PRESENT STATUS OF DEMO-NITE SIC/SIC CLADDING R&D

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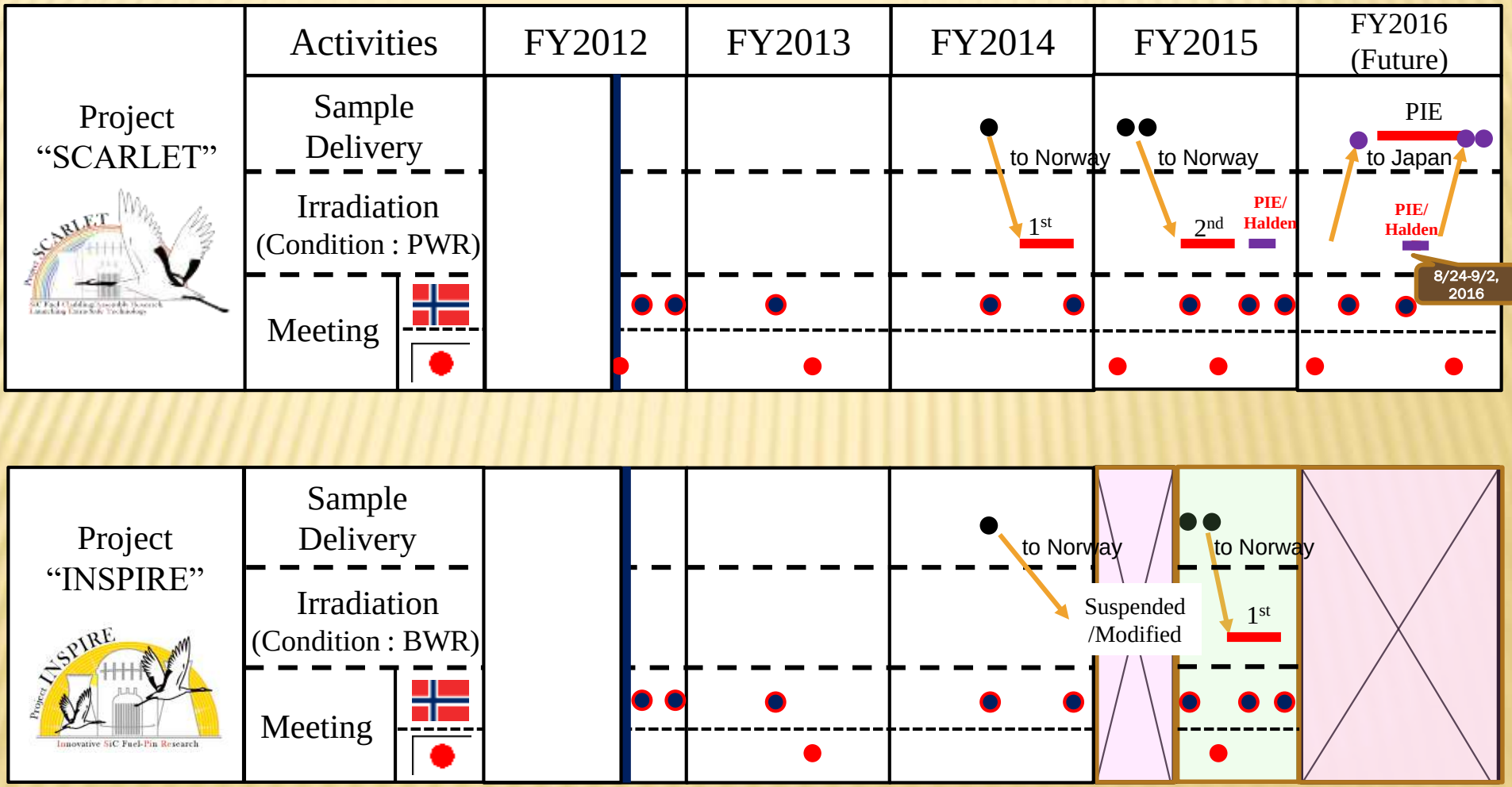
*

IEST Co., Ltd. has terminated NITE-SiC/SiC Production;
NITE Corporation is the only supplier of DEMO-NITE Products

THE ACTIVITIES WITH IFE, HALDEN



Targeted Goals of SCARLET/INSPIRE Projects

1 meter long SiC/SiC Cladding by DEMO-NITE Process

SiC/SiC Cladding by DEMO-NITE Process
Near theoretical density
Excellent gas-leak tightness

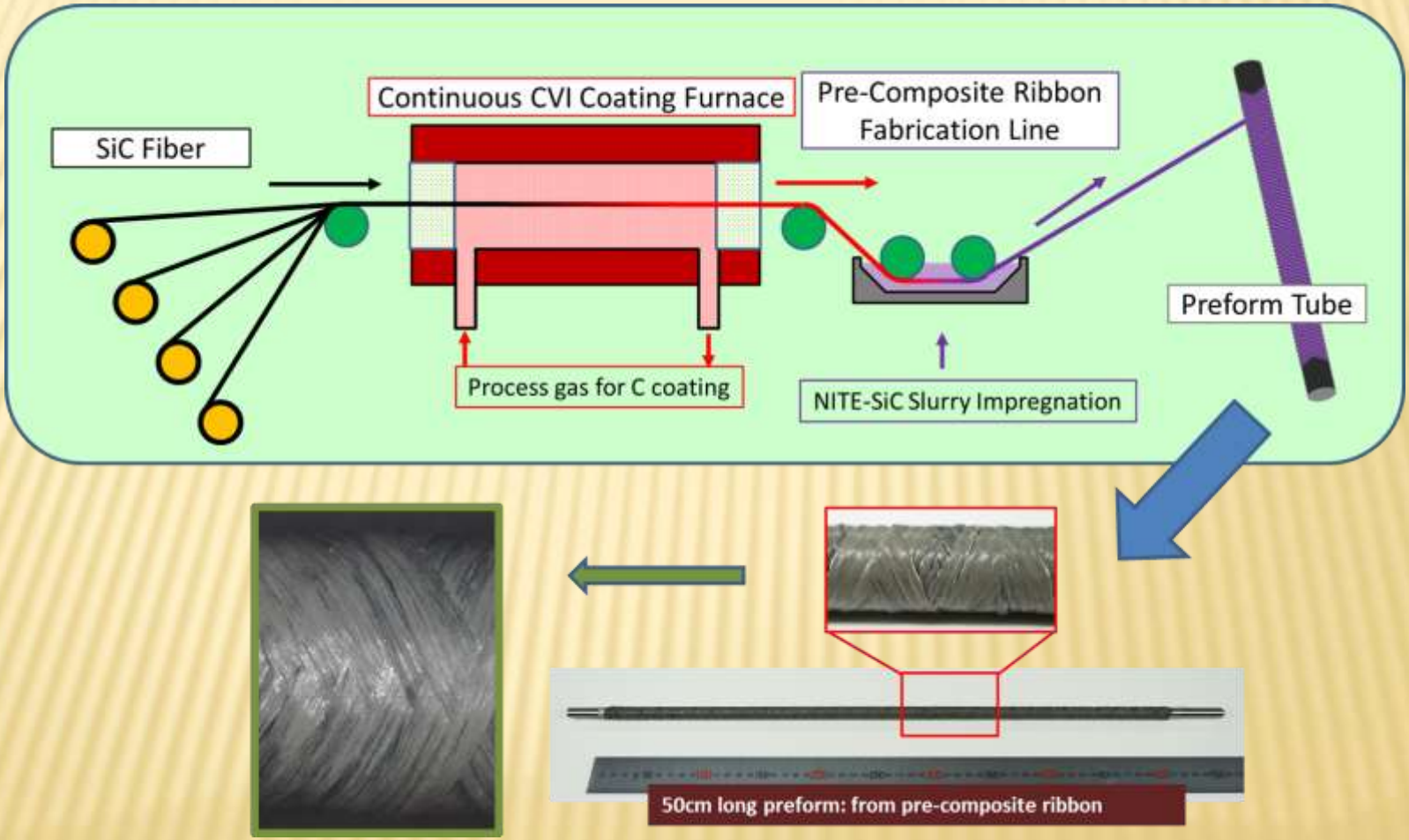
10 mm^{id}/ 12 mm^{od}, 1 mm^{t}, 1000mm^{l}

Model Fuel Pin Nuclear Fueled for HBWR Test

Model Fuel Pin Assembly

CONCEPTUAL DRAWING OF DEMO-NITE PROCESS

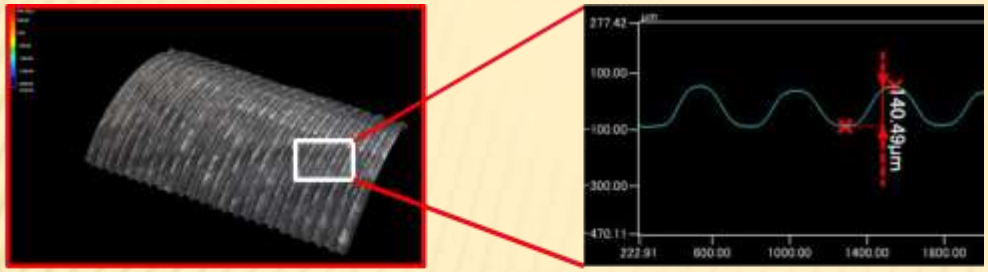
- FIBER TO PREFORM: PROTOTYPE SYSTEM ESTABLISHED -



Long SiC/SiC claddings (1000mm) have been fabricated by large scale HIP facility in August, 2016.

