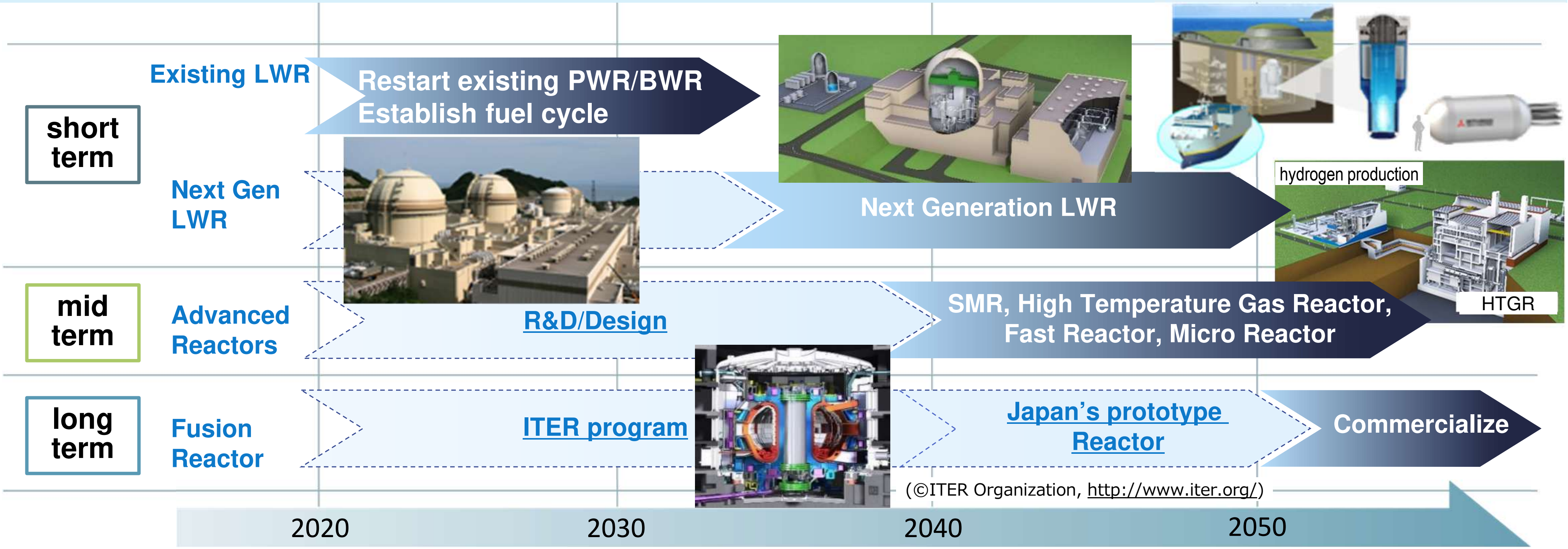
MHI Development of Advanced Reactors

26, Jan, 2024

MITSUBISHI HEAVY INDUSTRIES, LTD.

MHI Road map to achieve Carbon Neutrality

- MHI's roadmap is set for short, mid and long term to contribute to carbon neutrality.
- For short term, top priority is to **recover the public trust** on nuclear energy lost by Fukushima incident. MHI **supports restart and safety enhancement for existing plants**.
- For mid term, MHI is developing an advanced light water reactor "SRZ-1200" (Next-generation PWR).
- For long term, MHI **develops several advanced reactors such as SMR to meet diverse social needs in the future** and continue to work on **fusion reactor** as "permanent energy source".

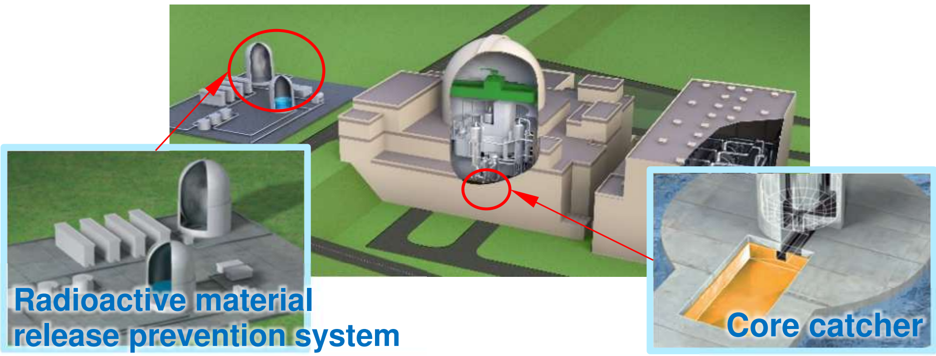


(1) Line-up of MHI's advanced reactors

- In addition to **Advanced LWR "SRZ-1200"** , MHI promotes development of **advanced new reactors (Small LWR, High-Temperature Gas Reactor, Fast Reactor and Micro Reactor) to meet future social needs**.

