Conceptual system design of non-nuclear grade IS process to be coupled with the HTTR

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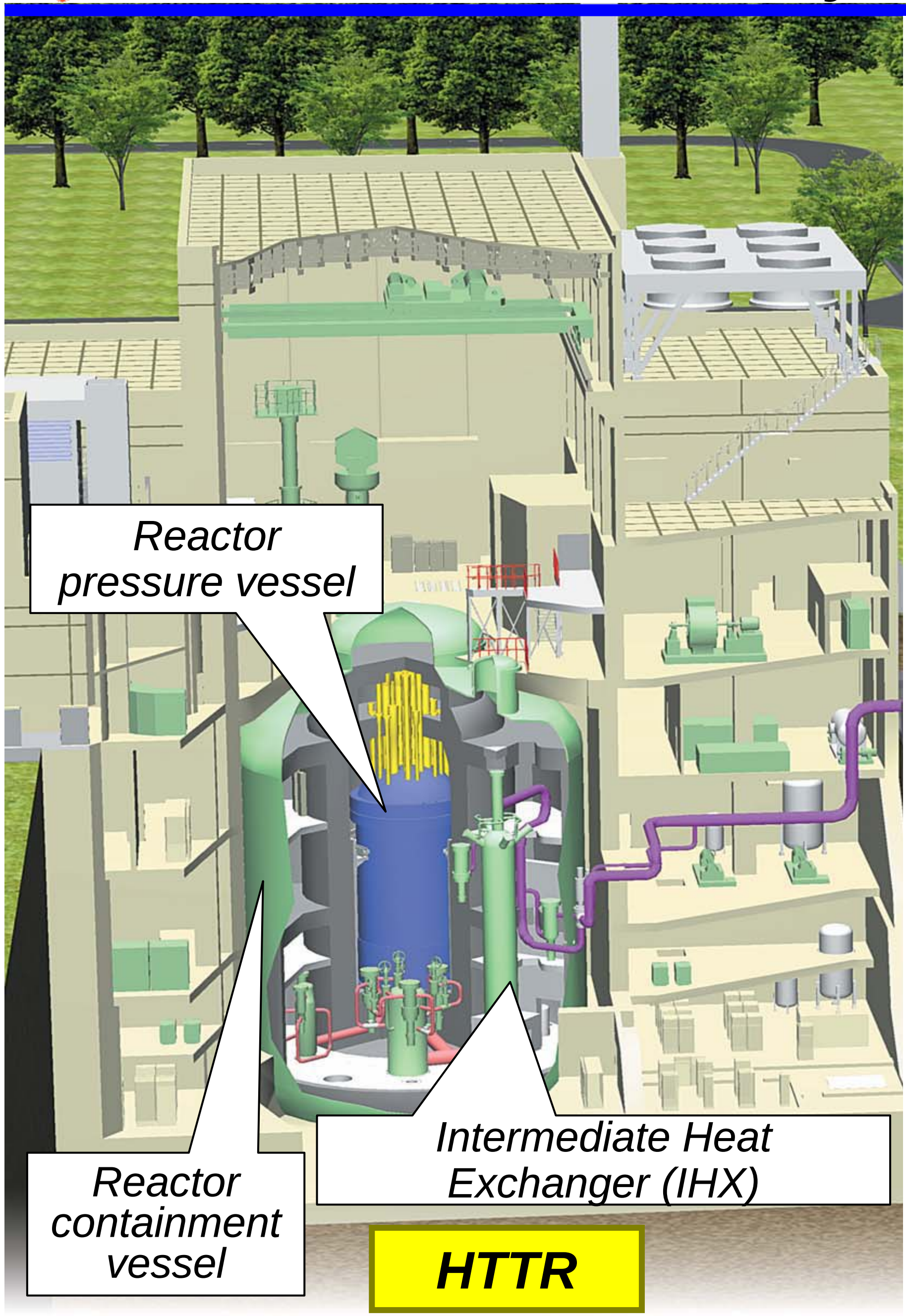
Outline of my presentation

- *Summary of JAEA's HTTR project*
- *Establishment of Non-Nuclear Grade IS Process*
  - *Objective… Why non-nuclear? Why HTTR-IS ?*
  - *R&D for non-nuclear*
  - *Individual research item and its results*
- *Conclusion*

Summary of the HTTR project



Objective

Establishment of HTGR technology
- Accumulation of long-term operation data
- Demonstration of inherent safety feature

Establishment of heat utilization technology
- Demonstration of hydrogen production

Major specification

Thermal power	30MW
Fuel	Coated fuel particle Prismatic block type
Coolant	Helium gas
Inlet / Outlet temperature	395°C / 950°C (maximum)
Pressure	4 MPa

History

1968	R&D on HTGR started
1990	Construction started
1998	First criticality
2001	Attained 30MW, 850°C
2004	Attained 30MW, 950°C (World first)
2010s	To be connected to the IS process

Why Non-Nuclear ? Why HTTR-IS ?

- Any chemical plant, e.g. hydrogen production system, should be built as non-nuclear grade from economical point of view.
  e.g. Construction, Easy operation, Easy maintenance…

- To establish the non-nuclear, several technical issues exist from safety point of view.

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- HTTR-IS demonstration can solve technical issues
  HTTR-IS demonstration will acquire **Public Acceptance on nuclear produced hydrogen.**

- And then, the door will open for **non-nuclear industries** e.g. gas and oil companies, **to enter as a construction company.**

What technical issue ? What major R&D ?

