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Research Article

Quantitative Assessment of Gaseous Effluents during Routine Operation: A Comparative Study of Planned Nuclear Power Plants at Lubiatowo-Kopalino and Pątnów Sites in Poland

Edyta Agata Macieja and Juyoul Kim

Department of Nuclear Power Plant Engineering, KEPCO International Nuclear Graduate School, 658-91 Haemaji-ro, Seosaeng-myeon, Ulju-gun, Ulsan 45014, Republic of Korea

Correspondence should be addressed to Juyoul Kim; jykim@kings.ac.kr

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On September 2021, Polish government declared that six pressurized water reactors with combined capacity of 6–9 GWe will be built by 2040 to reduce Poland's reliance on coal. Due to the adopted schedule, construction of the first nuclear power plant will begin in 2026, with the first reactor capacity of 1–1.6 GWe to be operational in 2033. The Polish authorities announced in 2022 the selection of two locations and technologies for Poland's first commercial nuclear power plants. Westinghouse AP1000 reactor was selected by Polish government to be built as the first plant in the location of Lubiatowo-Kopalino, on the coast of the country. In the meantime, Poland's ZE PAK, Polska Grupa Energetyczna, and Korea Hydro & Nuclear Power have signed the letter of intent to collaborate on the project that evaluates the feasibility of building South Korean APR1400 on Pątnów site in central Poland. The objective of this study was to acquire and examine the gaseous effluents released during the standard operation of the AP1000 and APR1400 reactor technologies, with the primary goal of focusing on estimating the potential exposure of the general public. The effluents were calculated by using the GALE code based on each nuclear reactor technical specification. The obtained results were compared with those included in the Design Control Document for each reactor. Subsequently, the HotSpot software was used to calculate the radiation risk for downwind areas by utilizing GALE code results as source terms together with specific meteorological data corresponding for each localization. The results for AP1000 at Lubiatowo-Kopalino site and for APR1400 at Pątnów site were analysed and compared in the study. As the study findings were evaluated with the Polish radiation limits for the general public, all doses remained below the legal thresholds. With no previous alike studies conducted, this research begins the analysis of radiation impacts associated with the planned nuclear power plant in Poland during normal operation.

1. Introduction

With the implementation of the "2020 Climate and Energy Package" and the "2030 Climate Target Plan" [1, 2] by the European Union, the urgency for Poland's energy sector to embrace transformation has been catalysed. As energy demand grows and climate challenges emerge, the development of abundant, affordable, and environmentally responsible energy technologies is considered one of the most important goals for humankind in the years to come. In this regard, nuclear power is considered as a viable option for meeting the energy needs of the future generations. In September 2021, the Polish government authorities announced the commitment to build six pressurized water reactors with a total capacity of 6–9 GWe by 2040 [3]. The primary objective behind this decision is to decrease Poland's reliance on coal as an energy source [4]. The implementation schedule dictates that the construction of the first nuclear power plant will initiate in 2026. The first plant with a capacity of 1–1.6 GWe should be operational by 2033. Subsequent units will be introduced at intervals of approximately two to three years, in accordance with the desired timeline. At the end of 2022, the Polish authorities made an announcement, revealing the selected two locations and two technologies for the first commercial nuclear power plants in Poland [5]. Figure 1 illustrates the Google Earth image displaying the planned nuclear power plant locations in Poland. The Government selected Westinghouse Electric Company to build AP1000 nuclear power reactor in the location of Lubiatowo-Kopalino, on the coast of the country. In the meantime, Poland's ZE PAK, Polska Grupa Energetyczna, and Korea Hydro & Nuclear Power have signed the letter of intent to coordinate on the project evaluating the feasibility of building nuclear power plant of South Korean APR1400 on Pątnów site in central Poland.

As the standard operation of nuclear power plants (NPPs) involves the generation and release of radionuclides into the environment, the decision to construct the first NPP in Poland has raised concerns among the general public and regulatory bodies. The nuclear power program's primary objective is to protect the general public and environment against the potential risks posed by ionizing radiation from nuclear materials and facilities [6]. Aligned with the fundamental safety principles laid out by the International Atomic Energy Agency (IAEA) [7], this program emphasizes a commitment to safety and the protection of both current and future generations, given the operational lifespan anticipated to span several decades.

The radiation dose limits for the general public have been established worldwide. To ensure adherence for international standards, Poland has set its own dose limits based on the recommendations of the IAEA. The radiation dose limits are set out in the Regulation of the Council of Ministers adopted on 18 January 2005 on dose limits of ionizing radiation [8]. According to the prescribed regulations for general public, the permissible effective dose is designated as 1 mSv per one year. The permissible radiation exposure limits for the general public concerning specific organs are as follows. For the lenses of the eyes, the equivalent dose limit is 15 mSv. For all other tissues or organs, the equivalent dose limit is 50 mSv. Within the study, the radiation doses resulting from the normal operation of the planned AP1000 at the Lubiatowo-Kopalino and APR1400 at the Pątnów site were calculated and compared in relation to the Polish dose limits.

Several academic publications have investigated the radiation exposure resulting from normal operation at different geographic locations of APR1400 and AP1000 reactor designs. Specifically, investigations into the APR1400 nuclear reactor operating in South Korea [9] and the United Arab Emirates [10] highlighted adherence for regulatory safety limits as resulting doses were significantly below established thresholds. Additionally, a study concerning the AP1000 reactor in China [11] found no observable radiological impact on the surrounding ecosystem and public health resulting from the plant operations.

