Recent Activities & Summary of Study in Japan on Severe Accident Monitoring for Nuclear Power Plants

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TOSHIBA CORPORATION
Mitsubishi Heavy Industries, Ltd.

“SA-計装(Kei-Sou)”

Stands for

“Severe Accident -
Instrumentations & Monitoring Systems”

< Contents >

1. Summary of Study of Severe Accident Instrumentations & Monitoring System

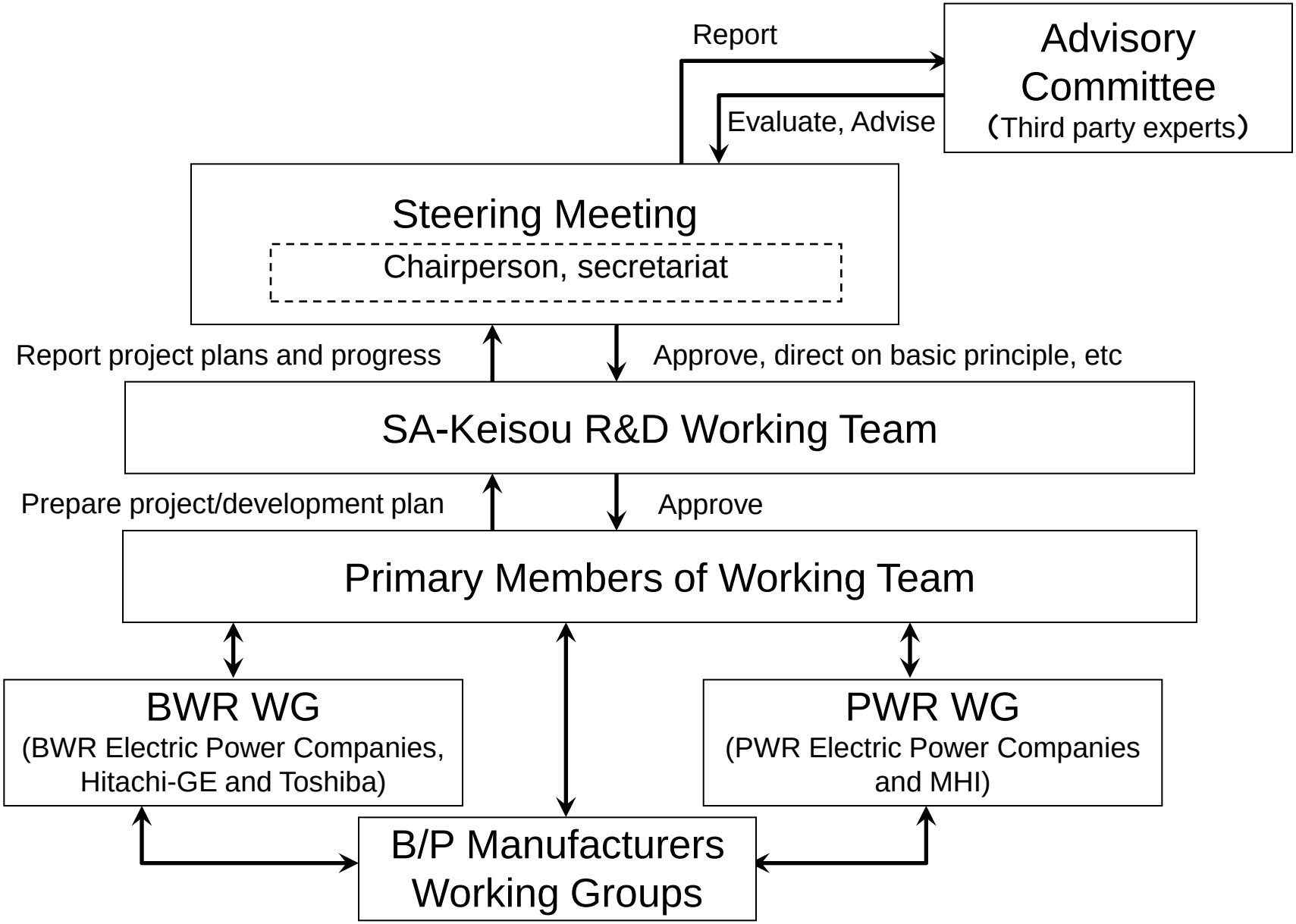
1.1 Objective

- Through this research & development program, the specific requirements for the SA-Keisou (Severe Accident instrumentations & monitoring systems) will be prepared.

- If a severe accident happens, the SA-Keisou could contribute to suppressing the accident by measuring the important parameters (e.g., water level, pressure, etc.).

- The program also enhance technical level in the nuclear industry in Japan and promote safety and utilization of the nuclear power plants.

1.2 Promoting Organization



- Objective of SA Classification
  - Definition of typical SA condition corresponding to event progress after core damage.
  - Determination of environment conditions and classification of measurement variables corresponding to SA conditions.
- Approach of determination of environmental conditions
  - Selection of typical event trees indicating each SA condition.
  - Determination of environmental conditions based on analysis using event trees.
- Approach of classification of measurement variables
  - Determination of measurement variables corresponding to instrument purposes of SA conditions.
  - Instrument purposes are to;
    - confirm plant conditions;
    - confirm initiation and success of operations for mitigating event.

