WORKSHOP ON NUCLEAR GRAPHITE RESEARCH

Organized by ORNL and Sponsored by NRC

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JAPANESE RESEARCH ACTIVITIES

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Goal of HTTR Project

2005

Reactor Technology (HTTR)

- Attainment of reactor-outlet coolant temperature of 950℃ (April, 2004)
- Safety demonstration test
- Long-term operation at 950℃

Hydrogen Production Technology

IS Process

- Completion of 1 week continuous hydrogen production (Jun, 2004)
- Improvement of system efficiency
- Pilot test (under planning)

System Integration

- Safety evaluation
- Isolation valve tests

HTGR Plant Design and Gas Turbine Technology

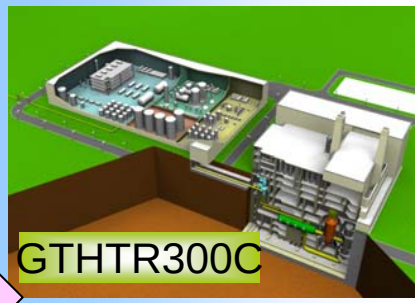
- Design of cogeneration HTGR system (GTHTR300C)
- Tests of compressor, magnetic bearing etc.

Hydrogen Production with HTTR-IS System (1000m³/h)

2020-30

Commercial HTGR System

Hydrogen production for commercial use in 2020s



Future Plan – R&D items -

Medium-range plan in JAEA → To be proposed

		2005	2010	2015	2020
		VHTR(GTHTR300C) Conceptual design	Detailed design	Evaluation	
Reactor	HTTR test	Performance tests Safety tests	Reactor-IS simulation		
	Fuel	Irradiation test on burnup, Manufacture of ZrC,	Irradiation of ZrC	High-burnup SiC	
	Material	Graphite test C/C component test	Irradiation tests		
Heat Utilization	Components	Compressor (Gas turbine) IHX			
	Hydrogen production	Data base system	Pilot plant test	HTTR-IS	

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Safety Demonstration Test

FY	2002	2003	2004	2005	2006	2009
CRW	★	★	Delayed		★	(Phase 1 in progress)
TGC1, 2	★	★			★	
TGC3			(Phase 2 under preparation)			★
VCSS						★
OT				(Phase 2 planned)		★

CRW Reactivity insertion test (Control rod withdrawal test)

TGC1, 2 Gas circulators trip test
by running down one and two out of three gas circulators

TGC3 Loss of forced cooling test
by running down all gas circulators

VCSS Vessel cooling system stop test

OT Off-normal load condition test of heat utilization system, etc.

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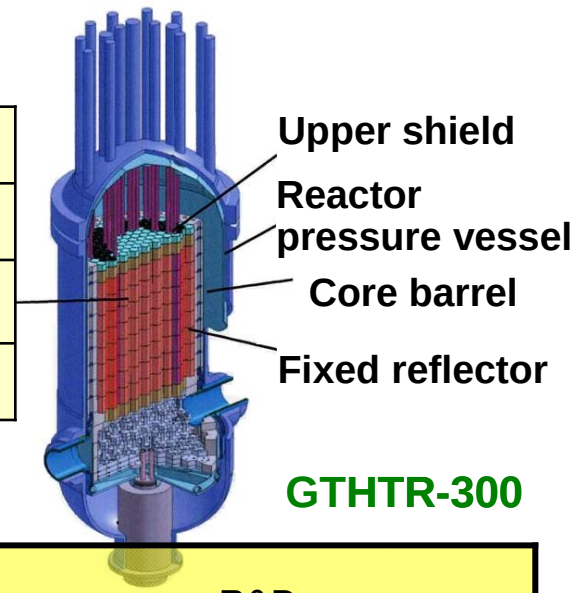
R&D Items for VHTR

	HTTR	VHTR
Power density	2.5 MW/m^3	5.8 MW/m^3
Burn-up	22 GWD/t	150~200 GWD/t
Fluence	~ 1.5×10^{25}n/m^2	~ 6×10^{25}n/m^2



Component	HTTR	VHTR	R&D
Fuel, Reflector blocks	IG-110	IG-110 (primary) IG-430 (advanced)	Global code/ standard Irradiation data Lifetime extension

IG-430 has 20-40% higher strength than IG-110

IG-110 is mature nuclear graphite and primary candidate for VHTR.

