DEVELOPMENT OF DEFENCE-IN-DEPTH EVALUATION METHOD AGAINST EXTERNAL EVENTS

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ABSTRACT

Japanese new regulatory requirements based on the lessons learned from the Fukushima Daiichi accident were issued and applied in the licensing of existing reactors. However, the concept of defence-in-depth against external events does not seem to become clear in the new regulatory requirements as well as in the process of the new regulatory compliance review of several Japanese NPPs. In this paper we propose an idea to develop the evaluation method of defence-in-depth against external events. This is a sequel to the technical paper which was presented to PSAM13 (Ref.1).

1. Introduction

Japan Nuclear Safety Institute (JANSI) was established after the Fukushima Daiichi accident as a new entity that can serve as a powerful industry driver and also has autonomy of making judgments unaffected by the intentions of nuclear operators. JANSI evaluates safety improvement measures from advanced and broader perspectives, and play the powerful function of extending proposals or recommendations to nuclear operators, while working in coordination with related organizations in and outside Japan. JANSI has mainly been focusing on the assessment of defence-in-depth against severe accidents using IAEA SRS-46 (Ref.2, Ref.3). In addition, we need to expand our scope to the assessment of defence-in-depth against external events.

2. Action plan

We are making an effort to develop the evaluation method of defence-in-depth against external events according to the three steps as shown in Figure-1.

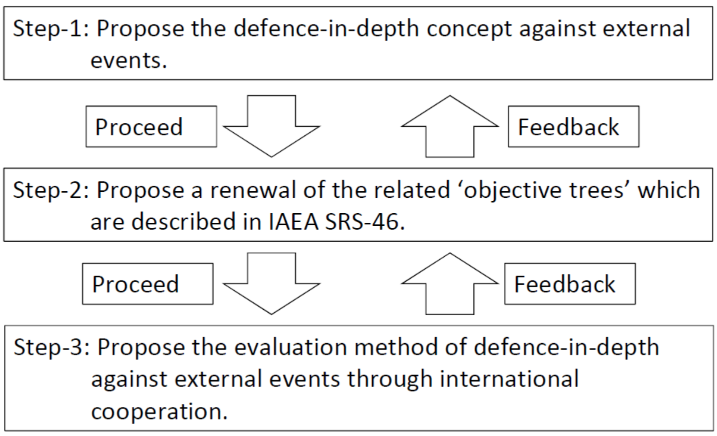

Figure-1: Action plan

3. Japanese new regulatory requirements related to the defence-in-depth concept

According to Nuclear Regulation Authority (NRA), several policies related to the defence-in-depth concept are applied to the new regulatory requirements, and the structure of new requirements is shown in Figure-2.

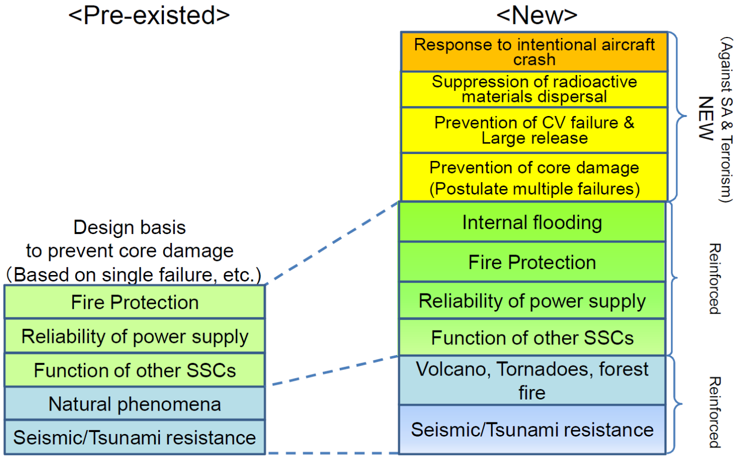

Figure-2: Japanese Structure of New Requirements (Ref. 4)

4. Safety improvement activities of Japanese nuclear operators

According to the Federation of Electric Power Companies of Japan (FEPC), all the Japanese nuclear operators have been implementing extensive safety improvement activities including the measures against earthquake, tsunami, and severer accidents as shown in Figure-3.