The studies related to nuclear energy in Poland deviate from an explicit emphasis on the evaluation of radiation exposure during standard operation of planned Polish nuclear power plants. For instance, paper [12] directs its attention toward economy, society, and environment effects of low-emission energy technology development in Poland, including nuclear energy. However, the study did not

Figure 1: Google Earth image depicting the planned locations of nuclear power plants in Poland: Lubiatowo-Kopalino on the coast and Pątnów in the central region of the country.

examine radiation exposure within its analysis section of environmental effects. Instead, the examination encompasses subcriteria such as for instance carbon emissions, waste generation, landscape alteration, and the potential for failure or accidents. Another study [13] presents arguments in support of nuclear power integration into the Polish energy sector. The study emphasizes considerations such as energy security, economic competitiveness, energy efficiency, and environmental impact; however, it also omits an examination of radiation doses.

2. Materials and Methods

Figure 2 illustrates the schematic representation of the adopted methodology frameworks employed in this study.

Based on the nuclear power plant technical characteristics obtained from the Design Control Documents (DCDs) for AP1000 [14] and APR1400 [15], the Gaseous and Liquid Effluents (GALE) code was used to calculate the gaseous effluents produced by the plants during normal operation condition. The GALE-PWR code consists of four codes that compute the effluents from Pressurized Water Reactors (PWRs) and Boiling Water Reactors (BWRs). The gaseous effluents are calculated in GALE using PWRGE (PWR Gaseous Effluents), which is a subprogram of GALE. The computation of the source term for radionuclides released by a nuclear power station during its normal operation is performed using a Fortran-based program. This program effectively utilizes a variety of input data. The input information for the program was acquired during the research process of this study, from the DCDs of both reactor types. The GALE-PWR is advanced software that performs sophisticated calculations essential to the nuclear industry based on methodologies, including NRC RG 1.112 [16], NUREG-0017 [17], and ANSI/ANS 18.1 [18]. This tool is designed to build analytical capabilities by using a diverse array of default values. The calculation is based on four components. Firstly, it relies on ANSI/ANS-18.1-1999 Tables and Adjustment Factors, providing a solid and dependable framework rooted in industry-standard data. As a result, analysis is performed with precision and consistency. Secondly, the code investigates Release and Transport

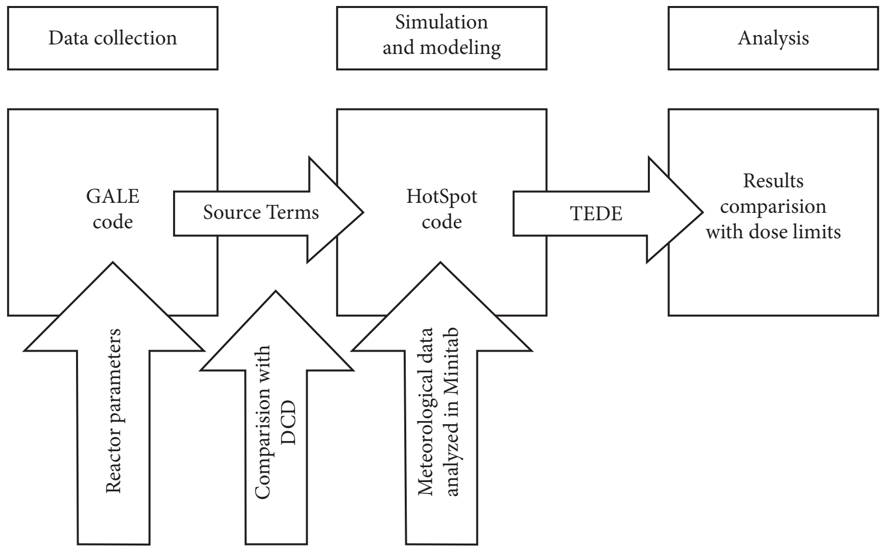

Figure 2: Methodology of the study for the estimation of radioactive release during normal operation condition of the NPPs.

Mechanisms, exploring the complex processes governing the dispersion and appearance of radioactive materials in liquid and gaseous waste streams. A third component is the incorporation of Plant-Specific Design Features to manage the release of radioactive materials into the environment and ensure the safety and sustainability of nuclear power plants. Lastly, NUREG-0017 provides valuable insights drawn from operational experiences of NPPs, enhancing the code's comprehensive approach. The individual nuclide release rates are calculated using equations presented in the user guide of the program [19]. Presented below are descriptions of some calculation methods employed by the GALE code for the determination of specific effluent rates, as outlined in the code's user guide. In terms of tritium release, the code uses release rate of $1.48E \times 10^{10}$ Bq/yr per MWth which is based on a review of the tritium release rates at a number of PWRs and specific measurements at the R.E. Ginna plant. This was made during the first two core cycles, during which this reactor operated 605 effective full-power days. The observed tritium buildup during this period was 5.217×10^{13} Bq. For the same period, 9.1×10^{5} MWd of thermal power was generated. Using these data and considering an 80-percent plant capacity factor (according to the GALE guidebook, this percentage of tritium is found in the gaseous effluents released from the auxiliary building ventilation system) and tritium decay, equation (1) shows the annual average tritium release:

$$\left(\frac{5.217\text{E} + 13\text{ Bq}}{9.1\text{E} + 05}\right)(0.8)\left(365\,\frac{\text{d}}{\text{yr}}\right)\left(\text{e}^{-6.93\text{E}-01\,(1)/12.3)}\right) = 1.591\text{E} + 10\,\frac{\text{Bq/yr}}{\text{MWt}}. \quad (1)$$

