

IAEA Coordinated Research Projects (CRPs) on ATF: ACTOF (2014-2019) and ATF-TS (2020-2023)

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IAEA Webinar on Accident Tolerant Fuels and Their Impact on
Spent Fuel Management

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CRP on Analysis of Options and Experimental Examination of Fuels with Increased Accident Tolerance (ACTOF), 2014-19



❑ Objectives

- To support options for the development of nuclear fuel with an improved tolerance of severe accident conditions
- To support modelling of new fuel designs with advanced cladding or fuel
- To acquire data through experiments on new fuel types and cladding materials to support their use for fuel with improved accident tolerance

❑ Participants (17 organizations from 13 MSs)

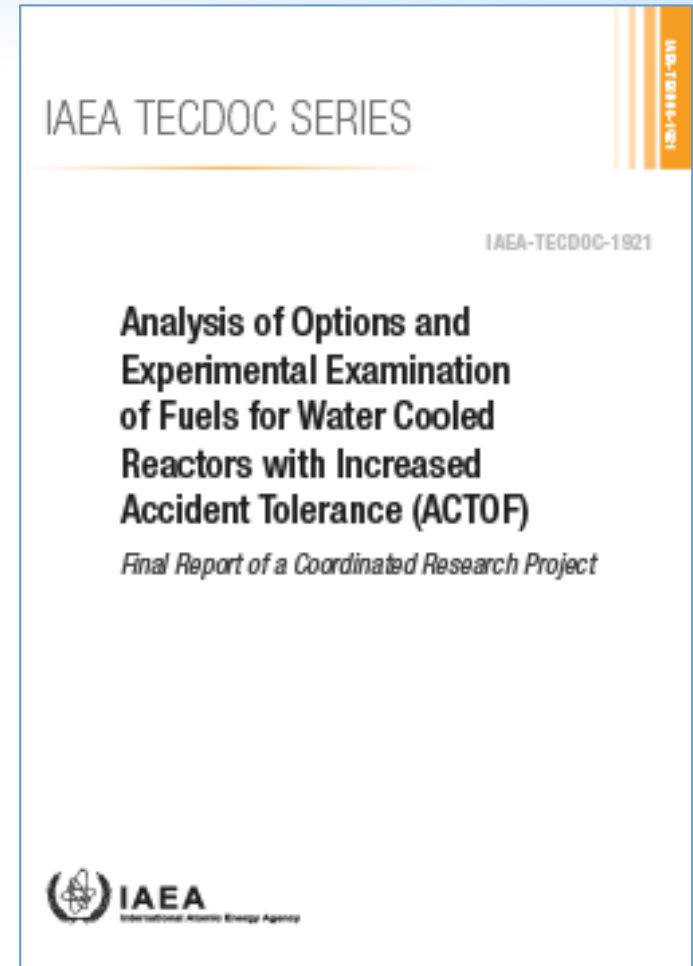
Argentina (CNEA), Brazil (USP), China (CNPRI, CIAE, NPIC), Finland (VTT), Germany (KIT), India (BARC), Italy (NINE), Korea (KAERI), Poland (INCT), Russian Federation (VNIINM, IBRAE), United States (Westinghouse, Batelle), Czech Republic (CTU), JAEA (Japan) [*joined at RCM-2*]

❑ Observers

OECD-NEA, EPRI (USA), US NRC, GRS (Germany) – *active*

ACTOF Joint Actions

- Round Robin Tests
- Benchmark Exercise
- Severe Accident
Experimental and Modelling
Exercise



Round Robin Tests

❑ 7 participants

- WEC (Westinghouse): coordination
- CTU: Czech Technical University /UJP Praha (Czech Republic)/ MTA EK (Hungary)
- Karlsruhe Institute of Technology (KIT), Germany
- VTT Materials for Power Engineering, Finland
- Institute of Nuclear Chemistry and Technology (INCT), Poland
- University of Sao Paulo (USP), Brasil

❑ Activity was divided into three subtasks (the involvement is summarized in Table):

- Sample production
- Long-term corrosion test (VVER or PWR chemistry)
- High-temperature steam oxidation

