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PSA methodology for classification of Practical Elimination for APR1400 in terms of Source Term Category of Level 2 PSA

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1. Introduction

The definition of Practical Elimination (PE) was introduced in the IAEA Safety Standards Series No. NS-G-1.10 and was adopted in SSR-2/1. The paragraph 6.5 in SSR-2/1 states that some severe accidents such as hydrogen detonation and containment bypass must be considered to address PE of Severe Accidents.

APR1400 has various advanced safety features to mitigate severe accidents to address PE of Severe Accidents. The mitigation systems of APR1400 related to Severe Accidents stated in SSR-2/1 are discussed for their effectiveness for PE.

This paper has described the methodology for classification of Practical Elimination (PE) for APR1400 in terms of source term category (STC) of Level 2 PSA.

2. Requirements for PE

The concept of PE of large or early radioactive release is utilized for preventing severe accident conditions. Three steps to achieve the goal applied to the APR1400 are as follows:

- Identify phenomena that have to be practically eliminated
- Provide design provisions to prevent occurrence of each phenomenon
- Demonstrate practical elimination by being either physically impossible or extremely unlikely with high level of confidence

The phenomena of severe accidents that are to be practically eliminated are consistent with the international guidance such as IAEA TECDOC-1791 and WENRA RHWG report.

Accident sequences that have the potential to cause a Large Release or Early Release shall be Practically Eliminated. At least the following phenomena shall be demonstrated to be PE using PSA and/or deterministic analysis according to EUR Rev.E.

- Hydrogen detonation
- Large steam explosion
- Direct containment heating
- Large reactivity insertion including heterogenous boron dilusion
- Rupture at high pressure – e.g. Reactor Pressure Vessel (RPV) and Reactor Coolant System (RCS)
- Fuel failure in a Spent Fuel Storage Pool
- Primary containment over pressurization
- Late containment failure due to Basemat Melt-through (BMT)
- Severe Accidents challenging the containment system – e.g. Containment Bypass such as SGTR, ISLOCA, CIS-open
- Severe Accidents in the shutdown during containment-open

Deterministic and Probabilistic Targets of EUR_Rev.E are presented in Figure 1. According to the probabilistic target of EUR, the core damage frequency (CDF) target for all of the internal and external events is set to $1x10^{-5}$/RY, while the large release frequency (LRF) is $1x10^{-6}$/RY.

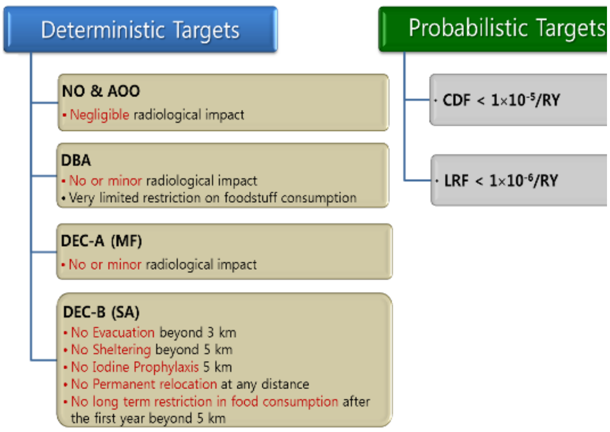

Fig. 1. Deterministic and Probabilistic Safety Targets for EUR_Rev.E

One of the objectives of PSA is to demonstrate how to meet probabilistic targets. In addition, the early failure of the containment or very large releases of radioactive materials shall have a cumulative frequency well below the target of 10^{-6}/RY. The “cliff edge effect” could be avoided when this cumulative frequency is at least one order of magnitude below the Criteria for Limiting Impact (CLI).

3. Design Provisions of APR1400 for PE

APR1400 has various advanced safety features to mitigate severe accidents to address practical elimination. The severe accident mitigation systems are designed to limit the off-site releases after the accidents with core melt. They consist of Rapid Depressurization (RD) function, Hydrogen Control System (HG), Containment Spray and Backup System (CSS and ECSBS), Cavity Flooding System (CFS), and Containment Isolation System (CIS) which are described as followings.

- The RD function using Pilot-Operated Safety Relief Valves (POSRVs) rapidly depressurizes the RCS to eliminate a High Pressure Melt Ejection (HPME).
- The HG is designed to control combustible gas like hydrogen gas inside the containment and IRWST within acceptable limits.
- The CSS and ECSBS are designed to reduce containment pressure and temperature during an accident and to remove iodine radionuclides and aerosols from the containment atmosphere.
- The CFS designed to flood the reactor cavity facilitates the cooling and stabilization of the debris to mitigate late containment failure.
- The containment isolation system (CIS) is designed to confine the release of any radioactivity from the containment following an accident.

