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Analysis of Accident Progression and Source Term in Level-2 PSA for a Shutdown Period

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1. Background and Objectives

Background

- Japan Nuclear Energy Safety Organization (JNES) has been developing a methodology of Level-2 Shutdown PSA.
- BWRs core damage frequencies during a shutdown period were estimated to be smaller than that of the rated power operation.
- The discharge timings and the release fractions of radioactive materials would become severer than those of the rated power operation.

Objectives

- To confirm dominant sequences leading to large release of radioactive materials during a shutdown period for BWR-4 plant
- To examine Effectiveness of Accident Management measures (AMs) during a shutdown period with level 2 PSA methodology
  - -Alternative water injection to be same as AM measure for the rated power operation.
  - -Particular AM candidate to make closure of containment hatches for some phases with mounting the head of containment vessel but still opening hatches.

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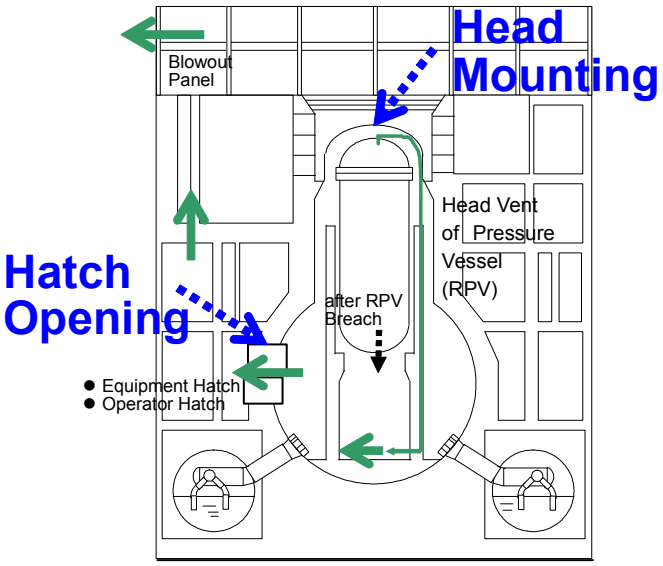
2. Plant Damage States during a Shutdown Period
2.1 Categorization of Plant Operating States (POSs)

- In this Level-2 PSA study, POS-C was divided into POS-C1 and C2 depending on the condition with mounting or dismounting head of containment.
- Enclosed POSs by green line shows plant status with mounting heads of reactor vessel and containment. Particular accident management candidate (closure of containment hatches) is applicable for the POSs (POS-S, C2, D).

Work Items for Annual Inspection	Open Vessel		Fuel Exch.	Control Rods Inspection	Fuel Shuffling	Recovery of Press. Vessel	Recovery of Cont. Vessel	Prepar-ation of Startup
POS Name	S	A	B			C1	C2	D
Available RHR	RHR Initiation		RHR Exchange: B to A				RHR Exchange: A to B	
Rx. Water Level	Normal		Top Level of Well			Normal Level		
Status of Rx. Press. Ves. (RPV)	Dismounting of RPV Head						Mounting of RPV Head	
Status of Contain. Ves. (PCV)	Dismounting of PCV Head and Opening Hatches						Mounting of PCV Head and Opening Hatches	
POS Period (% of 73 Days)	1 %	11 %	47%			19%	5%	17%



(NOTE) Green arrows show release path of radioactive materials

(NOTE) Red triangles show the timings of switching operation for residual heat removal system which is possible to be induced LOCA by human error.