Advanced LWR "SRZ-1200"

- ✓ Power source for existing grids (1,200MWe)
- ✓ Achieves world's highest-level safety with innovated technologies, aiming the commercialization in the mid 2030s

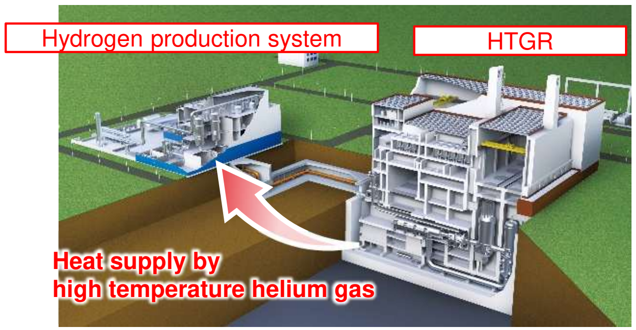


Small LWR (SMR)

- ✓ Distributed power source for small grids (300MWe)
- ✓ Full-passive safety system, inintegrated reactor incorporating main components of the primary system into the vessel

High-Temperature Gas Reactor(HTGR)

- ✓ Large-scale & stable hydrogen production using high temperature heat (over 900°C)
- ✓ Contributes to the decarbonization in industrial sector (steel industry, etc.)



Fast Reactor

- ✓ Realization of a closed nuclear fuel cycle, leading to the effective use of resources, reduction in volume and toxicity of high-level radioactive waste


※

Micro Reactor

- ✓ Muti purpose portable reactor (for remote island, disaster affected area, etc.)
- ✓ Full solid reactor core (MHI original design)

※This figure includes an outcome of R&D program entrusted by METI.

(2) Development of advanced LWR "SRZ-1200"

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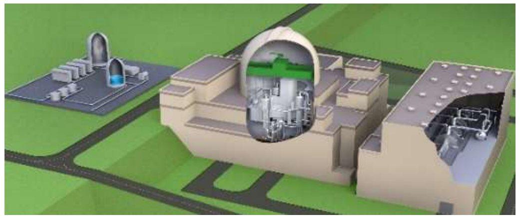
- MHI is developing **advanced LWR "SRZ-1200"** with innovative technologies, **which achieves world's highest-level safety.** Commercialization target **in the mid 2030s**.
- **New plant construction** is essential to **sustain industrial infrastructure and workforce**.
- Also **developing small LWR to meet future social needs**, leveraging the technologies obtained through development of SRZ-1200.

~2020 | 2030 | 2040 | 2050~

Current safety standard

New Standard for SMR

"SRZ-1200"

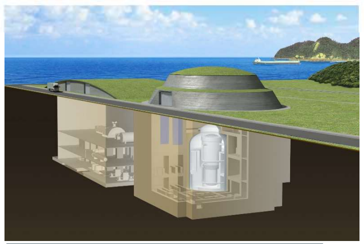


1,200MWe class

- Achieves enhanced safety and competitiveness based on proven technologies
- Limit radioactive effect inside of plant site even in accident.

Distributed power source

Small LWR (SMR)



300MWe class

- Reduce BoQ by integrating main components into reactor vessel

Supreme Safety

- Highly resistant to earthquakes, tsunami and acts of terrorism act, etc.
- Confine radioactive materials and limit its effects within the plant site.

Environmentally Friendly

- Zero CO_2 emission, and flexible operation in coexistence with renewable energy.

Large scale and stable supply of energy

- Large and stable power supply unaffected by international situation and weather change.

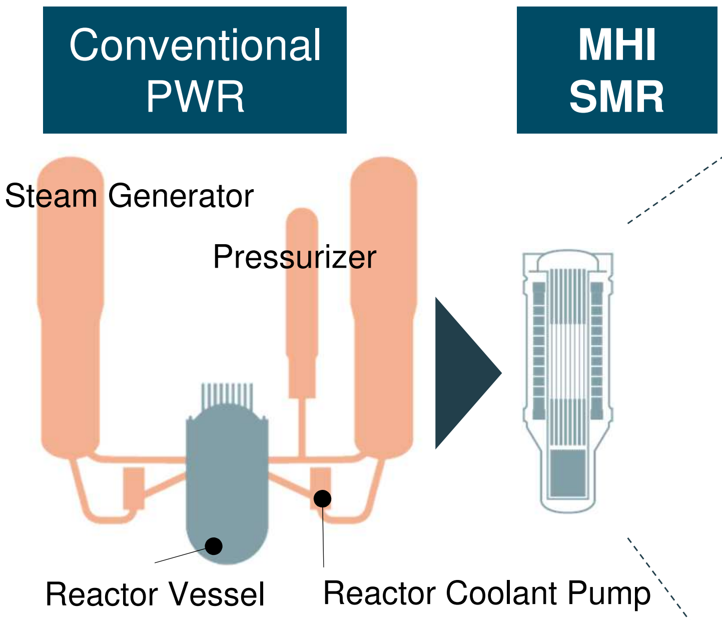
"SRZ" represents;