- *No-influence to the nuclear reactor during accidents and abnormal events which may occur in the hydrogen plant system.*

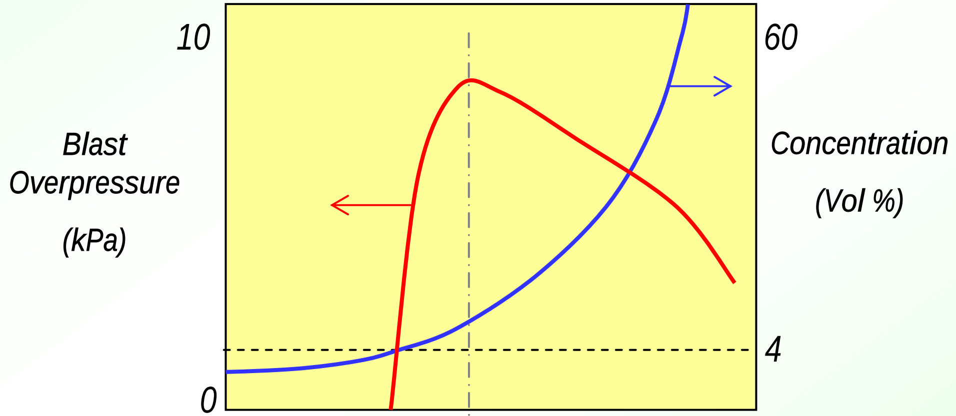
- *Safety philosophy* ***should be established.***
  a. *Hydrogen explosion, toxic gas leakage*
  b. *Thermal disturbance*
  c. *Isolation nuclear system from hydrogen plant system*

- *Major R&D* ***to be conducted:***
  a. *Establishment of* ***evaluation methodology***
  b. *Establishment & validation of system for thermal disturbance*
  c. *Development of* ***high-temperature isolation valve****, IHX and establishment of* ***tritium reduction*** *methodology*

Evaluation of Hydrogen Explosion

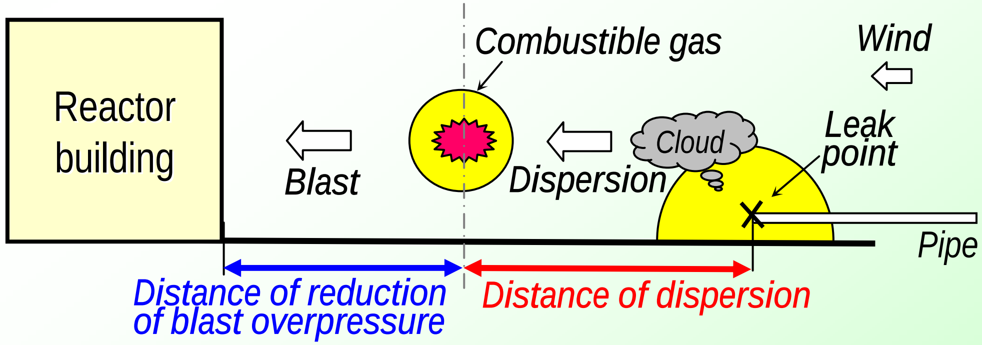
Reactor should keep its safety against the damage from hydrogen explosion.

Evaluation methodology should be established prior to safety case review by the government.



Conservatively assumed sequence

- Pipe rupture and hydrogen leakage
- Mixture with air
- Formation of hydrogen cloud
- Dispersion towards reactor forced by wind
- Blast (4-75vol%)



- Distance of dispersion* $R = 90\,(M \cdot d)^{0.2}\, \zeta_h\, \zeta_{ws}$

  M: Volume of hydrogen, d: Diameter of rupture pipe

  ζ_h: Ratio by leakage height, ζ_{ws}: Ratio by wind speed

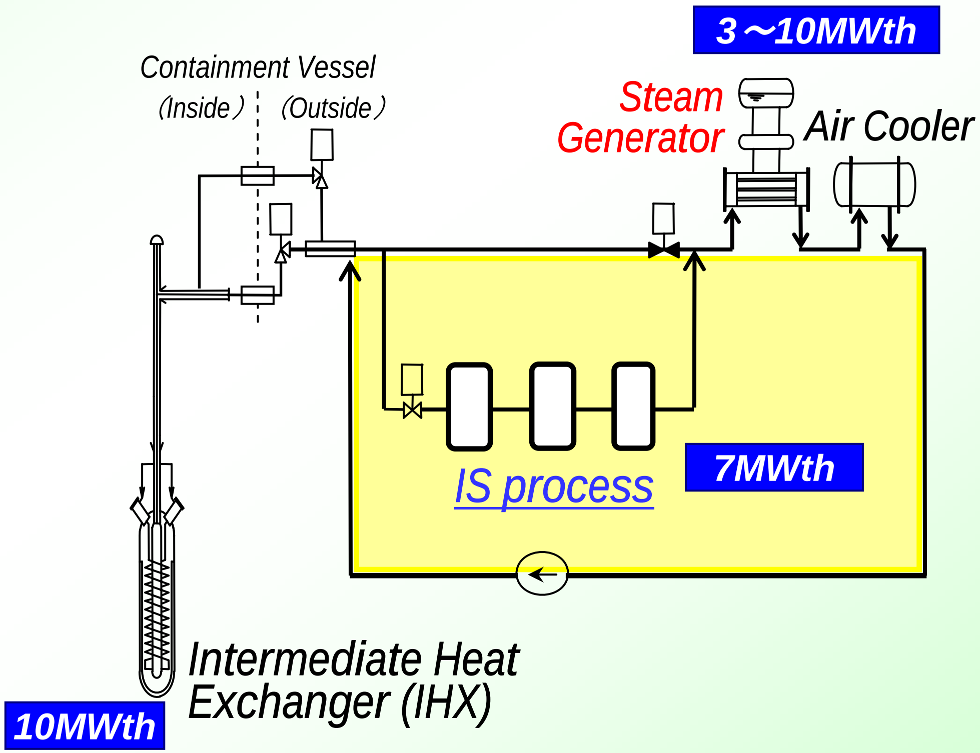
Wall arrangement can reduce the distance of dispersion.

* T. Murakami, et al., J. Atom. Energ. Soc. Jpn., 5, 4, 316 (2006).

Evaluation methodology for hydrogen explosion was developed.

Absorption for thermal disturbance

Absorption system which can mitigate thermal disturbance initiated by hydrogen plant is necessary for the continuous operation of the nuclear reactor.



