tests

5.2.2. Pre-oxidation for ring compression tests

The oxidation was carried out at three different temperatures (900, 1000, 1100°C) in a constant flow of steam-hydrogen mixture [14]. At each temperature several samples with 8 mm length were oxidized during different times in order to achieve different oxidation ratios. The extent of oxidation did not exceed 18 % ECR. In 2004 (1. test series) the hydrogen content of the steam was 0, 20, 28 or 36 vol. %. During the fourth series (2006) the H-content was 5 and 65 vol. % in the steam.

The experimental data are tabulated in the data files 'cohyra_ox1.prn' and 'cohyra_ox4.prn' printed in Appendix 13. The tabulated oxidation rate constants were derived from the measured weight gains and oxidation times assuming parabolic relation.

5.2.3. Pre-oxidation for ring tensile tests

The specimens with 2 mm length were oxidized in constant steam-hydrogen flow at the temperature of 900, 1000, or $1100 \,^{\circ}$ C. The extent of oxidation did not exceed 6 % ECR in the performed experiments. The range of hydrogen content in the steam was 0 - 36 vol. %.

The measured data and the derived oxidation rate constants are tabulated in the data file 'cohyra_ox2.prn' and printed in Appendix 14.

5.2.4. Pre-oxidation for ballooning tests

The 100 mm long Zr1%Nb tube specimens were oxidized under isothermal conditions in constant steam-hydrogen flow. Only the outer surface of the specimens was oxidized, since both ends of the tubes were plugged. The maximum oxidation ratio was 5 %. The hydrogen content in the steam was 20 or 36 vol. %.

The information of these experiments are summarized in the data file 'cohyra_ox3.prn' and printed in Appendix 15.

5.2.5. Determination of hydrogen content

After a high temperature desorption (hot extraction) the amount of absorbed hydrogen was determined by gas chromatographic method using CHROMPACK MODEL 438A Gas Chromatograph with thermal conductivity detector (TCD). The broken pieces of the cladding rings after mechanical testing were used for high temperature desorption.

The measured data are tabulated in the data files 'cohyra_ox1.prn, cohyra_ox4.prn cohyra_ox2.prn, cohyra_ox3.prn, cohyra_compr.prn and cohyra_tensile.prn' and printed in Appendix 13-17.

5.2.6. Results and conclusions

The experiments confirmed that the mass gain due to the hydrogen-rich steam oxidation is linearly proportional to the square root of the exposure time. The mass gain for surface area can be described as follows:

$$\frac{\Delta m}{F} = k \cdot t^{1/2} = A \cdot \exp(\frac{-Q}{RT}) \cdot t^{1/2}$$
⁽¹⁹⁾

Where:

Δm	mass gain (mg)
F	surface area (cm ²)
А	pre-exponential factor
Q	activation energy (J)
R	gas constant = 8.314 J/(mol·K)
Т	temperature (K)
t	time of steam exposure (s)
k	reaction rate constant $(mg/cm^2/s^{1/2})$

On the basis of the mass gain data measured for E110 in 20 vol. % hydrogen-steam atmosphere the following relation was derived for the oxidation rate constants versus temperature (Figure 28):

$$k = 117 \cdot \exp\left(\frac{-8680}{T}\right) \tag{20}$$

The oxidation rates constants measured in pure steam and in different steam- H_2 mixture are represented in Figure 28 and Figure 29.



Figure 28. Oxidation rate constants for E110 as a function of reciprocal temperature in steamhydrogen mixture (first test series)



Figure 29. Oxidation rate constants for E110 as a function of reciprocal temperature in steamhydrogen mixture (fourth test series)

The mass gain rate constants measured in 65 vol.% H-steam mixture have no significant difference as compared to the result in 5 vol.% H-steam mixture.

File: E110_database_2007.doc

Comparing the oxidation rate constants measured in pure steam and in hydrogen-rich steam atmosphere, it can be concluded that the hydrogen content in the steam decelerates the cladding oxidation [15].

Comparing the hydrogen contents of the cladding specimens oxidized in pure steam and in steam-hydrogen mixture, enhanced hydrogen absorption was observed in hydrogen rich steam atmosphere (Figure 30 and Figure 31).







Figure 30. Hydrogen content of Zr1%Nb claddings oxidized in pure steam and in steamhydrogen mixture at 900, 1000 and 1100 °C







Figure 31. Hydrogen content of Zr1%Nb claddings oxidized in pure steam and in steamhydrogen mixture at 900, 1000 and 1100 °C

6. RING COMPRESSION TESTS

6.1. Test series in steam atmosphere

For the samples with different oxidation conditions the same ring compression testing procedure was applied to characterize the embrittlement process of the two type alloys.

6.1.1. Description of the tests

The oxidized ring samples (E110 and Zircaloy-4) with 8 mm length were examined in radial compression tests using INSTRON 1195 universal testing machine. The velocity of the crosshead moving was 2 mm/min. The rings were loaded until the total plastic deformation or at least until the first indication of cracking. The load-displacement curves were recorded and the crushing force and deformation were determined.

The effect of ductile/brittle behaviour was expressed in the term of relative deformation.

6.1.2. Results and conclusions

Experimental data are summarised separately for Zr1%Nb and Zircaloy-4 ring specimens in the files 'comprzrn.prn and comprzry.prn'. The summary files are printed in Appendix 12.

The results of the radial compression tests well indicated the embrittlement of the cladding materials due to the oxidation process. Figure 32 shows typical compression diagrams for Zr1%Nb samples oxidized at 900°C at different extent of oxidation.



Figure 32. Force-displacement diagrams recorded during radial ring compression testing of Zr1%Nb samples oxidized in steam

The ring compression tests performed in AEKI showed different mechanical behaviour of the two alloys. At low (1 - 3 %) oxidation ratio the relative deformation for both types of samples was 40 – 60 % (Fig. 33). At ~5 % the difference became significant. Less than 10 % relative deformation was measured for Zr1%Nb and more than 10 % for Zircaloy-4. With increasing oxidation ratio the relative deformation decreased.



Figure 33. Relative deformation as a function of oxidation ratio for Zr1%Nb and Zircaloy-4 samples oxidized in steam

In Fig. 34 the experimental results are presented as relative deformation versus hydrogen content. It can be observed that the above 600 ppm hydrogen concentration both Zr1%Nb and Zircaloy-4 samples became brittle. The figure indicates that the Zircaloy-4 with close to zero hydrogen content can be very brittle as well, obviously due to the high extent of oxidation.



Figure 34. Relative deformation as a function of hydrogen content for Zr1%Nb and Zircaloy-4 samples oxidized in steam

6.2. Test series in hydrogen rich steam atmosphere

Investigation of the ductile-brittle transition of the cladding was the primary objective of the ring compression tests.

6.2.1. Description of the tests

The oxidized E110 ring samples with 8 mm length were examined in radial compression tests at room temperature using INSTRON 1195 universal testing machine. The velocity of the crosshead moving was 0.5 mm/min. The rings were loaded until the total plastic deformation or at least until the first indication of cracking. The load-displacement curves were recorded and the crushing force and deformation were determined. The cladding ductility was characterized with the specific energy at failure (i.e. the integral of the load-displacement curve for the unit length of the ring specimen):

$$E_{s} = \frac{1}{L} \int_{0}^{U_{c}} F(U) dU$$
(21)

Where:

 E_s specific energy (mJ/mm)

L length of the specimen (mm)

F force (N)

U displacement (mm)

 U_C displacement at first cracking (mm)

The experimental data are summarised in the files 'cohyra_compr.prn, cohyra_compr2.prn' and printed in Appendix 16. The compression curves and the load-displacement data are collected in the files 'cohyra_compr_curves.pdf', 'cohyra_compr2_curves.pdf', '(cohyra_compr_data01–39).prn' and '(cohyra_compr2_data01–28).prn'

6.2.2. Results and conclusions

The hydrogen uptake strongly reduced the ductility of the cladding. According to our earlier studies with oxidized E110 rings [16, 17], 50 mJ/mm specific energy was found as a boundary of ductility. In view of this limit, the cladding oxidized in 20 - 36 vol% hydrogen-steam mixture, became brittle above ~500 ppm hydrogen content (Figure 35).

However, the embrittlement of the claddings oxidized in 5 vol% H-steam mixture have no significant difference compared to the result on 65 vol% H-steam mixture (Figure 36). (The specimens oxidized in 5 and 65 vol% hydrogen-steam mixture were probably cut from another E110 cladding than the specimens oxidized in 20 - 36 vol% hydrogen-steam mixture).



Ring Compression Tests on E110

Figure 35. Specific energy at failure as a function of hydrogen content of the samples



Ring Compression Tests on E110

Figure 36. Specific energy at failure as a function of hydrogen content of the samples

The specific energies of specimens oxidized in pure steam and in different hydrogensteam mixture (5, 65 and 20 – 36 vol% H₂) are compared in Figure 37. The figure clearly indicates that, due to a more intense hydrogen absorption the embrittlement of the cladding takes place at lower oxidation level (about 3 %) in hydrogen rich steam atmosphere than in pure steam or in steam with low hydrogen content (5 vol%).



Ring Compression Tests on E110

Figure 37. Specific energy at failure versus the measured oxidation ratio

Representing the time of oxidation as a function of the temperature and distinguishing brittle and ductile specimens on the basis of the specific energy of ring compression, a ductility limit (τ - oxidation time till cladding embrittlement) could be defined (Figure 38):

$$\tau_{E110} = 2 \cdot 10^{-4} \exp(17500/T) \tag{22}$$

According to the results of the ring compression tests, the above correlation for the ductility limit of E110 is valid in hydrogen rich steam atmosphere, as well. Since the slow down of the oxidation compensates the mechanical deterioration of the cladding due to intense hydrogen uptake, the cladding embrittlement does not occur earlier in hydrogen-rich atmosphere than in pure steam.



Figure 38. Time of oxidation versus the reciprocal of the oxidation temperature

7. POST-TEST INVESTIGATIONS

7.1. Test series in hydrogen rich steam atmosphere

7.1.1. Visual observations

The photographs of oxidized E110 samples after ring compression and tensile tests are collected in the files 'cohyra_compr_photo.pdf, cohyra_tensile_photo.pdf'.

It has been observed that the oxidation in steam-hydrogen atmosphere produced cracked oxide layer at 900 and 1000 $^{\circ}$ C. The oxide scale flaked off from the cladding on most of the surface. The appearance of the oxide layer depended on the temperature and time of the hydrogen rich steam oxidation. At 1000 $^{\circ}$ C a cracked oxide layer with pinkish color was observed. The longer oxidation time resulted in a more cracked oxide layer. At higher temperature (1100 $^{\circ}$ C) the formation of a compact oxide layer was typical.

7.1.2. Metallographic analysis

Metallographic analysis of cross sections was performed with optical Reichert Me-F2 microscope. The investigation was carried out after the ring compression tests, thus some specimens can loose a part of their oxide layer.

The preparation of the specimens was the follows:

- Grinding
- Mechanical polishing
- Swab etching
- Washing in water
- Air drying

The cross sections of the oxidized E110 samples after ring compression test are collected in the file 'cohyra_compr_metgraph.pdf'.

Metallographic investigation of selected burst specimens was carried out as well. The cross sections are stored in the file 'cohyra_balloon_metgraph.pdf'

7.1.3. SEM analysis

The SEM analysis was performed on two types of samples:

- 1. Zr1%Nb tube samples prepared for ballooning test
- 2. Compressed ring samples with 8 mm length

From the first type of samples, sample pieces were cut from tubes, which were opened up at the ballooning tests. They were glued to SEM sample holders by means of special resin. Samples were studied directly, i.e. without any evaporated or sputtered carbon layer. Philips SEM 505 type of scanning electron microscope was operated at 5 KV (due to the sensitivity of the samples for the electron beam) by using a few $\times 10^{-10}$ A specimen current.

From the second type of samples, such pieces were selected, which had the oxide layers on both sides. These pieces were glued on the SEM holders in such way, that the cross section of them could be revealed. 20 kV accelerating voltage and a few times 10^{-10} A specimen current were applied.

7.1.3.1. Results of the ballooning samples

Figure 39 in the Appendix 20 shows digital secondary electron images (SEI) of the studied samples taken at 15 times of magnification. 4 mm x 4 mm sample areas are presented, revealing the opening up of the samples. It can be seen in the images that the opening up of the samples happened in various ways: sample Fuv_5 had the smallest opening size which did not decrease so much at the middle part.

Table 5. contains the data for lengths and widths of the openings up.

Mark of the sample	Opening length (mm)	Opening width (min, max; mm)
Fuv_1	3.93	0.26 - 0.49
Fuv_3	3.48	0.14 - 0.49
Fuv_5	1.67	0.28

Table 5. Opening sizes of the studied samples

Figures 40 and 41 (Appendix 20) show both ends of opening up for sample Fuv_3 and Fuv_5 at 100 times of magnification.

The digital secondary electron images of the studied samples are collected in the file 'cohyra_balloon_sem.pdf'.

7.1.3.2. Results of the compressed ring samples

Figure 42 in the Appendix 20 shows digital SEI images of selected compressed ring samples oxidized at 900 °C temperature for different periods. At 9720 s oxidation time the thickness of the oxide was about 20 μ m at some places, while at other areas about 50 μ m thick oxide layers (four layers) could be found. At 11520 s several oxide layers (altogether with 60-70 μ m thickness) can be revealed. These oxide layers could be removed easily. Beside the oxide layer(s) well crystallised alpha zirconium could be found, the thickness of it could be 40 – 60 μ m. The structure of the next phase, the beta-zirconium consisted of relatively large base crystals and Widmanstätten structure was typical for the studied samples. All these features can be seen in Figure 43.

Figure 44 (Appendix 20) shows digital SEI images for samples oxidized at 1000 °C. The thickness of the oxide layer(s) increased by increasing of the oxidation time: at 330 s the thickness of the oxide was 15-20 μ m. At 3900 s three oxide layers were found, having thicknesses between 10 and 15 μ m. At 6600 s generally two oxide layers could be seen, each of them had thickness of 20-40 μ m. The multiple oxide layers could be removed easily. The next layer, the alpha phase, stabilised by oxygen, had thicknesses from about 30 μ m up to 80 μ m. The beta phase consisted of larger crystals, inside of them lathes could be seen, which run parallel to each other. This is typical mainly for sample PUM-VH-12, which had the highest hydrogen content. Widmanstätten lines are also characteristic for the studied samples (see Figure 45). At the lowest hydrogen content (sample PUM-VH-1) the microstructure is typical for a ductile-rigid fracture.

Figure 46 shows digital SEI images for samples oxidized at 1100 °C. At 300 s the oxide layer (not always could be revealed) had thickness of 15-25 μ m, while at 1140 s two or three oxide layers could be found altogether with about 50 μ m thickness. Looking at the microstructure of the compressed ring samples, fracture surface similar to the original material could be seen at low amounts of added hydrogen. At higher hydrogen content fine-sized parallel plates could be found (see Figure 46).

The digital secondary electron images are stored in the file 'cohyra_compr_sem.pdf'.

8. DIRECTORY STRUCTURE OF THE DATABASE

The directory structure of the database followed the grouping presented in Chapter 2. The experimental data are stored in four main directories for the ballooning, the tensile, the compression and the oxidation tests. Separated directories contain the present and previous database reports and other English language publications.

All the experimental data are stored in formatted ascii files (*.prn) to support computerised processing independently from the applied operation system. The publications and figures are stored in pdf files. Photos are presented in jpeg, bmp or pdf formats.

Directories of the database and their contents

Directory \ Subdirectory	Content of the directory
OXIDATION	Oxidation Experiments
TENSILE	Tensile tests
TENSILE \ ZR1NB	with Zr1%Nb specimens
TENSILE \ ZRY-4	with Zircaloy-4 specimens
TENSILE\ COHYRADATA	Summarized experimental data and Load –
	displacement data
TENSILE\ COHYRAPICS	Photos of the specimens and tensile curves
BALLOON	Ballooning experiments
BALLOON \ BALL	Single rod tests BALL
BALLOON \ BALL \ CUTS	Photos of the cuts
BALLOON \ BALL \ EXP1	Data of the 1 st test series
BALLOON \ BALL \ EXP2	Data of the 2 nd test series
BALLOON \ 7ROD	7-rod bundle tests
BALLOON \ 7ROD \ CUTS	Photos of the cuts (compiled)
BALLOON \ 7ROD \ CUTS \ SPLIT	Bitmap of each cut
BALLOON \ 7ROD \ EXP	Experimental data, histories
BALLOON \ 7ROD \ PICS	Auxiliary photos
BALLOON \ 7ROD \ GRAPHS	Figures of the experimental data
BALLOON \ PUKI	Single rod tests PUKI (Zr1%Nb specimens)
BALLOON \ PUKI \ EXP	Experimental data, histories
BALLOON \ PUKI \ PICS	Photos of the burst specimens
BALLOON \ PUZRY	Single rod tests PUZRY (Zircaloy specimens)
BALLOON \ PUZRY \ EXP	Experimental data, histories
BALLOON \ PUZRY \ PICS	Photos of the burst specimens
BALLOON \ COHYRADATA	Summarized experimental data,
	temperature and pressure histories

BALLOON \ COHYRAPICS	Photos, cross sections and SEI of the burst
	specimens
COMPRESSION	Compression tests with
COMPRESSION \ ZR1NB	Zr1%Nb specimens
COMPRESSION \ ZRY-4	Zircaloy-4 specimens
COMPRESSION \ COHYRADATA	Summarized experimental data and Load –
	displacement data
COMPRESSION \ COHYRAPICS	Photos of the specimens, compression
	curves, cross sections and SEI of the rings
PUBLICAT	English language publications about the experiments
REPORT	Present database report
	Previous database report (2002)
	Previous database report (2006)

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Appendix 1:

Data of 7-rod bundle tests

```
# Summary sheet of VVER 7-rod bundle blockage tests (1999)
#
# Measured parameters
#
# P0
         - initial pressure (bar)
# P1
         - maximum pressure (bar)
# T1
         - temperature at failure (C)
# Tmax
         - maximum temperature (C)
#
         - average oxide layer at the elevation of burst (um)
 Oxid
# Block - flow area blockage rate (%)
#
 Atmo
         - atmosphere of the test
#
#
#
 References:
#
#
  [1] Horvath L., Windberg P., Hozer Z.: Felfuvodasos es besugarzasos
#
      meresek VVER futoelem burkolattal; OMFB-00033/98 (98-97-45-1636),
#
      Budapest, 1999 december.
#
#
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#
      VVER fuels to confirm safety criteria; ENS TopFuel 2001, P2-14
#
      Stockholm, Sweden, May 2001. (File: topfuel-01.pdf)
#
#
#
 Test
           ΡO
                    Ρ1
                           т1
                                   Tmax
                                           Oxid
                                                    Block
                                                            Atmo
#
                           [C]
                                   [C]
          [bar]
                   [bar]
                                            [um]
                                                     [ % ]
#
   1
          10.0
                   23.0
                           800
                                   1000
                                              0
                                                     72
                                                           # argon
   2
           3.0
                   7.5
                          1100
                                   1200
                                                     57
                                                           # argon
                                              0
   3
          20.0
                   35.0
                           900
                                    900
                                             0
                                                     59
                                                           # argon
          30.0
                   46.0
                           800
                                    900
   4
                                             0
                                                      _
                                                           # argon
   5
          30.0
                   53.0
                           800
                                    900
                                             0
                                                     76
                                                           # argon
                   55.0
   6
          30.0
                           900
                                    900
                                             _
                                                     43
                                                           # steam
          20.0
                                             _
   7
                   36.0
                           800
                                    900
                                                     55
                                                          # steam
   8
          10.0
                   20.0
                           900
                                    900
                                           165
                                                     57
                                                           # steam
   9
           3.0
                   7.0
                                   1300
                                            19
                                                     34
                                                           # steam
                            -
```

File: 'balloon\7rod\exp\bundle.prn'

AEKI 7-rod bundle tests # Total rod cross section areas as a function of the axial position # Bundle - number of test bundle # Axpos - axial position of cut measured from the location of the rods' failure (mm) Rod-i - cross section area of the i-th rod (mm^2) (A1+A2) # - total cross section area of the rods (mm^2) Summ Block - flow blockage rate (%) Bundle Axpos Rod-1 Rod-2 Rod-3 Rod-4 Rod-5 Rod-6 Rod-7 Summ Block # [mm] [mm^2] [mm^2] [mm^2] [mm^2] [mm^2] [mm^2] [mm^2] [%] # _____ _____ # 20.0 78.8 76.0 86.7 90.6 96.4 76.8 109.9 615.2 35.8 1 12.0 81.4 71.3 101.1 102.7 150.3 150.3 118.2 775.3 71.6 1 8.0 1 85.9 72.3 100.4 116.6 144.8 73.2 123.8 717.0 58.5 115.2 151.0 123.6 715.1 58.1 87.4 74.5 72.0 1 0.0 91.4 1 -10.0 73.0 68.3 75.4 86.6 135.8 64.8 93.2 597.1 31.7 -20.0 75.9 74.5 65.4 75.1 77.0 67.1 76.8 511.8 12.6 1 # 2 20.0 66.9 63.5 63.1 62.9 65.6 66.4 68.4 456.8 0.3 588.7 29.8 86.6 79.8 82.2 107.5 2 8.0 85.9 74.0 72.7 2 0.0 101.5 100.8 90.8 100.7 104.0 109.6 101.2 708.6 56.7 2 -8.0 74.9 76.9 76.7 86.3 76.4 87.3 83.9 562.4 24.0 616.7 36.1 2 87.5 91.9 77.5 97.8 -20.0 84.8 89.1 88.1 # 3 20.0 66.9 63.6 63.1 62.9 65.6 66.4 68.4 456.9 0.4 70.6 70.7 76.5 505.9 11.3 3 12.0 68.1 65.7 84.5 69.8 3 10.0 72.0 81.7 70.3 92.6 65.5 68.9 80.3 531.3 17.0 640.4 41.4 104.9 84.7 87.8 85.4 74.0 3 2.0 98.2 105.4 3 0.0 100.1 106.4 87.8 72.9 89.8 86.4 121.8 665.2 47.0 717.2 58.6 587.9 29.7 3 -2.0 107.8 115.5 96.6 77.7 95.7 92.8 131.1 -10.0 71.9 3 81.3 80.5 92.9 72.7 77.7 110.9 506.0 11.3 460.8 1.2 3 -12.0 69.0 66.9 91.4 66.8 64.1 63.2 84.6 3 -20.0 65.3 65.6 65.3 67.0 64.6 62.4 70.6 # 20.0 71.6 86.6 78.5 77.8 73.9 71.8 85.9 546.1 20.3 5 796.5 76.3 5 10.0 97.7 131.2 93.0 95.5 143.2 125.1 110.8 125.5 740.3 63.8 5 66.4 82.9 96.6 140.7 123.4 104.8 0.0 5 -10.0 74.4 80.1 77.8 87.1 143.8 94.0 85.6 642.8 41.9 5 -12.0 73.2 77.3 75.1 81.0 128.8 78.7 76.9 591.0 30.4 5 -20.0 71.7 74.1 73.8 77.0 80.1 75.1 77.0 528.8 16.4 # 20.0 486.6 7.0 572.1 26.1 6 69.2 70.5 70.4 71.3 69.7 66.8 68.7 6 10.0 73.5 79.6 85.3 104.8 71.4 71.3 86.2 6 0.0 91.8 84.9 80.0 110.2 82.5 87.6 110.4 647.4 43.0 547.6 20.7 -10.0 74.8 74.0 71.4 81.2 6 74.2 94.8 77.2 72.3 70.7 491.5 8.1 6 -20.0 68.0 69.4 69.3 72.2 69.6 # 69.7 73.0 67.8 69.0 492.2 8.3 7 20.0 70.9 71.4 70.4 7 568.2 25.3 10.0 82.0 79.8 88.2 83.6 78.2 76.2 80.2 702.5 55.3 534.3 17.7 96.8 7 95.3 99.0 95.0 106.9 105.0 0.0 104.5 7 -10.0 73.1 75.0 71.5 78.3 87.5 77.6 71.3 7 70.7 70.6 72.8 71.5 498.3 9.6 -20.0 69.9 71.5 71.3 # 71.9 78.4 77.7 67.3 68.0 496.0 9.1 8 20.0 67.7 65.0 642.1 41.8 708.3 56.6 8 10.0 100.8 100.6 74.6 109.6 80.2 90.7 85.6 8 0.0 106.0 102.2 80.4 107.9 97.8 105.7 108.3 77.8 8 -10.0 73.9 75.0 100.6 83.7 77.0 105.4 593.4 30.9 8 -20.066.3 66.7 65.9 65.1 63.8 62.7 63.9 454.4 -0.2 # 9 20.0 92.1 68.5 76.5 78.8 76.5 78.6 93.8 564.8 24.5 9 10.0 84.2 81.5 90.4 87.5 77.6 82.8 76.5 580.5 28.0 9 0.0 87.5 79.9 77.0 77.0 83.4 83.4 92.6 580.8 28.1 600.6 32.5 606.0 33.7 9 84.5 -10.0 92.9 87.0 78.1 78.1 95.5 84.5 9 -20.0 96.8 94.7 85.3 85.3 77.9 77.9 88.1

File: 'balloon\7rod\exp\block.prn'

Appendix 2:

