WORKSHOP ON NUCLEAR GRAPHITE RESEARCH

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# JAPANESE REGULATORY PERSPECTIVE

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# HTTR Graphite Components Design & Manufacturing Procedure

(1) Database

(2) Design

(3) Manufacturing / Construction

(4) In-service

Property data including irradiation effect

Proof test

***Structural design code***

***Inspection standards***

QA/QC management

No crack propagation or unexpected oxidation supposed

Reactor not in operation

Surveillance test

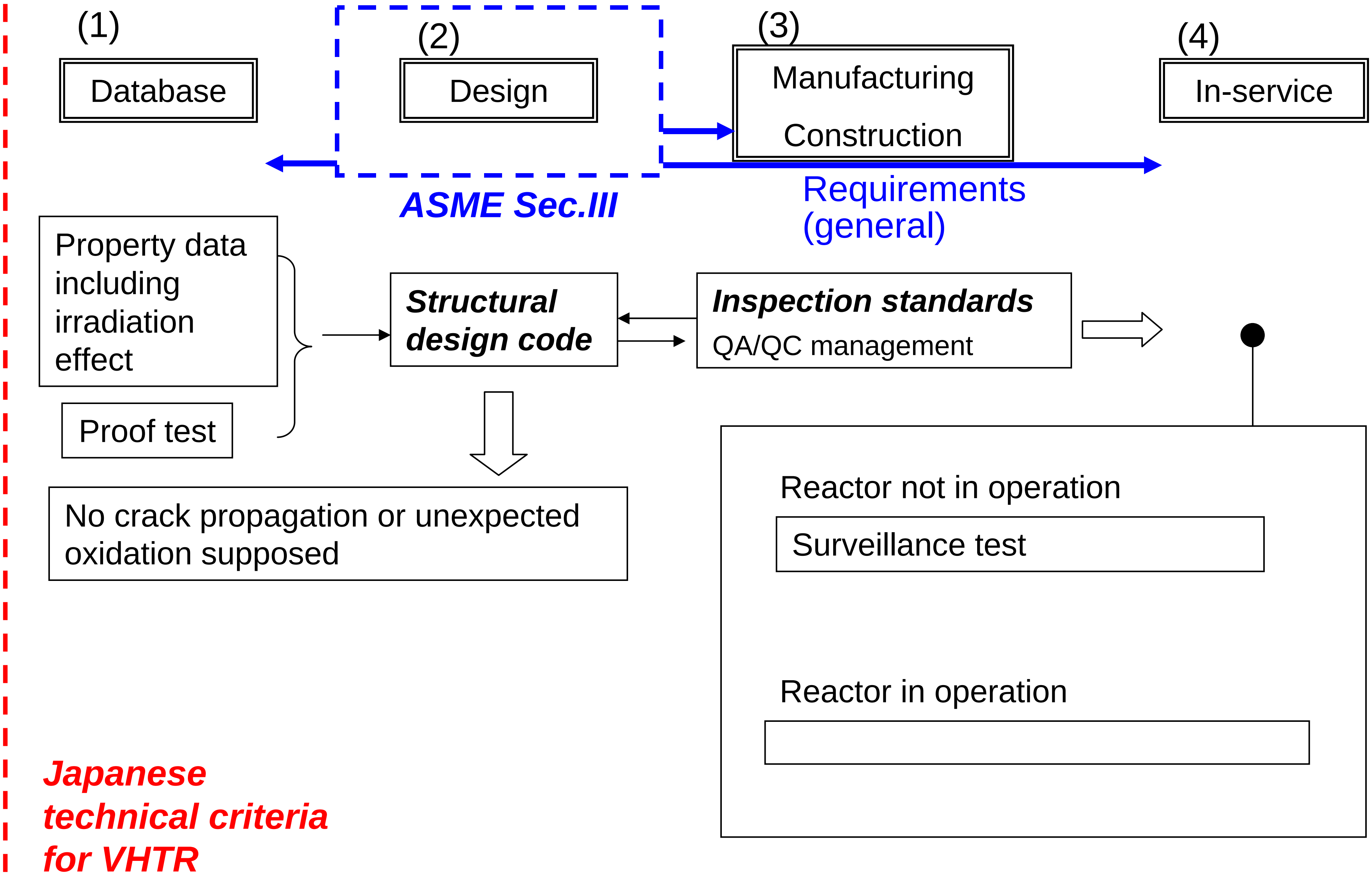
inspection by TV camera

Reactor in operation

Monitoring

- regional temperature distribution
- regional FP release amount

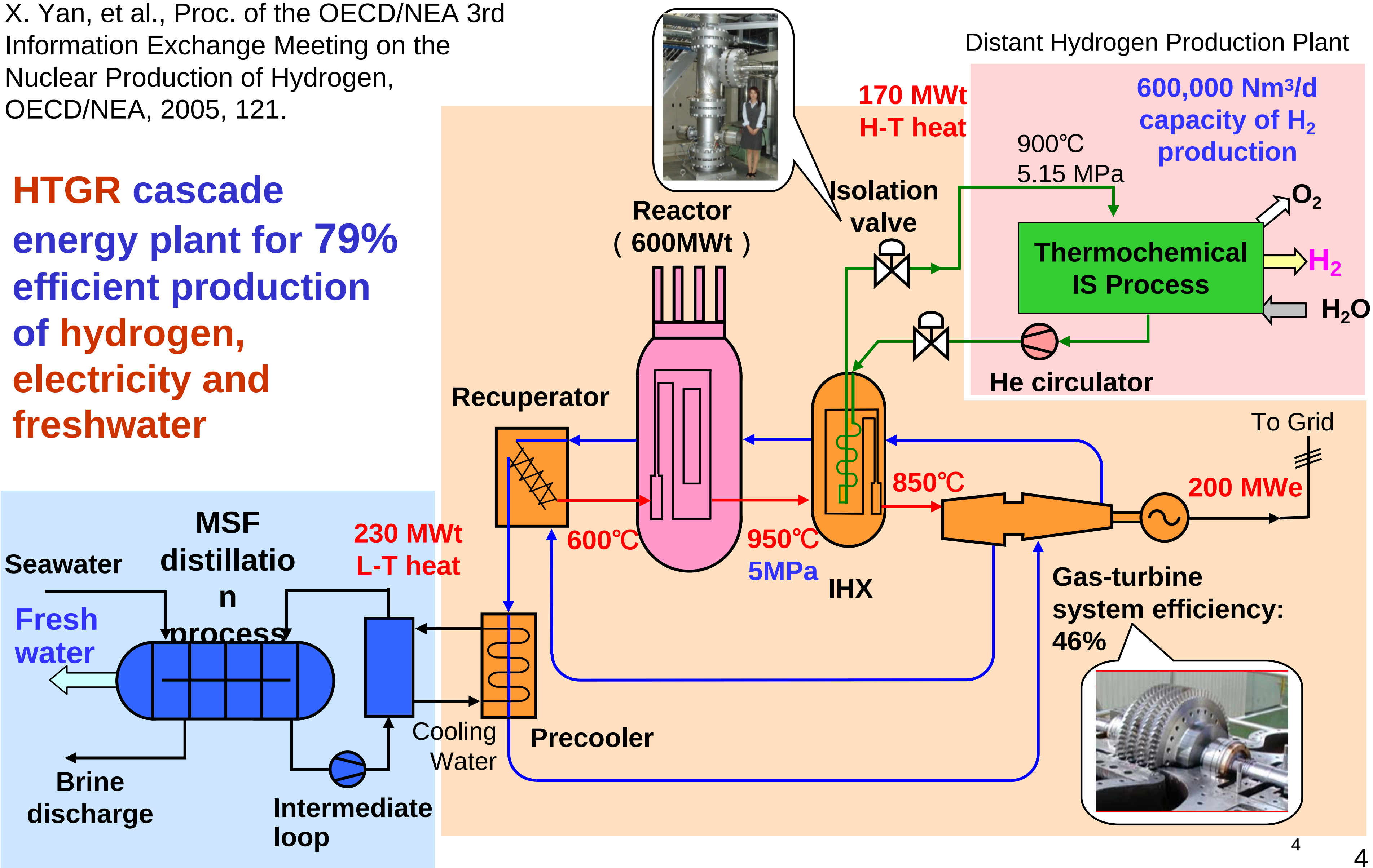
# Japanese Regulatory Perspective for VHTR



# (1) HTGR Cogeneration System (GTHTR300C)

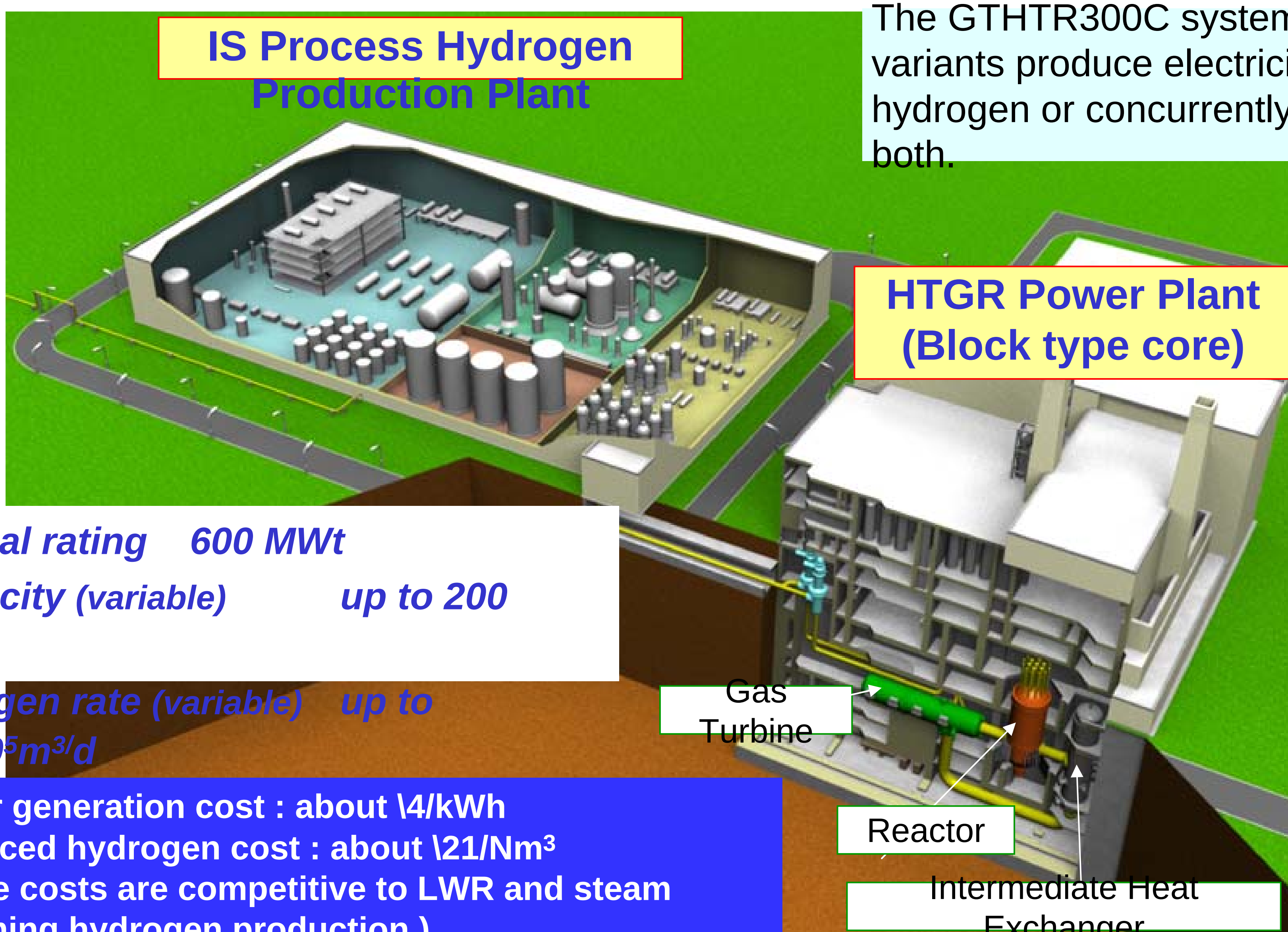
X. Yan, et al., Proc. of the OECD/NEA 3rd Information Exchange Meeting on the Nuclear Production of Hydrogen, OECD/NEA, 2005, 121.