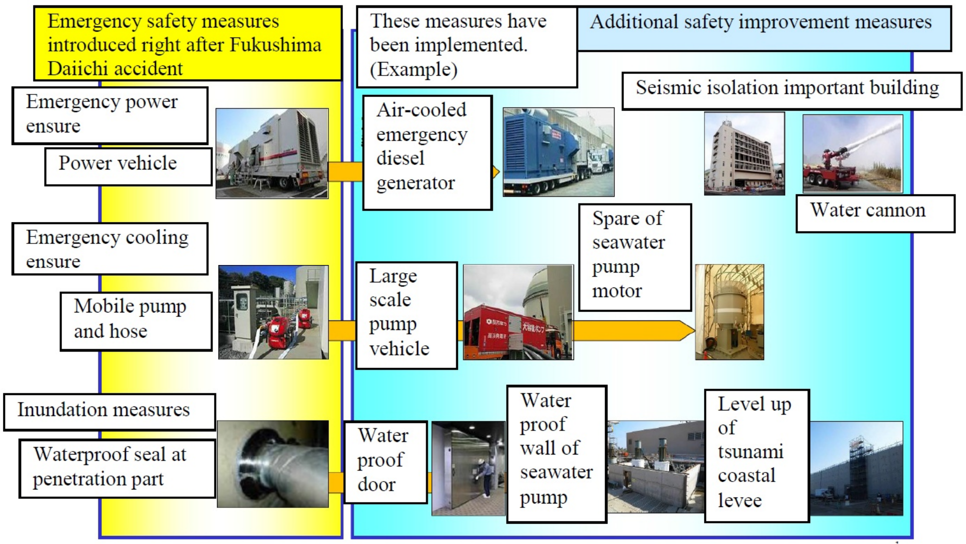

Figure-3: Emergency power and emergency cooling ensure, and inundation measures (Ref. 5)
(JANSI has translated Japanese explanation into English by its responsibility)

5. Assessment procedure of defence-in-depth for Japanese NPP against severe accidents conducted by JANSI using IAEA SRS-46

Figure-4 through Figure-6 and Table-1 shows the assessment procedure of defence-in-depth against severe accidents for Japanese NPP conducted by JANSI using IAEA SRS-46. Figure-4 shows the idea of objective trees described in IAEA SRS-46. Table-1 shows the list of the relevant 18 objective trees selected by JANSI. Figure-5 shows how to assess the defence-in-depth about each figure for objective trees in terms of sufficiency ratio. The calculation process is a little bit complicated, but if calculated sufficiency ratio is 100%, it means that all the provisions in objective trees are satisfied by the existing or planned severe accident measures. Figure-6 shows an evaluation result in terms of sufficiency ratio. The sufficiency ratios greatly increase with measures after the Fukushima Daiichi accident and become roughly equivalent to those of an existing European NPP. The evaluation is basically conducted based on the open information. There are two dents with low sufficiency ratio at the left and right side. The reason of low sufficiency ratios in the

No.39, 44, and 46 of SRS-46 is that these objective trees contain several advanced permanent severe accident measures including "In-vessel retention by external cooling". It is unlikely to apply these measures to the existing plants not only in European countries but also in Japan because it requires too much money and period. The reason of low sufficiency ratios in the No.74, 75, 76 of SRS-46 for an existing European NPP is that we cannot obtain the trade secret information including "Determination of performance of equipment outside design range".

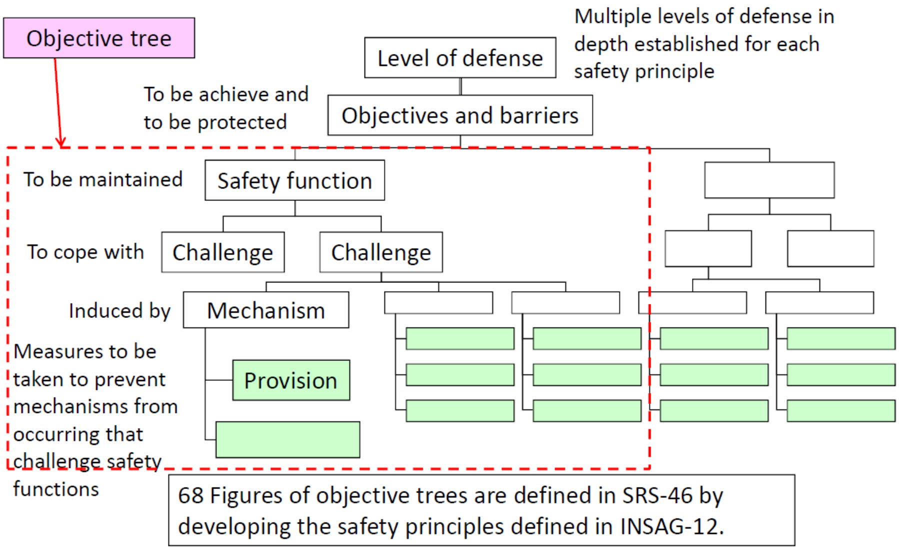

Figure-4: Idea of objective trees described in IAEA SRS-46

No.	Description of objective trees	No.	Description of objective trees
14	Radiological impact on the public and the local environment	58	Verification of design and construction
15	Ultimate heat sink provisions	62	Organization, responsibilities and staffing
33	Automatic shutdown systems (1)	63	Safety review procedures
34	Automatic shutdown systems (2)	68	Emergency operation procedures
39	Emergency heat removal	70	Engineering and technical support of operations
44	Confinement of radioactive material	74	Strategy for accident management
46	Protection of confinement structure	75	Training and procedures for accident management
48	Monitoring of plant safety status	76	Engineered features for accident management
50	Station blackout (SBO)	77	Emergency plans and emergency response facilities

