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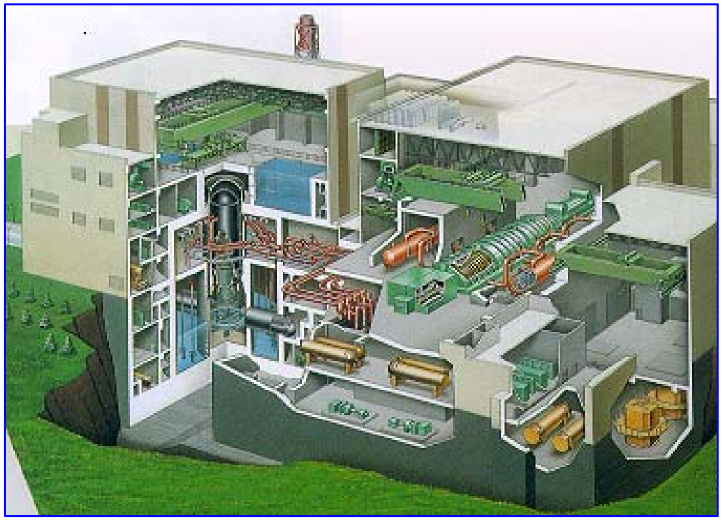
Safety Design Approaches of the ABWR for the Next Generation Innovative LWRs



INPRO Dialogue Forum on Nuclear Energy Innovations

February 2, 2010

T. Sato

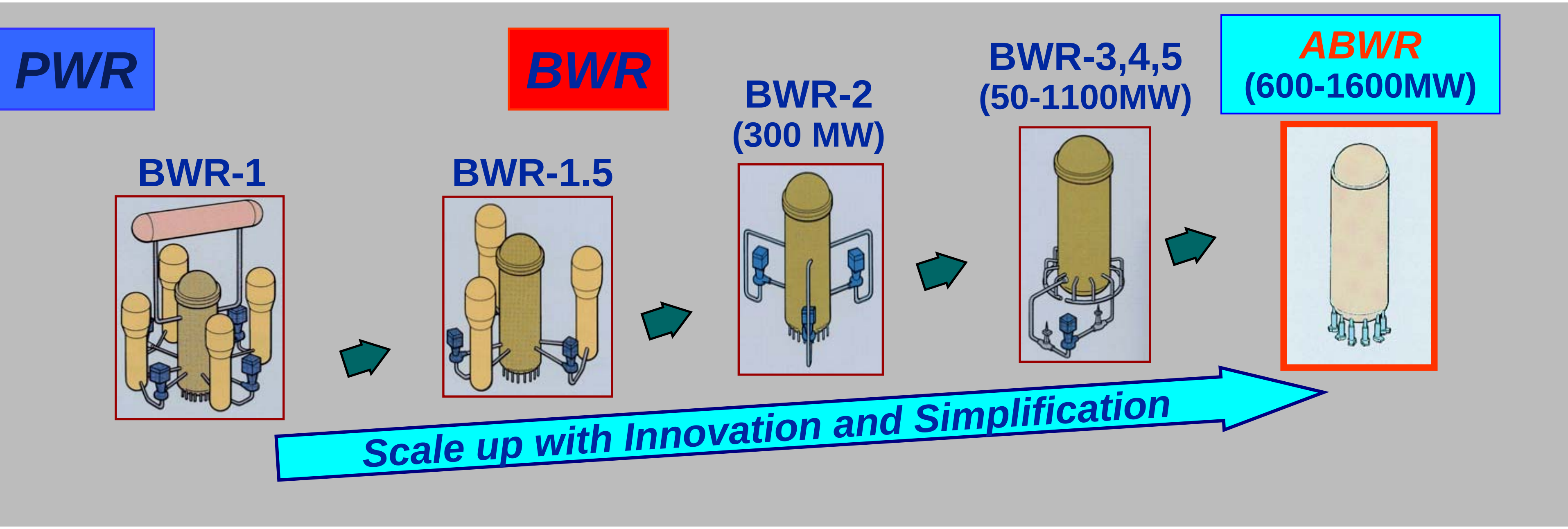
Toshiba Corporation

Basic Policy – Positive Cost Down

- **Improve safety and reduce plant total cost simultaneously**
  - **Reflect lessons learned, e.g., TMI2 accident, Browns Ferry ATWS event, while reducing cost.**
- **Consider a new innovative way to improve safety with less cost, that is Positive Cost Down.**
  - **Use simplification and innovation**
  - **Use PSA insights**
  - **Cut unnecessary cost and use it for risk dominant sequences**
- **Never pursue *minimum cost and minimum safety*, that is Negative Cost Down. It reaches to a mean plant concept.**

Primary System Innovation of BWR

BWR pursued scale up with certain Innovations and established a very Simplified Primary System.

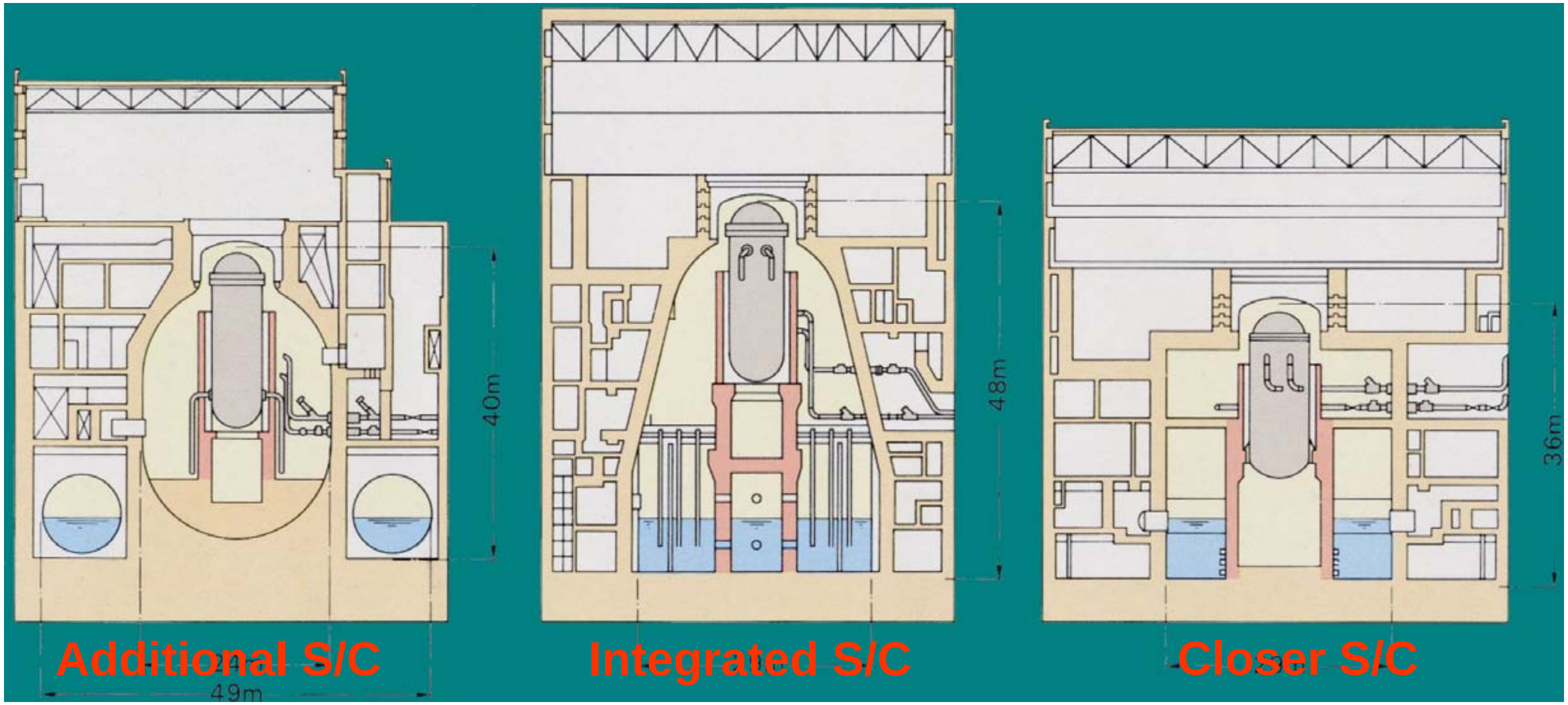


Now ABWR has No Large Pipe Break LOCA.

