Evaluation of Technological Appropriateness of the Implemented Accident Management Measures for BWR by Level 1 and Level 2 PSA Methods

- Examination of Effectiveness of AMs for BWRs in Japan -

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Background and Objectives

Date	Major Events for AM
After TMI-2	The electric utilities in Japan have implemented their own measures for preventing the occurrence of severe accidents and for mitigating their consequence.
May, 1992	The Nuclear Safety Commission (NSC) in Japan issued a decision statement "Accident Management as a Countermeasure for Severe Accidents at LWRs", which strongly encourages the utilities to prepare plans for effective AM.
July, 1992	The MITI requested electric utilities to prepare the AM, clarifying that it would not take any specific statutory requirements for design or operation of NPP.
Mar., 1994	The electric utilities submitted accident management study reports on each installation to the MITI. The MITI reviewed the technical adequacy of the reports with technical support by the INS/NUPEC.
Oct., 1994	The MITI presented to the NSC a general study report entitled "Preparation of AM for Light Water Type Nuclear Power Plants", in which the MITI urged electric utilities to implement accident management with an relevant operation manual by around the year 2000. The industries have been preparing the implementation of AMs to all PWRs and BWRs by February in 2002.
May, 2001	The "Review Programs of Accident Management" by METI (former MITI) started with technical supports by the INS/NUPEC.

In the present study,

effectiveness of Preventive & Mitigative AMs for BWRs with were examined:

- Prevention of Core Damage
  (Core Damage Frequency : Level 1 PSA)
- Mitigation of Accident Progression
  (Containment Failure Frequency : Level 2 PSA)

for BWR-3 with Mark-I, BWR-4 with Mark-I, BWR-5 with Mark-II and ABWR in Japan.

These 4 types of BWR cover all the BWRs in Japan.

BWR-2&3 Mark-I	3
BWR-4 Mark-I	8
BWR-5 Mark-IE, Mark-II, Mark-IIE	15
ABWR	2

Severe Accident Management for BWR in Japan

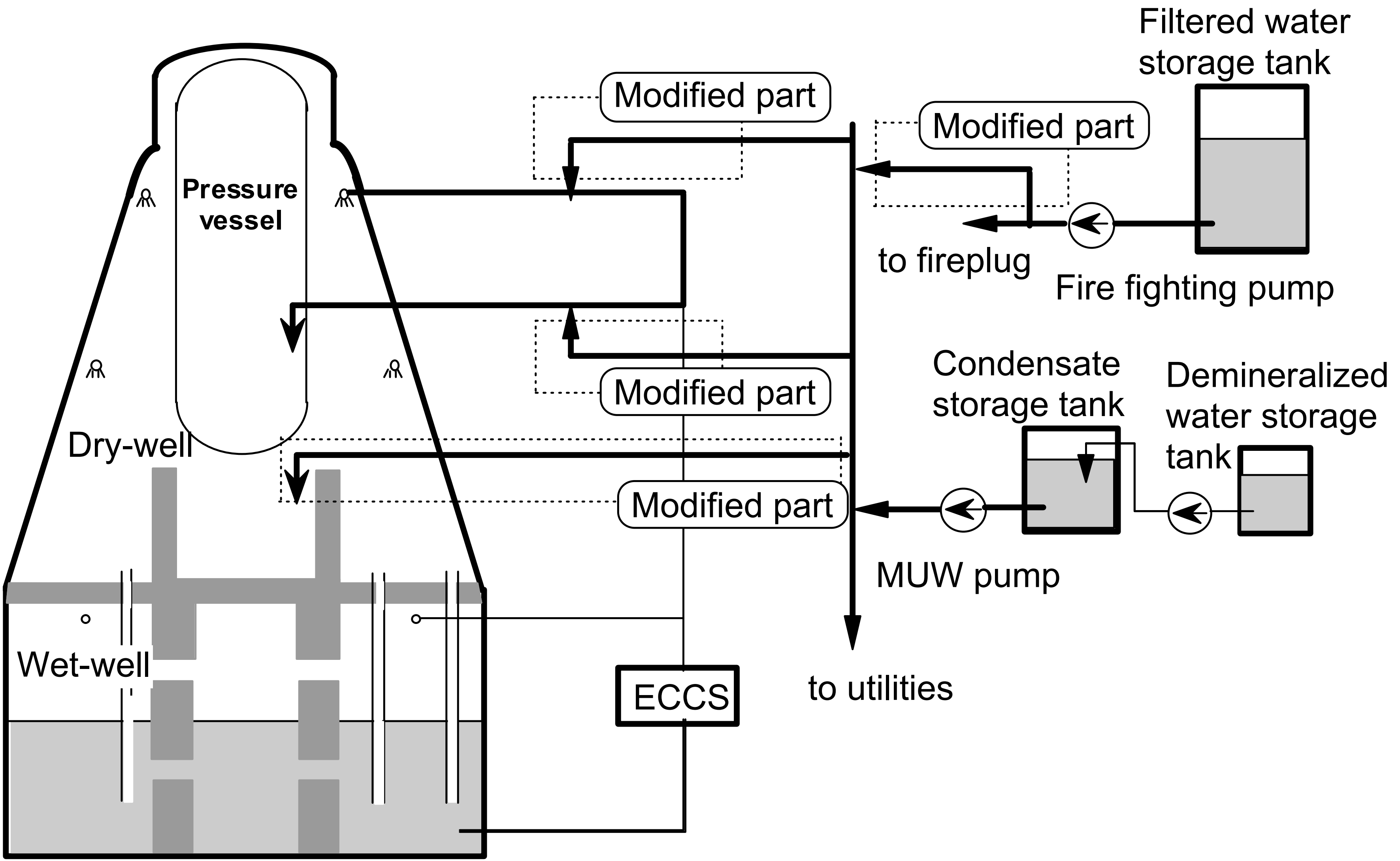
Preventive AMs

AM Functions	Equipment & Systems	Accident Sequences	Comments
Reactor Scram	- ARI activation with signals for high pressure of the RCS, or low liquid level - RPT activation with the same signals above	transient without scram (TC)	New signals are independent of conventional scram & ECCS signals. These systems have already implemented to ABWR in the design stage.
De-pressurization	- The automated depressurization system (ADS) is activated by a signal with low liquid level of the reactor vessel.	transient with failure to depressurization (TQUX)	This AM is not applied to BWR-3 and ABWR. BWR-3: Isolation Condenser is implemented. ABWR: high pressure ECCSs are already reinforced.
Alternative Water Injection	- Use of the make-up line. - Water supply from the fire protection system	transient with loss of ECCS injection (TQUV)	
Alternative Heat Removal	- The containment hardened vent	transient with loss of decay heat removal (TW)	
Supply AC Power	- Accommodation of 6.9kV & 480V from adjacent plant - power supply from emergency diesel generator (EDG)	loss of all AC power (TB)	This AM is applied to the specified plant.