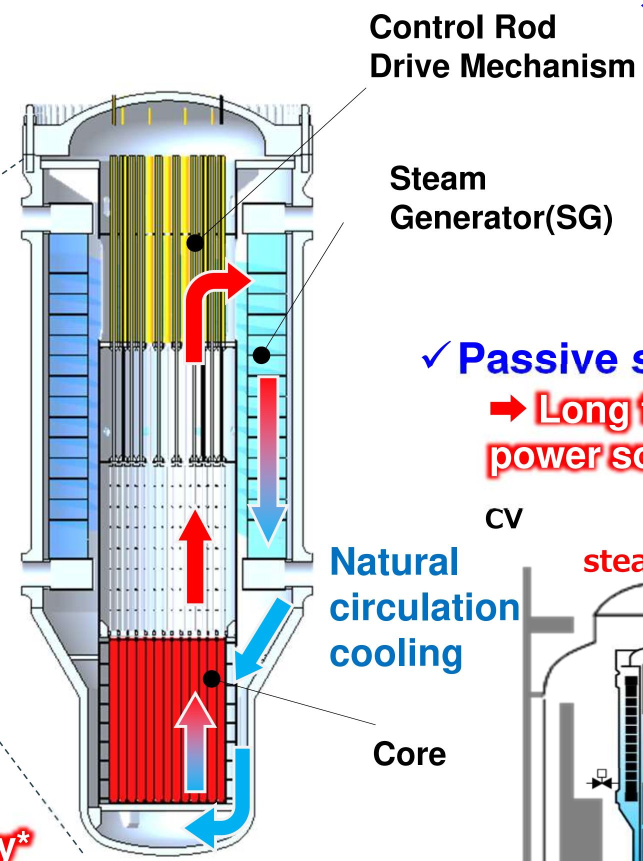
S: **S**upreme **S**afety, **S**ustainability
R: **R**esilient light water **R**eactor
Z: Ultimate type (**Z**) contributing to society by **Z**ero carbon emission.
(In Japan, "Z" also has a meaning of "ultimate type")

(3) Development of small LWR (1/4)

Main features of MHI SMR

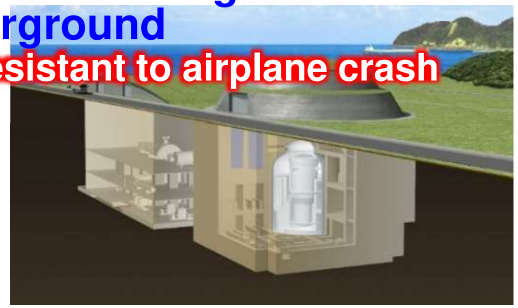
- **Integrated reactor** with natural circulation cooling, eliminating potential of LOCA
- **Passive safety system** without additional power source and water
- **Built in underground** to be resistant airplane crash and natural disasters





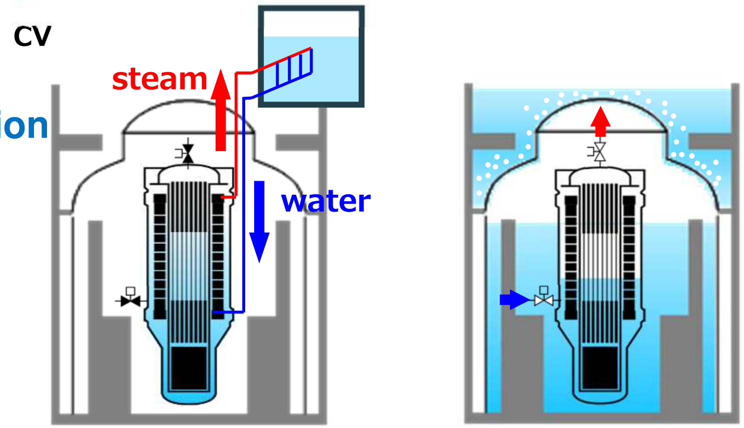
✓ **Reactor building embedded underground**

➡ **Resistant to airplane crash**



✓ **Passive safety system**

➡ **Long term cooling without additional power source/water**



Core cooling by SG

CV/core cooling

✓ **Integrated Reactor**

(eliminates main coolant piping/pump)

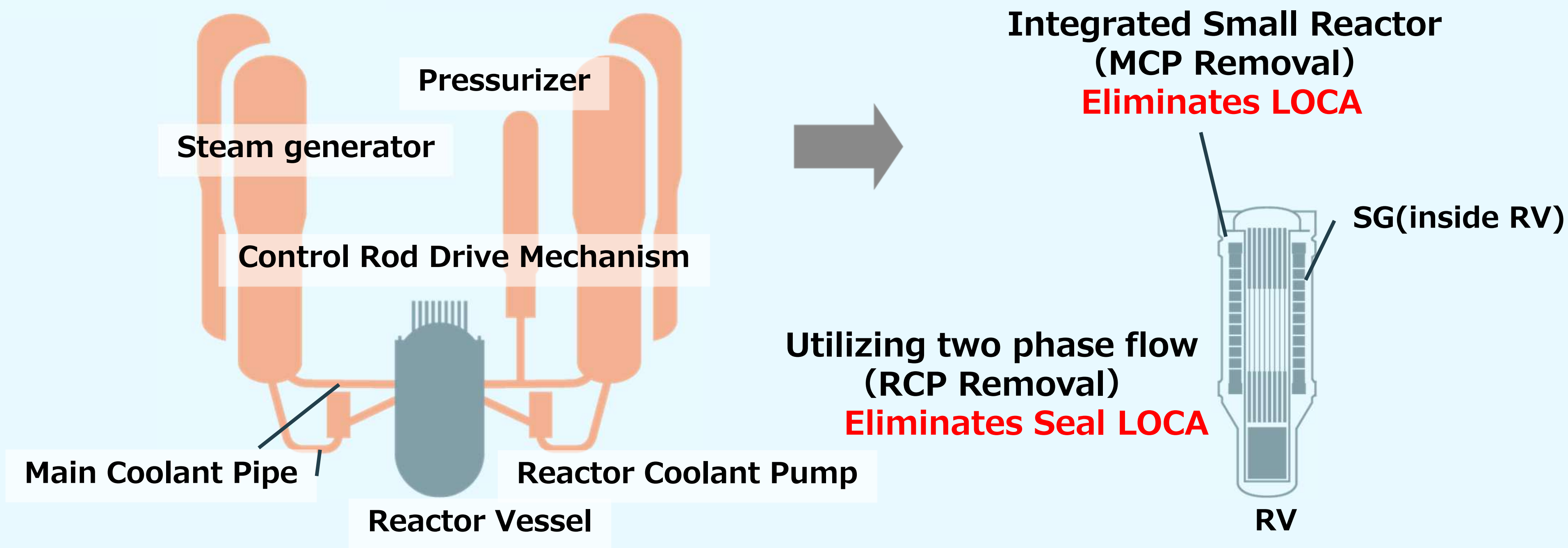
➡ **Elimination of accident possibility***

