Severe Accident Countermeasures of SFR (on Monju)

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1. Safety Approach of Monju

Safety Approaches in early LMFBR

- There were several LMFBR plants, actually designed, built and/or operated during the 1970s and 1980s.
  - Superphenix (France), SNR-300 (Germany), Clinch River Breeder Reactor Plant (the USA) and Monju (Japan)
- A rather coherent safety approach was taken in those LMFBRs. (In this stage, CDAs have already considered.)
  - Based on the defense-in-depth principles with appropriate consideration on sodium chemical reactions.
  - Even though their early designs considered Core Disruptive Accidents (CDAs) directly in the safety design, the treatment in safety evaluation was different from Design Basis Events (DBEs) with best-estimate method and assumptions being commonly used.
  - CDAs tend to be regarded clearly as an event category of beyond DBE.
  - The purpose of CDA analysis is to provide or confirm an additional safety margin of a plant strictly designed for DBEs.

CRBRP Regulatory

CDAs approach in the USA

- As for FFTF, HCDAs received much regulatory review attention in CRBRP regulation
  - Early agreement (1976) between NRC and the project that HCDAs would not be a design basis for containment
  - However, the role of severe accidents and characterization of their consequences dominated the attention of the interveners, the regulators, and project
- After several activities had been done,
  - The NRC Atomic Safety and Licensing Board ruled against intervener's contention that HCDAs should be a design basis
  - NRC staff stated: "It is our current position that the probability of core melt and disruptive accidents can and must be reduced to a sufficiently low level to justify their exclusion from the design basis accident spectrum."
  - CRBRP project built a technical case to justify exclusion
  - CRBRP met licensing requirements for construction without inclusion of HCDAs in the design basis

1. Safety Approach of Monju

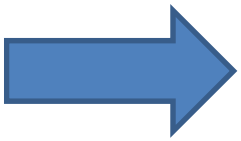
History of CDAs in Monju Licensing

- The CDAs were analyzed as a part of the special accident category in a range of beyond DBE, which was introduced because of limited operating experience in LMFBRs in Japan.
- PNC (former JAEA) developed analytical codes for CDAs and used them in Monju licensing process.
  - SAS3D, PISCES-2DELK, MIMIR-N2, etc.

- 1980.12.10: Application for Monju license to a Regulatory Body (Former Science and Technology Agency). Monju licensing process was started.
- 1983.5.27: Permission of Monju license by the Regulatory Body and Nuclear Safety Commission. The licensing process was finished.
- 1994.4.5: First criticality
- 1994.8.29: First connection to electrical grid
- 1994.12.8: Leak of secondary sodium

Nuclear Safety Commission Regulatory Guides for Reactor Under Development (NSCRG: D-FR-I.01) Published in November 1980

(5) Such events of which the probability of occurrence is lower than the “Accident” treated in (2.2), whereas the consequence is more significant, should be sufficiently investigated on the initiating events and on the protection measures against the successive event progression, taking into account that operation experience of LMFBR is scarce, and then proper constraint of radioactivity diffusion should be assured.



Subsection (5) event

1. Safety Approach of Monju

: A current scope of license of Light Water Reactor and Monju

	DBE	BDBE
LWR	Abnormal transient during operation & Accidents	Severe Accidents Accident management (Licensees' voluntary)
Monju	Abnormal transient during operation & Accidents	Severe Accidents Subsection (5) events ULOF UTOP After permission of the license, evaluation of all SAs events with PSA (level-1, -2) PLOHS, ULOHS, LORL

Specific events of FBRs
>Not maximum reactivity core configuration
>Generate mechanical energy
>Progress of phenomena is too rapid to react by operator

