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Analysis of Emergency Response in Nuclear Disaster

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1. Introduction

The accident at a nuclear power plant that involved damage to fuel in the reactor core or in a spent fuel pool could cause deaths, severe health and psychological effects, and could also have economic and sociological consequences affecting the public. These consequences could be mitigated by implementing protective actions promptly in the emergency planning zone (EPZ). The EPZ included precautionary action zone (PAZ) to reduce substantially the risk of severe deterministic effects, urgent protective action planning zone (UPZ). The importance of EPZ has been demonstrated in Fukushima Accident as protective actions; evacuation of public within 20 km and sheltering within 20~30 km (later on advised to evacuate voluntarily) prevented radiological consequences effectively. The public could be exposed to direct radiation in the downwind direction and also to radioactivity deposited on the ground and vegetation resulting in exposure through different pathways. Computer codes could be used to assess these actions by evaluating the dose consequences. RASCAL code, radiological assessment system for consequence analysis, was the software developed and used by the U.S. Nuclear Regulatory Commission (NRC), Emergency Operations Center in order to estimate the projected doses in case of radiological emergencies. The mitigation actions of the emergency plan should take place in the first few hours after an accidental release of radioactivity to atmosphere; model predictions would supplement monitoring data to increase understanding of the radiological situation and to form a basis for emergency health protection decisions. The nuclear power plants emergency plans included preparations for evacuation, sheltering, or other actions to protect the residents near nuclear power plants in the event of a serious incident. Each plant operator was required to exercise its emergency plan with offsite authorities at least once every two years to ensure state and local officials remain proficient in implementing their emergency plans [1].

2. Methods and Results

In this simulation, LTSBO and LOCA were considered in Shin Kori unit 3. Both accidents were performed in spring, summer, autumn and winter season. The real meteorological data was used to perform the study [2]. After the simulation the worst case was found in winter season. In this study, the following reactor parameters [3] of Shin Kori unit 3 were used in RASCAL.

Table I: Reactor parameters of Shin Kori unit 3

Reactor Power	3983 MWt
Average burnup	28914 MWd / MTU
Containment type	PWR Dry Ambient
Containment volume	3.13×10^{06} ft³
Design pressure	50 lb/in²
Design leak rate	0.10 %/d
Coolant mass	2.92×10^{05} kg
Assemblies in core	241
Steam generator type	U-Tube
SG water mass	218000 kg
Release Height	60 m

2.1 Long Term Station Blackout Scenario

The basic scenario for this accident was assumed to be have been initiated by an external event that results in a total loss of offsite power at Shin Kori unit 3 NPP. Reactor cooling was maintained for a period of several hours but was ultimately lost, at which point the coolant boils away. Core damage and releases from the core began after core uncovery. It was assumed that the reactor was shut down at 5:30 due to a nearby cyclone which caused the loss of offsite and onsite AC power. Emergency diesel generators (EDGs) were providing power and emergency core cooling system (ECCS) was available and operating for 5 hours. This input time was combined with the shutdown time to determine when the reactor coolant began to boil off. RASCAL then added a fixed boil-off duration based on NUREG-1935 (8 hours for PWR) to determine the time of core melt and release. The core was then recovered at 21:00.

EDGs became inoperable after the 5 hours and the core began to heat to the point of meltdown. Spray system of containment then became inoperable, which increased containment pressure and containment leakage to a release rate of 5% per day. Power was restored at 21:00 and containment pressure reduced by 04:30 of next day, which stopped the containment leakage [4]. This common scenario was used in all seasons, i.e., spring (12 March, 2017), summer (12 June, 2017), autumn (12 September) and winter (12 December, 2017).

Table II**:** Summary of LTSBO in winter

Shutdown	2017/12/12; 05:30
Release from core starts	2017/12/12; 18:30

Core damage estimated by	Core recovered status
Core recovered	2017/12/12; 21:00
Release Events	
2017/12/12; 18:30	Leak rate (% vol) 5 %/d
2017/12/12; 18:30	Sprays Off
2017/12/13; 04:30	Leak rate (% vol) 0 %/d

2.2 Loss of Coolant Accident Scenario

It was assumed that there was an earthquake around Shin Kori unit 3 NPP. After the effect of earthquake, there was a major rupture in the primary coolant system (loss of coolant accident). As a result, the reactor was tripped on 18:00, which started the decay clock for the isotopes in the reactor. Due to significant loss of coolant, the core was uncovered at 19:00. The release from the core passed into the containment building. Release from the containment was assumed at the design leak rate of APR1400 of 0.1%. When the release started the containment spray system was active. Containment release rate to the atmosphere was assumed 3% per day.