Data of single rod ballooning tests PUKI

<pre>T - temperature [C] p - burst prossure [bar] time - time to burst [a] dp/dt - pressure rate [bar] time - initial diseaser [mm] time - initial length [mm] time - initial length [mm] time - initial diseaser [mm] time</pre>	# I	sother	mal balloon:	ing tests	with Zr1%	Nb tube s	specimens	(1995)									
<pre>T - temperature [C] p - burst prossure (bar] time - time to burst [3] dp/dt - prossure rate [bar/s] D0 - initial diameter [mm] L0 - initial diameter [mm] L0 - initial diameter [mm] L1 - initial diameter [mm] L1 - initial diameter [mm] L2 - initial diameter [mm] L3 - initial diameter [mm] L4 - initial diameter [mm] L4 - initial diameter [mm] L5 - initial diameter [m</pre>	#																
<pre>p - burst pressure [par] time - time to burst [s] dp/dt - pressure rate [bar] time - time to burst [s] dp - initial indexter [mm] tid - deformed length [mm] tid - deformed length [mm] v0 - initial cube volume [m1] v1 - tube volume after test [n1] epstar - awarage tangential deformation [s] epstar - awarage tangential deformation [s] full C a. Gyori, Z. Motus L.: Putoelemviselkedes VVER reaktor- tipusnal; OWEB 94-97-47-0817/2.5, 1996. 10. T p time dp/dt D0 L0 L1 Ld V0 V1 epstav epstm epst oxlaver treatment File [C] [bar] [s] [bar/s] [mm] [mm] [mm] [mm] [mm] [m1] [m1] [s] [s] [s] [m] epstar</pre>	#	Т	- tempera	ature [C]													
<pre>time - time to burst [s] dp/dt _ pressure rate [bar/s] D0 - initial diameter [mm] D0 - initial diameter [mm] D1 - initial diameter [mm] 11 - imput after test [mm] 14 - imput after test [mm] 15 - initial tube volume (ml] 17 - tube volume after test [mm] 18 - average tangential deformation [%] 19 - epsan - maximum tangential deformation [%] 10 - epsan - epsan - avial deformation [%] 10 - epsan - epsa</pre>	#	р	- burst p	pressure	[bar]												
<pre>d q/dt - pressure rate [bar/3] D0 - initial length [mm] L1 - length after test [mm] L1 - length after test [mm] L1 - deformed length [mm] v0 - initial usergential deformation [%] epstm - awarage tangential deformation [%] epstm - axial deformation [%] f(] Frecska J., Matus L., Futoelemviselkedes VVER reaktor- tipusnal; OMFB 94-97-47-0817/2.4, 1995. (4] CS. Gyori, Z. Hozer, L. Maroti, L. Matus: VVER ballooning experiments; EMPG Meeting Lillehammer, March 1998; HPR-349/40. (File: ehpg-98.pdf) * No. T p time dp/dt D0 L0 L1 Ld V0 V1 epstav epstm epst oxiayer treatment File 1 844 25.90 357.0 0.0725 9.15 50.00 51.60 - 0.0 # a.r. pukl- 3 800 43.70 564.4 0.0772 8.93 50.53 50.20 43.00 3.166 4.50 22.68 0.34 -0.54 0.0 # a.r. pukl- 3 800 43.70 564.4 0.0772 8.93 50.52 50.20 44.00 3.166 4.50 22.57 7.11 -4.21 0.0 # a.r. pukl- 5 932 11.10 134.5 0.0828 8.95 50.53 50.20 44.00 3.164 4.50 22.37.05 -0.00 # a.r. pukl- 5 932 11.10 134.5 0.0828 8.95 50.53 50.20 44.00 3.164 4.50 22.37.05 -0.00 # a.r. pukl- 5 932 11.10 134.5 0.0828 8.95 50.55 50.20 44.00 3.164 4.50 22.57 56.57 -0.60 0.0 # a.r. pukl- 5 932 11.10 134.5 0.0828 8.95 50.55 50.00 44.20 3.164</pre>	#	time	- time to	o burst [s]												
<pre>b D - initial diameter [mm] L - initial upth [mm] L - length after test [mm] L - length after test [mm] P - initial tube volume [m1] V - initial upe after test [m1] e pstar - average tangential deformation [%] e pstar - thickness of outer Zro2 layer [um] References: (1) Precska J., Koncros G., Matus L., Vasaros L.: Kisorletek a VVER futuelmek meghatarozo parameterelnek meresere; OMTP 94-99-47-0017/2.4, 1995. (2) Precska J., Matus L., Pummer I.: Futoelemviselkedes VVER reaktor- tipusnal; OMFP 94-97-47-0017/2.5, 1996. (3) Maroti L., Matus L.; Futoelemviselkedes VVER reaktor- tipusnal; OMFP 94-97-47-0017/2.5, 1996. (4) Cs. Gyori, Z. Horer, L. Maroti, L. Matus: VVER ballooning experiments; EHFO Meeting Lillehammer, March 1998; HFR-349/40. (File: ehpg-98.pdf) * No. T p time dp/dt D0 L0 L1 Ld V0 V1 epstav epstm epsa oxlayer treatment File No. T p time dp/dt D0 L0 L1 Ld V0 V1 epstav epstm epsa oxlayer treatment File 1 844 25.90 387.0 0.0725 9.15 50.00 51.60 - 0.0 # a.r. puki- 2 852 23.50 281.30 0.0725 9.15 50.00 51.60 - 0.0 # a.r. puki- 2 852 23.50 281.30 0.0725 9.15 50.00 51.60 - 0.0 # a.r. puki- 2 852 23.50 281.30 0.0725 9.15 50.00 51.60 - 0.0 # a.r. puki- 2 852 23.50 281.3 0.0822 8.35 50.58 42.00 3.166 4.50 22.68 40.54 -0.54 0.0 # a.r. puki- 3 844 25.90 381.0 0.0725 9.15 50.00 51.60 - 0.0 # a.r. puki- 3 845 43.70 566.4 0.0738 8.35 50.52 44.00 3.166 4.50 22.68 40.54 -0.54 0.0 # a.r. puki- 3 845 43.70 566.4 0.0738 8.35 50.55 50.20 44.50 3.164 4.50 22.32 57.61 -4.21 0.0 # a.r. puki- 3 845 43.70 566.4 0.0738 8.38 50.55 50.50 44.50 3.164 4.50 22.32 57.61 -4.21 0.0 # a.r. puki- 3 900 10.60 136.4 0.0738 8.38 50.55 50.50 44.50 3.164 4.50 22.54 50.53 7.60 -0.64 0.00 # a.r. puki- 3 900 10.60 136.4 0.0738 8.36 50.55 50.50 44.50 3.164 4.50 22.54 50.53 7.60 4.61 0.0</pre>	#	dp/dt	- pressu	re rate []	bar/s]												
<pre>b 10 - initial length [mm] L1 - length after test [mm] L1 - deformed length [mm] L1 - deformed length [mm] V0 - initial terv test [mm] V0 - initial tervest [mm] V1 - tube volume after test [mm] V2 - tube volume after</pre>	#	D0	- initia.	l diamete:	r [mm]												
<pre>i.i lenght after test [mm] i.d - deformed length [mm] i.d - tube volume after test [m1] i.e patar - average tangential deformation [%] i.e.patar - average tangential defor</pre>	#	LO	- initia.	l length	[mm]												
<pre>V0 - initial tube volume [m] V0 - initial tube volume [m] V1 - tube volume after test [m] epst - average tangential deformation [%] epst - axial deformation [%] fulcelemek meghatarozo parametereinek meresere; OMFB 94-97-47-0817/2.4, 1995. [2] Frecska J., Matus L., Punmer I.: Futoelemviselkedes VVER reaktor- tipusnal; OMFB 94-97-47-0817/2.5, 1996. [3] Maroti L., Matus L.; Futoelemviselkedes VVER reaktoripusnal; Zarojelentes OMFB 94-97-47-0817/2.5, 1996. [4] (1] Cs. Gyori, Z. Hozer, L. Maroti, L. Matus: VVER ballooning experiments; EHPG Meeting Lillehammer, Maroh 1998; HPR-349/40. (File: ehpg-98.pdf) [5] [6] [6] [1] [4] [6] [1] [6] [1] [1] [7] [6] [8] [8] [1] [1] [1] [1] [8] [8] [1] [1] [1] [1] [2] [2] [2] [2] [2] [2] [2] [2] [2] [2</pre>	# #	LL 7 -1	- lengnt	arter te	st [mm]												
<pre>v0 - Initial Lube v0.ume after test [m1] v1 - tube v0.ume after test [m1] epstav - average tangential deformation [%] epstav - thickness of outer ZrO2 layer [um] References: [1] Frecska J., Konczos G., Matus L., Vasaros L.: Kiserletek a VVER futoelemek meghatarozo parametereinek meresere; OMFB 94-97-47-0817/2.4, 1995. [2] Frecska J., Matus L.: Putoelemviselkedes VVER reaktor- tipusnal; OMFB 94-97-47-0817/2.5, 1996. [3] Maroti L., Matus L.: Futoelemviselkedes VVER reaktortipusnal; Zarojelentes OMFB 94-97-47-0817, 1996. [4] Os. Gyori, Z. Hozer, L. Maroti, L. Matus: VVER ballooning experiments; EHFC Meeting Lillehammer, March 1998; HPR-349/40. (File: ehpg-98.pdf) [5] No. T p time dp/dt D0 L0 L1 Ld V0 V1 epstav epstm epsa oxlayer treatment File [6] [0 [bar] [s] [bar/s] [um] [um] [um] [um] [um] [um] [[s] [%] [%] [w] [um] [7] [8] 33 300 43.70 566.4 0.0772 8.95 50.03 51.60 - 0.0 # a.r. puki- 2 352 23.30 283.3 0.0822 8.95 50.35 50.08 42.00 3.166 4.50 22.68 40.34 -0.54 0.0 # a.r. puki- 2 363 203.30 283.3 0.0822 8.95 50.35 50.00 42.00 3.166 4.50 22.68 40.34 -0.54 0.0 # a.r. puki- 2 363 203.30 283.3 0.0822 8.95 50.35 50.02 43.00 3.166 4.50 22.68 40.34 -0.54 0.0 # a.r. puki- 3 300 43.70 566.4 0.0772 8.93 50.32 48.20 44.100 3.166 4.50 22.63 37.40 -0.54 0.0 # a.r. puki- 2 490 10.80 130.0 0.08311 8.93 50.55 50.20 43.00 3.164 4.50 22.32 37.06 -0.69 0.0 # a.r. puki- 3 590 11.10 134.5 0.0726 8.94 50.02 544.50 3.168 54.50 3.51.9 56.32 -1.66 0.0 # a.r. puki- 3 1002 8.81 114.4 0.0728 8.98 50.025 50.00 44.50 3.181 4.80 25.49 39.73 -0.50 0.0 #</pre>	Т Д	La	- delorme	ea length	[mm]												
<pre>vi = Club Volme alter use; (mi) epst = avarage tangential deformation [%] eps = axial deformation [%] eps = axial deformation [%] eps = axial deformation [%] oxlayer = thickness of outer ZrO2 layer (um) References: [] Frecska J., Konczos G., Matus L., Vasaros L.: Kiserletek a VVER futoelemek meghatarozo parameterinek meresere; OMFB 94-97-47-0817/2.4, 1995. [] Frecska J., Matus L., Pummer I.: Futoelemviselkedes VVER reaktor- tipusnal; OMFB 94-97-47-0817/2.5, 1996. [] Maroti L., Matus L.: Futoelemviselkedes VVER reaktortipusnal; Zarojelentes OMFB 94-97-47-0817, 1996. [] Maroti L., Matus L.: Futoelemviselkedes VVER reaktortipusnal; Zarojelentes OMFB 94-97-47-0817, 1996. [] OS. T p time dp/dt D0 L0 L1 Ld V0 V1 epstav epstm epsa oxlayer treatment File [C] [bar] [s] [bar/s] [mm] [mm] [mm] [ml] [ml] [%] [%] [%] [um] No. T p time dp/dt D0 L0 L1 Ld V0 V1 epstav epstm epsa oxlayer treatment File [] [bar] [s] [bar/s] [mm] [mm] [mm] [ml] [ml] [%] [%] [%] [0] [um] No. T p time dp/dt D0 L0 L1 Ld V0 3.166 4.50 22.68 40.34 -0.54 0.0 # a.r. puki- 2 852 23.30 283.3 0.0822 8.95 50.35 50.08 42.00 3.166 4.50 22.68 40.34 -0.54 0.0 # a.r. puki- 3 800 43.70 566.4 0.0712 8.91 55.0.20 41.00 3.150 6.00 45.27 57.41 -4.21 0.0 # a.r. puki- 4 900 10.80 130.0 0.0813 8.93 50.55 50.20 43.00 3.164 4.50 22.23 37.06 -0.69 0.0 # a.r. puki- 5 902 11.10 134.5 0.0725 8.94 55.05 49.52 44.50 3.168 5.50 3.51 55.32 7.41 -4.21 0.0 # a.r. puki- 6 952 10.40 144.8 0.0718 8.98 550.25 50.00 44.50 3.168 5.50 3.51 55.32 -4.40 3.40 -0.54 0.0 # a.r. puki- 6 952 10.40 144.8 0.0718 8.98 550.25 50.00 44.50 3.164 4.50 22.52 37.40 -0.69 0.0 # a.r. puki- 6 952 10.40 144.8 0.0718 8.98 550.25 50.15 44.550 3.164 5.50 25.40 -0.60 0.0 # a.r. puki- 7 1000 8.88 122.4 0.0728 8.96 550.53 50.15 44.550 3.161 4.90 26.75 35.45 -7.08 0.00 # a.r. puki- 7 1000 7.70 0.0755 8.96 50.01 4.95 50.55 50.15 45.55 0.3166 4.60 25.02 37.42 -0.79 0.00 # a.r. puki- 7 1000 7.70 0.0755 8.96 50.01 4.95 50.15 45.55 0.3166 4.50 21.60 27.40 7.70 8.00 # a.r. puki- 7 1000 7.70 0.0755 8.96 50.01</pre>	# #	VU 171	- initia.	l tube vo.	lume [ml]	1 1											
<pre>c opstav - avalage tangential deformation [%] epstav - maximum tangential deformation [%] epstav - maximum tangential deformation [%] epstav - avala deformation [%] collaper - avaial deformation [%] collaper - thickness of outer ZrO2 layer [um] References: [1] Frecska J., Konczos G., Matus L., Vasaros L.: Kiserletek a VVER futoelemek meghatarozo parametereinek meresere; (MFB 94-97-47-0817/2.4, 1995. [2] Frecska J., Matus L., Pummer I.: Futoelemviselkedes VVER reaktor- tipusnal; OMFB 94-97-47-0817/2.5, 1996. [3] Maroti L., Matus L.: Futoelemviselkedes VVER reaktortipusnal; Zarojelentes OMFB 94-97-47-0817, 1996. [4] Os. Gyori, Z. Hozer, L. Maroti, L. Matus: VVER ballooning experiments; EHPG Meeting billehammer, March 1998; HPR-349/40. (File: ehgg-98.pdf) [4] No. T p time dp/dt D0 L0 L1 Ld V0 V1 epstav epstm epsa oxlayer treatment File [5] [6] [bar] [s] [bar/s] [mm] [mm] [mm] [mm] [m1] [n1] [%] [%] [%] [mn] [7] [7] [8] 1 844 25.90 357,0 0.0725 9.15 50.00 51.60 - 0.0 # a.r. puki-C 2 852 23.30 283.3 0.0822 8.95 50.35 50.84 42.00 3.166 4.50 22.68 40.34 -0.54 0.0 # a.r. puki-C 3 800 43.70 566.4 0.0772 8.93 55.2 44.20 41.00 3.166 4.50 22.32 37.06 -0.69 0.0 # a.r. puki-C 4 900 10.80 130.0 0.0831 8.93 50.55 50.20 43.00 3.164 4.50 22.32 37.06 -0.69 0.0 # a.r. puki-C 4 900 10.80 130.0 0.0831 8.93 50.55 50.20 43.00 3.164 4.50 22.32 77.61 -0.69 0.0 # a.r. puki-C 5 952 10.10 134.5 0.0825 8.95 50.53 50.50 43.50 5.315 56.35 51.9 6.32 -1.06 0.0 # a.r. puki-C 6 952 10.10 134.5 0.0728 8.95 50.55 50.57 43.55 30.186 5.50 35.19 56.32 -1.06 0.0 # a.r. puki-C 6 952 10.10 134.5 0.0725 9.15 50.00</pre>	# #	VI opoto:	- Lube Vo	o tongont	er test [m. ial doform	L] ation [%]	1										
<pre>c post - axial deformation [%] epsa - axial deformation [%] epsa - axial deformation [%] collayer - thickness of outer ZrO2 layer [um] References: [1] Frecska J., Konczos G., Matus L., Vasaros L.: Kiserletek a VVER futoelemek meghatarozo parametereinek meresere; OMFB 94-97-47-0817/2.4, 1995. [2] Frecska J., Matus L., Pummer I.: Futoelemviselkedes VVER reaktor- tipusnal; OMFB 94-97-47-0817/2.5, 1996. [3] Maroti L., Matus L.: Futoelemviselkedes VVER reaktortipusnal; Zarojelentee OMFP 94-97-47-0817/2.5, 1996. [4] Cs. Gyori, Z. Hozer, L. Maroti, L. Matus: VVER ballooning experiments; EHPG Meeting Lillehammer, March 1998; HPR-349/40. (File: ehpg-98.pdf) [4] No. T p time dp/dt D0 L0 L1 Ld V0 V1 epstav epstm epsa oxlayer treatment File [0] [bar] [s] [bar/s] [mm] [mm] [mm] [mm] [m1] [m1] [%] [%] [%] [um] [* 1 844 25.90 357.0 0.0725 9.15 50.00 51.60 - 0.0 # a.r. puki-(2 852 23.30 283.3 0.0822 8.95 50.35 50.08 42.00 3.166 4.50 22.69 40.34 -0.54 0.0 # a.r. puki-(3 800 43.70 566.4 0.0772 8.93 50.22 44.50 3.164 4.50 22.23 77.41 -4.21 0.0 # a.r. puki-(4 900 10.80 130.0 0.0831 8.93 50.55 50.20 43.00 3.164 4.50 22.32 37.06 -0.69 0.0 # a.r. puki-(5 932 11.10 134.5 0.0825 8.98 50.25 50.00 41.00 3.164 4.50 22.37 3.06 -0.69 0.0 # a.r. puki-(5 932 11.10 134.5 0.0825 8.98 50.55 45.52 44.50 3.164 4.50 22.37 3.06 -0.69 0.0 # a.r. puki-(5 932 11.10 134.5 0.0702 8.98 50.25 50.00 43.55 3.515 4.50 3.164 4.50 22.37 3.06 -0.69 0.0 # a.r. puki-(6 952 10.40 144.8 0.0718 8.98 50.25 50.00 44.50 3.164 4.50 22.37 3.06 -0.69 0.0 # a.r. puki-(6 952 11.10 134.5 0.0728 8.96 50.55 45.55 45.55 3.154 4.50 3.164 5.07 23.742 -0.79 0.0 # a.r. puki-(6 952 11.10 134.5 0.0728 8.96 50.55 45.55 45.50 3.161 4.90 26.75 6.57 -0.80 0.0 # a.r. puki-(7 1000 7.00 100.7 0.076 8.96 50.55 50.154 45.55 3.166 4.50 23.73 3.50.5 35.79 0.00 # a.r. puki-(8 1052 8.11 114.5 0.0708 8.96 50.55 50.50 4.555 3.50.154 45.50 3.161 4.90 26.75 6.57 -0.79 0.00 # a.r. puki-(8 1052 8.11 114.5 0.0708 8.96 50.55 50.154 45.50 3.161 4.90 26.75 6.57 -0.80 0.00 # a.r. puk</pre>	# #	epsta	v - average	e tangent. m tangant	ial deform	ation [%]											
<pre>volume volume volu</pre>	# #	opea	- avial	doformati	on [9]	acion [%]											
<pre>References: [1] Frecska J., Konczos G., Matus L., Vasaros L.: Kiserletek a VVER futuelemek meghatarozo parametereinek meresere; OMFB 94-97-47-0817/2.4, 1995. [2] Frecska J., Matus L., Purmer I.: Futoelemviselkedes VVER reaktor- tipusnal; OMFB 94-97-47-0817/2.5, 1996. [3] Maroti L., Matus L.: Futoelemviselkedes VVER reaktortipusnal; Zarojelentes OMFB 94-97-47-0817, 1996. [4] Cs. Gyori, Z. Hozer, L. Maroti, L. Matus: VVER ballooning experiments; EHPG Meeting Lillehammer, March 1998; HPR-349/40. (File: ehpg-98.pdf) [4] Cs. Gyori, Z. Hozer, L. Maroti, L. Matus: VVER ballooning experiments; EHPG Meeting Lillehammer, March 1998; HPR-349/40. (File: ehpg-98.pdf) [5] [6] [bar] [s] [bar/s] [mm] [mm] [mm] [mm] [mm] [ml] [ml] [%] [%] [%] [um] [7] [8 44 25.90 357.0 0.0725 9.15 50.00 51.60 - 0.0 # a.r. puki-C 2 852 23.30 283.3 0.0822 8.95 50.35 50.08 42.00 3.166 4.50 22.68 40.34 -0.54 0.0 # a.r. puki-C 3 800 43.70 566.4 0.0772 59.15 50.00 51.60 - 0.0 # a.r. puki-C 4 900 10.80 130.0 0.831 8.93 50.53 50.20 43.00 3.156 4.50 22.23 37.06 -0.69 0.0 # a.r. puki-C 4 900 10.80 130.0 0.831 8.93 50.55 50.20 43.00 3.166 4.50 22.32 37.06 -0.69 0.0 # a.r. puki-C 5 952 10.40 144.8 0.0718 8.98 50.25 50.00 44.50 3.161 4.90 26.75 3.66.7 -0.80 0.0 # a.r. puki-C 6 952 10.40 144.8 0.0718 8.96 50.25 50.15 49.75 45.50 3.164 4.90 25.02 37.42 -0.79 0.00 # a.r. puki-C 8 1052 8.11 114.5 0.0708 8.96 50.55 50.15 49.75 45.50 3.166 4.60 25.02 37.42 -0.79 0.00 # a.r. puki-C 8 1052 8.11 114.5 0.0708 8.96 50.55 50.15 49.75 45.50 3.166 4.60 25.02 37.42 -0.79 0.00 # a.r. puki-C 8 1052 8.11 114.5 0.0708 8.96 50.55 50.15 49.75 45.50 3.166 4.60 25.02 37.42 -0.79 0.00 # a.r. puki-C 8 1052 8.11 114.5 0.0708 8.96 50.55 50.15 49.75 45.50 3.166 4.60 25.02 37.42 -0.79 0.00 # a.r. puki-C 8 1052 8.11 114.5 0.0708 8.96 50.55 50.15 49.75 45.50 3.166 4.60 25.02 37.42 -0.79 0.00 # a.r. puki-C 8 1052 8.11 114.5 0.0708 8.96 50.55 50.15 49.75 45.50 3.166 4.90 25.02 37.42 -0.79 0.00 # a.r. puki-C 8 1052 8.11 114.5 0.0708 8.96 50.55 50.15 49.75 45.50 3.166 4.</pre>	π #	ovlav	ar - thickne	aerormacri	tor $7rO2$]:	avor [um]	I										
<pre>References: [1] Frecska J., Konczos G., Matus L., Vasaros L.: Kiserletek a VVER futoelemek meghatarozo parametereinek meresere; OMFB 94-97-47-0817/2.4, 1995. [2] Frecska J., Matus L., Pummer I.: Futoelemviselkedes VVER reaktor- tipusnal; OMFB 94-97-47-0817/2.5, 1996. [3] Maroti L., Matus L.: Futoelemviselkedes VVER reaktortipusnal; Zarojelentes OMFB 94-97-47-0817, 1996. [4] Cs. Gyori, Z. Hozer, L. Maroti, L. Matus: VVER ballooning experiments; EHPG Meeting Lillehammer, March 1998; HPR-349/40. (File: ehpg-98.pdf) * No. T p time dp/dt D0 L0 L1 Ld V0 V1 epstav epstm epsa oxlayer treatment File [C] [bar] [s] [bar/s] [mm] [mm] [mm] [mm] [ml] [ml] [k] [k] [k] [um] * 1 844 25.90 357.0 0.0725 9.15 50.00 51.60 - 0.0 # a.r. puki-C 2 852 23.30 283.3 0.0822 8.95 50.35 50.08 42.00 3.166 4.50 22.68 40.34 -0.54 0.0 # a.r. puki-C 3 800 43.70 566.4 0.0772 8.93 50.52 48.20 41.00 3.150 6.00 45.27 57.41 -4.21 0.0 # a.r. puki-C 4 900 10.80 130.0 0.0831 8.93 50.55 50.20 43.00 3.164 4.50 22.32 37.06 -0.69 0.0 # a.r. puki-C 4 900 10.80 130.0 0.0831 8.93 50.55 50.20 43.00 3.164 4.50 22.32 37.06 -0.69 0.0 # a.r. puki-C 4 900 10.80 130.0 0.0831 8.93 50.55 50.20 44.50 3.168 5.50 3.519 56.32 -1.06 0.0 # a.r. puki-C 6 952 10.40 144.8 0.07718 8.98 50.25 49.52 44.50 3.181 4.80 25.49 3.7.3 -0.50 0.0 # a.r. puki-C 7 1000 8.88 122.4 0.0725 8.96 50.55 50.15 45.50 3.161 4.90 26.75 37.42 -0.60 0.0 # a.r. puki-Z 8 1052 8.11 114.5 0.0778 8.96 50.55 50.15 45.50 3.164 4.50 22.32 37.06 -0.69 0.0 # a.r. puki-Z 8 1052 8.11 114.5 0.0778 8.96 50.55 50.15 45.50 3.161 4.90 26.75 36.57 -0.80 0.0 # a.r. puki-Z 8 1052 8.11 114.5 0.0778 8.96 50.55 50.01 54.55 50.31.81 4.80 25.49 3.7.42 -0.7.80 0.0 # a.r. puki-Z 8 1052 8.11 114.5 0.0778 8.96 50.55 50.01 54.55 50.31.86 4.80 25.02 37.42 -0.7.9 0.0 # a.r. puki-Z 8 1052 8.11 114.5 0.0778 8.96 50.55 50.01 54.55 50.31.86 4.80 25.02 37.42 -0.7.9 0.0 # a.r. puki-Z 8 1052 8.11 114.5 0.0778 8.96 50.55 50.01 54.55 50.31.86 4.80 25.02 37.42 -0.7.9 0.0 # a.r. puki-Z 8 1052 8.11 114.5 0.</pre>	т #	OALdy	CI CHICKIN	CSS OI OU	CCI 2102 10	ayer [um]	I										
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<pre>[1] Frecska J., Konczos G., Matus L., Vasaros L.: Kiserletek a VVER futoelemek meghatarozo parametereinek meresere; OMFB 94-97-47-0817/2.4, 1995. # [2] Frecska J., Matus L., Pummer I.: Futoelemviselkedes VVER reaktor- tipusnal; OMFB 94-97-47-0817/2.5, 1996. # [3] Maroti L., Matus L.: Futoelemviselkedes VVER reaktortipusnal; Zarojelentes OMFB 94-97-47-0817/2.5, 1996. # [4] Cs. Gyori, Z. Hozer, L. Maroti, L. Matus: VVER ballooning experiments; EHPG Meeting Lillehammer, March 1996; HPR-349/40. (File: ehpg-98.pdf) # [6] No. T p time dp/dt D0 L0 L1 Ld V0 V1 epstav epstm epsa oxlayer treatment File [7] [6] [bar/s] [mm] [mm] [mm] [mm] [mm] [m1] [m1] [%] [%] [%] [um] 1 844 25.90 357.0 0.0725 9.15 50.00 51.60 - 0.0 # a.r. puki-0 2 852 23.30 283.3 0.0822 8.95 50.35 50.84 42.00 3.166 4.50 22.68 40.34 -0.54 0.0 # a.r. puki-0 3 800 43.70 566.4 0.0772 8.93 50.32 48.20 41.00 3.150 6.00 45.27 57.41 -4.21 0.0 # a.r. puki-0 4 900 10.80 130.0 0.0831 8.93 50.55 50.20 43.00 3.164 4.50 22.62 37.06 -0.69 0.0 # a.r. puki-0 5 902 11.10 134.5 0.0825 8.98 50.25 50.00 44.50 3.181 4.80 25.49 39.73 -0.50 0.0 # a.r. puki-0 6 952 10.40 144.8 0.0718 8.98 50.25 50.00 44.50 3.181 4.80 25.61 39.77 -0.80 0.0 # a.r. puki-0 8 1052 8.11 114.5 0.0708 8.96 50.55 50.13 55.01 44.50 3.186 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 8 1052 8.11 114.5 0.0708 8.96 50.55 50.14 40.56 3.186 4.50 20.03 7.42 -0.79 0.0 # a.r. puki-1 8 1052 8.11 114.5 0.0708 8.96 50.55 50.14 55.50 3.186 4.50 20.03 7.42 -0.79 0.0 # a.r. puki-1 8 1052 8.11 114.5 0.0708 8.96 50.55 50.14 55.50 3.186 4.50 20.03 7.42 -0.79 0.0 # a.r. puki-1 8 1052 8.11 114.5 0.0708 8.96 50.55 50.14 55.50 3.186 4.50 20.03 7.42 -0.79 0.0 # a.r. puki-1 8 1052 8.11 114.5 0.0708 8.96 50.55 50.51 55.50 3.186 4.50 20.03 7.42 -0.79 0.0 # a.r. puki-1 8 1052 8.11 114.5 0.0708 8.96 50.55 50.51 55.50 7.50 7.50 7.50 7.50 7.50 7.50 7.5</pre>	#	INCLUIC.															
<pre>futoelemek meghatarozo parametereinek meresere; OMFB 94-97-47-0817/2.4, 1995.</pre>	#	[1]	Frecska J.	, Konczos	G., Matus	L., Vasa	aros L.: H	Kiserletek	c a VVER								
<pre> OMFB 94-97-47-0817/2.4, 1995. # [2] Frecska J., Matus L., Pummer I.: Futoelemviselkedes VVER reaktor- tipusnal; OMFB 94-97-47-0817/2.5, 1996. # [3] Maroti L., Matus L.: Futoelemviselkedes VVER reaktortipusnal; Zarojelentes OMFB 94-97-47-0817, 1996. # [4] Cs. Gyori, Z. Hozer, L. Maroti, L. Matus: VVER ballooning experiments; EHPG Meeting Lillehammer, March 1998; HPR-349/40. (File: ehpg-98.pdf) # [5] [bar/s] [s] [bar/s] [mm] [mm] [mm] [mm] [ml] [ml] [%] [%] [%] [%] [um] # [6] [C] [bar] [s] [bar/s] [mm] [mm] [mm] [mm] [mm] [ml] [ml] [%] [%] [%] [um] # [1 844 25.90 357.0 0.0725 9.15 50.00 51.60 - 0.0 # a.r. puki-0 2 852 23.30 283.3 0.0822 8.95 50.35 50.08 42.00 3.166 4.50 22.68 40.34 -0.54 0.0 # a.r. puki-0 3 800 43.70 566.4 0.0772 8.93 50.35 50.08 42.00 3.166 4.50 22.68 40.34 -0.54 0.0 # a.r. puki-0 3 800 43.70 566.4 0.0772 8.93 50.35 50.02 44.20 3.166 4.50 22.68 40.34 -0.54 0.0 # a.r. puki-0 3 902 11.10 134.5 0.0825 8.98 50.05 49.52 44.50 3.168 5.50 35.19 56.32 -1.06 0.0 # a.r. puki-0 5 902 11.10 134.5 0.0825 8.98 50.05 49.52 44.50 3.168 5.50 35.19 56.32 -1.06 0.0 # a.r. puki-0 5 902 11.10 134.5 0.0825 8.98 50.25 50.00 44.50 3.181 4.80 25.49 39.73 -0.50 0.0 # a.r. puki-1 7 1000 8.88 122.4 0.0718 8.98 50.25 50.00 44.50 3.181 4.80 25.49 39.73 -0.50 0.0 # a.r. puki-1 8 1052 8.11 114.5 0.0708 8.96 50.15 49.75 45.50 3.161 4.50 25.02 37.42 -0.79 0.0 # a.r. puki-1 8 1052 8.11 114.5 0.0708 8.96 50.15 49.75 45.50 3.166 4.50 25.02 37.42 -0.79 0.0 # a.r. puki-1 </pre>	#		futoelemek	meghatar	ozo parame	tereinek	meresere;										