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Property Data and Proof Test on IG-110 for HTTR Development

- ✓ Property data

  Mechanical and thermal properties

  including irradiation and oxidation effects

- ✓ Proof tests on IG-110 graphite components

  Bottom structure seismic test

  Core components seismic test

  Support post bucking test

  Dowell/ socket fracture test

  Key/ keyway fracture test

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Strength Data for IG-110

The first loaded IG-110 graphite in the HTTR

	Average (MPa)	Standard deviation (MPa)	Number of specimens	Su value (MPa)
Tensile strength	29.6	1.49	640	26.1
Compressive strength	82.6	2.36	320	76.9

Su values for tensile and compressive strength were decided Survival probability of 99% at confidence level of 95%

The first loaded IG-110 has excellent performance.

It is possible to increase the Su values for proven IG-110 graphite. It gives lifetime extension of components.

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Typical Properties of IG-110 and IG-430 Graphites

Grade	IG-110	IG-430
Raw material	Petroleum pitch	Coal-tar pitch
Bulk density (Mg/m^3)	1.78	1.82
Tensile strength (MPa)	25.3	37.2
Compressive strength (MPa)	76.8	90.2
Young's modulus (GPa)	8.3	10.8
Poisson's ratio	0.14	
Su value for tensile (MPa)	19.4	
Su value for compressive (MPa)	61.4	

Both graphties are fine-grain graphite

IG-430 has 20-40% higher strength than IG-110

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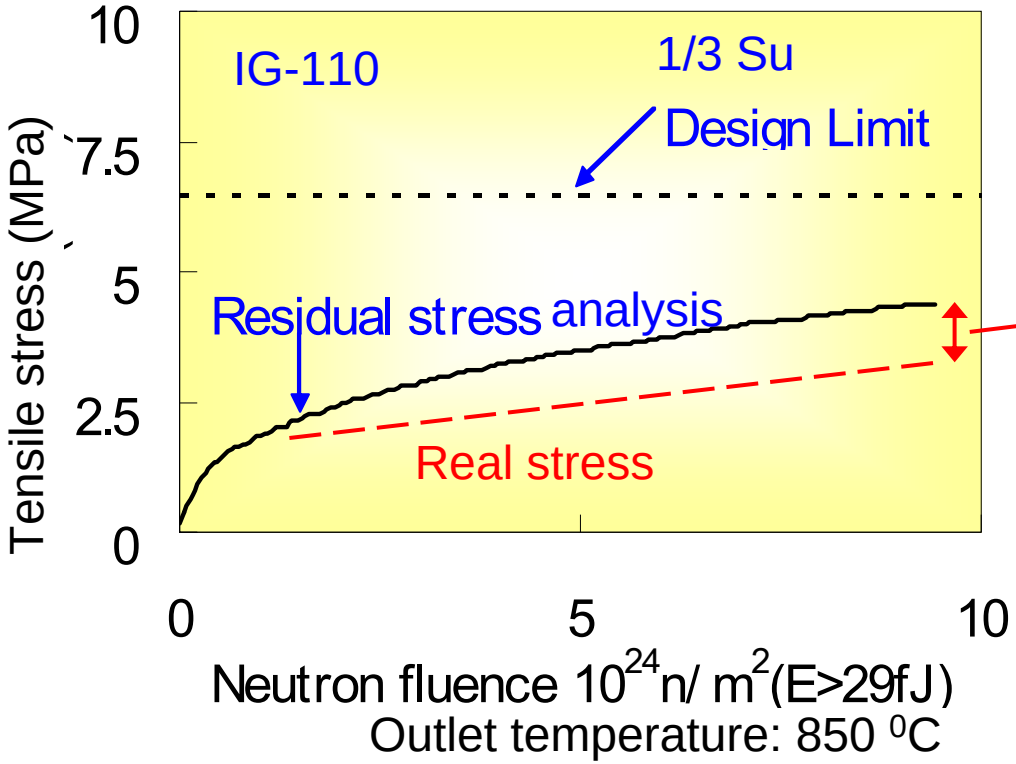
For Lifetime Extension of Components



(1)
By using higher strength graphite IG-430

Safety margin for analysis

(2) **The margin can be reduced by measuring the stress directly by non-destructive way.**