At 01:00 of the next day, operators were able to recover the core. Containment remained at high pressure which kept the release ongoing and pressure was not reduced until 05:00 of next day. At that time the release stopped or release rate was 0% [5]. This common scenario was also used for all seasons in LOCA.

Table III: Summary of LOCA in winter

Shutdown	2017/12/12; 18:00
Release from core starts	2017/12/12; 19:00
Core damage estimated by	Core recovered status
Core recovered	2017/12/13; 01:00
Release Events	
2017/12/12; 19:00	Leak rate (% vol) 3. %/d
2017/12/12; 19:00	Sprays On
2017/12/13; 05:00	Leak rate (% vol) 0. %/d

And, the following data was found in PAZ area after 2 days.

Table IV: TEDE at about 5 km in different season

Seasons	LTSBO (mSv)	LOCA (mSv)
Spring	7.8	0.056
Summer	13	0.080
Autumn	11	0.053
Winter	14	0.080

In this study, LTSBO was found as a worst scenario between LTSBO and LOCA because there was a core melt. Among all seasons the winter was the worst season which had a south-east wind direction in the evening. For LTSBO in winter, the maximum TEDE was 14 mSv at about 5 km in 2 days which was higher than the Korean standards. While for the case of LOCA, the maximum TEDE in summer and winter was 0.08 mSv at about 5 km in 2 days which was very low compared to the Korean standards. For both cases in winter, the characteristics of top 4 source terms released to the atmosphere and TEDE contour were shown in Fig. 1, Fig. 2, Fig. 3 and Fig. 4, respectively.

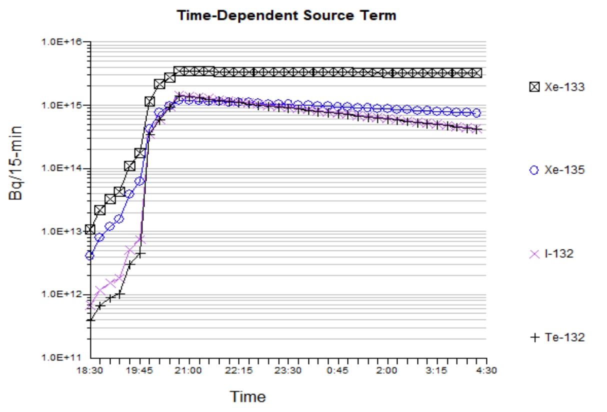

Fig. 1. Source terms of ^{133}Xe, ^{135}Xe, ^{132}I and ^{132}Te for LTSBO.

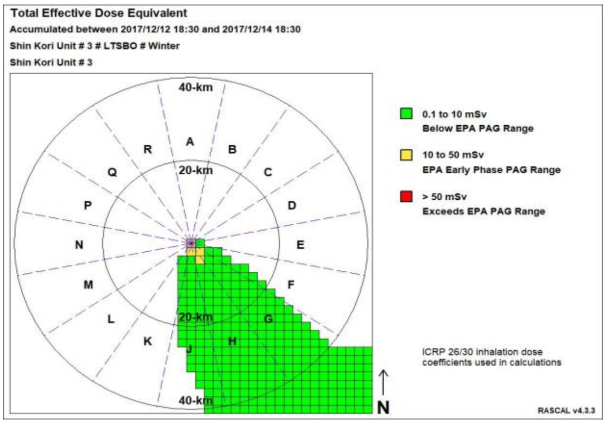

Fig. 2. Contour plot of TEDE for LTSBO.

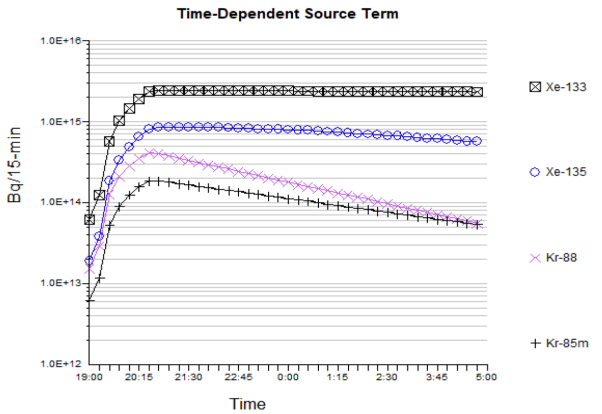

Fig. 3. Source terms of ^{133}Xe, ^{135}Xe, ^{88}Kr and ^{85m}Kr for LOCA.