Table-1: List of 18 objective trees selected by JANSI

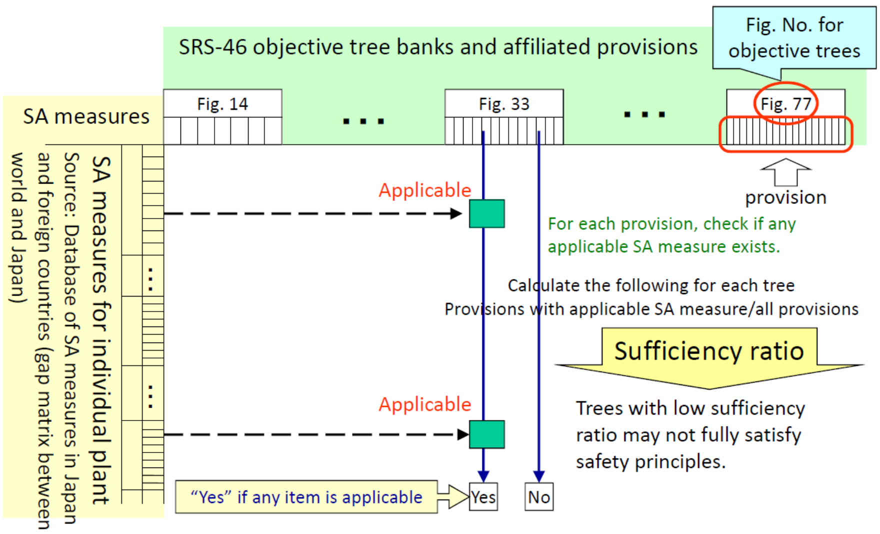

Figure-5: Assessment of the defence-in-depth about each figure for objective trees

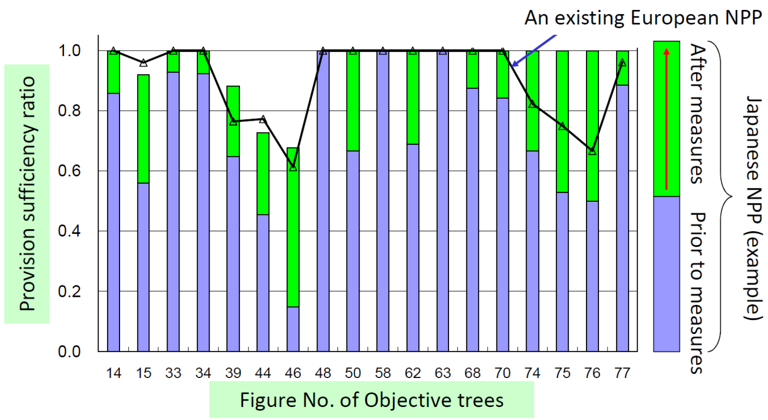

Figure-6: An evaluation result in terms of sufficiency ratio

6. Idea of the defence-in-depth concept against external events

Regarding the evaluation method development of the defence-in-depth, we have a plenty of discussion with Dr. Misak (of Nuclear Research Institute – UJV Rez, Czech Republic), who is one of the key contributors to drafting and review about IAEA SRS-46 (Ref. 6). We planned to use the above mentioned IAEA SRS-46 method not only to assess defence-in-depth against severe accidents but also against external events. However, Dr. Misak pointed out that IAEA SRS-46 had not been changed since its first publication in 2005, and it had not been reflected the lessons learned from the Fukushima Daiichi accident especially against extreme external events beyond design basis. To address these issues, we decided to develop the evaluation method of defence-in-depth against external events according to our action plan.
Figure-7 shows the idea of the defence-in-depth concept against external events relevant to the sequential defence-in-depth. Left-pointing arrows in the middle show the sequential defence-in-depth concept. Sequential defence-in-depth is popular among nuclear safety experts and generally divided into five levels. Should one level fail, the subsequent level comes into play. In contrast, the concept of defence-in-depth against external events does not seem to become clear in the new regulatory requirements. Therefore, we propose the idea of the defence-in-depth concept against external events. Up-pointing arrows in the lower part show the defence-in-depth against external events. As for the defence-in-depth against external events, the assumed strength of external events and the relevant area in sequential defence-in-depth are different at each level.

