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Session 3「Nuclear Innovation」

Technology Developments for Enhancement of Nuclear Power Plant Safety and Reliability

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Content

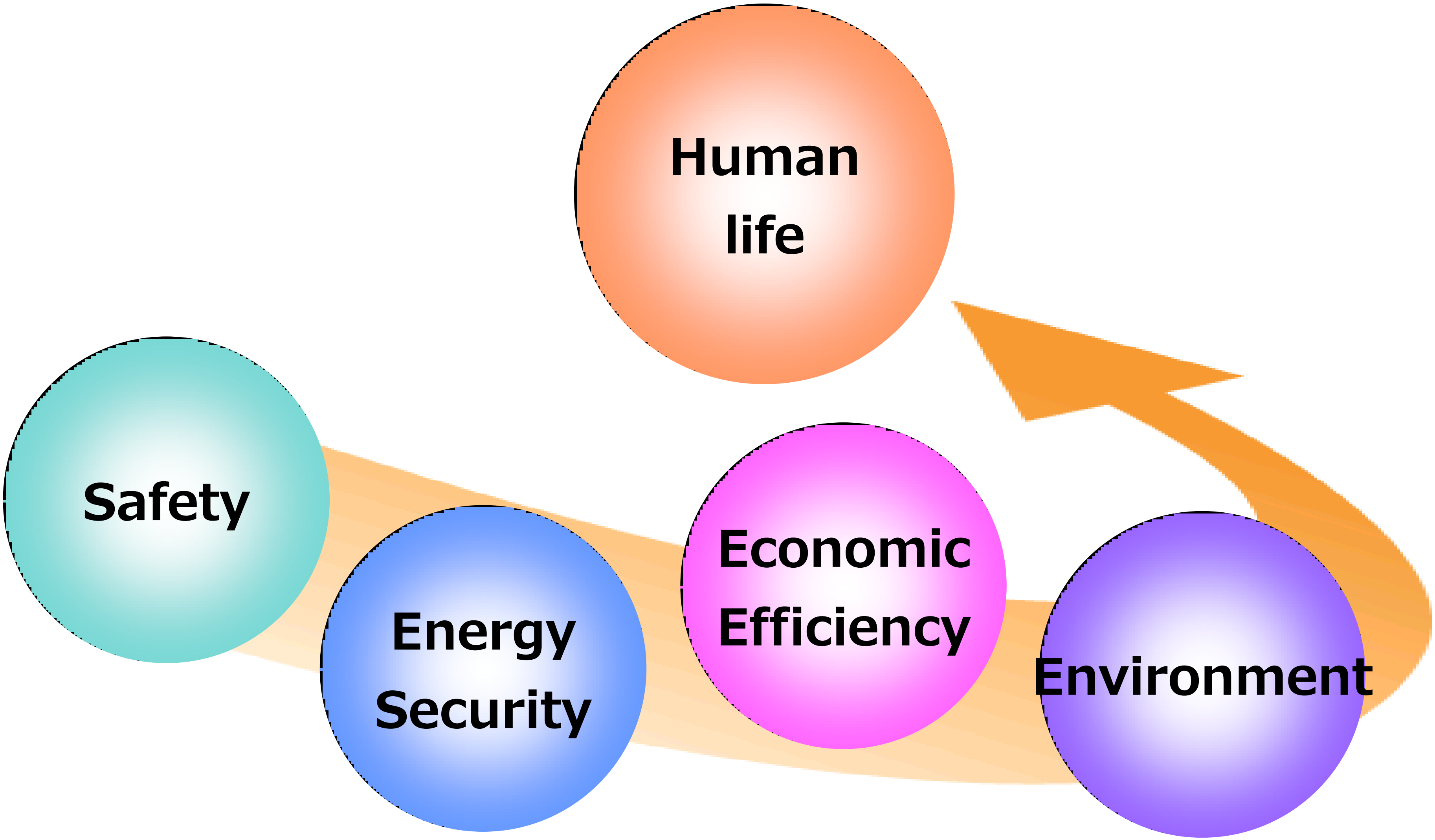
01 Challenges for the future

02 Technology developments for safety and reliability

03 Harmony with society

04 Closing remarks

Contribution of nuclear power to society



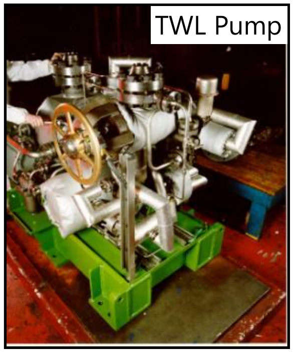
Contribute human life based on energy policy (3E + S)

Safety enhancement measures for plant restart

■ Safety enhancement equipment

■ High-pressure injection system

High-pressure injection system substitute for reactor core isolation cooling pump



■ Power supply

Enhancement with SCiB™
Air cooled power source (D/G, GTG)

AFI: Alternate Feedwater Injection
D/G: Diesel Generator
GTG: Gas Turbine Generator
R/B: Reactor Building
T/B: Turbine Building
NRA: Nuclear Regulation Authority

■ Hydrogen treatment /Mitigation of environmental impact

Hydrogen combustion equipment
Filtered venting system
Measure Hydrogen concentration

Hydrogen combustion equipment

Filtered venting system
(Reference: HP of Chubu Electric Power Co.)

■ Coolant system

Air-cooled heat-exchange equipment

(Reference: HP of Chubu Electric Power Co.)

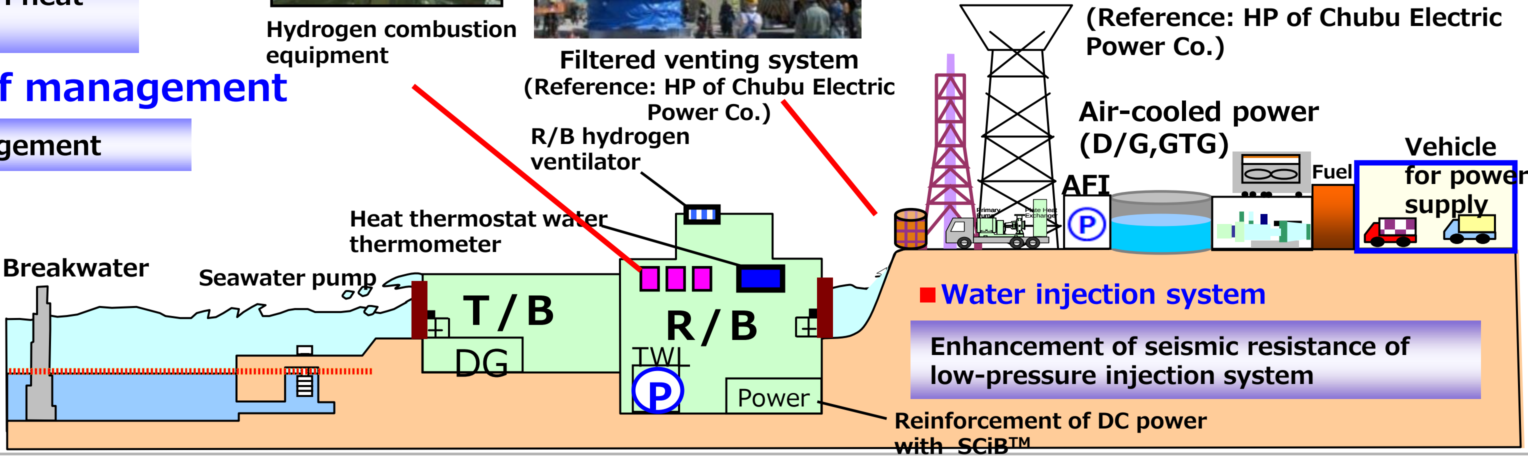
■ Monitoring instrument

Water thermometer in heat-thermal type

■ Enhancement of management

Severe accident management

System for simulating plant behavior at accident (NRA)



■ Water injection system

Enhancement of seismic resistance of low-pressure injection system

For sustainable social contribution of nuclear power

3E + S viewpoints		Challenges
S	Safety	・Enhance safety voluntarily and continuously ・Enhance reliability (Social acceptability)
E	Energy Security	・Maintain and develop human resources ・Promote efficiency of operation/maintenance
E	Economic Efficiency	・Reduce power generation cost (fuel, operation, etc.)
E	Environment	・Reduce radioactive waste