*such as LOCA (Loss of Coolant Accident)

Integrated Reactor

- MHI SMR integrates main components of the primary system (steam generator, primary coolant pump, pressurizes, etc.) into the reactor vessel.
- The concept eliminates the risk of loss-of-coolant accidents caused by the ruptures in the primary coolant piping.

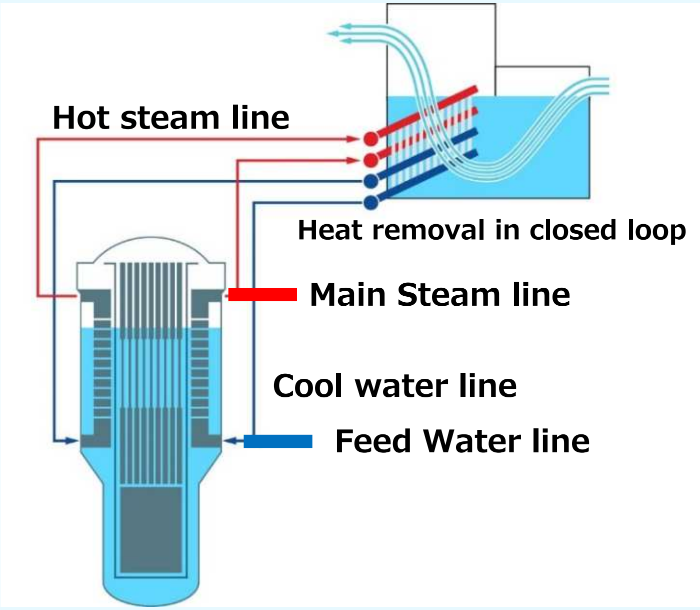
Essential Prevention



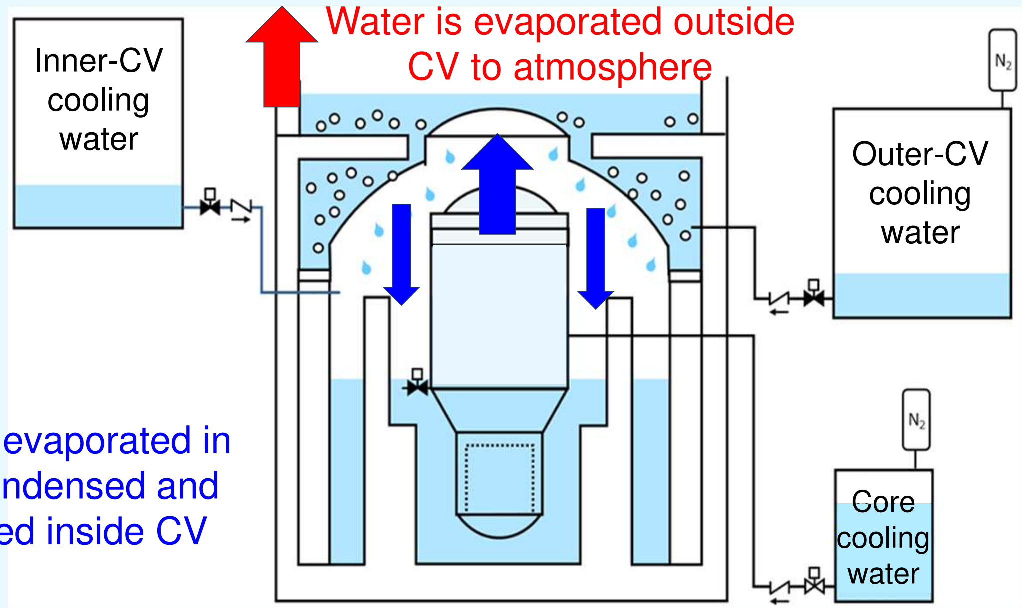
Passive safety system

- Two passive cooling systems provide the plant safety in accidental conditions without additional power source and water.
- The passive system with SG removes core heat by secondary coolant natural circulation through designated heat exchanger outside of the containment
- The passive core/containment(CV) cooling system transfers core heat outside containment.