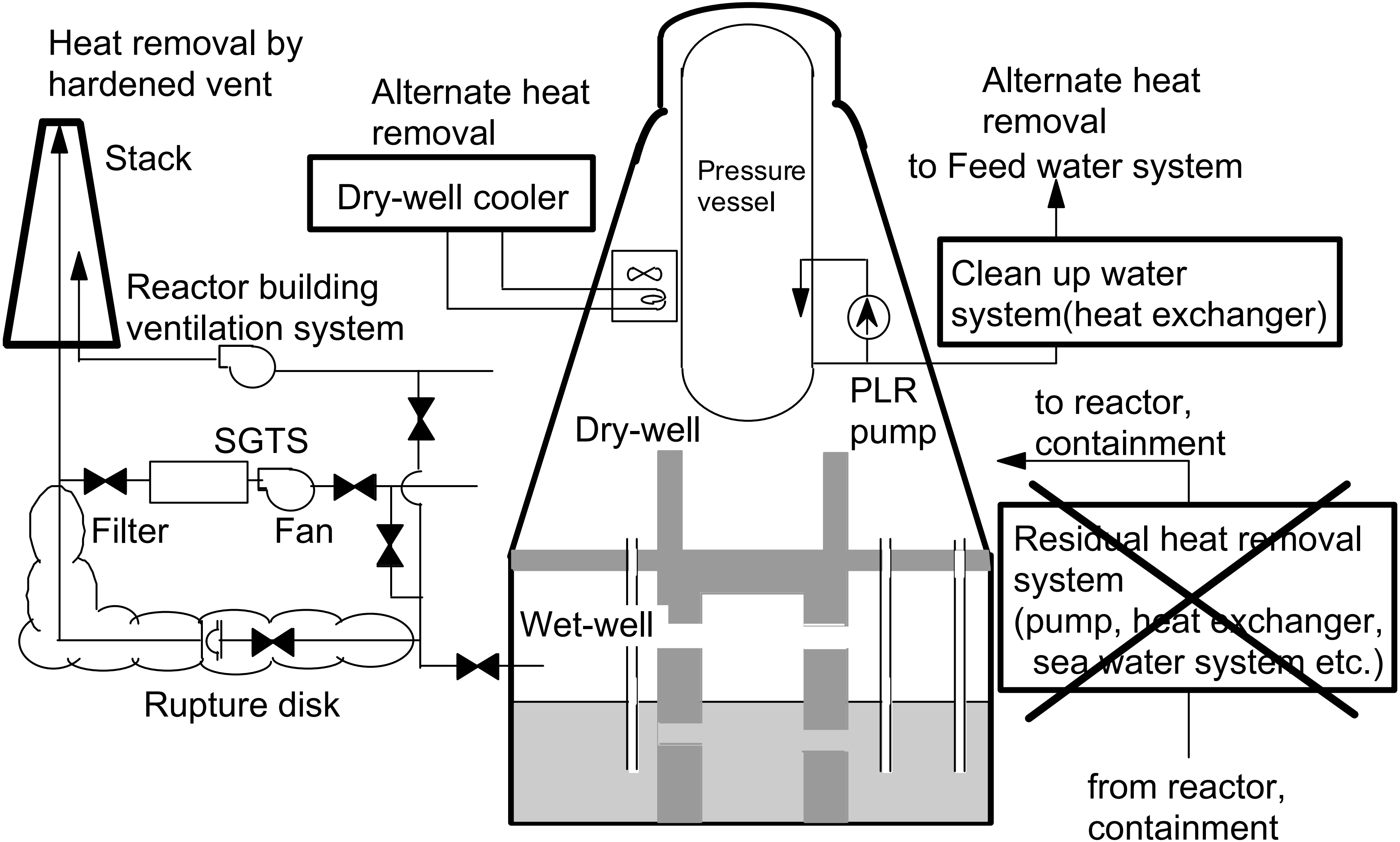
Mitigative AMs

AM Functions	Equipment & Systems	Accident Sequences
Depressurization (same as prevention)	- The automated depressurization system (ADS) is activated by a signal with low liquid level of the reactor vessel.	transient with failure to depressurization (TQUX)
Alternative Water Injection	- Use of the make-up line. - Water supply from the fire protection system	transient with loss of ECCS injection (TQUV) transient with failure to depressurization (TQUX) loss of all AC power (TB, TBU) LOCA with loss of ECCS injection (AE)
Alternative Water Injection to Containment	- Use of the make-up line. - Water supply from the fire protection system	same as above
Alternative Heat Removal	- Use of the drywell cooler, and use of the heat exchanger in the make-up line. - Recovery of the RHR system - The containment hardened vent	same as above
Supply AC Power	- Accommodation of 6.9kV & 480V from adjacent plant - power supply from emergency diesel generator (EDG)	loss of all AC power (TB, TBU)