1.3 SA Classification(2): Definition

●Classification of SA Conditions due to Event Progress

Plant conditions after the core damage are classified as SA1, SA2, SA3a, and SA3b.

SA1: Core is damaged, but core fuel is inside the Reactor Vessel (RV).
(Accident Management RCS Pressure Reduction is Achieved.)

SA2: RV Failure, and core fuel is outside the RV
(AM Water Injection into the Containment Vessel and Containment Natural Convection Cooling are Achieved.)

SA3a: Containment Failure (Water Feed Injection to Inside of CV is Success)

SA3b: Containment Failure (Water Feed Injection to Inside of CV is Failure)

Note) PWR(BWR): RV(RPV),CV(PCV)

1.3 SA Classification(3): Definition

●Environmental Conditions

★ Core Fuel, RV(RPV), CV(PCV) Conditions and Water Feed Injection vs. SA Classification

Condition	SA1	SA2	SA3a	SA3b
Fuel/Location	Meltdown /RV	Debris /RV or CV	Debris /RV or CV	Debris /RV or CV
Core	Damaged	Damaged	Damaged	Damaged
RV	Sound	Damaged	Damaged	Damaged
CV	Sound	Sound	Damaged	Damaged
Water Feed Injection	Success	Success	Success	Failure

Note) PWR(BWR): RV(RPV),CV(PCV)

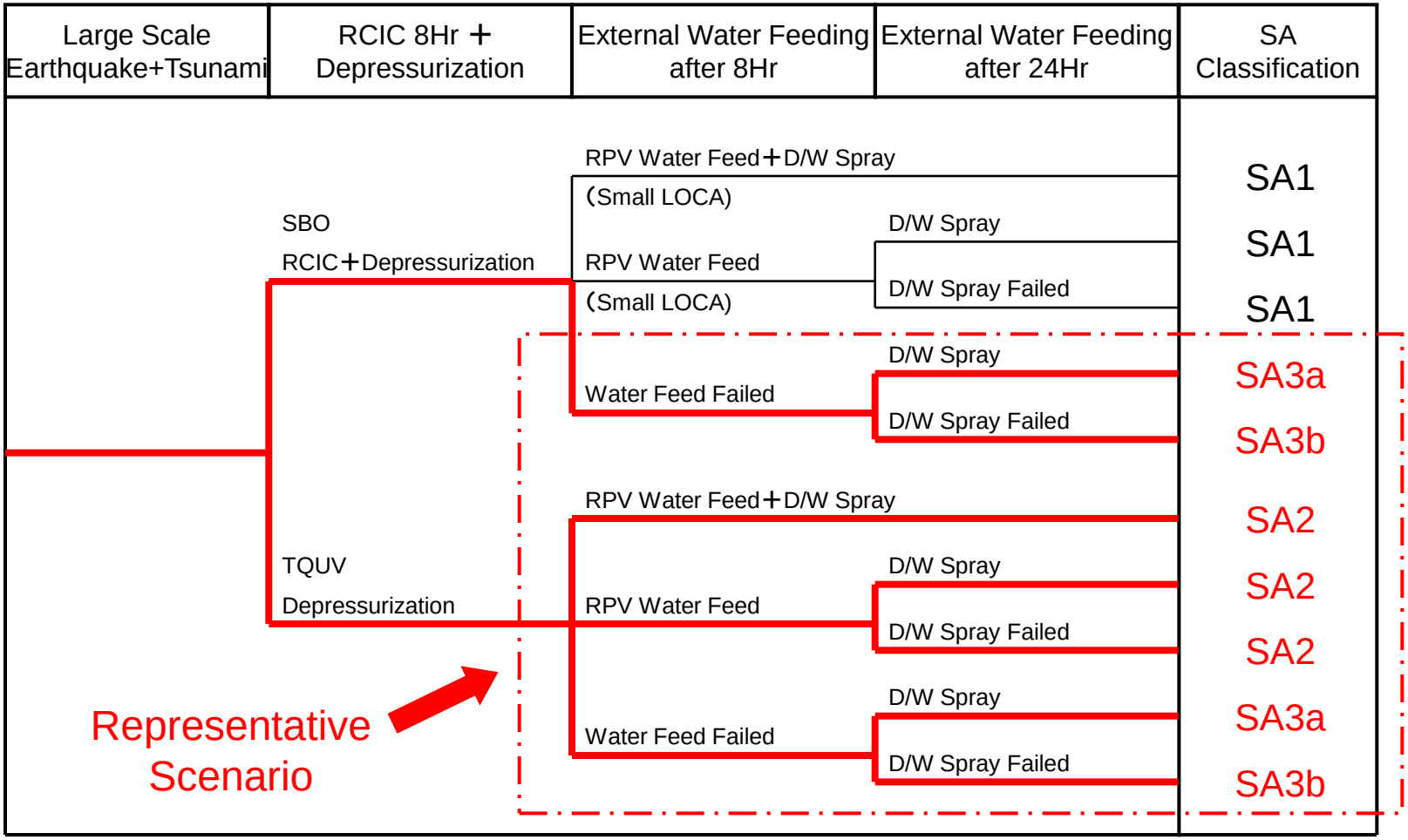
1.3 SA Classification(4):Comparison with Level of Defense in Depth [10]