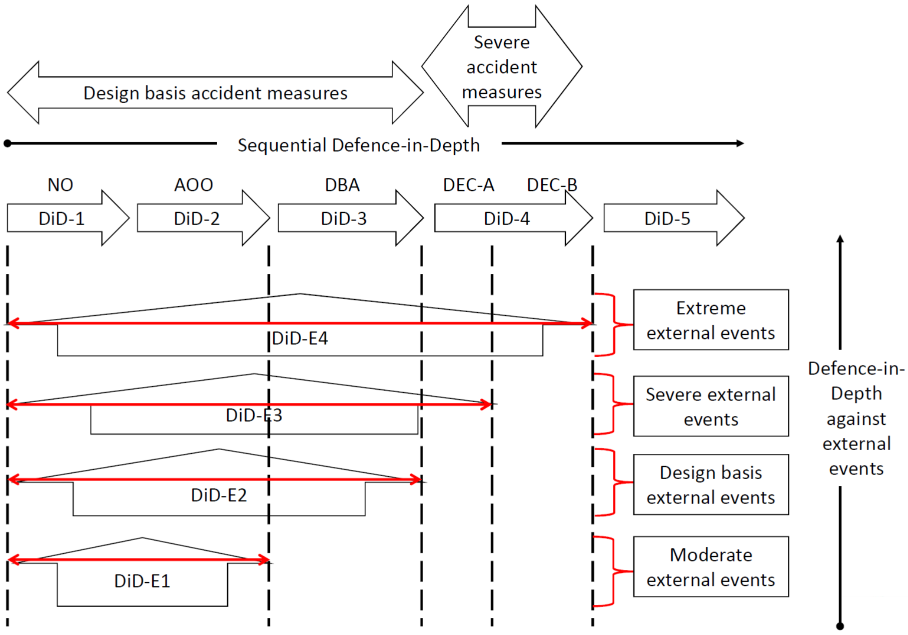

Figure-7: Idea of the defence-in-depth concept against external events

Table-2 summarizes the objectives of each level and the corresponding means (or strategies) that are essential for achieving them with related to Sequential Defence-in-Depth. Table-3 summarizes the objectives, the assumed strength of external events, the relevant areas in sequential DiD, and the strategies in Japan, with related to Defence-in-Depth against external events.

Levels of Sequential Defence-in-Depth <Authorized by IAEA>		
Levels of Defence-in- Depth	Objective	Essential means for achieving the objective
DiD-1	Prevention of abnormal operation and failures	Conservative design and high quality in construction and operation
DiD-2	Control of abnormal operation and detection of failures	Control, limiting and protection systems and other surveillance features
DiD-3	Control of accidents within the design basis	Engineered safety features and accident procedures
DiD-4	Control of severe plant conditions, including prevention of accident progression and mitigation of the consequence of severe accidents	Complementary measures and accident management
DiD-5	Mitigation of radiological consequences of significant releases of radioactive materials	Off-site emergency response

Table-2: Summary of Sequential Defence-in-Depth

Levels of Defence-in-Depth against external events <Proposed by JANSI>				
Levels of Defence-in- Depth	Objective (Related paragraph number in IAEA Safety Standards Series No.SSR-2/1 (Rev. 1) (Ref. 7))	Assumed strength of external events	Relevant area in Sequential DiD	Strategy in Japan
DiD-E1	Prevention of failures of operating systems (N/A)	Moderate external events	DiD-1 DiD-2	Automatic shutdown system against an earthquake
DiD-E2	Items important to safety shall be designed and located to withstand the effects of hazards or to be protected against hazards and against common cause failure mechanisms generated by hazards (5.15A)	Design basis external events	DiD-1 DiD-2 DiD-3	Conservative evaluation of design basis external events
DiD-E3	Secure an adequate margin to protect items important to safety, and to avoid cliff edge effects (5.21)	Severe external events	DiD-1 DiD-2 DiD-3 DiD-4 (part)	Secure an adequate margin in the design (Back-fit rule)
DiD-E4	Secure an adequate margin to protect items ultimately necessary to prevent an early radioactive release or a large radioactive release (5.21A)	Extreme external events	DiD-1 DiD-2 DiD-3 DiD-4	Confirmation of an adequate margin in the design (Stress test)

Table-3: Summary of Defence-in-Depth against external events

As a premise of a discussion, the following Japan's unique situation should be considered.
(1) Automatic shutdown system that is operated by the earthquake sensing device located on the base mat of Reactor Auxiliary Building of PWR and Reactor Building of BWR is installed at all Nuclear Power Stations in Japan. The system works by an earthquake smaller than the design basis earthquake. (DiD-E1)

(2) External natural events in Japan including earthquake and tsunami are evaluated much more conservative way reflecting the lessons learned from the Fukushima Daiichi accident. (DiD-E2)
(3) Japanese new regulatory requirements shall be applied to new Nuclear Power Stations as well as existing Nuclear Power Stations without exception. This special requirement is called “back-fit rule” in Japan. (DiD-E3)
(4) In Japan, the reactor operators shall submit “Safety Improvement Evaluation Report” within six months after the second restart of their Nuclear Power Stations during the commercial operation period. It includes the latest stress test results, and the submission would be after about two years from the first restart at the earliest. We believe that the report will be helpful to confirm an adequate margin in “Defence-in-Depth against external events”. (DiD-E4)
(5) Design basis accident measures in Japan include both Operating systems and Safety systems. In other words, Design basis accident measures are involved in Sequential Defence-in-Depth at three different levels (i.e. DiD-1, 2, 3).
(6) Severe accident measures are involved in Sequential Defence-in-Depth at level 4 (i.e. DiD-4).
Table-4 through Table-8 summarizes the strategies in Japan, the descriptions, the relevant areas in sequential DiD, and several examples with related to Defence-in-Depth against external events at DiD-E1 through DiD-E4.