Innovation is indispensable for solving various challenges

Content

Technology developments to solve challenges

■ Flat core catcher, Hydrogen treatment system, SiC Core material

<Current countermeasures> for debris and hydrogen in Severe Accident (SA) (Injection system, Venting system)	● Enhance safety of existing plants voluntarily ● Achieve no venting (Reduce radiation exposure, social acceptability) ● Enhance extreme safety/reliability/economy efficiency

■ Virtual plant (AI/Deep learning, VR, Construction plan)

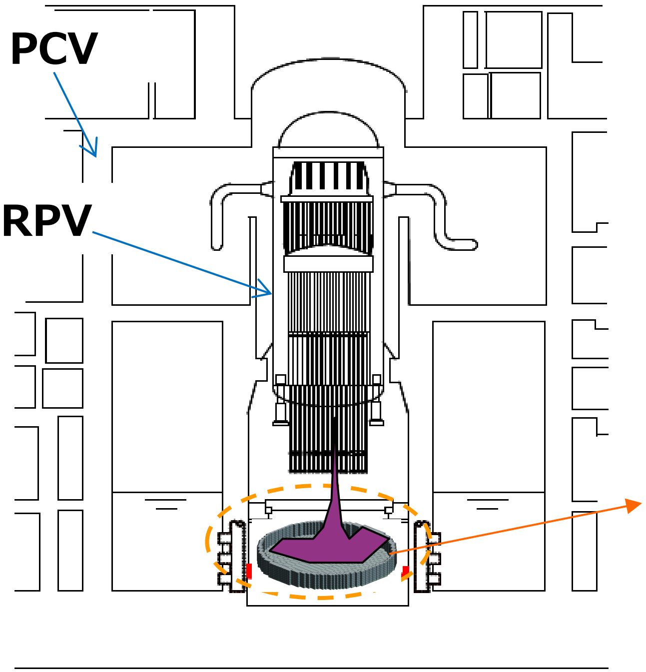
<Current countermeasures> for work planning, training (based on know-how, at site)	● Reduce human error by utilizing AI ● Enhance work efficiency and economic efficiency through optimization ● Training in the virtual plant

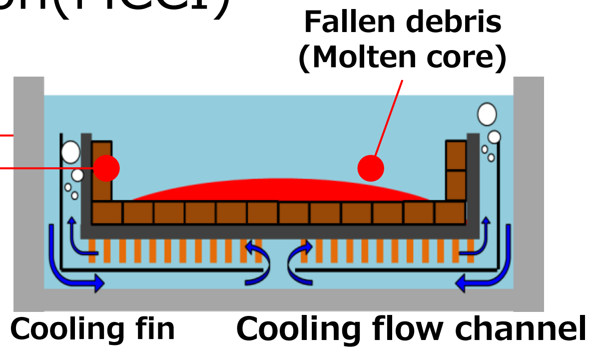
■ Reduce high-level radioactive waste

<Current countermeasures> for radioactive waste (geological disposal, treated as nuclear waste)	● Reduce radioactive waste by nuclear transmutation ● Acknowledge it as new resource

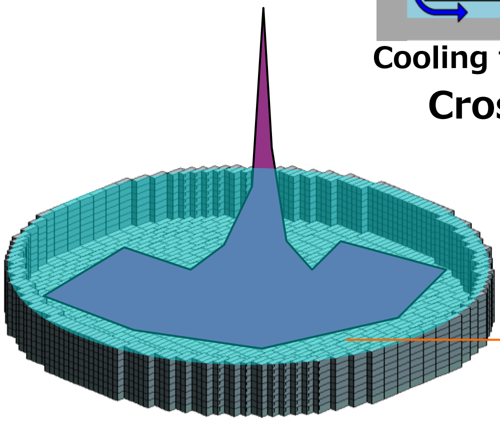
Flat Core Catcher

- Developed for further enhancement of safety in the existing plants limited space for installment
- To catch molten core in Severe Accident (SA)
- To prevent Molten Core Concrete Interaction(MCCI)





Cross-sectional diagram

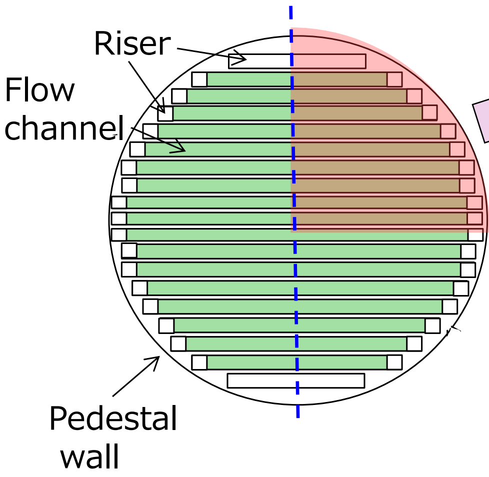

Flat Core Catcher

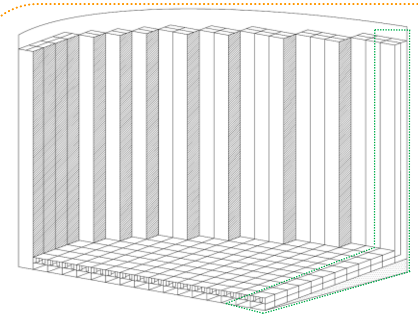

Block Structure

This project was funded by METI (Ministry of Economy, Trade and Industry).

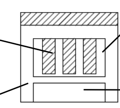
Developed for further enhancement of safety in the existing plants based on Fukushima Daiichi accident

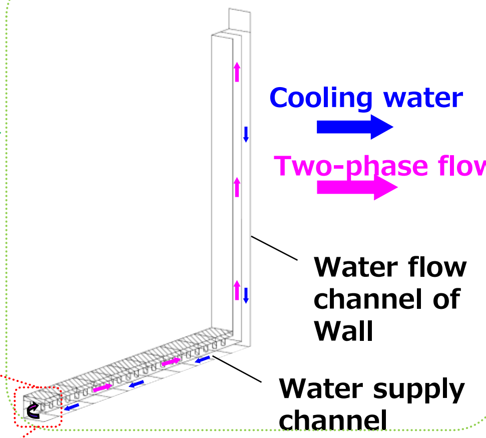
Flat Core Catcher





Enlarged figure of ¼ azimuthal part



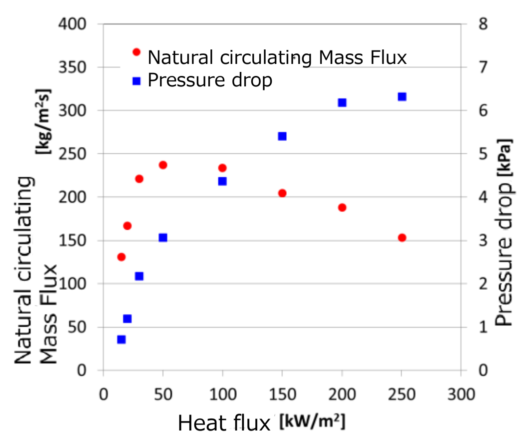


Flow channel configuration diagram

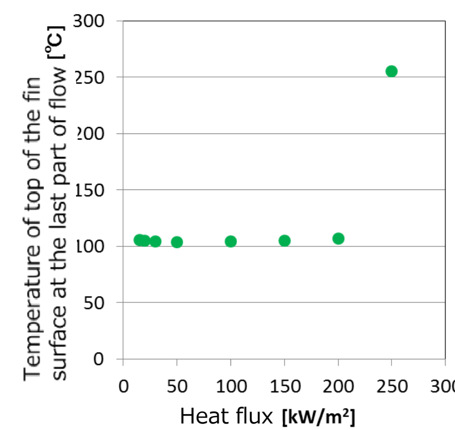
- Structural integrity was thoroughly assured with stable natural circulating flow under the condition of assumed heat flux of existing plants (100kW/m²)

  - The natural circulating flow gets 50kW/m² in maximum and makes mass flux of maximum 240kg/m²s.
  - It was verified in the experiment that copper fin keeps cool to be under 300℃.

Research and development for its application to a real model have been proceeded with a test equipment after the conceptual examination was completed as a national project.



