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Public Dose Assessment during the Operational States of APR1400

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1. Introduction

Normal operation of nuclear power plants (NPPs) involved production and release of radionuclides to the environment. Solid, liquid and gaseous effluents were discharged to the environment either periodically or continuously. Gaseous and liquid effluents were especially of interest since they were readily dispersed in waterways and the atmosphere [1]. Atmospheric dispersion (X/Q) and deposition (D/Q) factors determined the dispersal and subsequent deposition of radionuclides in the atmosphere. X/Q and D/Q were determined from atmospheric parameters of wind speed, wind direction and environment temperature. These factors were also influenced by atmospheric stability, i.e. how the air was mixed in the atmosphere [2]. Hydrological dispersion of radionuclide was determined from the concentration of aqueous solution released, the rate of release and dilution rate in the water body [3]. Exposure to radionuclides occurred through many pathways; plume, ground deposition, inhalation, taking food and water and performing activities in the environment. These contributed doses externally to the body, the gastro intestinal – lower large intestine (GI-LLI), bone, liver, kidneys, lungs, thyroid, skin, pancreas, spleen, gastro intestinal – upper large intestine (GI-ULI), airways, uterus, bone marrow and stomach. The effects of radiation were also influenced by the age of the person; adult, teenager, child, or infant [4]. Exposure to radionuclides posed health risks. Risks were reduced by setting limits to doses received by the public to normal operation of NPPs [5]. Taking the gaseous and liquid source terms of NPP normal operation, the dose to public could be estimated to address compliance with set limits. This study aimed at analyzing radiological dose resulting from the normal operation of a Nuclear Power Plant (NPP) to ensure compliance with the set standard regulations of radioactive effluent releases.

2. Methods and Results

2.1 XOQDOQ

XOQDOQ computer code was used by the nuclear regulatory commission (NRC) staff in the independent meteorological evaluation of routine or anticipated, intermittent releases of radionuclides at commercial nuclear power stations. Relative atmospheric dispersion factors, X/Q values, and deposition factors, D/Q values, were computed for 22 specific distances out to 80 kilometers from the site. X/Q and D/Q values for 10 distance segments were computed. X/Q and D/Q values were computed for user-inputted specific points of interest (Exclusion Area Boundary - EAB and Low Population Zone) [2]. Nearby Ulsan Metropolitan City meteorological data from 2016~2018 were used [6]. The data was not readily usable in XOQDOQ. A joint frequency distribution (JFD) was created and passed to XOQDOQ including locations of interest (EAB at 560 meters to South-South-West and LPZ at 3.5 kilometers to South-West directions [7]) using Microsoft Excel and the R programming language [8]. The "openair" package was used to plot weather related parameters in R, including wind roses [9]. Pasquill stability classes [10] was calculated using circular normal distribution statistics in R from the directional library [11]. The created JFD was used as the input of XOQDOQ.

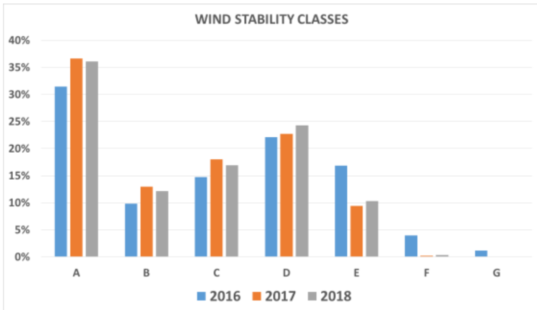

Fig. 1. Percentage of wind stability classes per year.

The year of 2016 was calmer than 2017 and 2018 as shown in Fig. 1. Predominant wind direction blew south and similar wind flow patterns were observed for the 2016~2018. The maximum dispersion factors were 2.75E-04, 1.10E-04, and 1.10E-04 for the year 2016, 2017, and 2018, respectively, all blowing to the south. The maximum deposition factors were 4.20E-07, 4.10E-07, and 4.40E-07 to south-east for the year of 2016, 2017, and 2018, respectively.

2.2 GASPAR

GASPAR computer code was used for analysis of doses to individuals and populations resulting from radioactive effluents discharged into the atmosphere from nuclear power plants. It estimated doses due to inhalation, ingestion and external exposure. GASPAR was used by the United States' Environmental Protection Agency (EPA) in provision of information to the National Environmental Policy Act (NEPA) which addresses compliance [12]. The two main inputs were the source term [13] and the formatted output results of the XOQDOQ, including population, meat, vegetable, and milk consumption. The population within 80 kilometer of radius was determined from geographic information system (GIS) tools at approximately 7 million people [14]. Beef consumption data was derived from fraction of imported beef and domestically produced beef adjusted for the population estimated at 35.4 million kilograms [15]. Vegetable consumption was determined from statistics of vegetable consumption patterns adjusted for the population estimated at 931 million kilograms [16]. Milk consumption data was derived from fraction of imported milk and domestically produced milk adjusted for the population estimated at 288 million liters [17].

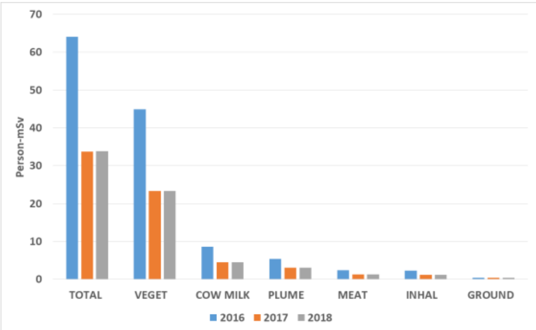

Fig. 2. As low as reasonably achievable (ALARA) Annual Integrated Population Dose summary by pathway (Person-mSv)

The maximum population dose was 65 person-mSv in 2016 (figure 2). The main contributor to population dose was vegetation followed by cow milk and the plume pathway. High doses in 2016 followed from the calm conditions that were experienced during the year.