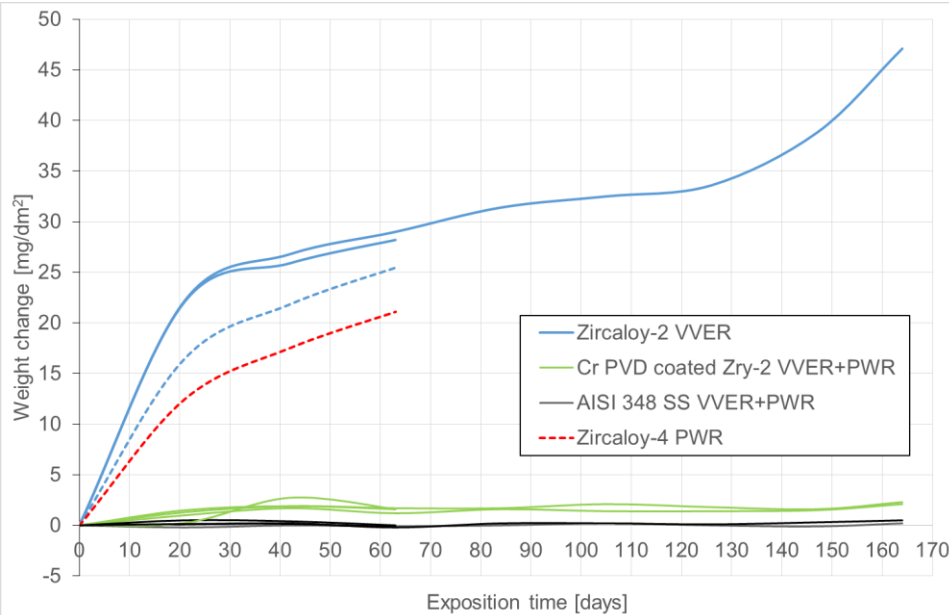
	CTU	KIT	INCT	VTT	USP	MTA EK
SAMPLE PRODUCTION	X	X	X		X	
LONG-TERM CORROSION	X		X	X		
HIGH-TEMPERATURE OXIDATION	X	X		X		X

ATF Sample Production

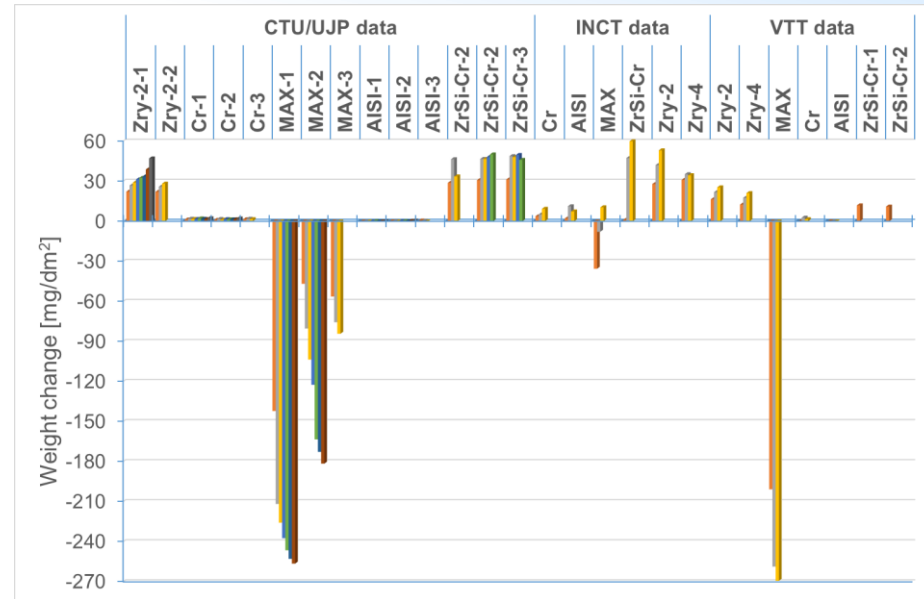
- Four types of ATF candidate cladding samples produced (3 coated cladding concepts + advanced steel)
 - Cr PVD coated Zry-2 and E110 (Zr1%Nb) cladding – produced by CTU
 - Cr/Cr₂AlC/Cr PVD coated Zry-4 – produced by KIT
 - ZrSi-Cr PVD coated Zry-2 – produced by INCT
 - AISI 348 stainless steel – produced by USP
- Westinghouse Electric Company provided Zry-2 substrates for Cr and ZrSi-Cr coated samples
- UJP Praha provided Zry1%Nb substrates