ZIRCALOY + SIC/SIC JOINT

-ALL SIC/SIC JOINT CAN BE MADE EXCEPT LASER WELDING -



+ or
Brazing,
Laser Weld

He Leak Tightness of SiC/SiC and Its Joint with Zircaloy:

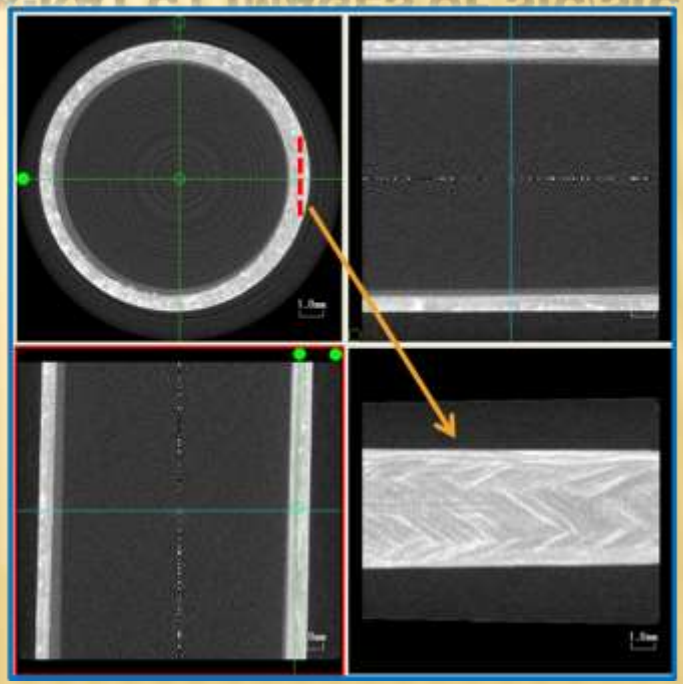
He leak rate:

Required for Halden Reactor: $<1\times10^{-9}P_a m^3/sec$

The champion data: $<1\times10^{-11}P_a m^3/sec$

mostly: $1\times10^{-10}P_a m^3/sec$

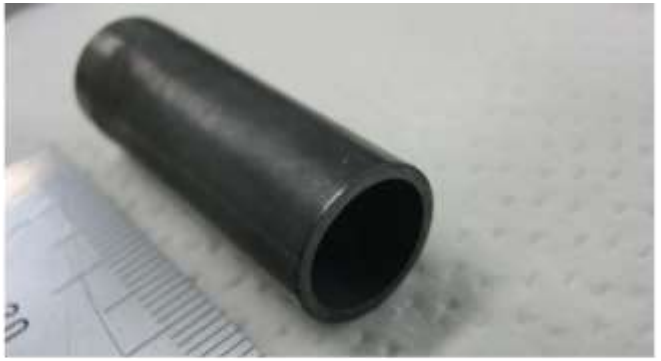
X-RAY CT IMAGES OF SIC/SIC



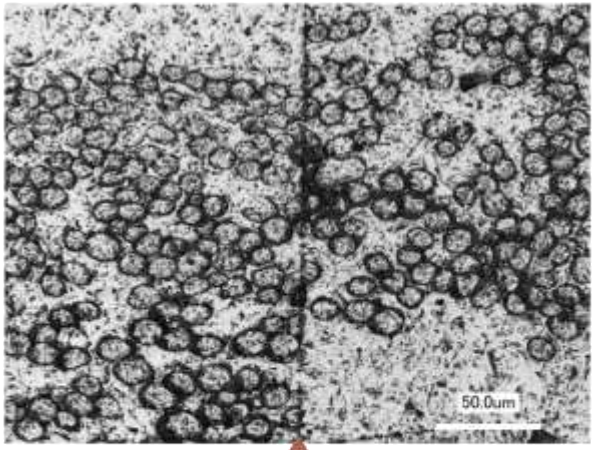
DEMO-NITE with woven 3D f.s.

FLAT FACE JOINING OF NITE-SIC/SIC TUBES

- BASED ON DEMO-NITE PROCESS -

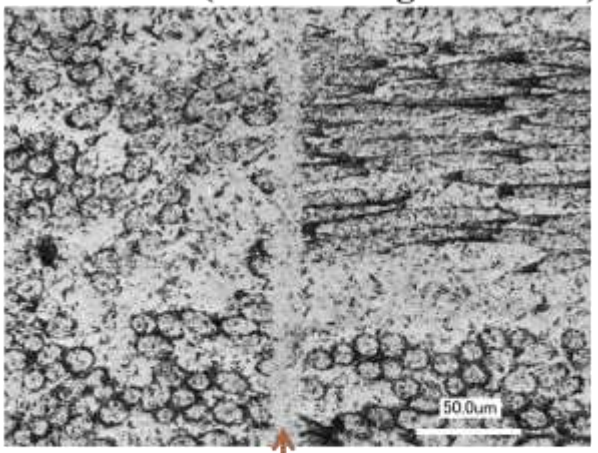


Without Insert



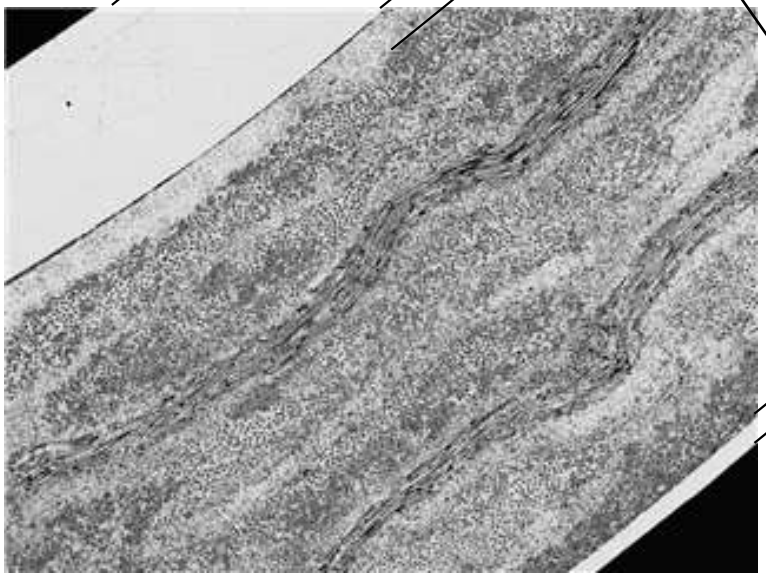
Bonded interface

With Insert (NITE-SiC green sheet)



Bonded interface

NITE-SIC/SIC TUBE WITH CVD SIC COAT



Green Sheet-SiC layer
(60μm)

Inner layer
CVD-SiC
(340μm)

SiC/SiC layer
(1000μm)

Outer layer
CVD-SiC
(30μm)

CVD coating, followed to DEMO-NITE Process

SIC/SIC COUPON SPECIMENS, OPEN TUBES AND SHIELD SEGMENTS FOR HALDEN IRRADIATION

(a) Coupon specimen

(b) Open tube

(c) Open tube with CVD-SiC coat

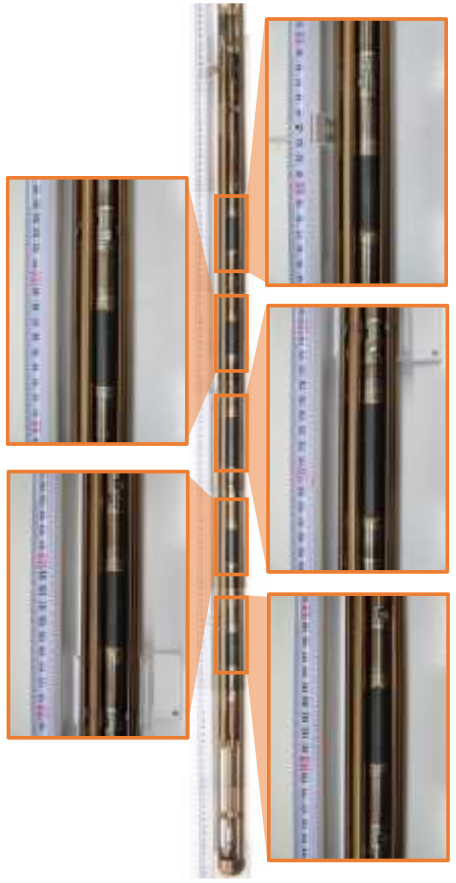
(d) Open segment
(SiC/SiC-Zry, brazing)

(e) Open segment
(SiC/SiC, diffusion bonding)

(f) Shield segment (SiC/SiC-Zry, brazing)

(g) Shield segment
(SiC/SiC, diffusion bonding)

(h) Shield segment
(SiC/SiC, brazing)



(i) Appearance of SiC/SiC segments installed in test rig, HBWR

REACTOR IRRADIATION FOR SIC/SIC CLAD DEVELOPMENT

		Encapsulated		Water Loop		Status
		Vac./He	H_2O	PWR	BWR	
1.	Coupon Irrad.	✔	○			JMTR/JOYO/HFIR/FFTF/EBR-II/BR2/BOR60
2.	Clad/Cut-out Irra.d	✔	○			
3.	Clad Irrad.	✔	○			
4.	Clad (open end) Irrad.			✔		MITR Experiment *(ref. D.M. Carpenter, MIT)*, *SCARLET@Halden*
					✔	SCARLET @Halden
5.	Clad (with Zry or SiC/SiC end caps) Irrad.			✔		SCARLET @Halden
					✔	INSPIRE @Halden
6.	Clad (with Zry end caps with/without fuel) Irrad.			✔wo		INSPIRE @Halden
				with	✔	INSPIRE @Halden ***Suspended***
7.	LTR Irrad.			○		*(SCARLET-Phase2)*
					○	*(INSPIRE-Phase2)*
8.	LTA Irrad.			○	○	

THE 2ND SCARLET SEGMENT IRRADIATION AT HALDEN

The second SCARLET segment irradiation test in IFA-775 at Halden started on September 11, 2015 and continued until November 23, 2015.