SA classification		DBA/BDBA		SA1	SA2	SA3a	SA3b
Fuel condition /Fuel position		Within RPV		Meltdown /Within RPV	Debris /RPV or PCV	Debris /RPV or PCV	Debris /RPV or PCV
Core condition		Sound		Damaged	Damaged	Damaged	Damaged
RPV condition		Sound		Sound	Damaged	Damaged	Damaged
PCV condition		Sound		Sound	Sound	Damaged	Damaged
Water Feed Injection		Success		Success	Success	Success	Failure
IAEA level of defense in depth		Level 3	Level 4			Level 5	
WENRA level of defense in depth		Level 3a	Level 3b	Level 4		Level 5	
Basic ideas of further SA regulation	Defense in depth layers	3－1	3－2	4－1		4－2	5
	Plant condition	DBA and maintain safety function (assume single failure criterion).	Loss of safety function based on design basis (multiplex failure).	Significant core damage.		Massive emission. Containment vessel damage.	Massive emission and spreading.
	Purpose of level of defense in depth	Prevention of significant core damage.		Prevention of massive emission. Prevention of containment vessel damage.		Emission control and spreading mitigation.	Prevention of human damage. Restoration of environment.
	Safety measures	ECCS, etc..	Preventive measure of significant core damage (SA measure I).	Preventive measure of containment vessel damage (SA measure II).		Measure of emission control and spreading mitigation.	Disaster prevention.

↑ Boundary between the third layer and the fourth layer

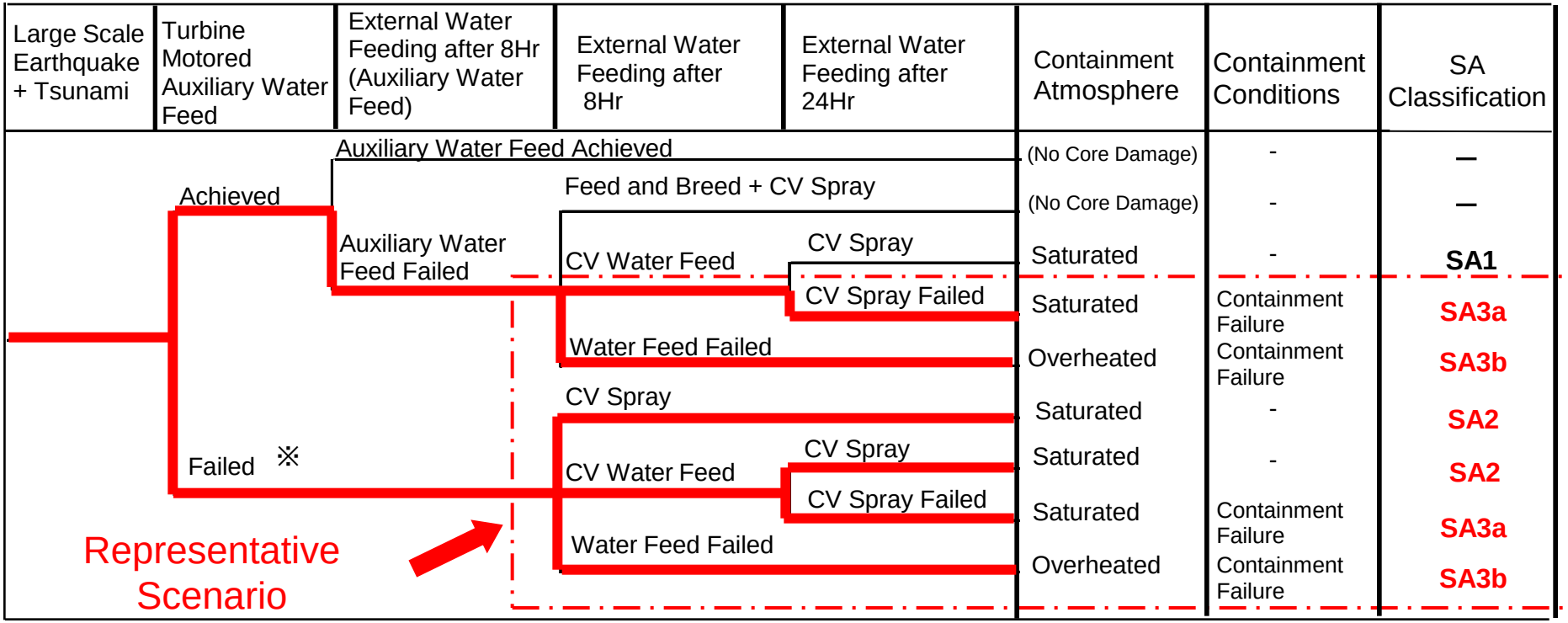
1.3 SA Classification(5):Relationship with Event Tree for BWR

Event Tree (Actions and Failures)



1.3 SA Classification(6): Relationship with Event Tree for PWR

Event Tree (Actions and Failures)