Alternative water injection

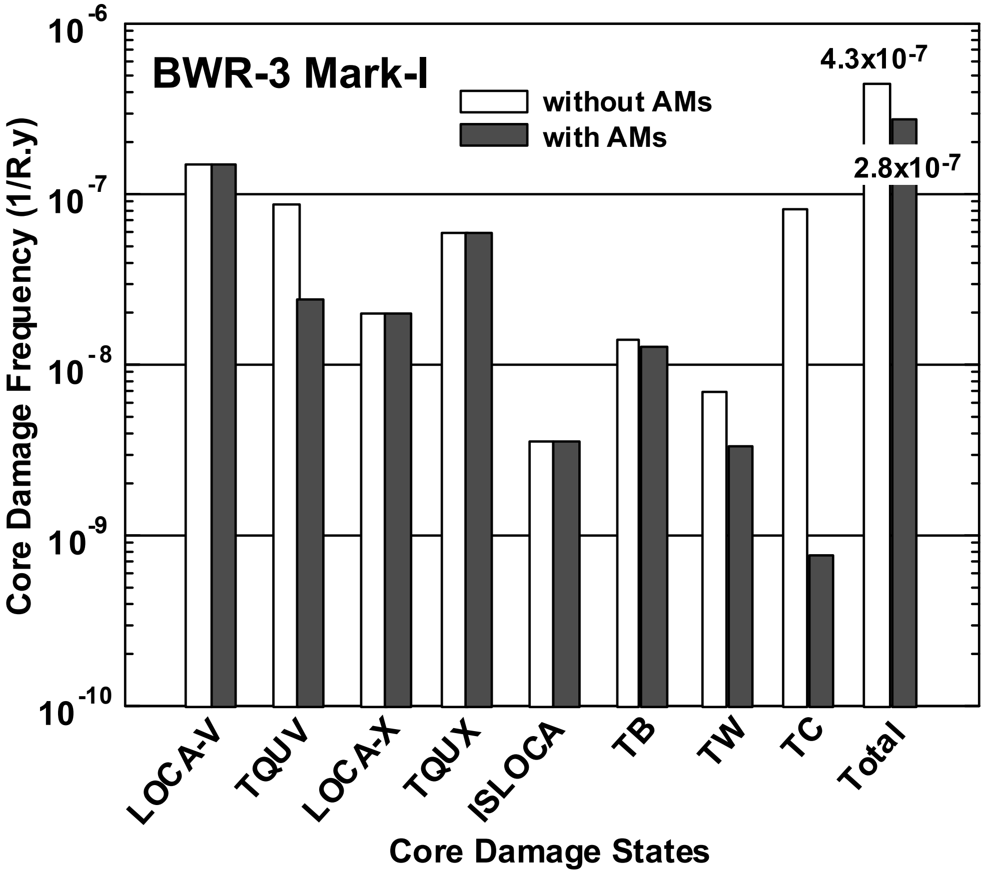


Equipment for containment heat removal



Effectiveness of Preventive AMs

CDF for BWR-3 with Mark-I Containment



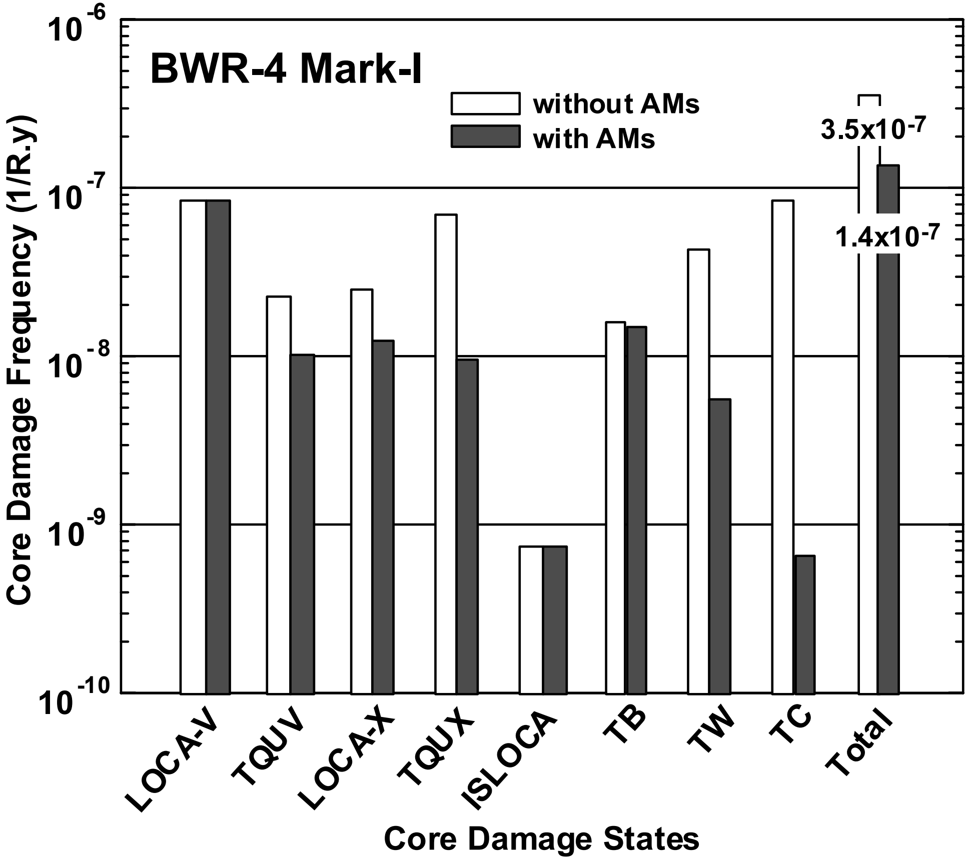
The reduction of the CDF for TC was significant large because common cause failure of scram contactor was effectively reduced by the ARI and RPT.

Since AMs for depressurization was not implemented, there is no reduction of CDF for LOCA-X.
As for LOCA-V, since there are no enough time to depressurize due to rapid accident progressions to the core damage, reductions of CDF was not expected

The CDF was reduced effectively by the alternative water injection for TQUV.

The CDF for TW was reduced by the containment vent systems.

CDF for BWR-4 with Mark-I Containment



The reduction of the CDF for TC was significant large because common cause failure of scram contactor was effectively reduced by the ARI and RPT.

The AM with reinforcement of ADS was significantly effective to reduced core damage frequency for TQUX.