- *The reactor has been operated at a thermal power level of 18-18.5 MW.*
- *SiC/SiC-Zircaloy joints have been excluded*
  - *Concerns of enhanced Galvanic corrosion*

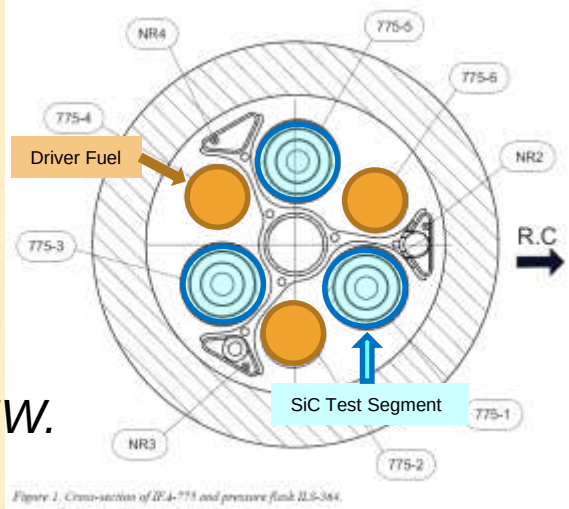


Figure 1. Cross-section of IFA-775 and pressure flask IL5-364.

The rig was connected to Loop 6 (light water high pressure loop system) operating under representative PWR conditions.

- Coolant inlet temperature : 270-290 ° C
- Coolant outlet temperature : 285-310 ° C
- Loop pressure : 162±2 bar
- Flow rate (flow velocity) : 1600±30 litre/hour

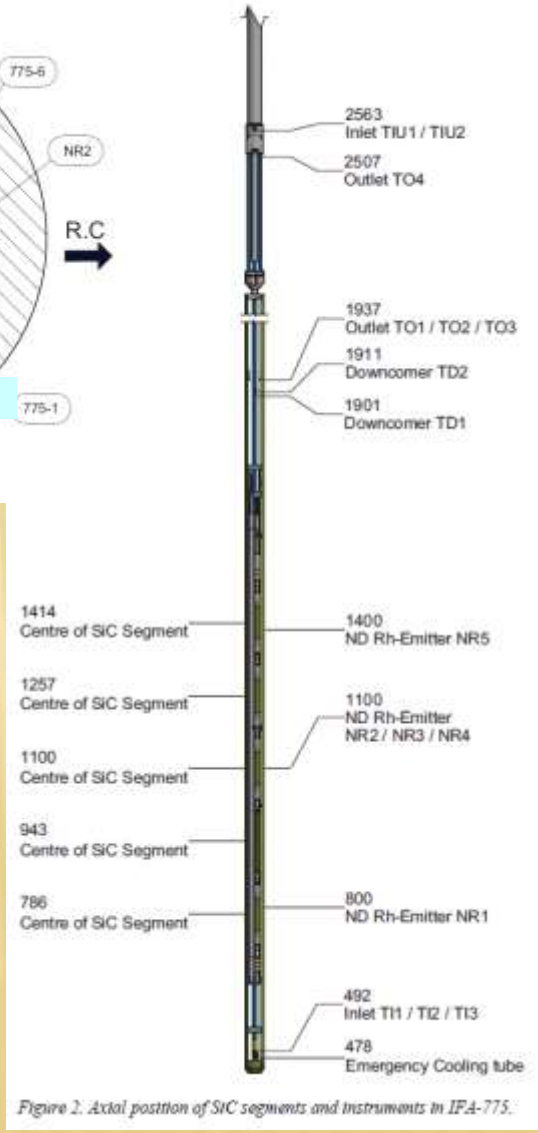
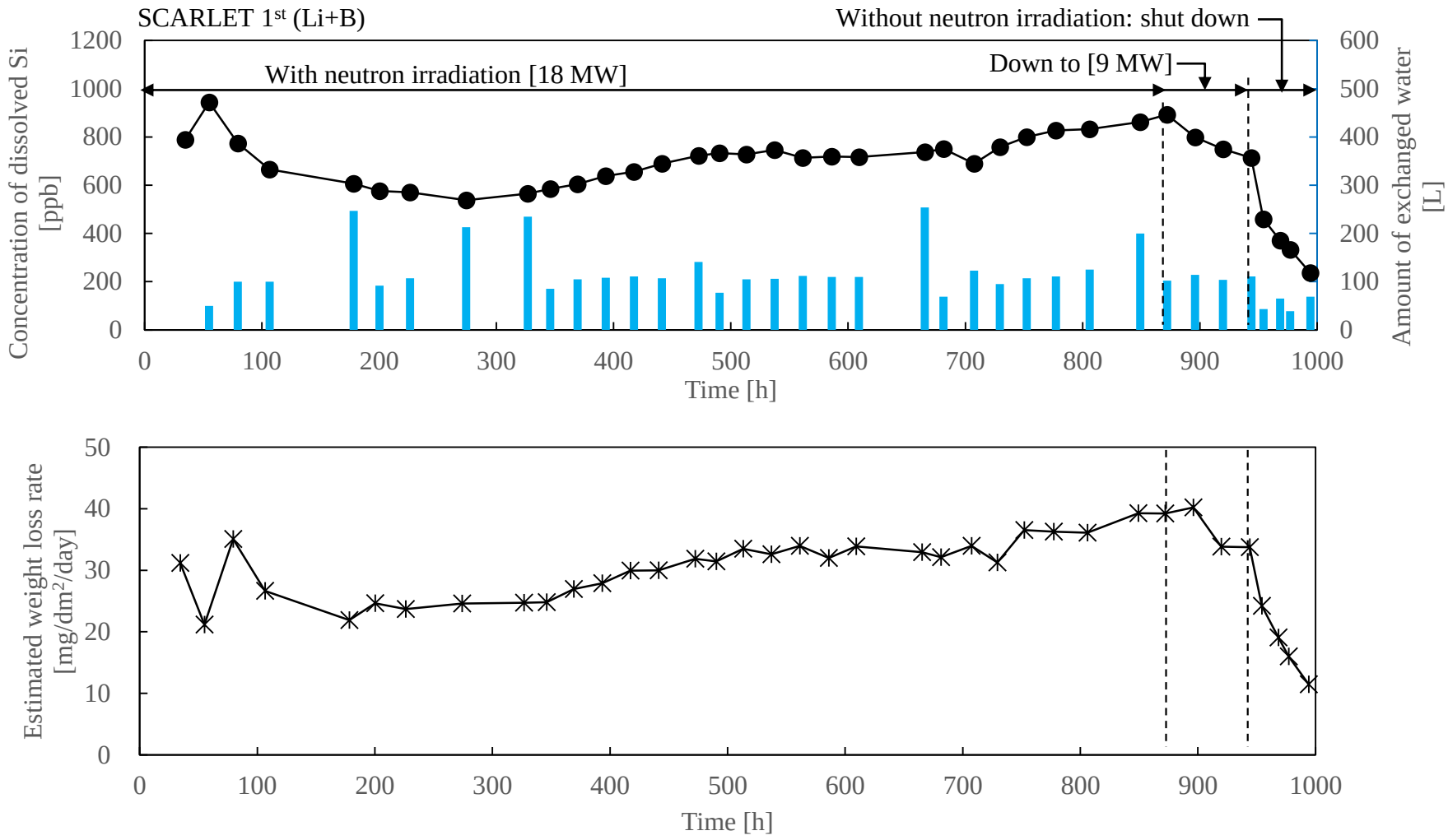


Figure 2. Axial position of SiC segments and instruments in IFA-775.