Absorption system:

- By-pass system
- Steam generator (Using evaporated latent heat of water)
- ･･･

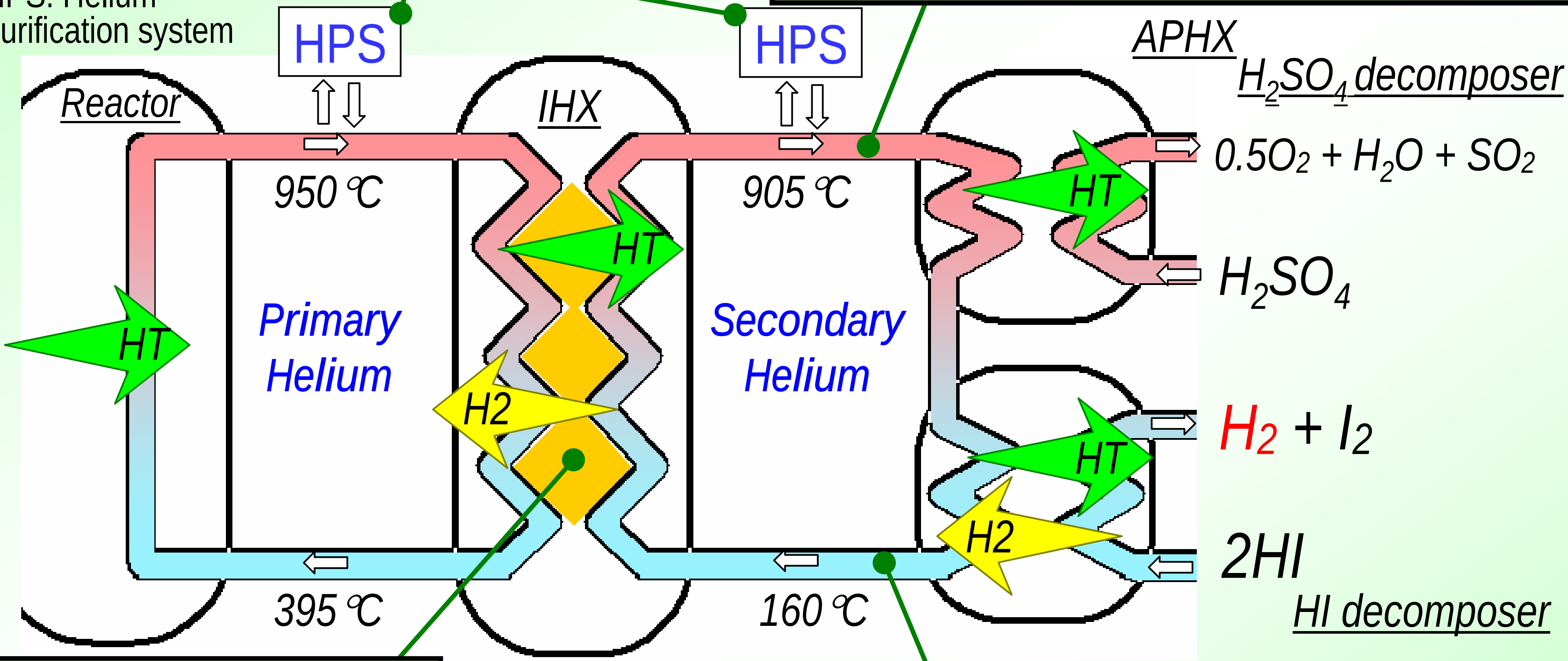
Mock-Up Test Facility of Steam Generator with Air Cooler had built and the absorption system was successfully confirmed.

Prevention of tritium permeation

I. Remove HT by HPSs

HPS: Helium purification system

II. H2 injection to decrease HT diffusion rate from primary to secondary (HTTR test item)



III. Oxidized layer control to reduce permeability

IV. Water injection H2O + HT ⇔ HTO + H2
Remove HTO by HPS: (HTTR test item)

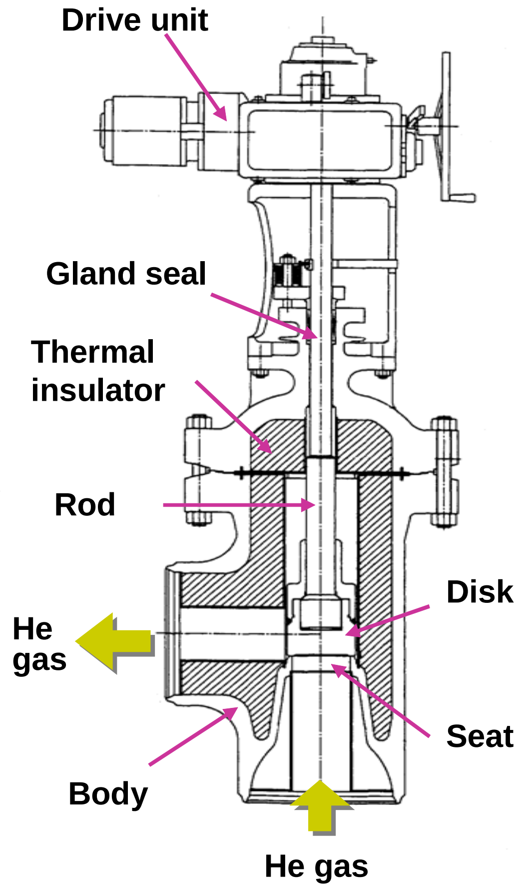
Tritium concentration in the non-nuclear system should be lower than its limit.
(HTTR data indicates that prevention of tritium permeation is necessary.)