Measured result of amount of natural circulating flow and pressure drop

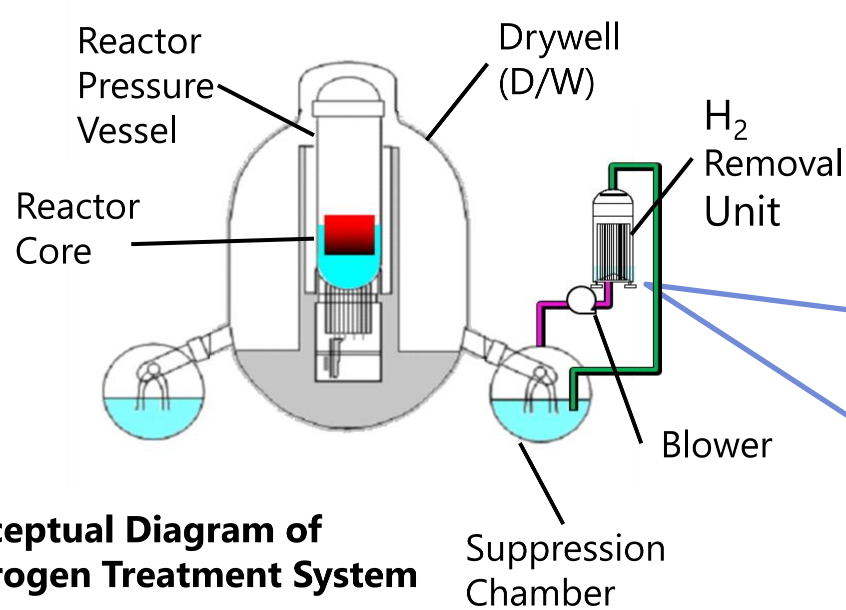


Temperature of fin surface at the last part of flow

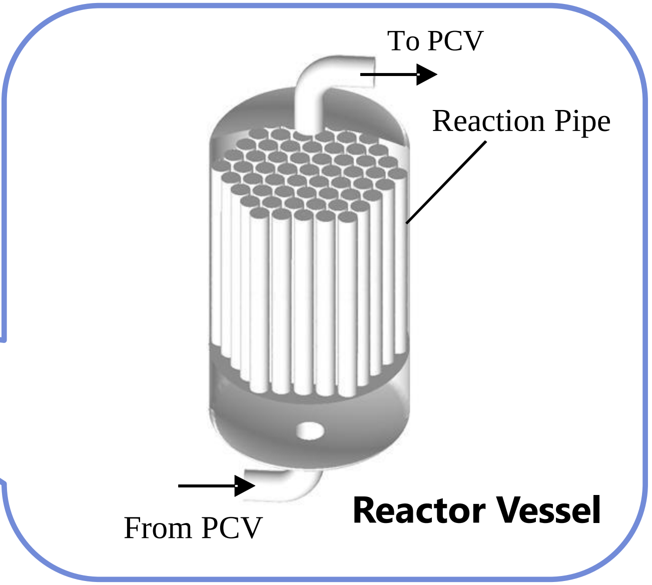
Hydrogen Treatment System

- To prevent overpressure of PCV due to hydrogen
- To reduce leakage of hydrogen and radioactive materials
- To achieve no-vent in combination with heat removal system

-Prevention of PCV Damage due to overpressure
-Prevention of hydrogen explosion of the building
-Reduction of dose rate



Conceptual Diagram of Hydrogen Treatment System

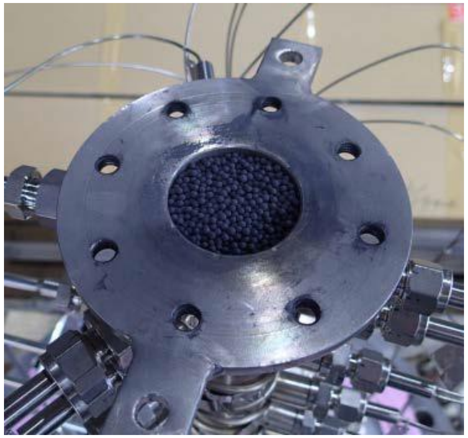


This project was funded by METI (Ministry of Economy, Trade and Industry).

To enhance social acceptability by achieving no-vent in SA

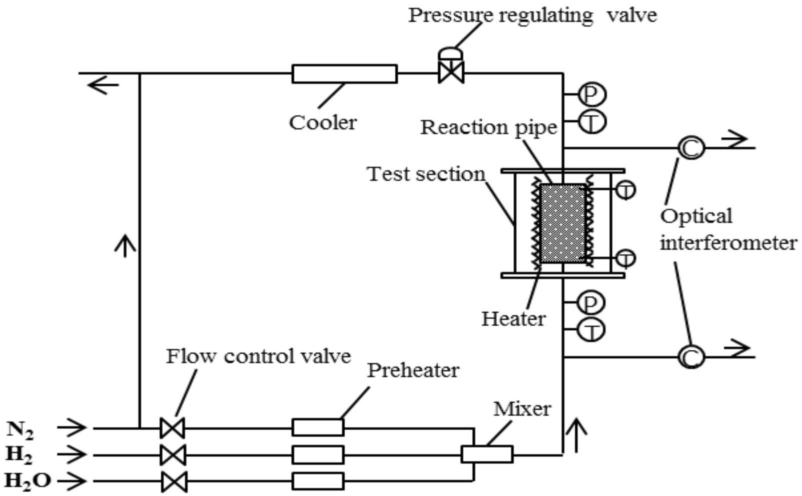
Hydrogen Treatment System

- To utilize H_2 oxidation reaction with metallic oxide ($H_2 + M_xO_y \rightarrow H_2O + M_xO_{y-1}$)
- To select CuO, MnO_2 , Co_3O_4 as reaction material
- To formularize reaction rate equation considering deterioration coefficient due to consumption of treatment material and vapor
- To create single dimension reactor evaluation model

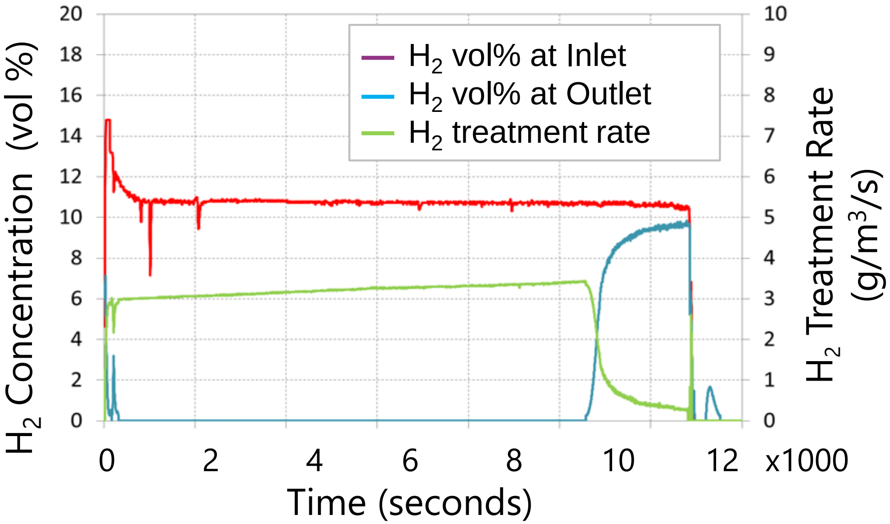


MO Particle Test Section

Development for application of a real model has been kept implemented



Schematic Drawing of Test Equipment



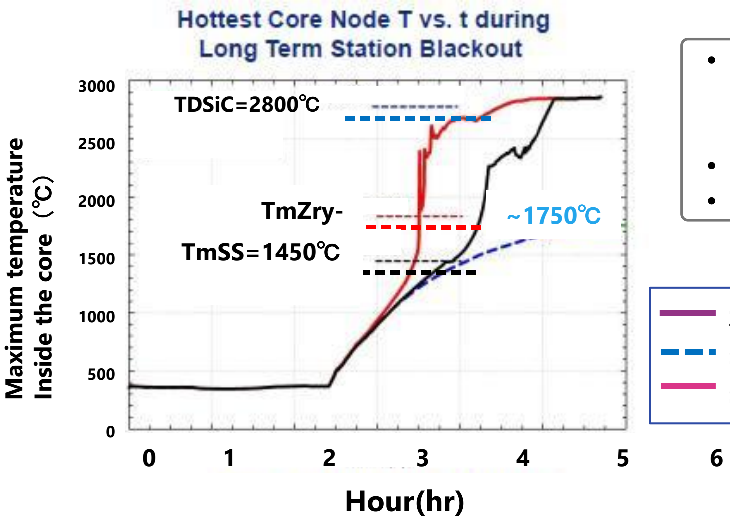
Test Result (CuO Φ2mm ,H_2 11vol%,250℃)

This project was funded by METI (Ministry of Economy, Trade and Industry).