Regarding the release of ^{14}C, the code used the annual release of 2.701×10^{11} Bq based on measurements at 10 operating PWRs, with all specific data included in code guidebook. The NUREG-0017 states that ^{14}C reacts to form volatile compounds, mainly CH, C_2H_6, and CO_2, which are collected in the waste gas processing system and released via the plant vent. Additionally, ^{14}C is released from the containment and auxiliary building vent due to primary coolant leakage into the containment and auxiliary building. Regarding the calculation of ^{41}Ar release, the code relies on the data provided in Tables 2–40 of NUREG-0017, Revision 1, which compiles available information on gaseous ^{41}Ar releases from operating PWRs. In accordance with this information, the code uses estimation that the annual quantity of Argon-41 released from a PWR is approximately 1.258×10^{12} Bq. Lastly, the iodine release rates are determined in the GALE code, considering two scenarios: iodine release from building ventilation systems and iodine released from the main condenser air ejector exhaust. The releases of ^{131}I from building ventilation systems are ascertained through measurements taken at various operational reactors during both routine plant operations and plant shutdowns. The NRC, the creator of the GALE code, has collaborated with the Idaho National Engineering Laboratory to acquire operational data pertaining to liquid and gaseous waste treatment systems for specific PWRs. Detailed information can be found in the GALE code guidebook. These measurements demonstrate a direct correlation between the releases of ^{131}I through building ventilation systems and the concentration of ^{131}I in the reactor coolant. Equation (2) shows the release of iodine expressed as "normalized" release that is calculated by the absolute measured release rate in Bq/yr divided by the reactor coolant concentration in μBq/g:

$$R_N = \frac{R_A}{C_{RW}}, \tag{2}$$

where R_N is the normalized release rate of ^{131}I (Bq/yr/μBq/g); R_A is an absolute (measured) ^{131}I release rate (Bq/yr); and C_{RW} is the measured reactor water ^{131}I concentration (μBq/g).

The radioiodine releases from the main condenser air ejector exhaust are calculated by code based on secondary side measurements at Point Beach Unit 1 ad Unit 2, Turkey Point Units 3 and Unit 4, and Connecticut Yankee NPP.

Similar to the previously discussed normalized release for building ventilation, the main condenser air ejector exhaust radioiodine releases are directly related to the secondary coolant ^{131}I concentration. Equation (3) shows the normalized radioiodine release for the air ejector exhaust:

$$R_N = \frac{R_A}{C_{RW} \times PC}, \tag{3}$$

where R_N is the normalized effective release rate of ^{131}I (Bq/yr/μBq/g); R_A is an absolute (measured) ^{131}I release rate (Bq/yr); C_{RW} is the measured secondary coolant ^{131}I concentration (μBq/g); and PC is measured radioiodine partition coefficient from secondary coolant water to steam in the steam generator.

The HotSpot software was used to calculate the radiation risk to downwind areas by utilizing GALE code results as source terms together with specific meteorological data corresponding for each localization. This code uses the Atmospheric Dispersion Model (ADM) and Gaussian Plume Model (GPM) to estimate compound release. The GPM mathematical form is shown in the following equation:

$$\chi(x, y) = \frac{Q}{\pi \sigma_y \sigma_z \mu} \exp\left[-\frac{1}{2}\left(\frac{y^2}{\sigma_y^2} + \frac{H^2}{\sigma_z^2}\right)\right], \tag{4}$$

where $\chi(x, y)$ is the ground level concentration (Bq/cubic metre), Q is the emission rate (Bq/sec), x is the downwind distance (m), y is the crosswind distance (m), $\sigma_y \sigma_z$ represents horizontal and vertical standard deviation (m), μ is the mean wind speed (m/s), and H is the height of release point to the ground level (m). The Gaussian model is considered as the most appropriate for calculating radioactive releases from nuclear power plants into the surrounding environment, primarily due to its ability to clearly describe the dispersion.

The weather data from the nearest meteorological station measurements were obtained from the open database [20]. The datasets associated with both localizations comprised an extensive aggregation of over 60,000 data points collected on an hourly basis, covering the period from June 2019 to March 2023. In this study, the methodological data were analysed by using statistical Minitab software to find the parameters required by the HotSpot code.

3. Results and Discussion

3.1. Source Term. The source terms of radiation releases of AP1000 and APR1400 reactors used in this study were determined from internal calculations by using GALE software after incorporating technical characteristics that were gathered from the DCSs. Table 1 includes the gaseous release rates of nuclides calculated by using GALE, along with the comparison with the DCD for AP1000 and APR1400 reactors.

The calculated rates of effluent release were compared with the ones outlined in the Design Control Document (DCD) for each reactor. As the DCD serves as the official and comprehensive record of design requirements and is pivotal for ensuring compliance with regulatory requirements of many sorts, review of results of release with the rates included in DCD for each reactor type was vital for a complete analysis.

The release rates of nuclides calculated in the study using the GALE code were compared with the rates specified in the official DCDs and are shown in Table 1 for APR1400 and AP1000. It exposed that the release rates obtained in the study demonstrate a similar trend within justifiable ranges. Moreover, it is noteworthy that the release rates determined for the study and the rates outlined in the DCDs display a similar order of magnitude for almost all nuclides. Several values in Table 1 match the release rates of gaseous effluents obtained in the study with those included in the DCDs. This can be attributed to the utilization of input parameters sourced from reactor DCDs for the study's calculation in GALE code. These identical parameters were employed in both the study's calculations and the release outlined in the DCDs. Therefore, it is not unexpected for certain values to coincide when utilizing the same input data obtained from DCDs. Figure 3 displays the comparison of the gaseous release between the reactors.

By examining Table 1, it becomes evident that Figure 3 can be seamlessly comprehended. The reactors demonstrate a similar magnitude in the release of gaseous effluents for nearly all nuclides, with two exceptions: ^{90}Sr, where the release rate of APR1400 was found to be lower than of AP1000 by one order of magnitude, and ^{135}Xe, where the release rate of AP1000 was identified to be lower by one order of magnitude than APR1400.