Summary of Defence-in-Depth against external events <Proposed by JANSI>					
DiD Level	Strategy in Japan	Description	Assumed strength of external events	Relevant area in Sequential DiD	Example
DiD-E1	Automatic shutdown system against an earthquake	Automatic shutdown system that is operated by the earthquake sensing device located on the base mat of Reactor Auxiliary Building of PWR and Reactor Building of BWR is installed at all Nuclear Power Stations in Japan. The system works by an earthquake smaller than the design basis earthquake.	Moderate external events	DiD-1 DiD-2	The system works by an earthquake level of 160 gal (horizontal) or 80 gal (vertical) at the reference Japan’s NPP.

Table-4: Summary of Defence-in-Depth against external events at DiD-E1

Summary of Defence-in-Depth against external events <Proposed by JANSI>					
DiD Level	Strategy in Japan	Description	Assumed strength of external events	Relevant area in Sequential DiD	Example
DiD-E2	Conservative evaluation of design basis external events	External natural events in Japan including earthquake and tsunami are evaluated much more conservative way reflecting the lessons learned from the Fukushima Daiichi accident.	Design basis external events	DiD-1 DiD-2 DiD-3	The following design external events are adopted to the reference Japan’s NPP. (1) Earthquake: Ss-1 (Horizontal: 540 gal, Vertical: 324 gal), Ss-2 (Horizontal: 620 gal, Vertical: 320 gal) (2) Tsunami: Defining position (Highest: +1.9 m, Lowest: -1.60 m), Water intake position (Highest: +4.94 m, Lowest: -5.43 m), Intake pit position (Highest: +5.02 m, Lowest: -3.40 m) (3) Snowstorm (Snowfall): Observed record near the Site (Maximum snowfall: 38 cm)

Table-5: Summary of Defence-in-Depth against external events at DiD-E2

Summary of Defence-in-Depth against external events <Proposed by JANSI>					
DiD Level	Strategy in Japan	Description	Assumed strength of external events	Relevant area in Sequential DiD	Example
DiD-E2	Conservative evaluation of design basis external events	External natural events in Japan including earthquake and tsunami are evaluated much more conservative way reflecting the lessons learned from the Fukushima Daiichi accident.	Design basis external events	DiD-1 DiD-2 DiD-3	(4) Volcano: Monitoring of volcanic activity against major calderas. Design layer thickness of the drop pyroclastic (15 cm) (5) Windstorm (Typhoon): Observed record near the Site (Maximum wind speed: 62.7 m/s) (6) Freezing: Observed record near the Site (Lowest temperature: -6.7 degrees Celsius) (7) Tornado: Design maximum wind speed (92 m/s) (8) Forest fire: Large scale forest fire more than a firebreak (9) Biological event: Large scale invasion of marine organisms like jellyfish leading to the loss of seawater intake function (10) Lightning strike: Large scale lightning surge

Table-6: Summary of Defence-in-Depth against external events at DiD-E2 (continued)

Summary of Defence-in-Depth against external events <Proposed by JANSI>					
DiD Level	Strategy in Japan	Description	Assumed strength of external events	Relevant area in Sequential DiD	Example
DiD-E3	Secure an adequate margin in the design (Back-fit rule)	Japan's new regulatory requirements shall be applied to new Nuclear Power Stations as well as existing Nuclear Power Stations without exception. This special requirement is called "back-fit rule" in Japan.	Severe external events	DiD-1 DiD-2 DiD-3 DiD-4 (part)	The same design external events are applied to "Design basis accident measures" as well as "Severe accident measures". At present, the extra margin is not required to "Severe accident measures". "Back-fit rule" was strictly applied to the reference Japan's NPP. It means that the reference NPP conforms fully to the latest requirements. Thus, the reference NPP has an adequate margin which is included in the design criteria.

Table-7: Summary of Defence-in-Depth against external events at DiD-E3

Summary of Defence-in-Depth against external events <Proposed by JANSI>					
DiD Level	Strategy in Japan	Description	Assumed strength of external events	Relevant area in Sequential DiD	Example
DiD-E4	Confirmation of an adequate margin in the design (Stress test)	Based on the request by NRA, the reactor operators shall submit "Safety Improvement Evaluation Report" within six months after the second restart of their Nuclear Power Stations during the commercial operation period. The Report includes the latest stress test results, and the submission would be after about two years from the first restart at the earliest.	Extreme external events	DiD-1 DiD-2 DiD-3 DiD-4	The Japan's reference NPP is expected to submit the Report in a few years.