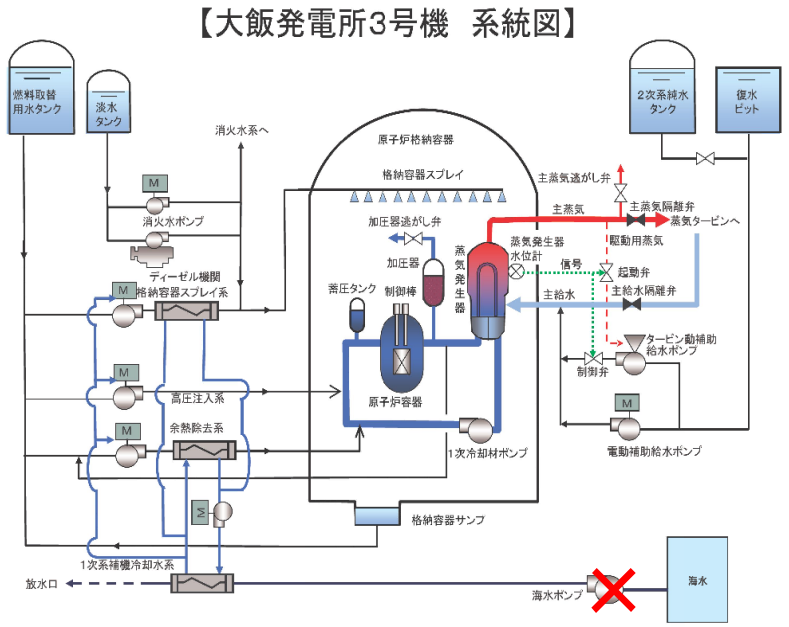
The similar events of SAs of LWR
>Fail to remove a decay heat
>Thermal degradation of core
>Progress of phenomena is not so rapid to react by operator

CDAs which are specific to a sodium coolant FBR has been considered and evaluated in Monju license as a beyond DBE