**HTGR cascade energy plant for 79% efficient production of hydrogen, electricity and freshwater**



# (2) HTGR Plant Design
## - Concept of HTGR Cogeneration System (GTHTR300C) -

The GTHTR300C system variants produce electricity, hydrogen or concurrently both.




***Thermal rating* 600 MWt**

***Electricity (variable)* up to 200 MWe**

***Hydrogen rate (variable)* up to $6.4X10^5 m^3/d$**

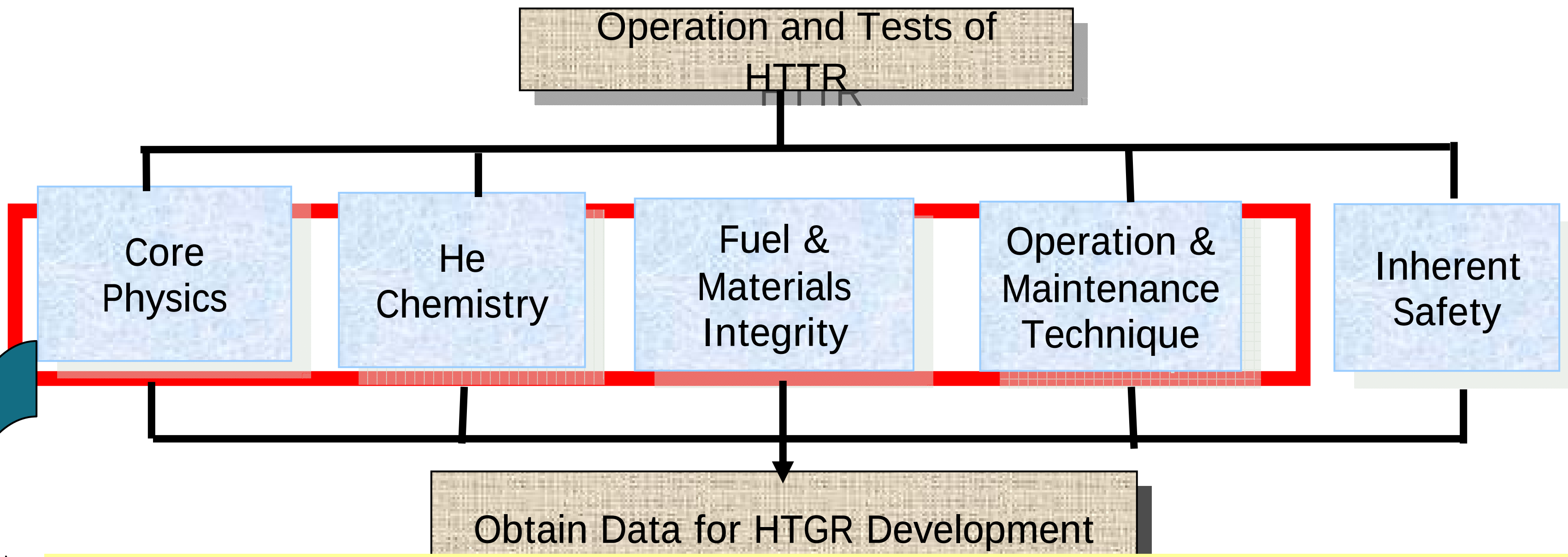
**Power generation cost : about \4/kWh**
**Produced hydrogen cost : about \21/$Nm^3$**
**(These costs are competitive to LWR and steam reforming hydrogen production.)**

# 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<br>Safety tests | Reactor-IS simulation | | |
| | Fuel | Irradiation test on burnup,<br>Manufacture of ZrC, | High-burnup SiC<br>Irradiation of ZrC | | |
| | Material | Graphite test<br>C/C component test | Irradiation tests | | |
| Heat Utilization | Components | Compressor (Gas turbine)<br>IHX | | | |
| | Hydrogen production | Data base<br>system | Pilot plant test | HTTR-IS | |

# Long High-temp.(50days/950°C) Operation of HTTR




Core Physics : Excess reactivity and other core physics parameters change by fuel burn-up

He Chemistry : Impurities behavior at high temperature under radiation environment
Performance of primary He purification system

Fuel and Materials Integrity : FP release, High temp. component (IHX), In-core components **(Graphite core support and reflectors)**

Operation and Maintenance Technique : Control of primary coolant (Leak, Purification,・・・)

- Experiences and knowledge database obtained in the design, construction and operation of HTTR are to be utilized effectively for the larger commercial HTGR.
- For this purpose the detailed evaluation of existing data as well as the new data obtained from the ongoing and future experiments are necessary.