Passive core cooling system with SG

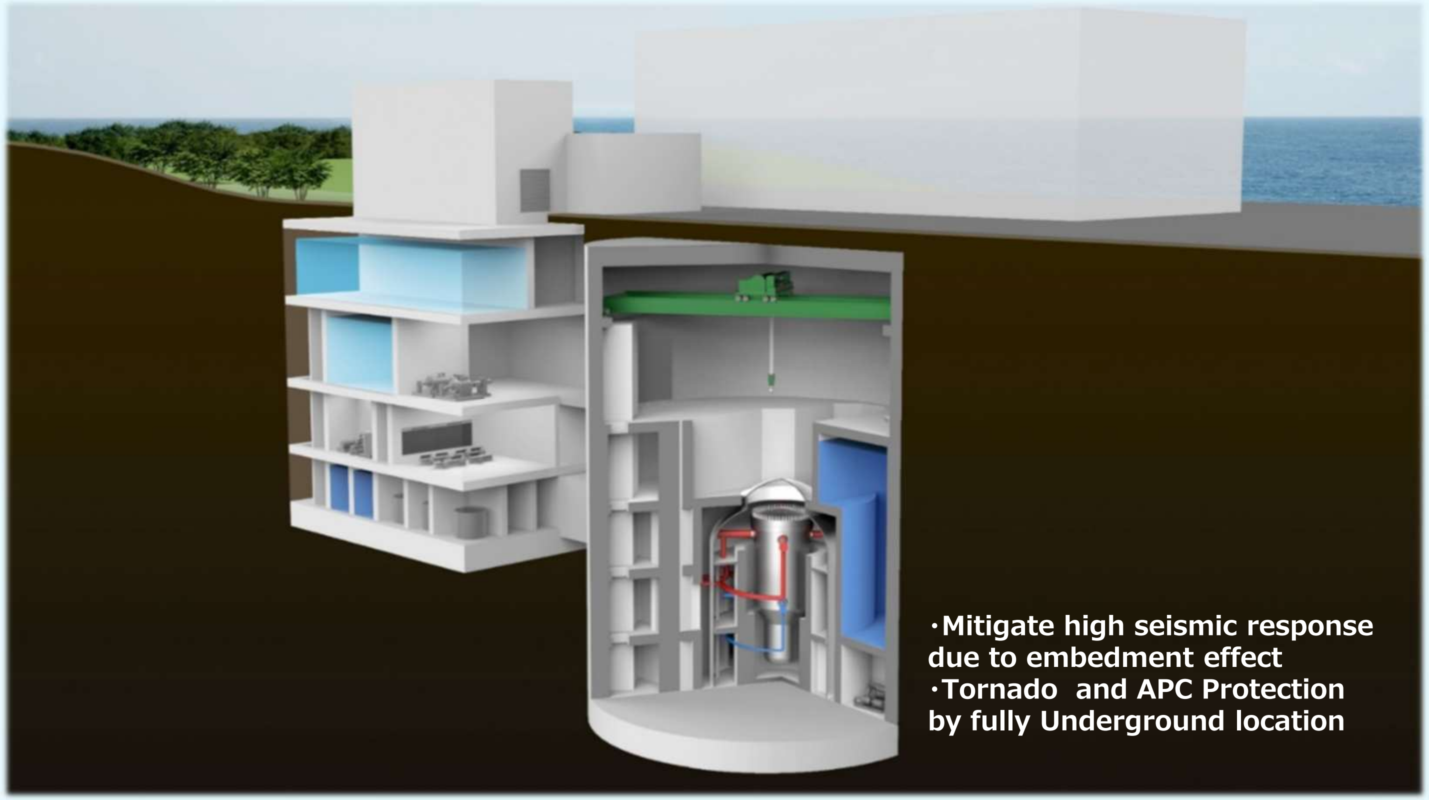


Passive core/containment cooling



Built in underground

- "Built in underground" concept provides safety measures against external hazards including natural disasters such as earthquakes (high seismic in Japan), tornadoes, as well as terrorism and intentional airplane crash.
- MHI SMR's downsized containment vessel is suitable for this concept.



(4) Development of High Temperature Gas-cooled Reactor (HTGR)

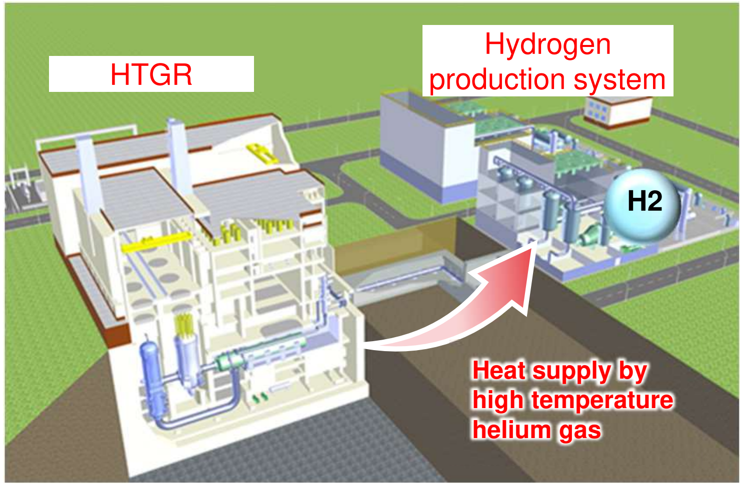
- Decarbonization in not only the energy sector, but in sectors with high CO_2 emission such as the steel industry, chemical and transportation is essential to achieve carbon neutrality by 2050.
- HTGR can provide **carbon-free high temperature heat (over 900°C*1) which can be used as a large and stable source for hydrogen production,** contributing **to decarbonization in the steel industry and other industries**.