3.2. Comparison with Real Release Data. The releases of chosen elements from the NPPs are published regularly in South Korea. Figure 4 illustrates a comparison between the gaseous effluents calculated in the study during the normal operation of the APR1400 reactor and the actual release of ^{3}H, ^{14}C, and ^{41}Ar from the APR1400 reactor at NPP Shin Kori Unit 3 in South Korea over the years 2016–2022 [21]. The figure illustrates that the releases are not constant, and each year, the release rate can vary. Furthermore, it indicates that the release rates calculated in the study exceed the actual data for any given year. This discrepancy is advantageous for further analysis as it prevents an underestimation of the releases, allowing for a more accurate assessment of radiation exposure. Additionally, it is important to notice that the comparison pertains to just one particular unit of APR1400.

In terms of actual releases from AP1000 reactors, the data are inaccessible. Currently, several AP1000 reactor units exist in China and the USA. The United Nations Scientific Committee on the Effects of Atomic Radiation

Table 1: Comparison of the obtained gaseous effluents for APR1400 and AP1000 with DCD.

Nuclide	Half-life	APR1400 GALE calculations (Bq/yr)	APR1400 DCD (Bq/yr)	AP1000 GALE calculations (Bq/yr)	AP1000 DCD (Bq/yr)
^{3}H	12.32 y	5.920×10^{12}	5.920×10^{12}	5.180×10^{12}	1.295×10^{13}
^{14}C	5.71*E*3 y	2.701×10^{11}	2.701×10^{11}	2.701×10^{11}	2.701×10^{11}
^{41}Ar	109.34 min	1.258×10^{12}	1.258×10^{12}	1.258×10^{12}	1.258×10^{12}
^{85}Kr	10.78 y	5.920×10^{15}	1.813×10^{14}	5.180×10^{15}	1.517×10^{14}
^{131m}Xe	11.93 d	8.880×10^{13}	8.140×10^{13}	7.400×10^{13}	6.660×10^{13}
^{133}Xe	5.25 d	2.738×10^{12}	2.590×10^{12}	1.998×10^{12}	1.702×10^{14}
^{133m}Xe	8.39 ms	5.180×10^{12}	4.810×10^{12}	3.219×10^{12}	3.219×10^{12}
^{135}Xe	9.14 h	1.850×10^{12}	1.887×10^{12}	8.880×10^{11}	1.221×10^{13}
^{131}I	8.02 d	9.620×10^{07}	6.660×10^{07}	7.400×10^{07}	4.440×10^{09}
^{133}I	20.81 h	5.550×10^{08}	8.510×10^{08}	3.367×10^{08}	1.480×10^{10}
^{90}Sr	28.90 y	2.331×10^{06}	2.331×10^{06}	4.440×10^{07}	4.440×10^{07}

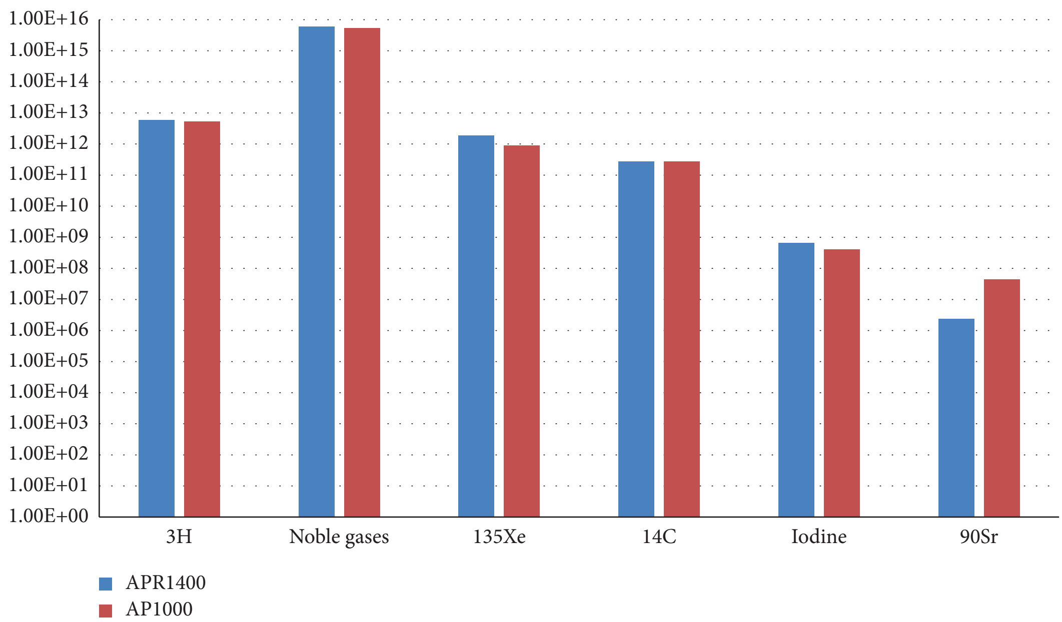

Figure 3: Comparison of the gaseous effluents (Bq/yr) calculated by GALE code for AP1000 and APR1400 (noble gases: ^{41}Ar, ^{85}Kr, ^{131m}Xe, ^{133}Xe, ^{133m}Xe, ^{135}Xe; iodine: ^{131}I, ^{133}I).