# (1) Property Data and Proof Test

✓Property data

For IG-110, PGX and ASR-0RB

Including irradiation and oxidation effects

✓Proof tests

Bottom structure seismic test

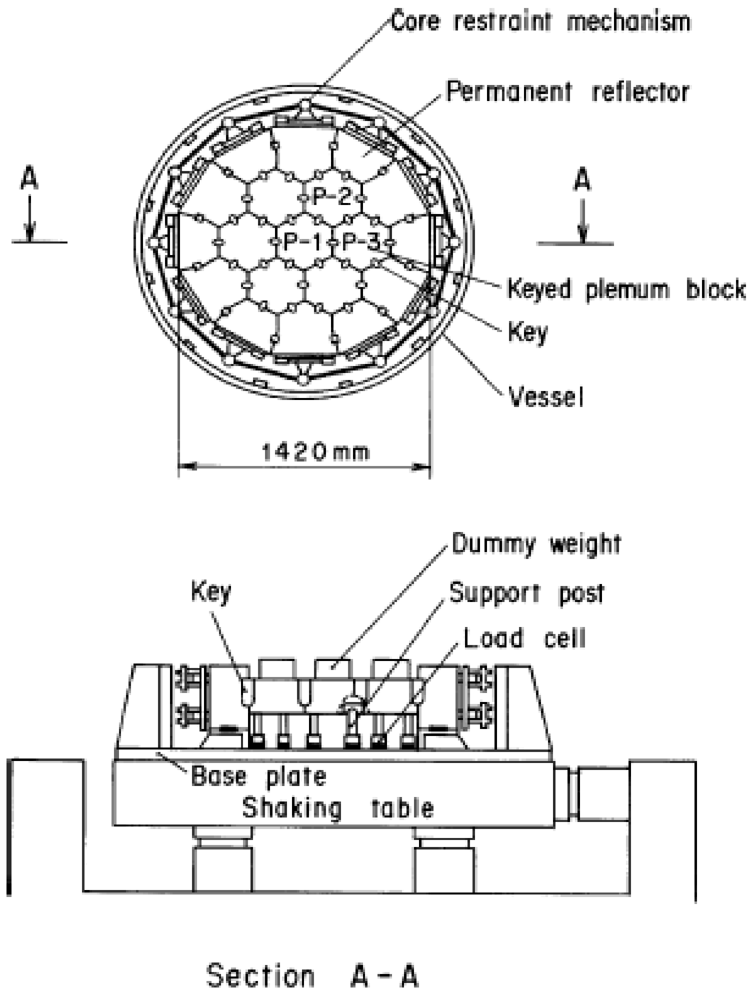
Core components seismic test

Support post bucking test

Dowell/ socket fracture test

Key/ keyway fracture test

# (1) Property Data and Proof Test

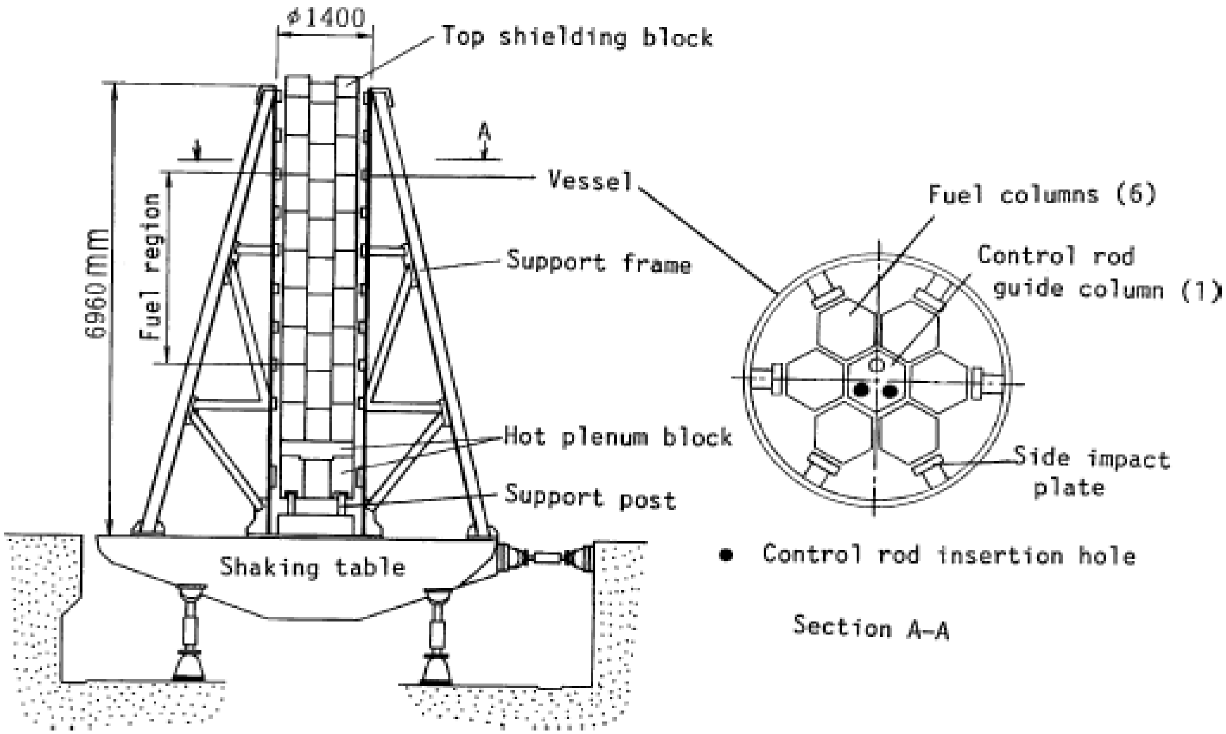



Core bottom structure seismic test apparatus

Integrity of the structure was confirmed.

Validity of technical criteria should be confirmed by proof tests.

# (1) Property Data and Proof Test




Core component array seismic test apparatus

| |
|---|
| Integrity of the structure was confirmed. |
| Seismic analysis code SONATINA-2V was developed. |
| Propose to describe in the ASME code as a specific example. |

*Japanese seismic standard was revised in 2006. Check for seismic waves following the new standard is underway.*

