Accident Tolerant Control Rod

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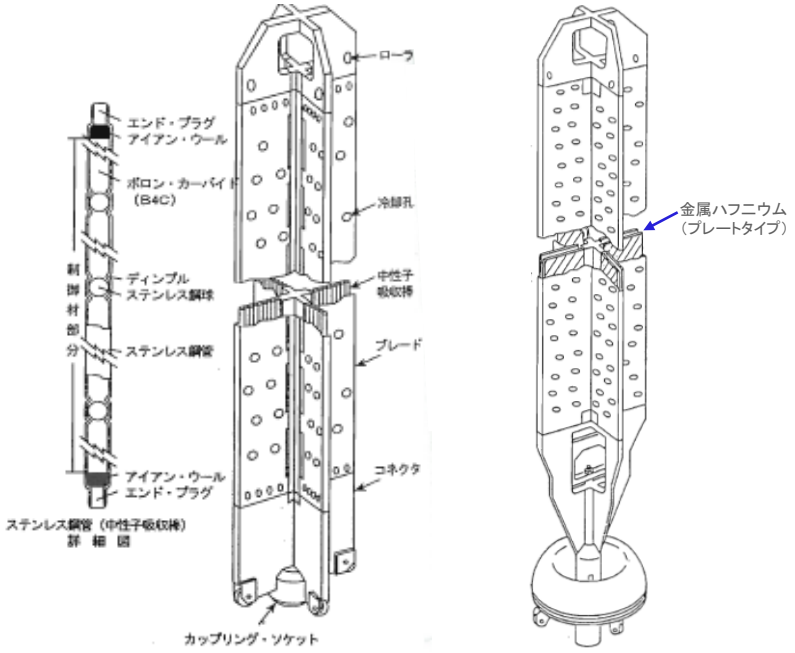
Current control rod in LWRs

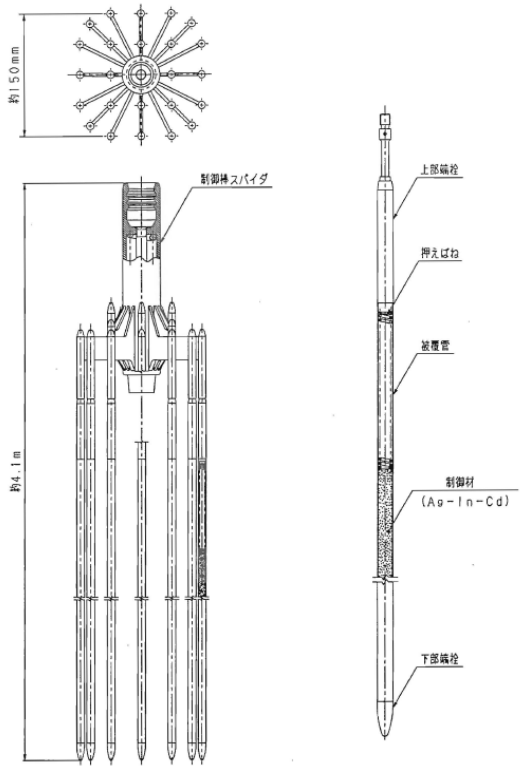
BWR: Boron carbide (B_4C) powder (with stainless steel cladding)
Metallic Hafnium (Hf) (with Stainless sheath)

PWR: Silver – Indium – Cadmium (Ag-In-Cd) alloy (with stainless steel cladding)
Boric acid (H_3BO_3) (= chemical shim)