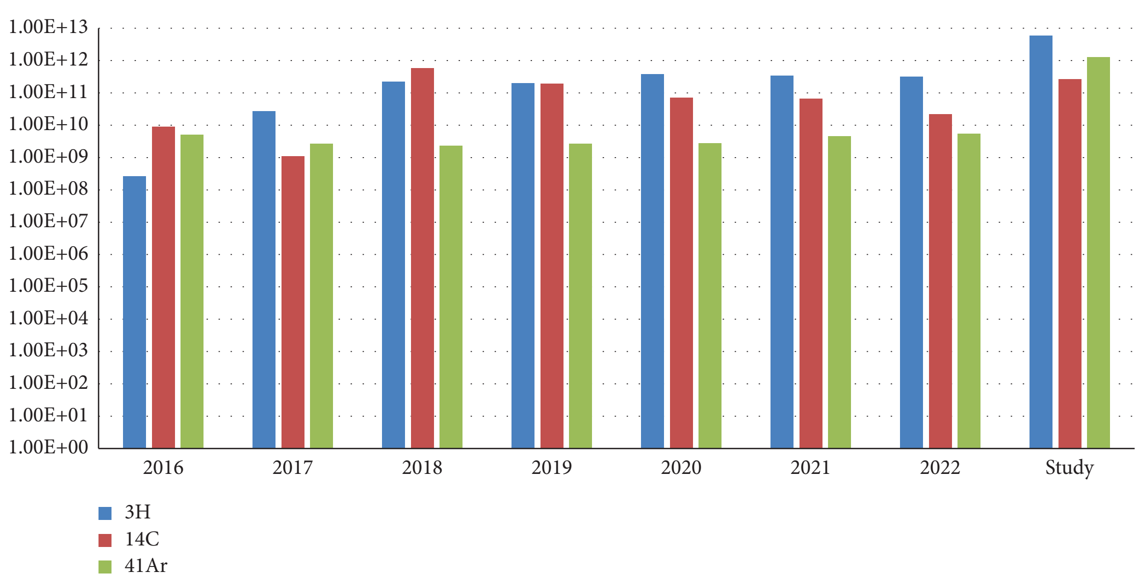

Figure 4: Comparison of gaseous effluents during normal operation from APR1400 reactor, as calculated in the study, with the actual release of ^{3}H, ^{14}C, and ^{41}Ar from NPP Shin Kori Unit 3 in South Korea during the years 2016–2022 [21].

(UNSCEAR) has published data summaries from nuclear plants worldwide, encompassing total releases of noble gases, particulates, and iodine from 1975 to 2004. However, these publications predate the commencement of commercial operations at NPPs in China, leading to a lack of data on releases from these AP1000 units. Moreover, data from other sources are not accessible for the AP1000 units in China. In the USA, there are two AP1000 units in Vogtle NPP, with Unit 3 commencing commercial operations in July 2023 and Unit 4 scheduled to start in 2024. As of now, there are naturally no available data on effluents from the normal operation of these units.

3.3. Meteorological Analysis. The weather data for each site contained approximately 60,000 hourly data points. In order to obtain the parameters necessary for the HotSpot code, the data were meticulously analysed using the Minitab software. This involved the need to determine if the dataset followed a normal distribution, subsequently guiding the selection of the appropriate method for calculating parameters such as wind speed, atmospheric stability class, and wind direction. The primary theoretical framework employed by Minitab software for evaluating data's normal distribution was based on the utilization of a p value test. It was verified that all the data deviated from a normal distribution, requiring the utilization of the median to determine the wind speed employed in the calculations for HotSpot. During the analysis, the four seasons for two locations were individually examined to determine the radiation doses resulting from the normal operation of the NPPs under various weather conditions existing in Poland. In order to accomplish this, the data were divided into seasons employing predefined date ranges that encompassed measurements taken: for spring between March 20th and June 20th, for summer between June 21st and October 23rd, for autumn between October 24th and December 21st, and for winter December 22nd and March 20th. The atmospheric stability class was determined to be C—slightly unstable conditions, for all the cases. The meteorological parameters necessary for the HotSpot analysis were categorized into four seasons for each of the localization. The details of the meteorological data analysis are displayed in Table 2.

3.4. HotSpot. Figure 5 presents the calculated total effective dose equivalent (TEDE) as a function of downwind distance for all atmospheric stability classes (A–F) for the four seasons: (a) spring, (b) summer, (c) autumn, and (d) winter, specifically for the AP1000 reactor at the Lubiatowo-Kopalino site. Figure 6 showcases the TEDE values for the APR1400 reactor at the Pątnów site across all four seasons. Figures 5 and 6 demonstrate that, for both reactors, the maximum dose distance was identified as 0.65 km. The Atmospheric stability classes (A–F) are characterized as follows: A—extremely unstable conditions, B—moderately unstable conditions, C—slightly unstable conditions, D—neutral conditions, E—slightly stable conditions, and F—moderately stable conditions.

Table 3 presents the TEDE values calculated using the HotSpot code for the AP1000 reactor at the Lubiatowo-Kopalino site divided into four seasons and comparison to the Polish dose limits established for the public. Table 4 shows the TEDE results for the APR1400 reactor at the Pątnów site for four seasons and comparison with the Polish dose limits for the public. Both tables also present the results of the effective dose equivalent (EDE) to organs for two analysed reactors throughout four seasons.

In Figure 7, the distribution of TEDE is presented on the map for the APR1400 reactor at the Pątnów site during summer season. This was achieved through the use of TEDE contour plot from the HotSpot code overlaid onto a Google Earth map.

Through experimentation utilizing the HotSpot tool and careful manipulation of various factors, an analysis was performed to elucidate the underlying reasons behind the consistently maximum dose distance, which was found to be 0.65 km and was observed across all seasons during the calculations. It was concluded that the sustained constancy throughout all seasons can be attributed to an unvarying factor in the composition of the radioactive release for each reactor, which remains unchanged and consistent in calculations for each individual season. Moreover, the identical value of maximum TEDE across different seasons is attributed to the consistent composition of radioactive releases and the incorporation of the same value of wind speed in the calculation for some of the seasons. The equivalent value of the wind speed was obtained from the Minitab analysis.