# (2) Graphite Structural Design Code

## Graphite Structural Design Code

*Deterministic approach*

1) Classification of graphite components
2) Failure theory

   *Maximum principal stress + Modified bi-axial stress limit*

3) Stress classification

   *Limit for primary and secondary stress*

4) Stress limit
5) Buckling limit
6) Stress analysis

   *Viscoelastic analysis by proven VIENUS code*

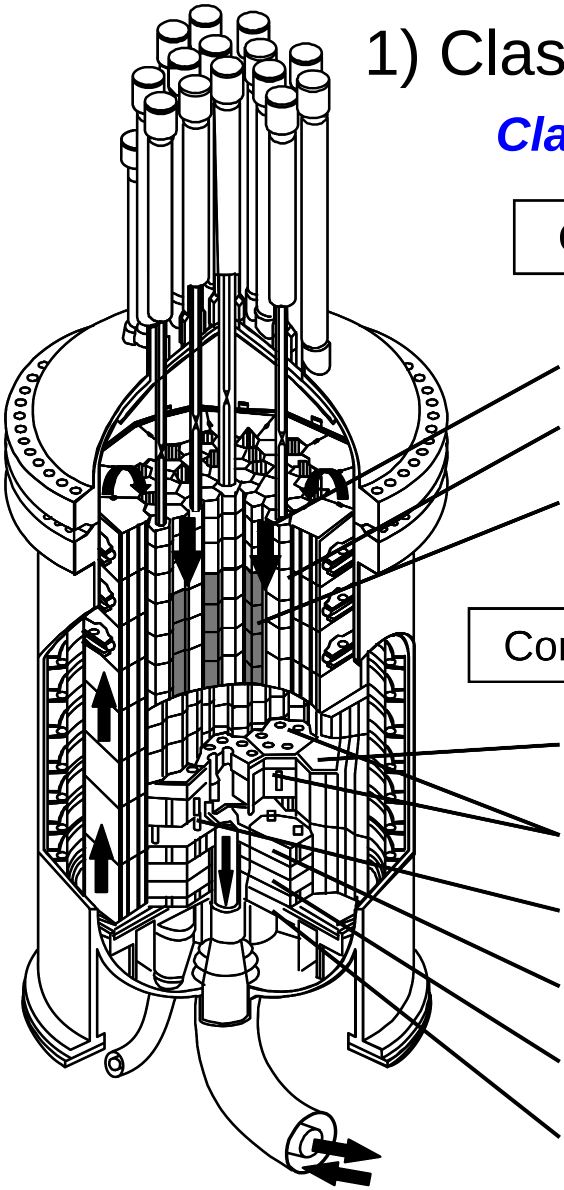
7) Specified minimum ultimate strength, Su
8) Oxidation effect
9) Quality control determined by Inspection Standard for Graphite
10) A set of design data

   *IG-110, PGX and ASR-0RB*

   *including irradiation and oxidation effects*

# (2) Graphite Structural Design Code

## 1) Classification of components



***Classified by structural functions (safety viewpoint)***

**Core graphite components**

Replaceability: routine

Irradiation effect: considered

- Replaceable reflector block ( IG-110 )
- Control rod guide block ( IG-110 )
- Fuel block ( IG-110 )

JAEA original design criteria

**Core support graphite components**

Serious safety function to keep core structure for reactor shutdown

Replaceability: difficult

- Permanent reflector block ( PGX )
- Hot plenum block ( PGX )
- Support post ( IG-110 )
- Lower plenum block ( PGX )
- Carbon block ( ASR-0RB )
- Bottom block ( PGX )

Design criteria was established on the basis of concept of former ASME draft

# (2) Graphite Structural Design Code

TOYO TANSO
Inspiration for Innovation

## 4) Stress limit

| Operation condition | Primary + secondary stresses: Membrane | Primary + secondary stresses: Menbrane + bending or Point | Peak stress: Peak | Peak stress: Fatigue(*) |
|---|---|---|---|---|
| I & II | 0.25Su | 0.33Su | 0.9Su | 1/3 |
| | 0.33Su | 0.5Su | 0.9Su | 1/3 |
| III | 0.5Su | 0.67Su | 0.9Su | 2/3 |
| | 0.5Su | 0.75Su | 0.9Su | 2/3 |
| IV | 0.6Su | 0.8Su | 1.0Su | 3/3 |
| | 0.7Su | 0.9Su | 1.0Su | 3/3 |

(*) Allowable fatigue life usage fraction
Upper line: core support conponents
Lower line: core components

*Core support components* have more severe limits than *core components* considering safety function.

# (2) Graphite Structural Design Code

## The first loaded IG-110 graphite in the HTTR

Table 2.4 Tensile and compressive data of HTTR first loaded IG-110 graphite.

| Tensile strength (MPa) | Average | Standard deviation | Number of specimens | $S_u$ value |
|---|---|---|---|---|
| HTTR first loaded data | 29.6 | 1.49 | 640 | 26.1 |
| Design data | 25.3 | 2.43 | 362 | 19.4 |
| Compressive strength (MPa) | Average | Standard deviation | Number of specimens | $S_u$ value |
| HTTR first loaded data | 82.6 | 2.36 | 320 | 76.9 |
| Design data | 76.9 | 6.41 | 373 | 61.4 |

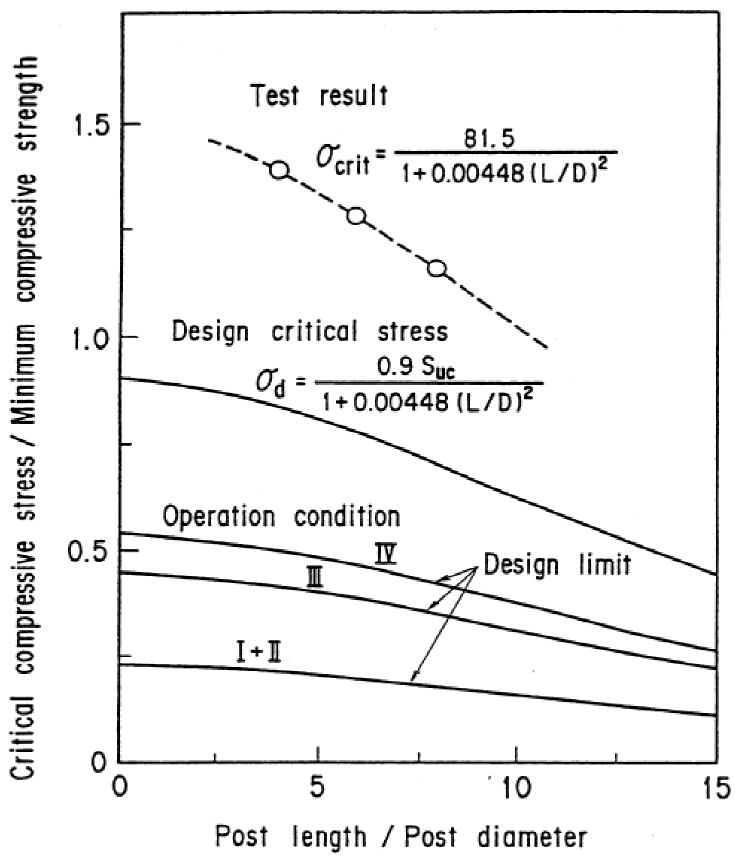
Su values for tensile and compressive strength were decided Survival probability of 99% at confidence level of 95%(JAEA-Technology 2006-048)

The first loaded IG-110 has much higher strength than design data.