High-Temperature Isolation Valve (HTIV)

- Major Specifications

Fluid :	Helium
Temp.:	905 ^{o}C
Pressure :	4.0 MPa
Flow rate :	9,070 kg/h
O.D. :	558.8 mm
I.D. :	204 mm
Height :	3m
Leakage rate	Less than 4.4 cm^3/s

- Development duration
  3 years

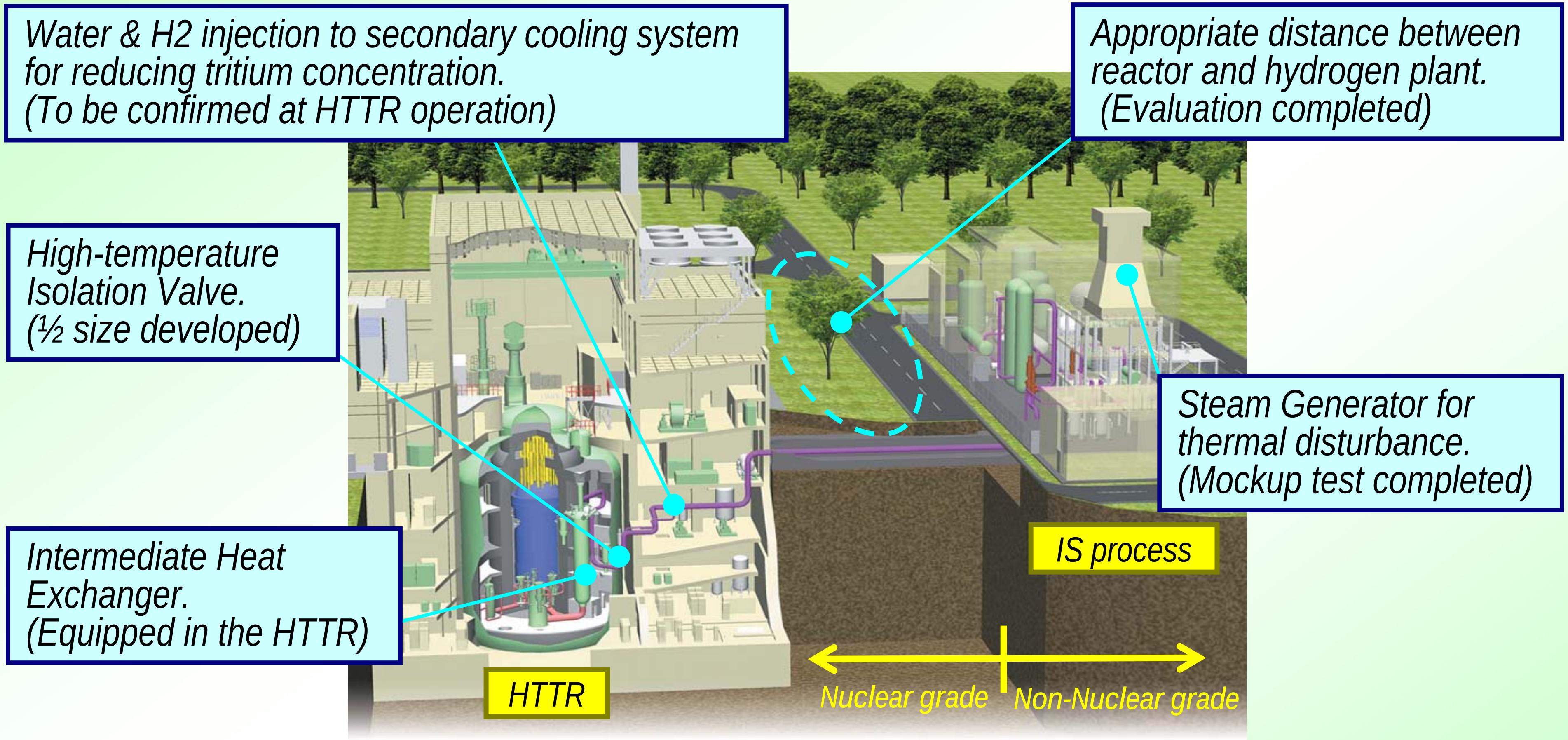


T. Nishihara, et al., J. Atom. Energ. Soc. Jpn., 3, 4, 69 (2004).

½ scale model of high-temperature isolation valve

½ scale model of High-Temperature Isolation Valve was developed and confirmed its sufficient seal performance up to 905^{o}C.

Conclusion



- *Technical feasibility was examined and the conceptual system design was completed on non-nuclear grade HTTR-IS hydrogen production system.*
- *Basic design and safety analysis are in progress.*

Welcome to JAEA for participating in the HTTR project to globally commercialize the VHTR hydrogen production systems.

Thanks for your attention.

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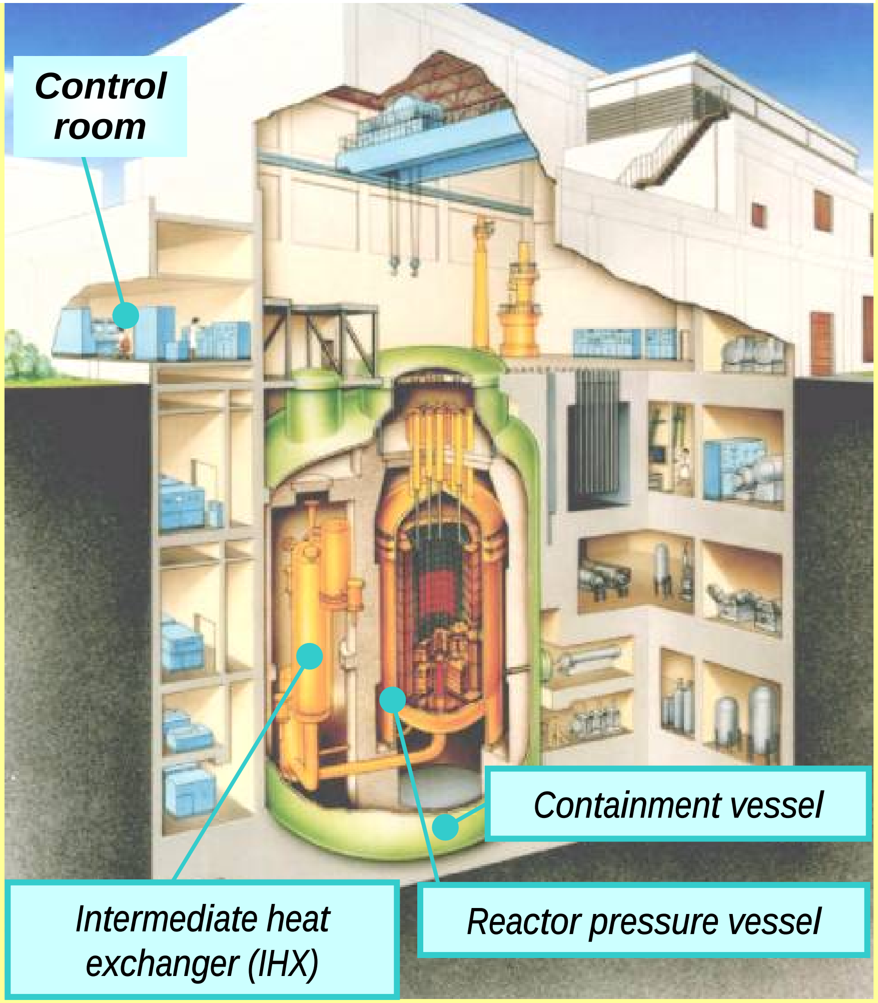
HTTR current R&D status