*1 HTTR achieved **the world's highest heat temperature (950°C)**.

MHI Contributions

HTGR	Hydrogen production
• CO_2-free heat supply of high-temperature (over 900°C)	• Steam Methane Reforming method ↓ Future • CO_2-free hydrogen production

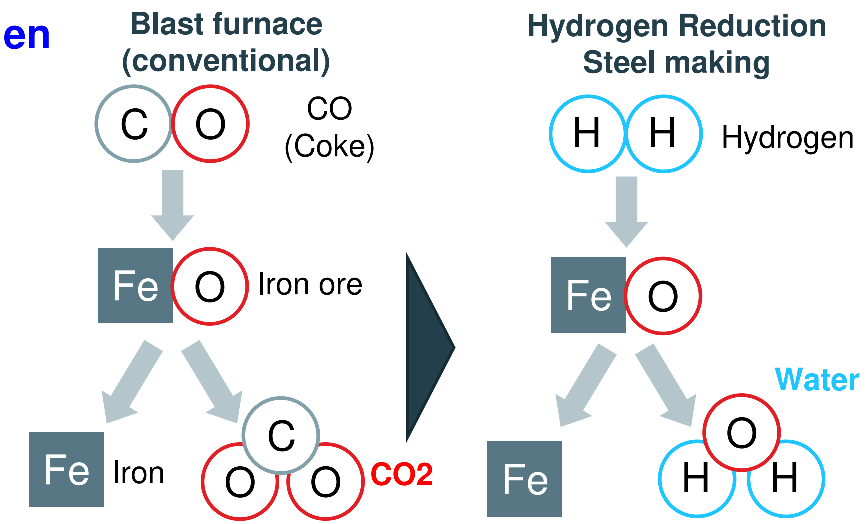
Heat



Hydrogen

Hydrogen utilization (e.g.steel industry)

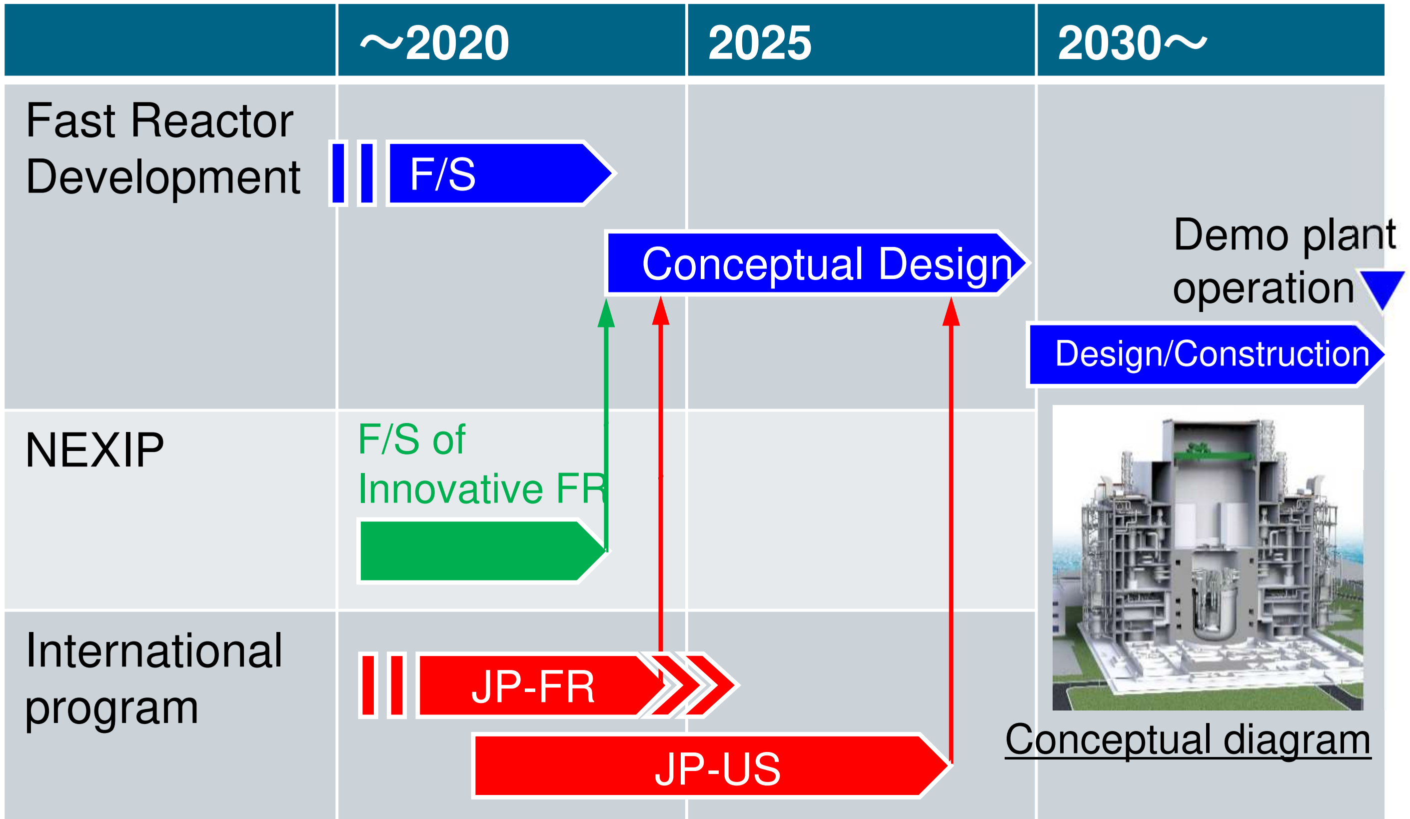
Hydrogen reduction ironmaking
• Replacement of cokes (C) in blast furnace with hydrogen • Stepwise increase in added hydrogen ratio to reduce CO_2 • Final target is 100% hydrogen reduction in the future