Simplification and innovation improve safety and reduce cost simultaneously.

Primary Containment Vessel Innovations

- **Self standing steel PCV**
  - Larger, taller, more expensive
  - Additional shield
  - Longer construction period
- **RCCV combined with R/B**
  - Smaller, Lower, less expensive
  - No additional shield
  - Enhanced seismic safety
  - 10 meter lower than Mark-II



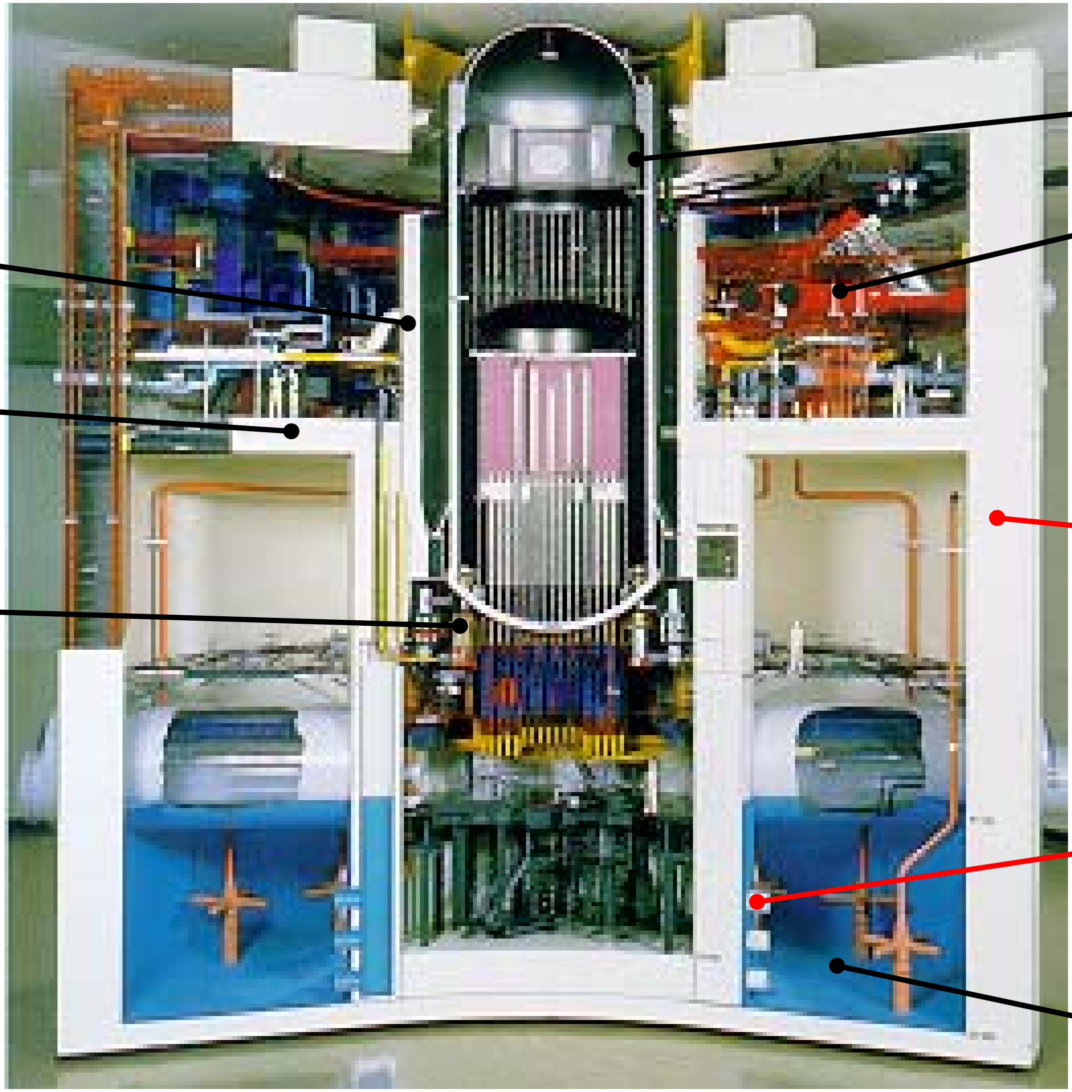
Mark-I
(1100 MWe class)

Mark-II
(1100 MWe class)

BWR

RCCV
(1350 MWe class)
ABWR

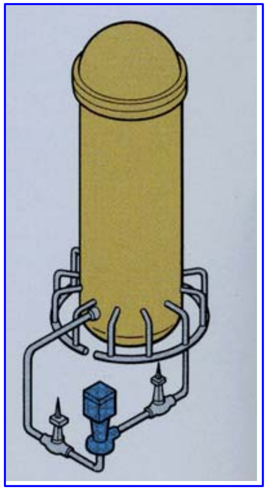
Optimized configuration of ABWR RCCV

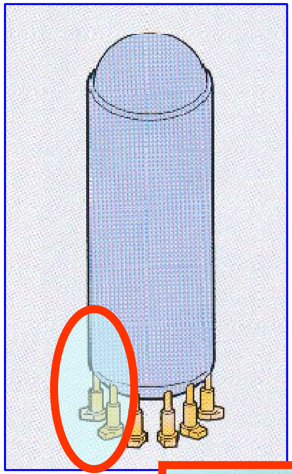


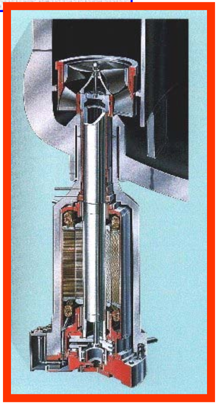
ABWR eliminated external loops and enabled a compact PCV.

