Radiological Consequence Analysis of a TMI-2 Type Accident at Barakah Nuclear Power Plant Unit 1

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1. Introduction

The project investigated the effects of the radiation from a severe APR 1400 accident at Unit 1 of the Barakah Nuclear Power Plant (BNPP), the latest nuclear reactor model developed by South Korea. An accident on a Three Mile Island (TMI) occurred in Unit 1 of the BNPP. The effects of the consequent radiation were compared and analyzed. Table 1 compares TMI Unit 2 and BNPP Unit 1 specifications.

Table 1: Comparison of TMI Unit 2 and BNPP Unit 1 specifications

Item	TMI Unit 2	BNPP Unit 1
Location	Dauphin County, Pennsylvania in US	Barakah, Abu Dhabi, UAE
Reactor Type	PWR	PWR
Capacity	906 MWe	1,400MWe
Commercial operation	December 30, 1978	April. 20, 2021
Date of Accident	March 28, 1979	July 2021*(Assumption)

1.1 APR 1400

Unsustainable energy is among the biggest problems globally, and it is associated with emissions that accelerate global warming and climate change. Various countries have invested in alternative energy sources to eliminate this environmental threat. For example, Korea designed the Advance Power Reactor 1400 (APR 1400), while the United Arab Emirates (UAE) developed the BNPP. Such nuclear projects have supported clean energy production and increased the overall power supply.

Korea made a big step towards reducing the overreliance on non-renewable, unsustainable energy by developing OPR 1000 and APR 1400. This advancement set precedence for other countries, such as the UAE and the USA, to establish similar projects. The UAE developed the BNPP, while the USA established the Three Mile Nuclear Power Station. However, these facilities have a high risk of catastrophic accidents. Thus, operators should develop monitoring systems to detect even the slightest defects.

For many years, the Optimized Power Reactor (OPR) 1000 was Korea's main power plant model. However, the plant's cooling system broke down, leading to its unprecedented stop. In response to the breakdown, the Korea Hydro and Nuclear Power Company improved the plant by developing the APR 1400. This system was first applied at the Shin-Kori Nuclear Power Plant. It boosted energy production from 1000 to 1400 MW [1]. Moreover, based on the design parameters, the plant's operation timeline was longer than the OPR 1000. APR 1400 also had enhanced safety standards to withstand extrinsic shocks, such as hot conditions. The attributes made the plant highly efficacious, resulting in the construction of four other similar facilities in the UAE.

1.2 Barakah Nuclear Power Plant

The four APR 1400 nuclear reactors established in the UAE constitute the BNPP. This plant is located in the Arabian Gulf, Abu Dhabi. Its commercial operation began on April 20, 2021, after a construction project costing approximately $ 24.4 billion [2]. While the UAE had implemented clean energy strategies before, the country still had a challenge in meeting the high energy demand to run the households, businesses, and industries. Thus, with the ability to produce 5,600 MW of power, the plant was expected to cater for about 25% of the total power requirement in the country [2]. This contribution was a great supplement to the already existing power sources. Thus, the BNPP has played a significant role in meeting the proliferating power demand. The UAE authorities also highly regard the plant since it is pivotal in meeting the goal of producing 50% clean and sustainable energy by 2050.

1.3 The Three Miles Island (TMI) Accident

The TMI accident was one of the most severe catastrophes regionally and worldwide. It emanated from a cooling failure that subsequently led to a meltdown of the first reactor. It began on the morning of March 28, 1979, with a failure of the subsidiary cooling circuit that led to a significant temperature rise in the central cooling system [3]. This development kept the pilot-operated relief valve, which was expected to close, open. The operators did not realize this failure since the monitoring instruments could not detect it. It was only after the cooling water filled the pressurizer that they realized something was amiss. Notwithstanding, the operators still did not notice the loss of coolant water. At this point, the pressure in the pressurizer was so low that the reactor's coolant pumps started vibrating. Thus, the operators stopped the water flow, depriving the system of cooling water and resulting in the core's overheating.

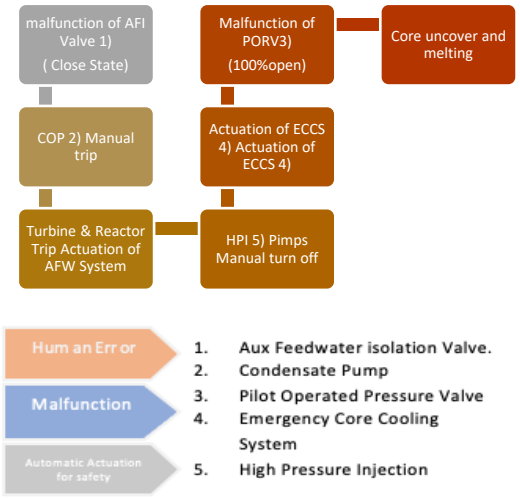

Fig. 1: Flow Chart of TMI Accident

2. The Personal Computer Transient Analyzer (PCTran)

The PCTran, a software package that can simulate a variety of accident and transient conditions for nuclear power plants, was used to derive the scenario timeline, source term, and leakage. This software operates in the Windows environment, and it accrues significant time savings. A high-resolution color mimic of the Nuclear Steam Supply System (NSSS) and containment displays the status of important parameters, facilitating the simulation of operator actions by interactive control. Figure 2 illustrates the derived mimics.