Table-8: Summary of Defence-in-Depth against external events at DiD-E4

7. A renewal of the related ‘objective trees’ which are described in IAEA SRS-46

Based on our idea of the defence-in-depth concept against external events mentioned above, we have started to prepare a proposal of a renewal of the related ‘objective trees’ which are described in IAEA SRS-46. For example, Figure-8 shows the original objective tree of FIG.23 described in IAEA SRS-46 regarding CCF (common cause failure). We believe that FIG.23 of SRS-46 should be updated to cover not only all the levels of Sequential Defence-in-Depth except for DiD-5 but also all the levels of Defence-in-Depth against external events. Although it is on the midway, an idea of a renewal of the FIG.23 of SRS-46 focusing on CCF due to external events, especially for earthquake and tsunami is shown in Figure-9 through Figure-11.

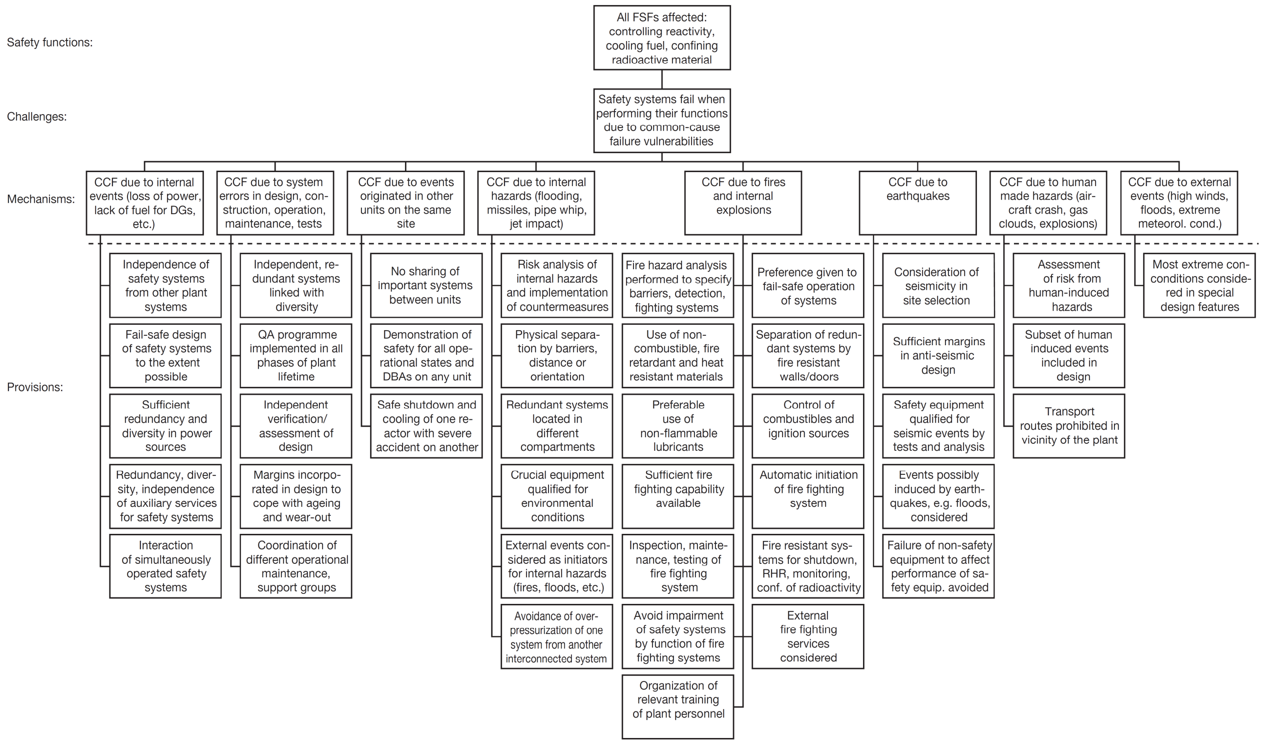

FIG. 23. Objective tree for Level 3 of defence in depth (CCF, common cause failure; DG, diesel generator; RHR, residual heat removal). Safety principle (177): dependent failures.

Figure-8: Original objective tree of FIG.23 described in IAEA SRS-46 (Ref. 3)