Two possible solutions for lifetime extension

(1) use advanced graphite

→ (2) evaluate stress by measurement

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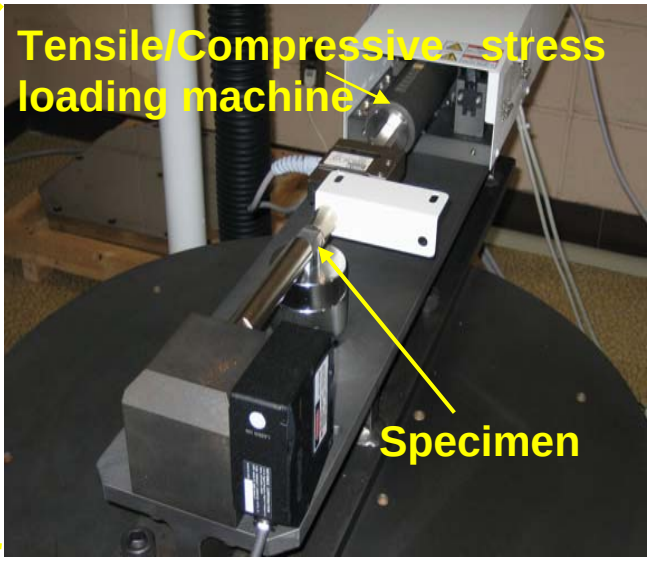
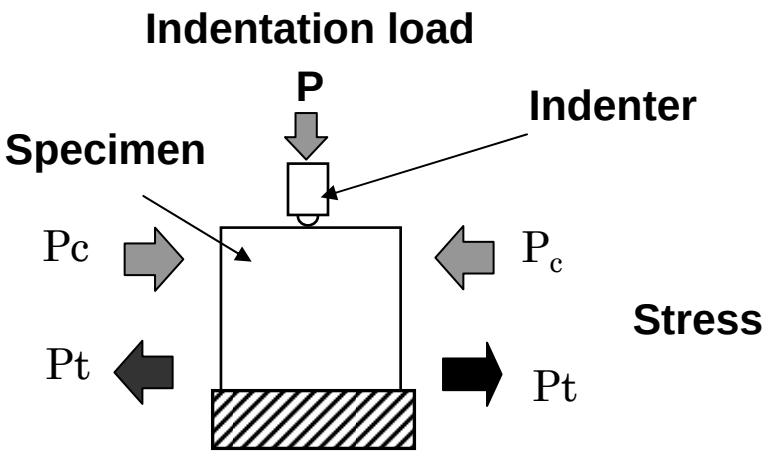
Apparatus for Micro-indentation Test





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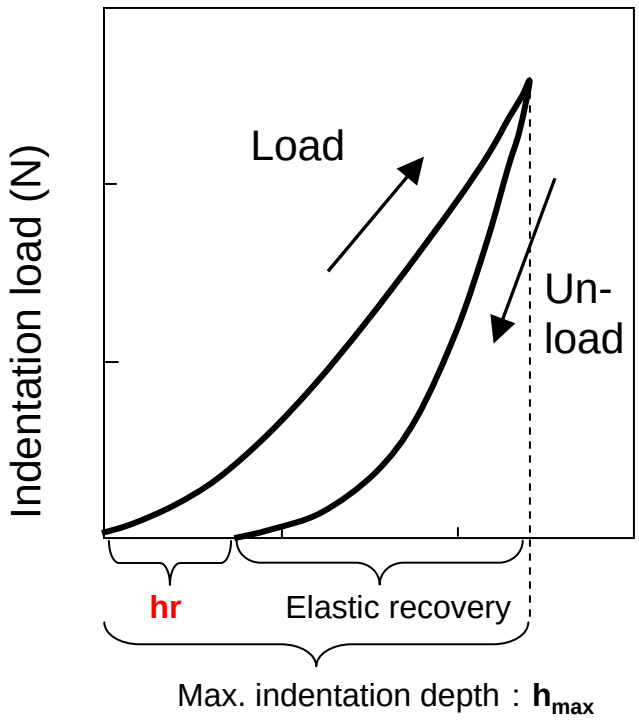
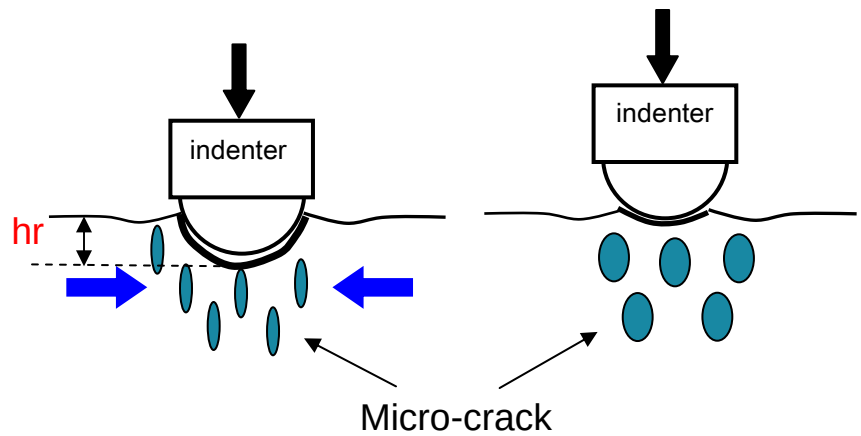
Load-depth curves for micro–indentation test