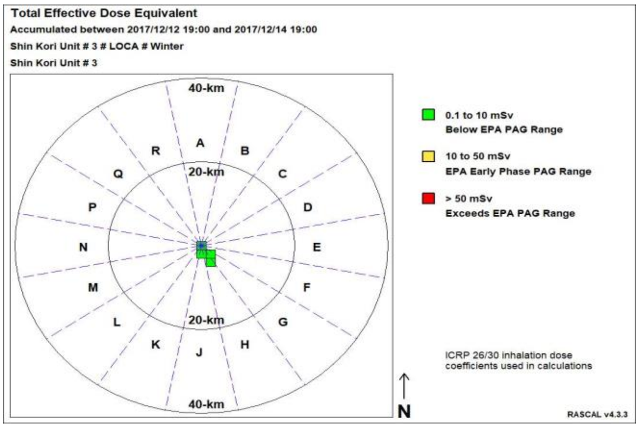

Fig. 4. Contour plot of TEDE for LOCA.

Sensitivity analysis was performed for both cases. The graphs of sensitivity analysis were shown in Fig. 5 and Fig. 6 for LTSBO and LOCA, respectively. For LTSBO, the highest and lowest dose were observed in winter and spring, respectively. While for the case of LOCA, the highest and lowest dose were observed in summer, winter and autumn.

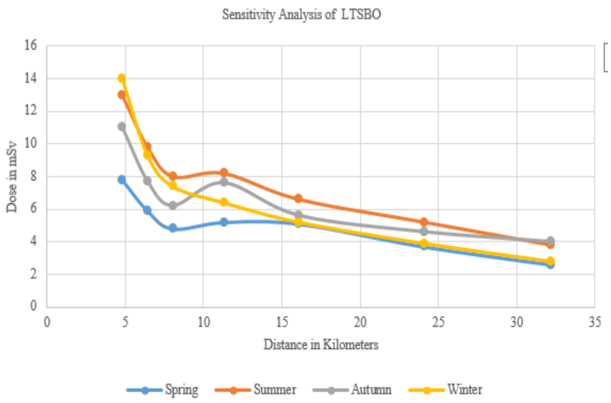

Fig. 5. Comparison results of four seasons for LTSBO.

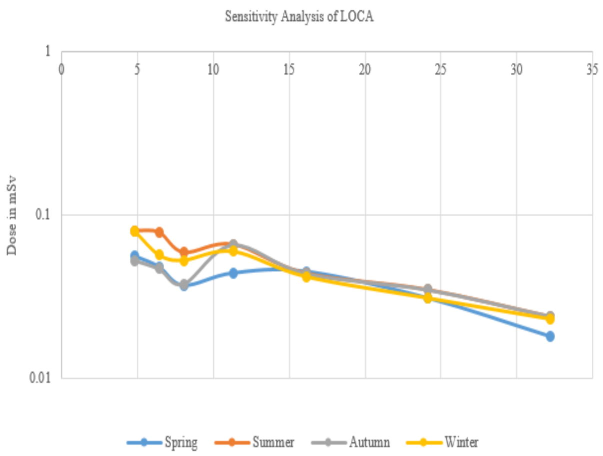

Fig. 6. Comparison results of four seasons for LOCA.

3. Conclusions

The purpose of this simulation was to find out the dose that arise from a hypothetical severe accident. The impact of the accident throughout the year was assessed. In case of LTSBO, the maximum TEDE was 14 mSv at about 5 km in 2 days, which was higher than Korean regulatory standards and therefore immediate action needs to be taken. In that case, an immediate evacuation for short time protection by the off-site emergency management center (OEMC) under nuclear safety and security commission (NSSC) in Korea would be decided. While for the case of LOCA, the maximum TEDE was 0.080 mSv at about 5 km in 2 days, which was very low compare to Korean regulatory standards. According to Korean regulatory standards for urgent public protection actions, it was below 10 mSv that recommended dose limit for sheltering hence no protective action might be taken at the time when the simulation was stopped. Sensitivity analysis was done for both LTSBO and LOCA. For LTSBO and LOCA accident it was found that winter was the worst season among all seasons. Therefore, more urgent steps regarding emergency management should be taken if the accident occurred in winter.

Acknowledgements

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