State of the Art Technologies of ABWR

Reactor Internal Pump







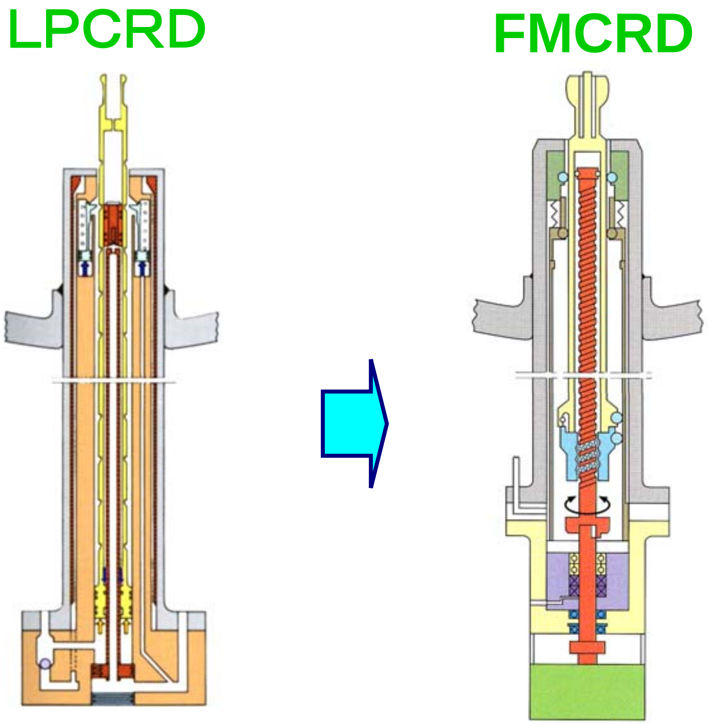
Elimination of recirculation piping

↓

Elimination of Large LOCA

- ***Improve safety** & economy*
- ***Reduce radiation exposure***

Fine Motion CRD



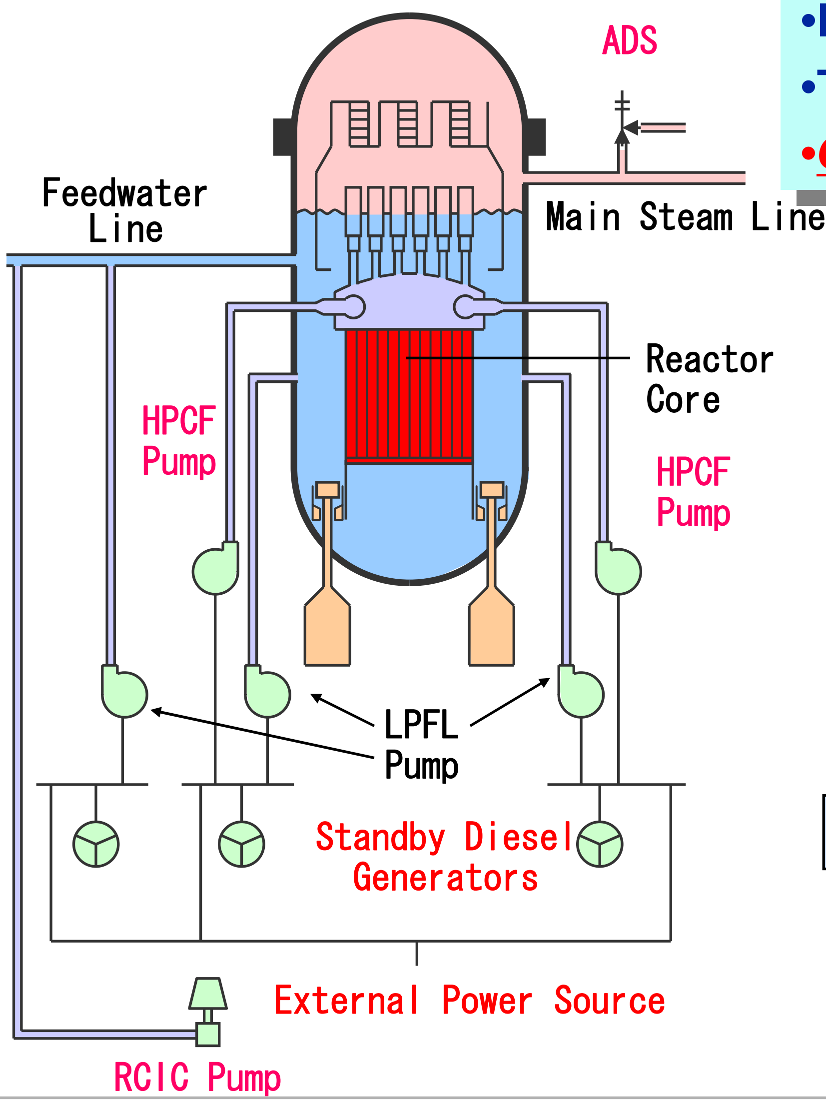
LPCRD — Control & Scram: Hydraulic

FMCRD — Control: Motor driven; Scram: Hydraulic (backup: motor run-in)

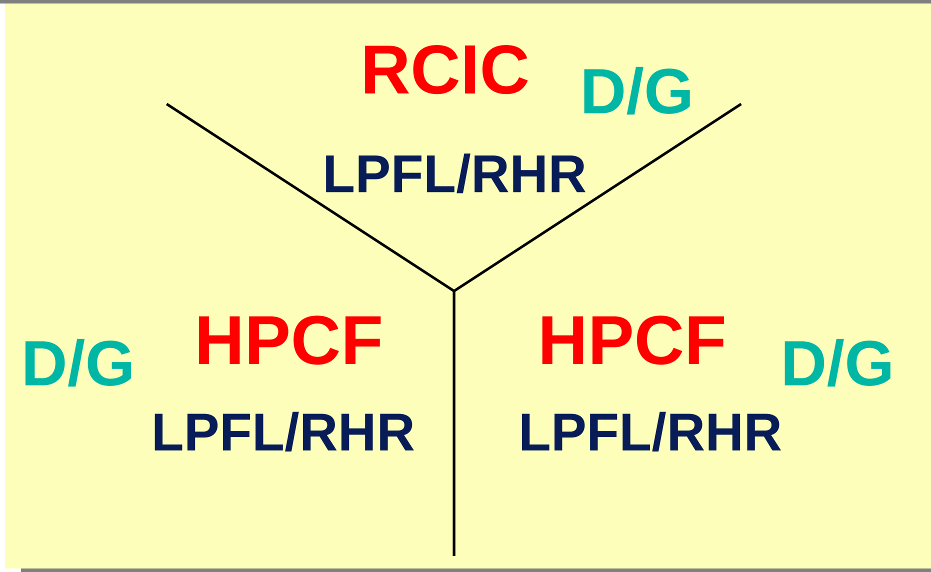
- ***Enhance safety & operability***
- ***Start-up time from 10 to 4 hours****

* From hot stand-by

Emergency Core Cooling System (ABWR)



- Complete ***3 Division HP ECCS***
- Designed for transients and small LOCA
- Total capacity is ***only 3408 t/h***.
- ***Only 6 pumps*** in total.