Main structure material: Austenitic Steel

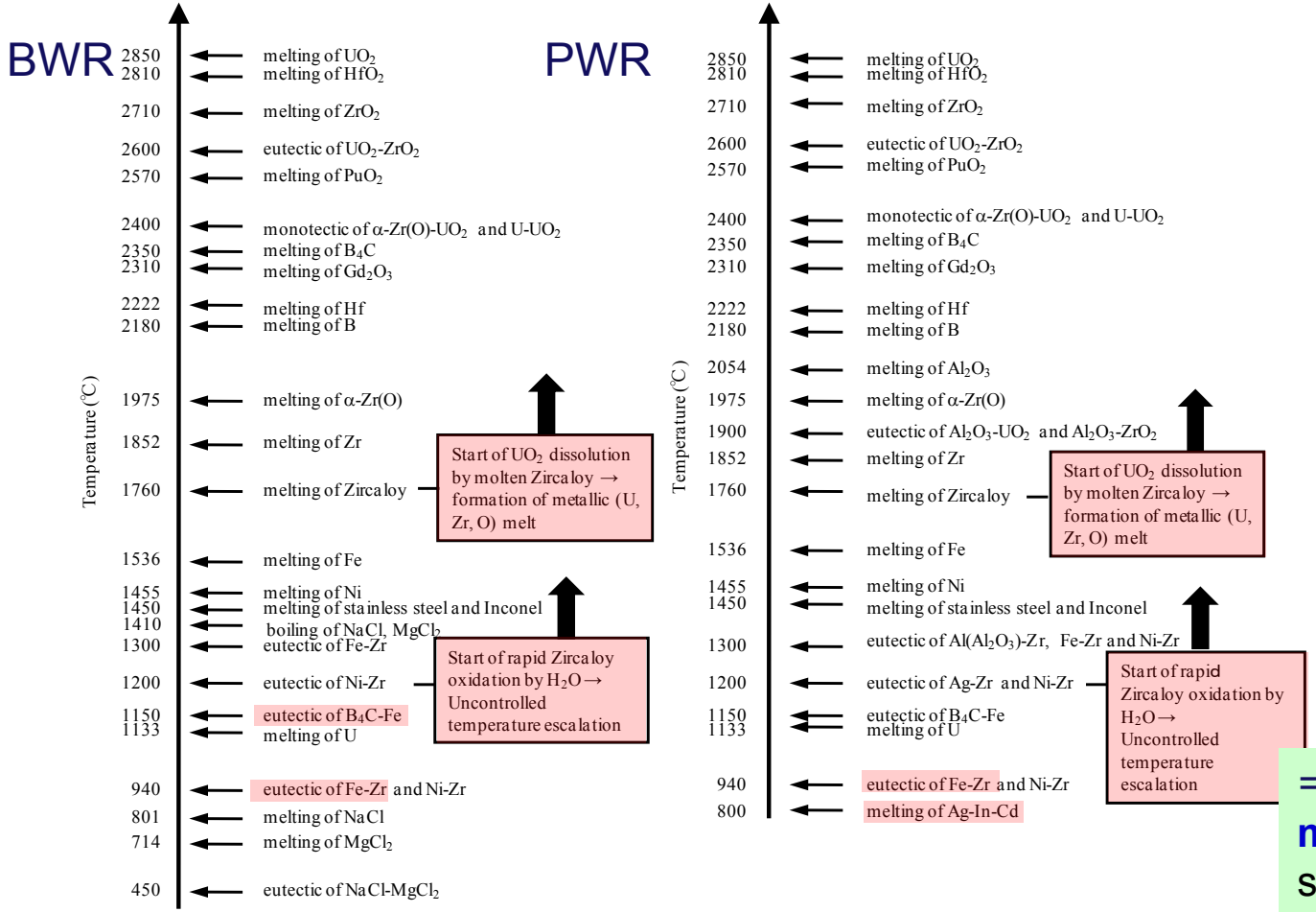


Control rod for BWRs



Control rod for PWRs

Behavior of current control rod at SA



Eutectic of Fe-Zr (940°C)
Eutectic of Fe-B_4C (1150°C)
Melting of Ag-In-Cd (800°C)

≦

Rapid Zircaloy oxidation by H_2O (~1200°C)
Melting of Zircaloy (1760°C)