3.5. Radiation Doses. The comparison between the APR1400 reactor at the Pątnów site and the AP1000 reactor at the Lubiatowo-Kopalino site was conducted by analysing the results from Tables 3 and 4. The findings demonstrated that both reactors, under normal operation conditions, emit gaseous effluents resulting in TEDE values significantly below the dose limits for the general public in Poland. Upon examination of the AP1000 reactor at Lubiatowo-Kopalino, it was recognized that the highest TEDE occurred during summer season, with the value of 7.26 μSv. The analysis of the APR1400 reactor at the Pątnów site indicated that its highest TEDE value was recorded during the summer and autumn seasons, with a value of 8.37 μSv. Furthermore, this value also represents the highest dose identified within the context of this research. Nonetheless, all the doses calculated in the study were consistently observed to be notably lower than the established effective dose limit of 1 mSv. The doses measured for the APR1400 are higher, primarily due to the greater electrical output of this reactor when compared to the AP1000 reactor. Additionally, the study included calculations of effective dose equivalent to organs. For the AP1000 reactor at Lubiatowo-Kopalino, the highest observed dose to organs was 1.44 μSv during the summer

Table 2: Meteorological parameters found by Minitab statistical analysis for Pątnów and Lubiatowo-Kopalino sites.

Season	Wind direction Pątnów	Wind direction Lubiatowo-Kopalino	Wind speed (m/s) Pątnów	Wind speed (m/s) Lubiatowo-Kopalino
Spring	270° W	0° N	4	4
Summer	270° W	22.5° NNE	3	3
Autumn	90° E	180° S	3	4
Winter	270° W	270° W	4	4

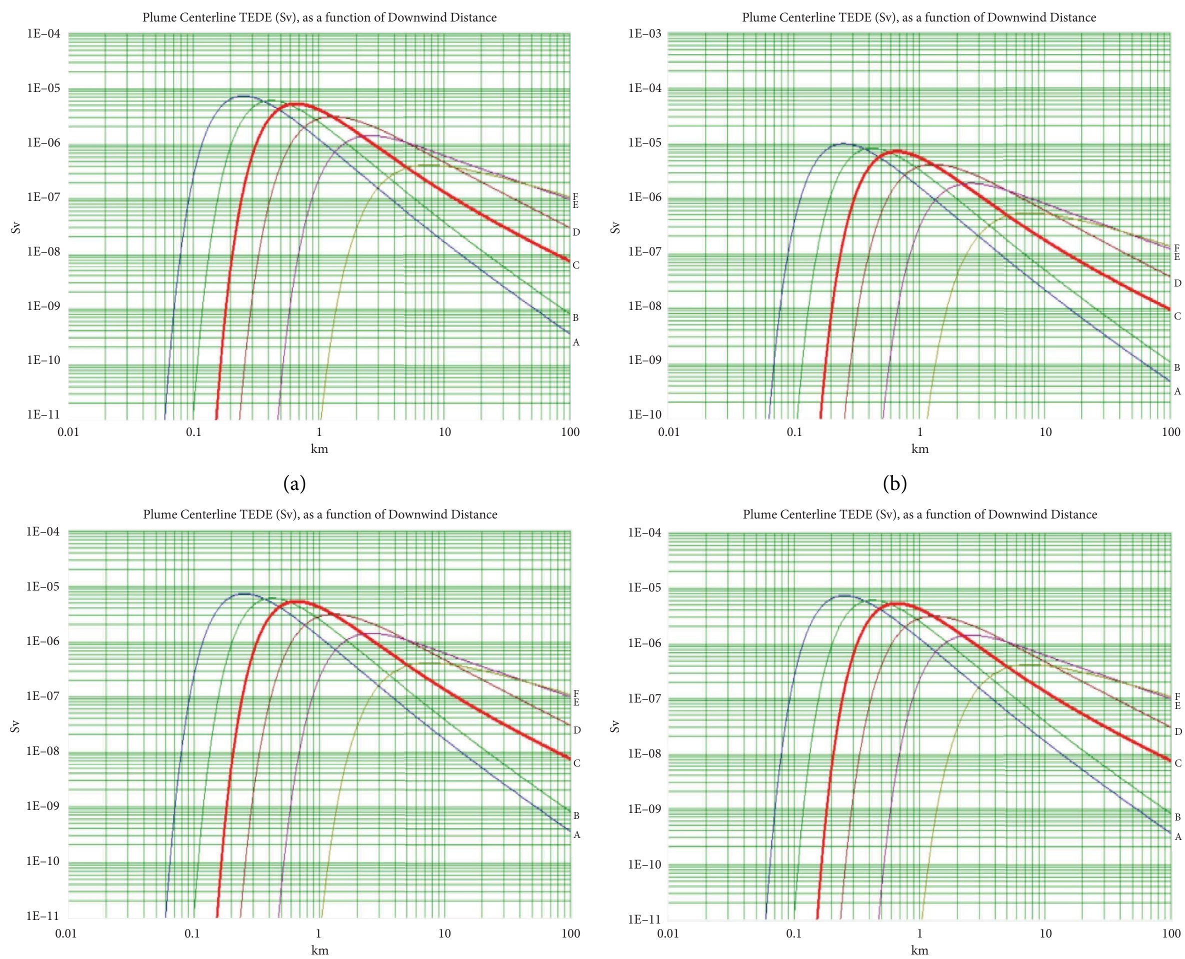

Figure 5: TEDE results as a function of downwind distance for all atmospheric stability classes (A–F) for AP1000 reactor at Lubiatowo-Kopalino localization for four seasons. (a) Spring. (b) Summer. (c) Autumn. (d) Winter. Class C highlighted in red.

season. As for the APR1400 reactor at the Pątnów site, the highest thyroid dose was found to be 1.65 μSv during the summer and autumn seasons. All doses were determined to be significantly below the limit set by Polish law, which is an equivalent dose of 50 mSv for the public. Outcomes strongly indicate that the doses from AP1000 in Lubiatowo-Kopalino and APR1400 in Pątnów during normal operation are notably below the limits established in Poland.