<pre># [2] Frecska J., Matu L., Futbelemviselkedes VVER reaktor- tipusnal; OMFB 94-97-47-0817/2.5, 1996. # [3] Maroti L., Matus L.: Futbelemviselkedes VVER reaktortipusnal; Zarojelentes OMFB 94-97-47-0817, 1996. # [4] Cs. Gyori, Z. Hozer, L. Maroti, L. Matus: VVER ballooning experiments; EHFG Meeting Lillehammer, March 1998; HPR-349/40. (File: ehpg-98.pdf) # Mo. T p time dp/dt D L0 L1 Ld V0 V1 epstav epstm epstm [%] [%] [%] [m] [m] [C] [bar] [s] [bar/s] [mm] [mm] [mm] [mm] [m1] [m1] [%] [%] [%] [%] [%] [m] 1 844 25.90 357.0 0.0725 9.15 50.00 51.60 - 0.0 # a.r. puki-0 2 852 23.30 283.3 0.0822 8.95 50.35 50.08 42.00 3.166 4.50 22.68 40.34 -0.54 0.0 # a.r. puki-0 3 800 43.70 566.4 0.0772 8.93 50.32 48.20 41.00 3.150 6.00 45.27 57.41 -4.21 0.0 # a.r. puki-0 4 900 10.80 130.0 0.0825 8.98 50.25 49.52 44.50 3.168 5.50 35.19 56.32 -1.06 0.0 # a.r. puki-0 5 902 11.10 134.5 0.0825 8.98 50.25 50.15 49.75 45.50 3.161 4.80 25.49 39.73 -0.50 0.0 # a.r. puki-0 6 952 10.40 144.8 0.0718 8.98 50.25 50.15 49.75 45.50 3.161 4.80 25.49 39.73 -0.50 0.0 # a.r. puki-1 7 1000 8.88 122.4 0.0728 8.96 50.15 49.75 45.50 3.161 4.80 25.49 39.73 -0.50 0.0 # a.r. puki-1 8 1052 8.11 114.5 0.0708 8.96 50.55 50.15 49.75 45.50 3.166 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 8 1052 8.11 114.5 0.0708 8.96 50.55 50.15 49.75 45.50 3.166 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 8 1052 8.11 114.5 0.0708 8.96 50.55 50.15 49.75 45.50 3.166 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 8 1052 8.11 114.5 0.0708 8.96 50.55 50.15 49.75 45.50 3.166 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 8 1052 8.11 114.5 0.0708 8.96 50.55 50.15 49.75 45.50 3.166 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 8 1052 8.11 114.5 0.0708 8.96 50.55 50.15 49.75 45.50 3.166 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 8 1052 8.11 114.5 0.0708 8.96 50.55 50.15 45.55 0.3166 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 8 1052 8.11 114.5 0.0708 8.96 50.55 50.15 45.55 0.3166 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 8 1052 8.11 114.5 0.0708 8.96 50.55 50.15 45.55 0.3166 4.80 25</pre>	#		OMFB 94-97-	-47-0817/	2.4, 1995.												
<pre># [2] Frecska J., Matus L., Pummer I.: Futoelemviselkedes VVER reaktor- tipusnal; OMFB 94-97-47-0817/2.5, 1996. # [3] Maroti L., Matus L.: Futoelemviselkedes VVER reaktortipusnal; Zarojelentes OMFB 94-97-47-0817, 1996. # [4] Cs. Gyori, Z. Hozer, L. Maroti, L. Matus: VVER ballooning experiments; EHPG Meeting Lillehammer, March 1998; HPR-349/40. (File: ehpg-98.pdf) # [4] Cs. Gyori, Z. Hozer, L. Maroti, L. Matus: VVER ballooning experiments; EHPG Meeting Lillehammer, March 1998; HPR-349/40. (File: ehpg-98.pdf) # [5] [bar] [s] [bar/s] [mm] [mm] [mm] [mm] [ml] [ml] [%] [%] [%] [um] # [6] [um] # [7] 1 844 25.90 357.0 0.0725 9.15 50.00 51.60 - 0.0 # a.r. puki-0 2 852 23.30 283.3 0.0822 8.95 50.35 50.08 42.00 3.166 4.50 22.68 40.34 -0.54 0.0 # a.r. puki-0 3 800 43.70 566.4 0.0772 8.93 50.32 48.20 41.00 3.150 6.00 45.27 57.41 -4.21 0.0 # a.r. puki-0 4 900 10.80 130.0 0.0831 8.93 50.55 50.04 32.04 3.0168 5.50 35.19 56.32 -1.06 0.0 # a.r. puki-0 5 902 11.10 134.5 0.0825 8.98 50.05 49.52 44.50 3.168 5.50 35.19 56.32 -1.06 0.0 # a.r. puki-0 5 902 11.10 134.5 0.0825 8.98 50.05 49.52 44.50 3.168 5.50 35.19 56.32 -1.06 0.0 # a.r. puki-0 7 1000 8.88 122.4 0.0712 8.96 50.15 49.75 45.50 3.161 4.90 26.75 36.57 -0.80 0.0 # a.r. puki-0 8 1052 8.11 114.5 0.0708 8.96 50.55 50.15 45.50 3.166 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-0 9 1100 7.70 1000 7.00705 8.96 50.15 49.55 45.50 3.166 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7.70 1000 7.00705 8.96 50.15 49.55 45.50 3.166 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7.70 1000 7.00705 8.96 50.15 40.0 49.51 45.50 3.166 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7.70 1000 7.00755 8.55 50.05 45.55 50.55 50.51 45.50 3.166 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7.70 1000 7.00755 8.55 50.55 50.55 50.51 45.50 3.166 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7.70 1000 7.00755 8.55 50.55 50.55 50.55 50.55 50.51 45.50 3.166 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7.70 1000 7.00755 8.55 50.55 50.55 50.55 50.51 45.50 3.166 4.80 25.02 37.42 -0.79 0.</pre>	#																
<pre># tipusnal; OMFB 94-97-47-0817/2.5, 1996. # [3] Maroti L., Matus L.: Futoelemviselkedes VVER reaktortipusnal; Zarojelentes OMFB 94-97-47-0817, 1996. # [4] Cs. Gyori, Z. Hozer, L. Maroti, L. Matus: VVER ballooning experiments; EHPG Meeting Lillehammer, March 1998; HPR-349/40. (File: ehpg-98.pdf) # * * No. T p time dp/dt D0 L0 L1 Ld V0 V1 epstav epstm epsa oxlayer treatment File * * [C] [bar] [s] [bar/s] [mm] [mm] [mm] [m1] [m1] [%] [%] [%] [[m] * * * * No. T p time dp/dt D0 L0 L1 Ld V0 V1 epstav epstm epsa oxlayer treatment File * * * [C] [bar] [s] [bar/s] [mm] [mm] [mm] [m1] [m1] [%] [%] [%] [%] * * * * * No. T p time dp/dt D0 L0 L1 Ld V0 V1 epstav epstm epsa oxlayer treatment File * * * * [C] [bar] [s] [bar/s] [mm] [mm] [mm] [m1] [m1] [%] [%] [%] [%] * * * * * * * * * * * * * * * * * * *</pre>	#	[2]	Frecska J.	, Matus L	., Pummer	I.: Futoe	elemvisel	edes VVEF	R reaktor-								
<pre># [3] Maroti L., Matus L.: Futoelemviselkedes VVER reaktortipusnal; Zarojelentes OMFB 94-97-47-0817, 1996. # [4] Cs. Gyori, Z. Hozer, L. Maroti, L. Matus: VVER ballooning experiments; EHPG Meeting Lillehammer, March 1998; HPR-349/40. (File: ehpg-98.pdf) # No. T p time dp/dt D0 L0 L1 Ld V0 V1 epstav epstm epsa oxlayer treatment File [C] [bar] [s] [bar/s] [mm] [mm] [mm] [mm] [mm] [m1] [m1] [%] [%] [%] [%] [um] 1 844 25.90 357.0 0.0725 9.15 50.00 51.60 - 0.0 # a.r. puki-0 2 852 23.30 283.3 0.0822 8.95 50.35 50.08 42.00 3.166 4.50 22.68 40.34 -0.54 0.0 # a.r. puki-0 3 800 43.70 566.4 0.0772 8.93 50.32 48.20 41.00 3.150 6.00 45.27 57.41 -4.21 0.0 # a.r. puki-0 4 900 10.80 130.0 0.0831 8.93 50.55 50.20 43.00 3.164 4.50 22.32 37.06 -0.69 0.0 # a.r. puki-0 5 902 11.10 134.5 0.0825 8.98 50.05 49.52 44.50 3.168 5.50 35.19 56.32 -1.06 0.0 # a.r. puki-0 6 952 10.40 144.8 0.0718 8.98 50.25 50.00 44.50 3.161 4.90 26.75 36.57 -0.60 0.0 # a.r. puki-1 7 100 8.88 122.4 0.0725 8.96 50.15 49.75 45.50 3.161 4.90 26.75 36.57 -0.60 0.0 # a.r. puki-1 8 1052 8.11 114.5 0.0708 8.96 50.55 50.15 45.50 3.166 4.60 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7 70 1007 0 0.0765 8.96 50.55 50.10 49.52 44.50 3.186 4.60 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 100 7 70 1007 0.0765 8.96 50.15 49.75 45.50 3.166 4.50 22.02 37.42 -0.79 0.0 # a.r. puki-1 9 100 7 70 1007 70 0.0765 8.96 50.15 49.75 45.50 3.166 4.60 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 100 7 70 1007 70 0.0765 8.96 50.55 50.10 44.50 3.186 4.60 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 100 7 70 1007 70 0.0765 8.96 50.55 50.10 44.50 3.166 4.50 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 100 7 70 1007 70 0.0765 8.96 50.55 50.15 45.50 3.166 4.60 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 100 7 70 1007 70 0.0765 8.96 50.55 50.15 45.50 3.166 4.50 2.204 34.48 -0.990 0.0 # a.r. puki-1 9 100 7 70 1007 70 0.0765 8.96 50.55 50.10 44.50 3.186 4.60 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 100 7 70 1007 70 0.0765 8.96 50.55 50.15 45.50 3.166 4.50 2.204 34.48 -0.990 0.0 # a.r. puki-1 9 100 7 70 1007 70 0.076</pre>	#		tipusnal; (OMFB 94-9	7-47-0817/	2.5, 1996	5 .										
<pre># [3] Maroti L., Matus L.: Futoelemviselkedes VVER reaktortipusnal; Zarojelentes OMFB 94-97-47-0817, 1996. # [4] Cs. Gyori, Z. Hozer, L. Maroti, L. Matus: VVER ballooning experiments; # EHPC Meeting Lillehammer, March 1998; HPR-349/40. (File: ehpg-98.pdf) # # No. T p time dp/dt D0 L0 L1 Ld V0 V1 epstav epstm epsa oxlayer treatment File # [C] [bar] [s] [bar/s] [mm] [mm] [mm] [mm] [m1] [m1] [%] [%] [um] # 1 844 25.90 357.0 0.0725 9.15 50.00 51.60 - 0.0 # a.r. puki-0 2 852 23.30 283.3 0.0822 8.95 50.35 50.08 42.00 3.166 4.50 22.68 40.34 -0.54 0.0 # a.r. puki-0 3 800 43.70 56.64 0.0772 8.93 50.32 48.20 41.00 3.150 6.00 45.27 57.41 -4.21 0.0 # a.r. puki-0 4 900 10.80 130.0 0.0831 8.93 50.55 50.20 43.00 3.164 4.50 22.32 37.06 -0.69 0.0 # a.r. puki-0 5 902 11.10 134.5 0.0825 8.98 50.05 49.52 44.50 3.168 5.50 35.19 56.32 -1.06 0.0 # a.r. puki-0 5 902 11.10 134.5 0.0825 8.98 50.25 50.00 44.50 3.181 4.80 25.49 39.73 -0.50 0.0 # a.r. puki-1 7 1000 8.88 122.4 0.0725 8.96 50.15 49.75 45.50 3.161 4.90 26.75 36.57 -0.80 0.0 # a.r. puki-1 7 1000 8.88 122.4 0.0728 8.96 50.55 50.15 49.75 45.50 3.164 4.50 22.02 37.42 -0.79 0.0 # a.r. puki-1 8 1052 8.11 114.5 0.0708 8.96 50.55 50.40 49.65 45.50 3.186 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7.70 1007 0.0765 8.96 50.40 49.65 45.50 3.186 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7.70 1007 0.0765 8.96 50.40 49.65 45.50 3.166 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7.70 1007 0.0765 8.96 50.40 49.65 50.31 46.50 3.186 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7.70 1007 0.0765 8.96 50.40 49.65 50.31 46.50 3.186 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7.70 1007 0.0765 8.96 50.40 49.65 50.31 46.50 3.186 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7.70 1007 7.0776 8.96 50.45 50.40 49.65 50 3.166 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7.70 1007 7.0776 8.96 50.45 50.40 49.65 50 3.166 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7.70 1007 7.0776 8.96 50.45 50.40 49.65 50 3.166 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7.70</pre>	#		-														
<pre># Zarojelentes OMFB 94-97-47-0817, 1996. # [4] Cs. Gyori, Z. Hozer, L. Maroti, L. Matus: VVER ballooning experiments; EHPG Meeting Lillehammer, March 1998; HPR-349/40. (File: ehpg-98.pdf) # [1] No. T p time dp/dt D0 L0 L1 Ld V0 V1 epstav epstm epsa oxlayer treatment File [C] [bar] [s] [bar/s] [mm] [mm] [mm] [mm] [ml] [ml] [ml] [%] [%] [%] [um] 1 844 25.90 357.0 0.0725 9.15 50.00 51.60 - 0.0 # a.r. puki-0 2 852 23.30 283.3 0.0822 8.95 50.35 50.08 42.00 3.166 4.50 22.68 40.34 -0.54 0.0 # a.r. puki-0 3 800 43.70 566.4 0.0772 8.93 50.32 48.20 41.00 3.150 6.00 45.27 57.41 -4.21 0.0 # a.r. puki-0 4 900 10.80 130.0 0.0831 8.93 50.55 50.20 43.00 3.164 4.50 22.32 37.06 -0.69 0.0 # a.r. puki-0 5 902 11.10 134.5 0.0825 8.98 50.25 50.00 44.50 3.181 4.80 25.49 39.73 -0.50 0.0 # a.r. puki-1 7 1000 8.88 122.4 0.0725 8.96 50.15 49.75 45.50 3.161 4.90 26.75 36.57 -0.80 0.0 # a.r. puki-1 8 1052 8.11 114.5 0.0708 8.96 50.55 50.15 45.50 3.186 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7 70 100 70 0.076 8.95 50.04 45.50 3.186 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7 70 100 70 0.076 8.95 50.04 45.50 3.186 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7 70 100 70 0.076 8.95 50.04 45.50 3.186 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7 70 100 70 0.076 8.95 50.04 45.50 3.186 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7 70 100 70 0.076 8.95 50.04 45.50 3.186 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7 70 100 70 0.076 8.95 50.04 45.50 3.186 4.50 22.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7 70 100 70 0.076 8.95 50.04 45.50 3.186 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7 70 100 70 0.076 8.95 50.04 45.50 3.186 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7 70 100 70 0.076 8.95 50.04 45.50 3.186 44.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7 700 100 7 0.076 8.95 50.04 45.50 3.186 44.50 22.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7 700 100 7 0.076 8.95 50.04 45.50 3.186 44.50 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7 700 100 7 0.076 8.95 50.04 45.50 3.186 45.50 3.186 4.80 25.</pre>	#	[3]	Maroti L.,	Matus L.	: Futoelem	viselkede	es VVER re	eaktortipu	ısnal;								
<pre># [4] Cs. Gyori, Z. Hozer, L. Maroti, L. Matus: VVER ballooning experiments;</pre>	#		Zarojelente	es OMFB 9	4-97-47-08	17, 1996.											
<pre># [4] Cs. Gyori, Z. Hozer, L. Maroti, L. Matus: VVER ballooning experiments;</pre>	#																
<pre># EHPG Meeting Lillehammer, March 1998; HPR-349/40. (File: ehpg-98.pdf) # # No. T p time dp/dt D0 L0 L1 Ld V0 V1 epstav epstm epsa oxlayer treatment File # [C] [bar] [s] [bar/s] [mm] [mm] [mm] [mm] [m1] [m1] [x] [x] [x] [x] [um] # 1 844 25.90 357.0 0.0725 9.15 50.00 51.60 - 0.0 # a.r. puki-0 2 852 23.30 283.3 0.0822 8.95 50.35 50.08 42.00 3.166 4.50 22.68 40.34 -0.54 0.0 # a.r. puki-0 3 800 43.70 566.4 0.0772 8.93 50.32 48.20 41.00 3.150 6.00 45.27 57.41 -4.21 0.0 # a.r. puki-0 4 900 10.80 130.0 0.0831 8.93 50.55 50.20 43.00 3.164 4.50 22.32 37.06 -0.69 0.0 # a.r. puki-0 5 902 11.10 134.5 0.0825 8.98 50.05 49.52 44.50 3.168 5.50 35.19 56.32 -1.06 0.0 # a.r. puki-0 6 952 10.40 144.8 0.0718 8.98 50.25 50.00 44.50 3.181 4.80 25.49 39.73 -0.50 0.0 # a.r. puki-1 7 1000 8.88 122.4 0.0725 8.96 50.15 49.75 45.50 3.161 4.90 26.75 36.57 -0.80 0.0 # a.r. puki-1 8 1052 8.11 114.5 0.0708 8.96 50.55 50.15 45.50 3.166 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7 70 100.7 0.0765 8.95 50.40 49.95 45.50 3.166 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7 70 100.7 0.0765 8.95 50.40 49.95 45.50 3.166 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7 70 100.7 0.0765 8.95 50.40 49.95 45.50 3.166 4.50 21.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7 70 100.7 0.0765 8.95 50.40 49.95 45.50 3.166 4.50 21.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7 70 100.7 0.0765 8.95 50.40 49.95 45.50 3.166 4.50 21.0 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7 70 100.7 0.0765 8.95 50.40 49.95 45.50 3.166 4.50 21.04 34.18 -0.89 0.0 0 # a.r. puki-1 9 1100 7 70 100.7 0.0765 8.95 50.40 49.95 45.50 3.166 4.50 21.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7 70 100.7 0.0765 8.95 50.40 49.95 45.50 3.166 4.50 21.04 34.18 -0.89 0.0 # a.r. puki-1 9 1100 7 70 100.7 0.0765 8.95 50.40 49.95 45.50 3.166 4.50 21.04 34.18 -0.89 0.0 # a.r. puki-1 9 1100 7 70 100 7 0.0765 8.95 50.40 49.95 45.50 3.166 4.50 21.04 34.18 -0.89 0.0 # a.r. puki-1 9 1100 7 70 100 7 0.0765 8.95 50.40 49.95 45.50 3.166 4.50 21.04 34.18 -0.89 0.0 # a.r. puki-1 9 1100 7 70 100 7 0.0765</pre>	#	[4]	Cs. Gyori,	Z. Hozer	, L. Marot	i, L. Mat	cus: VVER	balloonir	ng experim	ents;							
<pre># # # No. T p time dp/dt D0 L0 L1 Ld V0 V1 epstav epstm eps oxlayer treatment File # [C] [bar] [s] [bar/s] [mm] [mm] [mm] [mm] [ml] [ml] [k] [k] [k] [m] # 1 844 25.90 357.0 0.0725 9.15 50.00 51.60 - 0.0 # a.r. puki-0 2 852 23.30 283.3 0.0822 8.95 50.35 50.08 42.00 3.166 4.50 22.68 40.34 -0.54 0.0 # a.r. puki-0 3 800 43.70 566.4 0.0772 8.93 50.32 48.20 41.00 3.150 6.00 45.27 57.41 -4.21 0.0 # a.r. puki-0 4 900 10.80 130.0 0.0831 8.93 50.55 50.20 43.00 3.164 4.50 22.32 37.06 -0.69 0.0 # a.r. puki-0 5 902 11.10 134.5 0.0825 8.98 50.05 49.52 44.50 3.168 5.50 35.19 56.32 -1.06 0.0 # a.r. puki-1 6 952 10.40 144.8 0.0718 8.98 50.25 50.00 44.50 3.181 4.80 25.49 39.73 -0.50 0.0 # a.r. puki-1 7 1000 8.88 122.4 0.0725 8.96 50.15 49.75 45.50 3.161 4.90 26.75 36.57 -0.80 0.0 # a.r. puki-1 8 1052 8.11 114.5 0.0708 8.96 50.55 50.15 45.50 3.186 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7 70 0.0765 8.95 50.40 49.95 45.50 3.166 4.50 21.04 34.18 -0.89 0.0 # a.r. puki-1 9 1100 7 70 0.0 # a.r. puki-1 9 1100 7 70 0.0 765 8.95 50.40 49.95 45.50 3.166 4.80 21.04 34.18 -0.89 0.0 # a.r. puki-1 9 1100 7 70 0.0 # a.r. puki-1 9 1100 7 70 0.0 765 8.95 50.40 49.95 45.50 3.166 4.50 21.04 34.18 -0.89 0.0 # a.r. puki-1 9 1100 7 70 0.0 765 8.95 50.40 49.95 45.50 3.166 4.80 21.04 34.18 -0.89 0.0 # a.r. puki-1 9 1100 7 70 0.0 765 8.95 50.40 49.95 45.50 3.166 4.80 21.04 34.18 -0.89 0.0 # a.r. puki-1 9 1100 7 70 0.0 765 8.95 50.40 49.95 45.50 3.166 4.80 21.04 34.18 -0.89 0.0 # a.r. puki-1 9 1100 7 70 0.0 765 8.95 50.40 49.95 45.50 3.166 4.50 21.04 34.18 -0.89 0.0 # a.r. puki-1 9 1100 7 70 0.0 765 8.95 50.40 49.95 45.50 3.166 4.80 21.04 34.18 -0.89 0.0 # a.r. puki-1 9 1100 7 70 0.0 # a.r. puki-1 9 1100 7 70 0.0 765 8.95 50.40 49.95 45.50 3.166 4.80 21.04 34.18 -0.89 0.0 # a.r. puki-1 9 1100 7 70 0.0 765 8.95 50.40 49.95 45.50 3.166 4.80 21.04 34.18 -0.89 0.0 # a.r. puki-1 9 1100 7 70 0.0 765 8.95 50.40 49.95 45.50 3.166 4.80 21.04 34.18 -0.89 0.0 # a.r. puki-1 9 1100 7 70 0.0 765 78 75 75 75 75 78 76 75 78 76 75 78 76 78 76 77 79</pre>	#		EHPG Meetin	ng Lilleh	ammer, Mar	ch 1998;	HPR-349/4	10. (File:	: ehpg-98.	pdf)							
<pre># No. T p time dp/dt D0 L0 L1 Ld V0 V1 epstav epstm eps oxlayer treatment File # [C] [bar] [s] [bar/s] [mm] [mm] [mm] [mm] [mm] [ml] [ml] [ml</pre>	#																
# No. T p time dp/dt D0 L0 L1 Ld V0 V1 epsav epsav oxlayer treatment File # [C] [bar] [s] [bar/s] [mm] [mm] [mm] [mm] [ml] [ml] [ml] [ml] [%] [%] [w] # -<	#						- •	- 4									
# [C] [bar] [s] [bar/s] [mm]	# N	0. T	р	time	dp/dt	DU	LO	Ll	Ld	V0	V1	epstav	epstm	epsa	oxlayer	treatment	File
# 1 844 25.90 357.0 0.0725 9.15 50.00 - - - - 51.60 - 0.0 # a.r. puki-0 2 852 23.30 283.3 0.0822 8.95 50.35 50.08 42.00 3.166 4.50 22.68 40.34 -0.54 0.0 # a.r. puki-0 3 800 43.70 566.4 0.0772 8.93 50.32 48.20 41.00 3.150 6.00 45.27 57.41 -4.21 0.0 # a.r. puki-0 4 900 10.80 130.0 0.0831 8.93 50.55 50.20 43.00 3.164 4.50 22.32 37.06 -0.69 0.0 # a.r. puki-0 5 902 11.10 134.5 0.0825 8.98 50.25 50.00 44.50 3.168 5.50 35.19 56.32 -1.06 0.0 # a.r. puki-1 6 952 10.40 144.8 0.0718 8.98 50.25 50.100 44.50	#	[C] [bar]	[s]	[bar/s]	[mm]	[mm]	[mm]	[mm]	[m⊥]	[m⊥]	[%]	[%]	[%]	[um]		
1 844 25.90 357.0 0.0725 9.15 50.00 - - - - - - 0.0 # a.r. puki-0 2 852 23.30 283.3 0.0822 8.95 50.35 50.08 42.00 3.166 4.50 22.68 40.34 -0.54 0.0 # a.r. puki-0 3 800 43.70 566.4 0.0772 8.93 50.35 50.20 43.00 3.166 4.50 22.68 40.34 -0.59 0.0 # a.r. puki-0 4 900 10.80 130.0 0.0831 8.93 50.55 50.20 43.00 3.164 4.50 22.32 37.06 -0.69 0.0 # a.r. puki-0 5 902 11.10 134.5 0.0825 8.98 50.25 50.00 44.50 3.168 5.50 35.19 56.32 -1.06 0.0 # a.r. puki-1 6 952 10.40 144.8 0.0718 8.98 50.25 <t< td=""><td>#</td><td>0.4</td><td></td><td>057.0</td><td>0 0705</td><td>0 1 5</td><td>50.00</td><td></td><td></td><td></td><td></td><td></td><td>51 60</td><td></td><td>0 0</td><td>u.</td><td></td></t<>	#	0.4		057.0	0 0705	0 1 5	50.00						51 60		0 0	u.	
2 852 23.30 283.3 0.0822 8.95 50.35 50.08 42.00 3.166 4.50 22.68 40.34 -0.54 0.0 # a.r. puki-0 3 800 43.70 566.4 0.0772 8.93 50.32 48.20 41.00 3.150 6.00 45.27 57.41 -4.21 0.0 # a.r. puki-0 4 900 10.80 130.0 0.0831 8.93 50.55 50.20 43.00 3.164 4.50 22.33 7.06 -0.69 0.0 # a.r. puki-0 5 902 11.10 134.5 0.0825 8.98 50.05 49.52 44.50 3.168 5.50 35.19 56.32 -1.06 0.0 # a.r. puki-1 6 952 10.40 144.8 0.0718 8.98 50.25 50.00 44.50 3.181 4.80 25.49 39.73 -0.50 0.0 # a.r. puki-1 7 1000 8.88 122.4 0.0725 8.96 50.15 49.75 45.50 <td>T</td> <td>84</td> <td>4 25.90</td> <td>357.0</td> <td>0.0725</td> <td>9.15</td> <td>50.00</td> <td>-</td> <td>-</td> <td>-</td> <td>-</td> <td>-</td> <td>51.60</td> <td>-</td> <td>0.0</td> <td># a.r.</td> <td>puki-0</td>	T	84	4 25.90	357.0	0.0725	9.15	50.00	-	-	-	-	-	51.60	-	0.0	# a.r.	puki-0
3 800 43.70 566.4 0.07/2 6.93 50.32 48.20 41.00 3.150 6.00 45.27 57.41 -4.21 0.0 # a.r. puki-(4 900 10.80 130.0 0.0831 8.93 50.55 50.20 43.00 3.164 4.50 22.32 37.06 -0.69 0.0 # a.r. puki-(5 902 11.10 134.5 0.0825 8.98 50.05 49.52 44.50 3.164 4.50 22.32 37.06 -0.69 0.0 # a.r. puki-(6 952 10.40 144.8 0.0718 8.98 50.25 50.00 44.50 3.181 4.80 25.49 39.73 -0.50 0.0 # a.r. puki-1 7 1000 8.88 122.4 0.0725 8.96 50.15 49.75 45.50 3.161 4.90 26.75 36.57 -0.80 0.0 # a.r. puki-1 8 1052 8.11 114.5 0.0708	2	85.	2 23.30	283.3	0.0822	8.95	50.35	50.08	42.00	3.166	4.50	22.68	40.34	-0.54	0.0	# a.r.	puki-0
4 900 10.80 130.0 0.0831 8.93 50.55 50.20 43.00 3.164 4.50 22.32 37.06 -0.69 0.0 # a.r. puki-0 5 902 11.10 134.5 0.0825 8.98 50.05 49.52 44.50 3.168 5.50 35.19 56.32 -1.06 0.0 # a.r. puki-1 6 952 10.40 144.8 0.0718 8.98 50.25 50.00 44.50 3.181 4.80 25.49 39.73 -0.50 0.0 # a.r. puki-1 7 1000 8.88 122.4 0.0725 8.96 50.15 49.75 45.50 3.161 4.90 26.75 36.57 -0.80 0.0 # a.r. puki-1 8 1052 8.11 114.5 0.0708 8.96 50.15 45.50 3.168 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7.70 100.7 0.0735 8.95	3	80	J 43.70	200.4	0.0772	8.93	50.32	48.20	41.00	3.150	6.00	45.27	57.41	-4.21	0.0	# a.r.	puki-0
5 902 11.10 134.5 0.0825 8.98 50.05 49.52 44.50 3.168 5.50 35.19 56.32 -1.06 0.0 # a.r. puki-1 6 952 10.40 144.8 0.0718 8.98 50.25 50.00 44.50 3.181 4.80 25.49 39.73 -0.50 0.0 # a.r. puki-1 7 1000 8.88 122.4 0.0725 8.96 50.15 49.75 3.161 4.90 26.75 36.57 -0.80 0.0 # a.r. puki-1 8 1052 8.11 114.5 0.0708 8.96 50.15 45.50 3.166 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7.70 100.7 0.0765 8.95 50.40 49.55 50 3.168 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1	4	90	J 10.80	130.0	0.0831	8.93	50.55	50.20	43.00	3.164	4.50	22.32	37.06	-0.69	0.0	# a.r.	puki-u
7 1000 8.88 122.4 0.0725 8.96 50.15 49.75 45.50 3.161 4.80 25.49 59.75 -0.30 0.0 # a.r. puki-1 7 1000 8.88 122.4 0.0725 8.96 50.15 49.75 35.161 4.90 26.75 36.57 -0.80 0.0 # a.r. puki-1 8 1052 8.11 114.5 0.0708 8.96 50.15 45.50 3.186 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1 9 1100 7 0 0.0765 8.95 50.40 49.95 45.50 3.186 4.80 25.02 37.42 -0.79 0.0 # a.r. puki-1	5	90.	2 11.10 2 10.40	134.5 111 0	0.0825	8.98 8.98	50.US	49.52	44.30	3.100 3.101	2.30	33.19	30.32 30 72	-1.06	0.0	# a.r. # a.r	puki-1
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	0 7	100	∠ ⊥0.40 n 8.90	122 /	0.0725	0.30	50.25	10.00	44.50	3 161	4.00	23.49	36 57	-0.50	0.0	ra	puki-1
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	0	110	- 0.11 0 7 70	100 7	0.0765	8 95	50.33	19 95	45 50	3 169	4 50	21.02	34 18	-0.89	0.0	ra Har	puri-1

