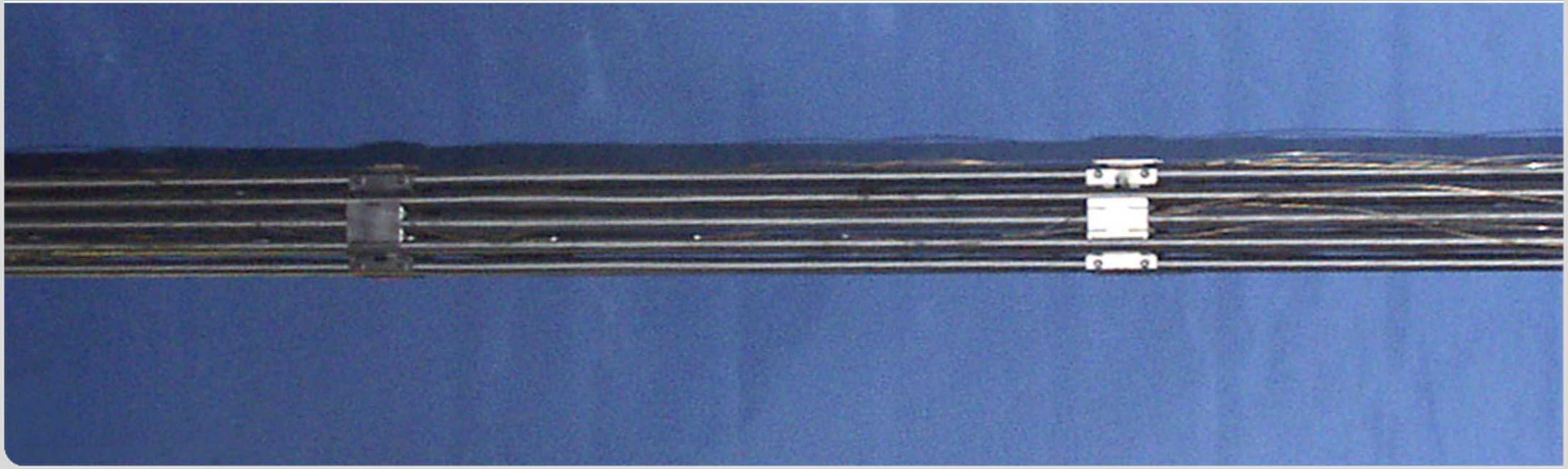
Karlsruhe Institute of Technology

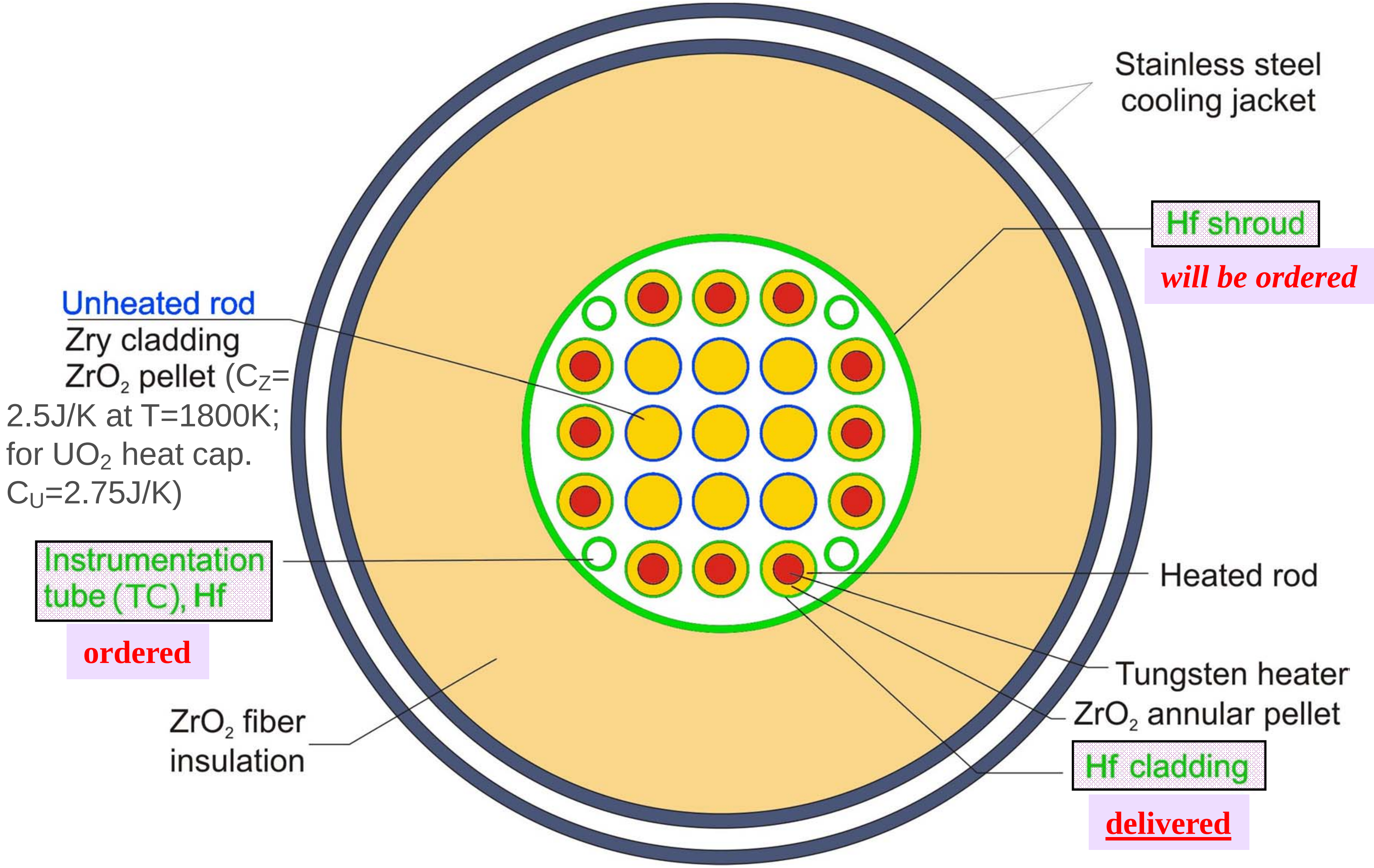
QUENCH-Debris
Bundle Tests on Debris Formation and Coolability
SARNET-2 WP5.1 proposal

presented by J. Stuckert

Institute of Apllied Materials



Kick-off meeting (April 2009): proposal of bundle tests on debris formation and coolability: 9 "prototypical" rods without heater



Melting points: Zry-4 ~ 2070 K, Hf ~ 2500 K

Decisions of Topical Meeting on QUENCH-Debris KIT, Karlsruhe, Germany, 18 Nov 2010

- The first test should be performed with hafnium components and including the debris formation phase. The conditions of the second test will be discussed after conduct of the first test, including the option of use of a pre-formed debris bed.

- The bundle should be significantly or even completely oxidised in the region of debris formation. Slow and controlled oxidation and temperature transients will favour reaching of this goal.