As for LOCA-V, since there are no enough time to depressurize due to rapid accident progressions to the core damage, reductions of the CDF is not expected

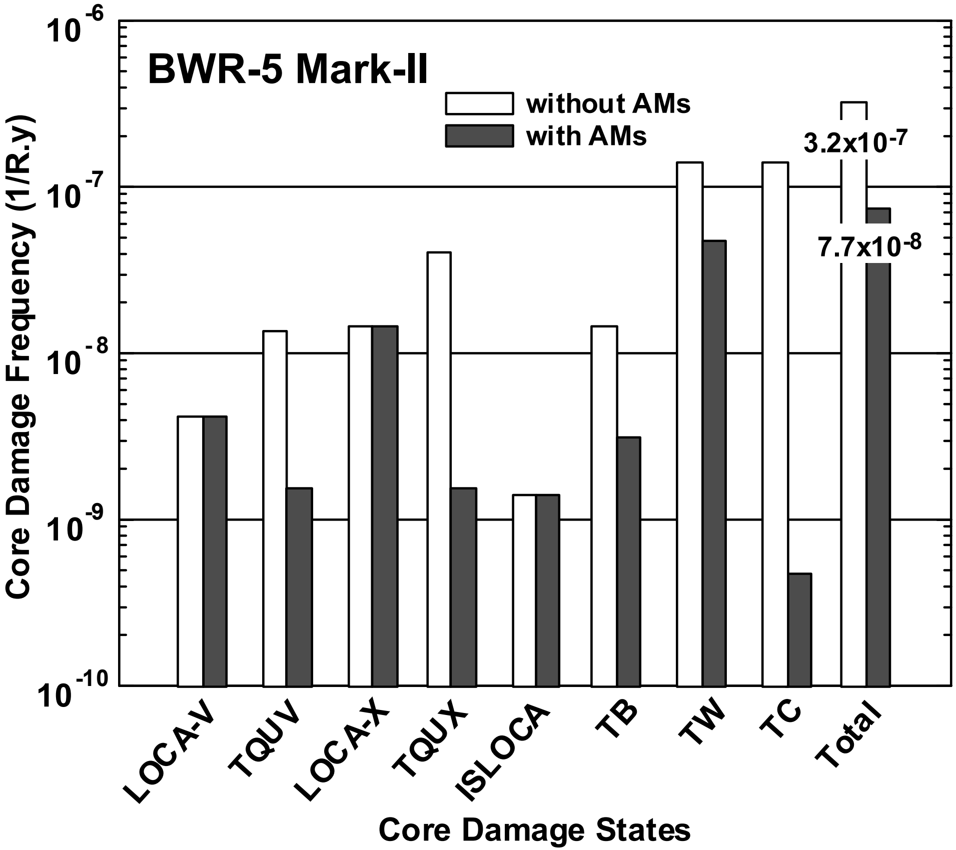
The CDF was reduced effectively by the alternative water injection for TQUV.

The CDF for TW was reduced by the containment vent systems.

CDF for BWR-5 with Mark-II Containment

The reduction of the CDF for TC was significant large because common cause failure of scram contactor was effectively reduced by the ARI and RPT.

The AM with reinforcement of automatic depressurization system (ADS) was significantly effective to reduced core damage frequency for TQUX.



As for LOCA-V, since there are no enough time to depressurize due to rapid accident progressions to the core damage, reductions of the CDF is not expected

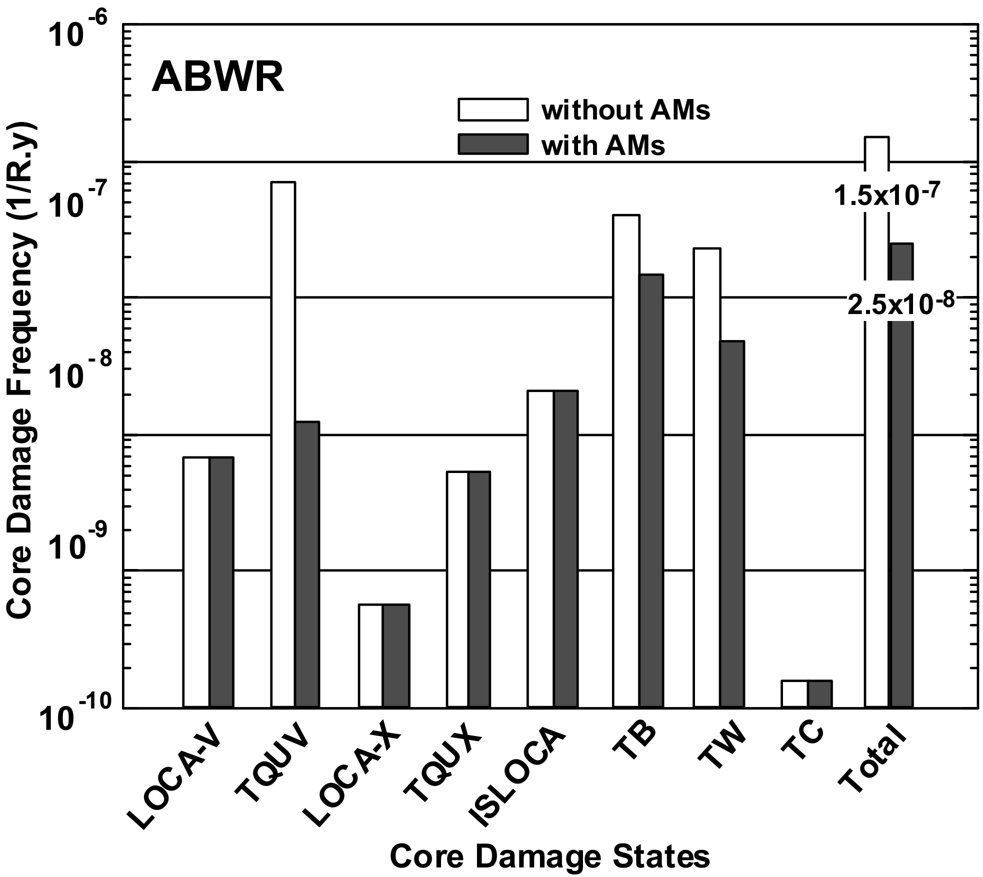
The CDF was reduced effectively by the alternative water injection for TQUV.