HTTR
Graphite-moderated/helium gas-cooled HTGR



Near term test plan

FY2007:

- ✓ *Long-term rated (850℃) operation (30 days)*
- ✓ *Loss of forced cooling test at low power level*

FY2008:

- ✓ *Long-term high-temperature (950℃) test operation (50 days)*
- ✓ *Loss of forced cooling test at high power level*
- ✓ *Vessel cooling system stop test (1 out of 2)*

FY2009:

- ✓ *Loss of forced cooling test at full power*
- ✓ *Vessel cooling system stop test (2 out of 2) : All blackout test*

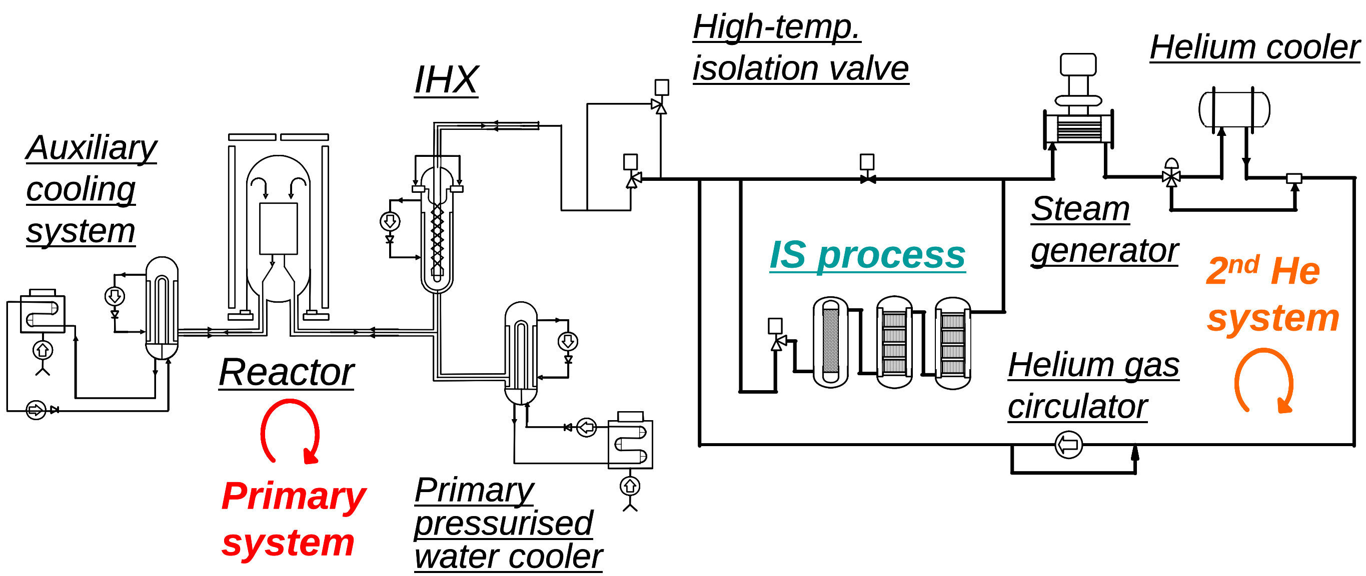
Proposed R&D towards Non-Nuclear

- Non-nuclear grade H2 production system
  - Establishment of safety philosophy
    - Event selection
      - Probabilistic safety assessment
    - Establishment of safety criteria
    - Exemption from internal events
      - H2 plant thermal load disturbance absorption
    - External events
      - Countermeasure for H2 explosion
      - Countermeasure for toxic gas inflow to reactor control room
    - Exemption from radioactivity release control
      - Reduction of tritium releasing to environment & mixing to product H2
  - Development of hardware for separation of nuclear from H2 plant
    - Isolation of H2 production system
      - Development of High-Temperature Isolation Valve (HTIV)
    - Control of thermal load of H2 production system

Safety criteria to be established

Event	Safety Criterion	Function
Flammable gas release	Gas concentration of intake air from ventilation system is lower than its explosion limit.	Preventing an explosion in the reactor building.
	Overpressure on the reactor building is lower than 20kPa. (In case of wall thickness of 30cm)	Preventing the top-level safety-related systems inside the reactor building.
Toxic gas release	Gas concentration in the control room is lower than its limits for long-lasting adverse health effects.	Safeguarding reactor operators against hazard.

Dynamic simulation code development



Dynamic simulation code base on RELAP5 Mod 3 is under developing and the code can:

- *Evaluate the credibility of the cooling system and plant dynamics of the HTTR-IS system during abnormal events initiated by the IS process*
- *Be utilized for the safety case review by the government*

Component model

Reactor[1)]	*Reactor kinetics*
Steam generator[2)] *Heat exchangers*	*Thermal hydraulics*
IS process *(in progress)*	*Chemical reaction*

1) K. Takamatsu, et al., Trans. At. Energy Soc. Japan., **3**[1], 76 (2004).
2) H. Ohashi, et al., Nucl. Eng. Des., **236**[13], 1396-1410 (2006).