⇒ **Control materials would melt and fall down** before severe core damage.
⇒ Injecting pure (sea) water into core would lead to **dilution of boric acid concentration.**

TMI-2 relocation

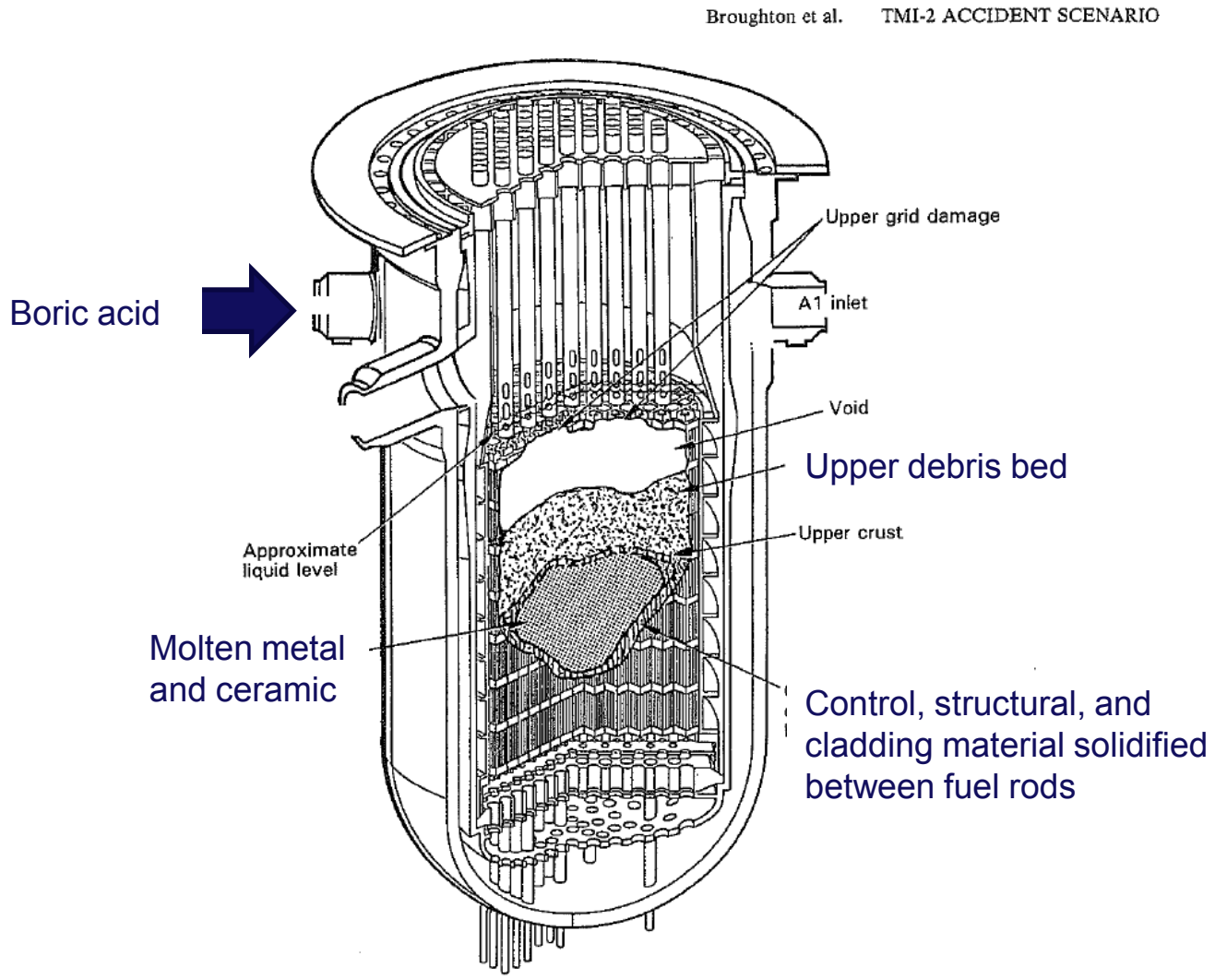


Fig. 12. Hypothesized configuration of core at 224 min (just prior to major core relocation).