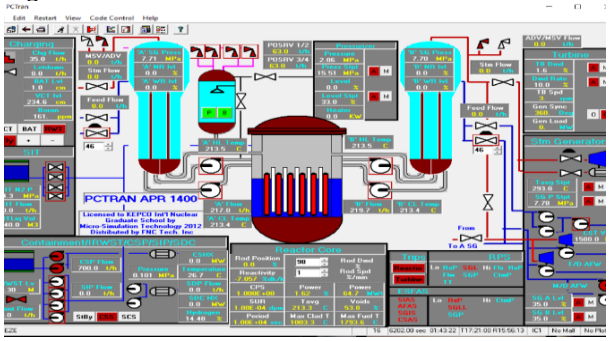

Fig. 2: The PCTran Mimic

The Source Term and the volume of emissions were less than those in the TMI accident. Table 3 summarizes the amount of generated inert gases and iodine. Notably, the emission of noble gases was 14.233 PBq, while the emission of radioiodine was 187.21 GBq. These figures were less than 93 PBq noble gases and 560 GBq radioiodine generated during the TMI accident. Due to these variations, the radiation effects were evaluated, assuming that the generated noble gases and iodine were all released to the off-site.

Table 2: The Source Term

Nuclides	Categories	Activity (Bq)
^{131}I	Halogens	3.77×10^{10}
^{132}I	Halogens	4.53×10^{10}
^{133}I	Halogens	6.05×10^{10}
^{134}I	Halogens	9.60×10^{9}
^{135}I	Halogens	3.42×10^{10}
^{83m}Kr	Noble gases	1.14×10^{10}
^{85m}Kr	Noble gases	4.92×10^{11}
^{85}Kr	Noble gases	4.19×10^{11}
^{87}Kr	Noble gases	1.17×10^{10}
^{88}Kr	Noble gases	6.40×10^{12}
^{131m}Xe	Noble gases	1.79×10^{10}
^{133m}Xe	Noble gases	4.20×10^{11}
^{133}Xe	Noble gases	6.42×10^{12}
^{135m}Xe	Noble gases	1.17×10^{10}
^{135}Xe	Noble gases	1.84×10^{10}
^{138}Xe	Noble gases	1.64×10^{10}
^{58}Co	Alkali metal	2.39×10^{3}
^{60}Co	Alkali metal	2.39×10^{3}
^{86}Rb	Alkali metal	2.39×10^{3}
^{89}Sr	Alkali metal	2.39×10^{3}
^{90}Sr	Alkali metal	2.39×10^{3}
^{99}Mo	Alkali metal	2.39×10^{3}
^{134}Cs	Alkali metal	2.39×10^{3}
^{136}Cs	Alkali metal	2.39×10^{3}
^{137}Cs	Alkali metal	2.39×10^{3}

3. Meteorological Data

The weather data was obtained from the UAE National Service of Metrology (NCM). The measurement point was at Barakah (latitude: 23 57 19 N longitude: 52 15 59 E). A wind rose was also prepared using the freeware WRPLOT view, and the measurement period was from October 2020 to April 2021. Figure 3 illustrates the results, while table 3 presents the weather data for the Barakah weather station.

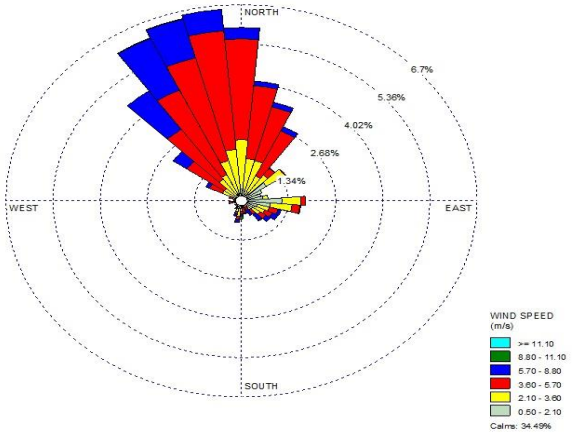

Fig. 3: The wind rose for Barakah

Table 3: The weather data for the Barakah weather station

Items	Highest	Lowest	Average
Temperature	42.4° C	4.54° C	23° C (Average)
Humidity	97.5 %	6.5 %	61 % (Average)
Location	Wind Speed		
	Maximum	Average	
10m	10.4 m/s	2.45 m/s	