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

# (2) Graphite Structural Design Code

## 5) Buckling limit of core support post



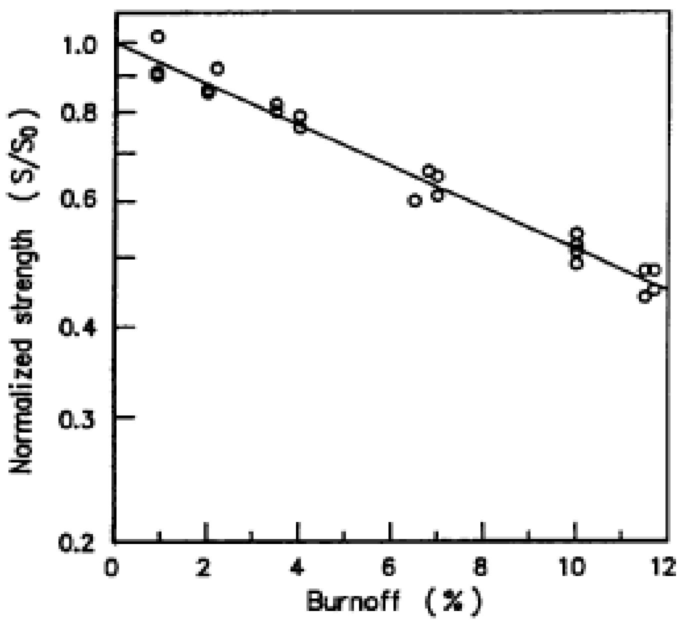

L : Post length
D : Post diameter
$S_{uc}$ : Specified minimum ultimate compressive strength

Rankine-Gordon type stress limit criteria was completed by test results

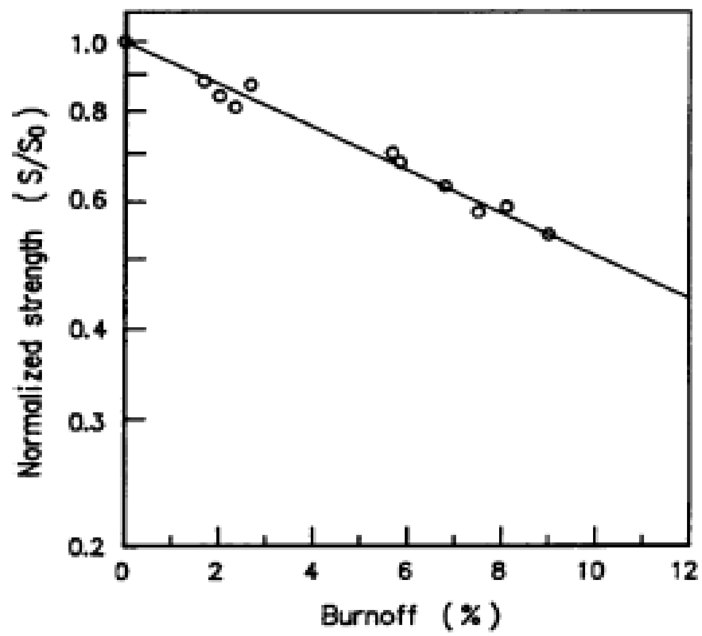
Specific example is not given in ASME code.

Propose to describe in the ASME code.

## 8) Oxidation effect




(a) Tensile strength




(b) Compressive strength

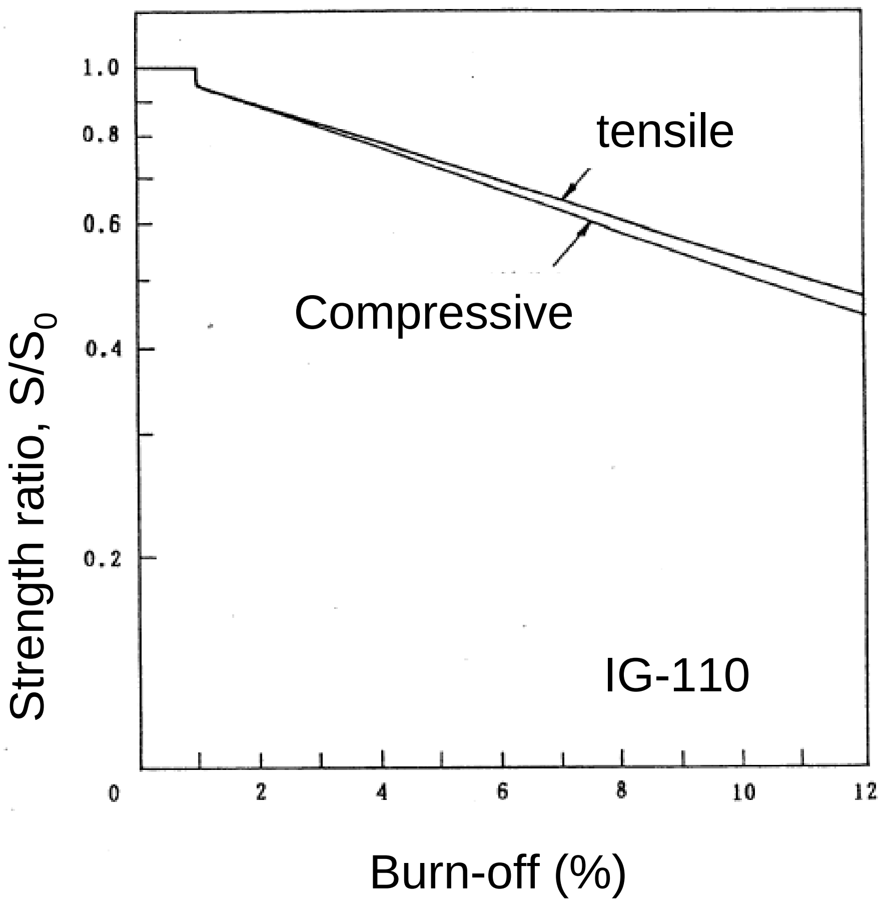
$S$ : Strength of unoxidized specimen
$S_0$: Strength of oxidized specimen

The oxidation-induced property change should be considered for safety analysis.