Code development for tritium behaviour

- *Numerical analysis code, THYTAN has been developed to estimate tritium behaviour.*
  - *Tritium generation in the core*

    $^{6}Li\ (n, \alpha)\ ^{3}H$, $^{7}Li\ (n, n\alpha)\ ^{3}H$, $^{3}He\ (n, p)\ ^{3}H$,

    $^{10}B\ (n, 2\alpha)\ ^{3}H$, $^{235}U(n, f)^{135}Xe$, ^{133}I,・・・, ^{3}H
  - *Removal by HPS (HPS: Helium Purification System)*
  - *Permeation to downstream*
  - *Isotope exchange reactions, etc.*

- *The THYTAN code will be validated by tritium concentration data measured by the HTTR 950^{o}C long term operation planned in 2008.*

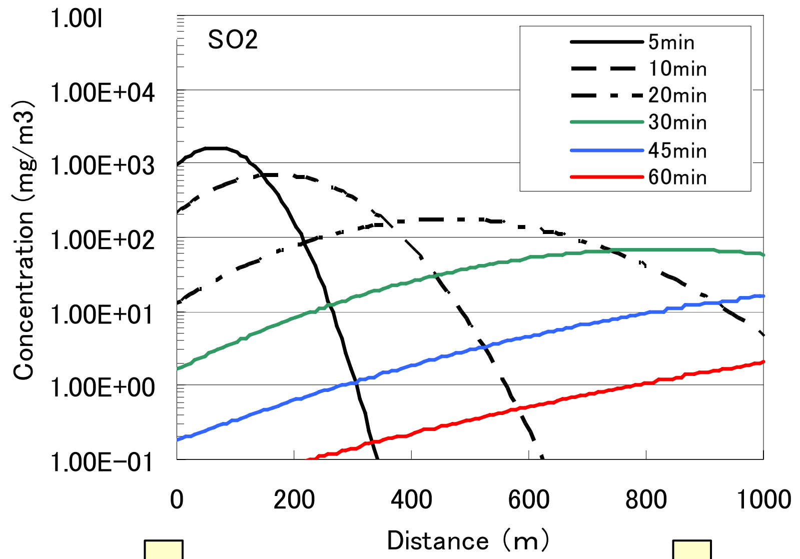
Evaluation of Toxic Gas

- *IS process generates and contains toxic gas. (SO2, SO3, HI, etc.)*
- *Inflowing toxic gas to reactor control room (C/R) should be avoided.*

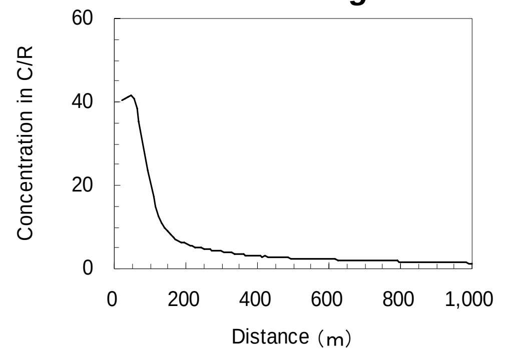
- *Toxic gas diffusion evaluation and risk analysis is underway.*
- *Ventilation and air conditioning system, gas-sensing system, offset distance are under designing.*

リファレンス追加

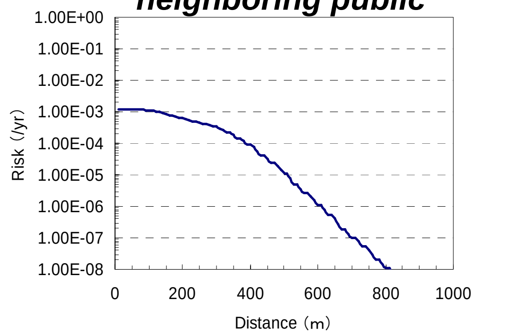
Examples of atmospheric toxic gas concentration



