An ATWS Analysis with a Realistic Evaluation Methodology

Min Shin Jung[a*], Gyu Cheon Lee[a], Eun Kee Kim[a]
[a]*KEPCO Engineering & Construction Company, Inc.*
150 Deokjin-Dong, Yuseong-Gu, Daejeon, Korea, 305-353
[*]*Corresponding author: msjung@kepco-enc.com*

1. Introduction

Anticipated Transients Without Scram (ATWS) would occur on failure of all the control and shutdown assemblies to insert into the core following an automatic reactor trip. The major concern of the ATWS derives from consequences of the high primary system pressure which is the characteristic of the transients. According to section 2.4 of YVL guides which are Finnish regulations for safety of nuclear power plants (NPP), the acceptance criterion for the ATWS analysis is that the pressure of the protected item does not exceed a pressure limit that is 1.3 times the design pressure [1]. The main purpose of this paper is to assess its impact on the APR1400 preliminarily, for Europe regulatory environments by applying European Utility Requirements (EUR) for Light Water Reactor Nuclear Power Plants.

2. Methods and Results

In this paper, the assumptions and methodology presented in Guide YVL 2.2 [1] are used to assess their impact on the integrity of the RCS during the ATWS event for APR1400.

2.1 Evaluation Approach

Loss of Normal Feedwater (LONF) event was turned out to produce the highest peak primary pressure during ATWS. Therefore, the LONF event is chosen as an initiation event for ATWS evaluation of APR1400. NSSS thermal hydraulic responses to the LONF event with failure of reactor trip are simulated using the RELAP5 Mod3.2 computer program [2]. Best estimate approach is adopted in this analysis by using nominal initial conditions and design data and giving credit to NSSS control systems, since it is considered to be a beyond design basis event.

In this paper, ATWS analysis for APR1400 is performed to confirm whether turbine trip signal, AFW actuation signal, ATWS signal, and EBS which are designed to prevent pressure increases are effective in maintaining the acceptable RCS pressure.

2.2 Initial Conditions and Parameters used in analysis

The initial conditions for the APR1400 are shown in Table 1. And the major NSSS parameters that may affect the ATWS event are shown in Table 2. MTC and FTC are assumed to be its most positive value, to minimize the core power decrease after isolation of the steam lines, where MTC and FTC are at various burn-up conditions in the first cycle. The other safety parameters for POSRVs, MSSVs and AFWP are assumed to be in nominal conditions. And the following items are assumed in this evaluation to mitigate the LONF followed by a reactor trip failure.

- Turbine trip signal on "Low steam generator level"
- AFW pump actuation on "Low steam generator level"
- ATWS signal on reactor trip signal and high rods position (or high flux)
- Emergency Borating System (EBS) actuation on ATWS signal
- Reactor Coolant Pump (RCP) trip on ATWS signal
- SBCS is available

As shown above, ATWS mitigation functions such as turbine trip, ATWS signal and EBS are assumed to satisfy EUR acceptance criterion for APR1400. Additionally failure of one EBS pump to start is conservatively assumed with respect to RCS peak pressure.

2.3 Analysis Results

Three cases are analyzed to determine whether ATWS mitigation functions such as ATWS signal, EBS, RCP trip are effective in achieving the desired outcome, which RCS pressure does not exceed 3200 psig for whole fuel cycle.

In general, the ATWS transient results in a RCS pressure rise, which is dependent on the MTC, the POSRV capacity, and the energy removal capacity of the steam generators. Also, the primary coolant temperature increase, since with LONF, heat removal is diminished while the reactor continues to generate power.