The CDF for TW was reduced by the containment vent systems.

The dominant accident sequence was a transient with loss of recovery of AC power within 24 hours. The accident management of power supply from adjacent plant through 6.9kV buss became effective for TB.

CDF for ABWR with RCCV

The ABWR type has no reduction of core damage frequency for TC, because ARI and RPT were already implemented in the design stage.



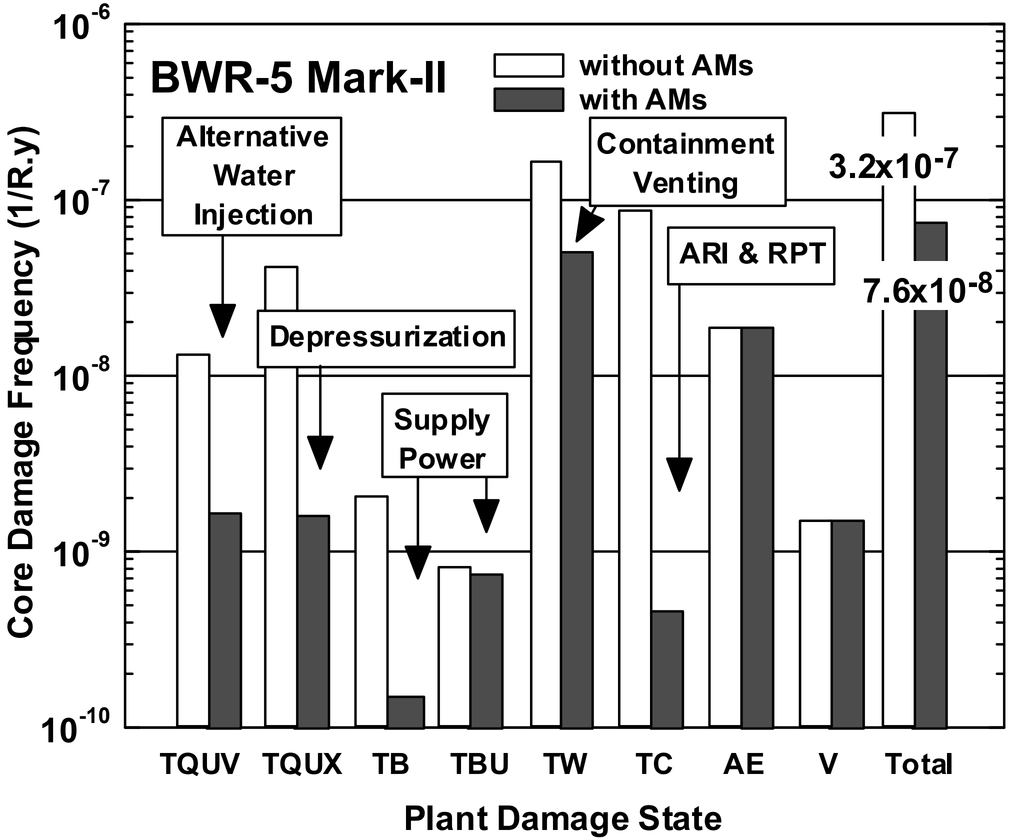
As for LOCA-X and LOCA-V, contribution of alternative water injection was not significant because reliabilities of high pressure & low pressure injection systems were kept high with redundant systems.

The ABWR type has no AMs for depressurization because of high reliability of high and low pressure injection systems.

The reduction of the CDF was not extensive, because the core damage during loss of AC power was dominated by mechanical failures of RCIC.

Effectiveness of Mitigative AMs

Approach with use of Level 2 PSA



Plant Damage States

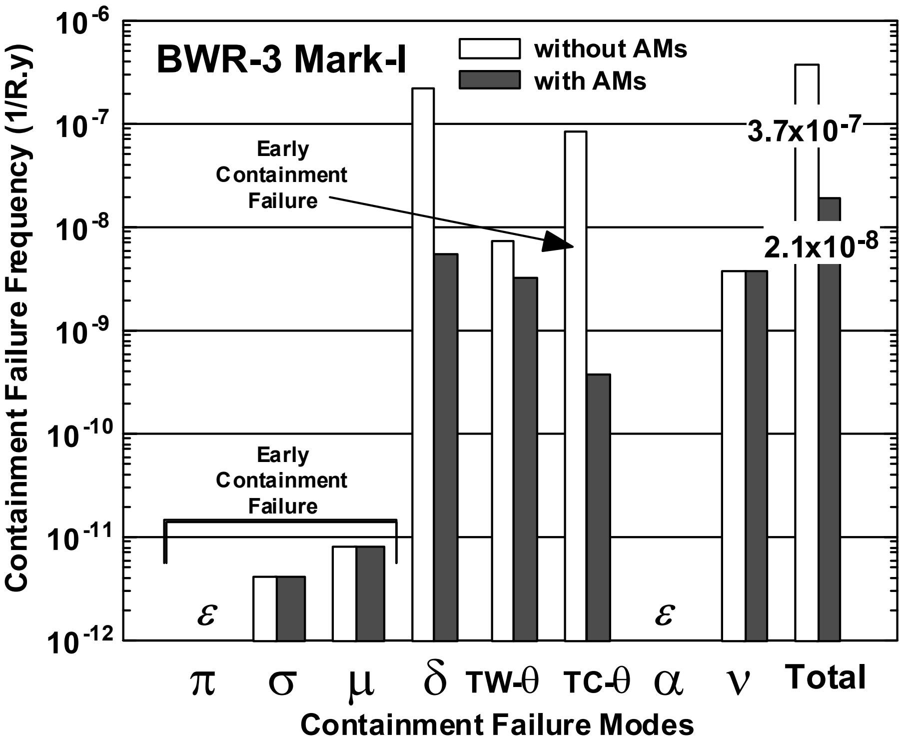
TQUV	Transient with loss of all ECCS injections (including small break LOCA)
TQUX	Transient with failure to depressurization of the reactor coolant system
TB	Transient with loss of all AC powers
TBU	Transient with loss of all AC & DC powers
TW	Transient with loss of decay heat removal
TC	Transient without scram
AE	LOCA with loss of all ECCS injections
V	Interface-systems LOCA

Development of Containment Event Trees and Containment Failure Mode

Containment Event Trees (CETs) were developed for each Plant Damage State (PDS), and Containment Failure Mode were attributed to the end of the CETs.