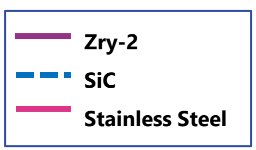
SiC Core material

- Less generation of hydrogen due to less oxidation reaction under SA condition
- Higher temperature stability in accident with higher melting point (2545℃) than Zr (1850℃)
- Less spent fuel due to high burnup with less neutron absorption

Example of Modular Accident Analysis Program（MAAP)



- **Zr rapidly gets oxidation exothermic reaction in high temperature range and generate hydrogen**
- **SUS reaches over the melting point**
- **SiC responses slowly in lower temerature**



Tm：Melting point
TD：Heat degradation temperature

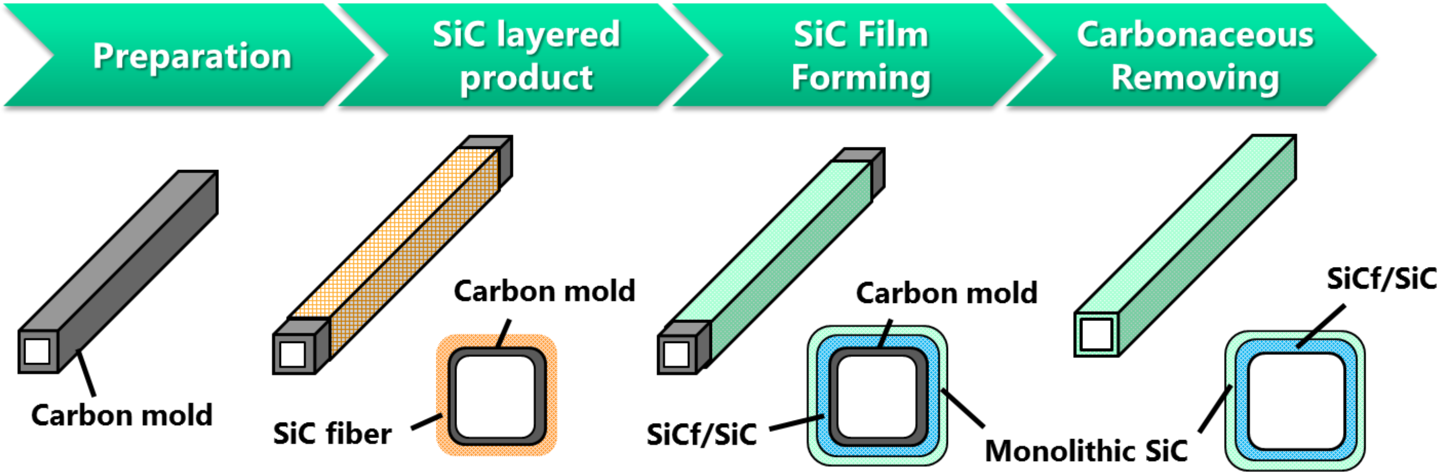
Westinghouse
MAAP analysis by C. Johnson, Henry, & Paik
ICAPP'12, WRFPM2014

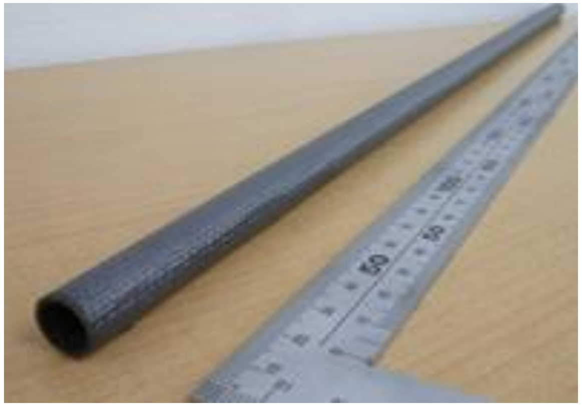
Safety enhancement by higher temperature stability in accident with fuel economy

SiC Core material

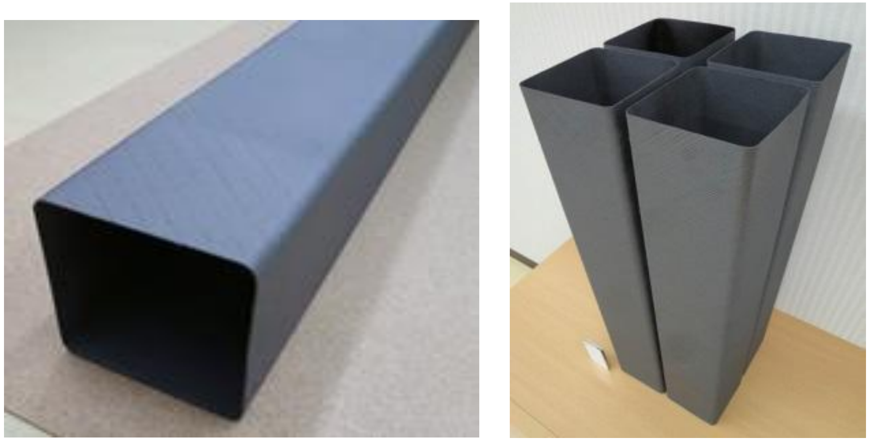
- Develop manufacturing technology of SiC complex material, which has high temperature stability in accident and fits to general use in LWR

Notes
CVD: Chemical vapor deposition
CVI : Chemical vapor infiltration





Cladding tube

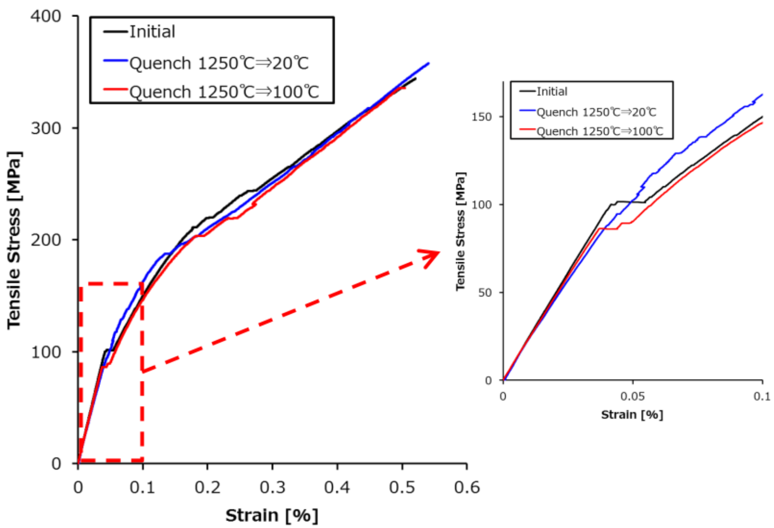


Channel box

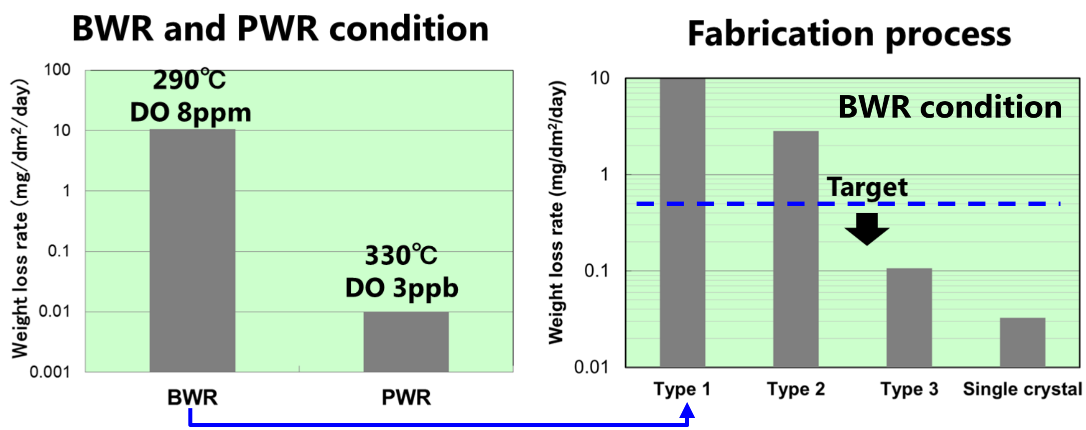
SiC Core material

- Produced prototype sample with length less than 1m and implemented evaluation test (Result of Tensile strength test and Corrosion test)