Comparison of LWR and FBR
Difference of ultimate heat sink

LWR

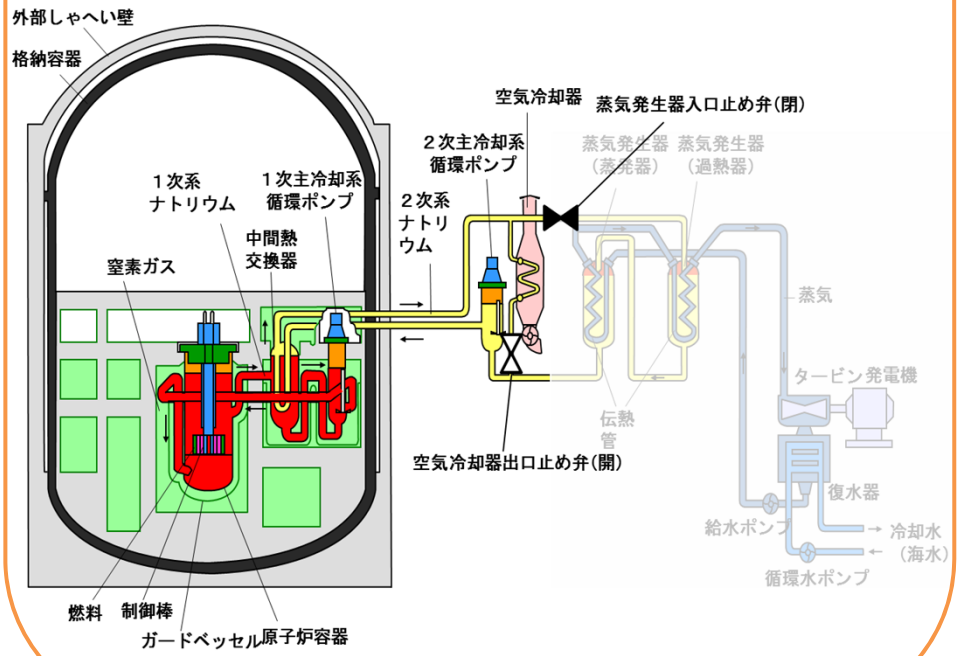
Ultimate heat sink: Sea water



http://www.kepco.co.jp/pressre/2011/pdf/1028_1j_04.pdfより引用、一部修正

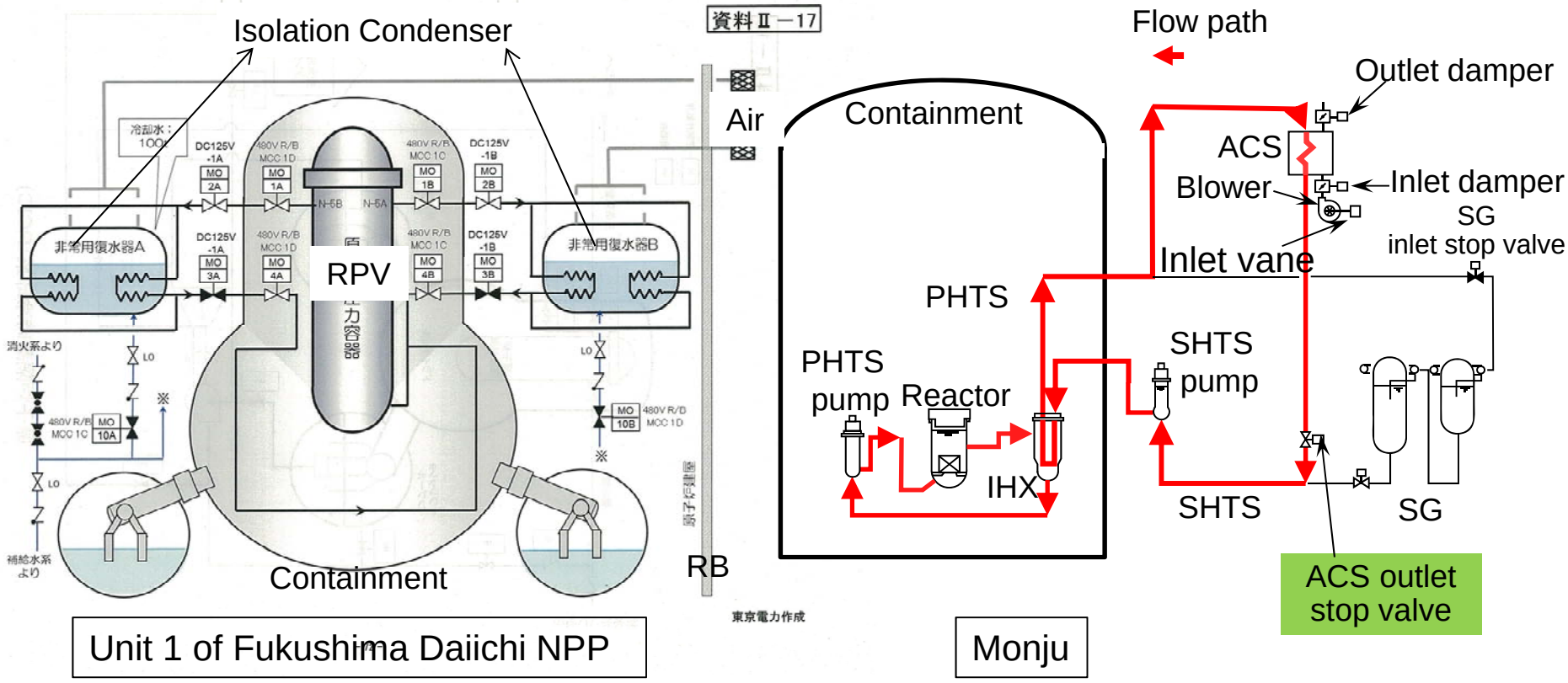
Monju

Ultimate heat sink: Air



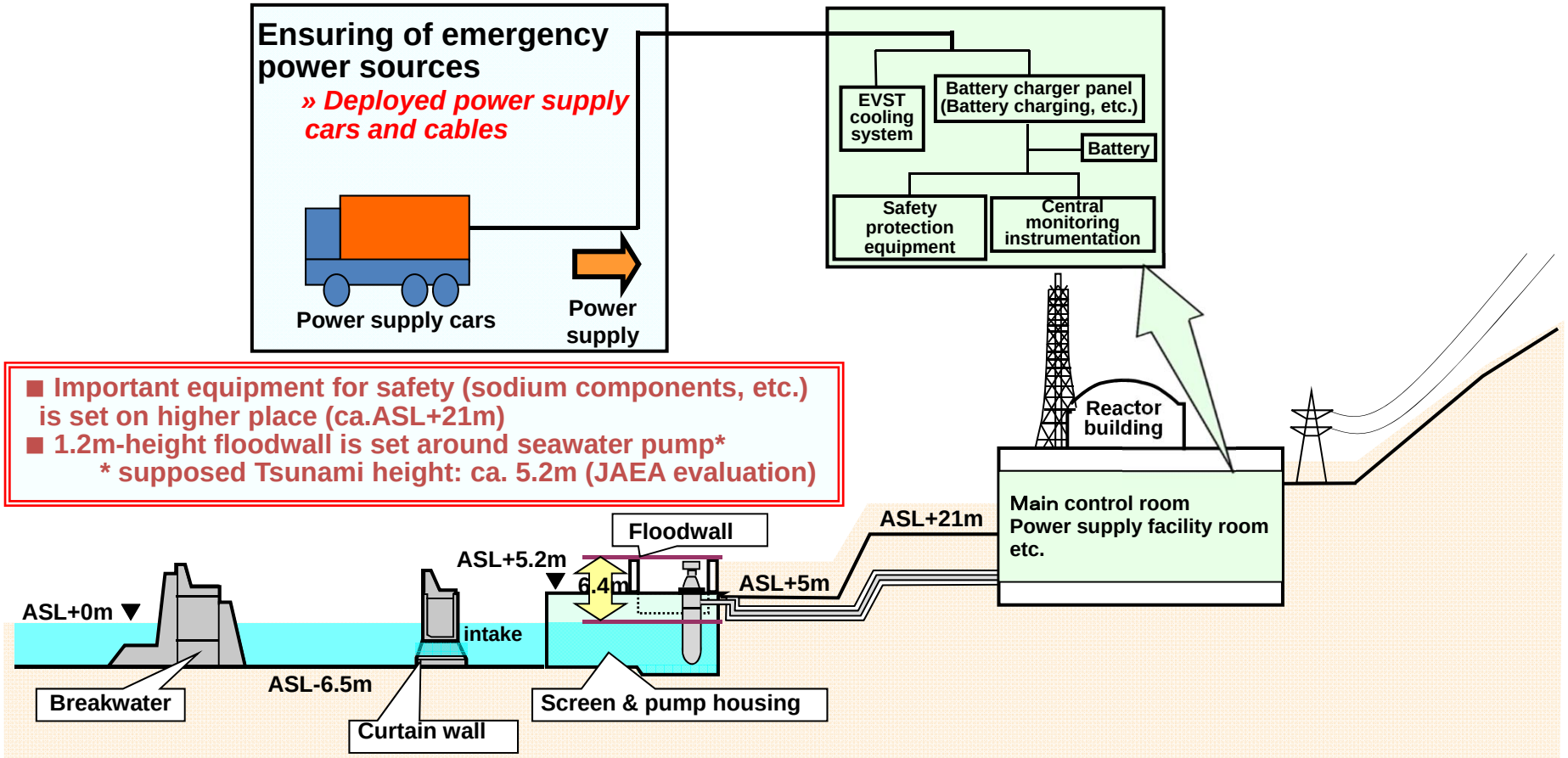
Comparison of LWR and FBR

In LWR, Isolation valves are needed in order to avoid loss of coolant under high pressure; The function of containment is incompatible with that of heat removal
In Monju (sodium reactor), Isolation valve is not needed. A tube of an IHX forms a reactor coolant boundary: Operation of Monju in an emergency is easier than LWR



2. Lessons Learned from Fukushima Daiichi NPP

Even if all electric power sources are lost by Tsunami, the decay heat of Monju is removed by natural circulation for a reactor core and an EVST. And there is plenty time to take safety countermeasures.
However, electric power supply should be needed to work instruments for avoiding operator's misunderstanding and not to freeze sodium coolant at its final stage.