- The axial temperature profile should be as flat as possible to maximise the extent of debris formation. Pre-test calculations will clarify if this is possible by optimising the steam and Ar flow rates or if design changes of the test section (material and length of heaters, shaped thermal insulation) are needed.

- Pre-tests will be performed to check if cracking of the pellets and debris formation could be expected during quenching the bundle with water.

Participants of pre-test calculations

- Paul Sherrer Institut PSI/Villigen : MELCOR, SCDAP/RELAP
- IBRAE/Moscow: SOCRAT
- IRSN/Cadarache: ICARE-CATHARE V2
- RUB-LEE/Bochum: ATHLET-CD
- GRS/Garching, Köln: ATHLET/CD

Thermal properties of Hf

temperature	specific heat	specific heat	thermal conductivity	thermal expansion	density
K	J/mol*K	J/kg*K	W/m*K	1/K	kg/m³
T	**cp**	**cp'**	λ	α	ρ
300	25.20	141.15	23	5.96E-06	13309.52
600	27.68	155.09	23	6.60E-06	13230.73
900	30.17	169.04	23	7.28E-06	13136.63
1200	32.66	182.98	23	7.99E-06	13026.27
1500	35.15	196.93	23	8.75E-06	12898.87
1800	37.64	210.88	23	9.54E-06	12753.78
2000	39.30	220.19	23	1.01E-05	12646.98