puki-02 puki-06

puki-08

puki-00 puki-10 puki-11 puki-12

puki-13

puki-14

10 1152 7.01 91.8 0.0754 8.96 50.18 49.80 45.00 3.167 4.40 19.85 29.03 -0.76 0.0 # a.r. puki-15 11 1201 6.47 82.5 0.0754 8.96 50.10 49.00 3.157 4.40 23.67 33.44 -1.20 0.0 # a.r. puki-17 13 001 23.77 2886.0 0.0079 8.94 50.10 44.00 3.143 7.00 54.83 78.24 -1.29 0.00 # a.r. puki-17 14 1194 6.45 96.63 0.0070 9.14 50.00 41.60 3.128 4.39 72.43 74.23 -1.29 0.00 # a.r. puki-21 15 1007 7.30 1002.10 0.0069 9.13 50.10 43.70 3.228 5.43 3.21.0 3.1.6 -0.99 0.0 # a.r. puki-22 19 1003 7.30 1002.10 0.0089 9.13 50.10 43.70 3.228 5.40 3.244 60.39	МТА	KFKI AEK	a														Database Report
10 1152 7.01 91.8 0.0764 8.96 0.018 49.80 45.00 31.62 4.80 10.85 28.03 -0.76 0.0 4 a.r. puki-15 12 301 7.23 870.9 0.0033 8.96 50.00 44.00 3.177 4.00 13.98 74.23 84.0 0.00 4 a.r. puki-15 13 801 7.2.3 870.9 0.0033 8.96 50.00 44.40 3.137 4.00 3.148 7.00 54.8 7.05 0.00 4 a.r. puki-15 14 1186 4.84 700.7 0.108 50.10 45.40 3.138 1.48 7.00 3.28 50.61 -1.59 0.00 4 a.r. puki-15 110 1.02 5.83 817.2 0.001 9.14 50.00 4.94.7 47.00 3.28 51.7 43.81 4.94.1 1.28 0.0 4 a.r. puki-12 13 1003 7.63 10.32 0.0028 9.13 50.01																	^
11 1201 6.47 82.5 0.0784 8.96 50.10 49.50 45.00 3.177 4.00 35.44 -1.20 0.0 4 a.r. pukl-16 13 801 23.70 285.0 0.0078 8.44 50.10 44.00 3.143 7.00 54.83 78.29 -3.23 0.00 4 a.r. pukl-13 14 146 4.84 70.0 0.0078 8.44 50.10 44.60 3.233 5.44 34.50 51.55 -1.53 0.00 4 a.r. pukl-13 15 1141 543 86.11 0.0067 8.14 50.02 49.45 3.235 51.31 22.10 0.0 4 a.r. pukl-22 18 1050 7.83 113.38 0.0069 9.13 50.12 49.75 47.00 3.228 5.48 36.54 69.59 -1.134 0.00 4 a.r. pukl-24 20 91 7.67 1101.3 0.0070 9.15 50.30 49.75 47.00 3.28 5.48<	10	1152	7.01	91.8	0.0764	8.96	50.18	49.80	45.00	3.162	4.40	19.85	28.03	-0.76	0.0	# a.r.	puki-15
12 901 7.23 870.9 0.0083 0.e6 50.00 44.00 3.170 4.00 13.99 29.95 -0.60 0.0 # a.r. puk1-17 13 501 64.84 700.7 0.0069 8.14 50.05 50.55 50.25 41.60 3.23 55.05 -1.59 0.0 # a.r. puk1-21 14 1196 4.84 700.7 0.0069 8.14 50.65 50.25 50.24 44.60 3.148 4.8 22.10 31.76 -0.99 0.0 # a.r. puk1-21 15 1101 6.05 86.11 0.0079 51.15 50.20 45.74 7.700 3.272 4.38 26.54 39.70 -0.06 0.0 # a.r. puk1-22 19 1003 7.67 101.3 0.0079 9.14 50.15 45.90 3.282 5.66 35.44 63.92 -0.80 0.0 # a.r. puk1-22 21 693 361.40 0.2840 84.04 0.2849 48.6	11	1201	6.47	82.5	0.0784	8.96	50.10	49.50	45.00	3.157	4.80	25.67	35.44	-1.20	0.0	# a.r.	puki-16
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	12	901	7.23	870.9	0.0083	8.96	50.30	50.00	44.00	3.170	4.00	13.99	29.95	-0.60	0.0	# a.r.	puki-17
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	13	801	23.70	2985.0	0.0079	8.94	50.10	48.45	44.00	3.143	7.00	54.83	78.29	-3.29	0.0	# a.r.	puki-18
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	14	1196	4.84	700.7	0.0069	9.16	50.45	49.65	41.60	3.323	5.54	34.50	55.05	-1.59	0.0	# a.r.	puki-19
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	15	1147	5.81	864.4	0.0067	9.13	50.55	50.25	43.60	3.308	5.36	31.12	46.36	-0.59	0.0	# a.r.	puki-20
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	16	1101	6.05	869.1	0.0070	9.14	50.60	50.10	45.40	3.318	4.78	22.10	31.76	-0.99	0.0	# a.r.	puki-21
18 1050 7.83 1133.8 0.0069 9.13 50.10 49.75 47.00 3.282 6.64 37.53 68.70 -0.66 0.0 # ar. puki-23 20 951 7.67 1101.3 0.0070 9.15 50.30 49.65 46.10 3.028 58.03 58.46 63.52 -0.80 0.0 # ar. puki-25 21 999 7.17 102.6 0.0069 9.14 50.15 48.23 24.23 5.96 38.45 63.52 -7.78 0.0 # ar. puki-25 22 699 65.30 244.0 0.0301 9.18 49.55 49.32 44.30 3.307 41.63 21.46 34.66 -1.26 13.9 # puko-11 puki-23 24 669 106.40 0.0314 9.18 50.16 50.15 46.03 3.47 4.13 17.66 -1.26 13.9 # puko-71 puki-23 25 688 65.40 0.228 9.13 50.15 46.10 3.346 4.57 11.61 37.4	17	1102	5.83	817.2	0.0071	9.16	50.02	49.45	45.70	3.295	5.11	26.61	43.97	-1.14	0.0	# a.r.	puki-22
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	18	1050	7.83	1133.8	0.0069	9.13	50.10	49.77	47.00	3.278	4.38	16.54	39.57	-0.66	0.0	# a.r.	puki-23
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	19	1003	7.30	1052.2	0.0069	9.14	50.20	49.75	47.00	3.292	6.04	37.53	68.70	-0.90	0.0	# a.r.	puki-24
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	20	951	7.67	1101.3	0.0070	9.15	50.30	49.65	46.10	3.306	5.27	28.39	49.81	-1.29	0.0	# a.r.	puki-25
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	21	999	7.17	1032.6	0.0069	9.14	50.15	49.75	45.90	3.289	5.80	35.44	63.92	-0.80	0.0	# a.r.	puki-26
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	22	699	85.30	2844.0	0.0300	9.13	52.30	48.23	42.30	3.422	5.96	38.45	69.58	-7.78	0.0	# a.r.	puki-27
24 699 108.40 364.40 0.0297 5.18 49.35 44.33 24.69 34.06 -1.26 13.9 # pubcor-11 pik1-29 25 688 05.90 0.0311 9.29 50.25 50.13 46.10 3.404 4.07 10.14 30.02 -0.24 45.67 # pubcor-20 puk1-31 27 688 59.40 0.224 0.0314 9.21 47.50 47.30 42.90 3.164 4.57 18.09 47.10 -0.142 41.4 # pubcor-09 puk1-32 28 802 57.75 1832.0 0.0315 9.16 50.40 50.35 50.20 45.10 3.384 4.57 18.09 47.10 -0.10 22.3 # pubcor-07 puk1-34 30 902 17.45 52.26 0.0120 9.16 50.46 3.340 4.12 11.99 23.50 -0.10 14.3 # pubcor-07 puk1-35 31 799 55.78 2943.2 0.0159 9.23 50.20 50.20 46.20 3.371 4.00 9.6	23	700	70.21	2345.0	0.0299	9.00	50.38	44.70	40.12	3,203	7.30	61.43	86.12	-11.27	0.0	# a.r.	puki-28
$ \begin{array}{c} 125 & 639 & 105.30 & 3515.0 & 0.031 & 5.18 & 50.90 & 50.43 & 46.50 & 3.367 & 4.55 & 17.66 & 27.49 & -0.92 & 20.0 & \pm pukor-20 & puk1-30 \\ 266 & 698 & 69.40 & 2228.0 & 0.0311 & 9.29 & 50.25 & 50.13 & 46.10 & 3.404 & 4.07 & 10.14 & 30.02 & -0.24 & 56.7 & \pm pukor-20 & puk1-31 \\ 27 & 698 & 59.20 & 1864.0 & 0.0314 & 9.12 & 47.50 & 47.30 & 42.90 & 3.163 & 3.67 & 8.51 & 17.64 & -0.42 & 41.4 & \pm pukor-20 & puk1-32 \\ 28 & 802 & 57.75 & 1832.0 & 0.0315 & 9.18 & 50.10 & 50.05 & 46.20 & 3.314 & 4.52 & 18.09 & 47.10 & -0.10 & 20.2 & \pm pukor-09 & puk1-33 \\ 30 & 902 & 17.45 & 532.6 & 0.0328 & 9.19 & 50.25 & 50.20 & 45.10 & 3.338 & 4.05 & 11.27 & 31.06 & -0.10 & 14.4 & \pm pukor-17 & puk1-34 \\ 31 & 799 & 55.78 & 2943.2 & 0.0190 & 9.17 & 50.60 & 50.55 & 46.50 & 3.328 & 4.05 & 11.32 & 13.03 & -0.12 & 14.6 & \pm pukor-17 & puk1-36 \\ 32 & 699 & 17.34 & 961.6 & 0.0180 & 9.19 & 50.20 & 50.14 & 45.50 & 3.328 & 4.05 & 11.32 & 13.03 & -0.12 & 14.6 & \pm pukor-17 & puk1-36 \\ 34 & 1003 & 14.92 & 940.5 & 0.0159 & 9.23 & 50.95 & 50.90 & 48.00 & 3.407 & 3.65 & 3.71 & 4.01 & -0.10 & 22.2 & \pm pukor-30 & puk1-38 \\ 35 & 1001 & 10.44 & 407.3 & 0.0169 & 9.18 & 50.85 & 50.80 & 46.00 & 3.367 & 4.05 & 13.80 & -0.10 & 12.8 & \pm pukor-14 & puk1-40 \\ 36 & 1100 & 8.77 & 490.2 & 0.0179 & 9.23 & 50.85 & 50.80 & 46.00 & 3.337 & 4.16 & 5.99 & 13.80 & -0.10 & 22.8 & \pm pukor-30 & puk1-42 \\ 38 & 751 & 55.60 & 368.7 & 0.0151 & 9.15 & 52.07 & 50.02 & 30.10 & 47.30 & 3.337 & 4.13 & 1.93 & 2.00 & -0.20 & 24.2 & \pm pukor-30 & puk1-42 \\ 41 & 650 & 95.42 & 7318.0 & 0.0120 & 9.15 & 52.07 & 49.80 & 42.29 & 3.425 & 5.92 & 39.64 & 74.77 & -4.36 & 0.0 & \# a.r. & puk1-44 \\ 42 & 700 & 93.60 & 7361.4 & 0.0127 & 9.15 & 52.07 & 49.80 & 42.29 & 3.433 & 7.97 & 1.03 & 80.23 & -1.17 & 3.0 0 & \# a.r. & puk1-45 \\ 41 & 650 & 95.42 & 7318.0 & 0.0129 & 9.15 & 52.07 & 49.80 & 42.29 & 3.432 & 7.47 & 7.4.36 & 0.0 & \# a.r. & puk1-46 \\ 41 & 650 & 95.42 & 7318.0 & 0.0129 & 9.15 & 52.07 & 49.80 & 42.29 & 3.432 & 7.47 & 7.1.3 & 80.0 & \# a.r. & puk1-45 \\ 41 & 650 & 95.42 & 7318.0 & 0.033 & 9.15$	24	699	108 40	3644 0	0.0295	9.00	49 95	49 32	44 30	3 304	4 93	24 69	34 06	-1 26	13.9	# nukox=11	puki-29
16 668 669.40 222.80 0.0311 9.10 50.755 50.753 46.10 3.404 41.07 10.14 50.72 10.84 10.84 10.75 10.14 50.72 10.84 10.14 10.14 50.72 10.84 10.14 10.14 50.72 10.84 10.14 10.14 50.72 10.84 10.14 10.14 50.72 10.14 10.14 50.72 10.14	25	698	105.90	3515 0	0.0201	9 1 8	50 90	50 43	46 50	3 367	4 55	17 66	27 49	-0.92	20 0	# pukox $= 20$	puki-30
10 00.0 00.0 1884.0 0.0011 0.0.0 1.0.0 0.0.0 1.0.0 0.0.0 1.0.0 0.0.0 1.0.0 0.0.0 1.0.0 0.0.0 1.0.0 0.0.0 1.0.0 0.0.0 1.0.0 0.	25	698	69.10	2228 0	0.0301	9.10	50.25	50.13	46.10	3 404	4.00	10 14	30 02	-0.24	56 7	# pukox=20	puki-31
28 802 53.20 189.0 0.0314 91.1 91.00 41.00 91.00 20.10 20.11 41.00 91.00 20.10 20.11 45.20 10.09 47.10 -0.10 20.2 23.3 91.0 50.10 50.10 50.15 46.50 3.314 41.20 91.00 20.2 47.43 91.00 20.12 45 10.0 31.34 41.2 11.99 23.50 -0.10 14.3 # pukox-17 puki-35 31 799 55.78 2943.2 0.0190 9.17 50.60 50.25 50.20 46.50 3.340 4.12 11.99 23.50 -0.10 14.3 # pukox-13 puki-36 32 899 17.34 961.6 0.0186 9.25 50.25 50.20 46.20 3.375 4.00 9.61 11.07 -0.10 22.28 # pukox-14 puki-36 34 1003 10.44 617.3 0.0169 9.18 50.85 50.80 46.00 3.464 4.03 10.40 21.52 -0.10 15.1 # pukox-14	20	600	50.20	1001 0	0.0311	9.29	47 50	47 20	40.10	2 162	2.07	0 51	17 64	-0.42	JU.7	# pukox 25	puki 22
29 802 3.7.3 122.0 0.0333 9.16 50.10 50.10 3.320 3.320 4.10 -0.10 20.2 # pukox-07 puki-33 30 902 17.45 532.6 0.0328 9.19 50.35 50.20 45.10 3.330 4.05 11.27 31.06 -0.30 19.4 # pukox-15 puki-36 31 799 55.78 2943.2 0.1180 9.17 50.60 50.20 46.50 3.320 4.12 11.39 23.50 -0.10 14.3 # pukox-17 puki-36 32 899 17.34 961.6 0.0180 9.19 50.20 46.50 3.324 4.03 1.1.32 13.03 -0.10 22.2 # pukox-17 puki-36 34 1003 14.492 940.5 0.0159 9.23 50.85 50.90 48.00 3.407 3.65 5.61 13.40 0.10 22.2 # pukox-14 puki-42 35 1001 10.44 617.3 0.0169 9.23 50.20 50.10 3.397 3.65	27	090	59.20	1004.0	0.0314	9.21	47.30	47.30	42.90	2 214	3.07	10.01	17.04	-0.42	41.4	# pukox-00	puki-32
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	20	002	20.72	1032.0	0.0315	9.10	50.10	50.05	40.20	3.314	4.52	10.09	47.10	-0.10	20.2	# pukox-09	puki-33
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	29	002	30./3	1212.0	0.0320	9.10	50.40	50.55	45.90	3.320	3.70	0.10	22.40	-0.10	20.3	# pukox=07	puki-34
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	30	902	1/.45	532.6	0.0328	9.19	50.35	50.20	45.10	3.338	4.05	11.27	31.06	-0.30	19.4	# pukox-15	puki-35
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	31	/99	55.78	2943.2	0.0190	9.17	50.60	50.55	46.50	3.340	4.12	11.99	23.50	-0.10	14.3	# pukox-13	puki-36
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	32	899	17.34	961.6	0.0180	9.19	50.20	50.14	45.50	3.328	4.05	11.32	13.03	-0.12	14.6	# pukox-17	puki-37
34 1003 14.92 940.5 0.0159 9.23 50.90 48.00 3.407 3.65 3.71 4.01 -0.10 22.2 # pukox-30 puki-39 35 1001 10.44 617.3 0.0169 9.18 50.80 50.80 46.30 3.397 3.76 5.69 13.80 -0.10 22.8 # pukox-14 puki-42 36 1100 8.77 490.2 0.0179 9.23 50.80 50.10 47.30 3.335 4.13 11.93 32.00 -0.20 24.2 # pukox-14 puki-42 37 1200 7.04 391.3 0.0181 9.16 52.20 50.20 39.58 3.445 5.92 39.64 74.77 -4.36 0.0 # a.r. puki-42 39 752 89.38 597.9 0.1462 9.13 52.57 48.46 40.06 3.437 6.10 42.02 53.54 -7.75 0.0 # a.r. puki-47 41 650 95.42 7318.0 0.0120 9.15 52.77 49.81 45.	33	900	22.41	258.1	0.0868	9.25	50.25	50.20	46.20	3.375	4.00	9.61	11.07	-0.10	22.8	# pukox-22	puki-38
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	34	1003	14.92	940.5	0.0159	9.23	50.95	50.90	48.00	3.407	3.65	3.71	4.01	-0.10	22.2	# pukox-30	puki-39
$ \begin{array}{cccccccccccccccccccccccccccccccccccc$	35	1001	10.44	617.3	0.0169	9.18	50.85	50.80	46.00	3.364	4.03	10.40	21.52	-0.10	15.1	# pukox-14	puki-40
37 1200 7.04 391.3 0.0180 9.20 50.10 47.30 3.335 4.13 11.93 32.00 -0.20 24.2 # pukox-08 puki-43 38 751 55.60 3688.7 0.0151 9.16 52.30 50.02 39.58 3.445 5.92 39.64 74.77 -4.36 0.0 # a.r. puki-43 39 752 89.38 597.9 0.1495 9.15 52.24 46.11 35.88 3.433 7.97 71.03 80.23 -11.73 0.0 # a.r. puki-45 40 651 134.40 919.3 0.1462 9.13 52.57 49.80 42.29 3.422 5.45 31.46 48.91 -4.36 0.0 # a.r. puki-47 42 700 93.60 7361.4 0.0127 9.15 50.72 49.81 45.29 3.384 4.72 20.49 40.95 -0.66 6.5 # pukox-40 puki-43 43 800 52.39 28.8 0.0223 9.15 50.75 50.36 46.11<	36	1100	8.77	490.2	0.0179	9.23	50.80	50.75	46.30	3.397	3.76	5.69	13.80	-0.10	22.8	# pukox-19	puki-42
3875155.603688.70.01519.1652.3050.0239.583.4455.9239.6474.77-4.360.0#a.r.puki-443975289.38597.90.14959.1552.2446.1135.883.4337.9771.0380.23-11.730.0#a.r.puki-454065113.440919.30.14629.1352.5348.4640.063.4376.1042.0253.54-7.750.0#a.r.puki-464165095.427318.00.01279.1552.0749.8042.293.4225.4531.4648.91-4.360.0#a.r.puki-474270093.607361.40.01279.1550.7249.8145.013.3334.3315.6220.96-1.796.3# pukox-41puki-484380052.392283.80.02299.1251.8351.4945.293.3844.7220.4930.43-0.777.1# pukox-40puki-504489917.23738.60.02339.1550.7550.3646.113.3354.6920.2930.43-0.777.1# pukox-37puki-5145100011.9651.3.30.02349.1549.7149.2945.083.2674.4217.821.92-0.847.5# pukox-34puki-514610118.223	37	1200	7.04	391.3	0.0180	9.20	50.20	50.10	47.30	3.335	4.13	11.93	32.00	-0.20	24.2	# pukox-08	puki-43
3975289.38597.90.14959.1552.2446.1135.883.4337.9771.0380.23-11.730.0#a.r.puki-454065095.427318.00.014629.1352.5348.4640.063.4376.1042.02 53.54 -7.750.0#a.r.puki-464165095.427318.00.01279.1552.0749.8042.29 3.422 5.45 31.46 48.91-4.360.0#a.r.puki-474270093.607361.40.01279.1550.7249.8145.01 3.333 4.3315.6220.96-1.796.3#pukox-41puki-484380052.392283.80.02239.1650.8650.7945.333.3503.736.2111.75-0.146.8#pukox-35puki-5045100011.96513.30.02339.1550.7550.3646.113.3354.6920.2930.43-0.777.1#pukox-34puki-524611018.22351.30.02349.1549.7149.2945.083.2674.4217.8231.92-0.847.5#pukox-34puki-5347702108.10651.40.16609.145.04649.7845.703.3164.4617.5119.80-1.356.9##pukox-39puki-53 </td <td>38</td> <td>751</td> <td>55.60</td> <td>3688.7</td> <td>0.0151</td> <td>9.16</td> <td>52.30</td> <td>50.02</td> <td>39.58</td> <td>3.445</td> <td>5.92</td> <td>39.64</td> <td>74.77</td> <td>-4.36</td> <td>0.0</td> <td># a.r.</td> <td>puki-44</td>	38	751	55.60	3688.7	0.0151	9.16	52.30	50.02	39.58	3.445	5.92	39.64	74.77	-4.36	0.0	# a.r.	puki-44
40 651 134.40 919.3 0.1462 9.13 52.53 48.46 40.06 3.437 6.10 42.02 53.54 -7.75 0.0 # a.r. puki-46 41 650 95.42 7318.0 0.0130 9.15 52.07 49.80 42.29 3.422 5.45 31.46 48.91 -4.66 0.0 # a.r. puki-47 42 700 93.60 7361.4 0.0127 9.15 50.72 49.81 45.01 3.33 4.33 15.62 20.96 -1.79 6.3 # pukox-41 puki-47 43 800 52.39 2283.8 0.0229 9.12 51.83 51.49 45.29 3.384 4.72 20.49 40.95 -0.66 6.5 # pukox-40 puki-49 44 899 17.23 738.6 0.0233 9.15 50.75 50.36 46.11 3.335 3.67 4.42 17.82 31.92 -0.84 7.5 # pukox-40 puki-51 45 1000 11.82 351.3 0.0237 9.15 50.	39	752	89.38	597.9	0.1495	9.15	52.24	46.11	35.88	3.433	7.97	71.03	80.23	-11.73	0.0	# a.r.	puki-45
41 650 95.42 7318.0 0.0130 9.15 52.07 49.80 42.29 3.422 5.45 31.46 48.91 -4.36 0.0 # a.r. puki-47 42 700 93.60 7361.4 0.0127 9.15 50.72 49.81 45.01 3.333 4.33 15.62 20.96 -1.79 6.3 # pukox-41 puki-48 43 800 52.39 2283.8 0.0229 9.12 51.83 51.49 45.29 3.384 4.72 20.49 40.95 -0.66 6.5 # pukox-41 puki-49 44 899 17.23 738.6 0.0233 9.15 50.75 50.36 46.11 3.335 4.69 20.29 30.43 -0.77 7.1 # pukox-37 puki-51 45 1000 11.96 51.3 0.0234 9.15 49.71 49.29 45.08 3.267 4.42 17.82 31.92 -0.84 7.5 # pukox-37 puki-51 46 1101 8.22 351.3 0.0237 9.15 50.46 <td< td=""><td>40</td><td>651</td><td>134.40</td><td>919.3</td><td>0.1462</td><td>9.13</td><td>52.53</td><td>48.46</td><td>40.06</td><td>3.437</td><td>6.10</td><td>42.02</td><td>53.54</td><td>-7.75</td><td>0.0</td><td># a.r.</td><td>puki-46</td></td<>	40	651	134.40	919.3	0.1462	9.13	52.53	48.46	40.06	3.437	6.10	42.02	53.54	-7.75	0.0	# a.r.	puki-46
42 700 93.60 7361.4 0.0127 9.15 50.72 49.81 45.01 3.333 4.33 15.62 20.96 -1.79 6.3 # pukox-41 puki-48 43 800 52.39 2283.8 0.0229 9.12 51.83 51.49 45.29 3.384 4.72 20.49 40.95 -0.66 6.5 # pukox-35 puki-49 44 899 17.23 738.6 0.0233 9.15 50.75 50.36 46.11 3.335 3.69 2.29 30.43 -0.77 7.1 # pukox-37 puki-51 45 1000 11.96 51.33 0.0234 9.15 49.71 49.29 45.08 3.267 4.42 17.82 31.92 -0.84 7.5 # pukox-34 puki-52 47 702 108.10 651.4 0.1660 9.14 52.14 49.03 42.65 3.419 6.11 40.03 46.48 -5.96 0.0 # a.r. puki-53 48 699 140.00 855.0 0.1582 9.15 50.46 <t< td=""><td>41</td><td>650</td><td>95.42</td><td>7318.0</td><td>0.0130</td><td>9.15</td><td>52.07</td><td>49.80</td><td>42.29</td><td>3.422</td><td>5.45</td><td>31.46</td><td>48.91</td><td>-4.36</td><td>0.0</td><td># a.r.</td><td>puki-47</td></t<>	41	650	95.42	7318.0	0.0130	9.15	52.07	49.80	42.29	3.422	5.45	31.46	48.91	-4.36	0.0	# a.r.	puki-47
43 800 52.39 2283.8 0.0229 9.12 51.83 51.49 45.29 3.384 4.72 20.49 40.95 -0.66 6.5 # pukox-35 puki-49 44 899 17.23 738.6 0.0233 9.16 50.86 50.79 45.33 3.350 3.73 6.23 11.75 -0.14 6.8 # pukox-35 puki-50 45 1000 11.96 513.3 0.0233 9.15 50.75 50.36 46.11 3.335 4.69 20.29 30.43 -0.77 7.1 # pukox-34 puki-51 46 1101 8.22 351.3 0.0234 9.15 49.71 49.29 45.08 3.267 4.42 17.82 31.92 -0.84 7.5 # pukox-34 puki-53 47 702 108.10 651.4 0.1660 9.14 52.14 49.03 42.65 3.419 6.11 40.48 -5.96 0.0 # a.r. puki-54 49 699 113.26 690.3 0.1641 9.15 50.53 50.44 <td< td=""><td>42</td><td>700</td><td>93.60</td><td>7361.4</td><td>0.0127</td><td>9.15</td><td>50.72</td><td>49.81</td><td>45.01</td><td>3.333</td><td>4.33</td><td>15.62</td><td>20.96</td><td>-1.79</td><td>6.3</td><td># pukox-41</td><td>puki-48</td></td<>	42	700	93.60	7361.4	0.0127	9.15	50.72	49.81	45.01	3.333	4.33	15.62	20.96	-1.79	6.3	# pukox-41	puki-48
44 899 17.23 738.6 0.0233 9.16 50.86 50.79 45.33 3.350 3.73 6.23 11.75 -0.14 6.8 # pukox-40 puki-50 45 1000 11.96 513.3 0.0233 9.15 50.75 50.36 46.11 3.335 4.69 20.29 30.43 -0.77 7.1 # pukox-37 puki-51 46 1101 8.22 351.3 0.0234 9.15 49.71 49.29 45.08 3.267 4.42 17.82 31.92 -0.84 7.5 # pukox-34 puki-52 47 702 108.10 651.4 0.1660 9.14 49.03 42.65 3.419 6.11 40.03 46.48 -5.96 0.0 # a.r. puki-53 48 699 113.26 690.3 0.1641 9.15 50.53 50.44 44.89 3.321 3.91 9.54 23.69 -0.18 22.3 # pukox-42 puki-55 50 698 78.42 3309.0 0.0237 9.15 50.45 46.35 <td< td=""><td>43</td><td>800</td><td>52.39</td><td>2283.8</td><td>0.0229</td><td>9.12</td><td>51.83</td><td>51.49</td><td>45.29</td><td>3.384</td><td>4.72</td><td>20.49</td><td>40.95</td><td>-0.66</td><td>6.5</td><td># pukox-35</td><td>puki-49</td></td<>	43	800	52.39	2283.8	0.0229	9.12	51.83	51.49	45.29	3.384	4.72	20.49	40.95	-0.66	6.5	# pukox-35	puki-49
45 1000 11.96 513.3 0.0233 9.15 50.75 50.36 46.11 3.335 4.69 20.29 30.43 -0.77 7.1 # pukox-37 puki-51 46 1101 8.22 351.3 0.0234 9.15 49.71 49.29 45.08 3.267 4.42 17.82 31.92 -0.84 7.5 # pukox-34 puki-52 47 702 108.10 651.4 0.1660 9.14 52.14 49.03 42.65 3.419 6.11 40.03 46.48 -5.96 0.0 # a.r. puki-53 48 699 140.00 885.0 0.1582 9.15 50.46 49.78 45.70 3.316 4.46 17.51 19.80 -1.35 6.9 # pukox-39 puki-55 49 699 113.26 690.3 0.1641 9.15 50.53 50.44 44.89 3.321 3.91 9.54 23.69 -0.18 22.3 # pukox-42 puki-55 50 698 78.42 3309.0 0.0237 9.15 50.45 <	44	899	17.23	738.6	0.0233	9.16	50.86	50.79	45.33	3.350	3.73	6.23	11.75	-0.14	6.8	# pukox-40	puki-50
46 1101 8.22 351.3 0.0234 9.15 49.71 49.29 45.08 3.267 4.42 17.82 31.92 -0.84 7.5 # pukox-34 puki-52 47 702 108.10 651.4 0.1660 9.14 52.14 49.03 42.65 3.419 6.11 40.03 46.48 -5.96 0.0 # a.r. puki-53 48 699 140.00 885.0 0.1582 9.15 50.46 49.78 45.70 3.316 4.46 17.51 19.80 -1.35 6.9 # pukox-39 puki-54 49 699 113.26 690.3 0.1641 9.15 50.53 50.44 44.89 3.321 3.91 9.54 23.69 -0.18 22.3 # pukox-42 puki-55 50 698 78.42 3309.0 0.0237 9.15 50.45 46.35 44.00 3.316 6.58 45.91 92.09 -8.13 0.0 # iodin pukjod-1 51 799 34.03 1906.0 0.0179 9.16 50.55 <td< td=""><td>45</td><td>1000</td><td>11.96</td><td>513.3</td><td>0.0233</td><td>9.15</td><td>50.75</td><td>50.36</td><td>46.11</td><td>3.335</td><td>4.69</td><td>20.29</td><td>30.43</td><td>-0.77</td><td>7.1</td><td># pukox-37</td><td>puki-51</td></td<>	45	1000	11.96	513.3	0.0233	9.15	50.75	50.36	46.11	3.335	4.69	20.29	30.43	-0.77	7.1	# pukox-37	puki-51
47 702 108.10 651.4 0.1660 9.14 52.14 49.03 42.65 3.419 6.11 40.03 46.48 -5.96 0.0 # a.r. puki-53 48 699 140.00 885.0 0.1582 9.15 50.46 49.78 45.70 3.316 4.46 17.51 19.80 -1.35 6.9 # pukox-39 puki-54 49 699 113.26 690.3 0.1641 9.15 50.53 50.44 44.89 3.321 3.91 9.54 23.69 -0.18 22.3 # pukox-42 puki-55 50 698 78.42 3309.0 0.0237 9.15 50.45 46.35 44.00 3.316 6.58 45.91 92.09 -8.13 0.0 # iodin pukjod-1 51 799 34.03 1906.0 0.0179 9.16 50.55 49.00 44.00 3.330 6.22 41.33 74.23 -3.07 0.0 # iodin pukjod-2 52 898 12.46 690.4 0.0180 9.16 50.50 5	46	1101	8.22	351.3	0.0234	9.15	49.71	49.29	45.08	3.267	4.42	17.82	31.92	-0.84	7.5	# pukox-34	puki-52
48 699 140.00 885.0 0.1582 9.15 50.46 49.78 45.70 3.316 4.46 17.51 19.80 -1.35 6.9 # pukox-39 puki-54 49 699 113.26 690.3 0.1641 9.15 50.53 50.44 44.89 3.321 3.91 9.54 23.69 -0.18 22.3 # pukox-42 puki-55 50 698 78.42 3309.0 0.0237 9.15 50.45 46.35 44.00 3.316 6.58 45.91 92.09 -8.13 0.0 # iodin pukjod-1 51 799 34.03 1906.0 0.0179 9.16 50.55 49.00 44.00 3.330 6.22 41.33 74.23 -3.07 0.0 # iodin pukjod-2 52 898 12.46 690.4 0.0180 9.16 50.50 50.20 46.00 3.326 4.74 21.10 47.28 -0.59 0.0 # iodin pukjod-3 53 1000 9.12 509.2 0.0179 9.15 50.30	47	702	108.10	651.4	0.1660	9.14	52.14	49.03	42.65	3.419	6.11	40.03	46.48	-5.96	0.0	# a.r.	puki-53
49 699 113.26 690.3 0.1641 9.15 50.53 50.44 44.89 3.321 3.91 9.54 23.69 -0.18 22.3 # pukox-42 puki-55 50 698 78.42 3309.0 0.0237 9.15 50.45 46.35 44.00 3.316 6.58 45.91 92.09 -8.13 0.0 # iodin pukjod-1 51 799 34.03 1906.0 0.0179 9.16 50.55 49.00 44.00 3.330 6.22 41.33 74.23 -3.07 0.0 # iodin pukjod-2 52 898 12.46 690.4 0.0180 9.16 50.50 50.20 46.00 3.326 4.74 21.10 47.28 -0.59 0.0 # iodin pukjod-3 53 1000 9.12 509.2 0.0179 9.15 50.30 49.90 46.50 3.306 4.95 24.02 46.18 -0.80 0.0 # iodin pukjod-4 54 649 95.31 7447.0 0.0128 9.15 50.20 46	48	699	140.00	885.0	0.1582	9.15	50.46	49.78	45.70	3.316	4.46	17.51	19.80	-1.35	6.9	# pukox-39	puki-54
50 698 78.42 3309.0 0.0237 9.15 50.45 46.35 44.00 3.316 6.58 45.91 92.09 -8.13 0.0 # iodin pukjod-1 51 799 34.03 1906.0 0.0179 9.16 50.55 49.00 44.00 3.330 6.22 41.33 74.23 -3.07 0.0 # iodin pukjod-2 52 898 12.46 690.4 0.0180 9.16 50.50 50.20 46.00 3.326 4.74 21.10 47.28 -0.59 0.0 # iodin pukjod-3 53 1000 9.12 509.2 0.0179 9.15 50.30 49.90 46.50 3.306 4.95 24.02 46.18 -0.80 0.0 # iodin pukjod-4 54 649 95.31 7447.0 0.0128 9.15 50.20 46.70 41.44 3.299 6.83 51.56 62.70 -6.97 0.0 # iodin pukjod-5	49	699	113.26	690.3	0.1641	9.15	50.53	50.44	44.89	3.321	3.91	9.54	23.69	-0.18	22.3	# pukox-42	puki-55
51 799 34.03 1906.0 0.0179 9.16 50.55 49.00 44.00 3.330 6.22 41.33 74.23 -3.07 0.0 # iodin pukjod 1 52 898 12.46 690.4 0.0180 9.16 50.50 50.20 46.00 3.326 4.74 21.10 47.28 -0.59 0.0 # iodin pukjod -3 53 1000 9.12 509.2 0.0179 9.15 50.30 49.90 46.50 3.306 4.95 24.02 46.18 -0.80 0.0 # iodin pukjod -3 54 649 95.31 7447.0 0.0128 9.15 50.20 46.70 41.44 3.299 6.83 51.56 62.70 -6.97 0.0 # iodin pukjod -5	50	698	78.42	3309.0	0.0237	9.15	50.45	46.35	44.00	3.316	6.58	45.91	92.09	-8.13	0.0	# iodin	pukiod-1
52 898 12.46 690.4 0.0180 9.16 50.50 50.20 46.00 3.326 4.74 21.10 47.28 -0.59 0.0 # iodin pukjod 2 53 1000 9.12 509.2 0.0179 9.15 50.30 49.90 46.50 3.306 4.95 24.02 46.18 -0.80 0.0 # iodin pukjod 2 54 649 95.31 7447.0 0.0128 9.15 50.20 46.70 41.44 3.299 6.83 51.56 62.70 -6.97 0.0 # iodin pukjod 2	51	799	34.03	1906.0	0.0179	9.16	50.55	49.00	44.00	3.330	6.22	41.33	74.23	-3.07	0.0	# jodin	pukiod-2
53 1000 9.12 509.2 0.0179 9.15 50.30 49.90 46.50 3.306 4.95 24.02 46.18 -0.80 0.0 # iodin pukjod-4 54 649 95.31 7447.0 0.0128 9.15 50.20 46.70 41.44 3.299 6.83 51 56 62.70 -6.97 0.0 # iodin pukjod-5	52	898	12.46	690.4	0.0180	9.16	50.50	50.20	46.00	3.326	4.74	21.10	47.28	-0.59	0.0	# jodin	pukiod-3
54 649 95.31 7447.0 0.0128 9.15 50.20 46.70 41.44 3.299 6.83 51.56 62.70 -6.97 0.0 # jodin publied=5	53	1000	9.12	509.2	0.0179	9.15	50.30	49.90	46.50	3.306	4.95	24.02	46.18	-0.80	0.0	# iodin	pukiod-4
	54	649	95.31	7447.0	0.0128	9.15	50.20	46.70	41.44	3.299	6.83	51.56	62.70	-6.97	0.0	# iodin	pukiod-5

File: 'balloon\puki\exp\pukizrnb.prn'

Appendix 3:

Data of single rod ballooning tests PUZRY

File

puzry-01

puzry-02

puzry-04

puzry-05

puzry-06

puzry-07

puzry-08

puzry-09

puzry-03

epsa

-1.70

-1.62

-1.60

-1.30

-1.16

-1.80

-1.60

-1.46 #

-1.56 #

#

#

#

#

#

#

[%]

Isothermal ballooning tests with Zircaloy-4 tube specimens (1995) Т - temperature [C] - burst pressure [bar] р time - time to burst [s] - pressure rate [bar/s] dp/dt D0 - initial diameter [mm] LО - initial length [mm] L1 - lenght after test [mm] Ld - deformed length [mm] V0 - initial tube volume [ml] V1 - tube volume after test [ml] epstav - average tangential deformation [%] epstm - maximum tangential deformation [%] - axial deformation [%] epsa References: Frecska J., Konczos G., Matus L., Vasaros L.: Kiserletek a VVER [1] futoelemek meghatarozo parametereinek meresere; OMFB 94-97-47-0817/2.4, 1995. [2] Frecska J., Matus L., Pummer I.: Futoelemviselkedes VVER reaktortipusnal; OMFB 94-97-47-0817/2.5, 1996. Maroti L., Matus L.: Futoelemviselkedes VVER reaktortipusnal; [3] Zarojelentes OMFB 94-97-47-0817, 1996. Cs. Gyori, Z. Hozer, L. Maroti, L. Matus: VVER ballooning experiments; [4] EHPG Meeting Lillehammer, March 1998; HPR-349/40. (File: ehpg-98.pdf) dp/dt No. D0 LO L1 Ld V0 # Т р time [C] [bar] [s] [bar/s] [mm] [mm] [mm] [mm] [ml] [ml] 1201.3 3.41 531.9 0.0064 10.73 50.00 49.15 43.61 4.519 8.21 1 50.00 1154.4 566.0 0.0065 10.75 4.536 2 3.70 49.19 43.73 8.39 1102.1 3.83 607.8 0.0063 10.75 50.00 49.20 44.07 4.536 8.89 3 1053.2 4.38 705.3 0.0062 10.76 50.00 49.35 4.544 4 44.85 8.67 5 997.9 5.02 810.7 0.0062 10.76 50.00 49.42 46.26 4.544 7.78 6 950.5 8.73 1805.4 0.0048 10.75 50.00 49.10 44.77 4.536 9.05 952.9 15.80 208.2 0.0759 10.75 50.00 44.22 4.536 7 49.20 8.60 8 1001.0 8.90 116.7 0.0763 10.75 50.00 49.27 44.58 4.536 9.52 9 1051.6 7.45 104.7 0.0712 10.75 50.00 49.22 44.21 4.536 9.23