The strength is decreased by oxidation with variation of data.

It is important to decide reasonable criteria.

## 8) Oxidation effect




JAEA criteria for oxidation

- ✓ Region oxidized > 80%: Geometry reduction (regarded as burn away)
- ✓ Strength reduction till 12% is evaluated following the figure

At low oxidation condition, its damage on material properties is negligible for safety analysis.

Propose to describe in the ASME code.

# (3) Inspection Standard for Graphite

Manufacturing process for components

(1) Material inspection

1) Graphite grade

2) Impurities

3) Mechanical strength

4) Dimensional stability at high temperatures

(only for carbon material)

(2) Dimension inspection

(3) Visual inspection

(4) Non-destructive test

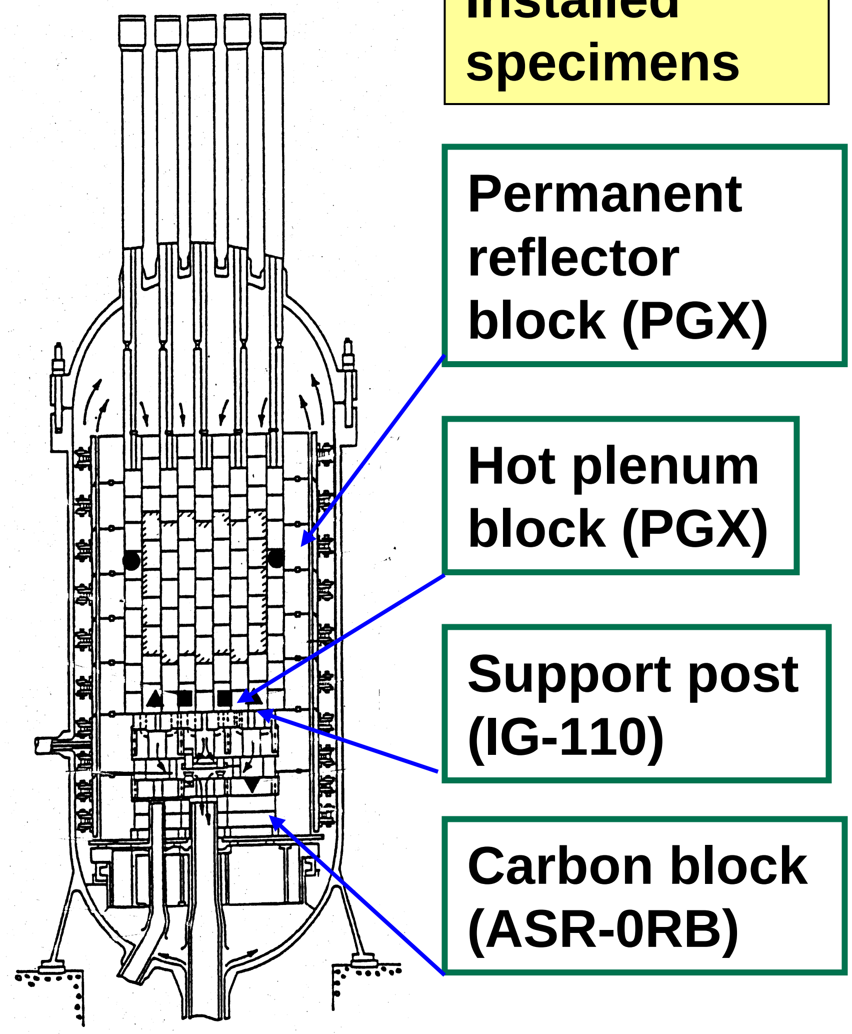
(Compulsory inspection for as-fabricated graphite)

# In-Service Inspection (ISI) of Graphite Components

1. TV camera monitoring

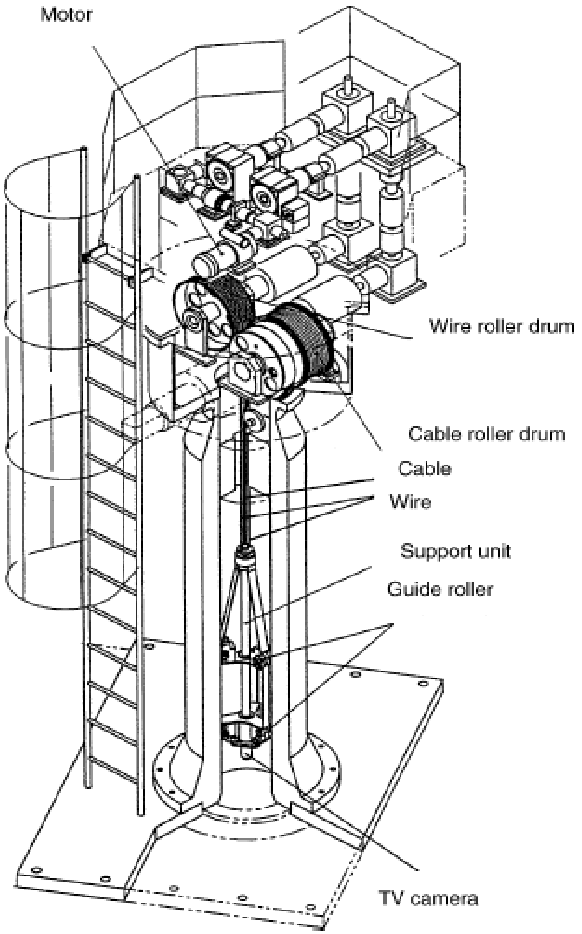
2. Surveillance test
   - Dimensional change
   - Bending strength
   - Compressive strength
   - Surface oxidation rate
   - Young's modulus

HTTR graphite blocks can be measured during refueling period.