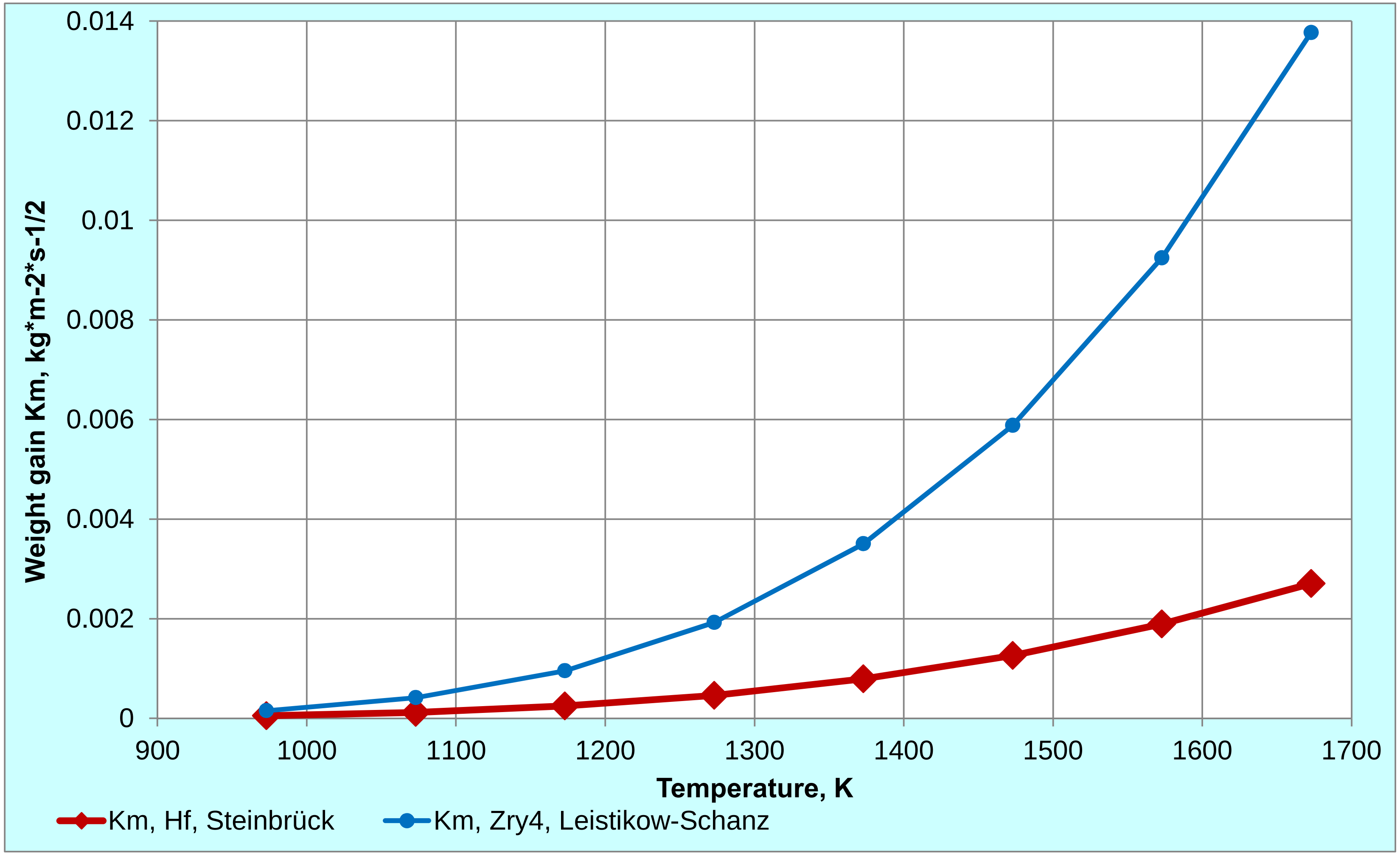
T>2016 K		
2100	35.20	197.19
2200	35.31	197.80
2300	35.42	198.41
2400	35.52	199.02
2500	35.63	199.63