V1

epstav

[%]

39.128

40.377

44.531

41.858

33.062

45.271

41.912

49.452

47.344

epstm

[%]

60.01

60.48

66.88

64.51

52.15

87.06

86.48

80.37

73.86

MTA	KFKI AEKI														Dat	tabase Report
10	1102.6 6.53	92.0	0.0710	10.76	50.00	49.06	43.81	4.544	9.15	46.865	72.76	-1.88	#	puzry-10		
11	1149.8 6.03	84.1	0.0717	10.75	50.00	49.20	43.85	4.536	8.61	42.276	61.30	-1.60	#	puzry-11		
12	1197.7 5.78	80.0	0.0723	10.75	50.00	49.00	43.35	4.536	8.98	45.942	71.62	-2.00	#	puzry-12		
13	698.8 88.83	2828.0	0.0314	10.76	50.00	46.06	45.43	4.544	8.61	40.854	81.48	-7.88	#	puzry-13		
14	702.2 106.16	892.4	0.1190	10.75	50.00	44.25	42.60	4.536	10.13	56.447	83.62	-11.50	#	puzry-14		
15	802.1 63.18	538.4	0.1173	10.76	50.00	44.21	41.20	4.544	10.45	60.536	109.53	-11.58	#	puzry-15		
16	750.3 83.06	678.5	0.1224	10.75	50.00	45.95	43.20	4.536	8.69	43.527	82.59	-8.10	#	puzry-16		
17	850.1 39.79	342.3	0.1162	10.76	50.00	48.20	45.90	4.544	9.35	46.697	92.61	-3.60	#	puzry-17		
18	900.2 26.89	233.7	0.1151	10.76	50.00	49.46	47.20	4.544	8.63	39.729	74.29	-1.08	#	puzry-18		
19	900.6 19.51	801.3	0.0243	10.76	50.00	49.37	47.10	4.544	9.90	50.037	91.79	-1.26	#	puzry-19		
20	849.7 27.22	1211.1	0.0225	10.75	50.00	49.54	46.90	4.536	10.20	52.686	99.42	-0.92	#	puzry-20		
21	800.8 45.30	2693.3	0.0168	10.76	50.00	46.18	44.70	4.544	9.27	47.079	88.55	-7.64	#	puzry-21		
22	749.9 60.80	4105.1	0.0148	10.76	50.00	45.33	43.10	4.544	9.72	52.358	99.90	-9.34	#	puzry-22		
23	748.6 72.58	1011.8	0.0717	10.75	50.00	44.44	42.40	4.536	10.14	56.748	103.87	-11.12	#	puzry-23		
24	698.8 80.75	4522.2	0.0179	10.75	50.00	44.35	41.70	4.536	10.31	58.946	107.71	-11.30	#	puzry-24		
25	698.3 79.78	4623.5	0.0173	10.76	50.00	45.67	43.10	4.544	9.39	49.567	84.84	-8.66	#	puzry-25		
26	698.4 106.05	888.8	0.1193	10.76	50.00	42.59	41.20	4.544	11.40	68.252	100.97	-14.82	#	puzry-26		
27	801.4 48.18	1946.0	0.0248	10.74	50.00	45.47	42.50	4.527	9.77	53.698	94.15	-9.06	#	puzry-27		
28	800.0 52.94	1244.7	0.0425	10.76	50.00	45.31	42.80	4.544	9.79	53.249	92.20	-9.38	#	puzry-28		
29	799.9 57.95	804.5	0.0720	10.76	50.00	44.21	41.80	4.544	10.58	60.896	107.86	-11.58	#	puzry-29		
30	800.4 72.51	275.7	0.2630	10.76	50.00	45.03	42.60	4.544	11.11	64.189	104.28	-9.94	#	puzry-30		
31	800.4 67.88	346.2	0.1961	10.75	50.00	44.40	42.40	4.536	10.18	57.079	90.39	-11.20	#	puzry-31		

File: 'balloon\puzry\exp\pukizry.prn'

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Appendix 4: Data of single rod ballooning tests BALL # Ballooning tests at temperature increase with pre-pressurized Zr1%Nb tube specimens (2000) dT/dt - temperature increase rate [K/s] # - initial pressure [bar] (nominal at cold state) p0 # т1 - temperature at burst [C] - pressure at burst [bar] (over pressure) p1 # D0 - initial diameter (nominal) [mm] # v0 - initial wall thickness (nominal) [mm] # LО # - initial length [mm] - cross section area of the cut (at elevation of the maximum deformation) [mm^2] # Α1 С1 - circumference of the cut (at the elevation of the maximum deformation) [mm^2] D1 - maximum diameter assuming idealised deformation [mm]: D1=(C1/4+SQRT((C1/4)**2-A1))/3.14159 - maximum tangential deformation [%] # epsm Atmo - atmosphere of the test References: No. of dT/dt D0 v0 LO A1 С1 # р0 Τ1 p1 D1 epsm Atmo # sample [K/s] [bar] [C] [bar] [mm] [mm] [mm] [mm^2] [mm] [mm] [8] # 1 6.4 10. 640. 15.90 9.15 0.70 150.0 33.2 108.3 17.04 86.2 # steam 2 8.2 10. 900. 14.00 9.15 0.70 150.0 25.6 96.7 15.22 66.3 # steam 3 8.9 40. 845. 60.80 9.15 0.70 150.0 25.8 72.7 11.34 23.9 # Ar 4 8.5 40. 863. 48.70 9.15 0.70 27.5 11.47 25.4 # 150.0 73.6 Ar 32.00 5 6.7 20. 876. 9.15 0.70 150.0 29.1 74.5 11.60 26.8 # Ar 32.90 6 11.4 20. 898. 9.15 0.70 150.0 20.2 71.6 11.21 22.5 # Ar 7 12.8 20. 889. 30.10 9.15 0.70 27.1 73.1 11.39 150.0 24.5 # steam 8 6.5 10. 840. 17.70 9.15 0.70 150.0 25.3 86.9 13.64 49.1 # Ar 9 13.0 10. 942. 14.10 9.15 0.70 150.0 28.6 92.5 14.52 58.7 # Ar 10 9.9 10. 921. 15.40 9.15 0.70 150.0 21.3 112.5 17.78 94.4 # Ar 12.3 12.62 11 40. 830. 68.10 9.15 0.70 150.0 27.3 80.7 37.8 # steam 12 13.5 40. 868. 56.10 9.15 0.70 150.0 19.7 66.1 10.33 12.9 # Ar

File: 'balloon\ball\exp1\ball-e1.prn'

ΜΤΑ ΚΓΚΙ ΑΕΚΙ

# # #	Isothermal	balloon	ing test	s at line	ear pre	ssure i	ncrease 1	with Zr18	Nb tube	specimer	is (2000))	
* # # # # # # # # # # #	dp/dt T p1 D0 v0 L0 A1 C1 D1 epsm Atmo	- pre - tem - pre - ini - ini - cro - cir - max - max - atm	ssure in perature ssure at tial dian tial wal tial lend ss section cumferend imum dian imum tand osphere o	Crease ra [C] (not burst [] meter (not l thickno gth [mm] on area of ce of the meter as gential of of the to	ate [K/ minal) bar] (or ominal) ess (nor of the e cut (a suming a deforma- est	s] [mm] minal) cut (at at the idealise tion [%	ssure) [mm] elevatio elevation ed deforn]	on of the h of the m nation [mi	maximu: maximum m]: D1=	m deforma deformat (C1/4+SQF	tion) [r ion) [m T((C1/4)	nm^2 n^2]) **2	2] 2-A1))/3.14159
# # # #	Reference	es:											
#	No. of	dp/dt	Т	p1	DO	v0	LO	A1	C1	D1	epsm		Atmo
#	sample	[bar/s]	[C]	[bar]	[mm]	[mm]	[mm]	[mm^2]	[mm]	[mm]	[%]		
#	13	0.6	800.	83.30	9.15	0.70	150.0	27.8	92.2	14.48	58.2	#	Ar
	14	2.7	800.	72.40	9.15	0.70	150.0	18.2	68.8	10.78	17.8	#	Ar
	15	2.8	800.	36.60	9.15	0.70	150.0	21.9	86.6	13.62	48.9	#	Ar
	16	6.3	800.	95.20	9.15	0.70	150.0	25.4	79.2	12.40	35.5	#	Ar
	17	0.6	900.	16.60	9.15	0.70	150.0	25.1	78.3	12.25	33.9	#	Ar
	18	2.7	900.	20.30	9.15	0.70	150.0	19.3	67.4	10.54	15.2	#	Ar
	19	4.5	900.	20.90	9.15	0.70	150.0	20.4	73.5	11.52	25.9	#	Ar
	20	6.5	1000.	18.30	9.15	0.70	150.0	23.7	96.6	15.22	66.3	#	Ar
	21	0.6	1000.	14.50	9.15	0.70	150.0	18.4	85.0	13.39	46.3	#	Ar
	22	2.9	1000.	16.50	9.15	0.70	150.0	18.3	82.1	12.92	41.2	#	Ar
	23	0.6	1100.	14.20	9.15	0.70	150.0	18.5	81.9	12.89	40.9	#	Ar
	25	6.6	1200.	11.60	9.15	0.70	150.0	18.1	82.9	13.05	42.7	#	Ar

File: 'balloon\ball\exp2\ball-e2.prn'

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Database Report

Appendix 5:

Data of tensile tests

 $\#\,$ AEKI tensile tests summary file: Zr1Nb (alloy E110) sheet specimens $\#\,$

#			
#	b	[mm]	width of sheet specimen
#	а	[mm]	thickness of sheet specimen
#	So	[mm2]	original cross-sectional area
#	Su	[mm2]	cross-sectional area at rupture
#	Fmax	[N]	maximum load
#	Fe	[N]	load at yield
#	Fu	[N]	load at rupture
#	Re	[MPa]	yield strength (Fe/So)
#	Rm	[MPa]	tensile strength (Fmax/So)
#	Ru	[Mpa]	true stress at burst (Fu/Su)
#	Lo	[mm]	initial gauge length
#	Lu	[mm]	gauge length after rupture
#	A20, A25	[%]	strain at rupture (100*(Lu-Lo)/Lo)
#	Z	[%]	contraction (100*(So-Su)/So)
#	ECR	[%]	equivalent oxidation on the basis of the measured mass gain
#	Т	[C]	temperature of tensile test

Sketch of the specimen



References:

#

#

#	[1]	Maroti	L.:	Sulyos	baleseti	folyamatok	laboratoriumi	vizsgalata;
#				OMFB 3	356/91092	7, Budapest	1991.	
#								

Test series in 1989 [1]

# 1	No.	Т	ECR	a	b	So	Su	Fmax	Rm	Fe	Re	Fu	Ru	Lo	Lu	A20	Z	Label
#		[C]	[%]	[mm]	[mm]	[mm2]	[mm2]	[N]	[MPa]	[N]	[MPa]	[N]	[MPa]	[mm]	[mm]	[%]	[%]	
#																		
	1	20	0.0	0.6	2.95	1.77	0.69	735	415.0	440	249.0	-	-	24.66	31.1	26.0	61.0 #	No. 1
1	2	20	0.0	0.6	3.00	1.80	0.77	750	417.0	470	261.0	-	-	24.65	30.3	23.0	57.2 #	No. 2
	3	20	0.0	0.6	3.00	1.80	0.92	729	405.0	344	191.0	-	-	20.0	24.4	22.0	49.0 #	No. 3
	4	20	0.0	0.6	3.00	1.80	0.94	733	407.0	432	240.0	-	-	20.0	25.4	27.0	48.0 #	No. 4

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5	20	0.0	0.6	3.00	1.80	0.97	783	435.0	409	227.0	-	-	20.0	24.6	23.0	46.0	#	No. 5	
6	20	0.0	0.6	3.00	1.80	0.83	761	423.0	419	233.0	-	-	20.0	24.8	24.0	54.0	#	No. 6	
7	20	17.0	0.6	3.00	1.80	1.48	704	391.0	441	245.0	-	-	20.0	21.6	8.1	17.6	#	No. 7	
8	20	19.0	0.6	3.00	1.80	1.19	684	380.0	400	222.0	-	-	20.0	21.6	8.2	34.0	#	No. 8	
9	20	35.0	0.6	3.00	1.80	1.10	529	294.0	387	215.0	-	-	20.0	21.1	5.5	39.0	#	No. 9	
10	19	0.0	0.6	3.06	1.84	0.60	645	351.3	520	283.2	817	816.7	-	_	-	68.0	#	No.10	
11	19	0.0	0.6	3.08	1.85	0.77	615	332.8	490	265.2	490	265.2	19.77	23.70	20.0	58.0	#	No.11	
12	310	0.0	0.6	3.07	1.84	0.44	370	200.9	320	173.7	320	173.7	19.33	24.33	26.0	76.0	#	No.12	
1.4	300	0.0	0.6	3.06	1.84	0.39	3/3	204.2	210	112 2	330	112 2	19.25	23.81	24.0	/9.0	Т Д	NO.13	
14	400	0.0	0.0	2.12	1 01	0.35	200	137.0	210	112.2	210	10.0	19.40	24.40	20.0	02.0	#	NO.14 No.15	
16	600	0.0	0.0	3.01	1 80	0.02	75	JJ.4 41 7	90 60	49.0	90 60	49.0	19.50	36.23	85 0	99.0	#	NO.15	
17	450	0.0	0.0	2.96	1 78	0.00	270	152 0	250	140 8	250	140 8	19.63	26 38	34 0	88 0	π #	No.17	
18	2.0	0.8	0.6	3.00	1.80	-	_	347.0	-	264.0	_	-	-	-	28.6	56.5	#	No.20	
19	2.0	0.7	0.6	3.00	1.80	-	_	346.0	_	295.0	_	_	_	_	19.0	59.4	#	No.21	
20	20	0.7	0.6	3.00	1.80	-	-	328.0	-	243.0	-	-	-	-	24.7	60.0	#	No.22	
21	20	1.4	0.6	3.00	1.80	-	-	363.0	-	247.0	-	-	-	-	21.6	61.1	#	No.23	
22	20	1.7	0.6	3.00	1.80	-	-	344.0	-	239.0	-	-	-	-	14.6	57.6	#	No.24	
23	20	2.1	0.6	3.00	1.80	-	-	452.0	-	292.0	-	-	-	-	13.8	41.6	#	No.25	
24	20	1.3	0.6	3.00	1.80	-	-	383.0	-	262.0	-	-	-	-	20.6	53.8	#	No.26	
25	20	1.6	0.6	3.00	1.80	-	-	374.0	-	302.0	-	-	-	-	20.2	47.8	#	No.28	
26	20	2.1	0.6	3.00	1.80	-	-	376.0	-	254.0	-	-	-	-	19.3	46.9	#	No.29	
27	20	3.9	0.6	3.00	1.80	-	-	384.0	-	332.0	-	-	-	-	11.0	33.1	#	No.30	
28	20	0.9	0.6	3.00	1.80	-	-	368.0	-	286.0	-	-	-	-	22.9	57.1	#	No.31	
29	20	1.0	0.6	3.00	1.80	-	-	348.0	-	259.0	-	-	-	-	17.4	53.8	#	No.32	
30	20	0.9	0.6	3.00	1.80	-	-	369.0	-	-	-	-	-	-	31.2	63.3	#	No.41	
31	20	1.4	0.6	3.00	1.80	-	-	369.0	-	336.0	-	-	-	-	23.3	54.4	#	No.42	
32	20	2.1	0.6	3.00	1.80	-	-	435.0	-	391.0	-	-	-	-	22.0	50.6	#	NO.43	
33 #	20	2.4	0.6	3.00	1.80	-	-	394.0	-	346.0	-	-	-	-	1/.1	41.8	#	NO.44	
# # Tost	eorioe	in 2000																	
#	001100	111 2000																	
# No.	Т	ECR	a	b	So	Su	Fmax	Rm	Fe	Re	Fu	Ru	Lo	Lu	A25	Z		Label	
#	[C]	[%]	[mm]	[mm]	[mm2]	[mm2]	[N]	[MPa]	[N]	[MPa]	[N]	[MPa]	[mm]	[mm]	[%]	[%]			
#																			
34	20	0.0	0.67	4.82	3.23	0.78	1203	372.5	834	258.3	944	1210.4	25.0	32.4	29.0	75.8	# I	R-ZN-S-HK-1	
35	20	0.0	0.67	4.86	3.26	0.80	1286	394.9	888	272.7	1017	1271.5	25.0	32.8	31.0	75.5	# E	R-ZN-S-HK-2	2
36	20	0.0	0.70	4.90	3.43	1.61	1468	428.0	1080	314.9	1103	685.3	25.0	33.5	34.0	53.1	# t	U-ZN-S-HK-1	
37	20	0.0	0.69	4.88	3.37	1.56	1392	413.4	1011	300.2	1068	684.5	25.0	32.3	29.0	53.7	# (U-ZN-S-HK-2	
38	150	0.0	0.69	4.81	3.32	-	1075	323.9	869	261.8	//8	-	25.0	32.7	30.0	-	# ±	R-ZN-S-HK-1	
39	150	0.0	0.68	4.95	3.3/	-	1001	312.2	845	251.U	/4/	-	25.0	34.8	39.0	-	# E	K-ZN-S-HK-2	
40	150 150	0.0	0.71	4.92	3.49	_	1145	349.5	9/5	219.1	890	_	25.U 25.0	32.8 22.7	31.0	_	# (# T	U-ZN-S-HK-1	>
41 42	300	0.0	0.70	4.03	3.30	-	1140 787	220./ 220 5	910	209.2 101 5	0/0 550	_	25.0	32.1 31 7	26.0	_	# (# T	0-4N-5-RK-2 0-7N-9-UV-1	
42	300	0.0	0.70	4.00 5 A3	3.42	_	227	229.0 23/ /	6004	187 0	500	_	23.U 25 0	32 6	20.0	_	1 H 4 T	R-ZN-S-HK-1	>
44	300	0.0	0.71	4 85	3 44	-	888	257 9	732	212 6	604	_	25.0	32.0	29 0	_	π 1 # 1	U-ZN-S-HK-1	
45	300	0.0	0.72	4.95	3.56	-	890	249.7	725	203.4	-	_	25.0	32.5	30.0	_	# t	U-ZN-S-HK-2	2
-									-										

File: 'tensile\zr1nb\sheetzrn.prn'

MTA KFKI AEKI

b		[mm]	width	of sheet	: specime	en .								
a		[mm]	thickn	thickness of sheet specimen										
So		[mm2]	origin	original cross-sectional area										
Su		[mm2]	cross-	cross-sectional area at rupture										
Fm	ax	[N]	maximu	m load										
Ŀе			load a	t yiela										
E'U		[N]	load a	t ruptui	re (
Re		[MPa]	yıela	strengtr	1 (Fe/So)									
Rm		[MPa]	tensii	tensile strength (Fmax/So)										
Ru T -		[Mpa]	true s	true stress at burst (Fu/Su)										
Т.,		[IIIII]	INILIA	initial gauge length										
LU A 2	5	[11111] [&]	gauge	at runt	urcer rup)*(Tu=To)	$(T \circ)$							
7	5	[%]	contra	ction /1	LUU* (SO-9	, (TT TO)	101							
4 FC	P	[%]	omitra	lont ovi	idation ($n + h - h^{3}$	eie of t	he measur	rod mas	s gain				
т Т	11	[0]	tompor	aturo of	F toneila	toet	.5 L 0 UL 1	Line medsu	ircu mas	5 yarn				
 	/	0 /			0	_\	 	 b _ a						
		 <		Lo 	> A									
Test . No.	series T [C]	in 2000 ECR [%]	a [mm]	Lo b [mm]	 > A So [mm2]	Su [mm2]	Fmax	Rm [MPa]	Fe [N]	Re [MPa]	Fu [N]	Ru [MPa]	L	
Test . No.	series T [C]	in 2000 ECR [%]	a [mm]	b [mm]	 > A So [mm2]	Su [mm2]	Fmax [N]	Rm [MPa]	Fe [N]	Re [MPa]	Fu [N]	Ru [MPa]	L [m	
Test No. 1	series T [C] 20	in 2000 ECR [%] 0.0	a [mm] 0.71	b [mm] 5.09	 > A So [mm2] 3.61	Su [mm2] 1.03	Fmax [N] 2009	Rm [MPa] 555.9	Fe [N] 1517	Re [MPa] 419.8	Fu [N] 1646	Ru [MPa] 1597.8	L [m: 25	
Test No.	series T [C] 20 20	in 2000 ECR [%] 0.0 0.0	a [mm] 0.71 0.70	b [mm] 5.09 4.85	So [mm2] 3.61 3.40	Su [mm2] 1.03 1.14	Fmax [N] 2009 1910	Rm [MPa] 555.9 562.7	Fe [N] 1517 1441	Re [MPa] 419.8 424.4	Fu [N] 1646 1532	Ru [MPa] 1597.8 1343.8	Lo [mr 25	
Test No. 1 2 3	series T [C] 20 20 150	in 2000 ECR [%] 0.0 0.0 0.0	a [mm] 0.71 0.70 0.71	b [mm] 5.09 4.85 4.96	So [mm2] 3.61 3.40 3.52	Su [mm2] 1.03 1.14	Fmax [N] 2009 1910 1556	Rm [MPa] 555.9 562.7 441.8	Fe [N] 1517 1441 1169	Re [MPa] 419.8 424.4 332.0	Fu [N] 1646 1532 1224	Ru [MPa] 1597.8 1343.8 -	Lo [mr 25 25	
Test . No. 1 2 3 4	series T [C] 20 20 150 150	in 2000 ECR [%] 0.0 0.0 0.0 0.0	a [mm] 0.71 0.70 0.71 0.68	b [mm] 5.09 4.85 4.96 4.91	So [mm2] 3.61 3.40 3.52 3.34	Su [mm2] 1.03 1.14 -	Fmax [N] 2009 1910 1556 1513	Rm [MPa] 555.9 562.7 441.8 453.2	Fe [N] 1517 1441 1169 1139	Re [MPa] 419.8 424.4 332.0 341.1	Fu [N] 1646 1532 1224 1408	Ru [MPa] 1597.8 1343.8 –	L, [mi 25 25 25 25	
Test . No. 1 2 3 4 5	series T [C] 20 20 150 150 300	in 2000 ECR [%] 0.0 0.0 0.0 0.0 0.0	a [mm] 0.71 0.70 0.71 0.68 0.74	b [mm] 5.09 4.85 4.96 4.91 5.10	So [mm2] 3.61 3.40 3.52 3.34 3.77	Su [mm2] 1.03 1.14 - -	Fmax [N] 2009 1910 1556 1513 1175	Rm [MPa] 5555.9 562.7 441.8 453.2 311.3	Fe [N] 1517 1441 1169 1139 940	Re [MPa] 419.8 424.4 332.0 341.1 249.1	Fu [N] 1646 1532 1224 1408	Ru [MPa] 1597.8 1343.8 - - -	L [m 25 25 25 25	

'tensile\zry-4\sheetzry.prn' File:

Lu

[mm]

A25

[%]