Plastic deformation model for indentation load at compressive stress



hr : depth by plastic deformation

Compressive load decreases micro-crack accommodation at un-loading process



Compressive

No-stressed

Tensile

Plastic deformation accommodates load

Micro-cracks accommodate load

⇩

Compressive stress will be evaluated by plastic deformation

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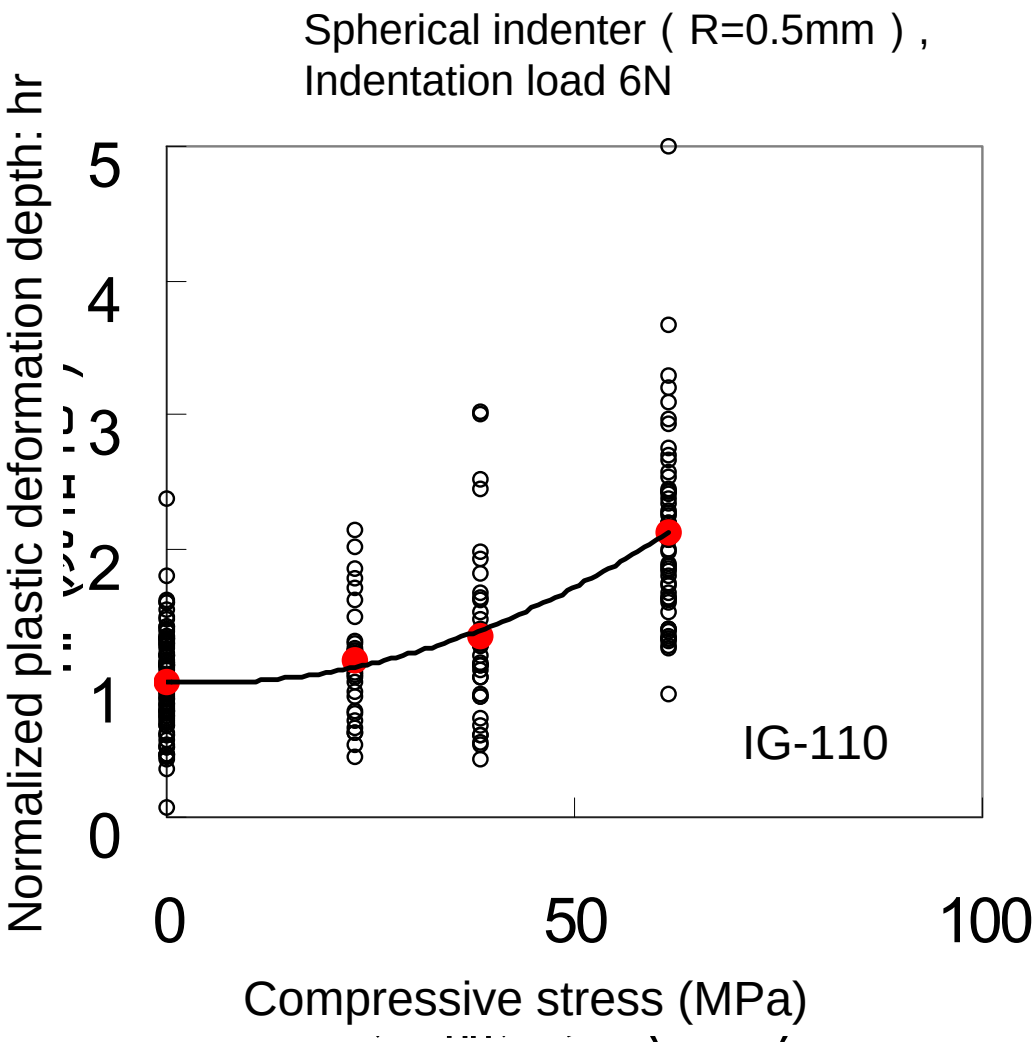
Plastic Deformation Depth after Un-loading