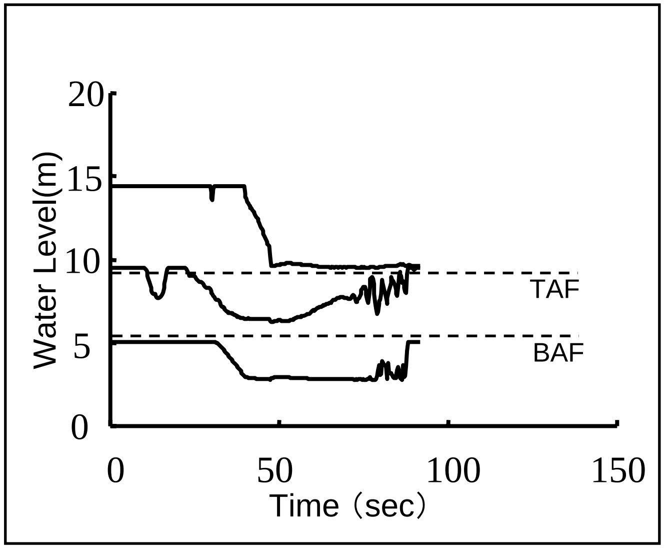
More than N-2 reliability for most events

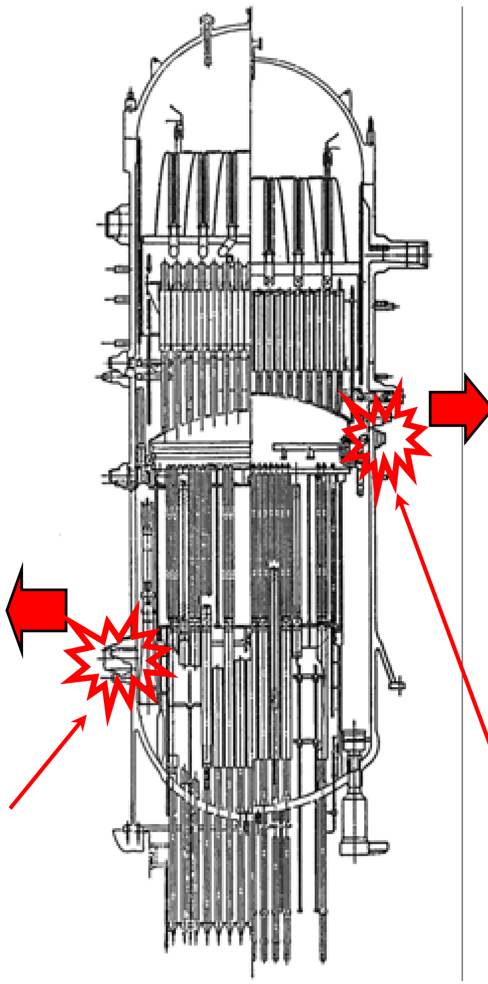
- N-1 for a DBA LOCA
- N-2 for dominant transients
- N-4 for any pipe break with AC
- N-5 for small LOCA with AC

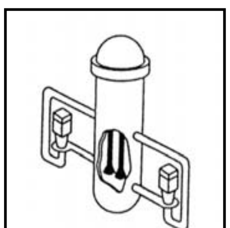
No Core Uncovery at a DBA LOCA

Elimination of large piping below core & 3 Division High Pressure ECCS ⇒ **No Core Uncovery for any pipe break + SF**

BWR





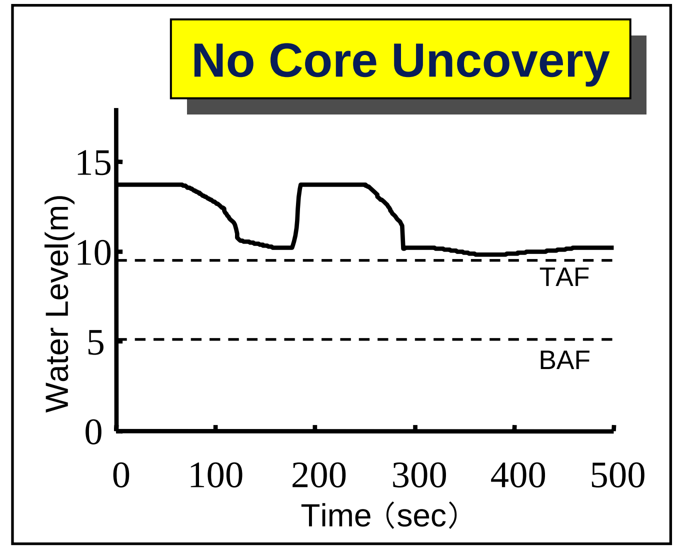


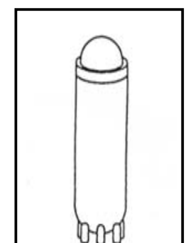
BWR-3,4,5

PLR Break

HPCF Break

ABWR





ABWR

Comparison of ECCS Capacity between ABWR and BWR5

TABLE : ECCS Capacity Comparison between ABWR and BWR5

	ABWR(1350MWe)	BWR5(1100MWe)
ECCS configuration	RCIC 182 t/h, LPFL/RHR 954 t/h; HPCS* 182/727 t/h, LPFL/RHR 954 t/h; HPCS* 182/727 t/h, LPFL/RHR 954 t/h	RCIC 136 t/h; HPCS 375/1419 t/h; LPCS 1419 t/h, LPCI/RHR 1605 t/h; LPCI 1605 t/h, LPCI/RHR 1605 t/h
HPCS	2 × 182/727 t/h	375/1419 t/h
LPCI/RHR Pump Hx	3 × 954 t/h 3 × 50%	2 × 1605 t/h 2 × 100%
LPCS	Eliminated	1419 t/h × 1
LPCI	Eliminated	1605 t/h × 1

Redundancy of HP ECCS is increased.

Redundancy of RHR is increased.