Z

[%] 31.2 24.0 71.5 # ZRY-S-HK-1 31.2 24.0 66.5 # ZRY-S-HK-2

 31.8
 27.0
 #
 ZRY-S-HK-1

 31.4
 25.0
 #
 ZRY-S-HK-2

 32.7
 30.0
 #
 ZRY-S-HK-1

 32.5
 30.0
 #
 ZRY-S-HK-2

Label

MTA KFKI AEKI

Do)	[mm]	outer d	iameter												
v		[mm]	wall thickness													
So)	[mm2]	origina	l cross-	section	al area										
Fm.	iax	[N]	maximum load													
Fe	2	[N]	load at	vield												
Rm	1	[MPa]	tensile	strengt	h											
Re	,	[MPa]	vield s	trength												
Lo [mm]		[mm]	initial gauge length (25 mm)													
Lu	1	[mm]	gaque length after rupture													
A2	25	[%]	strain at rupture													
Ox	id	[um]	oxid la	ver thic	kness ca	alculated	d from E	CR								
EC	CR	[%]	equival	ent oxid	lation of	n the bas	sis of tl	ne measur	ed mass	qain						
Т		[C]	tempera	ture of	tensile	test				5						
[2]	Grigen mechar hydroc (File:	r, Maroti nical pro gen conte : ehpg-99	, Matus, perties nt; EHPG .pdf)	Windber of ZrNb1 Meeting	rg: Ambie claddin May 199	ent and l ng with o 99, Loen	high tem differen ; HPR-35	berature c oxygen L/35.								
[2] Test	Griger mechar hydrog (File: series	r, Maroti nical pro gen conte : ehpg-99 s in 1998	, Matus, perties nt; EHPG .pdf) [1,2]	Windber of ZrNb1 Meeting	rg: Ambie claddin May 199	ent and l ng with (99, Loen)	high tem differen ; HPR-35	oerature oxygen L/35.	_	-	_	_	205			
[2] Test No.	Griger mechar hydrog (File: series T [C]	r, Maroti hical pro gen conte : ehpg-99 s in 1998 Oxid [um]	<pre>, Matus, perties nt; EHPG .pdf) [1,2] ECR [%]</pre>	Windber of ZrNb1 Meeting Do [mm]	rg: Ambie claddin May 199 v [mm]	ent and l ng with o 99, Loen So [mm2]	high temj differen ; HPR-35 ; Fmax [N]	eerature coxygen L/35. Rm [MPa]	Fe [N]	Re [MPa]	Lo [mm]	Lu [mm]	A25 [%]		Lab	
[2] Test No. 1	Griger mechar hydrog (File: series T [C] 20	r, Maroti hical pro gen conte : ehpg-99 s in 1998 Oxid [um] 0.0	<pre>, Matus, perties nt; EHPG .pdf) [1,2] ECR [%] 0.0</pre>	Windber of ZrNb1 Meeting Do [mm] 9.13	rg: Ambie claddin May 199 v [mm] 0.70	ent and l ng with o 99, Loen So [mm2] 18.54	high tem differen ; HPR-35 Fmax [N] 6700	Rm [MPa] 361.0	Fe [N] -	Re [MPa] -	Lo [mm] 25	Lu [mm] 38.3	A25 [%] 53.1	#	Lab No.	
[2] Test No. 1 2	Griger mechar hydrog (File: series T [C] 20 20	r, Maroti hical pro gen conte : ehpg-99 s in 1998 Oxid [um] 0.0 0.0	<pre>, Matus, perties nt; EHPG .pdf) [1,2] ECR [%] 0.0 0.0</pre>	Windber of ZrNb1 Meeting Do [mm] 9.13 9.14	rg: Ambie claddin May 199 v [mm] 0.70 0.69	ent and 1 ng with 0 99, Loen, [mm2] 18.54 18.32	high tem differen ; HPR-35 Fmax [N] 6700 6810	erature c oxygen L/35. Rm [MPa] 361.0 372.0	Fe [N] - -	Re [MPa] -	Lo [mm] 25 25	Lu [mm] 38.3 38.4	A25 [%] 53.1 53.4	#	Lab No. No.	
[2] Test No. 1 2 3	Griger mechar hydroo (File: series T [C] 20 20 20	r, Maroti hical pro gen conte : ehpg-99 s in 1998 Oxid [um] 0.0 0.0 9.5	<pre>, Matus, perties nt; EHPG .pdf) [1,2] ECR [%] 0.0 0.0 1.0</pre>	Windber of ZrNb1 Meeting Do [mm] 9.13 9.14 9.15	rg: Ambie claddin May 199 [mm] 0.70 0.69 0.74	ent and 1 ng with (99, Loen) So [mm2] 18.54 18.32 19.55	high tem differen ; HPR-35: Fmax [N] 6700 6810 9020	Rm [MPa] 361.0 372.0 461.0	Fe [N] - -	Re [MPa] - - -	Lo [mm] 25 25 25	Lu [mm] 38.3 38.4 32.3	A25 [%] 53.1 53.4 29.1	# #	Lab No. No.	
[2] Test No. 1 2 3 4	Grigen mechar hydroc (File: t series T [C] 20 20 20 20	r, Maroti hical pro gen conte : ehpg-99 0xid [um] 0.0 0.0 9.5 11.0	<pre>, Matus, perties nt; EHPG .pdf) [1,2] ECR [%] 0.0 0.0 1.0 1.1</pre>	Windber of ZrNb1 Meeting Do [mm] 9.13 9.14 9.15 9.17	rg: Ambie claddin May 199 [mm] 0.70 0.69 0.74 0.75	ent and l ng with (99, Loen) So [mm2] 18.54 18.32 19.55 19.84	high tem differen ; HPR-35 Fmax [N] 6700 6810 9020 9190	Rm [MPa] 361.0 372.0 461.0 463.0	Fe [N] - -	Re [MPa] - - - -	Lo [mm] 25 25 25 25 25	Lu [mm] 38.3 38.4 32.3 31.3	A25 [%] 53.1 53.4 29.1 25.2	# # #	Lab No. No. No.	
[2] Test No. 1 2 3 4 5	Grigen mechar hydroc (File: series T [C] 20 20 20 20 20	r, Maroti hical pro gen conte : ehpg-99 s in 1998 Oxid [um] 0.0 0.0 9.5 11.0 21.0	<pre>, Matus, perties nt; EHPG .pdf) [1,2] ECR [%] 0.0 0.0 1.0 1.1 2.1</pre>	Windber of ZrNb1 Meeting Do [mm] 9.13 9.14 9.15 9.17 9.17	v [mm] 0.70 0.75 0.74	ent and l ng with (99, Loen) So [mm2] 18.54 18.32 19.55 19.84 19.60	high tem differen ; HPR-35 Fmax [N] 6700 6810 9020 9190 9940	Rm [MPa] 361.0 372.0 461.0 463.0 507.0	Fe [N] - - -	Re [MPa] - - - -	Lo [mm] 25 25 25 25 25 25 25	Lu [mm] 38.3 38.4 32.3 31.3 28.8	A25 [%] 53.1 53.4 29.1 25.2 15.0	# # # #	Lab No. No. No. No.	
[2] Test No. 1 2 3 4 5 6	Grigen mechan hydroc (File: series T [C] 20 20 20 20 20 20 20	r, Maroti hical pro gen conte : ehpg-99 s in 1998 Oxid [um] 0.0 0.0 9.5 11.0 21.0 21.0	<pre>, Matus, perties nt; EHPG .pdf) [1,2] ECR [%] 0.0 0.0 1.0 1.1 2.1 2.1</pre>	Windber of ZrNb1 Meeting Do [mm] 9.13 9.14 9.15 9.17 9.17 9.17 9.20	v [mm] 0.70 0.74 0.74 0.74	so [mm2] 18.54 18.32 19.55 19.84 19.60 19.67	high temp differen ; HPR-353 Fmax [N] 6700 6810 9020 9190 9940 9740	Rm [MPa] 361.0 372.0 461.0 463.0 507.0 495.0	Fe [N] - - - -	Re [MPa] - - - - - -	Lo [mm] 25 25 25 25 25 25 25 25	Lu [mm] 38.3 38.4 32.3 31.3 28.8 -	A25 [%] 53.1 53.4 29.1 25.2 15.0	# # # # #	Lab No. No. No. No. No.	
[2] Test No. 1 2 3 4 5 6 7	Grigen mechan hydroc (File: series T [C] 20 20 20 20 20 20 20 20 20 20	r, Maroti hical pro gen conte : ehpg-99 s in 1998 Oxid [um] 0.0 0.0 9.5 11.0 21.0 21.0 40.0	<pre>, Matus, perties nt; EHPG .pdf) [1,2] ECR [%] 0.0 0.0 1.0 1.1 2.1 2.1 4.0</pre>	Windber of ZrNb1 Meeting Do [mm] 9.13 9.14 9.15 9.17 9.17 9.17 9.20 9.24	v [mm] 0.70 0.69 0.74 0.75 0.74 0.74 0.74 0.74 0.74 0.78	so [mm2] 18.54 18.32 19.55 19.84 19.60 19.67 20.73	high temp differen ; HPR-35 Fmax [N] 6700 6810 9020 9190 9940 9740 7280	Rm [MPa] 361.0 372.0 461.0 507.0 495.0 351.0	Fe [N] - - - -	Re [MPa] - - - - - - -	Lo [mm] 25 25 25 25 25 25 25 25 25	Lu [mm] 38.3 38.4 32.3 31.3 28.8 _ _	A25 [%] 53.1 53.4 29.1 25.2 15.0 	* * * * * *	Lab No. No. No. No. No. No.	
[2] Test No. 1 2 3 4 5 6 7 8	Grigen mechan hydroc (File: series T [C] 20 20 20 20 20 20 20 20 20 20 20	r, Maroti hical pro gen conte : ehpg-99 s in 1998 Oxid [um] 0.0 0.0 9.5 11.0 21.0 21.0 40.0 42.0	<pre>, Matus, perties nt; EHPG .pdf) [1,2] ECR [%] 0.0 0.0 1.0 1.1 2.1 2.1 4.0 4.2</pre>	Windber of ZrNb1 Meeting Do [mm] 9.13 9.14 9.15 9.17 9.17 9.17 9.20 9.24 9.23	v [mm] 0.70 0.69 0.74 0.75 0.74 0.74 0.74 0.78 0.78	so [mm2] 18.54 19.60 19.60 19.60 19.60 20.73 20.71	high tem differen ; HPR-35: Fmax [N] 6700 6810 9020 9190 9190 9740 7280 6180	Rm [MPa] 361.0 372.0 461.0 463.0 507.0 495.0 351.0 298.0	Fe [N] - - - - -	Re [MPa] - - - - - - - - - - -	Lo [mm] 25 25 25 25 25 25 25 25 25 25	Lu [mm] 38.3 38.4 32.3 31.3 28.8 - -	A25 [%] 53.1 53.4 29.1 25.2 15.0 	* * * * * * * *	Lab No. No. No. No. No. No.	
[2] Test No. 1 2 3 4 5 6 7 8 9	Grigen mechar hydroc (File: series T [C] 20 20 20 20 20 20 20 20 20 20 20 20 20	r, Maroti hical pro gen conte : ehpg-99 s in 1998 Oxid [um] 0.0 0.0 9.5 11.0 21.0 21.0 40.0 42.0 54.0	<pre>, Matus, perties nt; EHPG .pdf) [1,2] ECR [%] 0.0 0.0 1.0 1.1 2.1 2.1 4.0 4.2 5.6</pre>	Windber of ZrNb1 Meeting Do [mm] 9.13 9.14 9.15 9.17 9.17 9.17 9.20 9.24 9.23 9.27	v [mm] 0.70 0.74 0.75 0.74 0.74 0.75 0.74 0.78 0.78 0.80	ent and l ng with (99, Loen, [mm2] 18.54 18.32 19.55 19.84 19.60 19.67 20.73 20.71 21.29	high tem differen ; HPR-35: Fmax [N] 6700 6810 9020 9190 9940 9940 7280 6180 5030	Rm [MPa] 361.0 372.0 461.0 463.0 507.0 495.0 351.0 298.0 236.0	Fe [N] - - - - - - - - -	Re [MPa] - - - - - - - - - - - - - -	Lo [mm] 25 25 25 25 25 25 25 25 25 25 25	Lu [mm] 38.3 38.4 32.3 31.3 28.8 - - - - -	A25 [%] 53.1 53.4 29.1 25.2 15.0 - - - -	* * * * * * * * *	Lab No. No. No. No. No. No. No.	
[2] Test No. 1 2 3 4 5 6 7 8 9 10	Grigen mechar hydroc (File: series T [C] 20 20 20 20 20 20 20 20 20 20 20 20 20	r, Maroti hical pro gen conte : ehpg-99 S in 1998 Oxid [um] 0.0 0.0 9.5 11.0 21.0 21.0 40.0 42.0 54.0 69.0	<pre>, Matus, perties nt; EHPG .pdf) [1,2] ECR [%] 0.0 0.0 1.0 1.1 2.1 4.0 4.2 5.6 7.1</pre>	Windber of ZrNb1 Meeting Do [mm] 9.13 9.14 9.15 9.17 9.17 9.17 9.20 9.23 9.27 9.33	v [mm] 0.70 0.69 0.74 0.75 0.74 0.74 0.78 0.78 0.78 0.80 0.82	so [mm2] 18.54 18.32 19.55 19.84 19.60 19.67 20.73 20.71 21.29 21.92	high tem differen ; HPR-35 Fmax [N] 6700 6810 9020 9190 9940 9740 7280 6180 5030 3860	Rm [MPa] 361.0 372.0 461.0 463.0 507.0 495.0 351.0 298.0 236.0 176.0	Fe [N] - - - - - - - - - -	Re [MPa] - - - - - - - - - - - - - - - - - - -	Lo [mm] 25 25 25 25 25 25 25 25 25 25 25 25	Lu [mm] 38.3 38.4 32.3 31.3 28.8 - - - - -	A25 [%] 53.1 53.4 29.1 25.2 15.0 _ _ _ _	* * * * * * * * * * * *	Lab No. No. No. No. No. No. No. No.	
[2] Test No. 1 2 3 4 5 6 7 8 9 10 11	Grigen mechar hydroc (File: series T [C] 20 20 20 20 20 20 20 20 20 20 20 20 20	r, Maroti hical pro gen conte : ehpg-99 s in 1998 Oxid [um] 0.0 0.0 9.5 11.0 21.0 21.0 21.0 40.0 40.0 42.0 54.0 69.0 104.0	<pre>, Matus, perties nt; EHPG .pdf) [1,2] ECR [%] 0.0 0.0 1.0 1.1 2.1 2.1 4.0 4.2 5.6 7.1 10.4</pre>	Windber of ZrNb1 Meeting Do [mm] 9.13 9.14 9.15 9.17 9.17 9.17 9.20 9.24 9.23 9.27 9.23 9.27 9.33 9.38	v [mm] 0.70 0.74 0.75 0.74 0.75 0.74 0.78 0.78 0.80 0.82 0.84	so [mm2] 18.54 18.52 19.55 19.84 19.60 19.67 20.73 20.71 21.29 21.92 22.54	high tem differen ; HPR-353 Fmax [N] 6700 6810 9020 9190 9940 9740 7280 6180 5030 3860 1820	Rm [MFa] 361.0 372.0 461.0 463.0 507.0 495.0 351.0 298.0 236.0 176.0 81.0	Fe [N] - - - - - - - - - - - -	Re [MPa] - - - - - - - - - - - - - - - - - - -	Lo [mm] 25 25 25 25 25 25 25 25 25 25 25 25 25	Lu [mm] 38.3 38.4 32.3 31.3 28.8 - - - - - -	A25 [%] 53.1 53.4 29.1 25.2 15.0 - - - - -	* * * * * * * * * * * * *	Lab No. No. No. No. No. No. No. No.	
[2] Test No. 1 2 3 4 5 6 7 8 9 10 11 12	Grigen mechan hydroc (File: series T [C] 20 20 20 20 20 20 20 20 20 20 20 20 20	<pre>c, Maroti hical pro gen conte : ehpg-99 s in 1998</pre>	<pre>, Matus, perties nt; EHPG .pdf) [1,2] ECR [%] 0.0 0.0 1.0 1.1 2.1 2.1 4.0 4.2 5.6 7.1 10.4 19.9</pre>	Windber of ZrNb1 Meeting Do [mm] 9.13 9.14 9.15 9.17 9.17 9.20 9.24 9.23 9.27 9.23 9.27 9.33 9.38 9.48	v [mm] 0.70 0.69 0.74 0.75 0.74 0.78 0.78 0.78 0.80 0.82 0.84 0.89	so [mm2] 18.54 18.32 19.55 19.84 19.60 19.67 20.73 20.71 21.29 21.92 22.54 24.02	high tem differen ; HPR-353 Fmax [N] 6700 6810 9020 9190 9940 9740 7280 6180 5030 3860 1820 340	Rm [MPa] 361.0 372.0 461.0 463.0 507.0 495.0 351.0 298.0 236.0 176.0 81.0 14.0	Fe [N] - - - - - - - - - - - - - -	Re [MPa] - - - - - - - - - - - - - - - - - - -	Lo [mm] 25 25 25 25 25 25 25 25 25 25 25 25 25	Lu [mm] 38.3 38.4 32.3 31.3 28.8 - - - - - - - - -	A25 [%] 53.1 53.4 29.1 25.2 15.0 - - - - - -	* * * * * * * * * * * * * * * *	Lab No. No. No. No. No. No. No. No. No.	
[2] Test No. 1 2 3 4 5 6 7 8 9 10 11 12 13	Grigen mechan hydroc (File: series T [C] 20 20 20 20 20 20 20 20 20 20 20 20 20	<pre>c, Maroti hical pro gen conte : ehpg-99 s in 1998</pre>	<pre>, Matus, perties nt; EHPG .pdf) [1,2] ECR [%] 0.0 0.0 1.0 1.1 2.1 2.1 4.0 4.2 5.6 7.1 10.4 19.9 0.0</pre>	Windber of ZrNb1 Meeting Do [mm] 9.13 9.14 9.15 9.17 9.17 9.20 9.24 9.23 9.24 9.23 9.27 9.33 9.27 9.33 9.38 9.48 9.15	v [mm] 0.70 0.69 0.74 0.75 0.74 0.78 0.78 0.78 0.80 0.82 0.84 0.89 0.71	so [mm2] 18.54 19.60 19.60 19.60 19.67 20.73 20.71 21.29 21.92 22.54 24.02 18.83	high tem differen ; HPR-35: Fmax [N] 6700 6810 9020 9190 9740 7280 6180 5030 3860 1820 340 5220	Rm [MPa] 361.0 372.0 461.0 463.0 507.0 495.0 351.0 298.0 236.0 176.0 81.0 14.0 277.0	Fe [N] - - - - - - - - - - - - - - -	Re [MPa] - - - - - - - - - - - - - - - - - - -	Lo [mm] 25 25 25 25 25 25 25 25 25 25 25 25 25	Lu [mm] 38.3 38.4 32.3 31.3 28.8 - - - - - - - - - - - - - - - - - -	A25 [%] 53.1 53.4 29.1 25.2 15.0 	* * * * * * * * * * * * * * * *	Labo No. No. No. No. No. No. No. No. No.	
[2] Test No. 1 2 3 4 5 6 7 8 9 10 11 12 13 14	Grigen mechan hydroc (File: series T [C] 20 20 20 20 20 20 20 20 20 20 20 20 20	<pre>c, Maroti hical pro gen conte : ehpg-99 s in 1998</pre>	<pre>, Matus, perties nt; EHPG .pdf) [1,2] ECR [%] 0.0 0.0 1.0 1.1 2.1 2.1 4.0 4.2 5.6 7.1 10.4 19.9 0.0 1.2</pre>	Windber of ZrNb1 Meeting Do [mm] 9.13 9.14 9.15 9.17 9.17 9.17 9.20 9.24 9.23 9.27 9.23 9.27 9.33 9.28 9.48 9.15 9.16	v [mm] 0.70 0.69 0.74 0.75 0.74 0.75 0.74 0.78 0.78 0.80 0.82 0.84 0.82 0.84 0.89 0.71 0.73	so [mm2] 18.54 19.55 19.84 19.60 19.67 20.73 20.71 21.29 21.92 22.54 24.02 18.83 19.33	high tem differen ; HPR-35: Fmax [N] 6700 6810 9020 9190 9940 9740 7280 6180 5030 3860 1820 3860 1820 340 5220 6940	Rm [MPa] 361.0 372.0 461.0 463.0 507.0 495.0 351.0 298.0 236.0 176.0 81.0 14.0 277.0 359.0	Fe [N] - - - - - - - - - - - - - - - - - - -	Re [MPa] - - - - - - - - - - - - - - - - - - -	Lo [mm] 25 25 25 25 25 25 25 25 25 25 25 25 25	Lu [mm] 38.3 38.4 32.3 31.3 28.8 - - - - - - - - - - - - - - - - - -	A25 [%] 53.1 53.4 29.1 25.2 15.0 - - - - - - - - - - - - - - - - - - -	* * * * * * * * * * * * * * * * * *	Lab No. No. No. No. No. No. No. No. No. No.	

MTA KF	ΚΙ ΑΕΚΙ														
16	150	23.0	2.3	9.21	0.76	20.18	7660	380.0	-	-	25	28.5	14.1	#	No.20
17	150	31.0	3.2	9.22	0.78	20.68	8300	401.0	-	-	25	-	-	#	No.12
18	150	42.0	4.2	9.23	0.79	20.95	8230	393.0	-	-	25	28.1	12.5	#	No.34
19	150	72.0	7.0	9.3	0.81	21.6	3010	139.0	-	-	25	-	-	#	No.37
20	300	0.0	0.0	9.14	0.72	19.05	4570	240.0	-	-	25	40.4	61.5	#	No.43
21	300	12.0	1.2	9.15	0.74	19.55	5370	275.0	-	-	25	34.7	38.8	#	No.33
22	300	25.0	2.5	9.21	0.76	20.18	5450	270.0	-	-	25	28.7	14.6	#	No.17
#															
#															
# Test	t series	in 2000													
#															
# No.	Т	Oxid	ECR	Do	v	So	Fmax	Rm	Fe	Re	Lo	Lu	A25		Label
#	[C]	[um]	[%]	[mm]	[mm]	[mm2]	[N]	[MPa]	[N]	[MPa]	[mm]	[mm]	[%]		
#															
23	20	0.0	0.0	9.15	0.69	18.3	6765	368.9	4558	248.5	25	38.3	53.2	#	R-ZN-T-AR-1
24	20	0.0	0.0	9.15	0.69	18.3	6698	365.2	4369	238.2	25	36.7	46.8	#	R-ZN-T-AR-2
25	20	0.0	0.0	9.15	0.70	18.6	7113	382.8	4824	259.6	25	32.4	29.6	#	R-ZN-T-HK-1
26	20	0.0	0.0	9.14	0.71	18.8	6724	357.6	5179	275.4	25	32.8	31.2	#	R-ZN-T-HK-2
27	20	0.0	0.0	9.14	0.71	18.8	7376	392.3	4752	252.7	25	37.0	48.0	#	U-ZN-T-AR-1
28	20	0.0	0.0	9.14	0.71	18.8	7572	402.7	4762	253.3	25	36.7	46.8	#	U-ZN-T-AR-2
29	20	0.0	0.0	9.14	0.73	19.3	7673	397.8	5558	288.2	25	33.5	34.0	#	U-ZN-T-HK-1
30	20	0.0	0.0	9.14	0.72	19.0	7627	400.5	5352	281.0	25	32.3	29.2	#	U-ZN-T-HK-2
31	150	0.0	0.0	9.15	0.70	18.6	5678	305.6	3639	195.8	25	37.2	48.8	#	R-ZN-T-150-1
32	150	0.0	0.0	9.15	0.71	18.8	5507	292.5	4126	219.2	25	38.0	52.0	#	R-ZN-T-150-2
33	150	0.0	0.0	9.14	0.71	18.8	5716	304.0	3794	201.8	25	37.2	48.8	#	U-ZN-T-150-1
34	150	0.0	0.0	9.14	0.71	18.8	5693	302.8	3881	206.4	25	36.8	47.2	#	U-ZN-T-150-2
35	300	0.0	0.0	9.14	0.70	18.6	4512	243.1	2983	160.7	25	37.2	48.8	#	R-ZN-T-300-1
36	300	0.0	0.0	9.02	0.61	16.1	3600	223.4	2432	150.9	25	37.6	50.4	#	R-ZN-T-300-2
37	300	0.0	0.0	9.14	0.71	18.8	4934	262.4	3304	175.7	25	36.4	45.6	#	U-ZN-T-300-1
38	300	0.0	0.0	9.14	0.71	18.8	4780	254.2	3074	163.5	25	37.0	48.0	#	U-ZN-T-300-2

File: 'tensile\zr1nb\tubezrn.prn'

Database Report
MTA KFKI AEKI

# # # # # # # # #	Do v So Fmax Fe Rm Re Lo Lu Lu A25	[mm] [mm2] [N] [MPa] [MPa] [mm] [mm] [%]	outer d wall th origina maximum load at tensile yield s initial gauge l strain	iameter ickness l cross- load yield strengt trength gauge l ength af at ruptu	-sectiona Ch Length (2 Eter rup) are	al area 25 mm) ture							
# # # Nc #	р. Т [С]	Do [mm]	v [mm]	So [mm2]	Fmax [N]	Rm [MPa]	Fe [N]	Re [MPa]	Lo [mm]	Lu [mm]	A25 [%]		Label
1 2 3 4 5 6	20 20 30 40 50 50 50 50 50 50 50 50 50 50 50 50 50	10.77 10.77 10.77 10.77 10.77	0.73 0.73 0.74 0.74 0.74 0.73	23.0 23.0 23.3 23.3 23.3 23.0	16320 16303 12459 12499 14451 14866	708.8 708.0 534.3 536.0 619.7 646.3	13022 12914 9256 9441 11653 12089	565.6 560.9 397.0 404.9 499.8 525.6	25 25 25 25 25 25	30.7 30.8 31.2 31.2 31.3 30.6	22.8 23.2 24.8 24.8 25.2 22.4	# # # #	ZRY-T-AR-1 ZRY-T-AR-2 ZRY-T-HK-1 ZRY-T-HK-2 ZRY-T-150-1 ZRY-T-150-2
8	300	10.76	0.74	23.3 23.3	10798	463.5	8887	381.5	∠5 25	31.0	23.2	# #	ZRY-T-300-1 ZRY-T-300-2

File: 'tensile\zry-4\tubezry.prn'

AEKI tensile tests summary file: Zircaloy-4 tube specimens

Appendix 6:

Data of oxidation tests PUKOX

One s	side ox:										
date:	: March	1996	7 0017 /	1 0 4)							
Proje	ect: OMI	E'B 94-97-4	/-081/ (ta	sk 2.4)							
Zriðr	ο τυρε	samples									
т ([C]	oxidat	tion tempe:	rature							
t I	[s]	oxidat	ion time								
m0	[q]		initial m	ass							
m1	[d]		mass afte	r oxidati	on						
dm	[mg]		mass gain								
ECR	[%]		equivalen	t claddin	lg reacte	d (dm/m	0/3.508)				
D	[mm]		outer dia	meter of	the samp	le					
L	[mm]		length of	the samp	le						
F	[cm^2]]	surface a	rea							
Х	[um]		calculate	d ZrO2 la	yer thic	kness					
k	[mg/cr	m^2/s^0.5]	rate cons	tant							
Refer [1] 3	rence: J. Frec: reaktor	ska, L. Ma [.] tipusnal; (tus, I. Pu OMFB 94-97	mmer, L. -47-0817	Vasaros: / 2.5, A	Futoele EKI, Bud	emviselke dapest 11	edes VVER 996.	L		
Refer [1] 3	rence: J. Frec: reaktor	ska, L. Ma tipusnal; (tus, I. Pu OMFB 94-97 m1	mmer, L. -47-0817	Vasaros: / 2.5, A	Futoele EKI, Bud	emviselk dapest 1	edes VVEF 996.	v	k	sample
Refer [1] 3 T	rence: J. Frec: reaktori t	ska, L. Ma tipusnal; (m0	tus, I. Pu OMFB 94-97 m1	mmer, L. -47-0817 dm	Vasaros: / 2.5, A ECR	Futoele EKI, Bud D	emviselk dapest 19 L	edes VVEF 996. F	x	k	sample
Refer [1] 3 T 900	rence: J. Frec: reaktor t 400	ska, L. Ma tipusnal; (m0 8.39070	tus, I. Pu OMFB 94-97 m1 8.43962	mmer, L. -47-0817 dm 48.92	Vasaros: / 2.5, A ECR 1.66	Futoele EKI, Bud D 9.13	emviselke dapest 19 L 70.0	edes VVEF 996. F 20.07	x 17.1	k 0.122	sample # pukox-
Refer [1] 3 T 900 900	rence: J. Frec: reaktor t 400 400	ska, L. Ma tipusnal; (m0 8.39070 8.60770	tus, I. Pu OMFB 94-97 m1 8.43962 8.64080	mmer, L. -47-0817 dm 48.92 33.10	Vasaros: / 2.5, A ECR 1.66 1.10	Futoele EKI, Bud D 9.13 9.13	emviselke dapest 19 L 70.0 71.58	edes VVEF 996. F 20.07 20.52	x 17.1 11.6	k 0.122 0.081	sample # pukox- # pukox-
Refei [1] 3 T 900 900 900	rence: J. Frec: reaktor t 400 400 400	ska, L. Ma tipusnal; (m0 8.39070 8.60770 8.53580	tus, I. Pu OMFB 94-97 m1 8.43962 8.64080 8.56812	mmer, L. -47-0817 dm 48.92 33.10 32.32	Vasaros: / 2.5, A ECR 1.66 1.10 1.08	Futoele EKI, Bud D 9.13 9.13 9.13	emviselk dapest 19 L 70.0 71.58 70.98	edes VVEF 996. F 20.07 20.52 20.35	x 17.1 11.6 11.3	k 0.122 0.081 0.079	sample # pukox- # pukox- # pukox-
Refer [1] d T 900 900 900 900	rence: J. Frec: reaktor t 400 400 400 400	ska, L. Ma tipusnal; 0 m0 8.39070 8.60770 8.53580 8.08350	tus, I. Pu DMFB 94-97 m1 8.43962 8.64080 8.56812 8.13603	mmer, L. -47-0817 dm 48.92 33.10 32.32 52.53	Vasaros: / 2.5, A ECR 1.66 1.10 1.08 1.85	Futoele EKI, Bud D 9.13 9.13 9.13 9.13	emviselke dapest 19 L 70.0 71.58 70.98 67.22	edes VVEF 996. F 20.07 20.52 20.35 19.27	x 17.1 11.6 11.3 18.4	k 0.122 0.081 0.079 0.136	sample # pukox- # pukox- # pukox- # pukox-
Refei [1] 3 T 900 900 900 900 900 900	rence: J. Frec: reaktor t 400 400 400 400 400 400	ska, L. Ma tipusnal; 0 m0 8.39070 8.60770 8.53580 8.08350 8.08350 8.55020	tus, I. Pu DMFB 94-97 m1 8.43962 8.64080 8.56812 8.13603 8.59430	mmer, L. -47-0817 dm 48.92 33.10 32.32 52.53 44.10	Vasaros: / 2.5, A ECR 1.66 1.10 1.08 1.85 1.47	Futoele EKI, Bud D 9.13 9.13 9.13 9.13 9.13 9.13	emviselke dapest 19 L 70.0 71.58 70.98 67.22 71.10	edes VVEF 996. F 20.07 20.52 20.35 19.27 20.38	x 17.1 11.6 11.3 18.4 15.4	k 0.122 0.081 0.079 0.136 0.108	sample # pukox- # pukox- # pukox- # pukox- # pukox-
Refei [1] 3 T 900 900 900 900 900 900 900 900 900	rence: J. Frec: reaktor t 400 400 400 400 400 400 400 400	ska, L. Ma tipusnal; m0 8.39070 8.60770 8.53580 8.08350 8.08350 8.55020 8.16370	tus, I. Pu DMFB 94-97 m1 8.43962 8.64080 8.56812 8.13603 8.59430 8.28207	mmer, L. -47-0817 dm 48.92 33.10 32.32 52.53 44.10 118.37	Vasaros: / 2.5, A ECR 1.66 1.10 1.08 1.85 1.47 4.13	Futoele EKI, Bud D 9.13 9.13 9.13 9.13 9.13 9.13 9.13	emviselke dapest 19 L 70.0 71.58 70.98 67.22 71.10 67.89	edes VVEF 996. F 20.07 20.52 20.35 19.27 20.38 19.46	x 17.1 11.6 11.3 18.4 15.4 41.4	k 0.122 0.081 0.079 0.136 0.108 0.304	sample # pukox- # pukox- # pukox- # pukox- # pukox- # pukox- # pukox-
Refei [1] 3 T 900 900 900 900 900 900 900 900 900	rence: J. Frec: reaktor t 400 400 400 400 400 400 400 400	ska, L. Ma tipusnal; m0 8.39070 8.60770 8.53580 8.08350 8.08350 8.55020 8.16370 7.98640	tus, I. Pu DMFB 94-97 m1 8.43962 8.64080 8.56812 8.13603 8.59430 8.28207 8.06745	mmer, L. -47-0817 dm 48.92 33.10 32.32 52.53 44.10 118.37 81.05	Vasaros: / 2.5, A ECR 1.66 1.10 1.08 1.85 1.47 4.13 2.89	Futoele EKI, Bud D 9.13 9.13 9.13 9.13 9.13 9.13 9.13	emviselke dapest 19 70.0 71.58 70.98 67.22 71.10 67.89 66.41	edes VVEF 996. F 20.07 20.52 20.35 19.27 20.38 19.46 19.04	x 17.1 11.6 11.3 18.4 15.4 41.4 28.3	k 0.122 0.081 0.079 0.136 0.108 0.304 0.213	sample # pukox- # pukox- # pukox- # pukox- # pukox- # pukox- # pukox-
Refei [1] 3 T 900 900 900 900 900 900 900 900 900 9	rence: J. Frec: reaktor t 400 400 400 400 400 400 400 400 400	ska, L. Ma tipusnal; 0 m0 8.39070 8.60770 8.53580 8.08350 8.55020 8.16370 7.98640 8.55280	tus, I. Pu DMFB 94-97 m1 8.43962 8.64080 8.56812 8.13603 8.59430 8.28207 8.06745 8.62218	mmer, L. -47-0817 dm 48.92 33.10 32.32 52.53 44.10 118.37 81.05 69.38	Vasaros: / 2.5, A ECR 1.66 1.10 1.08 1.85 1.47 4.13 2.89 2.31	Futoele EKI, Bud D 9.13 9.13 9.13 9.13 9.13 9.13 9.13 9.13	emviselka dapest 19 70.0 71.58 70.98 67.22 71.10 67.89 66.41 71.12	edes VVEF 996. F 20.07 20.52 20.35 19.27 20.38 19.46 19.04 20.39	x 17.1 11.6 11.3 18.4 15.4 41.4 28.3 24.2	k 0.122 0.081 0.079 0.136 0.108 0.304 0.213 0.170	sample # pukox- # pukox- # pukox- # pukox- # pukox- # pukox- # pukox- # pukox-
Refei [1] 3 T 900 900 900 900 900 900 900 900 900 9	rence: J. Frec: reaktor t 400 400 400 400 400 400 400 400 400	ska, L. Ma tipusnal; (m0 8.39070 8.60770 8.53580 8.08350 8.55020 8.16370 7.98640 8.55280 8.57900	tus, I. Pu DMFB 94-97 m1 8.43962 8.64080 8.56812 8.13603 8.59430 8.28207 8.06745 8.62218 8.63682	mmer, L. -47-0817 dm 48.92 33.10 32.32 52.53 44.10 118.37 81.05 69.38 57.82	Vasaros: / 2.5, A ECR 1.66 1.10 1.08 1.85 1.47 4.13 2.89 2.31 1.92	Futoele EKI, Buc D 9.13 9.13 9.13 9.13 9.13 9.13 9.13 9.13	emviselke dapest 19 70.0 71.58 70.98 67.22 71.10 67.89 66.41 71.12 71.34	edes VVEF 996. F 20.07 20.52 20.35 19.27 20.38 19.46 19.04 20.39 20.45	x 17.1 11.6 11.3 18.4 15.4 41.4 28.3 24.2 20.2	k 0.122 0.081 0.136 0.108 0.304 0.213 0.170 0.141	sample # pukox- # pukox- # pukox- # pukox- # pukox- # pukox- # pukox- # pukox- # pukox-
Refer [1] 3 T 900 900 900 900 900 900 900 900 900 9	rence: J. Frec: reaktor t 400 400 400 400 400 400 400 400 400 4	ska, L. Ma tipusnal; 0 m0 8.39070 8.60770 8.53580 8.08350 8.55020 8.16370 7.98640 8.55280 8.57900 8.45455	tus, I. Pu DMFB 94-97 m1 8.43962 8.64080 8.56812 8.13603 8.59430 8.28207 8.06745 8.62218 8.63682 8.51287	mmer, L. -47-0817 dm 48.92 33.10 32.32 52.53 44.10 118.37 81.05 69.38 57.82 58.32	Vasaros: / 2.5, A ECR 1.66 1.10 1.08 1.85 1.47 4.13 2.89 2.31 1.92 1.97	Futoele EKI, Buc D 9.13 9.13 9.13 9.13 9.13 9.13 9.13 9.13	emviselka dapest 19 L 70.0 71.58 70.98 67.22 71.10 67.89 66.41 71.12 71.34 70.31	edes VVEF 996. F 20.07 20.52 20.35 19.27 20.38 19.46 19.04 20.39 20.45 20.16	x 17.1 11.6 11.3 18.4 15.4 41.4 28.3 24.2 20.2 20.4	k 0.122 0.081 0.079 0.136 0.108 0.304 0.213 0.170 0.141 0.145	sample # pukox- # pukox- # pukox- # pukox- # pukox- # pukox- # pukox- # pukox- # pukox- # pukox-
Refer [1] 3 T 900 900 900 900 900 900 900 900 900 9	rence: J. Frec: reaktor t 400 400 400 400 400 400 400 400 400 4	ska, L. Ma tipusnal; (m0 8.39070 8.60770 8.53580 8.08350 8.55020 8.16370 7.98640 8.55280 8.55280 8.57900 8.45455 8.36375	tus, I. Pu DMFB 94-97 ml 8.43962 8.64080 8.56812 8.13603 8.59430 8.28207 8.06745 8.62218 8.63682 8.51287 8.40365	mmer, L. -47-0817 dm 48.92 33.10 32.32 52.53 44.10 118.37 81.05 69.38 57.82 58.32 39.90	Vasaros: / 2.5, A ECR 1.66 1.10 1.08 1.85 1.47 4.13 2.89 2.31 1.92 1.97 1.36	Futoele EKI, Buc D 9.13 9.13 9.13 9.13 9.13 9.13 9.13 9.13	emviselka dapest 19 L 70.0 71.58 70.98 67.22 71.10 67.89 66.41 71.12 71.34 70.31 69.88	edes VVEF 296. F 20.07 20.52 20.35 19.27 20.38 19.46 19.04 20.39 20.45 20.16 20.03	x 17.1 11.6 11.3 18.4 15.4 41.4 28.3 24.2 20.2 20.4 13.9	k 0.122 0.081 0.136 0.108 0.213 0.170 0.141 0.145 0.100	sample # pukox- # pukox-