Post Test Examinations

Selected results – Long term corrosion tests



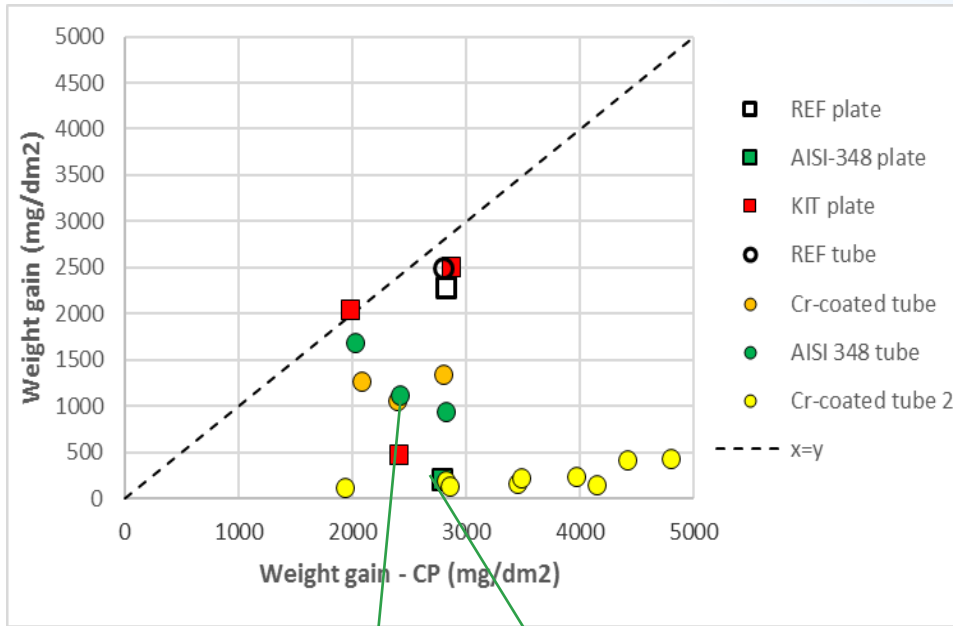
Weight gains from the corrosion test in VVER and PWR water chemistry



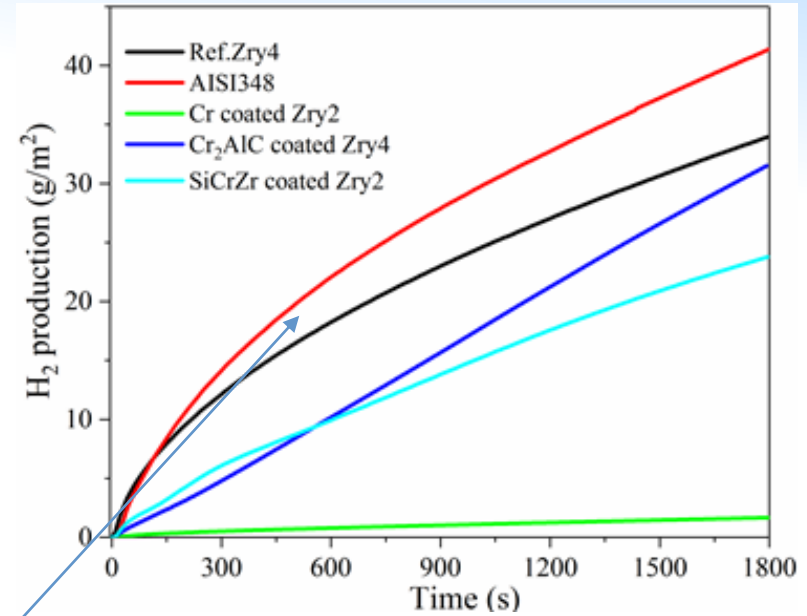
Dissolution and spallation of MAX phase coated samples in both VVER and PWR conditions