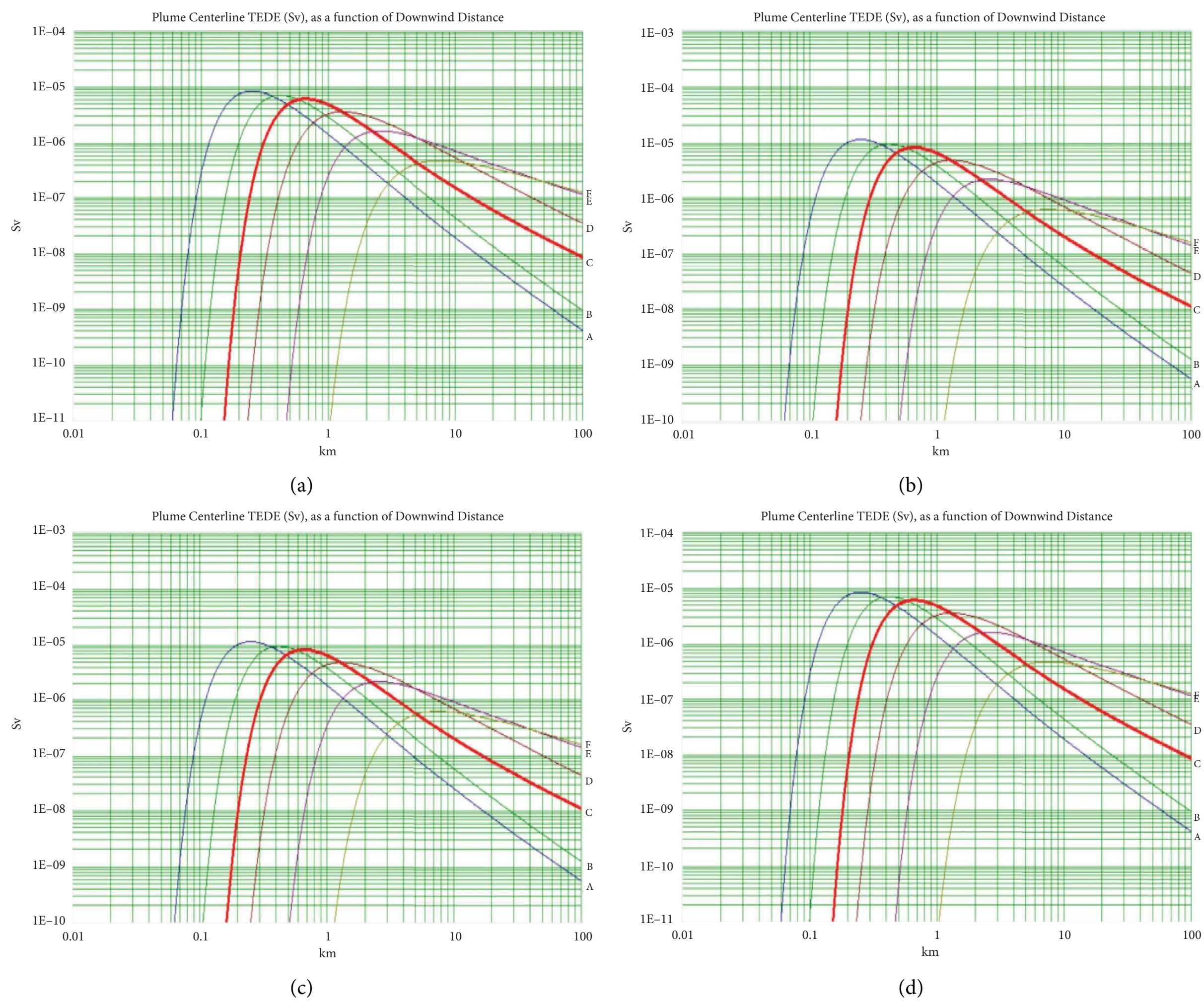

Figure 6: TEDE results as a function of downwind distance for all atmospheric stability classes (A–F) for APR1400 reactor at Pątnów localization for four seasons. (a) Spring. (b) Summer. (c) Autumn. (d) Winter. Class C highlighted in red.

Table 3: Results of maximum TEDE and maximum effective dose equivalent to organs for calculations of AP1000 in Lubiatowo-Kopalino and comparison with limits for general public.

General public	Dose limit (mSv)	Spring (μSv)	Summer (μSv)	Autumn (μSv)	Winter (μSv)
Maximum TEDE	1	5.45	7.26	5.45	5.45
Maximum EDE to organs	50	1.08	1.44	1.08	1.08

Table 4: Results of maximum TEDE and maximum effective dose equivalent to organs for calculations of APR1400 in Pątnów and comparison with limits for general public.

General public	Dose limit (mSv)	Spring (μSv)	Summer (μSv)	Autumn (μSv)	Winter (μSv)
Maximum TEDE	1	6.28	8.37	8.37	6.28
Maximum EDE to organs	50	1.24	1.65	1.65	1.24

Figure 7: Calculated distribution of the TEDE from the APR1400 reactor at Pątnów localization in summer season overlaid onto a Google Earth map. Dose contour values for the plume were 1 μSv (inner, red), 0.1 μSv (middle, green), and 0.01 μSv (outer, blue).