Accident Tolerant Control rod (ATC)

1. To keep enough shutdown margin at sever accident.

Neutron absorber materials should have following properties:

1) Higher neutron absorption than current control rod

Gd, Sm, Eu , Dy etc.

2) Higher melting or eutectic point than ~1200°C where rapid Zircaloy oxidation occurs

Gd_2O_3, Sm_2O_3, Eu_2O_3, Dy_2O_3 etc.

3) High miscibility with molten fuel materials

Miscible with UO_2 = Gd_2O_3, HfO_2 etc.

2. To minimize the influence on the peration conditions of reactors, and To keep control rod worth for a long-term.

4) High neutron flux regions, loading current control rod（B_4C or Ag-In-Cd）.

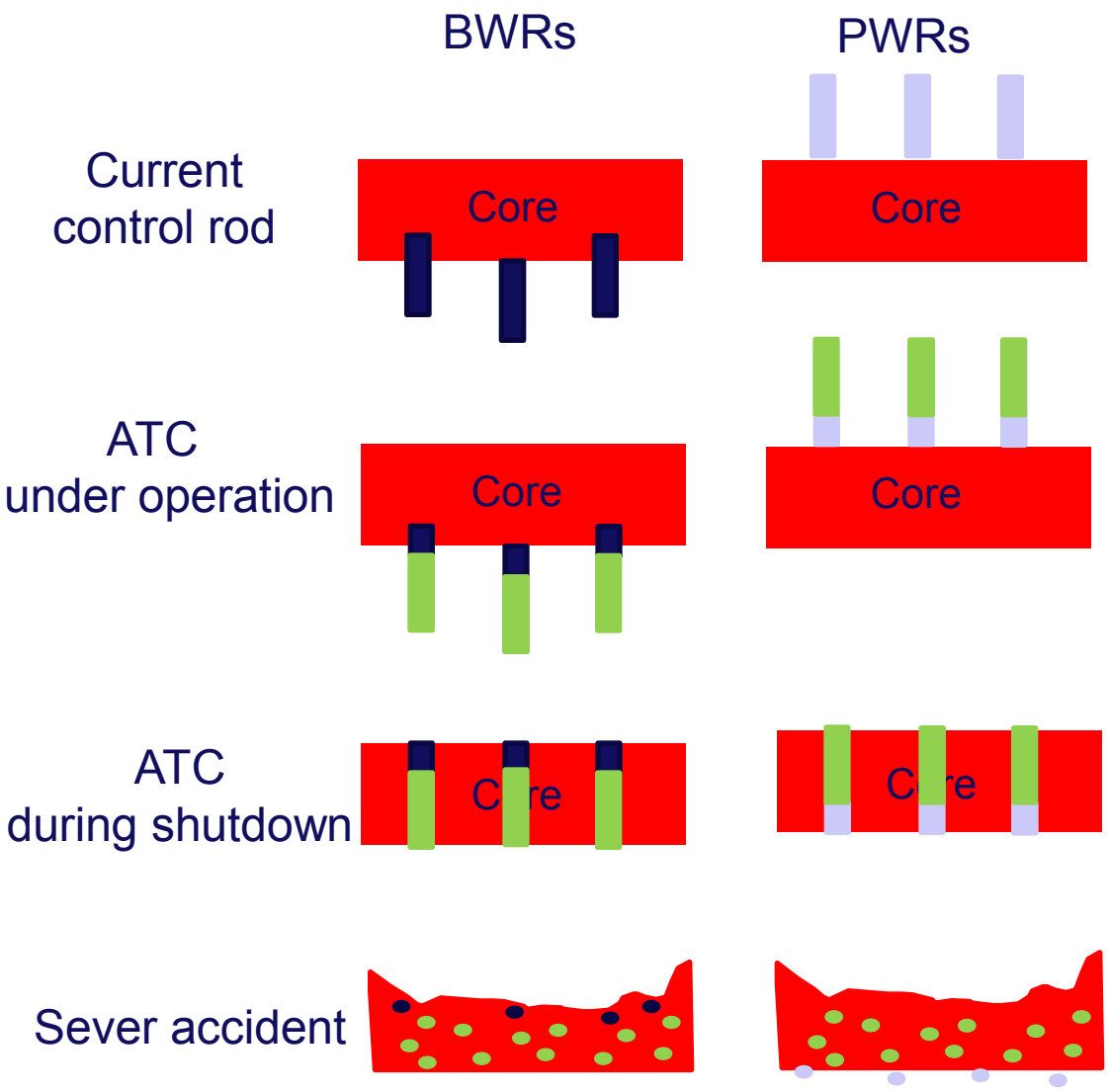
Mitigate the effect on reactor control in operation