Current Status of Stress Tests

- The event tree of a station blackout and a loss of ultimate heat sink were prepared to analyze a prototype fast breeder reactor, Monju.
- The method of estimation for a margin to an earthquake was prepared to investigate important equipment for safety.
- The decay heat from a reactor core and an EVST of Monju can be safely removed by natural circulation without any electrical power supply.
- The effectiveness of emergency safety countermeasures at a station blackout is confirmed: a water supply to a fuel pool and a continuous supply of electric power to instruments.

3. Suitability of Monju for SDC

Safety design of Monju

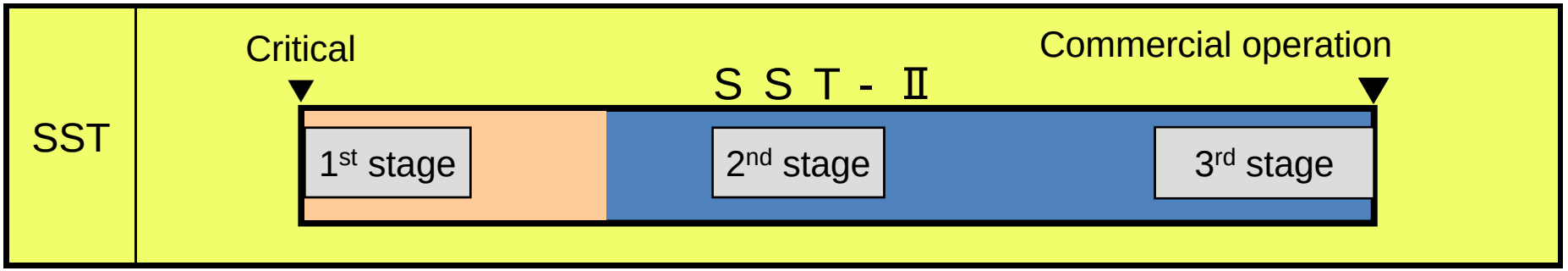
- To satisfy the third level of defense in depth
  - The safety design with characteristics of a sodium cooled FBRs
  - Two independent reactor shutdown system, Decay heat removal system, System of countermeasures against sodium leakage, System of countermeasures against water leak in a steam generator
- To consider the fourth level of defense in depth
  - To maintain core coolability by natural circulation under total blackout
  - To retain molten materials in a reactor vessel, even if a core melts
    - ✓ Success in “In-vessel retention”

The safety design of Monju satisfies the safety design philosophy of the fourth generation power plant

4. Confirmation of Natural Circulation by Monju

The sequence of Monju System Startup Tests (SSTs) are as below.