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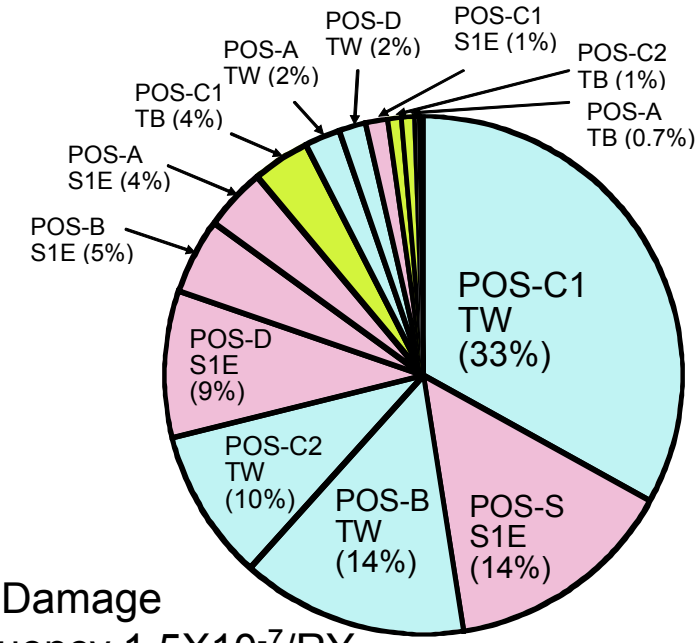
2.2 Categorization of Plant Damage States (PDSs)

- The dominant accident sequence that has the largest frequency is Loss of decay heat removal (TW). Its fraction becomes about 60% of whole core damage frequency, due to decrease of availability for mitigation system from multiple to single train by maintenance in three phases of POS-B, POS-C1 and POS-C2.
- The accident sequence that has the second large frequency is Induced LOCA (S1E). Its fraction becomes about 30%, due to human error of switching operation for the residual heat removal system in phases of POS-S, POS-B and POS-D.



Core Damage Frequency $1.5X10^{-7}$/RY

PDS	Sequences
TW	Transient with loss of decay heat removal
S1E	Induced LOCA by human error on RHR switching operation with loss of all ECCS injections in all phase except POS-A or Medium size LOCA with loss of all ECCS injections in phase POS-A
TB	Transient with loss of all AC powers

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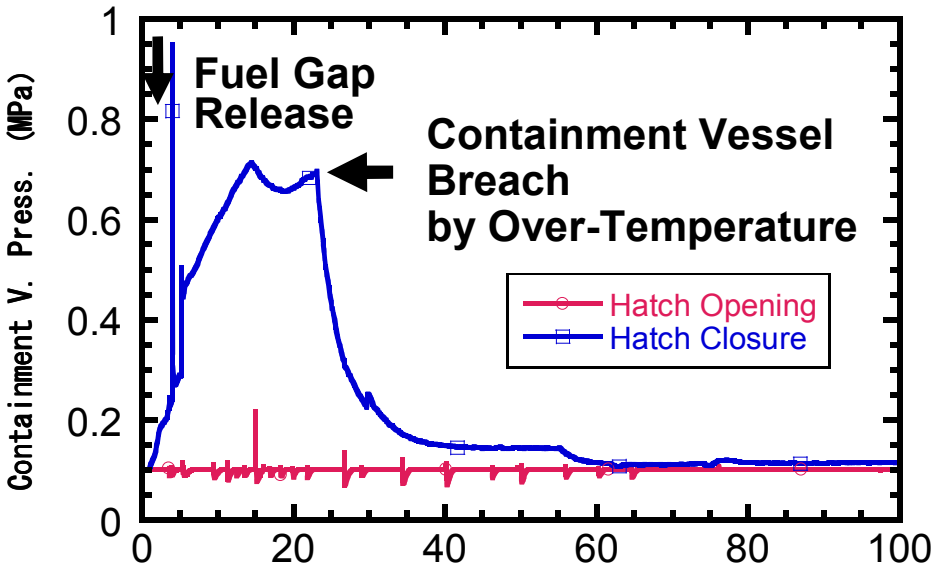
3. Accident Management (AM) Measures during a Shutdown Period

- **Two AMs were examined their effectiveness by MELCOR analysis:**
  (1) Alternative water injection from the fire protection system with connecting pipes
  (2) Closure of containment hatches for applicable phases with mounting the head of containment vessel but still opening hatches.
- **It is important that these AM systems and their supporting systems should be available their function for accident mitigation in any maintenance work.**