1.4 Selection of Measuring Variables(1) for BWR

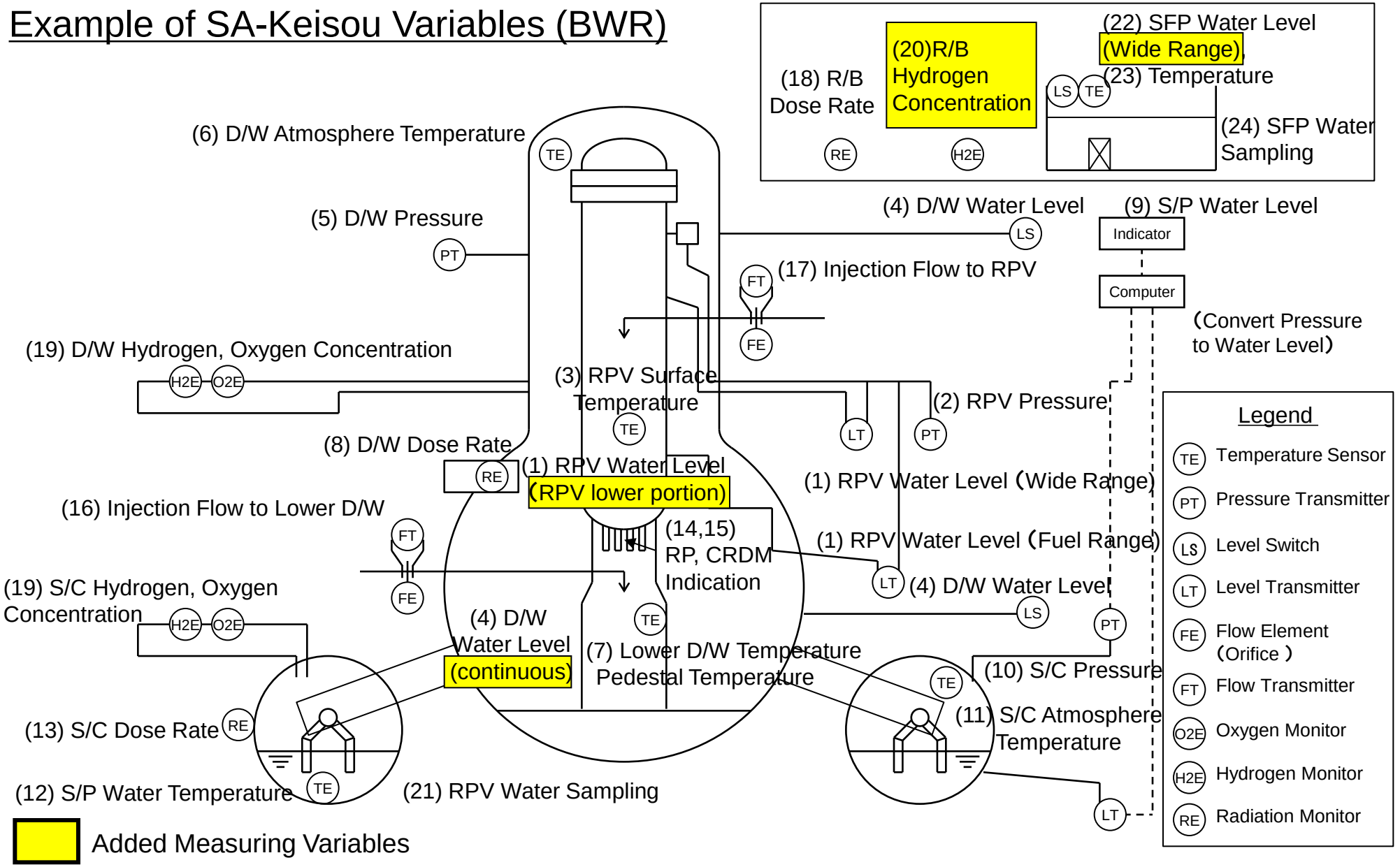
● Selected Variables for BWR (Added Variables in red)

No.	Variables
1	RPV Water Level (RPV lower portion)
2	RPV Pressure
3	RPV Surface Temperature
4	D/W Water Level (Continuous)
5	D/W Pressure
6	D/W Atmosphere Temperature
7	Pedestal Atmosphere Temperature
8	D/W Dose Rate
9	S/P Water Level
10	S/C Pressure
11	S/C Atmosphere Temperature
12	S/P Water Temperature

No.	Variables
13	S/C Dose Rate
14	Rod Position Indication Value
15	CRDM Indication Value
16	Injection Flow to Lower D/W
17	Injection Flow to RPV
18	R/B Area Radiation Monitor
19	D/W, S/C Hydrogen, Oxygen Concentration
20	R/B Hydrogen Concentration
21	RPV Water Sampling Analysis <still under debate >
22	SFP Water Level (Wide Range)
23	SFP Water Temperature
24	SFP Water Sampling Analysis <still under debate >

1.4 Selection of Measuring Variables for BWR

Example of SA-Keisou Variables (BWR)