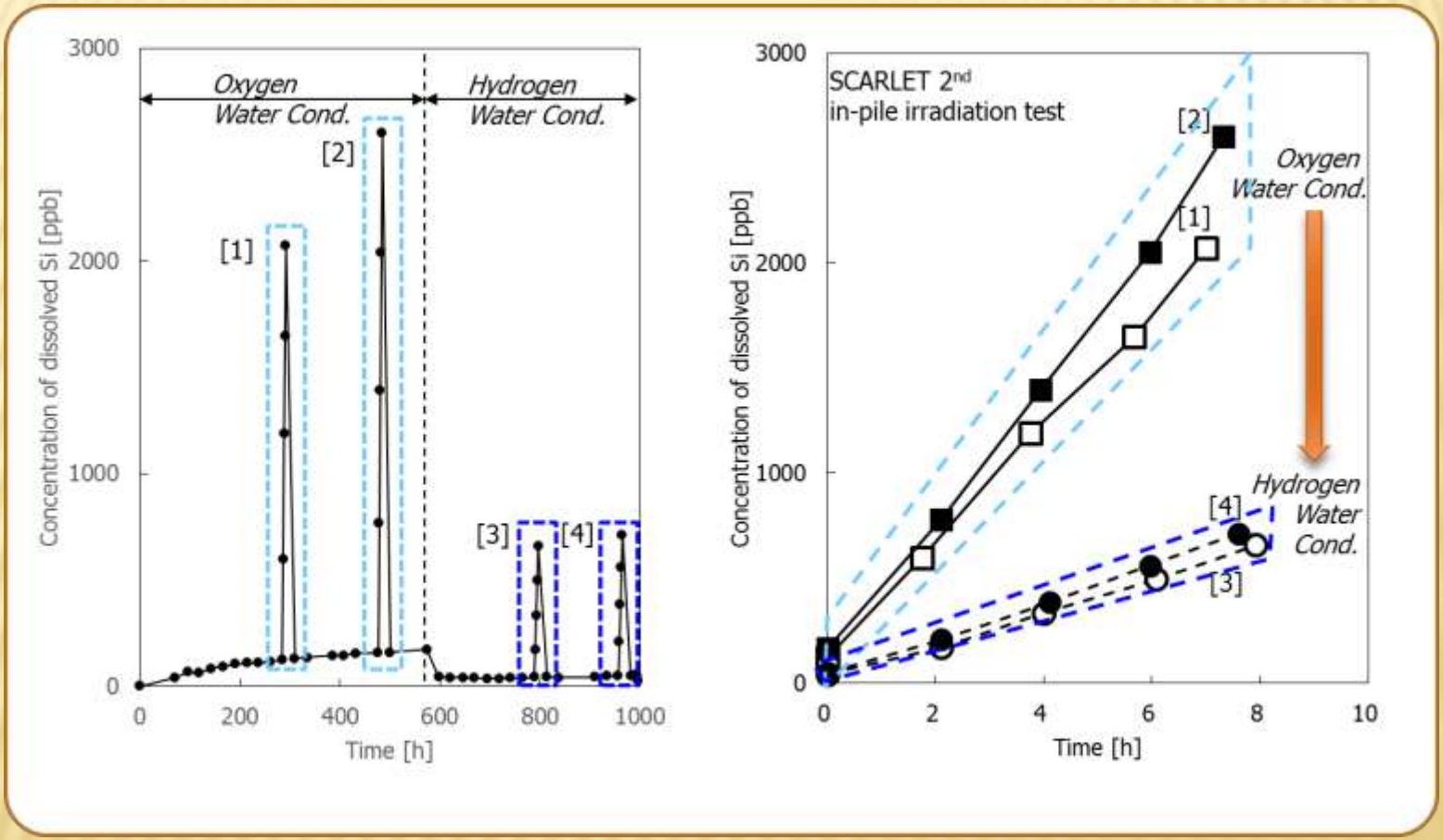
TEST CONDITIONS FOR IN-PILE IRRADIATION TEST AT HBWR

		Water chemistry comparison between BWR and PWR						
		BWR	***IFA-776 INSPIRE***		*PWR*	***IFA-775 1st SCARLET***	***IFA-775 2nd SCARLET***	
Terms	Unit	reactor water	Loop Water		1st system	Loop Water	Loop Water	
Duration	day		2016/1/15 ~2015/2/13			2014/12/22 ~2015/2/1	2015/9/11 ~2015/10/23	
Temperature	C	285	In 279.5 Out 283.5	In 285 Out 287	310	In 270~290 Out 285~310	In 280 Out 300	
Pressure	MPa	6.7	~7.7	~7.1	13.4	16.2	12.7	
Flow rate	ℓ/h		570~670	470~520		1600	1650	
Reaction control		Control rod + Void (flow)	-		Control rod + B	-	-	
Boron	ppm	-	-		100-2000	**~1000**	**-**	
Lithium	ppm	-	-		<3.5	**~4.5**	**-**	
Oxygen	ppb	200 [<10]	-		<5	**-**	**200~300**	-
Hydrogen	ppm	10 [50]	**1.8~2.2**		2~3	**2.2~3.2**	-	**1.8~2.2**

CHANGES OF WATER CHEMISTRY
SCARLET 1ST IN-PILE IRRADIATION TEST

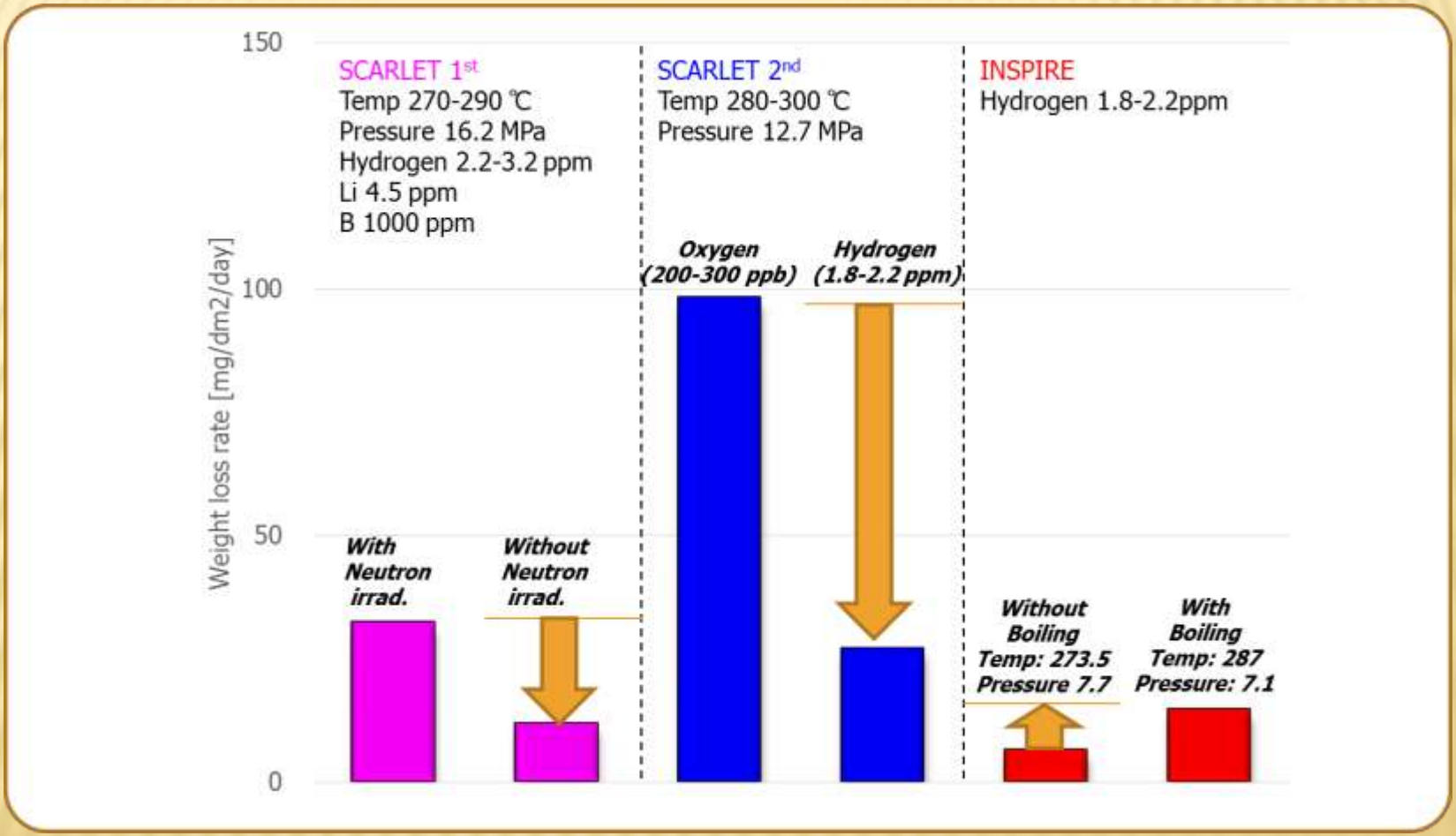


CHANGES OF WATER CHEMISTRY
SCARLET 2ND IN-PILE IRRADIATION TEST



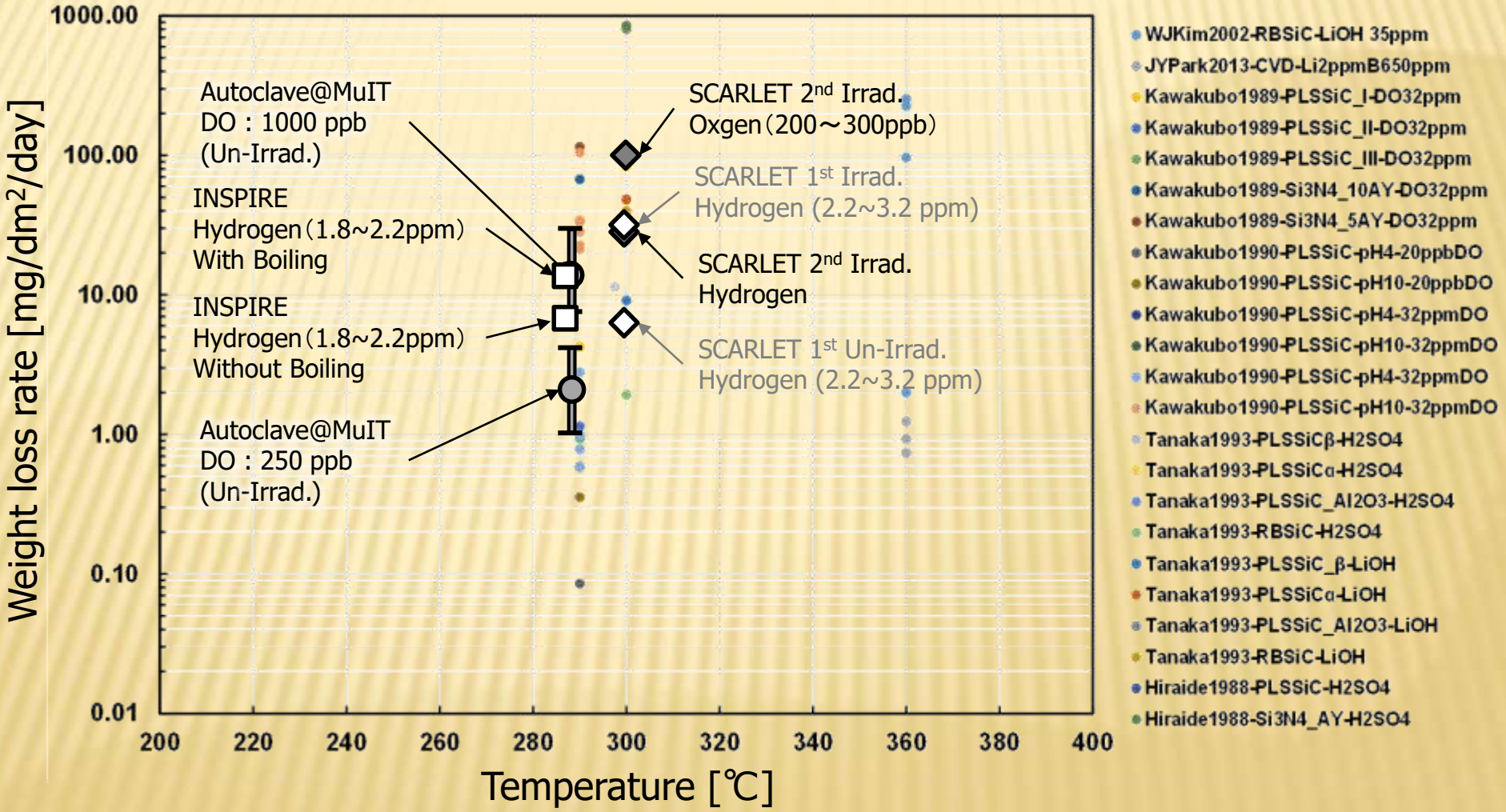
(1)-(4): Loop water purifiers were stopped to measure Si dissolution