Compressive stress was given by testing machine on IG-110 sample



- plastic deformation depth hr was increased by compressive stress as expected
- it is possible to evaluate compressive stress condition by micro-indentation characteristics

- variation of data
  - -reduce by improving experimental condition
  - -evaluated by statistic approach

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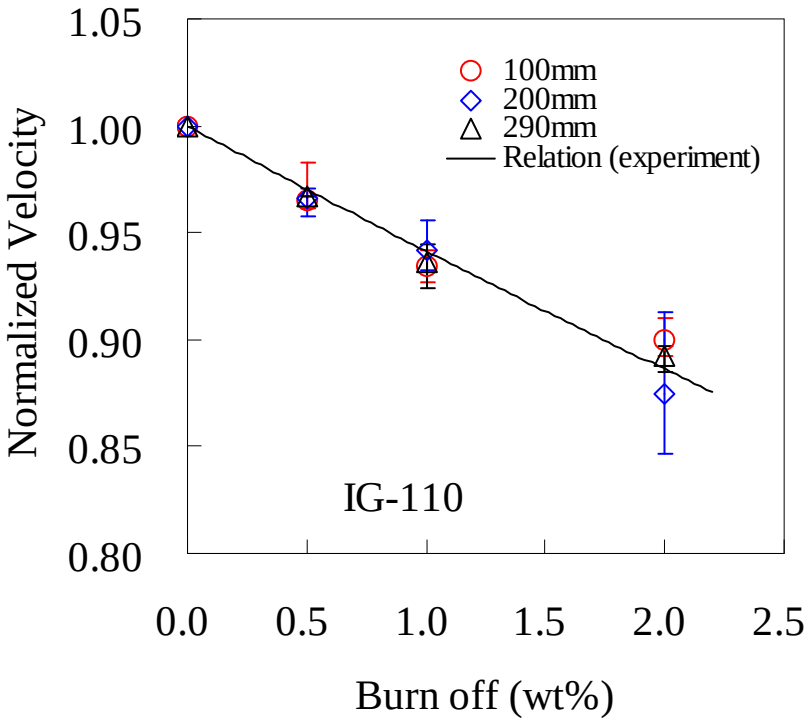
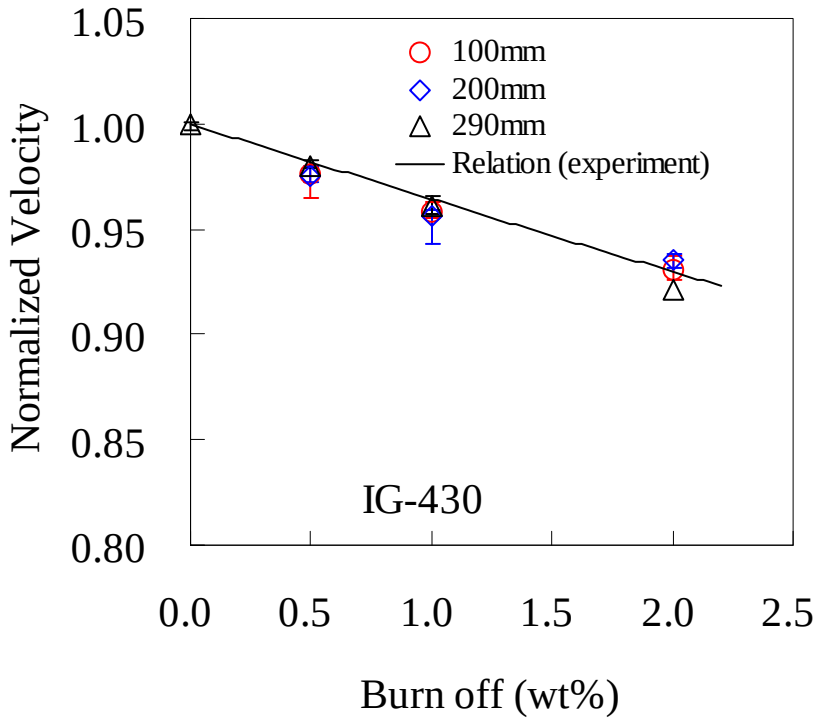
Ultrasonic Wave Velocity as a Function of Oxidation Burnoff





Specimen size 100×200×290(mm)