Result of Tensile test



Autoclave test for CVD (Chemical Vapor Deposition)-SiC



➢ **Corrosion rate significantly depends on water chemistry and the fabrication process**

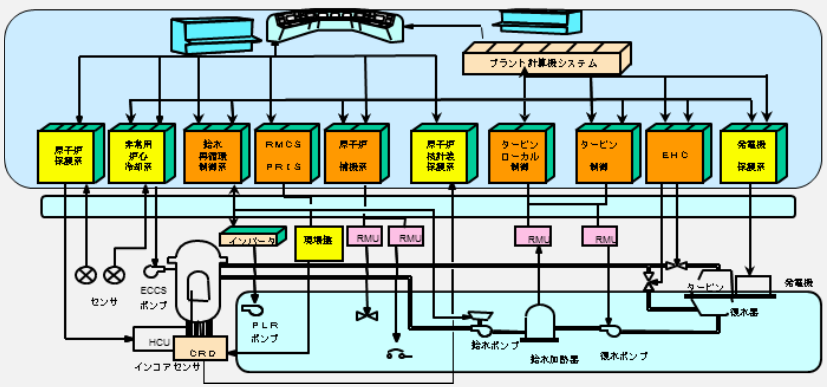
Optimize structural design of complex material and develop manufacturing technology for longer sample (~4m)

Virtual Plant

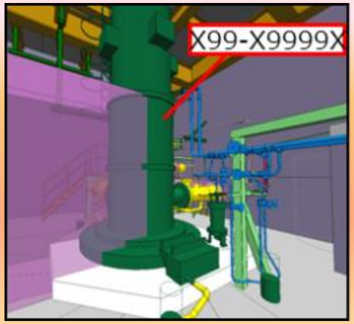
- Apply AI and deep learning
- Apply virtual technology for Engineering, Operation and Maintenance
- Coordinate with configuration management data base

Virtual Plant (VP)

Plant Simulator



3D Data



3DCAD

Laser scanning

Support Operation and Maintenance by various technologies

Electric isolation supporting system

- Prevent abnormal alert and unplanned plant stop due to incomplete isolation
- Prevent human error utilizing AI (Deep learning)
- Promote efficiency of isolation action plan of engineers as a countermeasure of less human resources
- Apply for education and train program of operators

Current Isolation operation based on personal work

- Examination/operation depends on personal skill
- Drawings cover wide range and massive
- Inspection of electrical operation is implemented on paper drawing

→ Reliability and workload totally depend on person

Supporting system (System less dependent on human resources)

Structuring function of paper drawing ▶ **Isolation automatic design function** ▶ **Isolation plan evaluation function**

- **Structuring function of paper drawing**: Extract circuit information from paper drawing
- **Isolation automatic design function**: Make a plan by automatically selecting isolation object with AI, etc.
- **Isolation plan evaluation function**: Evaluate validity (effect) of isolation plan and show the result on drawing

Assure reliability during plant operation and get utilized workers training

Electric isolation supporting system

Isolation automatic design function

- Isolate test object (M/C) without alert
- Design on/off pattern of breaker in terms of task load

Step1

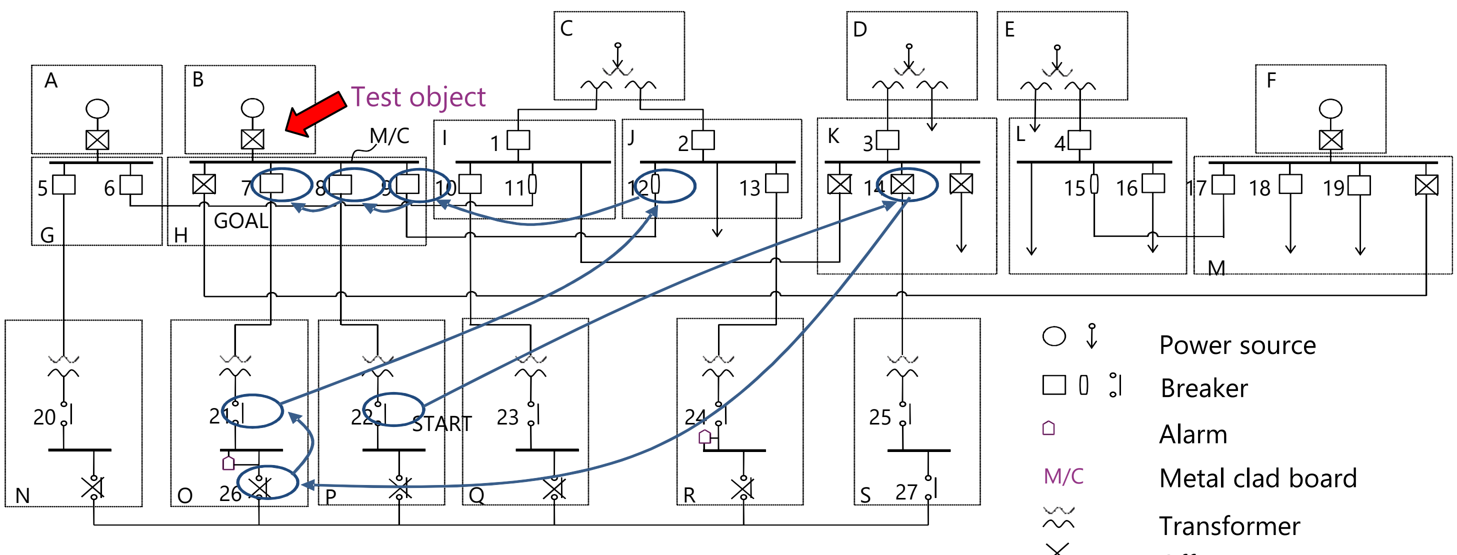
Single line connecting diagram → Isolate test object (M/C) without alert
Derive on/off pattern of breaker → on/off pattern of breaker

Reduce calculation time with Deep Neural Network (DNN)

Step2

Information of building (Arrangement of equipment, radiation dose, WBGT, etc.) → Screen on/off pattern of breaker in terms of task load → Optimized pattern and procedure

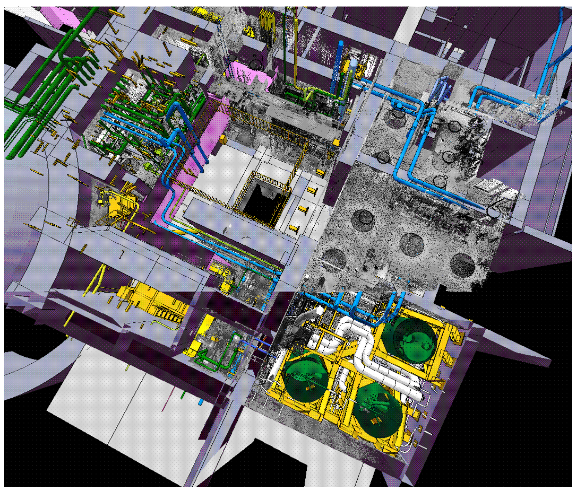
Interpret ambiguous information with Deep Q Network (DQN)



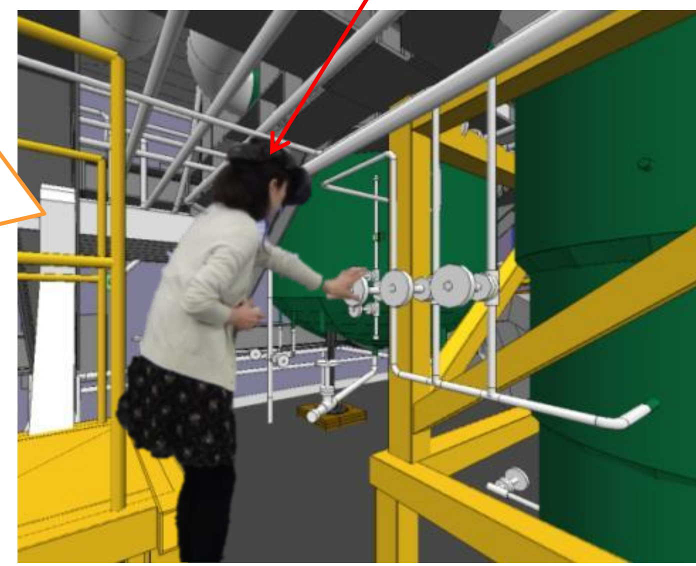
Virtual Reality(VR)