Concentration of toxic gas in C/R



Toxic gas risk for neighboring public



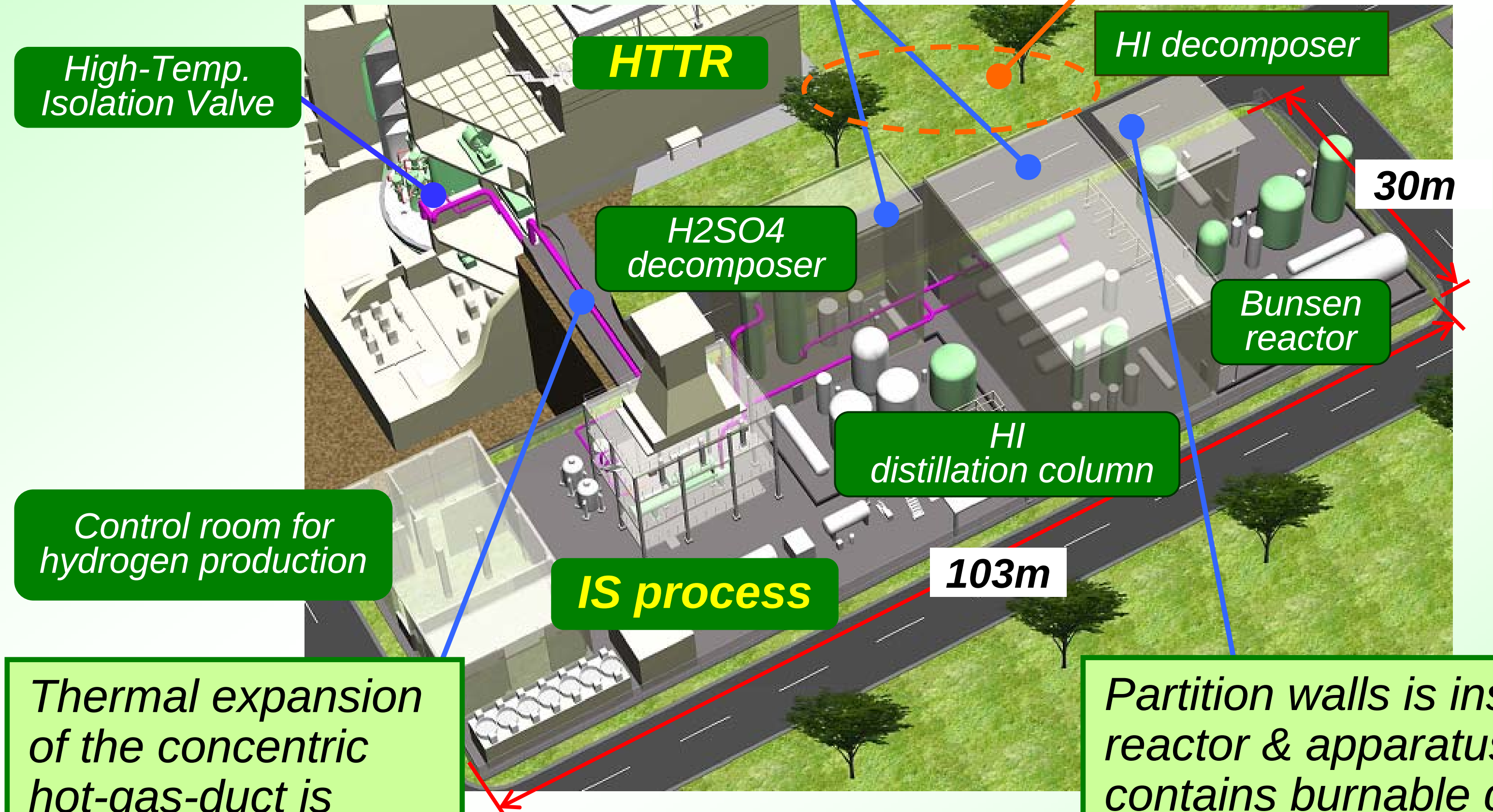
Prevention of tritium permeation

- *IS process should be exempted from radioactivity release control.*
- *Methodology to reduce tritium concentration in the produced hydrogen should be developed.*
- *Code for tritium behaviour should be developed for safety case study.*

Candidate Layout of HTTR-IS system

*High pressure apparatus which contains **toxic gases** is covered by **walls, ceiling, & ventilation systems***

***No apparatus** between the reactor & HI decomposer.*

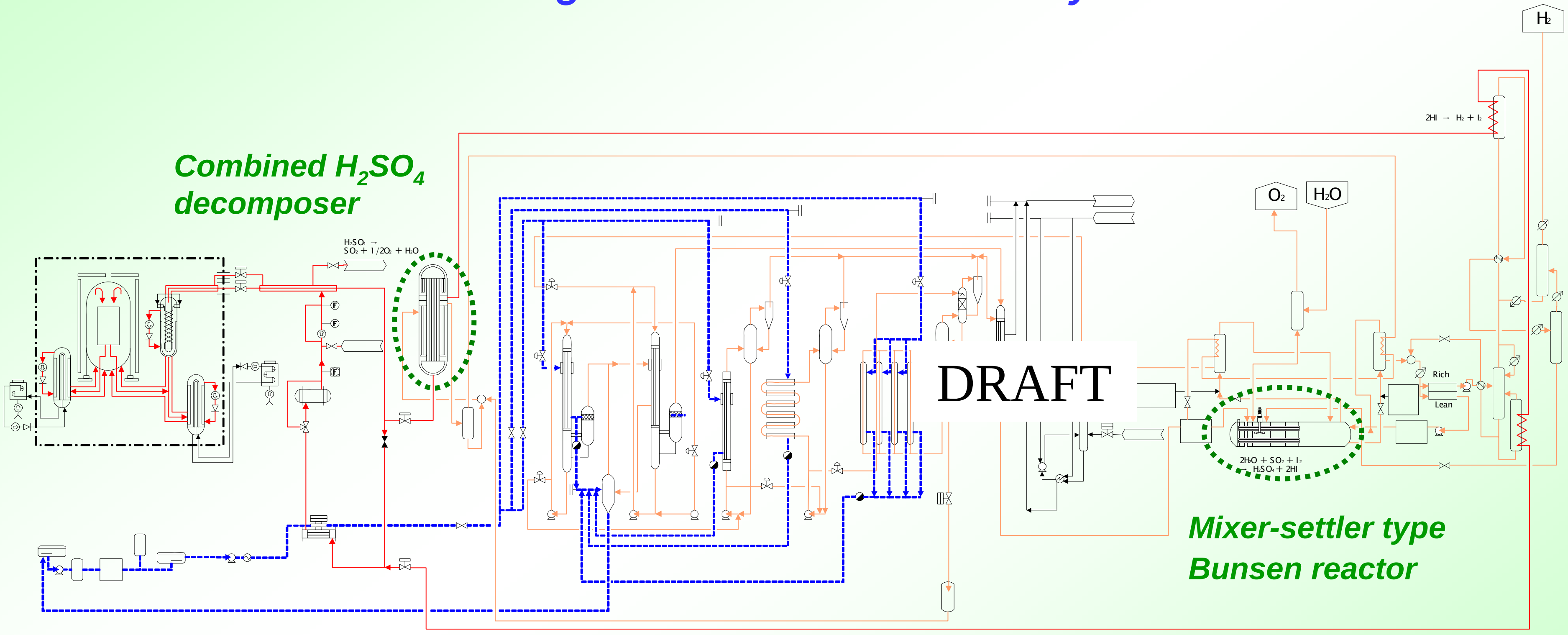


*Thermal expansion of the concentric hot-gas-duct is absorbed by **high-temp. bellows***

Partition walls is installed between reactor & apparatus which contains burnable gases. Appropriate distance is kept between reactor & partition walls.