4. HotSpot Health Physics Codes

The radiological effects were performed using HotSpot. Notably, the Department of Energy (DOE) developed the HotSpot Health Physics Codes, which are currently undergoing maintenance. The HotSpot program has been distributed worldwide since 1988. Its codes are a conservative (estimated radiation dose is usually greater) estimation of the radiation effects associated with the atmospheric release of radioactive materials

The Exclusion Area Boundary (EAB) of Barakah Unit 1 is 360m, and the Low Population Zone (LPZ) is 3km. The effective dose and thyroid dose for Design Basis Accidents (DBA) at EAB and LPZ is 250 mSv and 3,000 mSv, respectively. Figure 4 illustrates the target organ committed dose equivalent at the location. Contrarily,

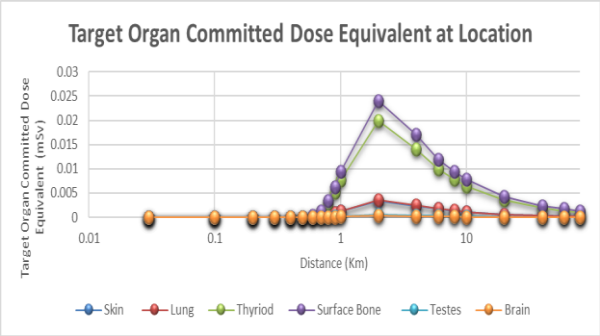

Fig. 4: The target organ committed dose equivalent at location

figures 5-6 present the Plume Contour and Plume Graph (TEDE and thyroid) derived using the weather data of Barakah Unit 1 and HotSpot.

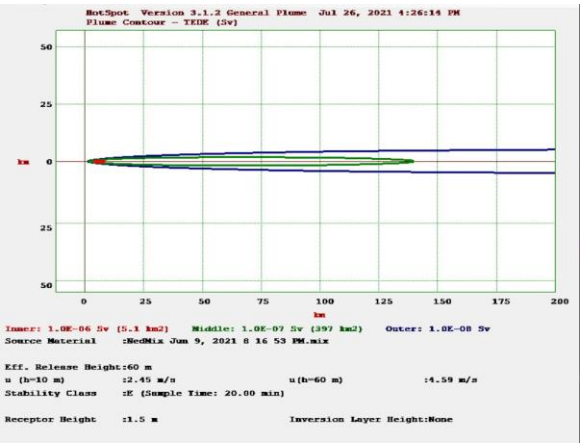

Fig.5: Total Effective Dose Plot

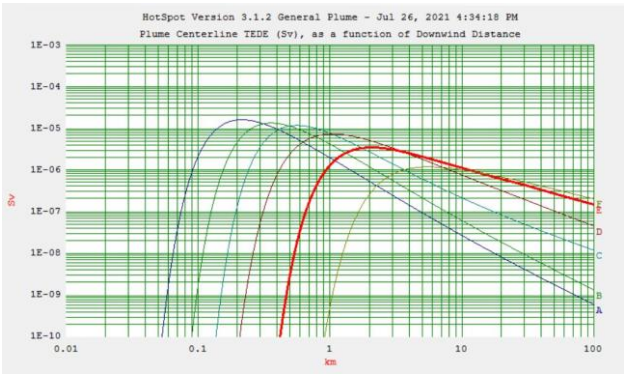

Fig. 6: Total Effective Dose Graph

Generally, the maximum wind direction from northwest to northwest draws the plume. Figures 7 illustrate the general plume dosage and general plume deposition as derived using Google Earth Pro.

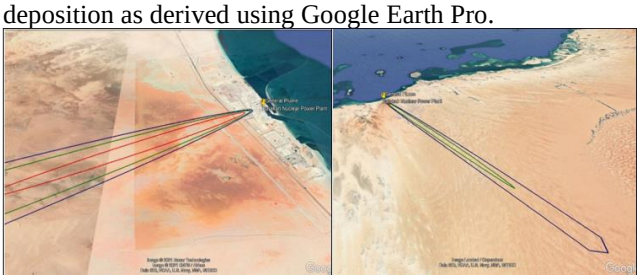

Fig.7: The General Plume Dose in Google Earth Pro

5. Conclusion

This project analyzed the effects of the radiation from the TMI accident. The Source Term was obtained using PCTran. The actual emitted Source Term and amount of emission were comparable to the TMI accident emissions. The emission of noble gases was 14.233 PBq, while the emission of radioiodine was 187.21 GBq. These figures were less than 93 PBq noble gases and 560 GBq radioiodine generated during the TMI accident. The radiation dose calculations and radiological effects of the TMI accident were performed by considering the Barakah 1 unit using HotSpot code. The analysis revealed that the TMI accident caused an average dose of 14 μSv to the approximately 25000 people living near the plant. Thus, the accident posed a significant threat to all life in the plant's vicinity.

Acknowledgement

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