MTA KFKI	AEKI										
900	400	8.56880	8.60960	40.80	1.36	9.14	69.96	20.08	14.3	0.102	# pukox-13
900	400	8.58425	8.62752	43.27	1.44	9.13	70.07	20.09	15.1	0.108	# pukox-14
900	400	8.45230	8.50790	55.60	1.88	9.13	70.02	20.07	19.4	0.138	# pukox-15
900	400	8.54925	8.60540	56.15	1.87	9.14	70.06	20.11	19.6	0.140	# pukox-16
900	400	8.45465	8.49650	41.85	1.41	9.14	70.05	20.10	14.6	0.104	# pukox-17
900	800	8.44665	8.52097	74.32	2.51	9.14	70.01	20.09	26.0	0.131	# pukox-18
900	800	8.18320	8.24850	65.30	2.27	9.12	70.11	20.08	22.8	0.115	# pukox-19
900	800	8.38460	8.44185	57.25	1.95	9.12	70.07	20.07	20.0	0.101	# pukox-20
900	800	8.10850	8.17992	71.42	2.51	9.14	67.35	19.33	25.0	0.131	# pukox-21
900	1600	8.45900	8.52410	65.10	2.19	9.14	70.26	20.16	22.8	0.081	# pukox-22
900	1600	8.43950	8.52430	84.80	2.86	9.14	70.10	20.12	29.6	0.105	# pukox-23
900	3600	8.16475	8.33860	173.85	6.07	9.14	67.82	19.46	60.8	0.149	# pukox-24
900	2700	8.55678	8.67281	116.03	3.87	9.14	71.07	20.40	40.6	0.109	# pukox-25
900	2700	8.53035	8.63455	104.20	3.48	9.14	70.85	20.33	36.4	0.099	# pukox-26
900	2700	8.52930	8.65526	125.96	4.21	9.14	70.84	20.33	44.0	0.119	# pukox-27
900	2700	8.45131	8.63780	186.49	6.29	9.14	70.20	20.15	65.2	0.178	# pukox-28
900	1800	8.42320	8.58547	162.27	5.49	9.14	69.96	20.08	56.7	0.190	# pukox-29
900	1800	8.44443	8.50795	63.52	2.14	9.14	70.14	20.13	22.2	0.074	# pukox-30
900	200	8.42790	8.45795	30.05	1.02	9.15	70.0	20.11	10.5	0.106	# pukox-31
900	200	8.47422	8.50630	32.08	1.08	9.15	70.06	20.13	11.2	0.113	# pukox-32
900	100	8.15526	8.17805	22.79	0.80	9.14	70.04	20.10	8.0	0.113	# pukox-33
900	75	8.48485	8.50633	21.48	0.72	9.15	70.02	20.12	7.5	0.123	# pukox-34
900	50	7.93585	7.95458	18.73	0.67	9.12	70.06	20.06	6.5	0.132	# pukox-35
900	50	8.18182	8.19855	16.73	0.58	9.14	70.07	20.11	5.8	0.118	# pukox-36
900	50	8.47975	8.50000	20.25	0.68	9.15	70.03	20.12	7.1	0.142	# pukox-37
900	50	8.10985	8.12715	17.30	0.61	9.13	70.02	20.07	6.0	0.122	# pukox-38
900	60	8.32770	8.34748	19.78	0.68	9.15	70.07	20.13	6.9	0.127	# pukox-39
900	60	8.56655	8.58597	19.42	0.65	9.16	69.71	20.05	6.8	0.125	# pukox-40
900	60	8.40010	8.41810	18.00	0.61	9.15	70.03	20.12	6.3	0.115	# pukox-41
900	600	8.17185	8.23750	65.65	2.29	9.15	69.97	20.10	22.9	0.133	# pukox-42
900	1200	8.59810	8.73995	141.85	4.70	9.15	70.09	20.14	49.6	0.203	# pukox-43
900	1200	8.59178	8.70910	117.32	3.89	9.15	70.04	20.12	41.0	0.168	# pukox-44

File: 'oxidation\pukox.prn

Database Report

```
Data of oxidation tests EU-PECO
Appendix 7:
# Double side oxidation in steam
# date: June 1995
# Project: EU PECO (Contract FI3SCT920001)
# Zr1%Nb tube samples
# Geometry: outer diameter = 9.14mm, wall thickness = 0.7mm , length = 40mm
# Surface area= 2158.3mm^2
#
#
 Т
      [C]
                         oxidation temperature
#
  t
      [s]
                         oxidation time
#
  dm
      [mq/cm^2]
                        mass gain
#
  k
       [mg/cm^{2}s^{0.5}]
                        rate constant
#
                         ZrO2 layer thickness
  Х
      [um]
#
#
#
  Reference:
#
#
  [1] J. Frecska, G. Konczos, L. Maroti, L. Matus: Oxidation and hydriding
#
      of Zr1%Nb alloys by steam at 900-1200 C; KFKI-1995-17/G report.
#
     (File: kfki-95-17.pdf)
#
#
#
  No.
         Τ
                t
                         dm
                                   k
                                             Х
                                                     sample
#
        900
               100
                       1.18
                                 0.118
                                            4.5
                                                     95-20
   1
   2
        900
               300
                       2.16
                                 0.125
                                           14.0
                                                     95-19
   3
        900
                       3.36
                                           37.0
                                                     95-5
               1000
                                 0.106
                       4.78
   4
        900
               2000
                                 0.107
                                           44.0
                                                     95-4
   5
        900
               4000
                                 0.095
                                                     95-2
                        6.01
                                           48.0
   6
        900
               10000
                       13.14
                                 0.131
                                                     95-3
                                           81.0
#
   7
       1000
               500
                       5.15
                                 0.230
                                           44.0
                                                     95-9
   8
       1000
               1025
                        6.36
                                 0.199
                                           77.0
                                                     95-6
   9
                       8.43
                                 0.188
                                           82.0
                                                     95-7
       1000
               2000
  10
       1000
               4000
                       12.48
                                 0.197
                                          103.0
                                                     95-8
#
  11
       1100
               125
                       4.38
                                 0.392
                                           45.0
                                                     95-14
  12
       1100
               250
                       7.10
                                 0.449
                                           53.0
                                                     95-13
  13
       1100
               500
                       9.86
                                 0.441
                                           84.0
                                                     95-12
  14
       1100
               1000
                       14.1
                                 0.446
                                           89.0
                                                     95-11
  15
       1100
               2000
                       18.85
                                 0.422
                                          117.0
                                                     95-10
  16
       1200
               62.5
                         5.78
                                 0.731
                                           48.0
                                                     95-15
  17
       1200
               125
                         8.88
                                 0.795
                                           54.0
                                                     95-16
  18
       1200
               250
                       12.44
                                 0.787
                                           84.0
                                                     95-17
  19
       1200
               500
                       17.25
                                 0.771
                                           95.0
                                                     95-18
```

```
File: 'oxidation\eu-peco.prn'
```

Data of oxidation tests IAEA-CRP Appendix 8: # Double side oxidation in steam # date: 1997 # Project: IAEA CRP (Contract 9284/R0) # Zr1%Nb tube samples # Geometry: outer diameter = 9.14mm, wall thickness = 0.7mm length =5mm # Surface area= 3.01cm^2 # # Т [C] oxidation temperature # t oxidation time [s] # dma [mg] absolute mass gain mass gain / surface area # [mg/cm^2] dm # [mg/cm^2*s^0.5] rate constant k # # # Reference: # # [1] J. Frecska, L. Matus, L. Vasaros: Hydrogen uptake of Zr1%Nb cladding # by steam oxidation during loss of coolant accident; IAEA CRP 9284/RO, # Final report, September 1997. (File: iaea-9284.pdf) # # # # Sample Т t dma dm k No. # 1 500 163000 1.38 0.461 0.00114 # 500A2 2 500 653000 3.05 0.986 0.00122 # 500B1 3 500 653000 2.91 0.980 0.00121 # 500B3 # 600 2400 0.83 0.276 0.00563 # 600A1 4 5 600 2400 1.31 # 0.435 0.00888 600A2 0.502 6 600 10800 1.51 0.00483 # 600B1 7 600 138600 5.95 1.980 0.00532 # 600C2 # 8 700 700A1 171 0.74 0.245 0.01875 # 9 700 171 0.79 0.261 0.01994 # 700A2 10 700 1200 1.91 0.635 0.01834 # 700B3 11 700 4800 3.19 1.060 0.01530 # 700C1 12 700 4800 3.19 1.058 0.01528 # 700C3 # 13 800 69 1.17 0.390 0.04691 # 800A1 14 800 69 1.14 0.380 0.04575 # 800A2 15 800 277 2.40 0.796 # 800B1 0.04785 800 277 16 2.29 0.762 0.04579 # 800B2 17 800 1107 3.86 1.281 0.03850 # 800C1 18 800 1107 3.82 1.270 0.03817 # 800C2 # 19 30 900 1.74 0.579 0.10572 # 900A1 1.67 20 900 30 0.556 # 900A2 0.10148 21 900 120 3.00 0.998 0.09107 # 900B1 22 900 120 3.06 # 900B2 1.017 0.09286 23 900 480 1.51 0.503 0.02296 # 900C1 24 900 480 1.35 0.448 0.02046 # 900C2

File: 'oxidation\iaea-crp.prn'

```
Data of oxidation tests OAH-ABA
Appendix 9:
# Double side oxidation in steam
# date: June 2000
# Project: OAH-ABA-41/00
# Zr1%Nb tube samples
# Geometry: outer diameter = 9.14mm, wall thickness = 0.7mm
#
# L
      [mm]
                   length of a sample
# Т
      [C]
                   oxidation temperature
# t
      [s]
                   oxidation time
#
 dma [mg]
                   absolute mass gain
#
      [mg/cm^2]
                  mass gain / surface area
 dm
#
      [mg/cm^2*s^0.5] rate constant ( Dm/SQRT(t) )
 k
#
#
 References:
#
#
  [1] L. Matus, L. Vasaros: Hydrogen release kinetics during steam
#
      oxidation of Zr1%Nb and zircaloy-4; 6th International QUENCH
#
      Workshop, Forschugzentrum Karlsruhe, October 10-12, 2000.
#
      (File: quench-6-00.pdf)
#
#
  [2] Matus L., Horvath M. Vasaros L.: Zr1%Nb es Zircaloy-4
#
      osszehasonlitasa vizgozos oxidacioban; OAH-ABA-41/00, 2000.
#
#
  [3] Hozer Z. et al.: Ring compression tests with oxidised and
#
      hydrided Zr1%Nb and Zircaloy-4 claddings; KFKI-2002-01/G.
#
      (File: kfki-02-01.pdf)
#
#
#
          Т
  No.
                 t
                        dma
                                dm
                                          k
                                                 L
                                                          sample
#
   1
         900
                360
                       5.58
                                1.208
                                        0.064
                                                 8.00
                                                        #
                                                           N-14
   2
         900
                1000
                       12.53
                                2.767
                                        0.087
                                                 7.83
                                                        #
                                                           N-13
                                                           N-11
   3
         900
                3000
                       29.30
                                6.455
                                        0.118
                                                 7.85
                                                        #
                       47.18
                                                 7.93
                                                           N-12
   4
         900
                7000
                                10.297
                                        0.123
                                                        #
   5
         900
              11000
                       64.36
                                14.178
                                        0.135
                                                 7.85
                                                        #
                                                           N-10
   6
         900
              14000
                       66.28
                                14.550
                                       0.123
                                                 7.88
                                                        #
                                                           N-9
#
   7
        1000
                100
                       6.66
                                        0.145
                                                 7.93
                                                        #
                                                           N-7
                               1.454
   8
        1000
                700
                       21.1
                                4.637
                                        0.175
                                                 7.87
                                                        #
                                                           N-2
   9
        1000
                1200
                       32.53
                                                 7.93
                                                        #
                                                           N-6
                                7.100
                                        0.205
  10
        1000
                1800
                       57.83
                                12.710
                                                 7.87
                                                        #
                                                           N-5
                                        0.300
  11
        1000
                3600
                       82.05
                                                 8.00
                                                        #
                                                           N-3
                                17.764
                                        0.296
  12
        1000
                6000
                       103.85
                               22.613 0.292
                                                 7.95
                                                        #
                                                           N-1
  13
        1100
               19
                       5.25
                                1.166
                                        0.268
                                                 7.78
                                                        #
                                                           N-19
  14
        1100
                133
                       16
                                3.533
                                        0.306
                                                 7.83
                                                        #
                                                           N-18
                                                        #
  15
        1100
               704
                       39.3
                                8.548
                                        0.322
                                                 7.96
                                                           N-17
                                        0.324
  16
        1100
                1500
                       57.59
                                12.555
                                                 7.94
                                                        #
                                                           N-16
  17
        1100
                2400
                                16.305
                                                 7.86
                                                        #
                                                           N-15
                       74.1
                                        0.333
        1100
                5000
                                                        #
  18
                       107.17
                               23.554
                                       0.333
                                                 7.87
                                                           N-8
                               1.641
  19
        1200
                7
                       7.43
                                        0.620
                                                 7.83
                                                        #
                                                           N-25
                       16.98
                                3.693
                                                 7.96
                                                        #
  20
        1200
                49
                                        0.528
                                                           N-24
                                                        #
  21
        1200
               167
                       34.55
                               7.620
                                        0.590
                                                 7.84
                                                           N-23
                                                        # N-22
  22
        1200
                380
                               11.035 0.566
                                                 7.86
                       50.15
  23
        1200
                                                 7.90
                                                        # N-21
                646
                       66.00
                               14.455 0.569
```

File: 'oxidation\oahzrnb.prn'

1205

90.85

1200

24

19.783 0.570

7.95

N-20

```
# Double side oxidation in steam
# date: June 2000
# Project: OAH-ABA-41/00
# Zircaloy-4 tube samples
# Geometry: outer diameter = 10.74mm, wall thickness = 0.73mm
#
#
 L
                         lengh of a sample
        [mm]
#
 Т
                         oxidation temperature
        [C]
#
 t
        [s]
                         oxidation time
# dma
        [mg]
                         absolute mass gain
#
 dm
        [mg/cm^2]
                         mass gain / surface area
        [mg/cm^2*s^0.5] rate constant ( Dm/SQRT(t) )
#
 k
#
# References:
#
#
 [1] L. Matus, L. Vasaros: Hydrogen release kinetics during steam
#
      oxidation of Zr1%Nb and zircaloy-4; 6th International QUENCH
#
      Workshop, Forschugzentrum Karlsruhe, October 10-12, 2000.
#
      (File: quench-6-00.pdf)
#
#
  [2] Matus L., Horvath M. Vasaros L.: Zr1%Nb es Zircaloy-4
#
      osszehasonlitasa vizgozos oxidacioban; OAH-ABA-41/00, 2000.
#
#
  [3] Hozer Z. et al.: Ring compression tests with oxidised and
#
      hydrided Zr1%Nb and Zircaloy-4 claddings; KFKI-2002-01/G.
#
      (File: kfki-02-01.pdf)
#
#
#
 No.
          Т
                 t
                        dma
                                 dm
                                          k
                                                  L
                                                           sample
#
         900
                300
                         9.4
                                 1.72
                                                 7.93
                                                        #
   1
                                        0.100
                                                           Y-11
                                                        #
   2
         900
               1000
                        14.4
                                 2.64
                                        0.084
                                                 7.92
                                                           Y-10
                                 4.50
                5000
                                                        #
   3
         900
                       25.06
                                        0.064
                                                 8.12
                                                           Y-8
              11000
                                                        #
   4
         900
                       28.85
                                 5.32
                                        0.051
                                                 7.88
                                                           Y-9
#
   5
        1000
                  87
                          12
                                 2.19
                                        0.235
                                                 7.97
                                                        #
                                                           Y-6
   6
        1000
                 464
                       24.85
                                 4.56
                                        0.212
                                                 7.92
                                                        #
                                                           Y-5
   7
        1000
                2600
                       50.15
                                 9.25
                                        0.181
                                                 7.88
                                                        #
                                                           Y-1
   8
        1000
               3300
                       63.97
                               11.52
                                        0.201
                                                 8.09
                                                        #
                                                           Y-7
   9
        1000
               4090
                        83.8
                               15.42
                                        0.241
                                                 7.90
                                                        #
                                                           Y-4
  10
        1000
               7270
                      181.25
                                33.40
                                        0.392
                                                 7.89
                                                        #
                                                           Y-3
  11
        1000 11360
                      314.75
                                58.61
                                        0.550
                                                 7.80
                                                        #
                                                           Y-2
                                                 7.95
                                                           Y-17
  12
        1100
                 27
                       11.70
                                 2.14
                                        0.412
                                                        #
        1100
                102
                       22.55
                                 4.14
                                        0.410
                                                 7.93
                                                        #
                                                           Y-16
  13
  14
        1100
                398
                       41.33
                                7.64
                                        0.383
                                                 7.86
                                                        #
                                                           Y-15
  15
        1100
                900
                       65.10
                                11.54
                                                 8.23
                                                        # Y-14
                                        0.385
  16
        1100
               1500
                       83.95
                                14.78
                                        0.382
                                                 8.29
                                                        # Y-13
                                                        # Y-12
  17
        1100
               3000
                     110.64
                               20.25
                                        0.370
                                                 7.95
  18
        1200
                 10
                       14.57
                                 2.63
                                        0.832
                                                 8.07
                                                        #
                                                           Y-23
                                                 7.98
                                                           Y-22
        1200
                       23.85
                                 4.35
  19
                 40
                                        0.688
                                                        #
  20
        1200
                163
                       43.39
                                 7.93
                                                 7.96
                                                           Y-21
                                        0.621
                                                        #
                                                           Y-20
  21
        1200
                       63.85
                                11.63
                                                 7.99
                                                        #
                 367
                                        0.607
  22
        1200
                 790
                       91.41
                                16.54
                                        0.588
                                                 8.05
                                                        #
                                                           Y-18
                                                        # Y-19
  23
        1200
                1100 105.67
                               19.29
                                                 7.97
                                        0.582
```

File: 'oxidation\oahzry.prn'

MTA KFKI AEKI

А	ppen	dix 10:			Data	of oxidation	on tests H	TARTOX							
#	Doub	ole side	oxidat	ion in ste	am										
#	date	e: Decemb	per 1998	3											
#	Zr1 ⁹	%Nb tube	samples	5											
#	Geor	metry: ri	ing samp	ples of di	fferent s	izes with	out hydr	ogen con	itent						
#															
#	Т	[C]	oxi	dation te	mperature										
#	t	[s]	oxi	dation ti	me										
#	m1	[g]	mas	ass of sample before oxidation											
#	m2	[g]	mas	ss of samp	le after o	oxidation									
#	L1	[mm]	ler	ngth of sam	mple befor	e oxidat	ion								
#	L2	[mm]	ler	ngth of sam	mple after	oxidati	on								
#	dL	[응]	<pre>%] relative change of length</pre>												
#	D1	[mm]	dia	ameter of	a sample k	pefore ox	idation								
#	D2	[mm]	dia	ameter of	a sample a	after oxi	dation								
#	dD	[%]	rel	ative cha	nge of dia	ameter of	a sampl	e							
#	f	[cm^2]	sur	face area	of a samp	ole befor	e oxidat	ion							
#	dm	[mg/cm^2	2] mas	s gain											
#	k	[mg/cm^2	2*s^0.5] rate con	stant										
#															
#	Reie	erence:													
#															
#	[1]	L. Vasar	COS, L.P	Matus: Ste	am oxidat:	lon of Zr	-alloys	WITH H C	content,						
#		release	or apso	orbea niar	ogen; stn	Internat	lonal Qu	ENCH WOI	rksnop,	01-5 \					
# #		Forschur	igscenti	rum Karlsr	une, Octo	ber 19-21	1999. (file: qu	lencn-5-9	9.par)					
#															
π #	No	Ψ	+	m1	m2	dm	т.1	т.2	dī.	1ח	2ת	dD	f	k	
#	NO.	T	L	1111	1112	GIII			СШ	DI	DZ	QD	T	17	
"	1	800	3600	0.4854	0.49045	5.05	4.45	4.49	0.90	9.05	9.16	1.22	2.69	0.031	
	2	900	880	0.49965	0.5051	5.45	4.48	4.50	0.45	9.07	9.11	0.44	2.72	0.068	
	3	1000	220	0.49706	0.50372	6.66	4.44	4.48	0.90	9.08	9.13	0.55	2.70	0.166	
	4	1100	60	0.49027	0.49583	5.56	4.44	4.45	0.23	9.07	9.09	0.22	2.70	0.266	
	5	1100	900	0.52011	0.54677	26.66	4.76	4.82	1.26	9.03	9.07	0.44	2.84	0.313	
	6	1100	900	0.51605	0.5434	27.35	4.64	4.73	1.94	9.01	9.1	1.00	2.77	0.330	
	7	1100	900	0.4776	0.50323	25.63	4.3	-	-	9.02	-	-	2.59	0.329	
	8	1100	900	0.49615	0.5226	26.45	4.45	-	-	9.02	-	-	2.67	0.330	

File: 'oxidation\htartox.prn'

Appendix 11: Data of oxidation tests OMFB-94

```
# Double side oxidation in steam
# date: 1994
# Project: OMFB 94-97-47-0817 (task 2.2)
# Zr1%Nb tube samples
# Geometry: outer diameter = 9.16mm, wall thickness = 0.72mm
#
# L
      [cm]
                        length of a sample
# F
                        surface area
      [cm^2]
# Т
                        oxidation temperature
      [C]
# t
                        oxidation time
      [s]
# dm
     [mg/cm^2]
                        mass gain
# k
    [mg/cm^2*s^0.5]
                       rate constant
#
#
#
       Т
               t L
                              F
                                     dm
                                              k
#
     1010
           500
                   3.75
                          20.27
                                  71.7
                                           0.158
     1010 1000
                   3.67
                          19.84
                                  88.7
                                           0.141
     1010 1200
                   3.88
                          20.96
                                  117.9
                                           0.162
     1010 2000
                   3.73
                          20.16
                                  132.2
                                           0.147
     1010 4000
                   3.86
                          20.85
                                  296.3
                                           0.225
     1010 4000
                   3.715 20.08
                                           0.180
                                  229
```

File: 'oxidation\omfb-94.prn'

MTA KFKI AEKI

App	pendix 12:		Data of ring compression tests												
#		AEK	KI compression tests summary file												
#		date	e: 2000												
#		Zr1	%Nb ring s	amples											
#															
#		ECR	[%] equivalent oxidation on the basis of the measured mass gain												
#		Hc	[wppm] hydrogen content of the sample after the oxidation												
#		Ha	[%] absorbed hydrogen												
#		DO	[mm] diameter before oxidation												
#		D [1	[mm] diameter after oxidation												
#		F []	N] force												
#		dl	[mm]	um] deformation [%] relative deformation											
#		a1/1	D [き] T]												
# #		E []	J] energy												
#	No	FCD	Ча	Чэ	DO	Π	F	al	d1 / D	F		gample			
π	1	1 62	7 9	1 1 3	9 1 5	9 1 9	822 4	5 67	61 7	3762 1	#	N=14			
	2	3 69	355 9	22 72	9 15	9 23	616	1 43	15 49	711 2	" #	N-13			
	3	8.63	1325.1	36.18	9.15	9.27	421.9	0.35	3.78	70.9	#	N-11			
	4	13.76	2359	40	9.16	9.38	186.6	0.19	2.03	16.4	#	N-12			
	5	18.86	2896.2	36	9.15	9.38	116.8	0.22	2.35	15.2	#	N-10			
	6	19.32	2629.7	31.74	9.15	9.39	147.7	0.19	2.02	11.7	#	N-9			
	7	1.94	1.3	0.16	9.15	9.18	840.7	4.98	54.25	3505.8	#	N-7			
	8	6.20	907.8	34.42	9.15	9.25	482.5	0.43	4.65	92.9	#	N-2			
	9	9.47	1811.9	44.56	9.15	9.28	376.8	0.33	3.56	48.1	#	N-6			
	10	16.95	3135.1	43.37	9.16	9.38	164.4	0.19	2.03	12.1	#	N-5			
	11	23.72	3273.8	31.92	9.16	9.43	125.5	0.15	1.59	7.3	#	N-3			
	12	30.23	2330.1	17.95	9.17	9.38	105.8	0.15	1.6	6.1	#	N-1			
	13	1.57	17.6	2.68	9.16	9.17	872.3	5.2	56.71	3294.2	#	N-19			
	14	4.72	598.2	29.91	9.16	9.19	478.4	0.32	3.48	80	#	N-18			
	15	11.42	906.8	18.46	9.16	9.25	320.3	0.32	3.46	43.5	#	N-17			
	16	16.82	678.8	9.43	9.16	9.29	264	0.24	2.58	35.8	#	N-16			
	17	21.78	704	7.6	9.17	9.32	197.4	0.24	2.58	21.7	#	N-15			
	18	31.47	920.3	6.87	9.15	9.35	70.5	0.09	0.96	3.36	#	N-8			
	19	2.19	4.4	0.47	9.16	9.17	761.5	3.82	41.66	2582.9	#	N-25			
	20	4.93	11	0.52	9.16	9.19	765.1	0.84	9.14	420.1	#	N-24			
	21	10.16	785.6	18.19	9.16	9.22	330.1	0.33	3.58	43.8	#	N-23			
	22	14.76	611.2	9.75	9.16	9.24	298.6	0.32	3.46	41.4	#	N-22			
	23	19.35	549.5	6.66	9.16	9.25	217.9	0.29	3.14	27.5	#	N-21			
	24	26.58	580.3	5.11	9.16	9.32	121.5	0.22	2.36	11.7	#	N-20			

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#		AEKI	AEKI compression tests summary file									
#		date	e: 2000									
#		Ziro	caloy ring	samples								
#												
##		ECR	[%]	equi	valent ox	idation c	on the bas	is of the	measure	d mass ga	in	
#		Hc	[wppm]	hydr	ogen cont	ent of th	e sample a	after the	oxidati	on		
#		Ha	[%]	absc	rbed hydr	rogen						
#		DO	[mm]	diam	neter befo	ore oxidat	ion					
#		D [r	nm]	diam	neter afte	er oxidati	on					
#		F [1	1]	ford	ce							
#		dl	[mm]	defo	ormation							
#		dl/I	D [응]	rela	tive defo	ormation						
#		E [r	nJ]	ener	дХ							
#												
#	No	ECR	HC	Ha	DO	D	F	dl	dl/D	E		Sample
	1	2.28	2.6	0.22	10.74	10.84	789.5	5.38	49.63	3301.1	#	Y-11
	2	3.49	2.3	0.13	10.74	10.89	677.5	4.44	40.77	2549.3	#	Y-10
	3	5.93	1.6	0.05	10.74	10.93	674.7	1.68	15.37	836.9	#	Y-8
	4	7	0.4	0.01	10.74	10.94	615.9	1.5	13.71	669.7	#	Y-9
	5	2.89	1.2	0.08	10.74	10.83	661.3	4.91	45.34	2665.8	#	Y-6
	6	6.02	0.9	0.03	10.74	10.9	619	2.09	19.17	1013.9	#	Y-5
	7	12.26	0.6	0.01	10.75	10.95	462.6	1.69	15.43	302.2	#	Y-1
	8	15.18	8	0.1	10.74	10.97	431.7	0.64	5.83	179.7	#	Y-7
	9	20.37	997.2	9.52	10.74	11.09	288.6	0.48	4.33	73.7	#	Y-4
	10	44.03	1853.8	8.18	10.74	11.44	118.6	0.31	2.72	17.5	#	Y-3
	11	77.29	110.2	0.28	10.75	12.23	26.1	0.18	1.48	2.9	#	Y-2
	12	2.83	0.6	0.04	10.74	10.82	758.3	5.7	52.68	3452.1	#	Y-17
	13	5.45	1.4	0.05	10.74	10.85	690.1	4.33	39.91	2744.5	#	Y-16
	14	10.11	2.6	0.05	10.74	10.89	659.2	2.25	20.66	1179.3	#	Y-15
	15	15.21	1.6	0.02	10.74	10.9	553.6	1.09	10	382.5	#	Y-14
	16	19.49	2.1	0.02	10.74	10.93	424.5	0.7	6.4	183.8	#	Y-13
	17	26.77	5.5	0.04	10.74	10.97	256.8	0.51	4.65	72.2	#	Y-12
	18	3.48	1.6	0.085	10.74	10.82	706.5	4.13	38.17	2473.1	#	Y-23
	19	5.76	0.7	0.025	10.74	10.84	676.7	1.85	17.07	1044.3	#	Y-22
	20	10.48	0.9	0.016	10.74	10.87	625.4	0.92	8.46	313.4	#	Y-21
	21	15.36	1.4	0.017	10.74	10.88	407.9	0.59	5.42	119.1	#	Y-20
	22	21.85	4.9	0.043	10.74	10.92	279.8	0.41	3.75	72.1	#	Y-18
	23	25.73	1.1	0.008	10.74	10.93	206.4	0.41	3.75	43.7	#	Y-19

Appendix	13:	

Data of oxidation tests COHYRA

# Double side oxidation in hydrogen rich steam atmosphere								
# date: 2004-2005								
# Project: Zr Cladding Oxidation in Hydrogen Rich Atmosphere (COHYRA)								
# Zr1%Nb tube samples								
# Wall thickness = 0.65 mm	1							
#								
# T [C]	oxidation temperature							
# t [s]	oxidation time							
# Hs [vol. %]	hydrogen content in the steam							
# dma [g]	absolute mass gain							
# D [mm]	outer diameter of the sample							
# L [mm]	length of the sample							
# F [cm^2]	surface area							
# k [mg/cm^2/s^0.5]	rate constant							
# ECR [%]	equivalent cladding reacted							
# Hc [wppm]	hydrogen content of the sample after the oxidation							
#								
# Reference								

#[11] E. Perez-Feró, L. Vasáros, Cs. Győri, P. Windberg, Z. Hózer: Oxidation of E110 cladding in

hydrogen rich steam atmosphere, AEKI, Budapest, June 2005 #

#

Ħ												
#	No	Т	t	Hs	dma	D	L	F	k	ECR	Hc	Sample
#												
	1	1000	330	20	0.0062	9.1	8.08	4.63	0.0736	1.8	357.9 #	PUM-VH-1
	2	1000	840	20	0.0167	9.1	8.04	4.61	0.1249	4.8	675.4 #	PUM-VH-2
	3	1000	3720	20	0.037	9.12	8.08	4.65	0.1306	10.7	1459.6 #	PUM-VH-3
	4	1000	6600	20	0.0521	9.16	8.01	4.63	0.1385	15.2	2270.2 #	PUM-VH-4
	5	1000	330	28	0.0079	9.16	8.03	4.64	0.0937	2.3	572.9 #	PUM-VH-5
	6	1000	510	28	0.0157	9.16	8.04	4.65	0.1496	4.6	1185.4 #	PUM-VH-6
	7	1000	2700	28	0.0362	9.16	8.02	4.64	0.1503	10.5	2712.1 #	PUM-VH-7
	8	1000	4380	28	0.0508	9.16	8.04	4.65	0.1652	14.8	2755.2 #	PUM-VH-8
	9	1000	330	36	0.0063	9.15	8.08	4.66	0.0744	1.8	533.8 #	PUM-VH-9
	10	1000	840	36	0.0191	9.16	8.03	4.64	0.142	5.6	1211.2 #	PUM-VH-10

MTA I	KFKI A	EKI
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11	1000	3000	36	0.0391	9.16	8.02	4.64	0.154	11.4	2490.3	#	PUM-VH-11
12	1000	3900	36	0.0588	9.16	7.97	4.61	0.2043	17.2	4086.9	#	PUM-VH-12
13	900	810	36	0.006	9.16	8.07	4.66	0.0452	1.7	501.7	#	PUM-VH-13
14	900	2520	36	0.0176	9.16	8.15	4.71	0.0745	5	1040.9	#	PUM-VH-14
15	900	6600	36	0.0358	9.16	8.1	4.68	0.0942	10.2	2838.3	#	PUM-VH-15
16	900	9720	36	0.0481	9.15	8.02	4.63	0.1054	14	4360.9	#	PUM-VH-16
17	900	600	28	0.0057	9.15	8.02	4.63	0.0503	1.7	264.9	#	PUM-VH-17
18	900	2220	28	0.0155	9.15	8.02	4.63	0.071	4.5	909.7	#	PUM-VH-18
19	900	6000	28	0.0359	9.15	8.02	4.63	0.1001	10.5	2851.3	#	PUM-VH-19
20	900	11520	28	0.0499	9.15	8.1	4.67	0.0995	14.3	3797.2	#	PUM-VH-20
21	900	690	20	0.0072	9.15	8.12	4.68	0.0585	2.1	747.6	#	PUM-VH-21
22	900	2640	20	0.0184	9.16	8.18	4.72	0.0759	5.3	707.9	#	PUM-VH-22
23	900	7200	20	0.0342	9.16	8.06	4.66	0.0865	9.8	2279.9	#	PUM-VH-23
24	900	14880	20	0.0485	9.15	8.11	4.68	0.085	13.9	2554.4	#	PUM-VH-24
25	1100	110	20	0.0075	9.14	8.07	4.65	0.1537	2.1	529.6	#	PUM-VH-25
26	1100	300	20	0.0159	9.15	8.1	4.67	0.1964	4.6	492.2	#	PUM-VH-26
27	1100	780	20	0.0368	9.15	8.08	4.66	0.2826	10.5	1598.4	#	PUM-VH-27
28	1100	1380	20	0.0512	9.15	8.07	4.66	0.296	14.7	1454.3	#	PUM-VH-28
29	1100	100	28	0.0075	9.14	8.08	4.66	0.1611	2.1	610.9	#	PUM-VH-29
30	1100	300	28	0.019	9.15	8.08	4.66	0.2353	5.5	2188.7	#	PUM-VH-30
31	1100	720	28	0.0369	9.15	8.02	4.63	0.297	10.6	2526.6	#	PUM-VH-31
32	1100	1140	28	0.0499	9.16	8.1	4.68	0.3159	14.3	3330.4	#	PUM-VH-32
33	1100	100	36	0.0066	9.15	8.06	4.65	0.1419	1.9	744.7	#	PUM-VH-33
34	1100	300	36	0.0169	9.16	8.05	4.65	0.2098	4.9	1259.2	#	PUM-VH-34
35	1100	720	36	0.0369	9.16	8.07	4.66	0.2949	10.6	2776.2	#	PUM-VH-35
36	1100	1380	36	0.0545	9.15	8.05	4.65	0.3158	15.6	2548.5	#	PUM-VH-36
39	1000	480	0	0.0155	-	-	-	-	4.5	-	#	Proba 1000 H2/5
												_