1.4 Selection of Measuring Variables for PWR

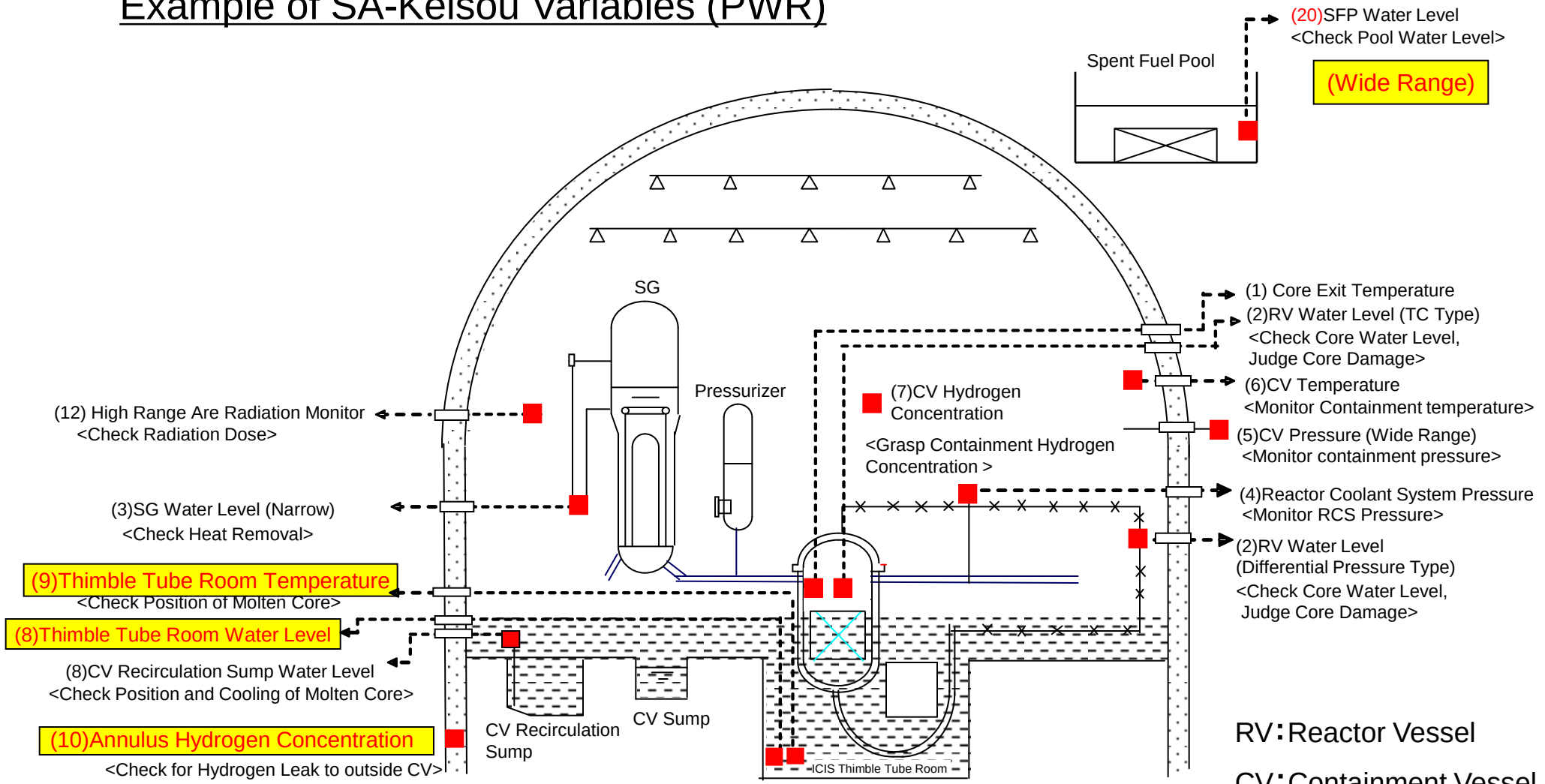
● Selected Variables for PWR (Added Variables in red)

No	Variables
1	Core Exit Temperature
2	RV Water Level
3	SG Water Level (Narrow Range)
4	RCS Pressure
5	CV Pressure (Wide Range)
6	CV Temperature
7	CV Hydrogen Concentration
8	ICIS Thimble Tube Room Water Level CV Recirculation Sump Water Level
9	ICIS Thimble Tube Room Temperature
10	Annulus Hydrogen Concentration
11	Monitoring Post
12	High Range Area Radiation Monitor

No	Variables
13	Exhaust High Range Gas Monitor
14	Main Steam Line Monitor
15	RWST Water Level
16	Neutron Monitor
17	CCW Surge Tank Pressure
18	CCW Flow
19	Fire Service Water Integrate Flow
20	SFP Water Level (Wide Range)
21	SFP Temperature
22	SFP Area Monitor
23	SFP Hydrogen Concentration

1.4 Selection of Measuring Variables for PWR

Example of SA-Keisou Variables (PWR)