Table 1. Initial Conditions

Parameter	Value
Core Power (MWt)	3983
Reactor Vessel Inlet Coolant Flow Rate (Liter/min)	2,028,913
PZR Water Level (%)	50.0
Core Inlet Coolant Temperature (°C)	290.56
Pressurizer Pressure (kg/cm^{2}A)	158.19
Steam Generator Water Level (% WR/% NR)	76.87/50.09

Table 2. Major Parameters Affecting ATWS Event

Parameter	Value
POSRV Rated Flow Rate per One valve at 173.66 kg/cm^{2}A psia (kg/min)	8164.6
Auxiliary Feedwater Actuation Setpoint (% of WR)	25
MTC ($10^{-4}\Delta\rho/^{o}C$)	-1.0564
EBS flow rate per pump (liter/min)	196.84
Boron concentration in EBS tank (ppm)	7000

The cases to evaluate effect on ATWS mitigation functions are ATWS with ATWS signal and turbine trip case, ATWS without ATWS signal case, and ATWS without ATWS signal and turbine trip case.

The analysis results of the cases show in Figure 1 that the APR1400 essentially requires the RCP trip on ATWS signal and turbine trip to satisfy acceptance criterion of EUR during the ATWS event, because turbine trip, which reduces steam flow and preserves steam generator inventory, can delay steam generator dry-out and reduce the RCS pressure peak. Also, ATWS signal, which is generated on reactor trip signal and high rod position, makes the EBS pumps start and the RCPs trip automatically. Thus it ensures the sub-criticality of the core in the long-term phase and mitigates the RCS pressure increase. In addition, the MTC is a measure of the reduction in the core reactivity as the water temperature increases.

The ATWS analysis results with a realistic evaluation methodology show that the maximum pressure at the RCP outlet is 206.32 kg/cm^{2}A (2934.6 psia) for ATWS signal and turbine trip case and 274.3 kg/cm^{2}A (3901 psia) for ATWS without ATWS signal Case and 275 kg/cm^{2}A (3916 psia) for ATWS without ATWS signal and Turbine trip case respectively. It shows that RCP trip on ATWS signal which is an unique feature of European NPPs and turbine trip should be required APR1400. However, EBS is not essential to mitigate the RCS peak pressure during ATWS event in this evaluation. Detailed assessments for EBS pump flow rate, EBS capacity, and boron concentration in EBS tank will be performed later.

To conclude, the RCP trip function on ATWS signal must be additionally installed for APR1400 under the condition of -1.0564 ($10^{-4}\Delta\rho/^{o}C$) MTC to satisfy that RCS peak pressure does not exceed 3200 psig on the ATWS event for whole fuel cycle. In addition, some design changes of the Diverse Protection System (DPS) such as upgrading the safety classification will be needed to give credit to turbine trip signal generated by DPS during ATWS event.

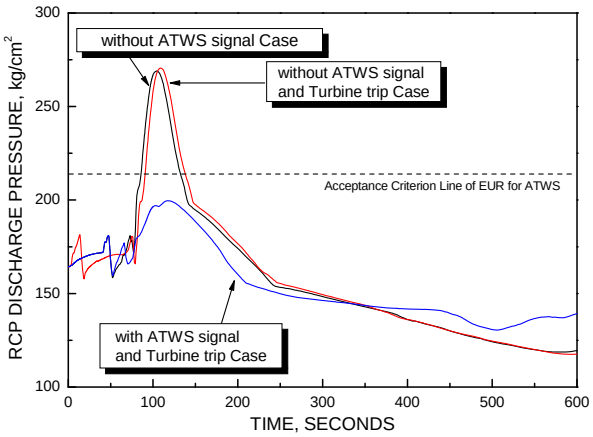

Fig. 1. RCP Discharge Pressure vs. Time

3. Conclusions

The main purpose of this paper is to assess its impact on the APR1400 for Europe regulatory environments by applying European Utility Requirements preliminarily.

As a result of ATWS analysis, design changes of the DPS such as upgrading the safety classification and adding the RCP trip function will be needed in APR 1400 at the condition of -1.0564 ($10^{-4}\Delta\rho/^{o}C$) MTC so that the results of ATWS analysis with a realistic evaluation methodology meet EUR acceptance criterion.

ACKNOWLEDGMENT

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REFERENCES

[1] YVL guide, STUK, Transient and Accident Analyses for Justification of Technical Solutions at Nuclear Power Plants.
[2] RELAP 5 Mod 3.2 Manual.