Post Test Examinations

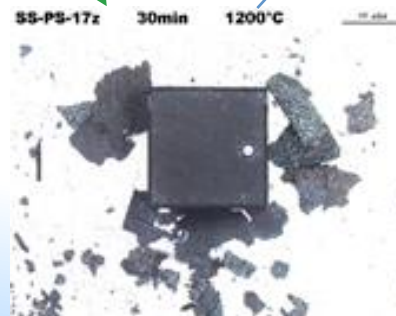
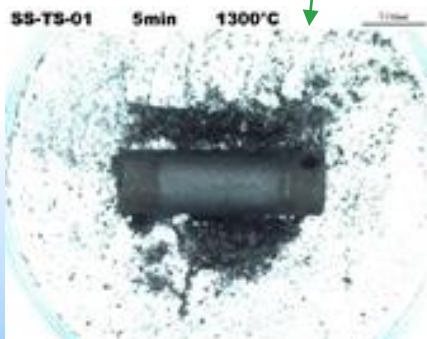
Selected results – HT Oxidation



Measured against calculated/expected weight gains (using Cathcart-Pawel correlation) in HT oxidation tests



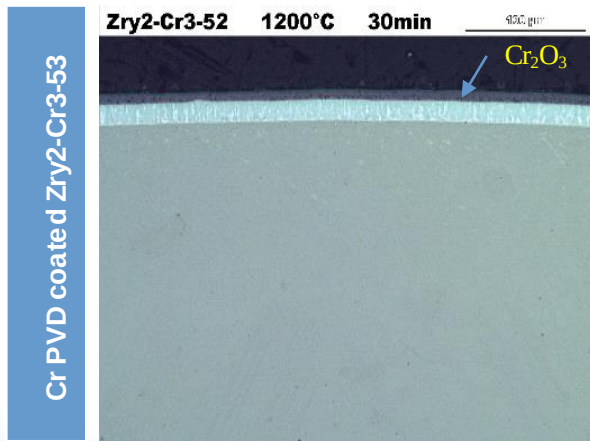
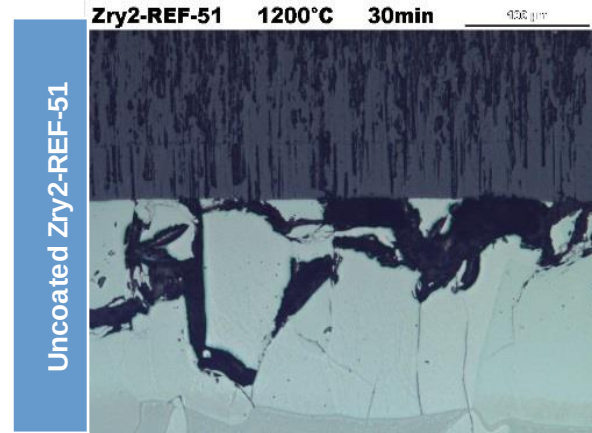
Hydrogen production in HT oxidation tests