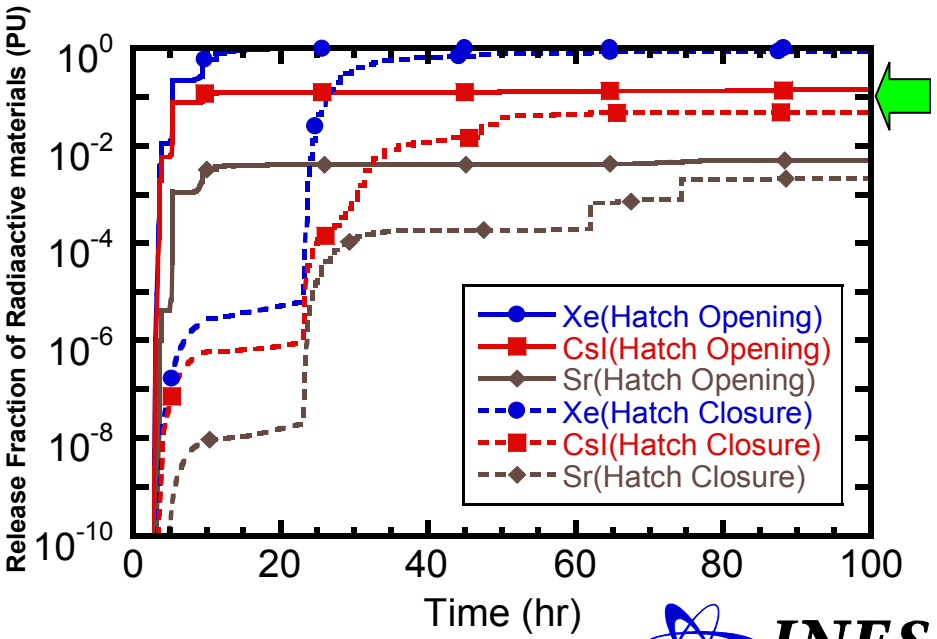
AM Functions	Equipment & Systems	Available Plant Damage States
AM1 Alternative Water Injection	-Use of MUWC system. -Water supply from Fire Protection system	TQUV, TQUX, TB, TBU, AE, S1E
Alternative Heat Removal	-Use of the drywell cooler and use of CUW system - Recovery of the RHR system -The containment hardened vent	TW
Supply AC Power	-Accommodation of 6.9kV & 480V from adjacent plant	TB, TBU
AM2 Closure of Containment hatches	-Manual Closure of Operator hatch and equipment hatches of Containment Vessel for some shutdown phases (POS-S, C2, and D)	**TB, S1E,TW**

3.1 Comparison of Characteristics with and without Closure of Containment hatches (AM2) in case of Induced LOCA (POS-S)

- This accident management is effective for three POSs: POS-S, POS-C2 and POS-D, because heads of reactor and containment vessel are mounted but containment hatches are still open.
- Release timing of CsI to the environment was delayed about 20 hours from the fuel gap release (3 hours) to the containment vessel breach by over-temperature (23 hours).
- Amount of CsI environmental release was decreased from 14% to 5% of total core inventory, due to the natural deposition of CsI in the containment.