- Visual Engineering of 3D design data from flexible angles
  - Identify space and equipment arrangement inside the complex plant efficiently
  - Simulate work plan considering equipment location and workability

Status of utilization



3D Data
(Laser scanning/3DCAD)



Stereoscopic display by VR

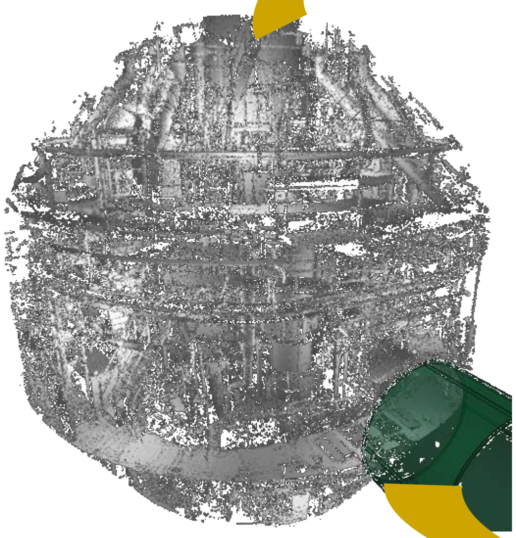
Utilize VR simulated experience for prior confirmation of actual operation or training program

Laser Scanning/3D CAD

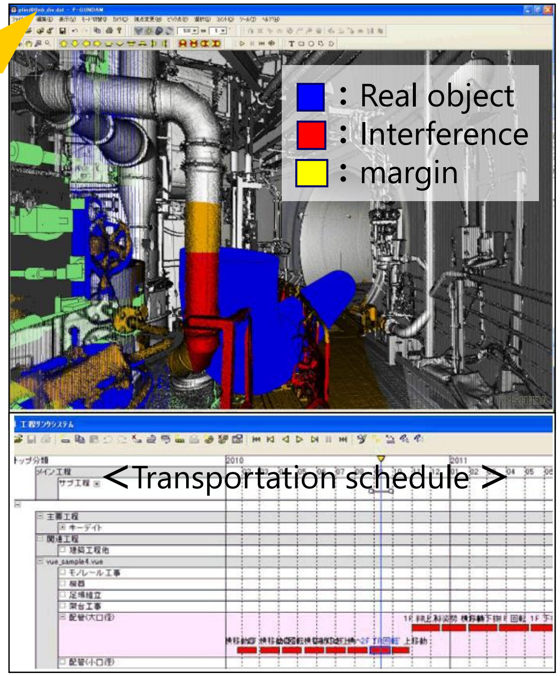
- To convert information to 3D data by obtaining adequate positional information of some parts which are in high or far locations
- Data could be made adjustment of positioning and studied without geographic or time constraints

Carrying route tracking

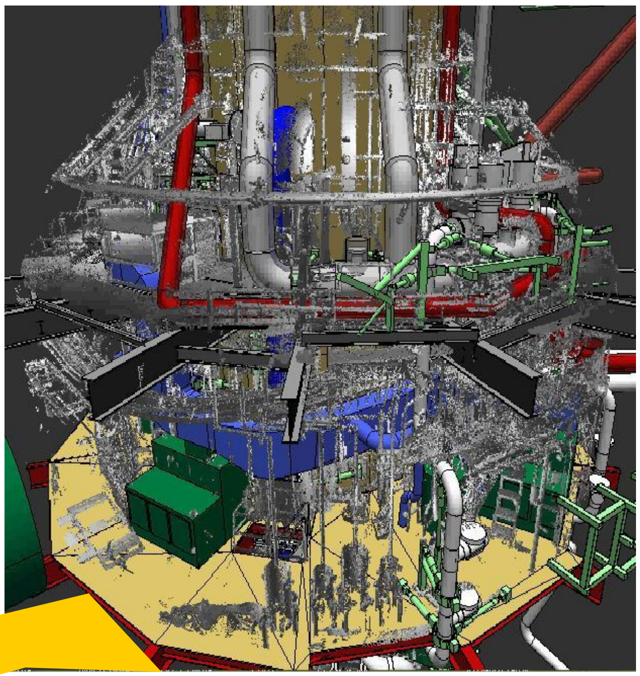
Simulation of the equipment transportation according to the schedule



Inside PCV



3DCAD Data

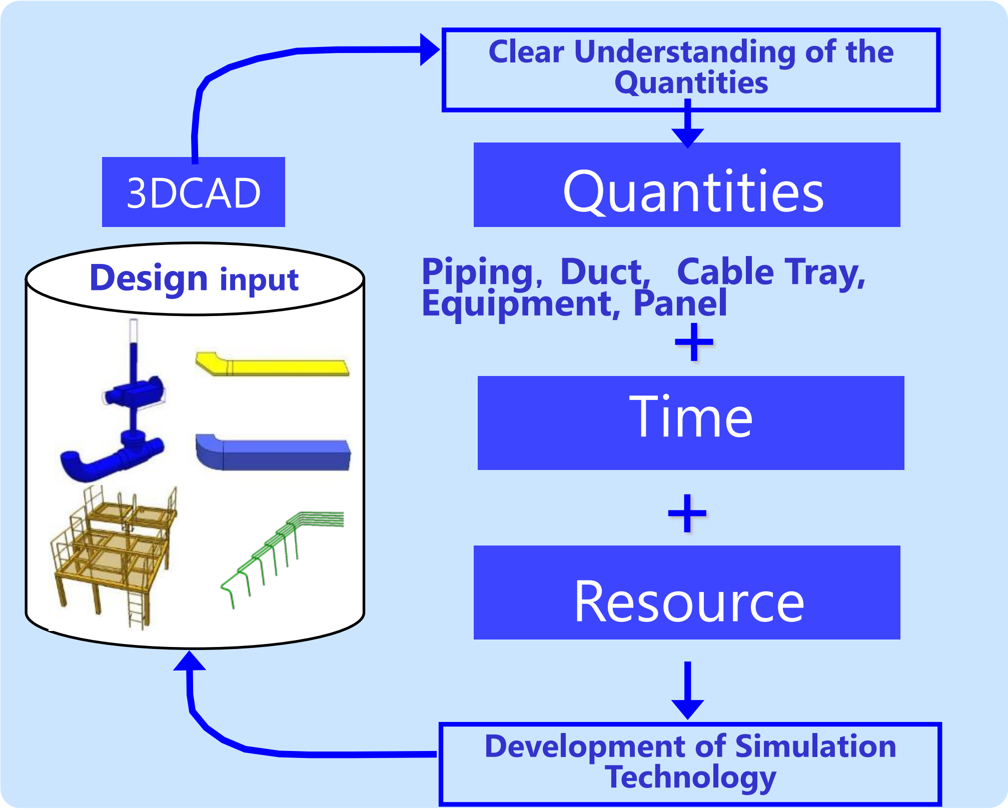


Generate 3DCAD data of Bulk commodity

3D data could minimize removal work at site preventing interference and serve other uses

6DCAD™

- Enable collective management of original 3D CAD data, work volume, process plan, human resources
- Support planning an optimum process plan by applying simulation technique