A natural circulation test will be planned at the third stage in Monju SSTs



SSTs are divided into 3 stages

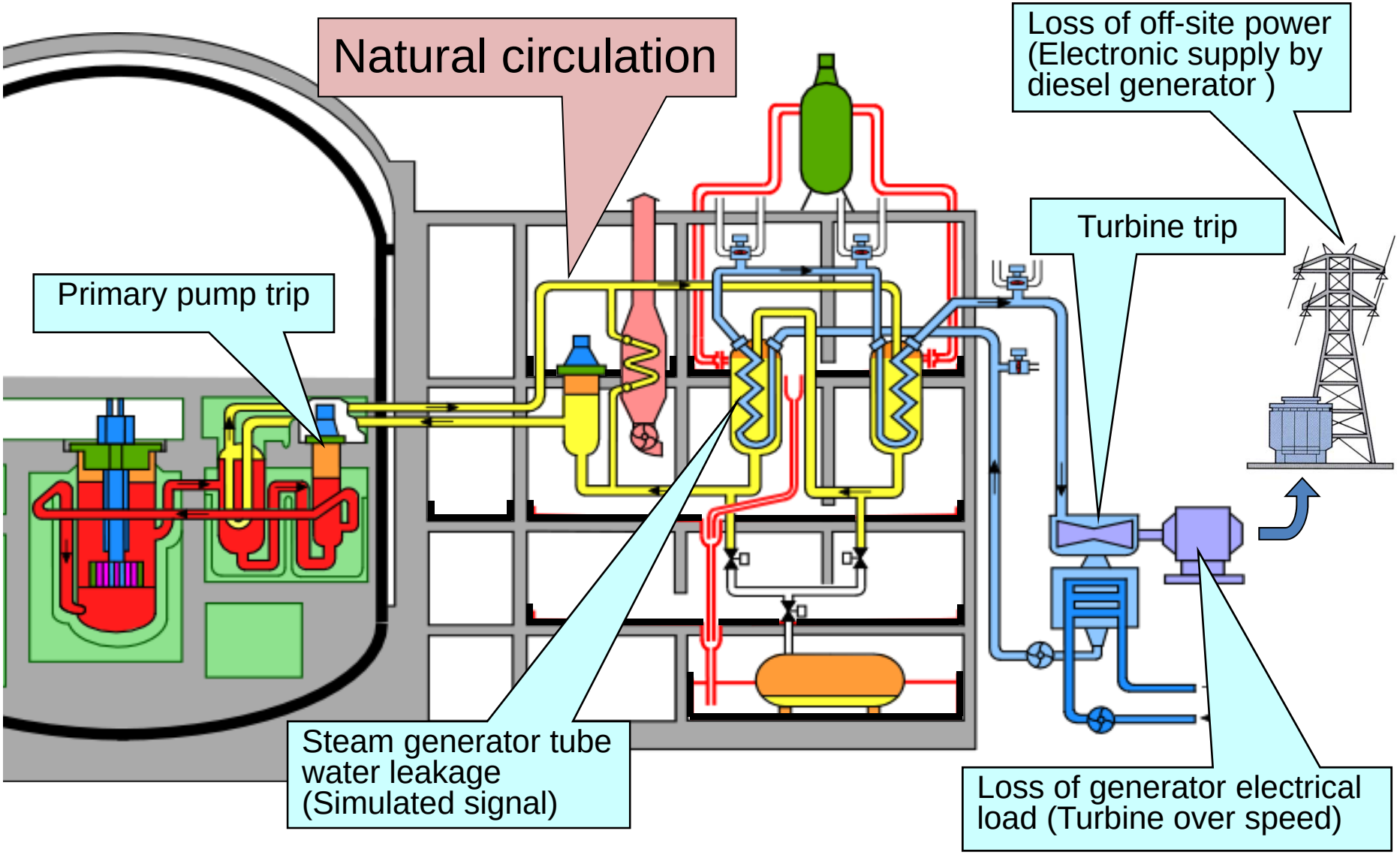
1）1st stage was core physical tests (0% electric power)
Performance of the Am-bearing MOX fuel core

2）2nd stage is the tests on 0 to 40% electric power
Overall plant function & performance tests
(including water/steam & turbine systems)

3) 3rd stage is the tests on 40 to 100% electric power
Overall plant function & performance up to full power operation