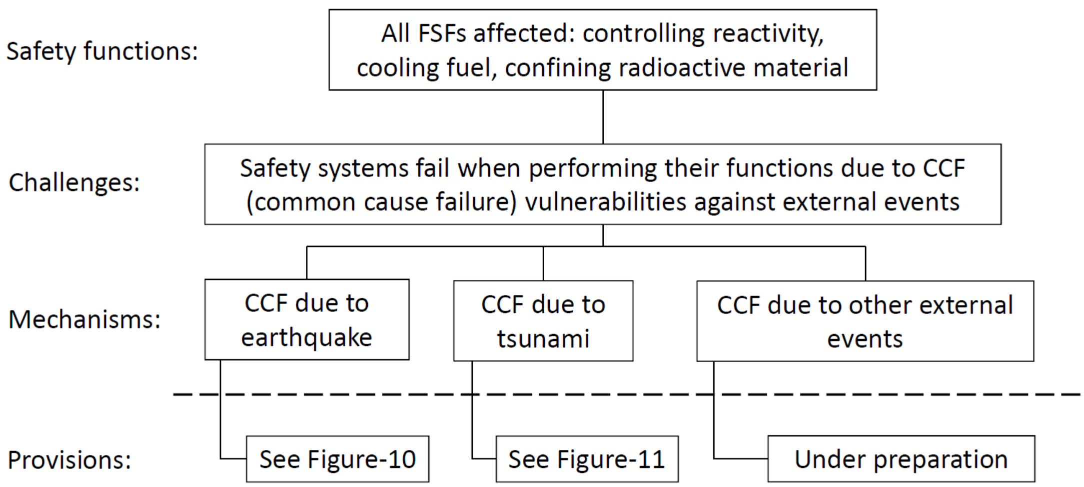

Figure-9: An idea of a renewal of the FIG.23 of SRS-46 focusing on CCF due to external events

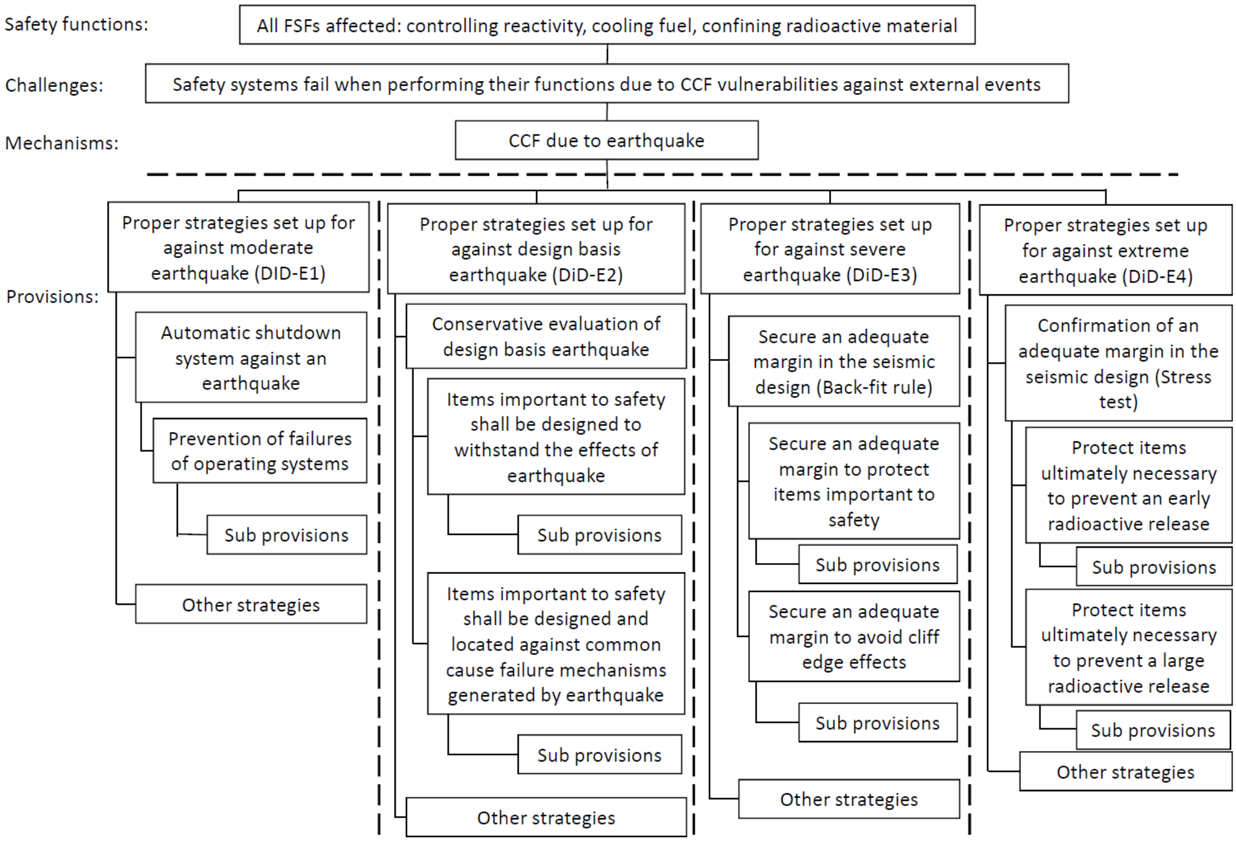

Figure-10: An idea of a renewal of the provisions focusing on CCF due to earthquake