1.5 SA Variables & SA Classification(1): Matrix of for BWR (Below is Draft Version)

Environment Conditions

Measurement Purposes / Performance

Measurement Variables

(SA Classification) Plant condition	(SA1) SA1 Core damage→Meltdown/RPV integrity is maintained/PCV integrity is maintained	(SA2) SA2 Meltdown/RPV is damaged/PCV integrity is maintained	(SA3a) SA3a Meltdown/RPV is damaged/PCV is damaged	(SA3b) SA3b Meltdown/RPV is damaged/PCV is damaged
Environmental condition in PCV ・Maximum temperature ・Pressure ・Humidity ・Radiation	・171 degree Celsius ・0.31 MPa ・Steam ・5×106 Gy/6 months	・300 degree Celsius ・1.0 MPa ・Steam ・5×106 Gy/6 months	・700 degree Celsius ・1.0 MPa ・Steam ・5×106 Gy/6 months	・1000 degree Celsius ・1.0 MPa ・Steam ・5×106 Gy/6 months
Environmental condition outside PCV ・Maximum temperature ・Pressure ・Humidity ・Radiation	・66 degree Celsius ・3.4 kPa ・100% ・3×105 Gy/6 months	・66 degree Celsius ・0.01 MPa ・Steam ・3×105 Gy/6 months	・100 degree Celsius ・0.01 MPa ・Steam ・2×106 Gy/6 months	・100 degree Celsius ・0.01 MPa ・Steam ・2×106 Gy/6 months
Required duration of performance	under debate			

No.	Parameters/Variables	Monitoring		Operation Confirmation						Monitoring			Operation Confirmation				Monitoring			Operation Confirmation				Monitoring
		Possibility of boundary damage and confirmation of event initiation	Cooling function	Containment function			Operation Confirmation				Possibility of boundary damage and confirmation of event initiation	Cooling function	Containment function		Operation Confirmation				Possibility of boundary damage and confirmation of event initiation	Cooling function	Containment function	Operation Confirmation				Cooling function
		◎Confirm fuel boundary damage and meltdown	◎Confirm core cooling function	◎Confirm integrity of reactor coolant pressure boundary (RPV)	◎Confirm integrity of PCV	◎Confirm hydrogen initiation within PCV	▲Injection to core	▲Depressurize RPV	▲PCV spray	▲PCV vent	◎Confirm damage of reactor coolant pressure boundary (RPV)	◎Confirm cooling of core debris outside RPV	◎Confirm integrity of PCV	◎Confirm hydrogen initiation within PCV	▲Injection to core	▲Injection to pedestal	▲PCV spray	▲PCV vent	◎Confirm PCV damage	◎Confirm cooling of core debris outside RPV	◎Confirm emission of FP from PCV	▲Injection to core	▲Injection to pedestal	▲PCV spray	▲Control combustible gas concentration within R/B	◎Confirm cooling of core debris outside RPV
1	RPV water level (RPV lower portion)	◎	◎	◎		○	▲	▲			◎															
2	RPV pressure			◎			▲	▲			◎															
3	RPV surface tempereture	○	◎	○				△			○															
4	D/W water level (AM) (Continuous)											◎		○	△	▲		▲		◎		△	△			
5	D/W pressure (AM)			◎	◎	○		△	▲	▲	◎	○	◎	○	△	△	▲	▲	◎	○		△	△	△		
6	S/C waster level (AM)									▲								▲								
7	S/C pressure (AM)				◎	○		△	▲	▲			◎	○			▲	▲	◎					△		
8	D/W temperature			◎	◎				▲	△	◎	◎	◎		△	△	▲	△	○	◎		△	△	△		◇(Note 4)
9	D/W dose rate	◎	○	○			△				○															
10	S/C dose rate	◎	○				△																			
11	D/W,S/C hydrogen concentration, oxygen concentration (CAMS)	○	○	○		◎	△	△	△		○	○		◎	△	△			○	○		△	△			
12	R/B area radiation monitor				◎								◎						◎		◎					
13	Injection flow to RPV/ Flow of feedwater to RPV (AM)(Note 1)		○				△					○			△	△				○		△				
14	Pedestal atmosphere temperature			◎							◎	◎			△	▲	▲			◎		△	△	△		◇(Note 4)
15	Rod position indication value (Note 2)			○							○															
16	CRDM indication value (Note 2)			○							○															
17	Injection flow to pedestal/ Flow of feedwater to pedestal (AM)(Note 1)											○				△				○			△			
18	S/P water temperature							△	▲		○						▲							△		
19	S/C atmosphere temperrature				◎				▲	△			◎				▲	△	○					△		◇(Note 4)
20	R/B hydrogen concentration				○								○						○		○				▲	
21	RPV water sampling analysis/ Sampling of core water (Analysis of nulear species, etc.)(Note 3)	○																								

◎:Main parameters required for accomplishing measurement purpose

○:Dependent parameters required for accomplishing measurement purpose

▲:Parameters required for initiating operation and confirming success of operation

△:Parameters required for confirming success of operation

◇:Available parameters for comprehending plant condition

Note 1:No.13 and 17 is prefeable to be measured at feedwater line in front of RPV/PCV, but if feedwater line is established, outlet flow of resource of feedwater is supposed to be supplementally confirmed as a dependent parameter (backup parameter) and they are surveyed including that they are exluded from development object of phase I investigation.