Designator	Containment Failure Mode
τ	Wall melt-through
σ	Direct containment heating (DCH)
μ	High pressure melt ejection (HPME)
δ	Over-pressurization with steam/non-condensable gases
TW-θ	Over-pressurization with steam in transient with loss of decay heat removal
TC-θ	Over-pressurization with steam in transient without scram
α	In-vessel steam explosion
ν	Interface-systems LOCA & Containment bypass

CFF for BWR-3 with Mark-I Containment

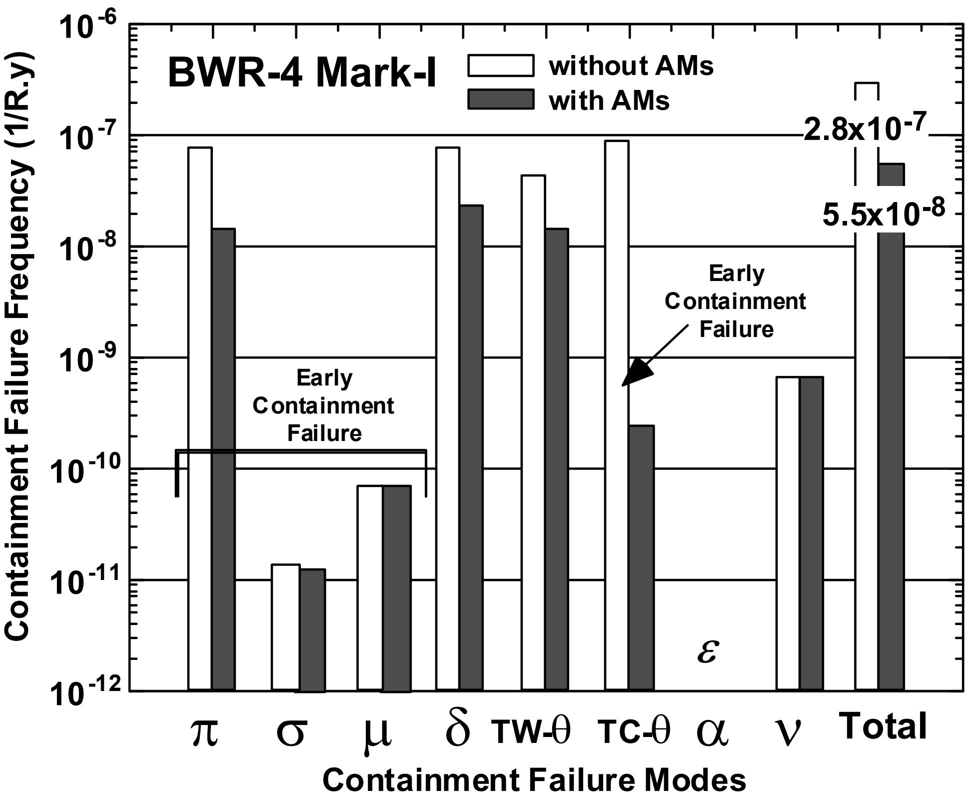


In the "Drywell Melt-through", the containment failure frequency due to TQUV, which was dominant sequence, was effectively reduced by the alternative water injection, the recovery of the component cooling system (CCS) and the containment vent.

The CFF due to "Over-pressurization during MCCI" was reduced by the alternative water injection, recovery of the CCS and the containment vent for TQUV and AE.

The alternative water injection, recovery of CCS and recovery of AC power became effective to reduced the CFF for TB, which was dominant accident sequence that leads to HPME and DCH.

CFF for BWR-4 with Mark-I Containment

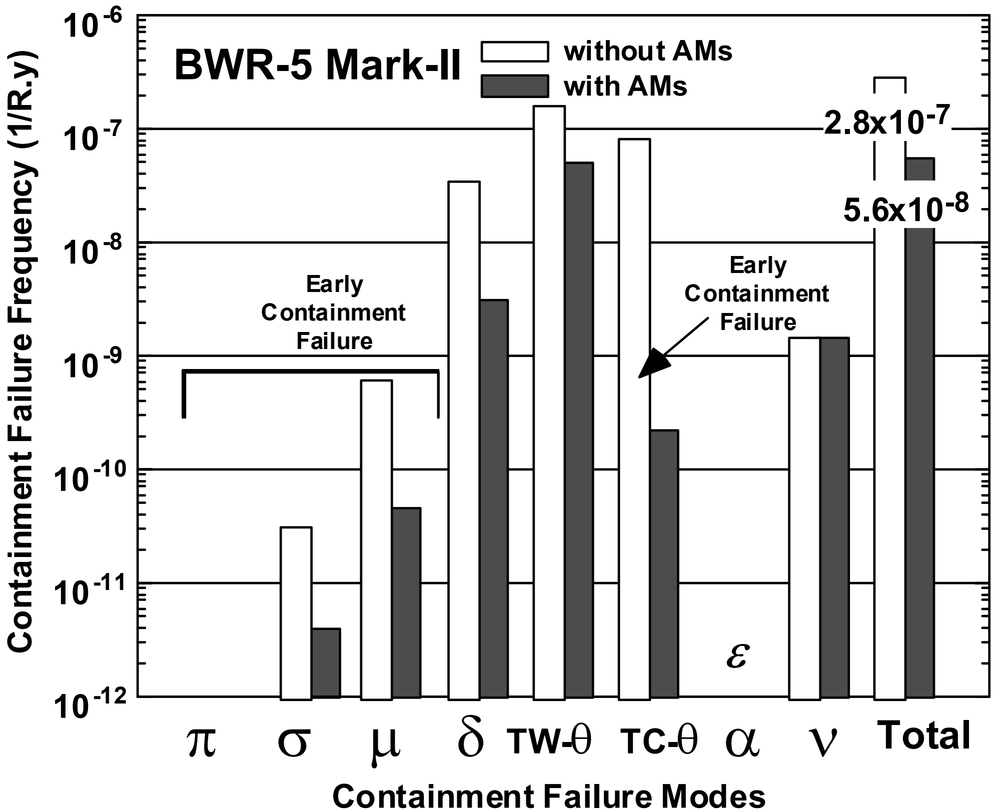


In the "Drywell Melt-through", the CFF due to AE, which was dominant sequence, was effectively reduced by the alternative water injection, the recovery of the decay heat removal system (RHR) and the containment vent.