4. Confirmation of Natural Circulation by Monju

Malfunction Tests



4. Confirmation of Natural Circulation by Monju

Reactor power

Heat transport system

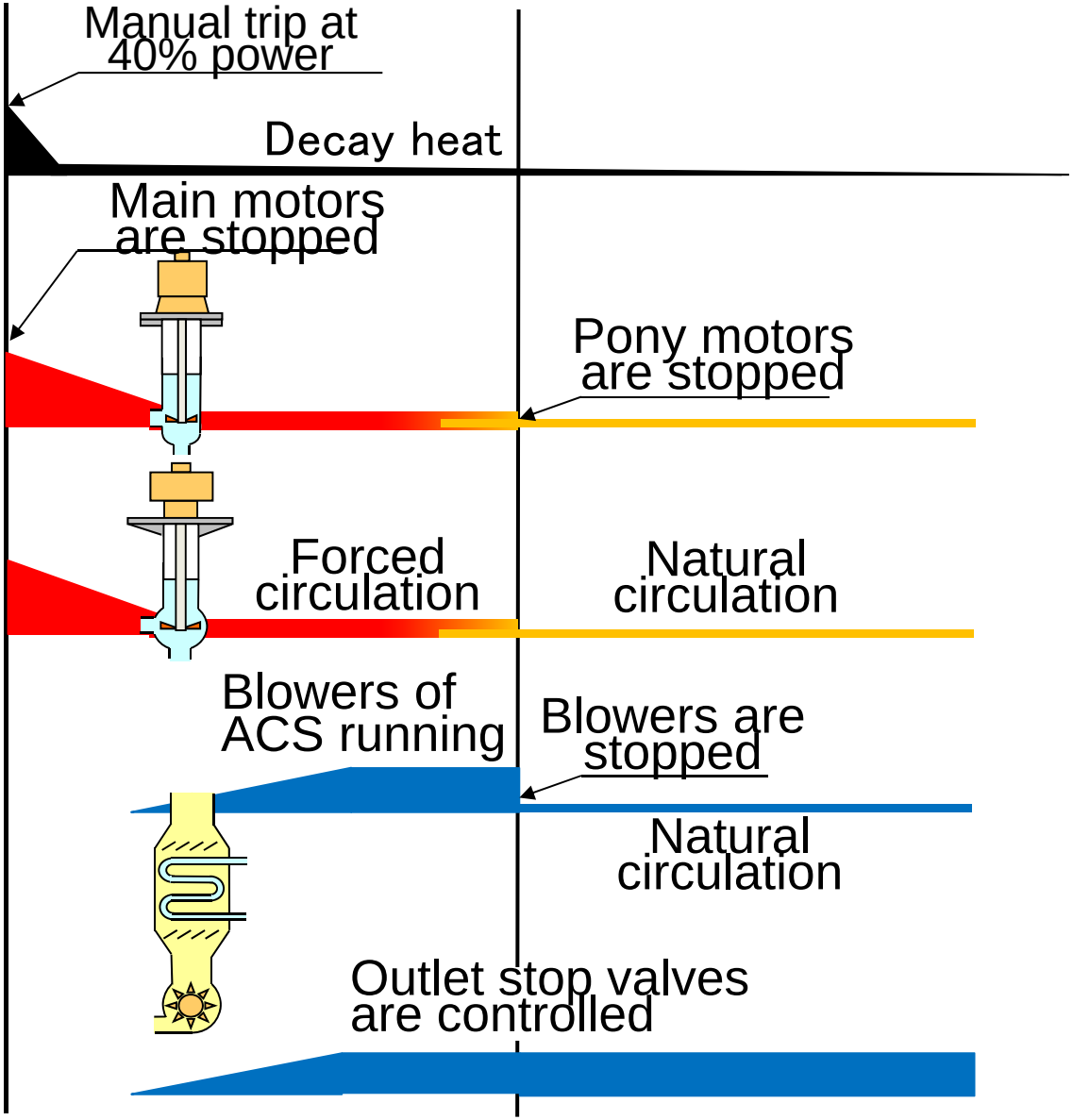
Primary heat transport (3 loops)

Secondary heat transport (3 loops)