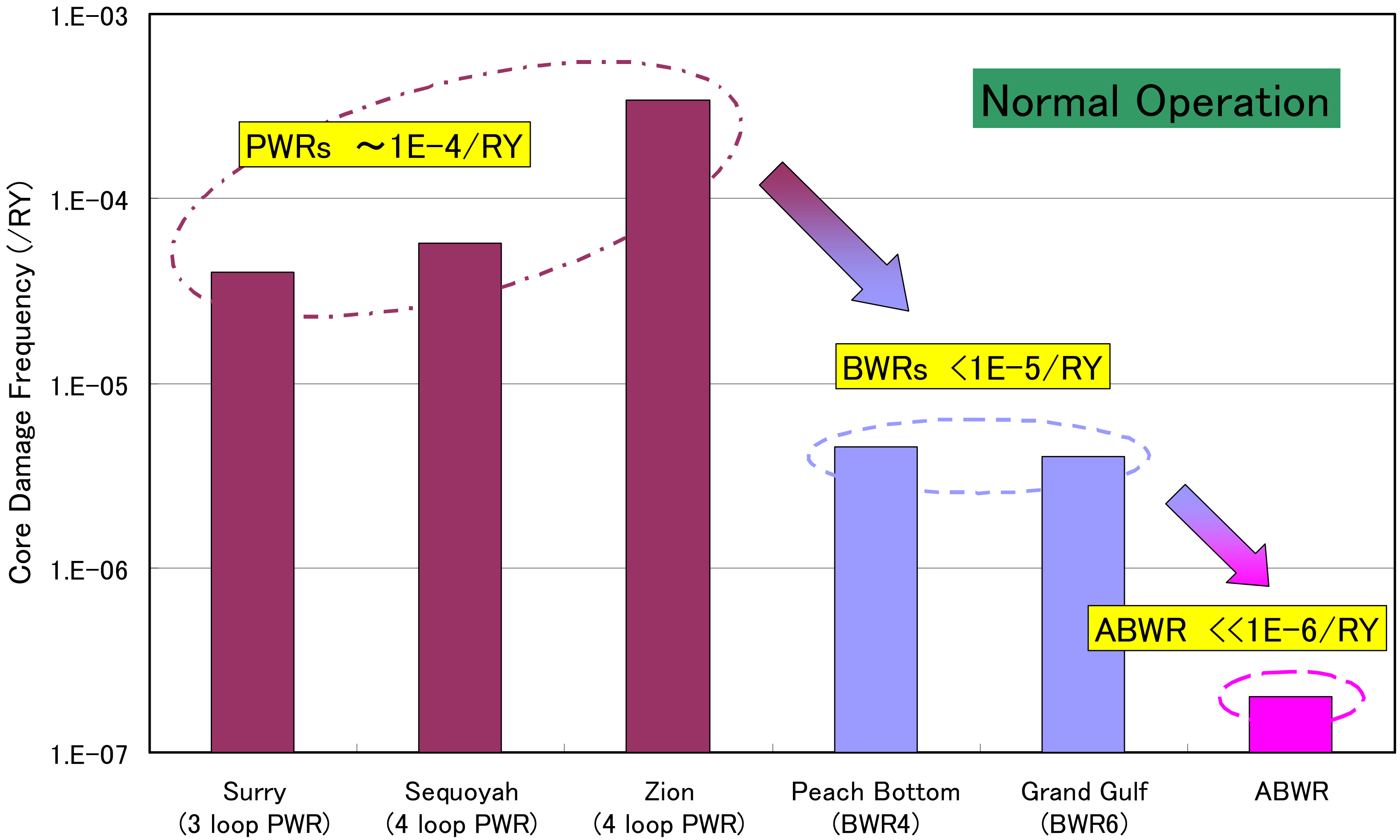
NUCLEAR TECHNOLOGY VOL. 99 JULY 1992

* Later changed to HPCF.

Ref.) NUCLEAR TECHNOLOGY Vol.99 JULY 1992 P.22-35

Large reduction of the ECCS Pump Capacity (eg. Low Pressure Capacity was reduced to 60%.)

Core Damage Frequency for Internal Events (The U.S. Evaluations)



Ref.) US ABWR:SSAR
Others:NUREG-1150

Safety System Comparison from PSA Insights

Plant	PWR	BWR/4	BWR/6	US ABWR
Makeup (transient)	3 Aux. FW	HPCI + RCIC	HPCS + RCIC	2 HPCF + RCIC
Heat removal	2 RHR	2 RHR Hx (4 pumps)	2 RHR	3 RHR
Manual ECCS Switchover	RWST to sump	Not necessary	Not necessary	Not necessary
Emergency Power	2 DG	2 DG + 2 shared DG	3 DG	3 DG + Alternate AC
Core makeup at SBO	none	HPCI + RCIC	RCIC	RCIC
Reactor Shutdown	Gravity SCRAM + Boron Injection	Hydraulic SCRAM + SLC	Hydraulic SCRAM + SLC	Hydraulic SCRAM + CR Motor run-in + SLC

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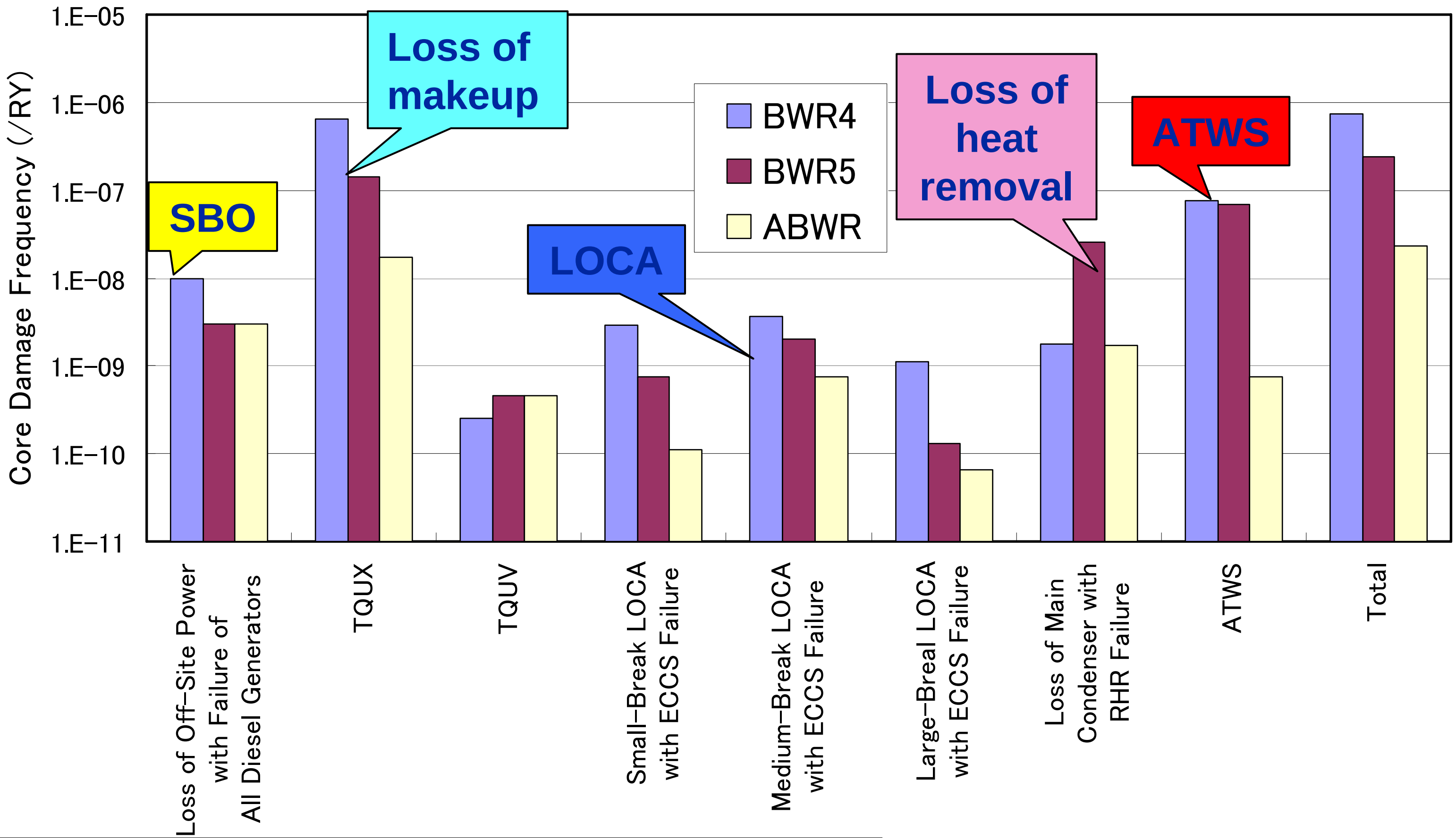
Comparison of CDF for Japanese BWRs

Internal Event (Normal Operation)



CDF is dominated by transient + multiple failures. LOCA is not dominant in BWR.