# (4) In-Service Inspection (ISI) of Graphite Components

## (1) Visual inspection by TV camera



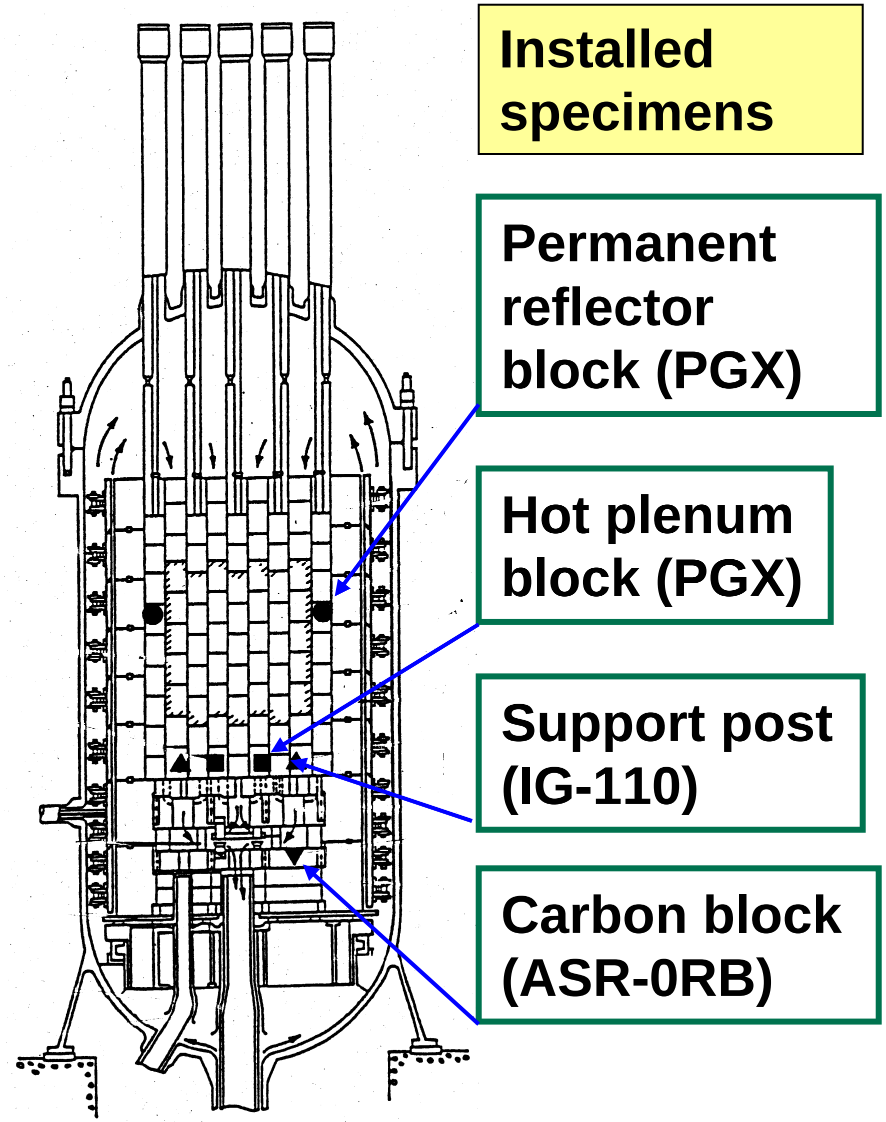

Object items: Inclination of support post, Gaps between blocks, etc.

Visual inspection will be carried out at refueling time.

# (4) In-Service Inspection (ISI) of Graphite Components

(2) Surveillance test

- Dimensional change
- Bending strength
- Compressive strength
- Surface oxidation rate
- Young's modulus



# Preparation of Design Standard for Commercial HTGR Graphite Components

A special committee at AESJ (Atomic Energy Society of Japan) discusses to establish technical criteria for VHTR graphite components.

Schedule: 2008.4～2009.3

Outline:

- Based on HTTR standards
- Including database, design, materials and in-service requirements
- Extrapolation of irradiation data
  - Dimensional change
  - Young's modulus
  - CTE
  - Thermal conductivity
  - Strength
  - Creep parameters
- Evaluation by fracture mechanics
- Accept probabilistic approach

# Design & In-service Inspection Standards for Commercial HTGR Graphite Components

- Special Committee Report on HTGR Design and In-service Inspection Standards (Draft) is to be published by the end of March 2009.

  The draft standards will be hopefully translated into English in the near future for its global usage for the design of HTGR graphite components.

- Research Report on the Analyzing Methods (Extrapolation) for the Existing Irradiation Data is to be published soon. (in press)

  By analyzing the existing irradiation data on wide varieties of graphites,

  tentative design curves were obtained for the following properties, particularly of IG-110.

  - Dimensional change, - Young's modulus, CTE, Thermal conductivity, Strength, Irradiation creep parameters

  It is expected that these curves are to be demonstrated by the future irradiation data, especially for irradiation creep.

Table 2
Comparison between Japan's design criteria and others

| Items | Japan | US | Germany |
|---|---|---|---|
| Core support component | | | |
| Failure theory | Maximum principal stress + modified Coulomb–Mohr theory | Maximum principal stress theory | Total strain energy theory |
| Buckling limits | Rankin–Gorden type | Karman type | Not specified |
| Pure shear stress limits | Considered | Not considered | Not specified |
| Oxidation effect | Considered | Not specified | Considered |
| Quality control | Specified | Not completed | Specified |
| Stress evaluation method | Same for both | | Weibull theory |
| Stress category | | | Not required |
| Safety factor | Considered | Considered | Considered |
| Minimum ultimate strength | Same for both | | Considered |
| Core component | Fundamental concept is the same as the core support component with some exceptions (safety factor, irradiation effects . . . etc.) | Not specified | Not specified |