5) Low flux regions, loading ATC materials.

Increase of shutdown margin & Long-term use of control rod

※ ATCR materials are reused.

Concept of ATC



- B_4C or Hf
- Ag-In-Cd
- Gd_2O_3 or Gd_2O_3-HfO_2 etc.

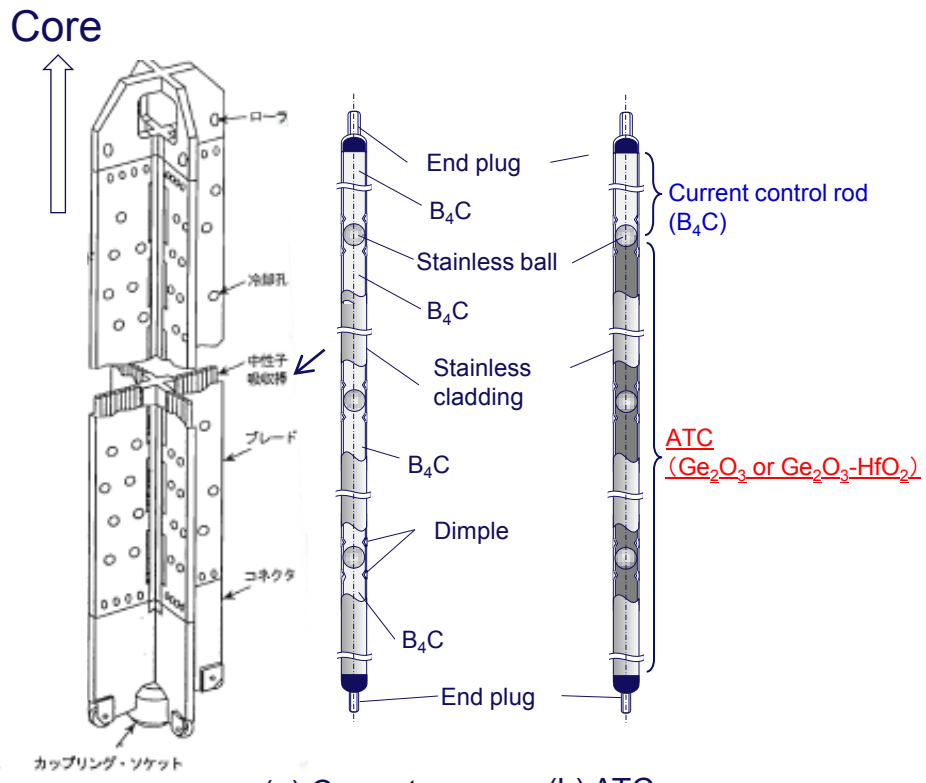
- Absorbers: Gd_2O_3 / HfO_2
-To keep burnable poison (Gd_2O_3) for a long-term
- To minimize the influence on reactor operation.
→ Vicinity of core: current materials