Ref.) NUCLEAR TECHNOLOGY Vol.99 JULY 1992 P.22-35

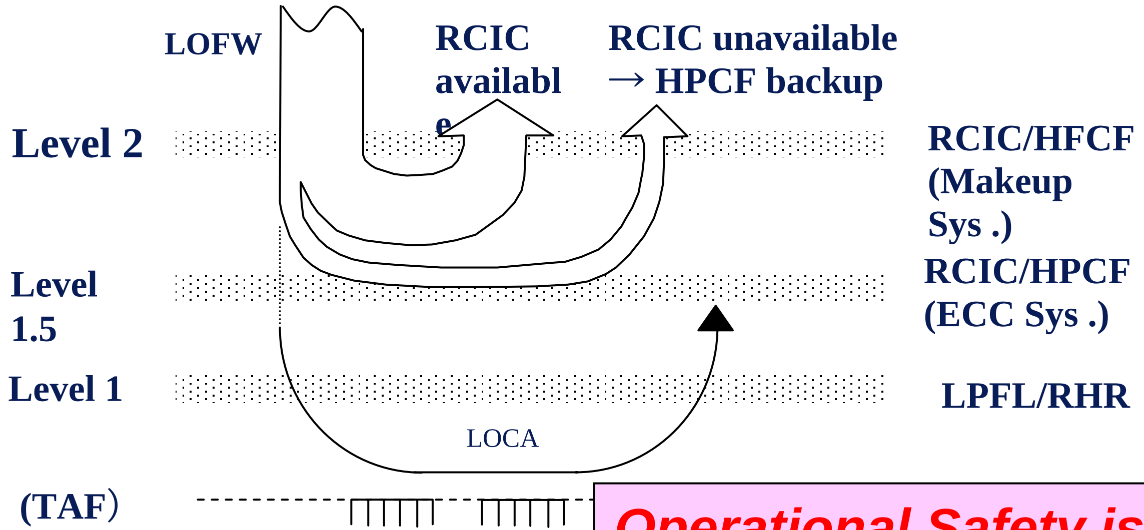
Safety Enhancement from PSA Insights

- CDF is dominated by transient rather than LOCA in BWR
  - Loss of makeup
  - Loss of heat removal
  - Station blackout
  - ATWS
- *Redundancy and diversity are enhanced* against those events.
  - However, *capacity of ECCS is rather much reduced*.

	BWR/4	ABWR
Makeup (HP)	**HPCI + RCIC**	2HPCF + RCIC
Heat Removal	**2RHR**	3RHR
Emergency Power	**2DG**	3DG
Shutdown	**Hydraulic**	Hydraulic + Motor run-in
ECCS capacity	**13,218 (m^3/h)**	3,408 (m^3/h)

Operational Safety of ECCS

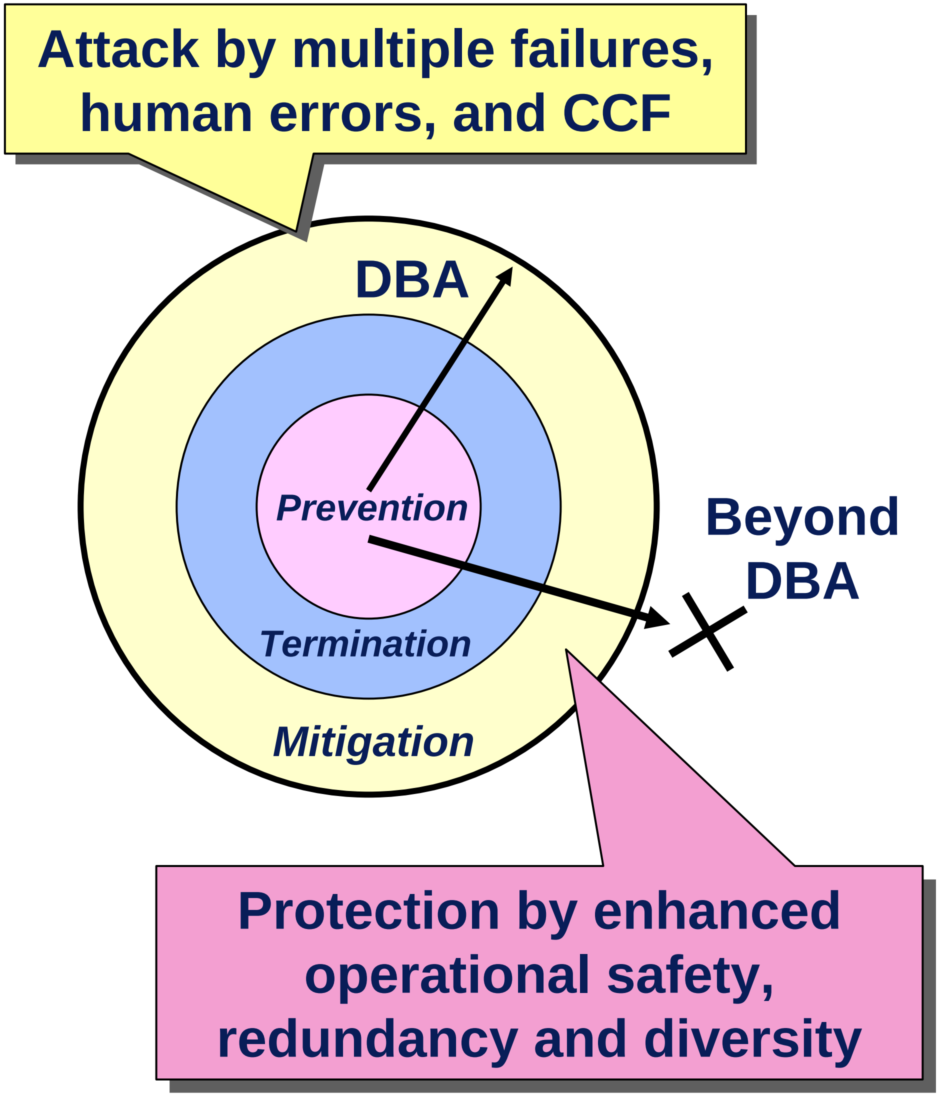
- Initiation levels of the high pressure ECCS are separated in ABWR.
  - RCIC starts at Level 2 as makeup system.
  - HPCF starts at Level 1.5 as ECCS.
- In BWR4 and 5 HPCI and HPCS start at Level 2 with RCIC and operators tend to stop HPCI and HPCS when a loss of FW occurs.
- In ABWR operators need not stop HPCF because only RCIC initiates at a loss of FW.
- If RCIC fails then HPCFs back up and initiate at Level 1.5. Operators need not and must not stop HPCFs if initiate.



ECCS Level Separation moderates operator stress at a transient and *minimize operator errors*.