ESTIMATED* WEIGHT LOSS RATES OF SIC DURING SCALRET 1ST, 2ND AND INSPIRE



Post irradiation weight measurement finished and analysis on-going

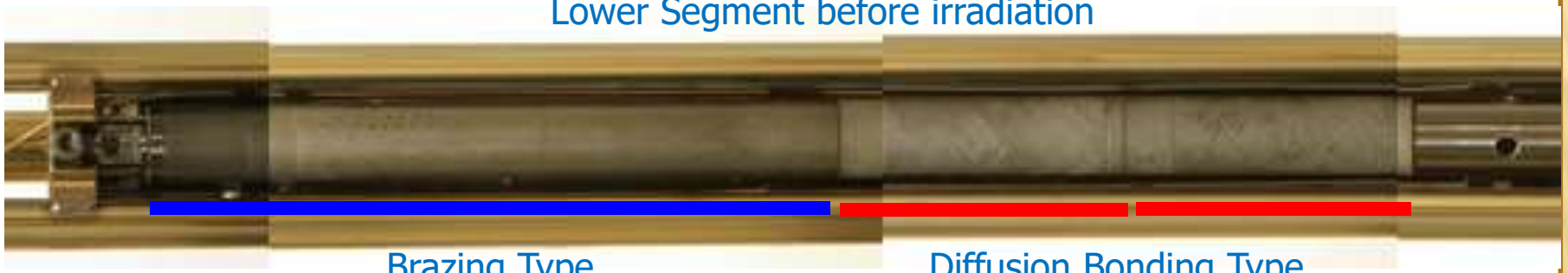
WEIGHT LOSS RATE OF SIC IN PRESSURIZED WATER



ALL SIC/SIC SEGMENTS FOR IRRADIATION

LOWER SEGMENT: NON-BOILING CONDITION

Lower Segment before irradiation

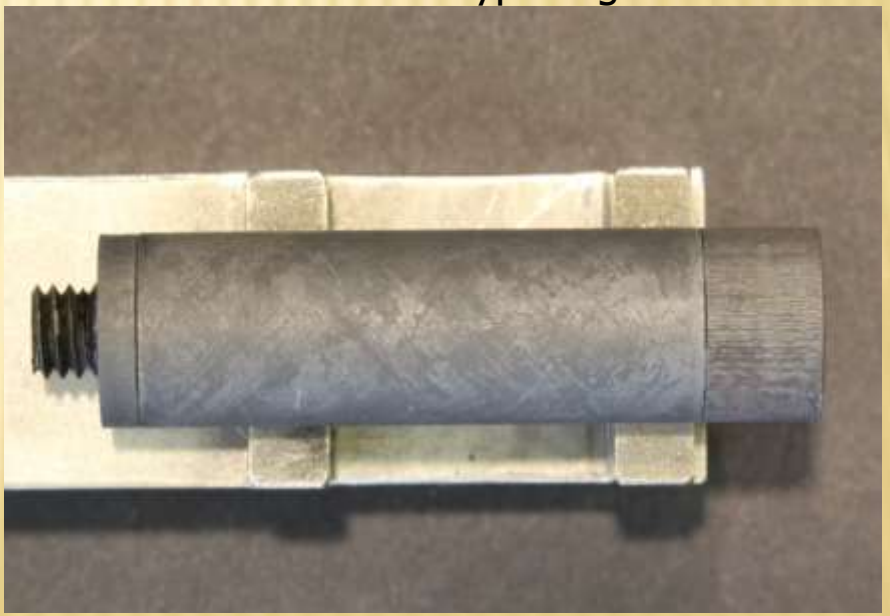


Brazing Type

Diffusion Bonding Type

Disassembling after irradiation

Disassembled DB type segment



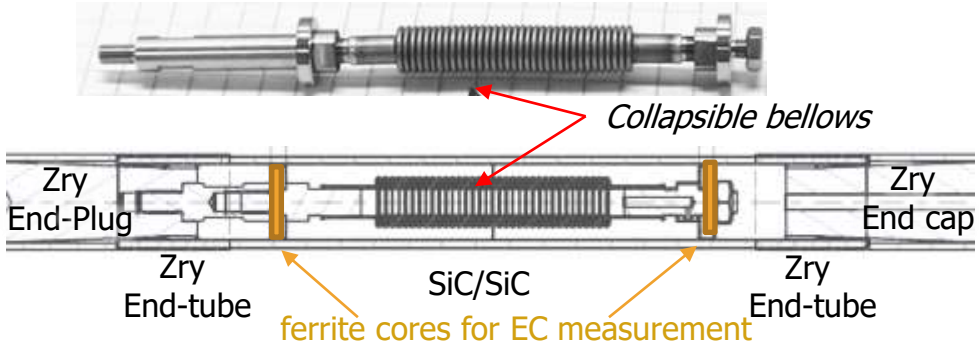
Weight measurement finished and microstructure inspections and mechanical test on-going

DAMAGE EVALUATION BY EDDY CURRENT MEASUREMENT

Appearance of joined parts were significantly changed. But, significant damage in SiC/SiC tube couldn't be observed.

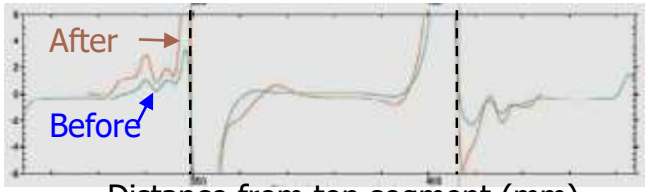
Collapsible bellows are kept their locations after the test.

→ No failure during In-pile irradiation test



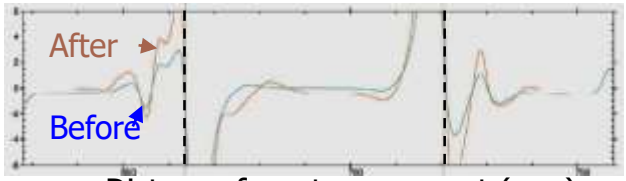
Segment A

Eddy current (location of ferrite cores)



Segment B

Eddy current (location of ferrite cores)



THE DROP TOWER TYPE TEST STAND
- MECHANICAL TEST AND SIC/SIC SAMPLE RETRIEVAL -

Potential energy of strike rod is;