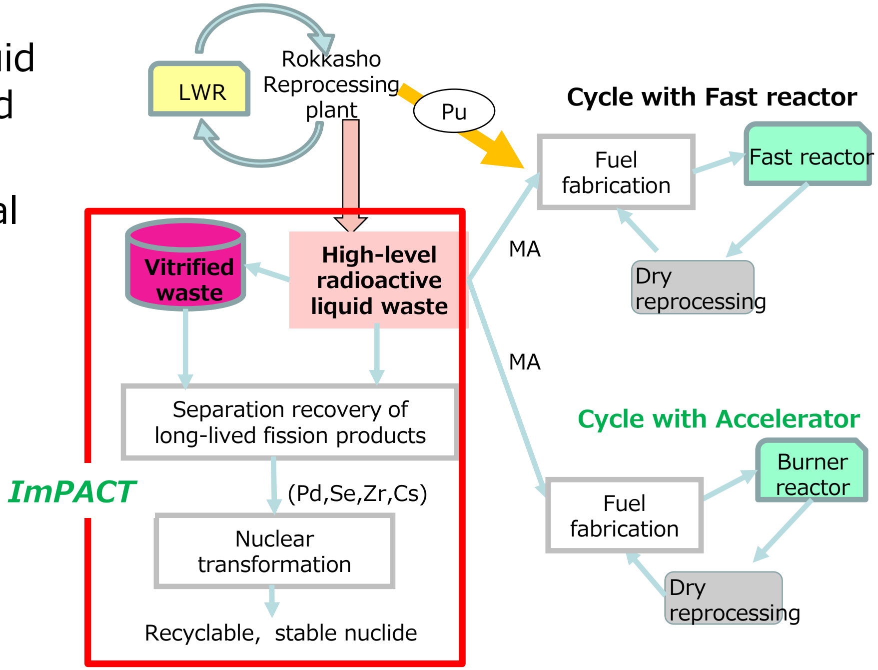
Reduce lead time and construction cost by optimum process plan

Reduce high-level radioactive waste

<u>This project is implemented under Impulsing Paradigm Change through Disruptive Technologies Program(ImPACT).</u>

- Collect useful element from radioactive waste to utilize as resources
- Reduce radioactivity by transmuting the radioactive waste to stable nuclide
- 2 themes of study for collecting LLFP* in isolation are now underway

  - Collect from high-level radioactive liquid waste by electrolysis or adsorption and solvent extraction
  - Collect from vitrified waste by chemical reduction or electrolytic refining



＊LLFP: long lived fission products
Radio isotope elements which have short short-life period
Se-79, Zr-93, Pd107, Cs135 are target elements.

This work was funded by ImPACT Program of Council for Science, Technology and Innovation (Cabinet Office, Government of Japan).

Solve resource and environmental problem by reducing radioactive waste simultaneously

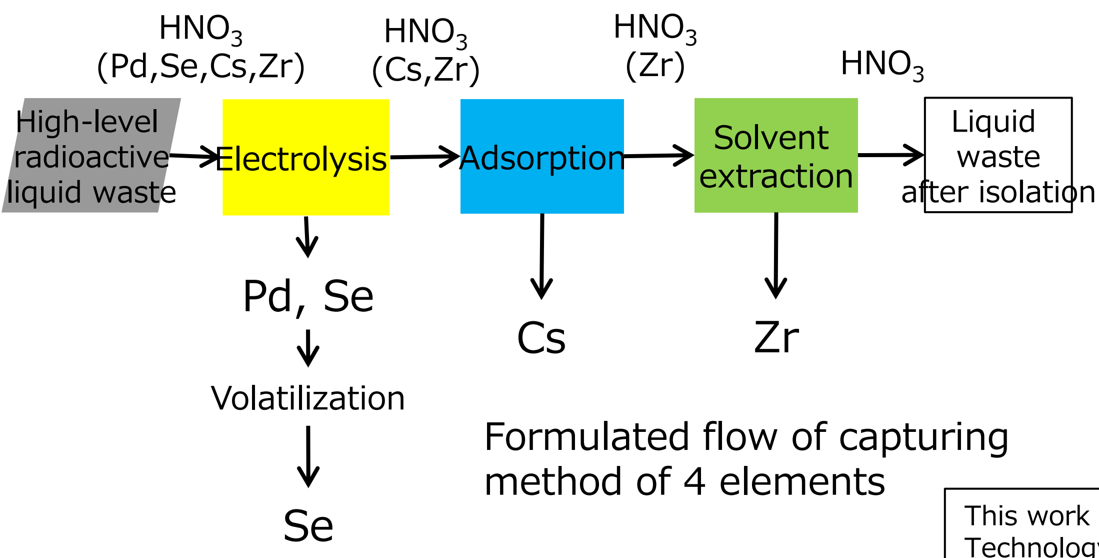
ImPACT

Practically realizing process of collecting LLFP from high-level radioactive liquid waste

- Combination of both methods of electrolysis (easy to collect metals) and adsorption and solvent extraction (useful for element partitioning)
- Capturing Pd,Se,Cs,Zr including LLFP which has more than several hundred thousands years of half-life (collection rate 90%)

Specifications

- No pretreatment required: High-level radioactive liquid waste can be treated as is
- No change in liquid status : Collecting nitric acid through wet electrolytic
- Reduce secondary waste : Regenerating adsorbent



Formulated flow of capturing method of 4 elements

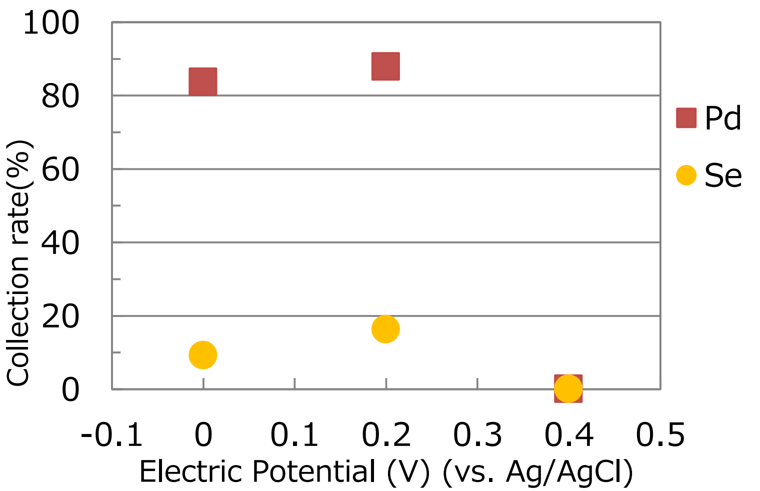


Diagram Collection of Pd,Se through electrolysis

This work was funded by ImPACT Program of Council for Science, Technology and Innovation (Cabinet Office, Government of Japan).

ImPACT

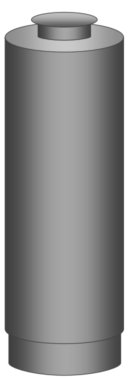
Practically realizing process of collecting LLFP from vitrified waste

- Technical development of collecting LLFP from vitrified waste

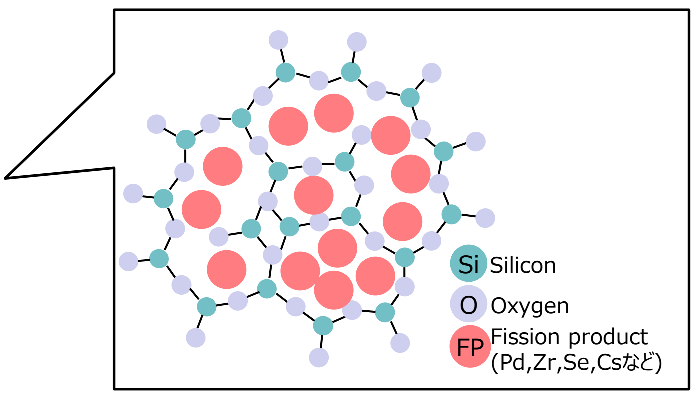
  ①Chemical reduction of molten salt : Degrade 99% of Si-O network structure, main component of vitrified waste (*)

  ②Electrolytic refining of molten salt : Count on capturing Pd and Zr from reduction product