In the "Over-pressurization during MCCI", the alternative water injection, recovery of the RHR and the containment vent became effective to reduced the CFF.

In "HPME & DCH", recovery of AC power became effective to reduce the containment failure frequencies.

CFF for BWR-5 with Mark-II Containment

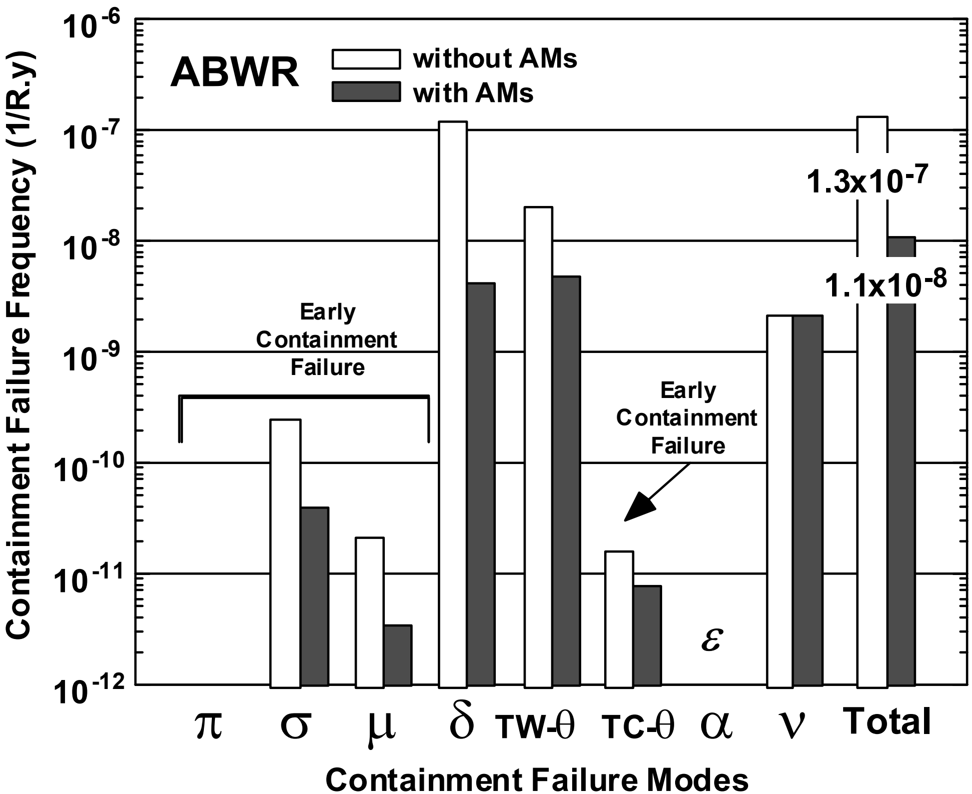


The drywell wall melt through would not be come out because the molten debris moves to downward in the reactor pedestal.

In the "Over-pressurization during MCCI", the alternative water injection, recovery of the RHR and the containment vent became effective to reduced the CFF.

In "HPME & DCH", recovery of AC power became effective to reduce the CFF.

CFF for ABWR with RCCV



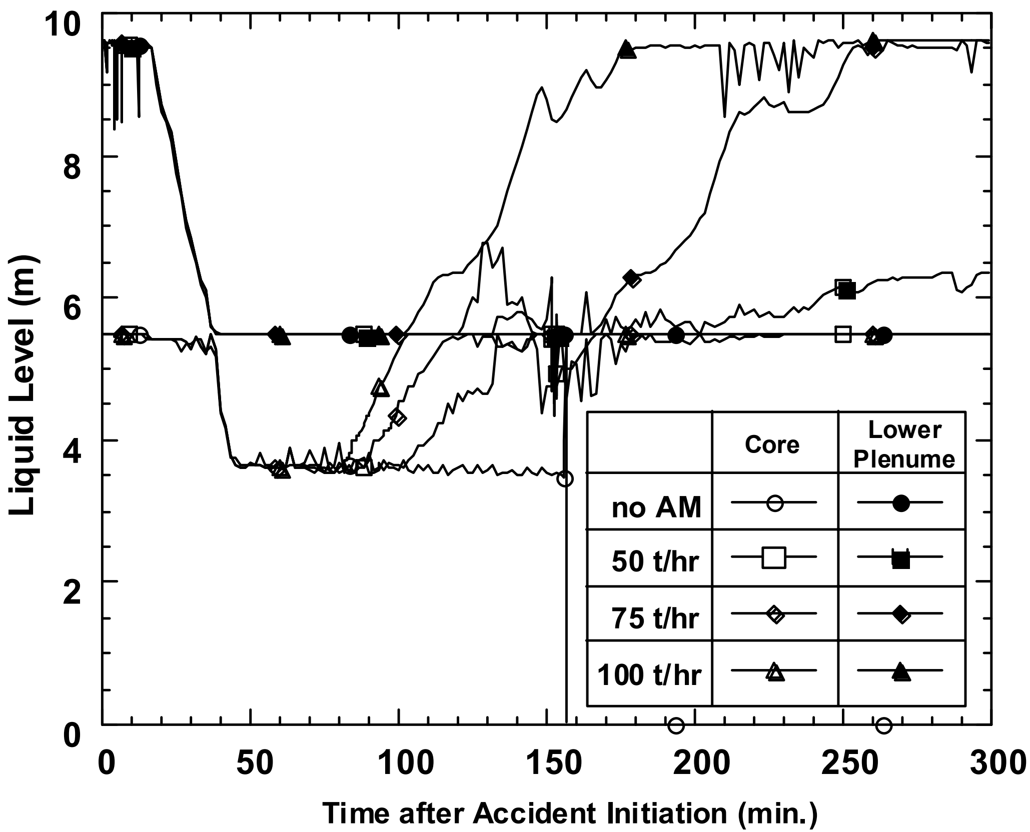
The drywell wall melt through would not be come out because the molten debris moves to downward in the reactor pedestal.