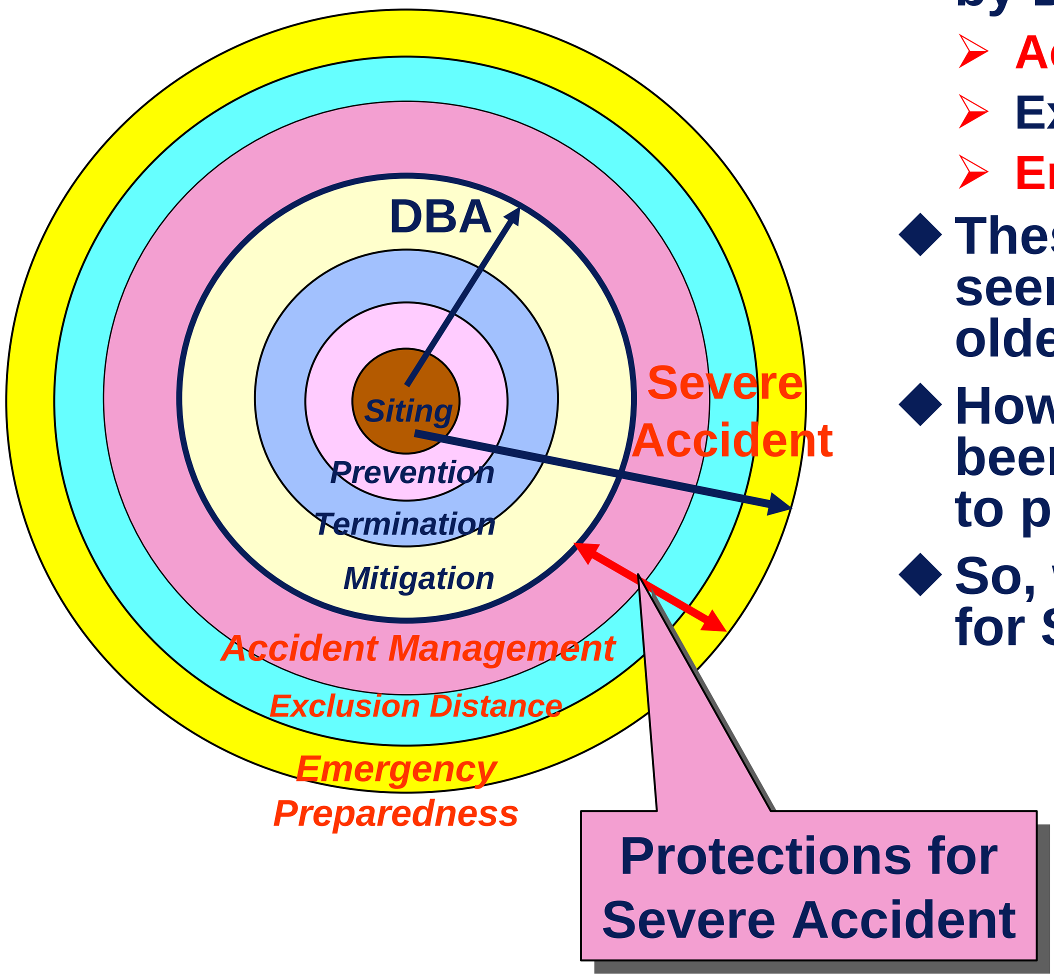
Operational Safety is **not counted in PSA. However, it is also *important to reduce risk*.**

Enhanced Defense in Depth of ABWR



- **ABWR enhanced each level of Defense in Depth.**
- **Prevention**
  - **Eliminated a large LOCA by RIP**
  - **Improved operational safety by L1.5 for HPCF**
- **Termination**
  - **Diverse CR insertion by FMCRD motor run-in**
- **Mitigation**
  - **Enhanced redundancy for core make up by 6 independent ECCS pumps**
  - **Enhanced redundancy for PCV cooling by 3 division RHR**
- **ABWR's three levels of safety are very robust. No SA is expected breaking through the three levels of safety.**
  - **CDF is less than 10^{-7}/ry in Japan**

Defense in Depth after Chernobyl 3 Accident

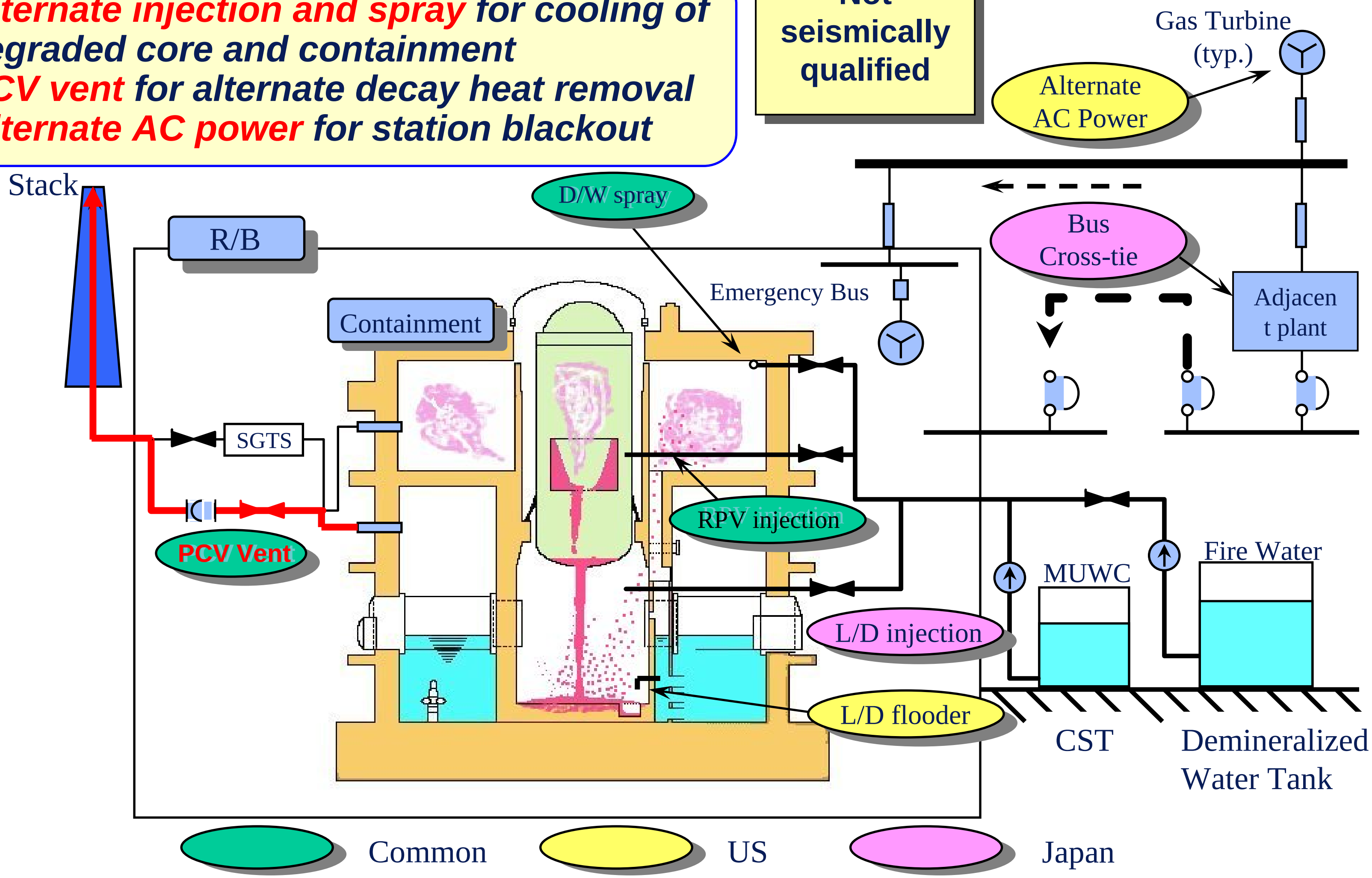


- **SA required additional three levels of safety (proposed by Dr. K. Sato)**
  - **Accident management**
  - **Exclusion Distance**
  - **Emergency Preparedness**
- **These seven levels of safety seem valid for conventional older plant.**
- **However, ABWR safety has been intentionally enhanced to prevent SA.**
- **So, what is the true reason for SA in ABWR?**

Add-on AM Measures of ABWR

- ***Alternate injection and spray*** ***for cooling of degraded core and containment***
- ***PCV vent*** ***for alternate decay heat removal***
- ***Alternate AC power*** ***for station blackout***

Not seismically qualified



Chernobyl 3 accident occurred after ABWR development. – AM countermeasures are added exactly the same way as the conventional BWR plants. PCV venting is the main feature.