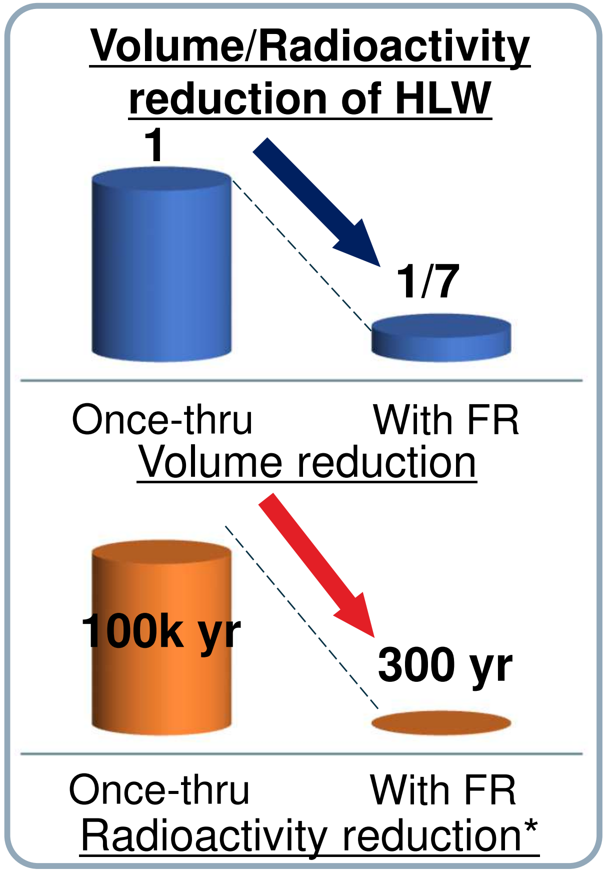


(5) Development of fast reactor

- Fast reactor utilizes fast neutron which contributes to **effective use of resources and reduction of volume/radiotoxicity of high-level radioactive waste(HLW)**.
- MHI group, as a prime company of fast reactor development in Japan, is participating in Japanese government program, international program (Japan-France / Japan-US), and takes lead of development of fast reactor with the goal of operation start by 2050 in Japan.
- The fast reactor development WG has resumed in Japan, and **a sodium-cooled reactor has been selected** as the most promising. Then **MHI has been selected as a prime company for demonstration reactor development. The conceptual design effort will start in 2024**.

<Development Schedule>





*years needed to radioactivity equivalent to natural uranium

(6) Development of micro reactor (1/2)

- **Portable reactor for multi-purpose** (energy security (storage), energy source for remote island and disaster area etc.).
- Reactor core has **a long service life and requires minimum operation and maintenance** throughout its life expectancy
- Solid core by utilizing high heat conduction material (avoidance of leakage incident)

[Main Specifications of Micro-reactor]