Pre-Conceptual design of the HTTR-IS system

Flow diagram of the HTTR-IS system



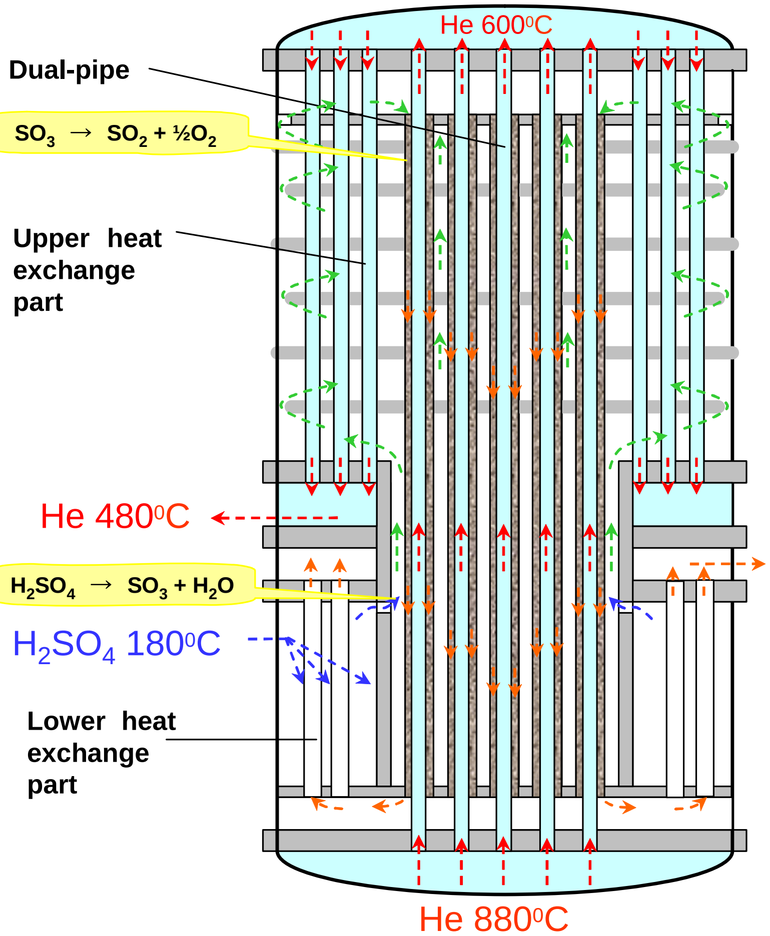
Hydrogen production rate

: Approximately 1000Nm^3/h

Pre-Conceptual design of the HTTR-IS system

*Proposal of Combined H_2SO_4 decomposer**

- *Combining 3 components*
  (H_2SO_4 evaporator,
  SO_3 decomposer,
  regenerative heat exchanger)
- *Component & Piping number reduction*
- *Connection number reduction*
- *Prevention the H_2SO_4 solution outflow to the downstream during the abnormal events*



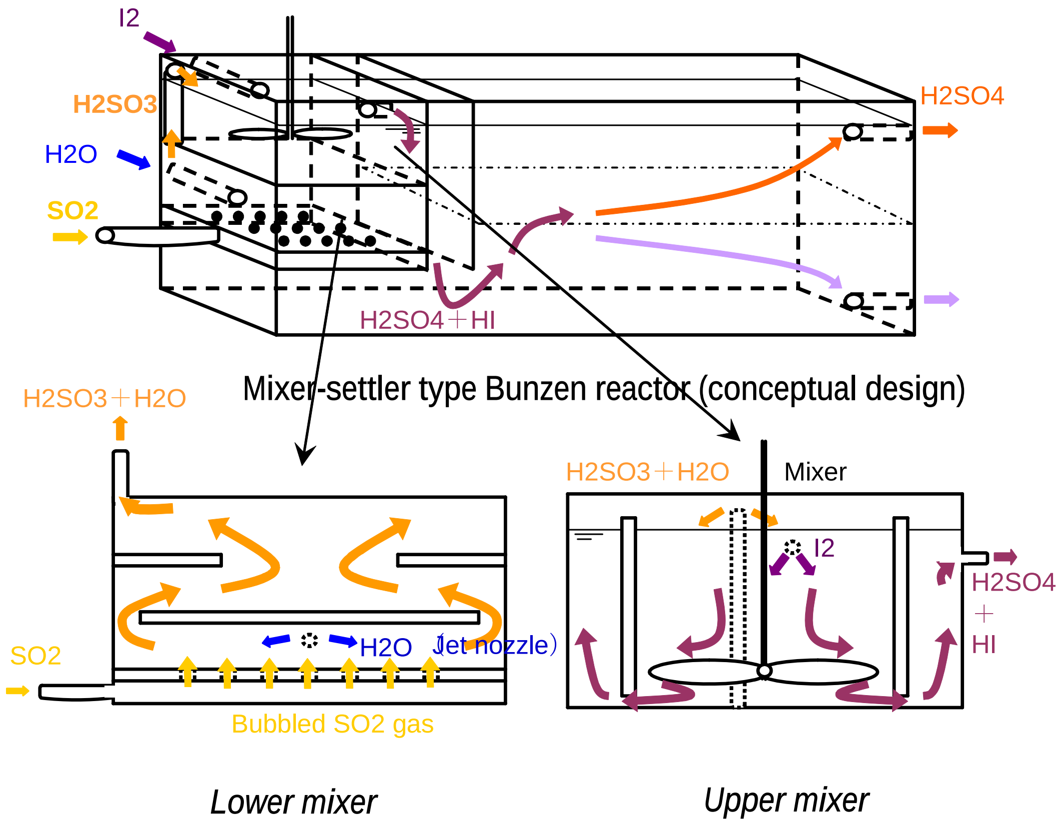
Combined type H_2SO_4 decomposer (conceptual design)

* Patent No. 2006-250310

Pre-Conceptual design of the HTTR-IS system

*Proposal of Mixer-settler Type Bunsen Reactor**

- *Combining 3 components (Bunsen reactor, Liquid-liquid separator, liquid transfer pump)*
- *Component & piping reduction*
- *Connection reduction*
- *Mixing & separation enhancement*
- *Vessel overheating prevention*



* Patent No.2006-255541