Residual Risks of External Events

- ABWR enhanced redundancy and diversity.
  - ABWR is intentionally designed to have N-2 reliability for dominant transient sequences.
- ABWR also improved operational safety to prevent human errors. Therefore, ABWR's three levels of safety are extremely robust.
- There is no residual risk coming from internal events for ABWR. ABWR is very safe in itself.
  - There is no chance for accident management and emergency preparedness to be actually exercised.
- Potential Residual Risks exist only in external events, including
  - Extremely Severe Earthquake far beyond design basis
  - Extremely Strong Cyclone, Hurricane, and Typhoon
  - Extremely Large Tsunami
  - Large Airplane Crash
  - Intentional Attack by Terror
- For the external events accident management and emergency preparedness are not reliable. The ground, roads, infrastructures are severely damaged. The utility systems for accident management are not seismically qualified and useless.
- Loss of heat sink caused by SBO, loss of all RCW, and loss of all RSW are the most probable scenarios for the residual risks.
- Adding more active systems, like four division D/G or four division RCW/RSW never eliminates the residual risks because external events constitute severe common causes.

Basic Policy 1 – Improve Safety

- **Reflect lessons learned after the ABWR that are not included in the safety design yet.**
  - **Chernobyl 3 accident – Provide SA proof safety design.**
    - ✓ Three day grace period for SA without any AM
    - ✓ No containment failure for SA (CCFP~0)
    - ✓ No over pressurization beyond Pd
    - ✓ No Evacuation even for SA caused by a giant earthquake
  - **9.11 terror – Provide protection against a large airplane crash *for standard design without cost increase*.**
  - **K site earthquake – Eliminate the residual risk of a giant earthquake that is far beyond the design basis.**

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Basic Policy 2 – Positive Cost Down

- **Any safety improvement in the Basic Policy 1 must be established in accordance with total plant cost reduction.**
- **Use new innovative measures to improve safety with less cost.**
  - **Use passive safety systems**
    - ✓ IC for three day seismic grace period
    - ✓ PCCS for no containment failure and three day grace period
  - **New containment design for No Evacuation Plant**
    - ✓ Provide debris retention method to prevent basemat melt through
    - ✓ Provide protection for hydrogen detonation and overpressurization.
  - **Protection for a large airplane crash as standard design**

Examples of In-Depth Hybrid Safety (IDHS)

HPFL | HPFL
LPFL/RHR | LPFL/RHR
DG | DG

+

IC
GDCS
PCCS

Active for DBA ↔ ***Passive for SA***

See Water UHS **Diversity** **Atmosphere UHS**

In-Depth and Independent

IDHS for N-1 design

HPFL
LPFL/RHR
DG

HPFL | HPFL
LPFL/RHR | LPFL/RHR
DG | DG

+

IC
GDCS
PCCS

Active for DBA ↔ ***Passive for SA***

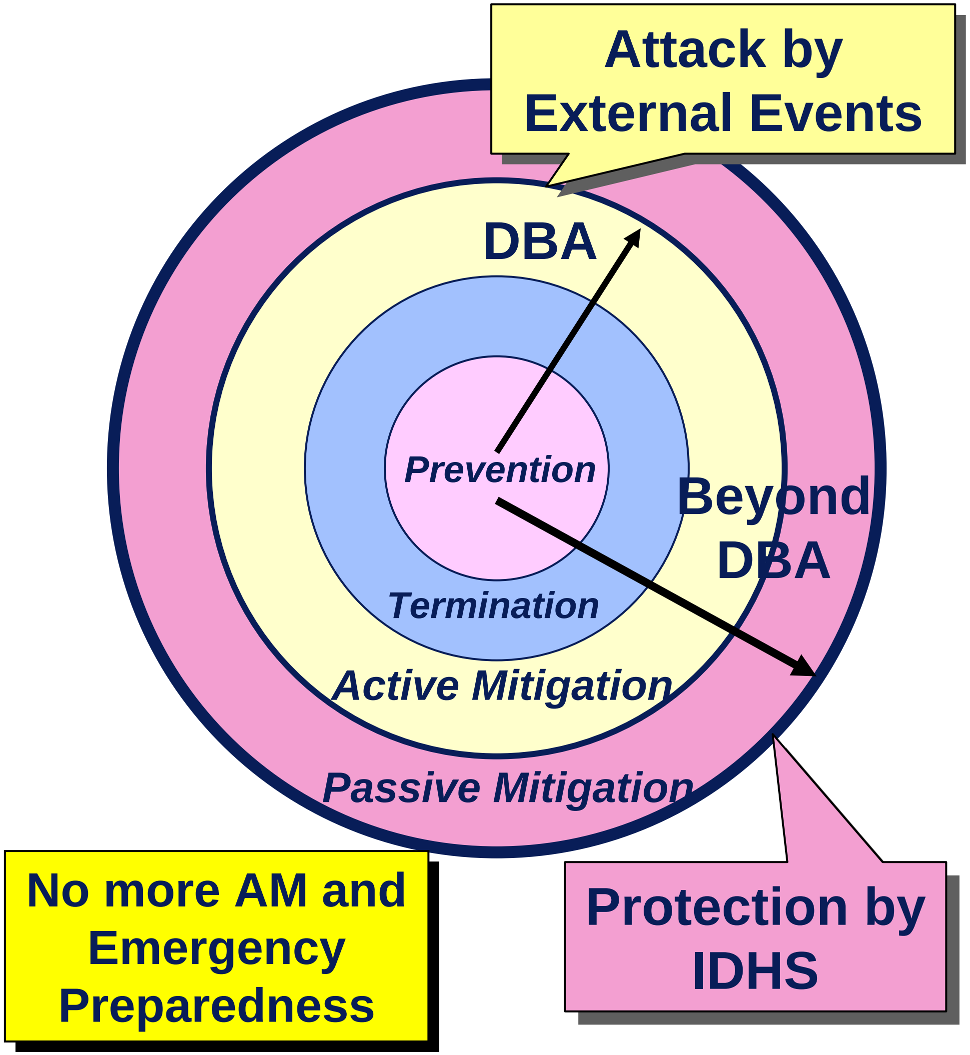
See Water UHS **Diversity** **Atmosphere UHS**

In-Depth and Independent

IDHS for Complete N-2 design

Diversity provided by the IDHS between active and passive systems only survives severe external events **by** ***assuring diverse paths to the UHS.***

Defense in Depth for Residual Risks



- **In-Depth Hybrid Safety provides an additional reliable protection for residual risks coming from external events.**
- **Diversity provided by the IDHS between active and passive only survives a severe attack by external events.**

Four Levels of Safety protect our Future ABWR.

Summary

- The current ABWR has established a very low CDF and there is no residual risk for internal events.
- For the future ABWR the following targets should be implemented in accordance with total plant cost reduction;
  - SA proof safety design
  - Three day grace period at SA and no containment failure
  - No Evacuation Plant
  - Three day seismic grace period
  - A large airplane crash protection
- Use passive safety systems and new containment design to attain these targets.
- Seismic risks are only the very low residual risks for the ABWR as long as constructed in Japan.
- All the residual risks are to be removed in the future ABWR even constructed all over the world.
- Future ABWR can be protected by IDHS or four levels of safety against extremely severe external events eliminating the residual risks completely.