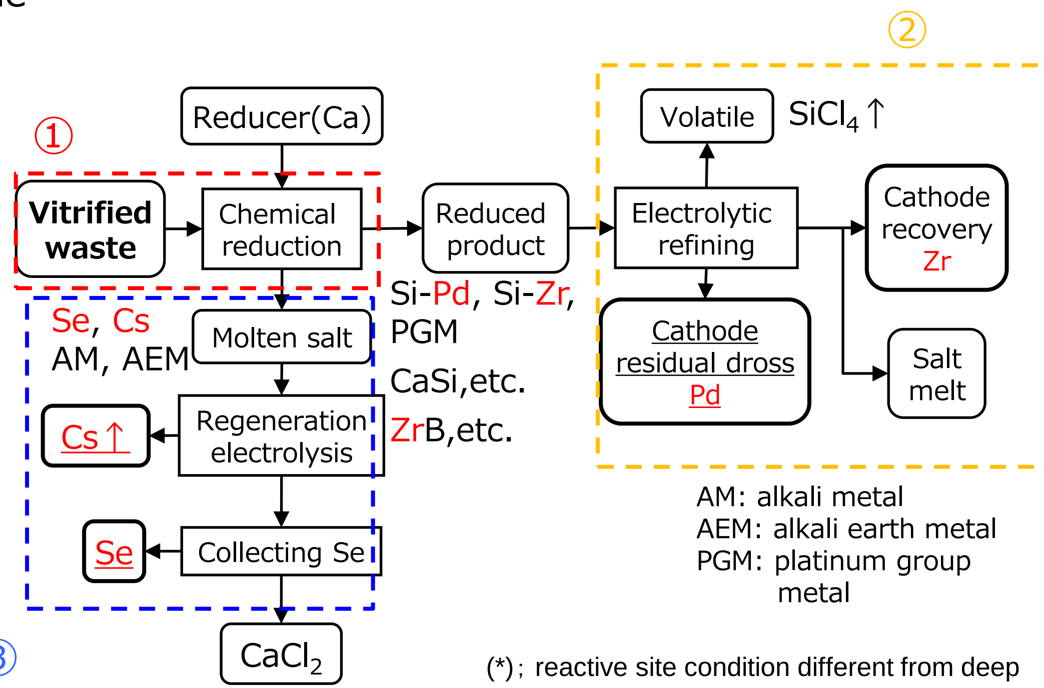
  ③Confirmed 99% of Se could be collected from soluble fraction of molten salt and Cs could be collected in principle



Vitrified waste



Inside image of vitrified waste



AM: alkali metal
AEM: alkali earth metal
PGM: platinum group metal

(*) : reactive site condition different from deep geological repository environment

This work was funded by ImPACT Program of Council for Science, Technology and Innovation (Cabinet Office, Government of Japan).

Content

01 Challenges for the future

02 Technology developments for safety and reliability

03 **Harmony with society**

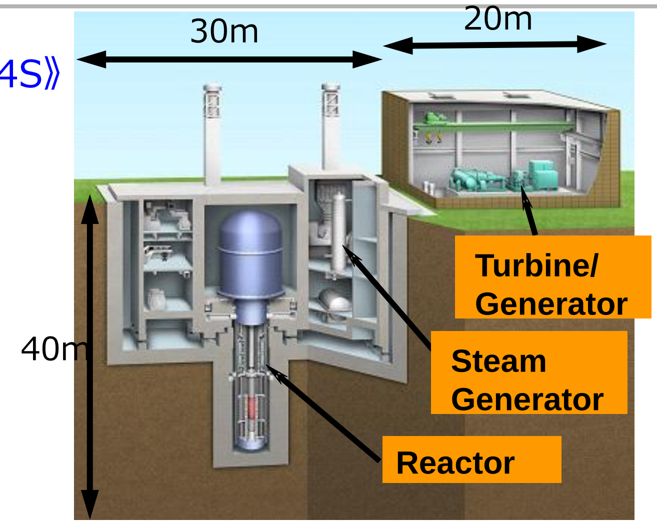
04 Closing remarks

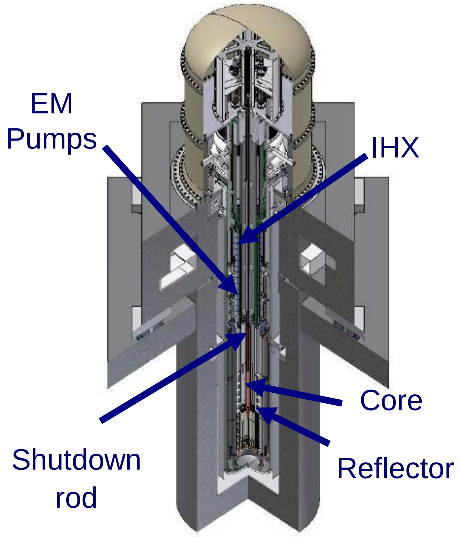
4S (Super-Safe, Small and Simple)

Long-term operation based on enhanced safety/reliability

- Sodium-cooled Fast Reactor
  Output 10MWe～50MWe
- Long Fuel replacement interval
  10MWe : 30years, 50MWe : 10years
- Safety design utilized natural phenomena
  Automatic reactor shutdown and heat removal without any human operation even at an accident
- Advanced technology
  Remove rotating system in reactor by applying electromagnetic pump.
  Planned to be applied to a fast reactor, ASTRID in France

《4S》



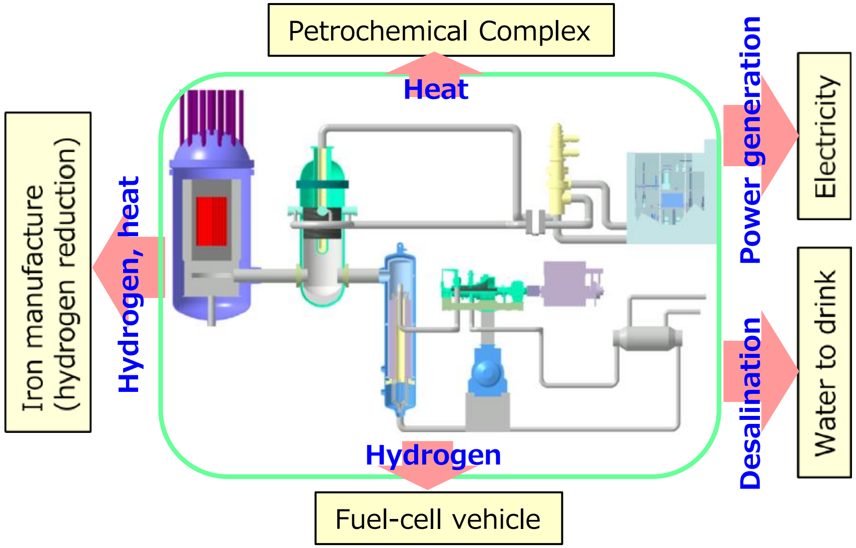


Preliminary review with NRC has been implemented

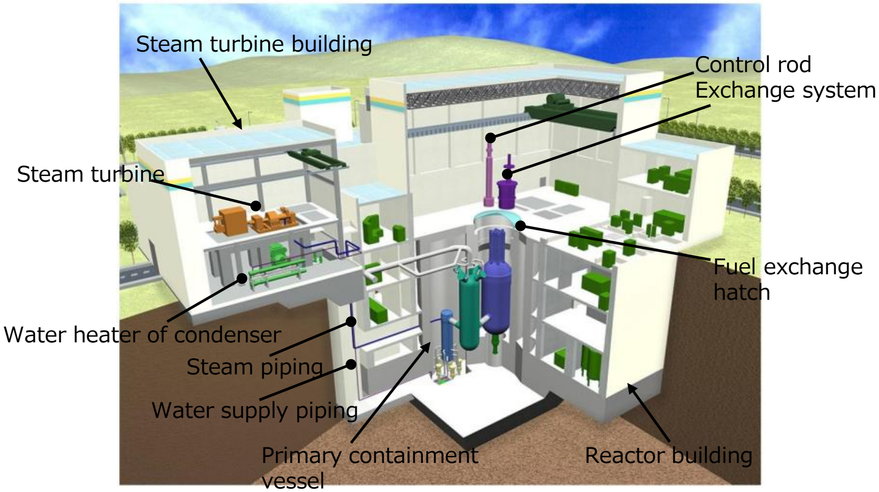
Realize long-term operation at a remote site with enhanced safety and reliability

High-temperature Gas Reactor

- **Enhance safety**
  - Ceramics coated fuel with high heat resistance → No fuel melting
  - Graphite moderator leads to slow change of temperatures at an accident → No need for immediate action at the accident
  - Inactive helium coolant → No chemical reaction with fuels (No hydrogen/vapor explosion)
- **Various heat utilization**
  (power generation, desalination, hydrogen production, etc.)



Reference : Web site of JAEA



Reference : JAEA-Technology 2013-016, pp.166

Support ‘harmony with hydrogen society’ and ‘contribution to various demand’ with inherent safety

Content

Closing remarks

- We will offer new value of nuclear power by developing technology to enhance energy security, economic efficiency and environmental acceptability with the highest priority in safety for further progress

- We will solve various challenges of engineering to enhance social acceptability of nuclear power

- We will proceed our technology and experience to the future generation with contributing human resources development and training

We will contribute to sustainable society through nuclear innovation

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