Comparison with Zr					
T	***cp***	***cp'***	*λ*	*α*	*ρ*
300	*26.00*	*285*	*22.7*	*5.21E-06*	*6506*
2000	*29.28*	*321*	*22.7*	*1.29E-05*	*6272*

Oxidation kinetics of Hf

weight gain ($kg/m^2*s^{1/2}$): $\mathbf{K_m=K_0*EXP(-E_A/(R*T))}$

with $K_0 = 0.76\ kg/m^2*s^{1/2}$; $E_A = 78423\ J/mol$

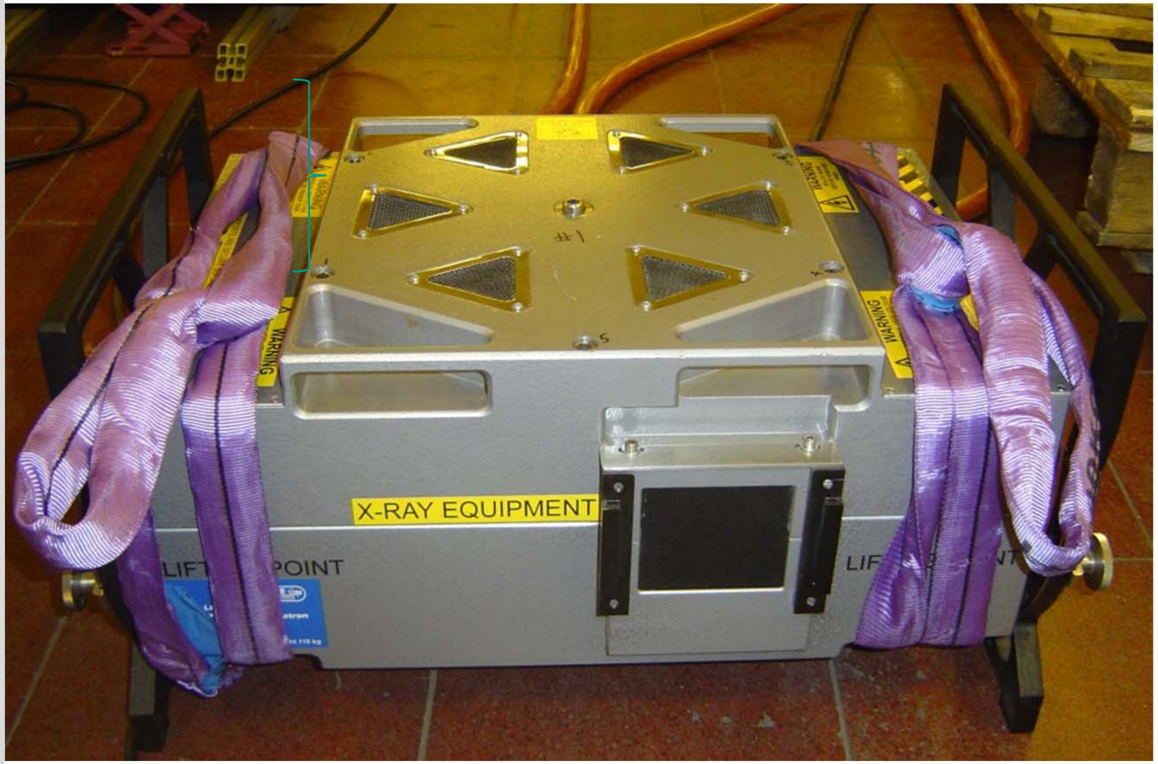


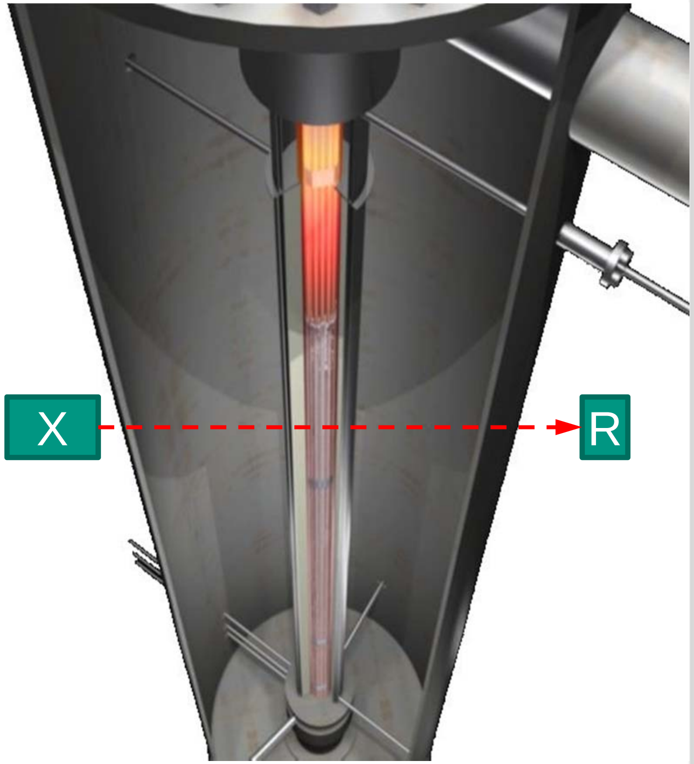
RIAR single rod test on reflood of fuel rods with burn-up of 65 MWd/kgU (ISTC 1648.2); reflood from 1700°C

UO_2 pellets <u>not</u> fragmented:
sintering at high temperature

→ QUENCH-DEBRIS test could be performed with not fragmented ZrO_2 pellets

Betatron 7.5 MeV for the bundle post-test radiography





Preliminary agreement with the BAM – federal company for material tests

Current QUENCH activity: preparation of QUENCH-16 test on air ingress in framework of the EU LACOMECO project

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Proposed by KFKI-AEKI/Budapest together with INRNE Sofia

Participants of pre-test calculations

- PSI/Villigen : SCDAP-SIM
- EDF/Clamart: MAAP4
- GRS/Garching: ATHLET/CD
- IRSN/Cadarache: ICARE-CATHARE V2