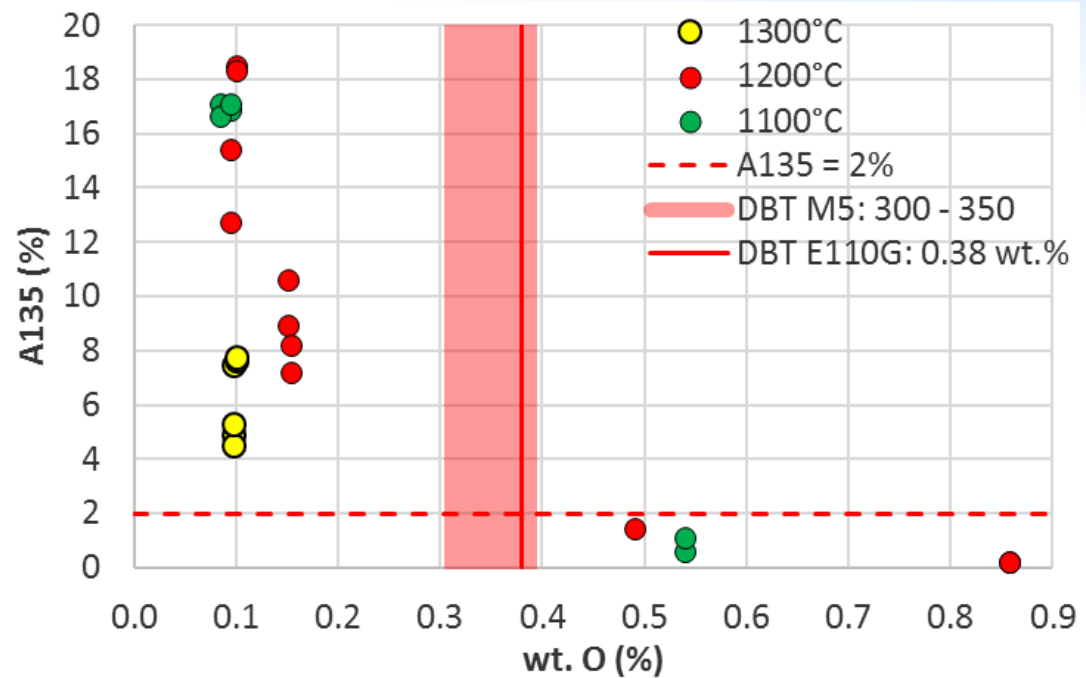
Spallation of oxide of AISI 348 alloy

ATF: Cr coated cladding

Results of ACTOF Round Robin Tests



Metallography of uncoated and
Cr-coated Zry-2



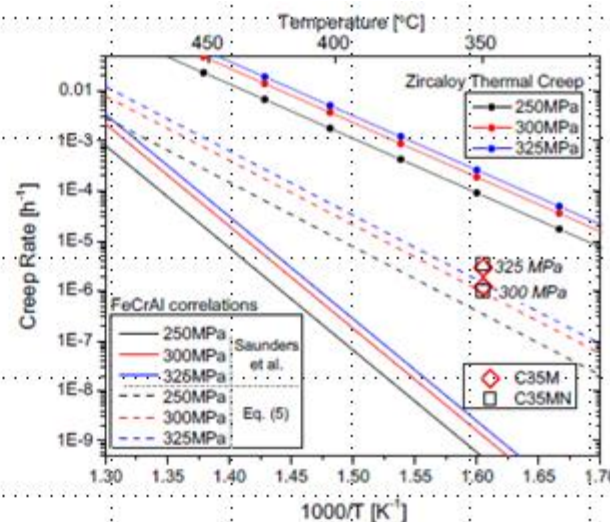
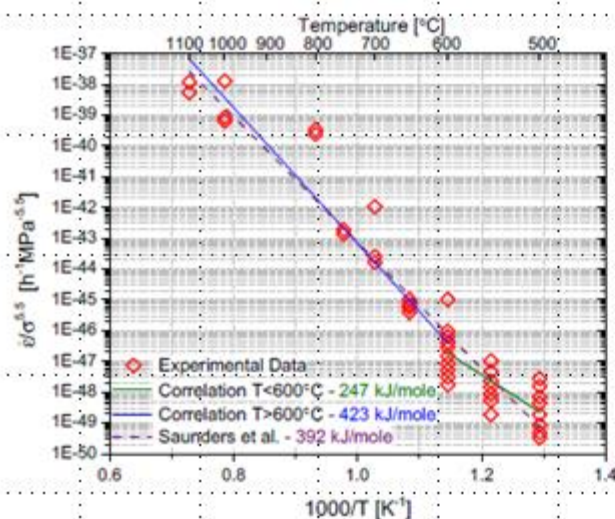
Residual ductility of the Cr-coated
Zr1%Nb samples in relation with oxygen
content in prior β -Zr layer
(CRPACTOF, M. Ševeček, CTU)
(instead of 17%-ECR)

ACTOF Joint Actions

Benchmark Exercise (FeCrAl against Zry-4)

□ Scope

- Provide material property data for FeCrAl (INL)
- Benchmark calculation for FeCrAl
 - Provide modelling input, normal operation case specification (UO₂-FeCrAl) and LOCA case specification, output format for FeCrAl (INL)
 - Perform benchmark calculation using different codes
 - Prepare report for benchmark calculation