4. PSA Level 2 Analysis for Internal Events

The at-power PSA Level 2 analysis is to ascertain the likelihood, magnitude, and timing of radiological releases to the environment following a severe accident. The analysis includes evaluation of the physical processes and phenomena involved in the release of radiological material from the fuel during a severe accident, assessment of the transport and deposition of this material inside the containment, determination of the potential containment failure modes, and identification of the phenomena contributing to the various failure modes.

The applied Level 2 PSA methodology is consistent with NUREG/CR-1335 and NUREG-1150. The Level 2 PSA for the EU-APR1400 has been performed for the following tasks:

- Plant Damage State Analysis
- Containment Event Tree Analysis
- Source Term Evaluation
- Sensitivity, uncertainty and importance analysis

The classification to define PE items for each Source Term Category (STC) is presented in Table I. Each STC has been assigned into PE items based on source term release characteristics. Source term characteristic such as the isotropic content, magnitude and the time of release are calculated with MAAP code for each release category. If the release of STC does not exceed any of CLI criteria, it is considered as a category with small release frequency (SRF).

Table I: STC Classification for APR1400 Level 2 PSA

STC No.	PE Items	Summary Description
STC 01	09-Bypass	SGTR w/o scrubbing
STC 02	09-Bypass	SGTR with scrubbing
STC 03	09-Bypass	ISLOCA w/o scrubbing
STC 04	09-Bypass	ISLOCA with scrubbing
STC 05	09-Bypass	CTMT Not isolation with CS
STC 06	09-Bypass	CTMT Not isolation w/o CS
STC 07	07-CTMT-OP	CFBRB with a leak failure size of CTMT
STC 08	07-CTMT-OP	CFBRB with a rupture failure size of CTMT
STC 09	N/A	NOCF w/o RPV breach (MeltStop)
STC 10	N/A	NOCF with RPV breach
STC 11	08-BMT	BMT (Basemat Melt-through)
STC 12	03-DCH	ECF with a leak failure size of CTMT
STC 13	03-DCH	ECF with a rupture failure size
STC 14	01-H2-DDT	LCF with CS, DRY, and a leak failure size of CTMT
STC 15	01-H2-DDT	LCF with CS, WET, and a leak failure size of CTMT
STC 16	07-CTMT-OP	LCF with NOCS, DRY, and a leak failure size of CTMT
STC 17	07-CTMT-OP	LCF with NOCS, WET, and a leak failure size of CTMT
STC 18	01-H2-DDT	LCF with CS, DRY, and a rupture failure size of CTMT
STC 19	01-H2-DDT	LCF with CS, WET, and a rupture failure size of CTMT
STC 20	07-CTMT-OP	LCF with NOCS, DRY, and a rupture failure size of CTMT
STC 21	07-CTMT-OP	LCF with NOCS, WET, and a rupture failure size of CTMT

5. PE Classification for Internal Events Level 2 PSA

In this study, the LRF (Large Release Frequency) is defined as the cumulative frequency of exceeding the CLI. Following the EUR for Probabilistic Safety Target, the cumulative frequency of exceeding the CLI shall be lower than 10^{-6}/RY.

The summary of PE classification for EU-APR1400 is shown in Table II. In terms of PE classification, all PE categories are clarified to decide whether it can meet the probabilistic safety target based on CLI.

Table II: PE classification for APR1400

PE Category No	Description	Approach Methods
1	Hydrogen Detonation	Deterministic PSA-STC14, 15, 18, 19
2	Large Steam Explosion	Deterministic
3	Direct containment Heating	Deterministic PSA-STC13
4	Large Reactivity Insertion	Deterministic
5	Rupture of Major Pressure Components	Deterministic

6	Failure in Spent Fuel Storage	Deterministic PSA-Spent Fuel Pool
7	Containment Over-pressurization – Deterministic and PSA	
	- LERF / LRF	PSA-STC08
	- LRF	PSA-STC07, 20, 21
	- Non-LRF	PSA-STC16, 17
8	Basemat Melt-through	PSA-STC11
9	SA with containment Bypass – Deterministic and PSA	
	- SGTR_LERF	PSA-STC01
	- SGTR_Non-LRF	PSA-STC02
	- NOTISO_LERF	PSA-STC06
	- NOTISO_Non-LRF	PSA-STC05
	- ISLOCA	PSA-STC03, 04
10	SA during shutdown with open CTMT	Deterministic PSA-Low Power Shutdown STC

6. Conclusions

PSA methodology of PE classification for APR1400 is studied in terms of source term category of Level 2 PSA. The characteristic of some STCs is similar with that of PE items but they should be classified from the definition of PE which include two kinds of targets such as deterministic and probabilistic.

Therefore, STC is reclassified according to the probabilistic definition of PE. Each STC is assigned to appropriate PE item based on the STC release characteristic such as the isotropic content, magnitude and the time of release using thermal hydraulic code.

By developing PSA Level 2 using the methodology including PE defined in the EUR, it is possible to provide insights and process to develop APR1400 PSA to address PE on the basis of IAEA safety Standard Series No. NS-G-1.10 and EUR Rev.E.

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