Oxidation temperature 500℃

$$v / v_0 = \exp(-6.04B)$$ for IG-110

$$v / v_0 = \exp(-3.64B)$$ for IG-430

***v/v_0* : velocity ratio**

***B* : burn-off**

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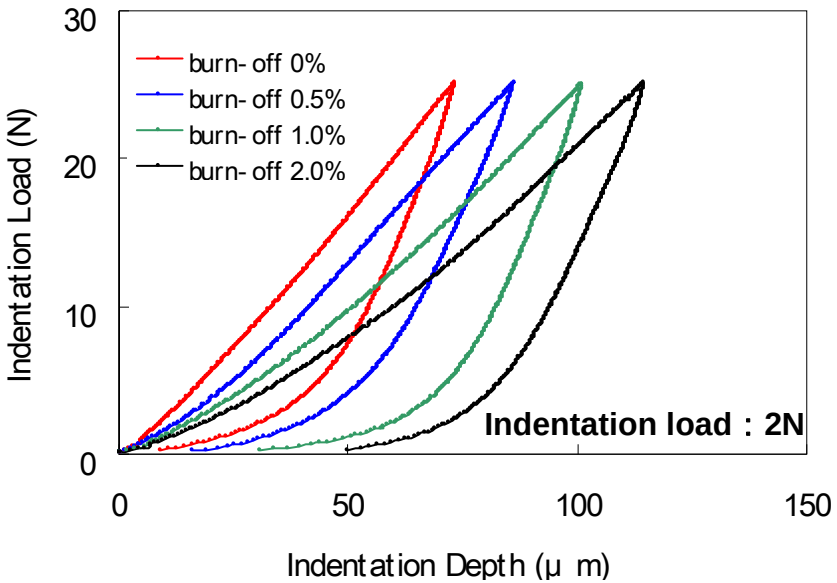
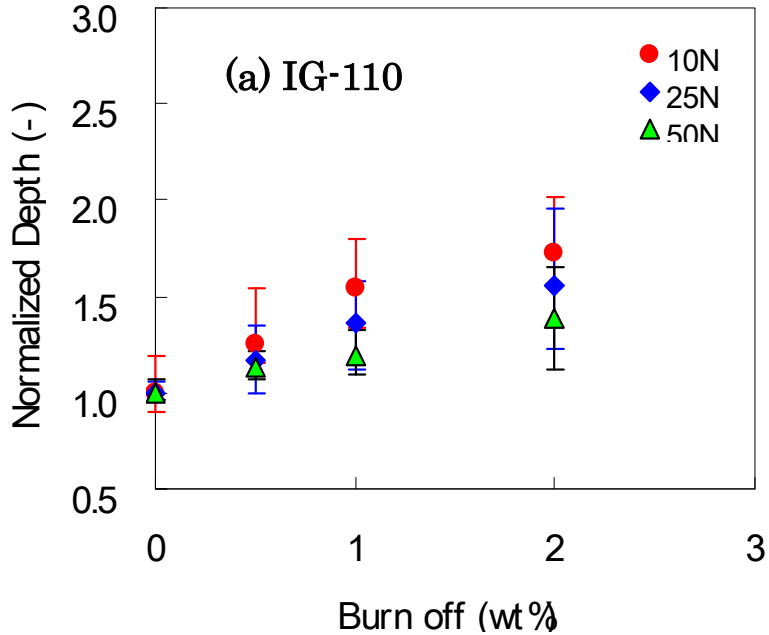
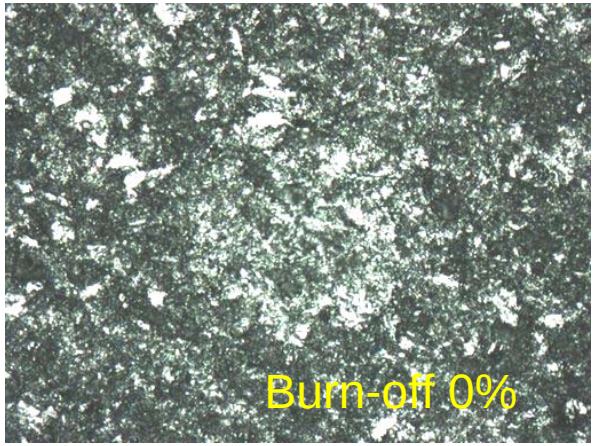
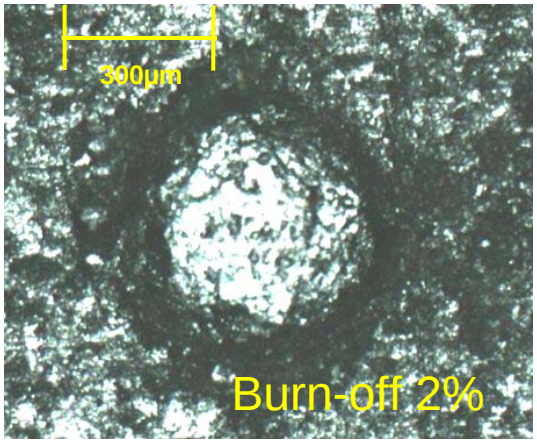
Micro-indentation Test for Oxidized IG-110