Note 2:No.15 and 16 are selected in existing AM (Accident Management) as parameters for confirming warning of RPV damage, but because they are for confirming numbers of loss of measurement and it is not necessary to enhance function of them, they are surveyed including that they are exlcluded from development object of phase I investigation.

Note 3:No.21 is selected as reflection of Fukushima response, but because it is sampling analysis and is necessary after calming down of accident, it is surveyed including that they are exlcluded from development object of phase I investigation.

Note 4:Resistance (critical value) is evaluated as instrumentation systems.

1.5 SA Variables & SA Classification(2): Matrix for PWR (Below is Draft Version)

Environment Conditions

Measurement Purposes / Performance

Measurement Variables

(SA Classification) Plant condition	(SA1) Core damage→Meltdown/RV integrity is maintained/CV integrity is maintained **SA1**	(SA2) Meltdown/RV is damaged/CV integrity is maintained **SA2**	(SA3a) Meltdown/RV is damaged/CV is damaged **SA3a**	(SA3b) Meltdown/RV is damaged/CV is damaged **SA3b**
Environmental condition in CV ・Maximum temperature ・Pressure ・Humidity ・Radiation	・190 degree Celsius ・0.414 MPa ・100% ・Under exisiting PAM condtion	below right SA3a condition	・200 degree Celsius ・1.6 MPa ・100% ・2MGy/year （Annular space is under 5MGy/year.）	・300 degree Celsius ・Atomosphere pressure ・100% ・2MGy/year （Annular space is under 5MGy/year.）
Environment condition outside CV ・Maximum temperature ・Pressure ・Humidity ・Radiation	・Atomosphere temperature ・Atomosphere pressure ・– ・–	Same as right SA3a condition	・Depending on location ・Atmosphere pressure ・– ・Depending on location	・Depending on location ・Atmosphere pressure ・– ・Depending on location
Required duration of performance		under debate		

Monitoring **Operation Confirmation** **Monitoring** **Operation Confirmation** **Monitoring** **Operation Confirmation** **Monitoring**

No.	Parameters/Variables	Possibility of boundary damage and confirmation of event initiation	Cooling function		Containment function						Operation Confirmation					Possibility of boundary damage and confirmation of event initiation	Cooling function				Operation Confirmation	Possibility of boundary damage and confirmation of event initiation	Cooling function	Containment function			
		Confirm core damage	Confirm condition of core cooling	Confirm submergence condition of heat exchanger tube	Confirm loss of isolation function of containment	Confirm falling down of core debris under RV	Confirm vapor explosion within RV	Confirm hydrogen initiation and combustion	Confirm contributory SG tube rupture	Confirm a great deal of emission of FP from containment	Confirm a great deal of emission of FP from secondary system	Depressurize primary system	Makeup to primary system	Feed water to SG	Makeup to RWST	Injection to containment	Confirm RV damage	Confirm cooling condition of core debris	Confirm loss of isolation function of containment	Confirm vapor explosion at outside of core	Confirm hydrogen initiation and combustion	Confirm direct heatup of CV atomosphere	Confirm CV damage by overheat	Confirm CV damage by overpressure	Confirm a great deal of emission of FP from containment	Confirm a great deal of emission of FP from secondary system	Makeup to primary system (Note 4)	Makeup to RWST (Note 4)	Injection to containment (Note 4)	CV spray (Note 4)	Natural convection cooling within CV	Heat storage to liquid layer within CV (Note 4)	Filtered vent (Note 4)	Confirm CV damage	Confirm cooling condition of core debris	Confirm hydrogen initiation and combustion	Confirm a great deal of emission of FP from containment	Confirm a great deal of emission of FP from secondary system	Same as Note 4	Confirm CV damage	Confirm cooling condition of core debris	Confirm hydrogen initiation and combustion	Confirm a great deal of emission of FP from containment	Confirm a great deal of emission of FP from secondary system
1	Core exit temperature	◎	◎										▲														▲																	
2	Reactor vessel (RV) water level		○			○																																					
3	Steam Generat (SG) water level (narrow range)			◎					○					▲																													
4	Reactor coolant pressure/RCS pressure		○				◎					▲					◎(Note 1)																											
5	Containment pressure/CV pressure (wide range)				○			○									◎(Note 1)	○	○	◎	○	○		◎						▲	▲	▲	▲	◎					◇					
6	Containment temperature/CV temperature							○										○			○	◎	◎											○	○	○				◇	◇	◇		
7	Containment hydrogen concentration/ CV hydrogen concentration							◎													◎															◎						◇		
8-1	Reaocr cavity water level/ ICIS Thimble Tube Room water level (Note 2)															▲	○	◎											▲				△	▲	▲		◎							
8-2	Containment recirculation sump water level / CV recirculation sump water level (Note 2)															△																											
9	Reactor cavity temperature/ ICIS Thimble Tube Room temperature					◎											○	○																	○								
10	Annulus hydrogen concentration								○												○														○						◇		
11	Monitoring post (Note 3)				◎					◎	◎							◎							◎	○									○		◎	◎		◇			◇	◇
12	Containment high range area raditation monitor/ High range area raditation monitor	○																																									
13	Contatinment exhaust radiation gas monitor/ Exhaust high rahge gas monitor				○					○								○							○											○							
14	Main steam line radiation monitor								◎		○														◎												○						
15	RWST water level												△		▲												△	▲															
16	NIS					○																																					
17	CCW surge tank pressure (wide range)																														△											
18	CCW flow																														△											
19	Fire service water accumulated flow/Integrate flow																														△		△									

◎:Main parameters required for accomplishing measurement purpose
○:Dependent parameters required for accomplishing measurement purpose
▲:Parameters required for initiating operation and confirming success of operation
△:Parameters required for confirming success of operation
◇:Available parameters for comprehending plant condition

} Envirionment resistance is required in accordance with survey result of 2011.