In the "Over-pressurization during MCCI", the alternative water injection, recovery of the RHR and the containment vent became effective to reduced the CFF.

In "HPME & DCH", recovery of AC power became effective to reduce the CFF.

Mitigation of Accident Progressions with AMs

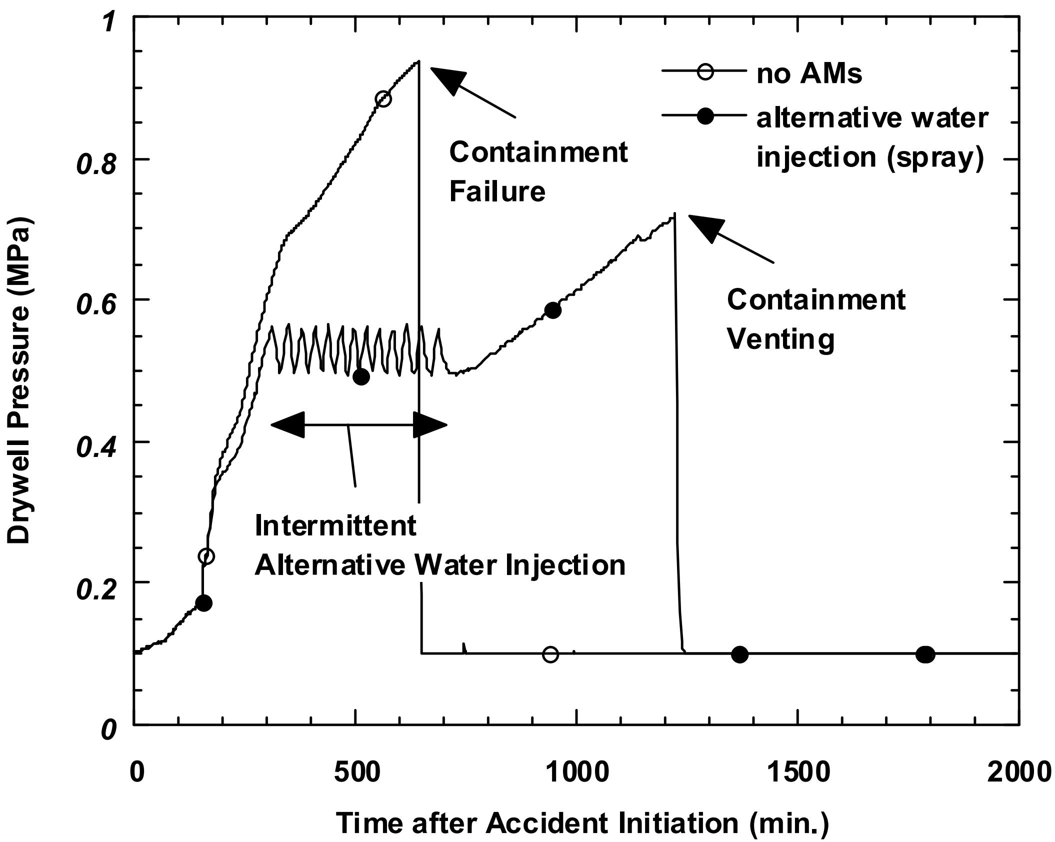
Alternative Water Injection after Core Damage



The MELCOR1.8.3 code was used to examine the effects of a mitigation on the accident progressions with AMs.

The sensitivity calculation was performed to examine capabilities of the alternative water injection. The calculated results indicated that the core is cooled down by the alternative water injection even if the after core damage.

Alternative Water Injection to PCV & Heat Removal



The pressure in the drywell was suppressed by the alternative water injection from the pool in the fire protection system to the containment.

In the case of failure to recovery of the RHR system, the calculated results showed that containment vent would be operated at about 1 day after from accident initiation.

Summary

- The results of the present study indicated that the reductions of the CDFs were estimated to be

  2/3 for BWR-3, 1/2 for BWR-4, 1/4 for BWR-5 and 1/6 for ABWR.

  In addition, the CDF for a BWR plant was estimated to be lower than $3x10^{-7}$ (1/R.y) considering with AMs. On the bases of the results in the present study, CDFs for BWRs were effectively reduced by the implemented AMs.

- The results slso indicated that the reductions of the CFFs were estimated to be

  1/18 for BWR-3, 1/5 for BWR-4, 1/5 for BWR-5 and 1/12 for ABWR.

  In addition, the CFF for a BWR plant was estimated to be lower than $6x10^{-8}$ (1/R.y) considering with AMs.

- The frequencies of early containment failure and containment bypass sequences that lead to the early large releases were significantly reduced to

  1/22 for BWR-3, 1/82 for BWR-4, 1/50 for BWR-5 and 1/1.1 for ABWR.

Conclusion

The present study examined the effectiveness of accident management countermeasures in terms of the Level 1 PSA and Level 2 PSA for the BWR-3 Mark-I, BWR-4 Mark-I, BWR-5 Mark-II and ABWR in Japan.

The results indicated that accident management countermeasures implemented to BWRs in Japan were effective to reduce core damage frequency and containment failure frequency. The core damage frequencies and containment failure frequencies for BWRs were estimated to be lower than 3x10-7 (1/R.y) and 6x10-8 (1/R.y), respectively.

In addition, containment failure frequencies that lead to early large release were significantly reduced with AMs for BWRs.