ORNL correlations
for thermal and
irradiation creep of
C35M

Benchmark Exercise

Participants

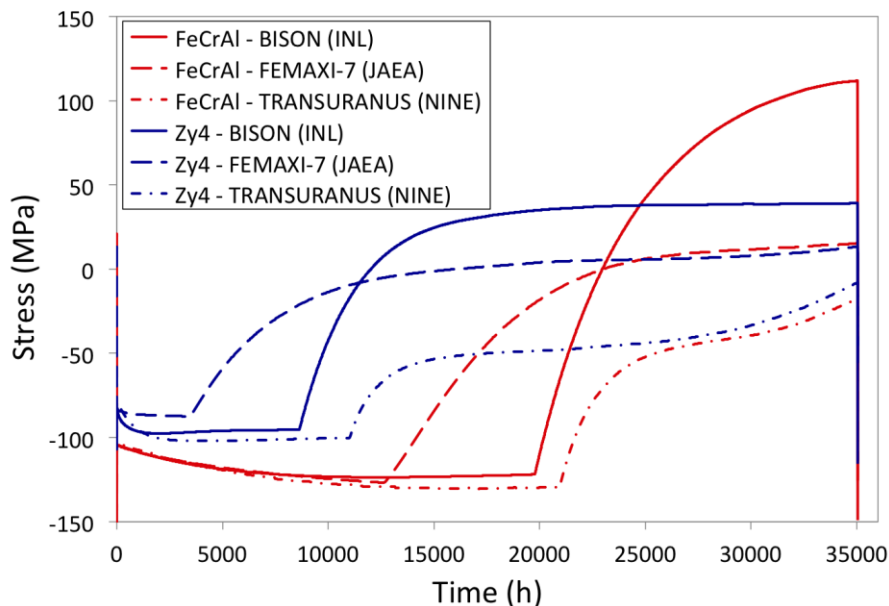
- Idaho National Laboratory (USA), **BISON** code
- N.I.N.E – Nuclear and Industrial Engineering (Italy), **TRANSURANUS** code
- University of São Paulo (Brazil), **modified FRAPCON-3.4** code
- CNEA – National Atomic Energy Commission (Argentina), **BACO** code
- JAEA – Japan Atomic Energy Agency (Japan), **FEMAXI-7** code



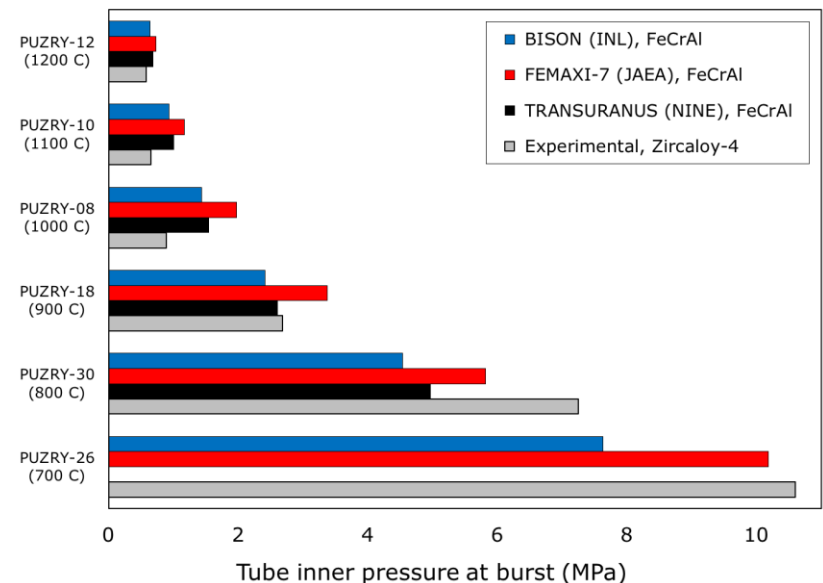
Benchmark Exercise

Conclusions

- Fuel performance codes from participating organizations were significantly extended to the analysis of several ATF concepts (including FeCrAl and SiC claddings, coated Zircaloy claddings and U_3Si_2 fuel)
- Benchmark was organized and finalized where the extended codes were compared for the analyses of fuel rod with FeCrAl cladding under both normal operation and design-basis accident (LOCA) conditions