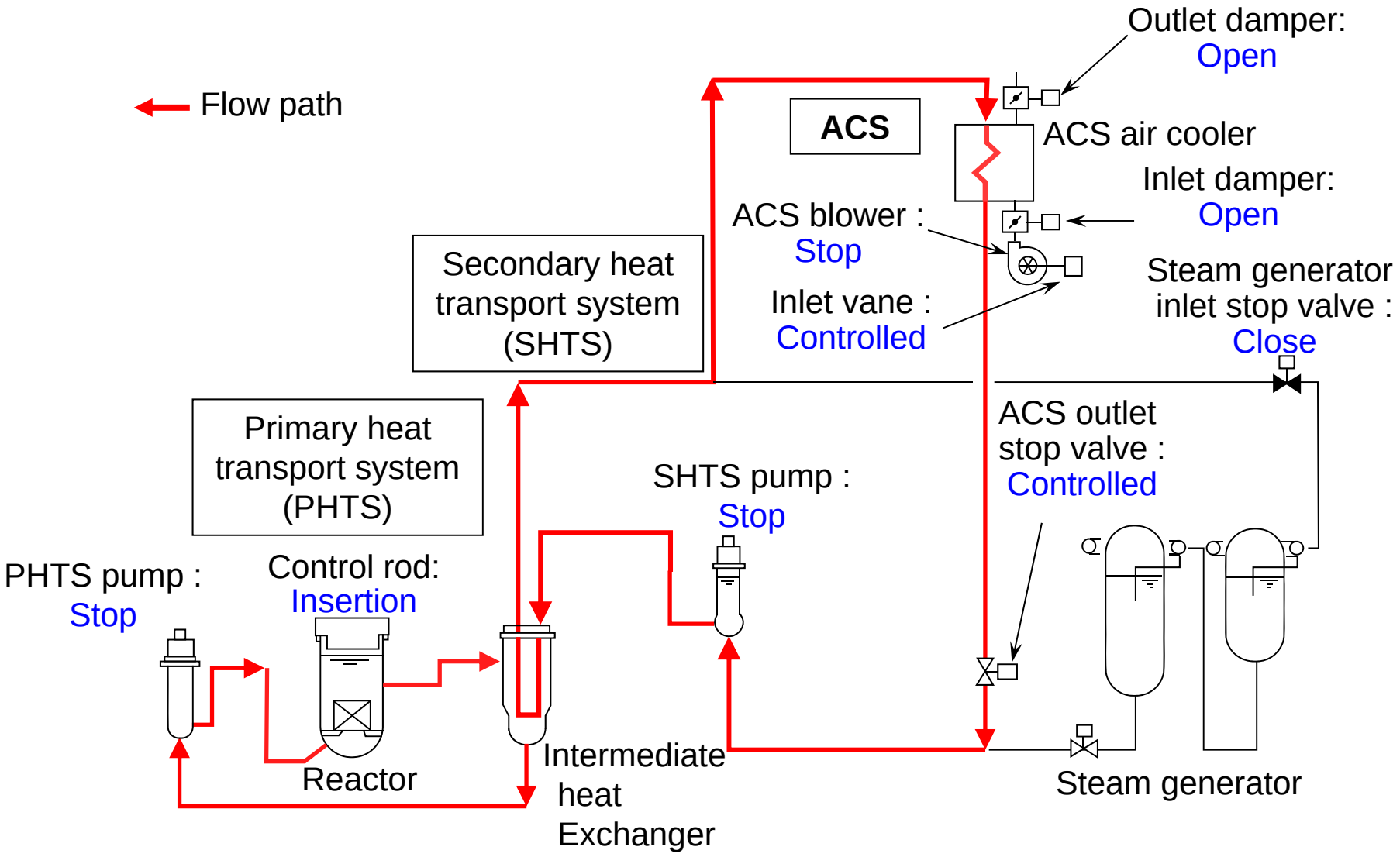
Auxiliary cooling system (ACS)

Air cooler (AC)

Outlet stop valve



Flow Path and State of Instruments in Natural Circulation



Conclusion

- Monju is a reactor which was applied with a safety philosophy anticipating the fourth generation power plant safety approach.
- The safety level of Monju is high, even if CDAs are considered.
- A natural circulation capability is very important in order to avoid a severe accident. JAEA will plan a natural circulation test in system startup tests of Monju.
- JAEA should make a continuous effort to enhance the safety capability of Monju.