} Environment resistance is required with limiting duration required for SA opearation.

Note 1 Confirm containment pressure instead of reactor coolant pressure after RV damage (because reactor coolant pressure quickly becomes same pressure as containment pressure after RV damage.)
Therefore, environment resistance of reactor coolant is included to verification condition of PAM.

Note 2 Reactor cavity water level overlaps existing measurement range of recirculation sump water level. Existing recirculation sump water level measurement utilizes diaphgram seal sensor and because it is thought that it is likely to be influenced by variation of environmental condition, reactor cavity water level is measured by applying such as thermocouple type.

Note 3 Monitoring post is surveryed including excluding from development object because it is located outside CV and it is possible to apply equipment such as portable type.
In addition, it is not limited to monitoring post if it can measure dose rate outside CV.

1.6 Design Requirements of Industrial Proposal(1)

NO.	Items	Requirements
1	Independence between Levels of Defense in Depth	Level of defense in depth of main parameters, which are categorized as Level 4, should be designed to have independence from Level 3 parameters. The definition of Level 3 and 4 is consistent with the defense in depth level identified in IAEA SSR-2/1.
2	Redundancy and Diversity	Redundancy and diversity requirements same as safety-related equipment are not required. Basically single configuration is applicable. However, the severe accident monitoring instrumentation should be designed to meet enough reliability for monitoring.
3	Separation and Independence	Level 4 parameters should be designed to have independence from level 3 parameters wherever practical. Redundant equipment should be independent and separated from each other wherever practical.
4	Environmental Qualification	Severe accident monitoring instrumentation should be designed to have environmental resistance, including temperature, pressure, and radiation. Conditions of temperature, pressure, and radiation under severe accident environment should be set with considering SA classification and arrangement location.
5	Seismic Qualification	Seismic qualification should be required.

1.6 Design Requirements of Industrial Proposal(2)

NO.	Items	Requirements
6	Power Supply	The power supply for severe accident monitoring instrumentation should be used.
7	Testability	Severe accident monitoring instrumentation should be designed to have periodic testing capability when the reactor is in operation or in shutdown.
8	Quality Assurance	Quality assurance such as design control should be conducted in accordance with JEAG 4111-2009 (Guideline for quality assurance widely used for Japanese nuclear power plants).
9	Indication and Record	Severe accident monitoring instrumentation should be designed to provide continuous monitoring display in the main control room and recording capability should be provided.
10	Flooding Protection	If internal flooding and external flooding occur, required flooding protection should be taken to accomplish function of severe accident monitoring instrumentation.
11	Fire Protection	Severe accident monitoring instrumentation should be designed that noncombustible and fire retardant materials are used wherever practical.

1.7 Summary

- The development of the SA-Keisou is needed to monitor the important parameters which contribute to the prevention of severe accidents at the plant.
- Extraction of measuring variables for SA-Keisou including additional variables is accomplished based on analysis of accident management guidance (AMG), and majour standards, the analysis of TEPCO's Fukushima Daiichi accident.
- Measuring variables for SA-Keisou have been determined.
  BWR : 24 variables (4 added variables)
  PWR : 23 variables (4 added variables)
- In the severe accident instrumentation, plant conditions after core damage are classified into the following:
  SA1: Core is damaged, but core fuel is inside the reactor vessel
  SA2: RV failure; core fuel is outside the reactor vessel
  SA3a: Containment failure (Water Feed Injection to inside of CV is success)
  SA3b: Containment failure (Water Feed Injection to inside of CV is failure)
- The parameters in relation to SA classification depending on plant situation, including measurement purpose such as monitoring and operation confirmation were also shown.

1.8 Schedule

R&D Plan contents	Fiscal 2011	Fiscal 2012	Fiscal 2013	Fiscal 2014
1. Defining the requirements for instrumentation systems				
① Selection of parameters required for SA				
② Setting for the environment conditions and etc of SA				
③ Defining the requirements				
2. The settling of the primary development plan				
① Public Offering of Technical Ideas				
② Setting for the basic specification on instrumentation systems				
③ Study of the development plan on instrumentation systems				
④ Investigation of the priority of the development plan				
3. The development of the SA instrumentation systems				
① Design and prototype production of instrumentation systems				
② Basic test and analysis on instrumentation systems				
③ Qualification tests on instrumentation systems				
4. Drawing up standards and guidelines for SA				
① Investigation of overseas standards				
② Drawing up standards and guidelines				

Phase 1: 2011 to 2nd quarter 2014

System Installation for actual NPPs : after completing tests (from 2013)

Thank you for your attention

END

終（O-wa-ri）