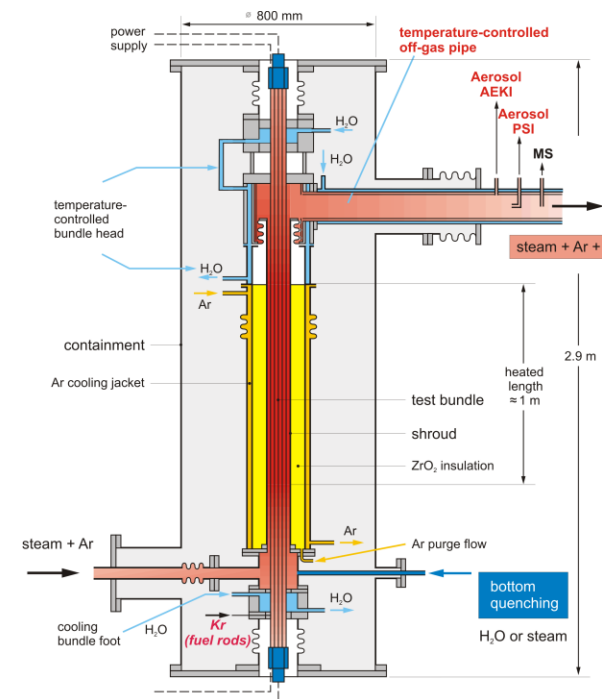
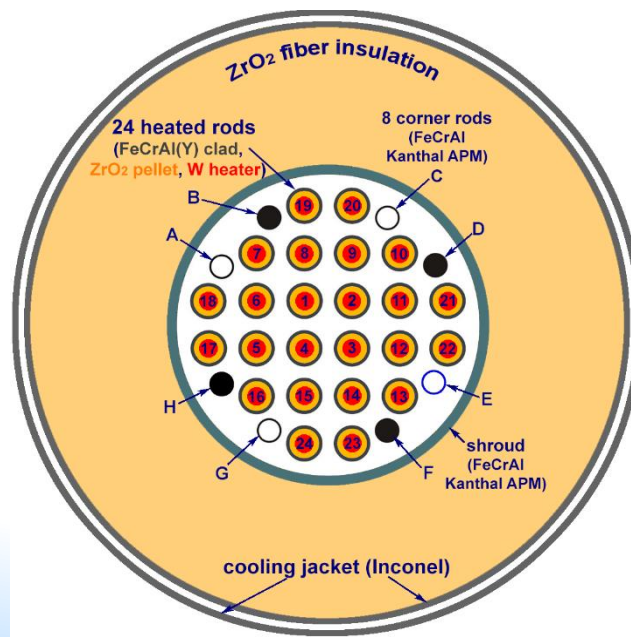
Cladding hoop stress (normal operation)



Burst pressure (LOCA)

QUENCH-19 (FeCrAl) bundle test at KIT

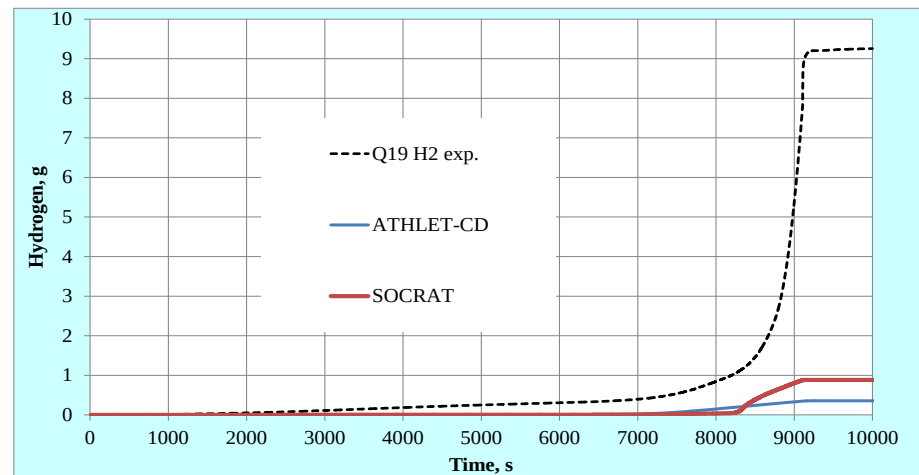
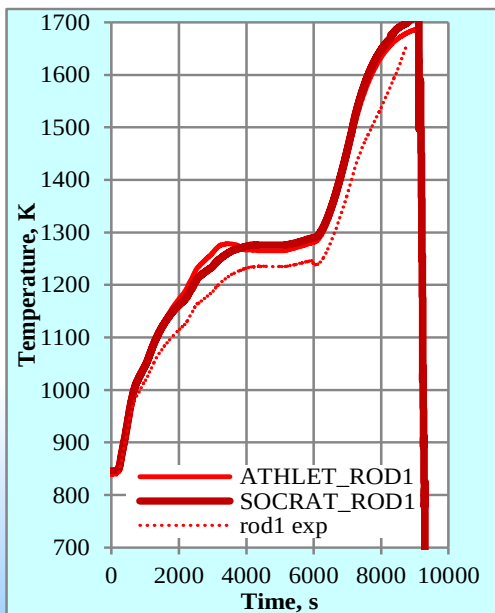
- Provide results of severe accident testing, including separate single rod test and Quench-19 FeCrAl test (KIT)
- Calculation for high temperature QUENCH-19 (FeCrAl) test using ATHLET-CD (GRS) and SOCRAT (IBRAE)