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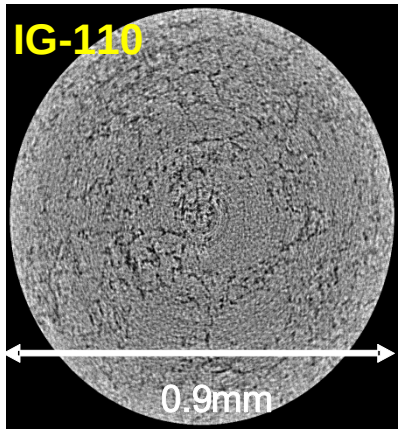
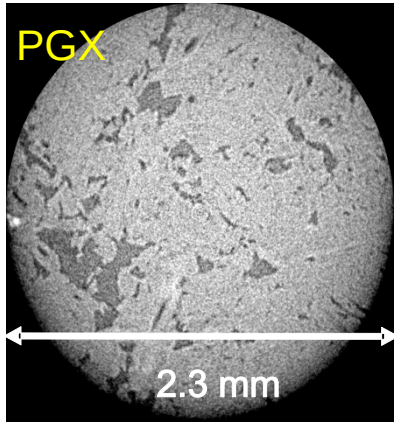
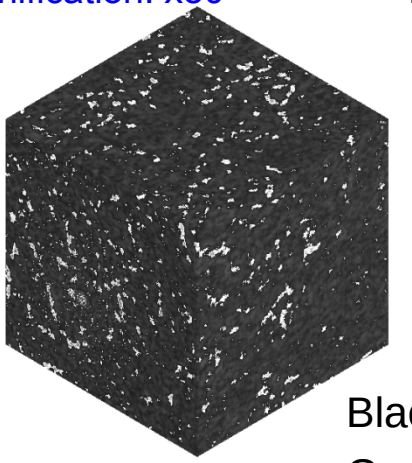
Development of 3D-Xray CT Technique for IG-110 and PGX Graphites

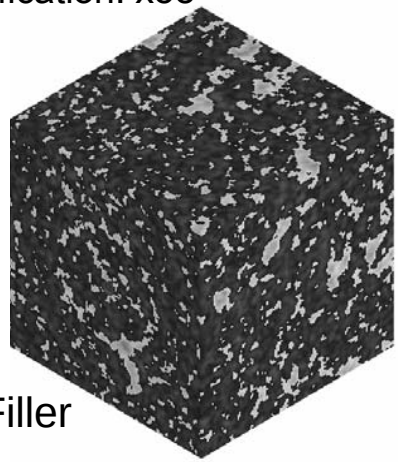


Magnification: x80



Magnification: x58





Black : Filler

Gray : Pore

3D-Xray CT images (upper)

3D-image model for filler and pore (lower)

Evaluation for irradiation effects

- Coarse-grained PGX

  Normal magnification of x58

- Fine-grained IG-110 :

  3D-image was successfully obtained by using high magnification of x80

Next study

- Modeling of irradiation effects on filler and pore
- Characterization with graphite material property data
- Demonstration by irradiated IG-110 data