4. Conclusions

In the scope of this study, the radiation doses resulting from the normal operation of the planned nuclear power plants in Poland were meticulously calculated and subsequently compared to the radiation limits established by the Polish regulatory framework for the general public. The gaseous effluent release rates were derived from internal calculations using the GALE code. The derived release rates demonstrate a close alignment with the magnitudes specified in the Design Control Documents for both reactor technologies. In order to assess the impact of radioactivity resulting from gaseous effluents, the HotSpot code was employed. This involved incorporating the source term of nuclide release rates derived from calculations of the GALE code, along with meteorological data specific to the respective locations. The calculations within the HotSpot software were individually conducted for the four distinct seasons existing in Poland, namely, spring, summer, autumn, and winter. This analysis encompassed the AP1000 reactor at the Lubiatowo-Kopalino site and the APR1400 reactor at the Pątnów site. A comprehensive examination demonstrated that all radiation doses were significantly lower than the regulatory dose limits set by Polish law. As one of the initial explorations in its field, this study offers a contribution to insights into public exposure during normal operation of the planned nuclear power plants in Poland.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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References

[1] Council of the European Union, “Energy and climate—elements of the final compromise brussels,” 2008, https://www.consilium.europa.eu/uedocs/cms_data/docs/pressdata/en/ec/104672.pdf.

[2] European Commission, “Communication from the commission to the european parliament, the council, the european economic and social committee and the committee of the regions, stepping up europe’s 2030 climate ambition,” 2021, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0562.

[3] Ministry of Climate, “Polish nuclear power programme,” 2020, https://www.gov.pl/web/paa-en/Polish-Nuclear-Power-Program.

[4] Ministry of Climate and Environment Republic of Poland, “Energy policy of poland until 2040 (epp2040),” 2021, https://www.gov.pl/web/climate/energy-policy-of-poland-until-2040-epp2040.

[5] sejm, “Resolution of the council of ministers on the construction of large-scale nuclear power plants in the republic of poland,” 2022, https://isap.sejm.gov.pl/isap.nsf/download.xsp/WMP20220001124/O/M20221124.pdf.

[6] International Atomic Energy Agency, *Strategic Environmental Assessment for Nuclear Power Programmes: Guidelines*, IAEA, Vienna, Austria, 2018.

[7] International Atomic Energy Agency, “Fundamental safety principles,” 2006, https://www.iaea.org/publications/7592/fundamental-safety-principles.

[8] Journal of laws of the Republic of Poland, “Ionizing radiation dose limits,” https://natlex.ilo.org/dyn/natlex2/r/natlex/fe/details?p3_isn=.

[9] K. TarusKiplabat, “Off-site dose assessment during the operational states of APR1400,” *Journal of Radiation Industry*, vol. 13, no. 3, pp. 287–294, 2019, https://inis.iaea.org/search/search.aspx?orig_q=RN:51116596.

[10] M. Zubair, E. Ahmed, and D. Hartanto, “Estimation of public exposure during normal operation of unit-1 barakah nuclear power plant using gale and HOTSPOT,” *South African Journal of Chemical Engineering*, vol. 41, pp. 235–243, 2022.

[11] H. Ren, S. Yu, Z. Wang et al., “Assessment of radiation exposure and public health before and after the operation of Sanmen nuclear power plant,” *Frontiers in Public Health*, vol. 11, 2023,https://www.frontiersin.org/articles/10.3389/fpubh.2023.1131739, Article ID 1131739.

[12] M. Ligus and Evaluation of Economic, “Evaluation of economic, social and environmental effects of low-emission energy technologies development in Poland: a multi-criteria analysis with application of a fuzzy analytic hierarchy process (fahp),” *Energies*, vol. 10, p. 1550, 2017.

[13] J. Gierszewski, Ł. Młynarkiewicz, T. R. Nowacki, and J. Dworzecki, “Nuclear power in Poland’s energy transition,” *Energies*, vol. 14, no. 12, p. 3626, 2021.

[14] nrc, “Westinghouse ap1000 design control document rev. 19,” 2011, https://www.nrc.gov/docs/ML1117/ML11171A500.html.

[15] nrc, “Apr1400 design control document and environmental report,” 2018, https://www.nrc.gov/reactors/new-reactors/large-lwr/design-cert/apr1400/dcd.html.

[16] Regulatory Guide, *Calculation of Releases of Radioactive Materials in Gaseous and Liquid Effluents from Light-Water-Cooled Power Reactors*, U.S. Nuclear Regulatory Commission, Rockville, MA, USA, 2007.

[17] Nureg, *Calculation of Releases of Radioactive Materials in Gaseous and Liquid Effluents from Pressurized Water Reactors*, U.S. Nuclear Regulatory Commission, Rockville, MA, USA, 1985.

[18] Ansi/Ans, *Radioactive Source Term for Normal Operation of Light Water Reactors*, American Nuclear Society, La Grange Park, IL, USA, 1999.

[19] J. J. Tomon, K. J. Geelhood, and D. V. Colameco, *Calculation of Releases of Radioactive Materials in Gaseous and Liquid Effluents from Pressurized-Water Reactors Gale-Pwr 3.2 Code*, https://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0017/r2/index.html#pub-info.

[20] weather, "Weather online archive," https://rp5.ru/weather_in_the_world.

[21] Khnp, "Report on the investigation and evaluation of environmental radiation around nuclear power plants," https://npp.khnp.co.kr/board/list.khnp?boardId=BBS_0000032&menuCd=DOM_000000104003000000&contentsSid=161.