#

ΜΤΑ ΚΓΚΙ ΑΕΚΙ

D 1	D
Databas	se Report

Doub date	le side : 2006	oxidatior	n in hy	drogen ri	ch steam	atmosph	ere				
Proj	ect: Zr	Cladding	Oxidat	ion in Hy	drogen Ri	.ch Atmo	sphere	(COHYRA)			
Zr1%	Nb tube	samples		-	2		-				
Wall	thickne	ss = 0.65	5 mm								
Т [С]		oxid	dation ter	mperature						
t [s]		oxid	dation tim	ne						
Hs [vol. %]		hydi	rogen cont	tent in t	he stear	n				
dma	[g]		abso	olute mas:	s gain						
D [m	m]		oute	er diamete	er of the	sample					
L [m	m]		leng	gth of the	e sample						
F [C	m^2]		sur	face area							
k [m	g/cm^2/s	^0.5]	rate	e constant	t						
ECR	[%]		equi	ivalent c	ladding r	eacted					
No	Т	t	Hs	dma	D	L	F	k	ECR		Sample
1	1000	480	0	0.0098	9.14	8	4.61	0.0969	2.8	#	TEO-1
2	1000	760	0	0.0146	9.14	8	4.61	0.1148	4.2	#	TEO-2
3	1000	2520	0	0.0478	9.14	8	4.61	0.2064	14.1	#	TEO-5
4	1000	810	5	0.0182	9.14	8	4.61	0.1386	5.4	#	VH-04
5	1000	330	5	0.0082	9.14	8	4.61	0.0978	2.4	#	VH-05
6	1000	2700	5	0.0477	9.14	8	4.61	0.199	14.1	#	VH-06
7	1000	1560	5	0.0296	9.14	8	4.61	0.1624	8.7	#	VH-07
8	1000	2700	5	0.0488	9.14	8	4.61	0.2035	14.4	#	VH-11
9	1000	2700	65	0.047	9.14	8	4.61	0.196	13.8	#	VH-12
10	1000	1560	65	0.0278	9.14	8	4.61	0.1525	8.2	#	VH-13
11	1000	810	65	0.0153	9.14	8	4.61	0.1165	4.5	#	VH-14
12	1000	1560	65	0.0302	9.14	8	4.61	0.1657	9	#	VH-18
13	1000	330	65	0.0098	9.14	8	4.61	0.1169	2.9	#	VH-19
14	1000	2700	65	0.042	9.14	8	4.61	0.1752	12.5	#	VH-20
15	900	2520	5	0.0138	9.14	8	4.61	0.0596	4.1	#	VH-01
16	900	7200	5	0.0393	9.14	8	4.61	0.1004	11.6	#	VH-02
17	900	810	5	0.0055	9.14	8	4.61	0.0419	1.6	#	VH-03
18	900	7200	65	0.0254	9.14	8	4.61	0.0649	7.5	#	VH-15
19	900	810	65	0.006	9.14	8	4.61	0.0457	1.8	#	VH-16

MTA KFKI AEKI												Database Re	port
20	900	2700	65	0.0147	9.14	8	4.61	0.0613	4.4	#	VH-17		
21	1100	300	5	0.0198	9.14	8	4.61	0.2478	5.9	#	VH-08		
22	1100	100	5	0.0103	9.14	8	4.61	0.2232	3	#	VH-09		
23	1100	720	5	0.0307	9.14	8	4.61	0.248	9	#	VH-10		
24	1100	100	65	0.0107	9.14	8	4.61	0.2319	3.2	#	VH-21		
25	1100	390	65	0.0241	9.14	8	4.61	0.2645	7.2	#	VH-22		
26	1100	720	65	0.0352	9.14	8	4.61	0.2843	10.5	#	VH-23		
27	1100	720	65	0.0333	9.14	8	4.61	0.269	9.9	#	VH-24		
28	1100	720	65	0.0331	9.14	8	4.61	0.2673	9.9	#	VH-25		

Appendix 14:

Data of oxidation tests COHYRA

# Double # date: 2 # Projec # Zr1%M # Wall t	e side ox 2004-200 t: Zr Cla Nb tube s hickness	idation in 5 dding Oxi samples = 0.65 m	hydroge idation ir m	en rich st n Hydrog	eam atmos gen Rich A	sphere tmosph	ere (COH	IYRA)					
#													
# T [C]			oxidati	ion temp	erature								
#t[s]			oxidati	ion time									
# Hs [vo	ol. %]		hydrog	gen conte	ent in the s	team							
# dma [g	g]		absolu	te mass	gain								
# D [mn	n]		outer c	liameter	of the sam	ple							
# L [mm	1]		length	of the sa	ample								
# F [cm'	^2]		surface	e area									
# k [mg/	/cm^2/s^	0.5]	rate co	nstant									
# ECR [%]		equiva	lent clac	Iding react	ed	0 1						
# Hc [w]	ppm]		hydrog	gen conte	ent of the s	ample a	after the c	oxidation					
# #													
# #	No	т	t	Цe	dma	D	т	F	k	ECP	Но		Sample
# #	INU	1	ι	115	uma	D	L	1	к	LUK	11c		Sample
	1	1000	160	20	0.0016	913	2.14	1 49	0.0851	18	624 3	#	PUM2-VH-1
	2	1000	390	20	0.0047	9.13	2.14	1.49	0.1601	5.2	1253.4	#	PUM2-VH-2
	3	1000	150	28	0.0015	9.14	2.13	1.48	0.0826	1.7	331.8	#	PUM2-VH-3
	4	1000	360	28	0.0046	9.14	2.14	1.49	0.1629	5.1	1412.3	#	PUM2-VH-4
	5	1000	160	36	0.0016	9.16	2.13	1.49	0.0851	1.8	283.4	#	PUM2-VH-5
	6	1000	360	36	0.0044	9.14	2.15	1.49	0.1553	4.9	1443.7	#	PUM2-VH-6
#													
	7	900	390	36	0.0018	9.12	2.13	1.48	0.0616	2	675.8	#	PUM2-VH-7
	8	900	1980	36	0.0048	9.13	2.14	1.49	0.0726	5.3	1235.6	#	PUM2-VH-8
	9	900	360	28	0.0015	9.14	2.14	1.49	0.0531	1.7	382.6	#	PUM2-VH-9
	10	900	1740	28	0.0044	9.13	2.15	1.49	0.0707	4.9	1009.3	#	PUM2-VH-10
	11	900	510	20	0.002	9.12	2.13	1.48	0.0599	2.2	302.4	#	PUM2-VH-11
	12	900	1920	20	0.0043	9.13	2.15	1.49	0.0658	4.8	696.4	#	PUM2-VH-12

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13	1100	50	20	0.0018 9.14	2.15	1.49	0.1704 2	159.4 #	PUM2-VH-13
14	1100	180	20	0.0043 9.12	2.13	1.48	0.2166 4.8	979.4 #	PUM2-VH-14
15	1100	55	28	0.0016 9.13	2.14	1.49	0.1451 1.8	306.3 #	PUM2-VH-15
16	1100	200	28	0.005 9.14	2.17	1.5	0.235 5.5	1018.9 #	PUM2-VH-16
17	1100	55	36	0.0018 9.13	2.15	1.49	0.1627 2	298.5 #	PUM2-VH-17
18	1100	190	36	0.0051 9.13	2.14	1.49	0.2489 5.7	1329.1 #	PUM2-VH-18
19	1100	180	36	0.0049 9.16	2.15	1.5	0.244 5.4	1497.4 #	PUM2-VH-19

Appendix 15:

Data of oxidation tests COHYRA

# One si # date: 2	ide oxida 2004-200	ation in hy)5	drogen ri	ch stear	n atmosphe	ere							
# Projec	et: Zr Cla	dding Oxi	dation ir	Hydrog	gen Rich A	tmosphe	re (COF	IYRA)					
# Zr1%]	Nb tube s	samples											
# Geom	etry: out	er diamete	r = 9.14i	nm, wa	ll thickness	s = 0.65 m	ım, leng	th =100m	m				
# Surfac	e area=	28.71cm^2	2										
#													
# T [C]			oxidati	on temp	berature								
#t[s]			oxidati	on time									
#Hs [vo	ol. %]		hydrog	en cont	ent in the s	team							
# dma [g	dma [g] absolute mass gain												
# k [mg/	$\frac{1}{4} \text{k} [\text{mg/cm}^2/\text{s}^{0.5}] \qquad \text{rate constant}$												
# ECR [%]		equiva	lent clac	lding react	ed							
#Hc [w	ppm]		hydrog	en cont	ent of the s	ample af	ter the o	xidation					
#						-							
#													
#	No	Т	t	Hs	dma	k	ECR	Hc		Sample			
#													
	1	900	1800	36	0.0648	0.0532	0.7	647	#	P1			
	2	900	960	20	0.0663	0.0745	0.7	645.7	#	P2			
	3	1000	540	36	0.1226	0.1838	1.2	477.9	#	P3			
	4	1000	900	20	0.4995	0.5799	4.8	551.2	#	P4			
	5	1100	180	36	0.1544	0.4008	1.5	627.9	#	P5			
	6	1100	300	20	0.1245	0.2504	1.2	430.3	#	P6b			
	7	1000	900	0	0.0452	0.0525	0.5	_	#	P7			

Appendix 16:

Data of compression tests COHYRA

#	AEKI	compres	ssion tests :	summar	y file										
#	date:	2004-200)5												
#	Projec	et: Zr Cla	dding Oxi	dation in	n Hydrog	en Rich	Atmosphe	ere (COH	YRA)						
#	Zrľ%	6Nb ring	samples						<i>,</i>						
#		U	1												
#	ECR	[%]	equivaler	nt oxida	tion on th	ne basis o	f the mea	sured ma	ss gain						
#	Hc [w	/ppm]	hydrogen	n conten	t of the s	ample af	ter the ox	idation	-						
#	a [mn	n	width			-									
#	b [mn	n]	wall thic	kness											
#	D [mi	m]	outer dia	meter											
#	F [N]	-	force												
#	dl [m	m]	deformat	ion											
#	dl/D [[%]	relative d	leforma	tion										
#	E [mJ		energy												
#	rducp	[%]	residual	ductility	7										
#	rducm	[mm]	residual	ductility	7										
#	Espec	[mJ/mm] specific	energy a	at failure										
ш															
# #															
# #	No	ECD	II.		h	D	Б	41	41/D	Б	ndram	u daa ama	Earnala	Comm10	
# #	INO	EUK	пс	a	U	D	Г	ui	ui/D	E	raucp	Taucin	Espec	Sample	
	1	1.8	357.9	8.1	0.73	9.15	702.6	2.54	27.76	1497.56	5 22.62	2.07	184.88	#	PUM-VH-1
	2	4.8	675.4	8.11	0.72	9.19	709.4	0.593	6.45	242.18	1.52	0.14	29.86	#	PUM-VH-2
	3	10.7	1459.6	8.15	0.75	9.25	193.5	0.177	1.91	16.02	0.17	0.016	1.97	#	PUM-VH-3
	4	15.2	2270.2	8.14	0.75	9.26	144.5	0.12	1.3	8.58	0	0	1.05	#	PUM-VH-4
	5	2.3	572.9	8.05	0.72	9.16	639.3	1.103	12.04	544.94	7.75	0.71	67.69	#	PUM-VH-5
	6	4.6	1185.4	8.11	0.71	9.18	589.8	0.457	4.98	146.95	0.76	0.07	18.12	#	PUM-VH-6
	7	10.5	2712.1	8.13	0.75	9.29	188.2	0.137	1.47	12.09	0	0	1.49	#	PUM-VH-7
	8	14.8	2755.2	8.17	0.74	9.28	96.5	0.217	2.34	9.65	0	0	1.18	#	PUM-VH-8
	9	1.8	533.8	8.09	0.71	9.15	675.1	2.27	24.81	1300.92	2 19.89	1.82	160.81	#	PUM-VH-9

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11	11.4	2490.3	8.12	0.73	9.23	186	0.17	1.84	11.47	0	0	1.41	#	PUM-VH-11
12	17.2	4086.9	8.14	0.72	9.35	149.9	0.11	1.18	7.7	0	0	0.95	#	PUM-VH-12
13	1.7	501.7	8.04	0.7	9.16	952.8	5.493	59.97	3843.24	4 51.97	4.76	478.01	#	PUM-VH-13
14	5	1040.9	8.25	0.73	9.29	451.1	0.377	4.06	79.43	0.3	0.028	9.63	#	PUM-VH-14
15	10.2	2838.3	8.23	0.75	9.36	285.2	0.247	2.64	29.58	0	0	3.59	#	PUM-VH-15
16	14	4360.9	8.21	0.74	9.44	175	0.173	1.83	12.34	0	0	1.5	#	PUM-VH-16
17	1.7	264.9	8.06	0.71	9.2	901	5.13	55.76	3411.71	48.04	4.42	423.29	#	PUM-VH-17
18	4.5	909.7	8.09	0.75	9.31	468.8	0.423	4.54	102.93	0.61	0.057	12.72	#	PUM-VH-18
19	10.5	2851.3	8.19	0.76	9.42	256.4	0.207	2.2	23.51	0	0	2.87	#	PUM-VH-19
20	14.3	3797.2	8.29	0.76	9.5	164.3	0.16	1.68	11.01	0	0	1.33	#	PUM-VH-20
21	2.1	747.6	8.16	0.72	9.24	762.8	3.543	38.34	2209.59	32.25	2.98	270.78	#	PUM-VH-21
22	5.3	707.9	8.32	0.73	9.33	496.2	0.417	4.47	108.44	0.43	0.04	13.03	#	PUM-VH-22
23	9.8	2279.9	8.25	0.74	9.38	325.8	0.257	2.74	42.11	0	0	5.1	#	PUM-VH-23
24	13.9	2554.4	8.3	0.74	9.39	196.8	0.177	1.88	16.27	0.11	0.01	1.96	#	PUM-VH-24
25	2.1	529.6	8.08	0.7	9.14	701	0.883	9.66	408.01	4.27	0.39	50.5	#	PUM-VH-25
26	4.6	492.2	8.13	0.74	9.16	725.6	0.743	8.11	312.72	2.51	0.23	38.47	#	PUM-VH-26
27	10.5	1598.4	8.17	0.74	9.28	225.3	0.177	1.91	17.88	0	0	2.19	#	PUM-VH-27
28	14.7	1454.3	8.16	0.74	9.26	195.4	0.167	1.8	14.26	0	0	1.75	#	PUM-VH-28
29	2.1	610.9	8.08	0.7	9.14	788	3.917	42.86	2648.53	3 35.01	3.2	327.79	#	PUM-VH-29
30	5.5	2188.7	8.06	0.74	9.21	326	0.26	2.82	36.14	0	0	4.48	#	PUM-VH-30
31	10.6	2526.6	8.15	0.75	9.21	281.5	0.233	2.53	22.54	0	0	2.77	#	PUM-VH-31
32	14.3	3330.4	8.17	0.74	9.19	204	0.173	1.88	13.73	0	0	1.68	#	PUM-VH-32
33	1.9	744.7	8.05	0.7	9.15	821.3	4.13	45.14	2807.16	5 38.25	3.5	348.72	#	PUM-VH-33
34	4.9	1259.2	8.06	0.75	9.22	402.2	0.343	3.72	53.67	0	0	6.66	#	PUM-VH-34
35	10.6	2776.2	8.15	0.74	9.2	249	0.213	2.32	19.25	0	0	2.36	#	PUM-VH-35
36	15.6	2548.5	8.12	0.76	9.23	193.4	0.173	1.87	12.45	0	0	1.53	#	PUM-VH-36
39	4.5	-	8.07	0.79	9.20	673.7	-	-	-	-	-	-	#	Proba 1000_H2/5

ΜΤΑ ΚΓΚΙ ΑΕΚΙ

	#		AEKI compre	ession tests	s summary f	ile								
	#		date: 2007											
	#		Project: Zr	Cladding (Dxidation i	n Hydrogen	Rich Atmosp	here (COHYR	A)					
	#		Zr1%Nb ring	g samples										
	#													
	#		ECR [%]	equiv	valent oxid	ation on th	e basis of	the measure	d mass gair	l				
	#		Hc [wppm]	hydro	ogen conten	t of the sa	mple after	the oxidati	on					
	#		a [mm]	width	1									
	#		b [mm]	wall	thickness									
	#		D [mm]	outer	r diameter									
	#		F [N]	force	5									
	#		dl [mm]	defoi	rmation									
	#		dl/D [%]	relat	tive deform	ation								
	#		E [mJ]	energ	ЗУ									
	#		rducp [%]	resid	dual ductil	ity								
	#		rducm [mm]	resid	dual ductil	ity								
#			Espec [mJ/m	nm] spec:	ific energy	at failure	5							
# #	No	ECR	Hc	a	b	D	F	dl	dl/D	E	Espec	rducm	rducp	Sample
#														
	1	2.8	578	8.03	0.73	9.23	665.9	1.847	20.0	217.5	27.08	1.34	14.5 #	TEO-1
	2	4.2	1384	8.02	0.74	9.23	726.9	0.807	8.7	319.7	39.86	0.22	2.3 #	TEO-2
	3	14.1	2713	8.18	0.80	9.32	198.6	0.270	2.9	17.9	2.19	0.01	0.1 #	TEO-5
	4	4.1	734	8.17	0.74	9.25	594.7	2.880	31.1	1684.1	206.14	-	- #	VH-01
	5	11.6	1970	8.18	0.80	9.38	366.7	0.453	4.8	68.8	8.42	0.01	0.1 #	VH-02
	6	1.6	218	8.09	0.71	9.21	682.6	2.837	30.8	1574.8	194.66	2.21	24.0 #	VH-03
	7	5.4	1405	8.08	0.72	9.23	626.6	0.717	7.8	220.0	27.23	0.11	1.2 #	VH-04
	8	2.4	888	8.08	0.71	9.19	681.9	2.913	31.7	1614.1	199.77	2.26	24.6 #	VH-05
	9	14.1	3323	8.17	0.76	9.34	179.0	0.257	2.8	15.6	1.91	0.00	0.0 #	VH-06
	10	8.7	1725	8.17	0.74	9.29	392.7	0.430	4.6	69.9	8.55	0.00	0.0 #	VH-07
	11	5.9	571	8.05	0.72	9.21	735.3	1.153	12.5	561.3	69.73	0.52	5.6 #	VH-08
	12	3.0	912	8.03	0.70	9.17	729.1	2.917	31.8	1767.7	220.13	2.30	25.1 #	VH-09
	13	9.0	1215	8.08	0.74	9.22	638.2	0.767	8.3	273.2	33.81	0.20	2.2 #	VH-10
	14	14.4	3880	8.18	0.78	9.30	185.6	0.247	2.7	15.4	1.88	0.00	0.0 #	VH-11
	15	13.8	6996	8.22	0.78	9.38	123.2	0.197	2.1	8.3	1.01	0.00	0.0 #	VH-12
	16	8.2	3840	8.13	0.73	9.29	198.1	0.253	2.7	17.3	2.12	0.00	0.0 #	VH-13
	17	4.5	1595	8.13	0.71	9.22	461.4	0.477	5.2	87.0	10.70	0.02	0.2 #	VH-14
	18	7.5	2473	8.18	0.74	9.30	308.0	0.450	4.8	44.4	5.43	0.00	0.0 #	VH-15
	19	1.8	458	8.09	0.71	9.22	922.0	5.523	59.9	3821.5	472.38	4.77	51.7 #	VH-16
	20	4.4	1036	8.13	0.73	9.30	514.7	0.553	5.9	136.5	16.79	0.74	8.0 #	VH-17
	21	9.0	4661	8.15	0.75	9.27	214.2	0.280	3.0	19.2	2.36	0.00	0.0 #	VH-18
	22	2.9	2623	8.11	0.72	9.21	549.4	0.563	6.1	143.6	17.71	0.08	0.8 #	VH-19
	23	12.5	6063	8.16	0.74	9.36	165.9	0.253	2.7	12.4	1.52	0.00	0.0 #	VH-20
	24	3.2	1000	8.03	0.71	9.17	776.5	4.677	51.0	3086.4	384.36	3.09	33.7 #	VH-21
	25	7.2	2078	8.08	0.72	9.24	331.0	0.340	3.7	42.4	5.24	0.00	0.0 #	VH-22
	26	10.5	3335	8.09	0.73	9.25	204.4	0.257	2.8	16.2	2.00	0.00	0.0 #	VH-23
	27	9.9	2865	8.12	0.73	9.24	196.6	0.253	2.7	16.3	2.01	0.00	0.0 #	VH-24
	28	9.9	3565	8.08	0.73	9.24	194.7	0.267	2.9	15.4	1.90	0.00	0.0 #	VH-25

Appendix 17:

Data of tensile tests COHYRA

#	AEKI	tensile te	sts summa	ary file											
#	date: 2	004-2005	5												
#	Projec	t: Zr Clad	lding Oxio	dation ii	1 Hydrog	en Rich	Atmosph	ere (COH	YRA)						
#	Zr1%	Nb ring s	amples												
#															
#	ECR [%]		equiva	lent oxid	ation on	the basis	of the me	asured n	nass gair	ı				
#	Hc [w]	ppm]		hydrog	gen conte	nt of the	sample a	fter the ox	idation	-					
#	D [mn	1]		outer o	liameter		_								
#	a [mm]		width											
#	v [mm]		wall th	ickness										
#	So [mi	m2]		area of	f cross se	ction									
#	Fmax	[N]		maxin	um load										
#	Rm [N	[Pa]		tensile	strength										
#	al [mr	n]		width	after the	fracture									
#	v1 [mr	n]		wall th	ickness a	after the t	fracture								
#	Su [mi	m2]		area of	f its smal	lest cross	s section a	at the loca	tion of f	racture					
#	Z [%]			reduct	ion										
#															
#															
#	No	ECR	Hc	D	а	V	So	Fmax	Rm	al	v1	Su	Ζ		Sample
#	1	1.8	624.3	9.18	2.12	0.73	3.1	1507.1	486.9	2.01	0.7	2.81	9.09	#	PUM2-VH-1
	2	5.2	1253.4	9.26	2.13	0.73	3.11	648.1	208.4	2.1	0.72	3.02	2.76	#	PUM2-VH-2
	3	1.7	331.8	9.2	2.12	0.71	3.01	1470.5	488.5	1.88	0.63	2.37	21.31	#	PUM2-VH-3
	4	5.1	1412.3	9.23	2.15	0.73	3.14	684.8	218.2	2.08	0.73	3.04	3.26	#	PUM2-VH-4
	5	1.8	283.4	9.25	2.12	0.75	3.18	1456.5	458	1.92	0.68	2.61	17.89	#	PUM2-VH-5
	6	4.9	1443.7	9.22	2.15	0.73	3.14	390.6	124.4	2.15	0.73	3.14	0	#	PUM2-VH-6
	7	2	675.8	9.22	2.13	0.73	3.11	1365.7	439.2	1.6	0.68	2.18	30.03	#	PUM2-VH-7
	8	5.3	1235.6	9.28	2.17	0.75	3.26	562	172.7	2.15	0.73	3.14	3.56	#	PUM2-VH-8
	9	1.7	382.6	9.22	2.13	0.74	3.15	1402.9	445	1.56	0.65	2.03	35.67	#	PUM2-VH-9
	10	4.9	1009.3	9.27	2.17	0.74	3.21	683.8	212.9	2.17	0.74	3.21	0	#	PUM2-VH-10
	11	2.2	302.4	9.22	2.14	0.73	3.12	1372.6	439.3	1.6	0.68	2.18	30.35	#	PUM2-VH-11

12	4.8	696.4	9.26	2.18	0.72	3.14	877.5	279.5	2.16	0.72	3.11	0.92	#	PUM2-VH-12
13	2	159.4	9.19	2.14	0.72	3.08	1461.9	474.4	1.82	0.6	2.18	29.13	#	PUM2-VH-13
14	4.8	979.4	9.2	2.15	0.74	3.18	974.8	306.3	2.13	0.74	3.15	0.93	#	PUM2-VH-14
15	1.8	306.3	9.19	2.22	0.76	3.37	1455.3	431.3	1.88	0.65	2.44	27.57	#	PUM2-VH-15
16	5.5	1018.9	9.29	2.19	0.75	3.29	761.3	231.8	2.19	0.75	3.29	0	#	PUM2-VH-16
17	2	298.5	9.17	2.15	0.78	3.35	1475.8	440	2.01	0.7	2.81	16.1	#	PUM2-VH-17
18	5.7	1329.1	9.19	2.15	0.75	3.23	233.4	72.4	2.15	0.75	3.23	0	#	PUM2-VH-18
19	5.4	1497.4	9.25	2.14	0.74	3.17	417.3	131.8	2.14	0.73	3.12	1.35	#	PUM2-VH-19

Appendix 18:

Data of ballooning tests COHYRA

#1	sother	mal bal	looning t	ests at lin	ear pressi	ure increas	se with Z	r1%Nb	tube spe	cimens					
# (7 01		• • • •	TT 1	D' 1 A	· 1	(001)							
#1	Project	: Zr Cla	ading Or	xidation ii	n Hydrog	en Rich A	tmospne	re (COH	YKA)						
#	dp/dt	- pre	ssure inc	rease rate	[bar/s]										
#	TI	- ten	nperature	e at burst [[C]										
#	p0	- initi	al pressu	ire [bar]											
#	pl	- pres	sure at b	urst [bar]	(over pre	essure)									
#	t	- time	to burst [[s]											
#	Pe0	- ini	tial perin	neter [mm	1]										
#	v 0	- initi	al wall tl	hickness (nominal)	[mm]									
#	L0	- init	ial length	1 [mm]											
#	Pel	- ma	aximum p	perimeter	after the	burst									
#	epsm	- ma	aximum	deformati	on [%]										
#	Atmo	- at	mospher	e of the te	est										
#	Preox	- sa	imple nai	me at pre-	oxidation	n tests									
#															
#															
#		N T	0	1		1 / 1/	T 1	D 0	0	τo	D 1			, D	
#		No	p0	pl	t	dp/dt	11	Pe0	v0	L0	Pel	epsm	A	tmo Pre	ox
#		1	1	117	918	0.0127	1001.2	28 57	0.65	100	37	30	#	Ar	P1
		2	1	10.1	1261	0.008	999 3	28.57	0.65	100	35	23	#	Ar	P2
		3	1	10.9	1030	0.0106	1000 4	28.57	0.65	100	35	23	#	Ar	P3
		4	1	20.7	1432	0.0145	1000	28.57	0.65	100	35	$\frac{-2}{23}$	#	Ar	P4
		5	1	15.6	2096	0.0074	998.9	28.57	0.65	100	35	23	#	Ar	P5
		6	1	12.2	1302	0.0094	1003.6	28.57	0.65	100	35	23	#	Ar	P6b
		7	1	9.9	662	0.015	1003.4	28.57	0.65	100	33	16	#	Ar	P7
		8	1	8.6	958	0.009	1001.6	28.57	0.65	100	40	40	#	Ar	

Sample

Fuv-1 Fuv-2

Fuv-3

Fuv-4

Fuv-5

Fuv-6

Fuv-8

Fuv-15

Appendix 19:

Data of ballooning tests COHYRA

<pre># Isotherm # date: 200 # Project: # dp/dt # T1 # p0 # p1 # t # Pe0 # v0 # L0 # Pe1 # epsm # Atmo # Ppar # Hcal # Hc # #</pre>	al balloonin 05-2006 Zr Cladding - pressure - tempera - initial pre - pressure - time to bu - initial p - initial p - initial wa - initial ler - maximu - maximu - atmosp - partial p - calculate	ng tests at line g Oxidation in increase rate ture at burst [0 essure [bar] at burst [bar] (rst [s] erimeter [mm] Il thickness (r ngth [mm] um perimeter a um deformation here of the tess ressure of hydrogen con	ar pressure Hydrogen ([bar/s] C] (over pressu nominal) [m after the bur on [%] st lrogen [bar] ontent befo itent of the s	increase wi Rich Atmos ure) m] st re the test [cample after	wppm] the test [w	tube specin HYRA) ppm]	nens						
# N	o p() p1	t	dp/dt	Τ1	PeO	vO	LO	Pel	epsm	Hcal	Hc	
11	1 :	1 9.70	657	0.0148	1003.4	28.57	0.65	100	37.40	30.9	2250.0	692.7	#
	2 2	1 11.40	1086	0.0105	991.2	28.57	0.65	100	46.30	62.1	1350.0	1943.6	#
	3 :	1 10.20	990	0.0103	1000.2	28.57	0.65	100	40.35	41.2	515.0	710.0	#
	4	1 11.82	1153	0.0103	901.2	28.57	0.65	100	41.65	45.8	715.0	985.3	#
	5 1	14.87	1463	0.0102	900.2	28.57	0.65	100	38.00	33.0	715.0	468.2	#
	6	1 12.89	1232	0.0105	900.2	28.57	0.65	100	35.4	23.9	1100.0	1871.6	#
	7	1 8.60	958	0.0090	1001.6	28.57	0.65	100	40	40.0	_	_	#

Ppar Sample

0.1000 FUV-16H6 0.0358 FUV-19

0.0052 FUV-20 0.0050 FUV-21

_ Fuv-8

Ar-H 0.0050 FUV-22 Ar-H 0.0119 FUV-23

Atmo

Ar-H Ar-H

Ar-H Ar-H

Ar

Appendix 20: SEI images of the ballooning and compressed ring samples



Fuv-1

Fuv-3





Figure 39. Typical SEI images of burst samples 1, 3, and 5, respectively

File: E110_database_2007.doc



610 μm x 610 μm

Figure 40. Both ends of the opening up for sample Fuv-3



1.2 mm x 1.2 mm

610 μm x 610 μm

Figure 41. Both ends of the opening up for sample Fuv-5

File: E110_database_2007.doc



Sample PUM-VH-16 Sample PUM-VH-20 Figure 42. SEI images for compressed ring samples pre-oxidised at 900 °C for various times



beta Zr, Widmanstätten lines 250 μm x 250 μm sample area

Figure 43. Typical SEI images for sample PUM-VH-16 showing the various structural elements

 $120 \ \mu m \ x \ 120 \ \mu m$ sample area



0.8 mm x 0.8 mm sample area

Sample PUM-VH-1 330s oxid. time, 357.9 ppm H₂ Sample PUM-VH-4 6600 s oxid. time, 2270.2 ppm H₂



250 μm x 250 μm Sample PUM-VH-12 3900s oxid. time, 4086.9 ppm H₂

Figure 44. SEI images of compressed ring samples pre-oxidised for various times at 1000 °C temperature



65 μm x 65 μm

500 μm x 500 μm





 $125~\mu m~x~125~\mu m$



250 μm x 250 μm





65 μm x 65 μm



 $250~\mu m~x~250~\mu m$

Sample PUM –VH-12 Figure 45. Typical SEI images for samples pre-oxidised at 1000 °C





250 μm x 250 μm Sample PUM-VH- 26 Oxid. time 300 s, 492.2 ppm H₂



800 µm x 800 µm



 $65~\mu m \ x \ 65~\mu m$

Sample PUM-VH-32 Oxid. time: 1140 s, 3330.4 ppm H₂

Figure 46. SEI images for compressed ring samples pre-oxidised at 1100 °C