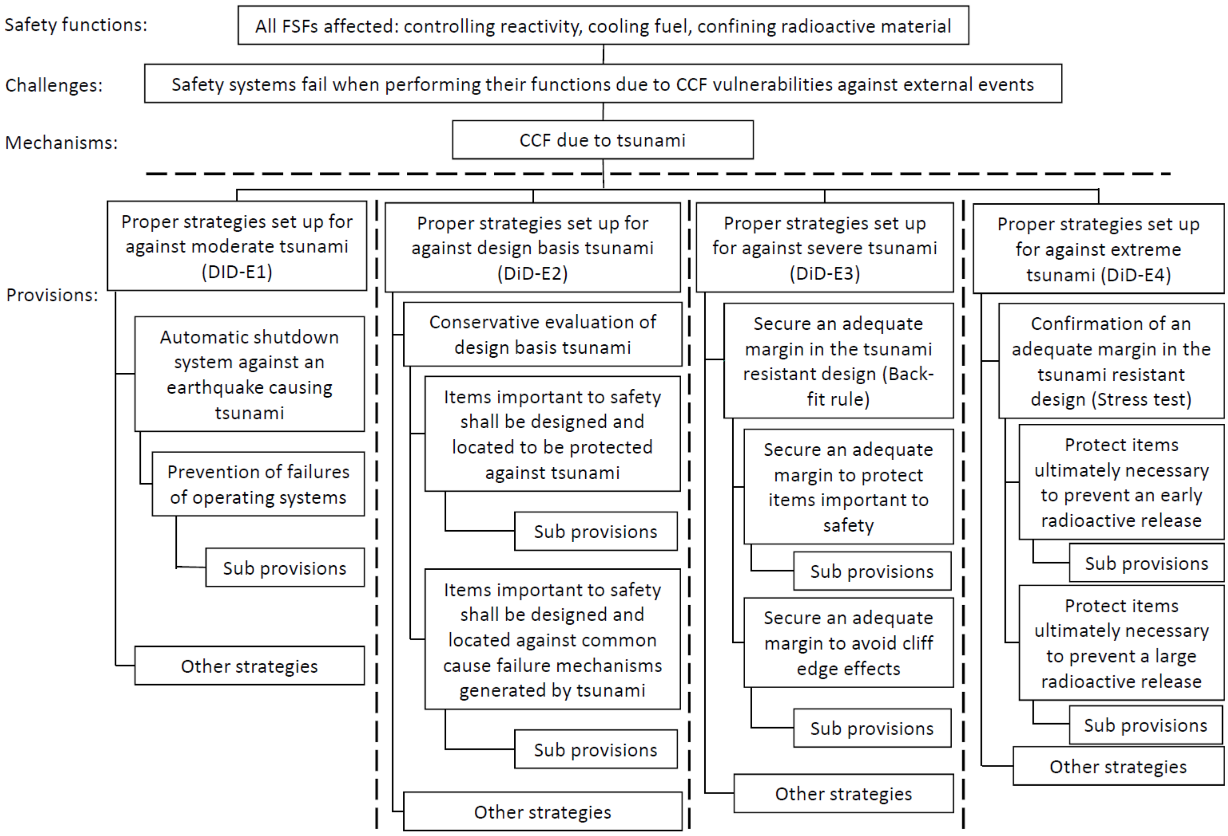

Figure-11: An idea of a renewal of the provisions focusing on CCF due to tsunami

8. Conclusions

JANSI has mainly been focusing on the assessment of defence-in-depth against severe accidents using IAEA SRS-46, but the scope should be expanded to include the assessment of defence-in-depth against external events. We planned to use the IAEA SRS-46 method not only to assess defence-in-depth against severe accidents but also against external events. However, we realized that IAEA SRS-46 had not been reflected the lessons learned from the Fukushima Daiichi accident especially against extreme external events beyond design basis. To address these issues, we decided to develop the evaluation method of defence-in-depth against external events. We have been making an effort to develop the evaluation method of defence-in-depth against external events according to our action plan. We propose an idea of the defence-in-depth concept against external events and we have started to prepare a proposal of a renewal of the related 'objective trees' which are described in IAEA SRS-46.

References

1. M. Inagaki, M. Ohtani, "CONCEPT OF DEFENCE-IN-DEPTH AGAINST EXTERNAL EVENTS IN JAPAN," Seoul, Korea, October 2-7 2016, 13th International Conference on Probabilistic Safety Assessment and Management (PSAM13)
2. S. Kurata, "Approach to Voluntary Safety Improvement and Status of SA Countermeasures," Tokyo, Japan, April 24, 2014, JANSI Annual Conference 2014 for Step up, JANSI
3. IAEA Safety Reports Series No.46, "Assessment of Defence in Depth for Nuclear Power Plants," Vienna, 2005
4. H. Yamagata, "The Defence in Depth Concept Applied to the New Regulatory Requirements in Japan," Vienna, Austria, 21-24 October 2013, Conference ID: 43048 (CN-205), International Conference on Topical Issues in Nuclear Installation Safety, IAEA
5. "Voluntary Safety Improvement Activities of Japanese Nuclear Operators," Tokyo, Japan, March 18, 2016, FEPC (Japanese)
6. J. Misak, "Post-Fukushima Severe Accident Mitigatory Measures," Tokyo, Japan, April 24, 2014, JANSI Annual Conference 2014 for Step up, JANSI
7. IAEA Safety Standards Series No.SSR-2/1 (Rev.1), "Safety of Nuclear Power Plants: Design," Vienna, 2016