Transferred to impact rod; and

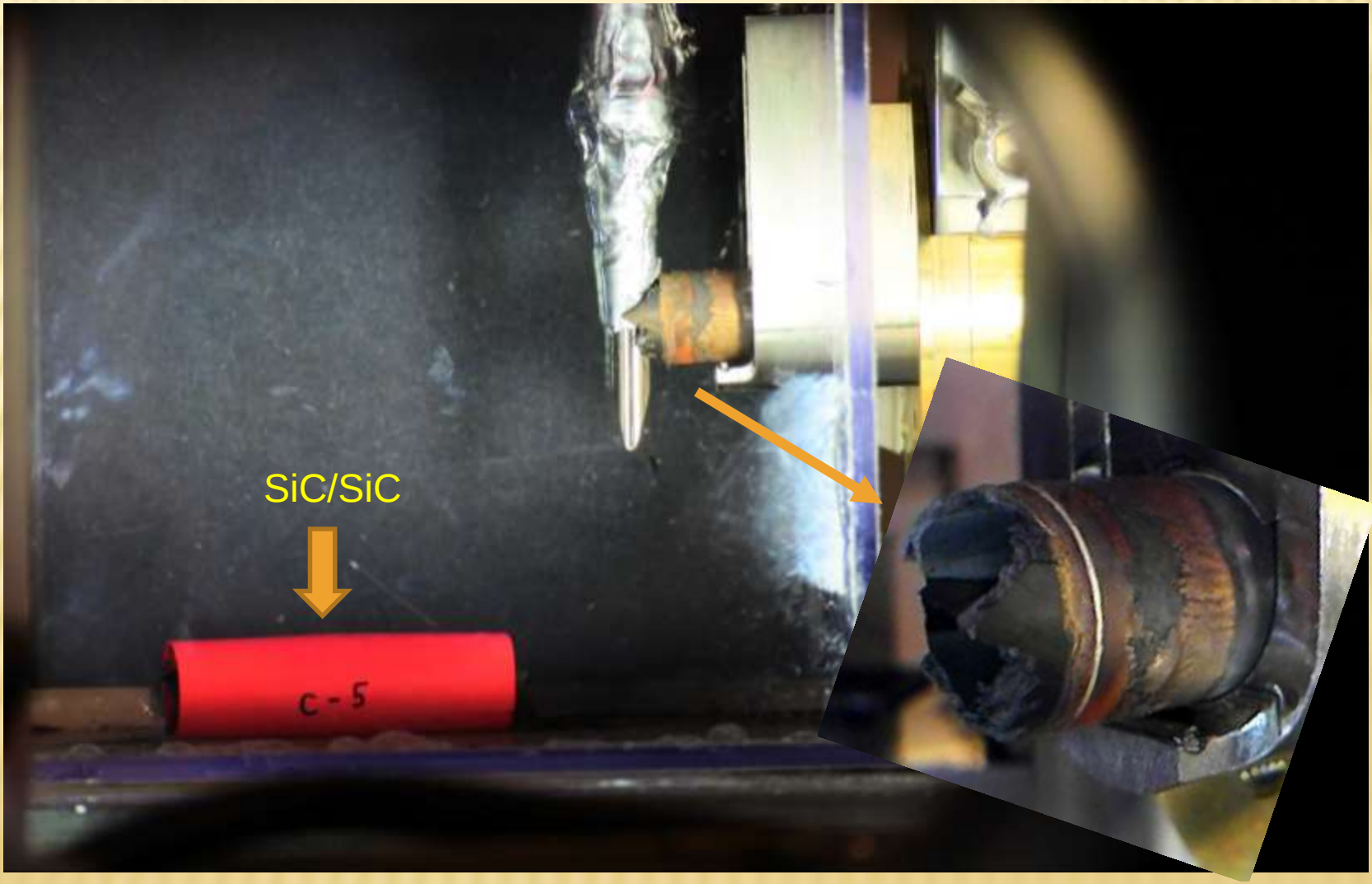
Impact rod placed onto test specimen cantilever held impacts specimen

Displacement and load measured:

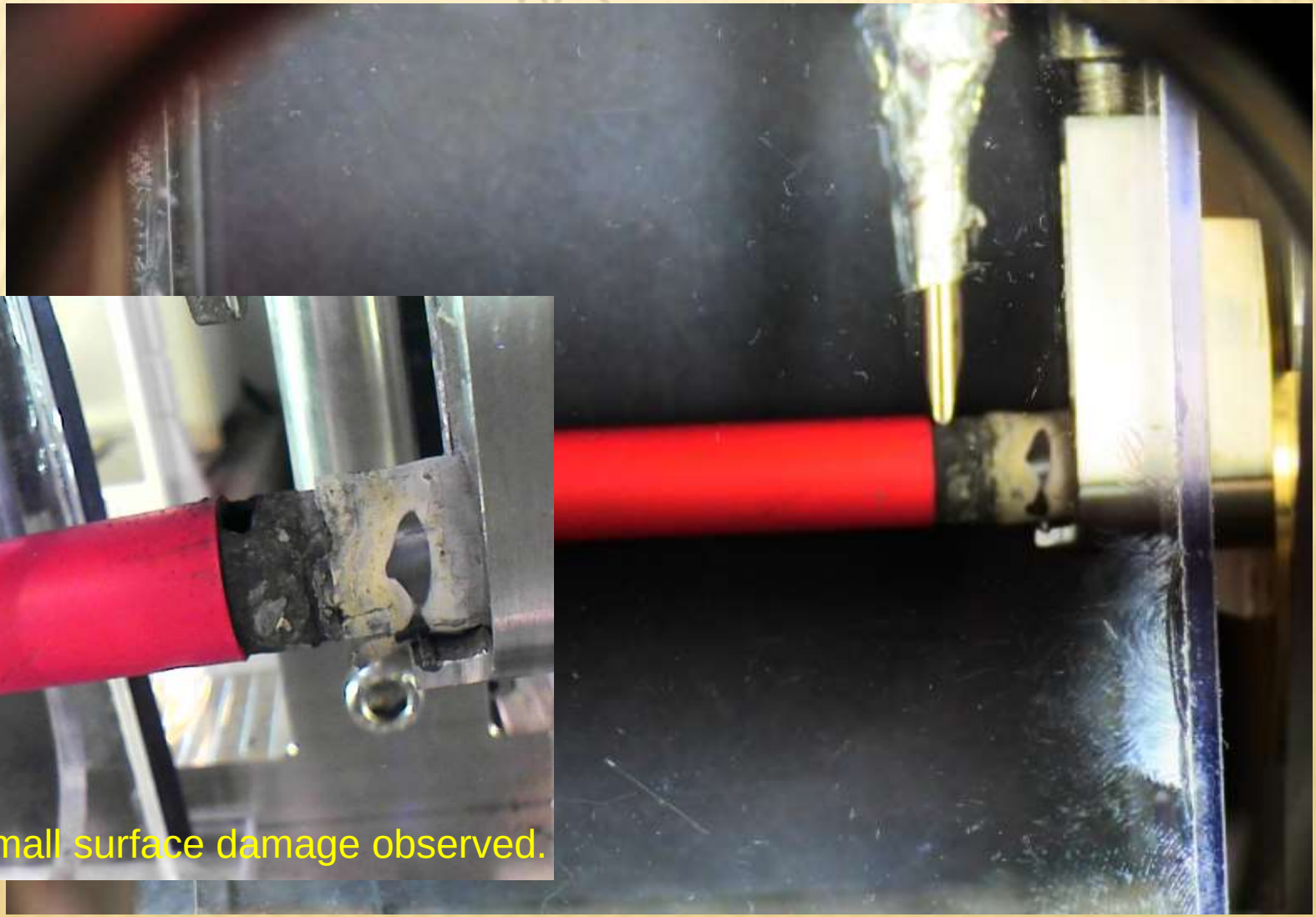
By laser beam reflector and strain gauges on impact rod

	Output	Sampling rate	Property obtained
Laser Sensor	Max. ±5V	1μs	Displacement [mm] by Output voltage [V] X 2
Strain gauge	0～100μST	20μs	Load [N] by Output signal [μST] ×1.3

RETRIEVAL OF SIC/SIC BY THE DROP TOWER TYPE TEST
- C5 -



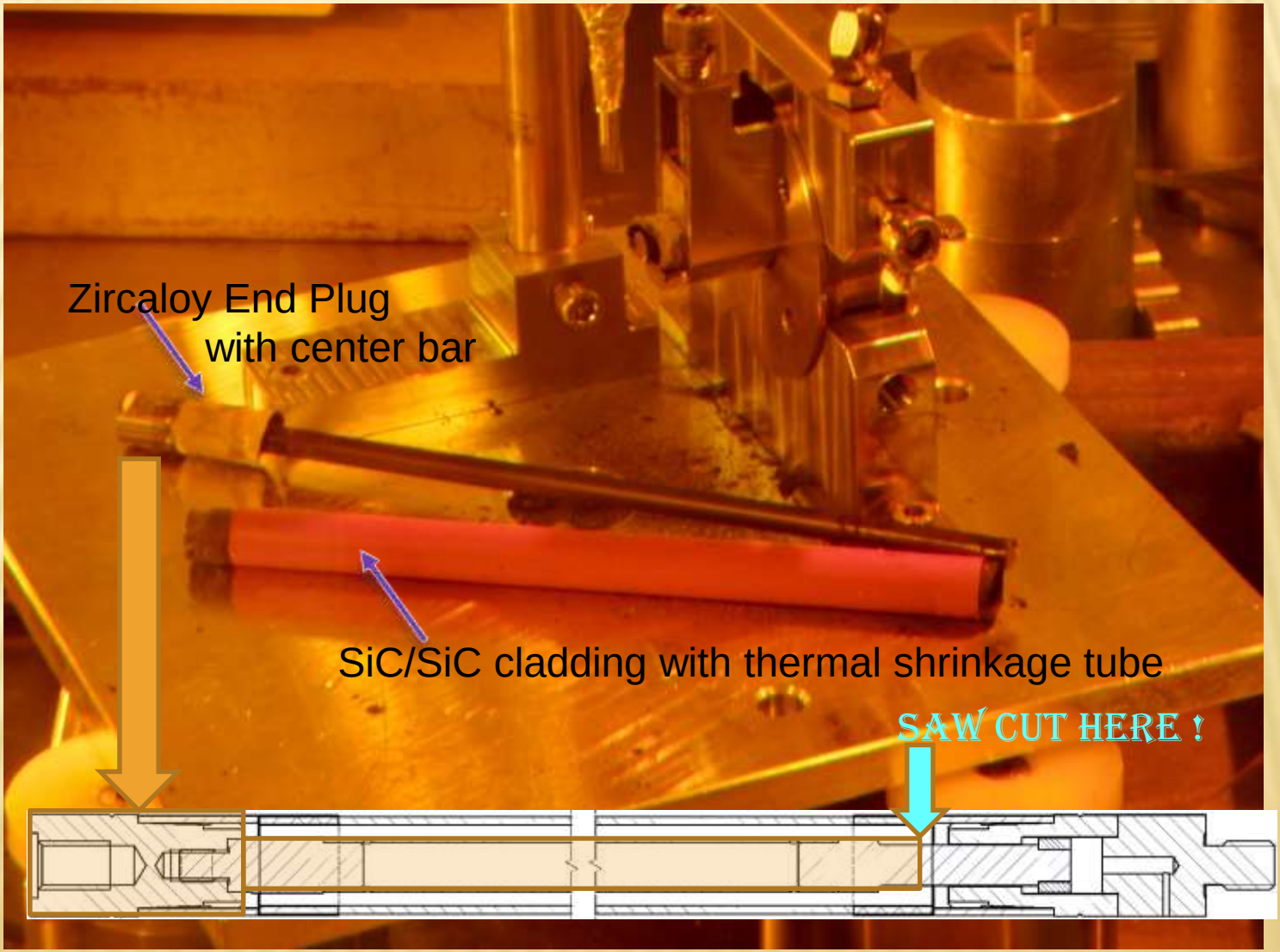
HIGH SPEED CAMERA IMAGE OF THE DROP TOWER TYPE TEST - 1A-2 -



Only a small surface damage observed.