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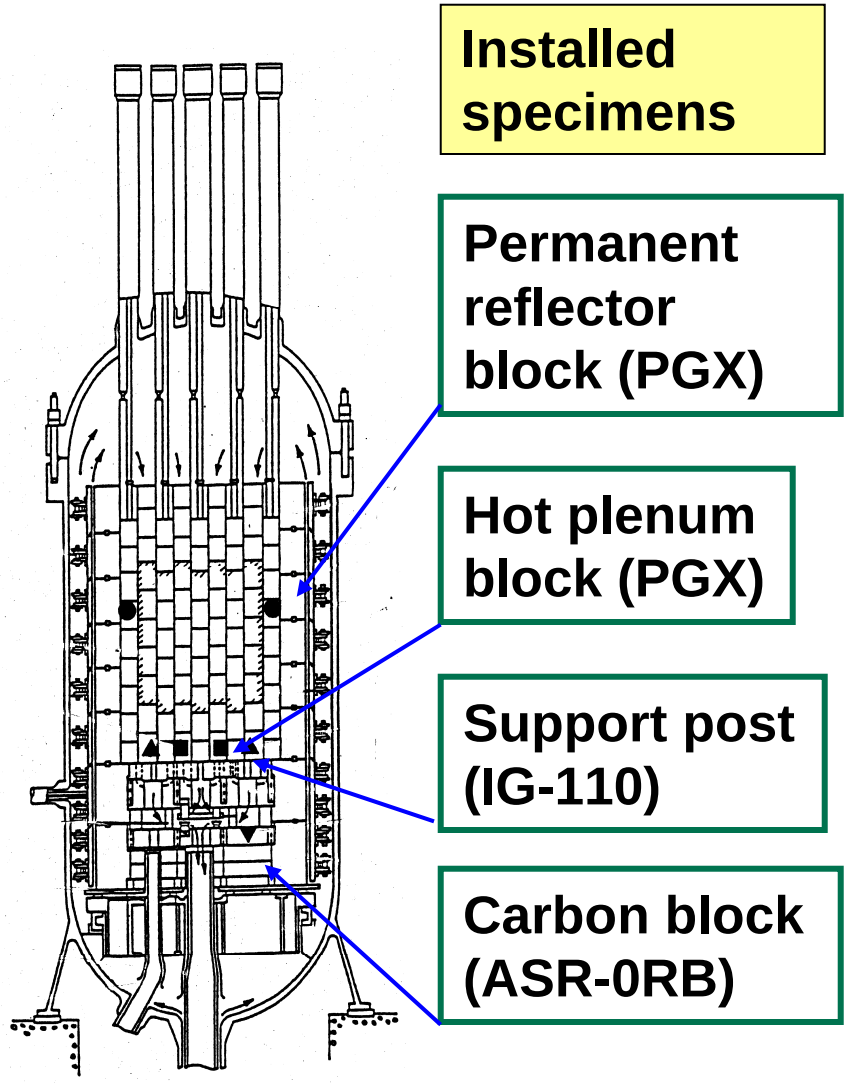
In-Service Inspection (ISI) of Graphite

1. TV camera monitoring

2. Surveillance test
   - Dimensional change
   - Bending strength
   - Compressive strength
   - Surface oxidation rate
   - Young's modulus

HTTR graphite blocks can be measured at refueling period.



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CTE Measurement in HTTR ISI

Irradiation-induced changes in CTE of IG-110, PGX and ASR-0RB will be measured at ISI of HTTR graphite components

- Specimens for CTE (Coefficient of Thermal Expansion) are installed in the HTTR graphite blocks

- CTE measurements will be carried out by taking out the specimens from blocks after the refueling.

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Mechanical properties measurement in HTTR ISI

Irradiation-induced changes in mechanical properties will be measured at ISI of HTTR graphite components

- Grade: IG-110, PGX and ASR-0RB
- Dimensional change, bending strength, compressive strength, dynamic Young's modulus and thermal diffusivity
- Specimens are installed in the HTTR graphite blocks

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Irradiation Induced Creep in HTTR ISI

Irradiation-induced creep will be measured by the loaded IG-110 block in the HTTR.

- Measurement will be carried out by taking out the specimens from blocks after the refueling.

- Fuel blocks have residual stress which is given by irradiation-induced creep effect on graphite.

- The stress will be released by cutting the block with residual stress. The creep effect will be evaluated by the dimensions of graphite block before and after the cut.

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Blockage of Fuel Element Coolant Channel or Reactivity Control Rod Block

Evaluation of FP transport by the fuel failure test simulating a blockage.

- Some of the coolant flow pass in the irradiation test blocks with fuels will be blocked by plugs.

- It simulates blockage of fuel element coolant channel due to graphite failure.

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Present Status of Irradiation Research Activities:

- Experimental Data (Graphite Characterization Group: JAEA/Toyo Tanso)

  Higher fluence, wider temperature range data needed.

  - Irradiation planned in Joyo, JAEA;
  - Collaboration with Petten Programs, INL ATR Irradiation Programs

- International Collaborations

  GIF (Generation IV International Forum)

  - VHTR R&D Project, Material Project Plan, Graphite: Irradiation Creep

  IAEA CRP

  - Development of Comprehensive Creep Model and Equations

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