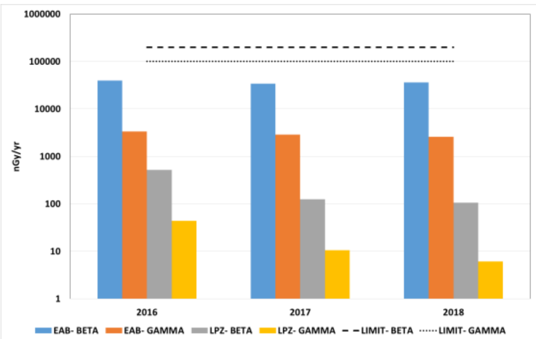

Fig. 3. Annual beta and gamma air doses ($nGy.yr^{-1}$) at EAB and LPZ.

C-14, H-3, Kr-85, Xe-131m and Ar-41 were shown to contribute the highest doses across the study period. Highest EAB air beta and gamma absorbed doses were 0.04 $mGy.yr^{-1}$ and 0.003 $mGy.yr^{-1}$ which were lower than NSSC limits of 0.2 $mGy.yr^{-1}$ and 0.1 $mGy.yr^{-1}$, respectively as shown in Fig. 3 [13].

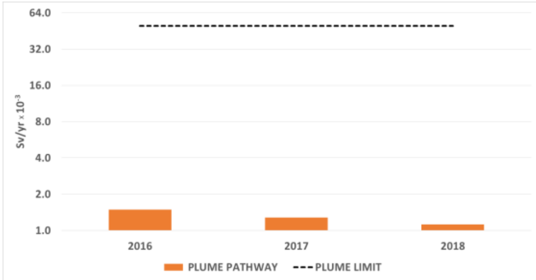

Fig. 4. Individual effective doses by plume pathway at EAB ($mSv.yr^{-1}$).

Skin doses were shown to be the highest across all age groups due to radionuclides being airborne. Child doses were higher than other age groups at both EAB and LPZ due to sensitivity of age to radiation as depicted in Fig. 4. Highest EAB child effective doses was 0.002 $mSv.yr^{-1}$ and skin equivalent dose at 0.051 $mSv.yr^{-1}$ which were below NSSC limits of 0.05 $mSv.yr^{-1}$ and 0.15 $mSv.yr^{-1}$, respectively [13]. The plume pathway was of interest since the EAB area considered was not agricultural.

2.3 LADTAP

LADTAP computer code was used by the United States' Environmental Protection Agency (EPA) in provision of information to the National Environmental Policy Act (NEPA) which addressed compliance to analyze liquid radioactive waste releases to surface waters [3]. It estimated doses to individuals (adults, teenagers and children) by considering internal exposures (water, fish, algae and invertebrates), and external exposures (shoreline, swimming and boating). The main input to LADTAP were the source term and site-specific parameters.

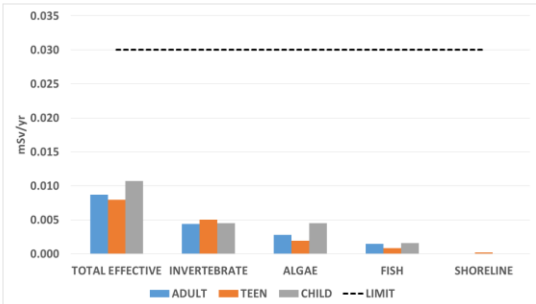

Fig. 5. Effective doses to age groups by pathway due to liquid effluents ($mSv.yr^{-1}$).

Effective dose from liquid effluents was highest to children at 0.01 $mSv.yr^{-1}$ which was below NSSC limits of 0.03 $mSv.yr^{-1}$ as shown in Fig. 5. Equivalent doses to any internal organ was 0.08 $mSv.yr^{-1}$ for gastrointestinal lower large intestine which was below NSSC limits of 0.1 $mSv.yr^{-1}$. Adults and teens were second and last most affected groups. Consumption of invertebrates and algae were shown to contribute highest dose. Children were most affected by the consumption of algae and fish. Teenagers were most affected by consumption of invertebrates and relatively by spending more time on shoreline activities. This could be attributed to consumption patterns of teenagers and the tendency to have more physical activity. Adults and children were similarly affected by algae and fish consumption which could be attributed to parents and children spending time mostly together.

3. Conclusions

Several analyses were performed in this study to assess the offsite radiological impact of normal and anticipated operational occurrences of APR1400. XOQDOQ required other data preprocessing tools to be effective. Windrose plots were pointers to dispersion and deposition characteristics of atmosphere. Atmospheric stability was primarily determined from vertical temperature difference and their unavailability in many weather stations could be compensated using horizontal standard deviation of wind direction. GASPAR code generated doses having received formatted data from XOQDOQ. Doses within the EAB and LPZ were considered important especially in the directions considered in this study. Food production being not practiced in the considered region of EAB gave a close reflection of actual doses received. The doses to the overall population should be considered as conservative estimates due to uneven distribution of population and agricultural production within the region considered. GASPAR results showed compliance to regulations. LADTAP code considers input parameters that represent population fractions, water-based foods, and activities. Ocean food consumption showed the significance of Korean traditional foods such as seaweed and invertebrates in contributing to overall doses. LADTAP results showed compliance with regulations. XOQDOQ, GASPAR and LADTAP operated on plain text input and output data which required detailed analysis. The results of this study showed the compliance of Shin-Kori unit 3 operation for gaseous and liquid effluents.

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