SIC/SIC CLADDING RETRIEVAL AFTER DROP TOWER TEST

- ZIRCALOY END CAPS CONNECTED WITH BELLOWS WAS SAW-CUT -



SUMMARY

At Halden, Norway, three irradiation experiments were completed including the first "in-situ" water chemistry data during the neutron irradiation under "dynamic" water condition : where, DEMO-NITE SiC/SiC claddings represented the high potentiality to establish all SiC/SiC reactor cores, even with Zircaloy endcaps.

- Corrosion of SiC/SiC was accelerated by the neutron irradiation.
- Corrosion of SiC/SiC significantly depends on the condition of water chemistry. And, the corrosion of SiC/SiC was drastically decreased under hydrogen water chemistry.
- Under boiling water condition, the corrosion rate of SiC/SiC was slightly increased.
- The significant degradation at joining part were confirmed by the galvanic corrosion caused by the joining of dissimilar materials. In the other side, there are no degradation of full SiC/SiC segment prepared by diffusion bonding.
- The microstructural change of CVD-SiC coat on SiC/SiC tubes were not observed. The effectiveness of CVD SiC coat as environmental barrier coating were confirmed.
- Preliminary mechanical property evaluation was accomplished by drop tower type test at Halden, showing no sign of degradation observed by neutron irradiation under dynamic reactor water environment

REPRESENTING RESULTS FROM

11th CMCEE
June 14-19, 2015
Hyatt Regency Vancouver,
Vancouver, B. C., Canada

High Performance SiC/SiC Component by NITE-method and Its Application to Energy and Environment

Akira Kohyama, Daisuke Hayasaka, Hirotatsu Kishimoto and Joon Soo Park
OASIS, Muroran Institute of Technology
Hokkaido, Muroran, Japan

HIGH TEMPERATURE STEAM TEST

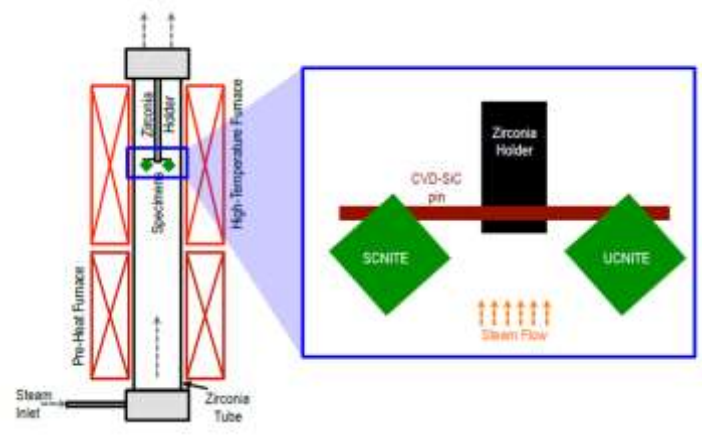
- DONE BY ORNL -

- ORNL HTST Facility
  - DEMO-NITE SiC/SiC with and without SiC EBC were tested.
  - Test Condition;

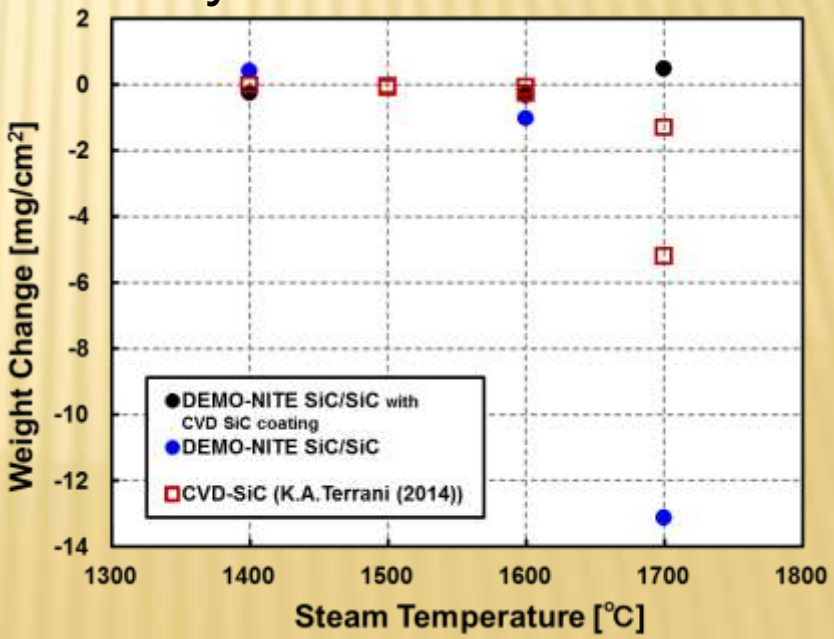
Max. S. Temperature: 1700 C

Exposure Time: 4 Hrs.

Steam Velocity: 52-62 cm/s

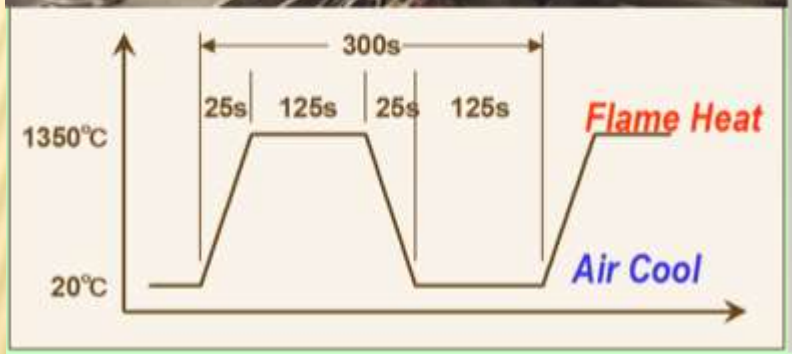


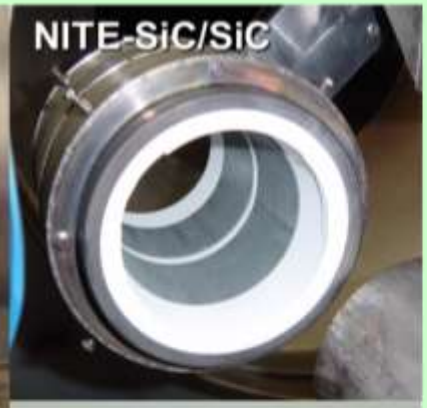
- Test Results
  - DEMO-NITE with SiC EBC presents excellent resistance.
  - DEMO-NITE without EBC presents large weight loss at 1700 C, but damage stayed only near surface.



NITE-SiC/SiC: Combustion Flame Exposure Test

- Done by MHI -





Crest-Ace

No detectable damage. No degradation in strength.

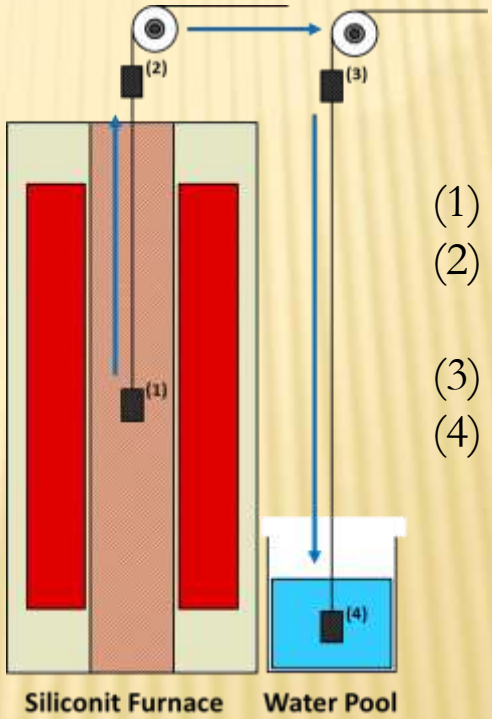
The test sample cut-out from this exact sample was tested in this work

CYCLIC WATER QUENCHING TEST - EXPERIMENTAL PROCEDURES -

- Materials Tested

Sample ID	Materials Tested	Remarks
KU-SiC/SiC	Original NITE SiC/SiC (CREST)	After 100 cycle test at MHI
Muroran-SiC	DEMO NITE SiC	As fabricated
Muroran-SiC/SiC	DEMO NITE SiC/SiC	As fabricated
Muroran-SiC/SiC with EBC	DEMO NITE SiC/SiC with CVD SiC	As fabricated

- Cyclic Water Quenching Test Facility (C-WQT F)



Max. Temp.: 1600 C

(1) Heating (15min)
(2) Pull-out from the furnace, transfer
(3) Drop-off (2sec)
(4) Quenching into the water

