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The Level 2 PSA Analysis Methodology for the APR1000 Based on the Requirements of IAEA SSR-2/1 and EUR Rev.E

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1. Introduction

The primary objective of the Level 2 PSA is to provide insights into potential plant vulnerabilities with regard to severe accident progression and the potential to cause a Large Release or Early Release (LRF).

According to the EUR Chapter 2.1 Section 2.5, LRF shall be Practical Eliminated. The definition of Practical Elimination (PE) is introduced in the IAEA Safety Standards Series No. NS-G-1.10 and is 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. Identification of such accident sequences shall be based on deterministic analyses, supported by engineering judgement, and probabilistic assessment.

APR1000 has various advanced safety features to mitigate severe accidents to address PE of Severe Accidents. This paper describes the Level 2 PSA analysis methodology to address PE for APR1000 PSA.

2. Requirements for PE in the EUR Chapter 2.1

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 APR1000 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 dilution
- 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

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 (LRF) 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 APR1000 for PE

APR1000 has various advanced safety features to mitigate severe accidents to address practical elimination. The severe accident mitigation features are designed to limit the off-site releases after the accidents with core melt. They consist of Emergency Rapid Depressurization System (ERDS), In Vessel Injection System & Cavity Flooding System (IVIS-CFS), Diverse Containment Spray System (DCSS), Hydrogen Mitigation System (HMS), and Containment Isolation System (CIS) which are described as followings. APR1000 provisions to avoid 10 phenomena of PE are shown in Fig. 1.

- The ERDS is independent from the SDVS and rapidly depressurizes the RCS to eliminate a High Pressure Melt Ejection (HPME) under all DEC-B conditions

- The IVIS-CFS designed to inject water into the reactor for In-Vessel Retention before vessel breach. Also, it designed to flood the reactor cavity before vessel breach in order to facilitate the cooling and stabilization of the debris to mitigate late containment failure
- The DCSS are designed to reduce containment pressure and temperature during an accident and to remove iodine radionuclides and aerosols from the containment atmosphere.
- The HMS is designed to control combustible gas like hydrogen gas inside the containment and IRWST within acceptable limits by Passive Autocatalytic Recombiners (PAR) in consideration of hydrogen generation during the DEC-B conditions
- The containment isolation system (CIS) is designed to confine the release of any radioactivity from the containment following an accident

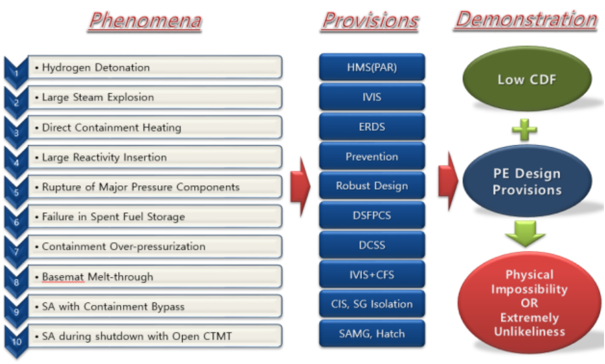

Fig. 1. APR1000 Provisions for 10 Phenomena of PE

5. STC and PE Classification for Level 2 PSA in APR1000

Each Source Term Category (STC) is presented in Fig. 2. Total number of STC is 17 and STC 05 and 06 remain containment integrity.

The summary of PE classification for APR1000 is shown 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). In terms of PE classification, all PE categories are clarified to decide whether it can meet the probabilistic safety target based on CLI.

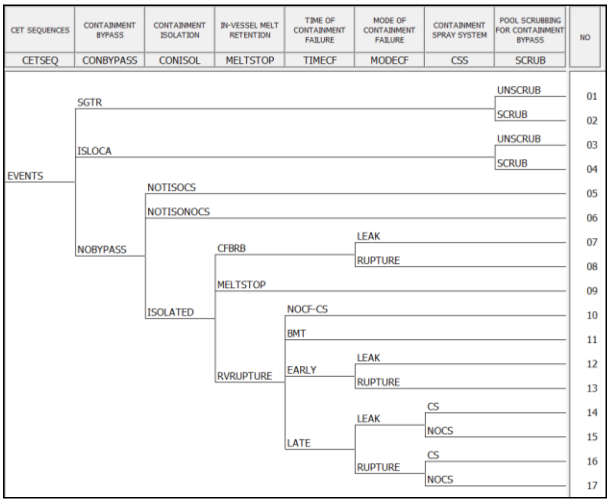

Fig. 2. STC in APR1000 Level 2 PSA

Table I: PE classification for APR1000 Level 2 PSA

PE Category No	Description	Approach Methods
1	Hydrogen Detonation	Deterministic PSA-STC14, 16
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, 15, 17
	- Non-LRF	PSA-STC15
8	Basemat Melt-through	PSA-STC09
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

The Level 2 PSA analysis methodology for APR1000 is studied based on the requirements of IAEA SSR-2/ and EUR Rev.E and the advanced design provisions of APR1000 to mitigate severe accident including PE phenomena.

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, it is possible to provide insights and process to develop APR1000 PSA to address severe accident and PE phenomena on the basis of IAEA safety Standard Series No. NS-G-1.10 and EUR Rev.E.

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