QUENCH-LACOMECO Pre-test calculations: boundary conditions and results

	PSI (SCDAPSIM with PSI air))	GRS (ATHLET-CD)	EDF (MAAP)
Heat-up +Pre-oxidation	0-5000 s 10 kW 3 g/s steam 3 g/s Ar	0-2000-5000 s 3.85 → 10 kW 3 g/s steam 3 g/s Ar	0-5000 s 10 kW 3 g/s steam 3 g/s Ar
Cooldown	5000-6000 s 4.0 kW 3 g/s steam 3 g/s Ar	5000-6000 s 4.0 kW 3 g/s steam 3 g/s Ar	5000-6000 s 4.0 kW 3 g/s steam 3 g/s Ar
Air	6000-ca.11700 (9260) s 4.0 kW 3 (1) g/s Ar 0.2 g/s air	6000-13500 s 4.0 kW 3 (1) g/s Ar 0.2 g/s air	6000-9000 s 4.0 kW 3 g/s Ar 0.2 g/s air
Quench	11700 (9260) s (at 1823 K) 0/4 kW Fast injection, then 50 g/s water	12470 (9420) s (at 1823 K) 0 kW Fast injection, then 50 g/s water	9000 s (at 1823 K) 0 kW Fast injection, then 50 g/s water
Max. oxide after pre-oxidation	186 µm	190 µm	ca. 242 µm
Duration air phase	5700 (3260) s	6470 (3420) s	3000 s
Duration oxygen starvation	3270 (1540) s	470 (920) s	1100 s
Remarks	**- shorter air phase and almost no starvation for 0.5 g/s air** **- no influence of 0/4 kW during quench**	**- rapid temp. increase for 0.5 g/s air to >2000 K** **- activation of ZrN model causes higher temperatures and longer starvation time**	**- no variation of gas flow rates**