Initial Point: One Day after Reactor Shutdown



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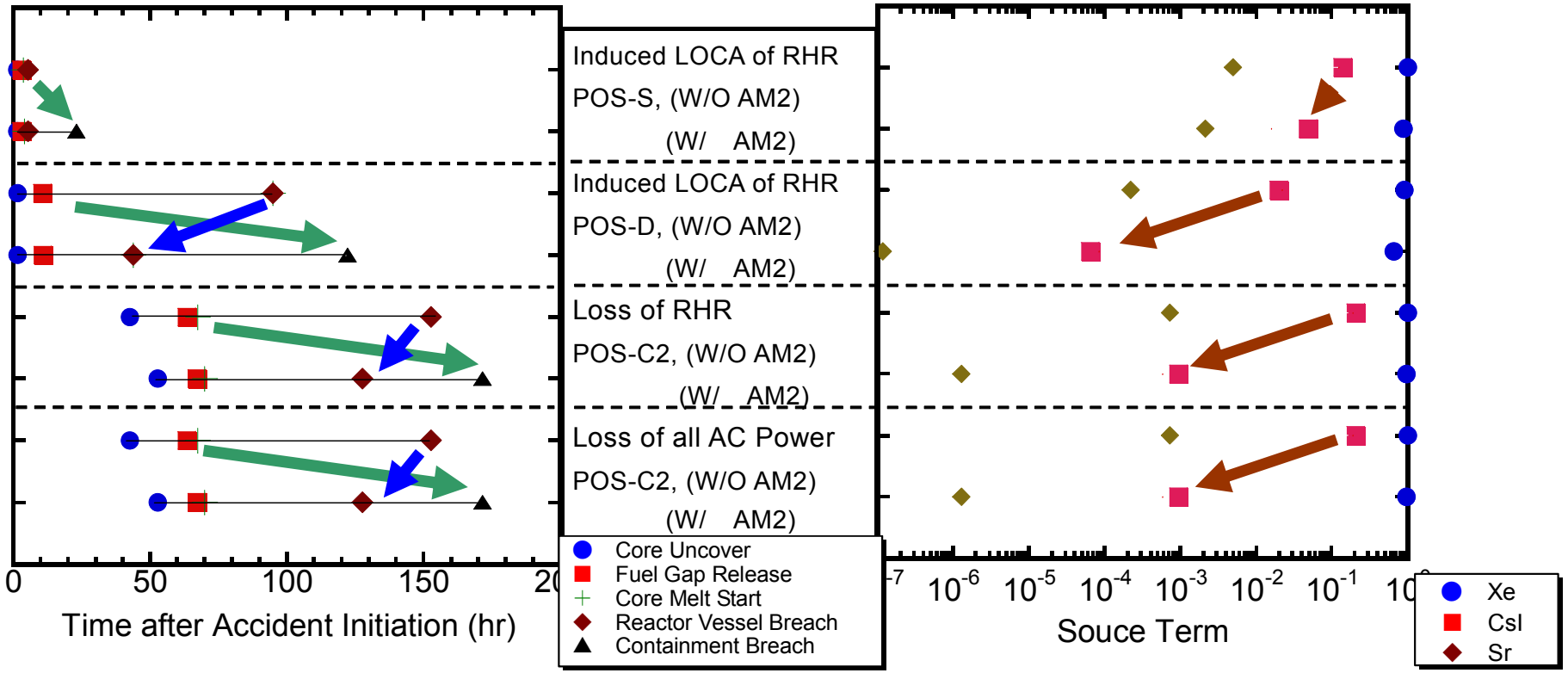
3.2 Comparison of Source Terms with and without Closure of Containment hatches (POS-S, C2, D)

- Closure of containment hatches enhances the reactor and containment pressure rise and leads the earlier reactor vessel breach, due to the reduction of boiling heat transfer from debris.
- However, this accident management candidate became effective on following points:

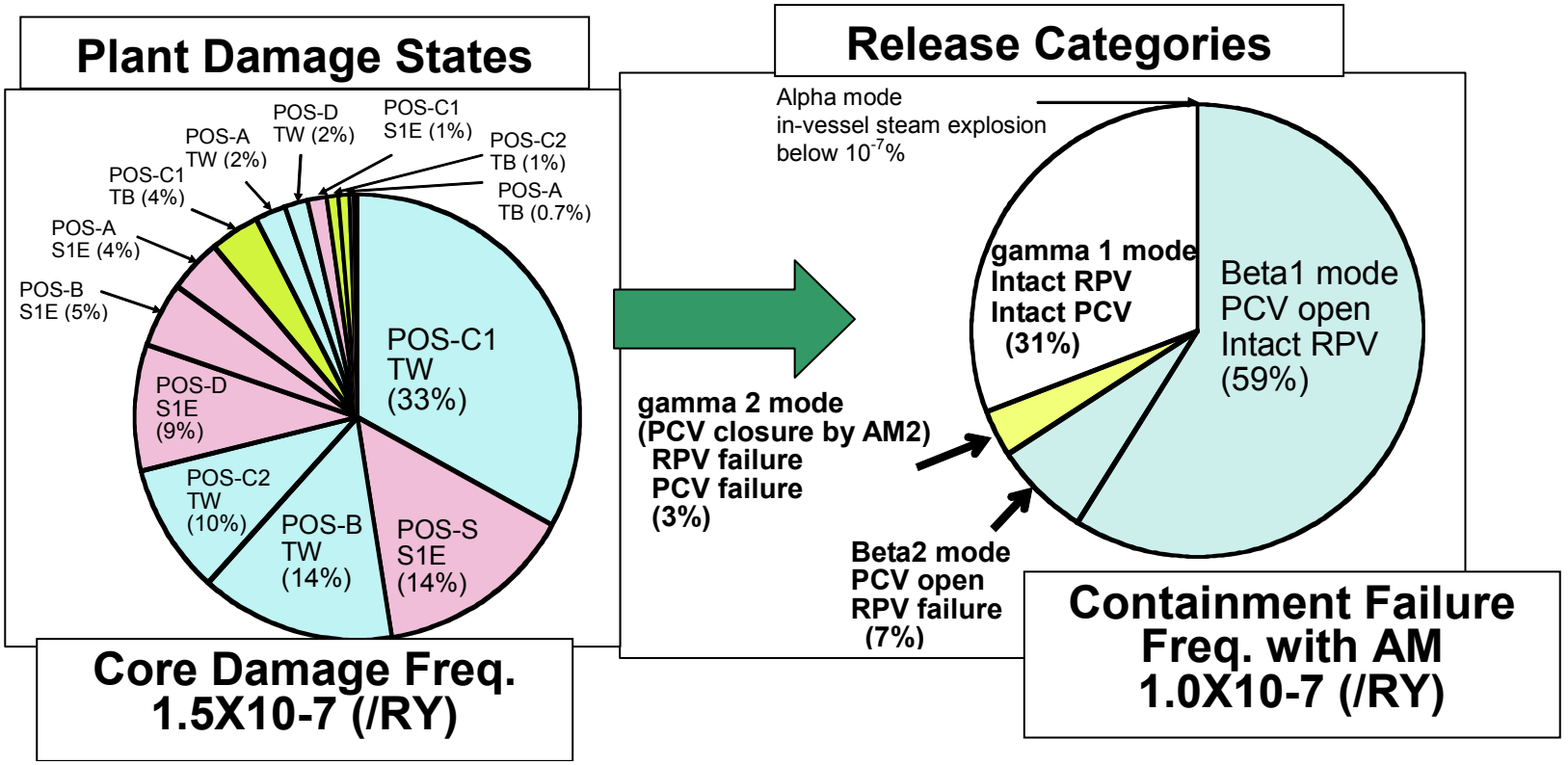
(1) To delay the release timing of radioactive materials about 20 to 110 hours.

(2) To reduce the amount of CsI environmental release about 1/ 3 - 1/300 times compared to cases without AM.



3.3 Quantification of Release Categories

- The accident management measures of alternative water injection (AM1) and containment hatches closure (AM2) were effective to reduce the large release frequency from 100% to about 70% of the total core damage frequency.
- White portion in the figure of release categories (about 30%) shows the intact status of reactor vessel and containment vessel.



4. Summary

- The present study clarified the accident progressions and source terms of events during a shutdown period of BWR-4 plant and effectiveness of accident management measures (AMs).

- The dominant sequences during a shutdown period for BWR-4 plant were pointed out:
  (1) TW (Loss of decay heat removal) was dominant sequence about 60% of whole core damage frequency.
  (2) The second accident sequence was S1E (Induced LOCA or Medium size LOCA) and its fraction is about 30%.

- Containment hatches closure as particular candidate of AM for a shutdown condition was effective countermeasure for following two points :
  (1) To delay release timings of radioactive materials from 20 to 110 hours than cases without AM.
  (2) To reduce source terms as its rate from 1/3 to 1/300.

- Two AM measures (Alternative water injection and containment hatches closure) were confirmed to be effective to reduce the large release frequency from 100% to about 70% of the total core damage frequency.

Thank You for Your Attention.