Severe Accident Experimental and Modelling

Conclusions

- Integral codes (ATHLET-CD and SOCRAT) have been applied and benchmarked against the severe-accident bundle test QUENCH-19 (KIT) with FeCrAl claddings
- CRP triggered new collaborations between some organizations beyond the ACTOF project timeframe (especially a great interest to international programs with ATF at QUENCH facility (KIT))



Simulation of temperature at elevation 950 mm (left) and hydrogen release (right)

New CRP on Testing and Simulation of Advanced Technology Fuels (ATF-TS) (2020-2023)



➤ Status

- CRP T12032
- Advised by TWG-FPT
- TM on Fuel Behaviour in Accident Conditions, with a Technical Session on the new CRP: China, June 25-27, 2019
- CM on preparation of new CRP Proposal: October 15-17, 2019
- 1st RCM: planned from 1 to 5 March, 2021 in Vienna
- Currently
 - Active: 18 Agreements and Contracts
 - Open for new participants

➤ Specific Research Objectives

- To perform experimental tests including single rod and bundle tests on ATF performance under normal, DB and DE conditions
- To benchmark fuel codes against new test data obtained during the CRP as well as existing data relevant for advanced fuel and cladding concepts from other experimental Programmes
- To develop LOCA evaluation methodology for ATF performance with a view for NPP applications

➤ Experimental Program

– Round Robin tests

- Coated claddings
 - ballooning and burst isothermal (CTU,...)
 - ballooning and burst transient and/or LOCA (Quench Rig facility, KIT)
- FeCrAl
 - high temperature oxidation tests (Thermo Balance facility, KIT)
 - autoclave oxidation tests and mechanical tests, etc. (CRIEPI, CTU, ...)
- SiC
 - autoclave oxidation, high temperature oxidation, collection of material properties data base (NPIC, JRC-Karlsruhe,...)

– Bundle tests

- DEGREE facility with ATF rods (Coated Zry-4) under SA and/or LOCA (CRIEPI, Japan)

– Irradiation tests data

- Doped fuel pellets HALDEN tests – TBC

New CRP on Testing and Simulation of Advanced Technology Fuels (ATF-TS) (2020-2023)



➤ **Modelling Program**

- **Fuel performance codes benchmarks, including modeling improvements and uncertainty analysis**
 - Material properties database for ATF (*ISS-USA*)
 - FeCrAl / coated Zr cladding / uncoated Zr cladding against new RRT burst tests
 - Doped fuel pellets HALDEN tests – TBC
- **SA Modelling benchmark**
 - Database: Quench-19, DEGREE
 - SA Codes : ASTEC, ATHLET-CD, MELCOR, MAAP, ...
- **LOCA evaluation methodology development for NPP applications (*lead by TRACTEBEL*)**
 - Qualification of Fuel rod codes for LOCA application based on IFA 650.10 with SOCRAT TH boundary conditions and uncertainty analysis, prediction for FeCrAl and/or coated Zr cladding
 - Application to PWR prototypic fuel rod with TH boundary conditions (2 scenarios: LB and SB LOCA) and uncertainty analysis, prediction for FeCrAl and/or coated Zr cladding



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*THANK YOU,
and welcome
to the IAEA Projects!*