- Post C-WQT Experiments

3 point bend test
SEM + EDX, Digital Laser Microscopy

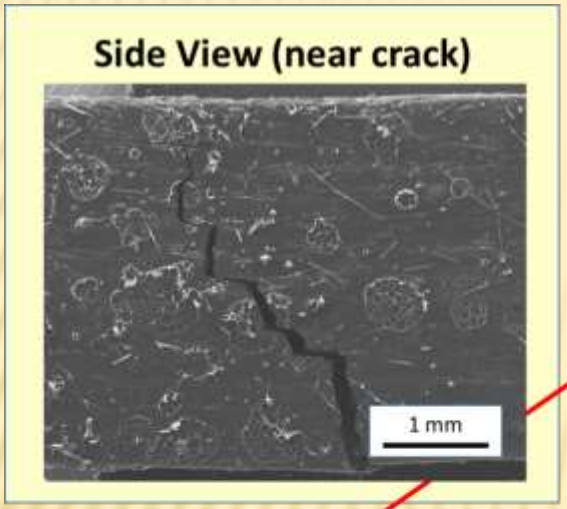
CYCLIC WATER QUENCHING TEST - EXPERIMENTAL RESULTS -

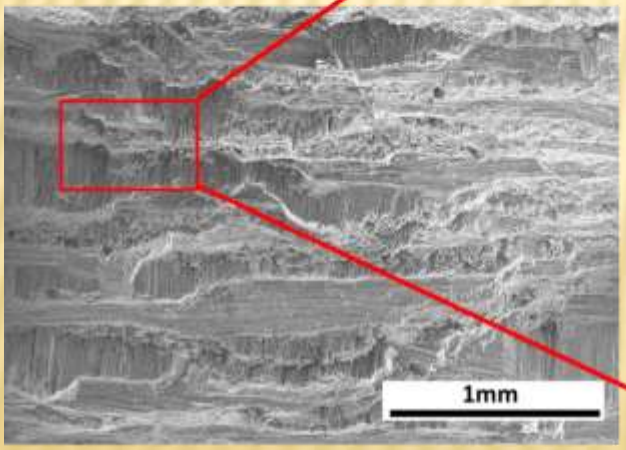
- Brief Summary of the C-WQT

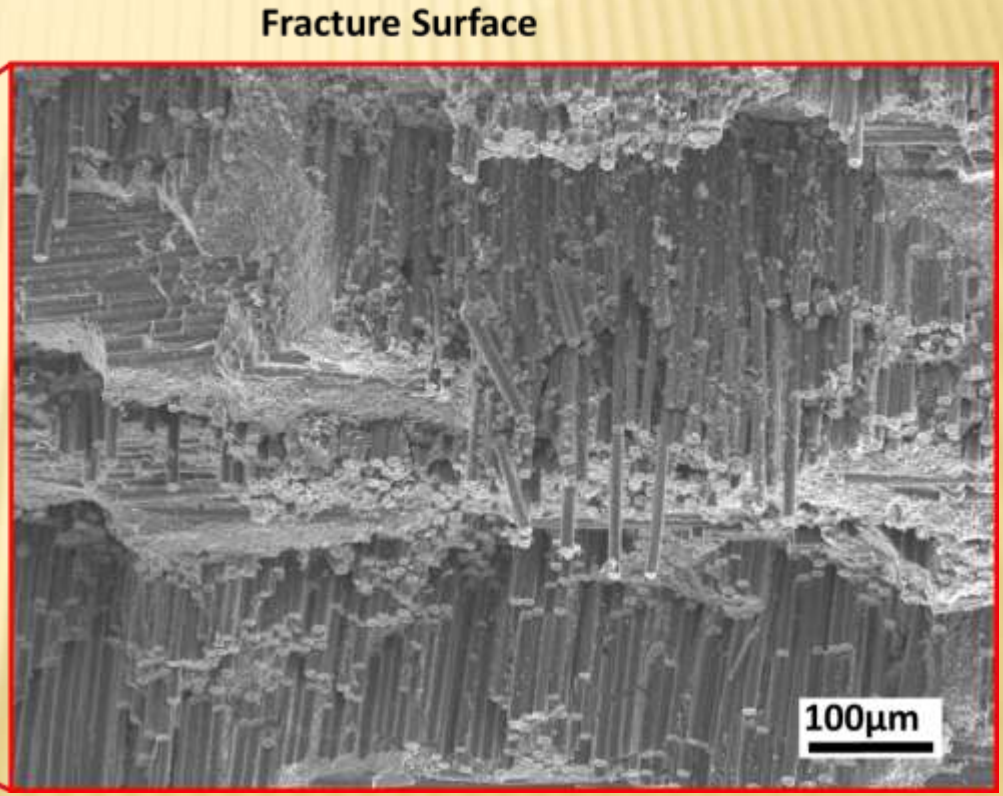
Sample ID	Test Condition	Remarks
KU-SiC/SiC	100 cycles of 1350-20 C exposure test at MHI, followed by 10 cycles of WQT at 1350 C	Followed to 100 cycle test at MHI, 10 cycles of WQT at 1350 performed with no clear crack formation observed.
Muroran-SiC	1500 C heating for 10 min. followed by WQ for 3 cycles	By the WQT, crack formation detected from the 1st WQT. By the 3rd WQT, sample was fractured into two and spin out over 1 m.
Muroran-SiC/SiC	1350 C heating for 10min.followed by WQ for 50 cycles	After 50 cycles of WQT, no clear crack formation observed. SiO_2 and/or Mullite bubbles and layers observed and loss of carbon interface and exfoliation of fiber bundles were observed.
Muroran-SiC/SiC with EBC	1350 C heating for 10min.followed by WQ for 10 cycles	After 10 cycles of WQT, no clear crack formation observed. SiO_2 and/or Mullite bubbles and layers observed on CVD surface. By the saw cutting of the sample, samples were broken. However, no exfoliation of CVD coating was observed.

FRACTURE SURFACE ANALYSIS RESULTS (3-2)

- MURORAN SIC/SIC AFTER 3 PBT FOLLOWED TO 50 CYCLE WQT -



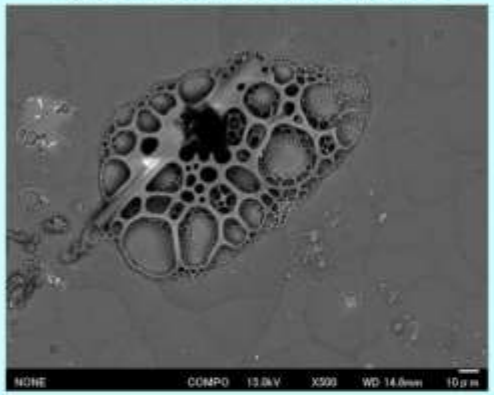


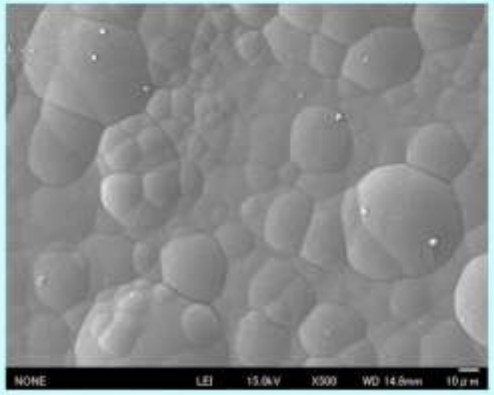


FRACTURE SURFACE ANALYSIS RESULTS (4)

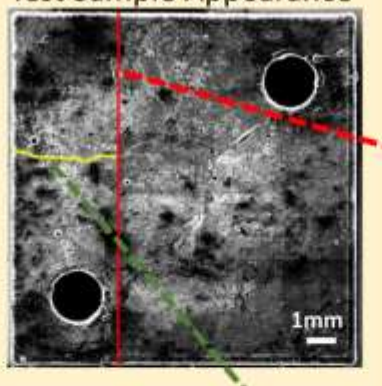
- MURORAN SIC/SIC WITH EBC AFTER SAW CUTTING FOLLOWED TO 10 CYCLE WQT -

Typical Surface Appearance

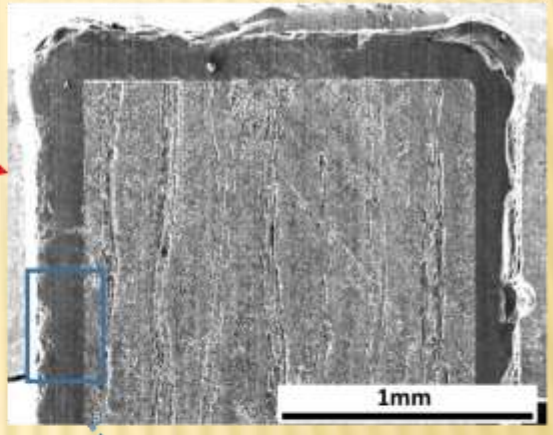




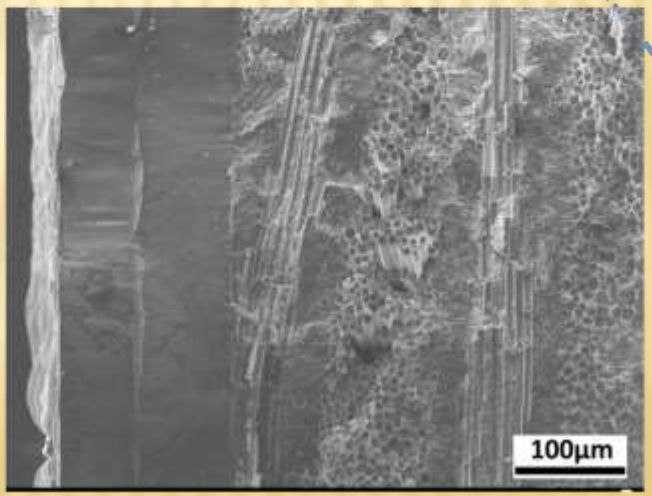
Test Sample Appearance



Cross Sectional View *(Through Thickness)*



Cross Sectional View



Cross Sectional View