- Higher shutdown margin than current control rod
- Restrictive loss of burnable poison
→ Reusable

-Remaining in the core material at SA or overheating
→ Gd_2O_3 / HfO_2 would mix with core debris

Structure of ATC

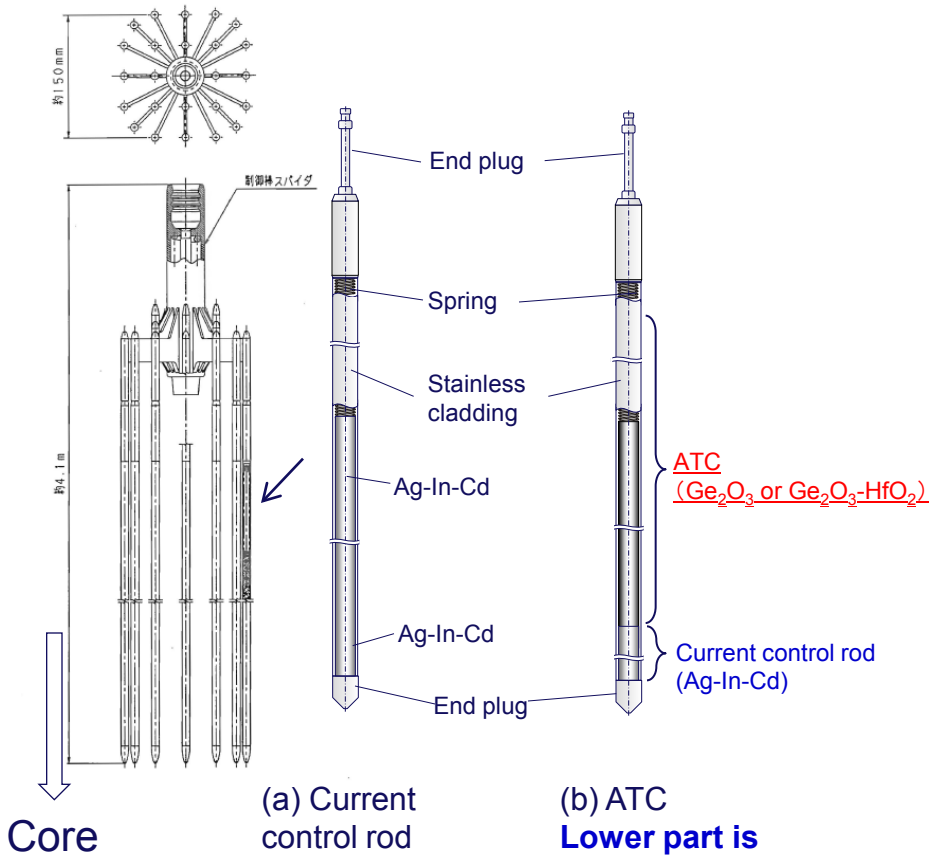
BWRs



(a) Current control rod

(b) ATC
Upper part is same as Current CR structure

PWRs



(a) Current control rod

(b) ATC
Lower part is same as Current CR structure

Future works

To improve the accident tolerance without significant effect on reactor control in operation, we will confirm

(1) Neutron absorption worth of ATC materials,
Gd_2O_3 or Gd_2O_3 - HfO_2

(2) Life time of ATC,
Loading position

(3) Melting behavior of ATC materials,
Compatibility with structural materials,
Gd_2O_3, Gd_2O_3 - HfO_2, Gd_2O_3 - Fe, Gd_2O_3 - Zr etc.

(4) Miscibility with molten core materials.
UO_2 - Gd_2O_3, UO_2 - HfO_2, ZrO_2 - Gd_2O_3 , Gd_2O_3 - Fe, etc.