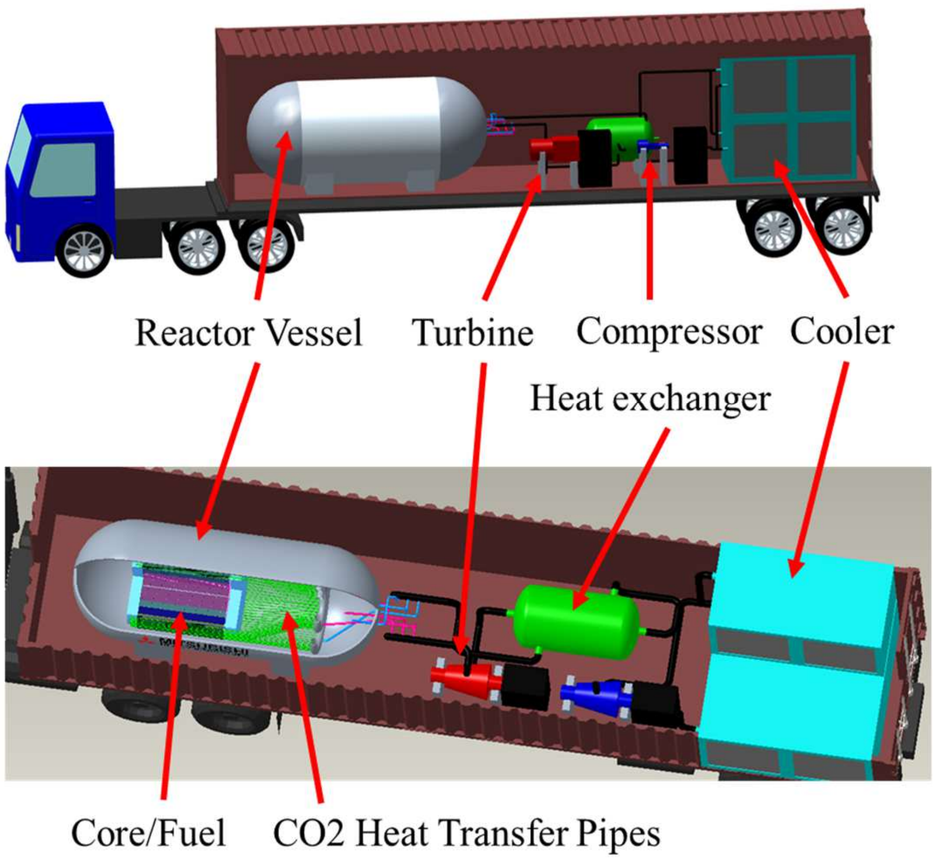
Core size	Diameter: 1 m or less Length: 2 m or less
Primary cooling system	Heat transfer by high thermal conductive materials
Output	1MWt~/0.3MWe~
Operating cycle	5 years or more
Design life	25

(6) Development of micro reactor (2/2)

- The thermal output exceeds 1MWt per module and total power demand is satisfied flexibly combining multiple units.
- **Based on "all-solid-state core" concept**, the reactor uses a highly thermal conductive graphite-based material that remove heat from core without liquid coolant.
- **Transport inside 40ft standard cargo container** by conventional transport systems.

Conceptual Specifications of the Microreactor

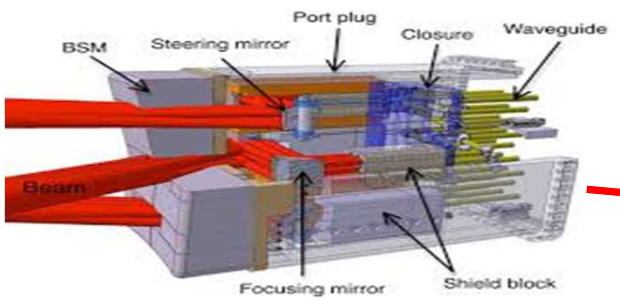
Item	Value
Fuel	HALEU
Core structure	Layer structure with Graphite type material (lighter weight)
Thermal Output	1MWt –
Electric Output	0.3MWe –
Operation /Control	Automated
Safety System	Full passive
Size	Inside Standard 40ft freight container



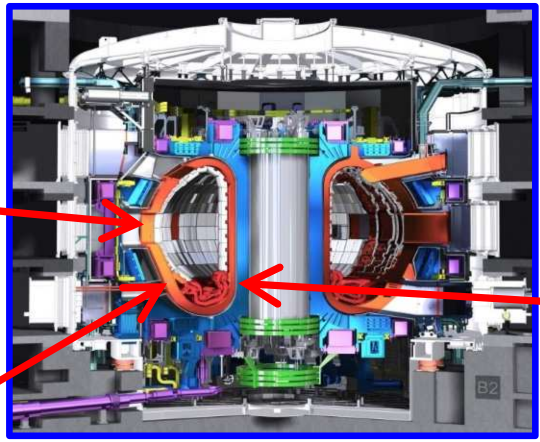
(7) Development of Fusion Reactor

- From a long-term perspective, **MHI promotes the development of fusion energy through the international collaboration.**
- MHI will actively support the **ITER project**[*1] based on **MHI's high-level detailed design** and **manufacturing technology** for the first plasma operation scheduled around 2025.
- In addition, MHI continues to advance the development of a fusion demonstration reactor.

*1: International megaproject for the world's largest fusion experiment by seven parties (Japan, EU, US, Russia, China, South Korea and India)



Plasma Heating System



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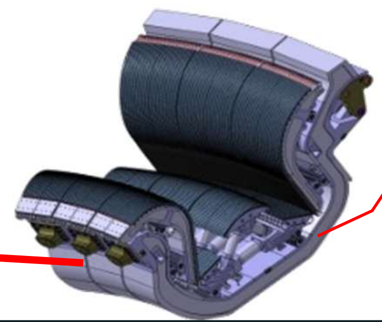
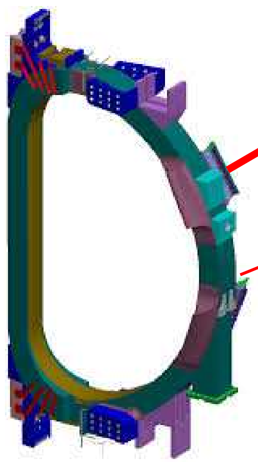


Contract for six units of the outer vertical target

Divertor (Outer Vertical Target)



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