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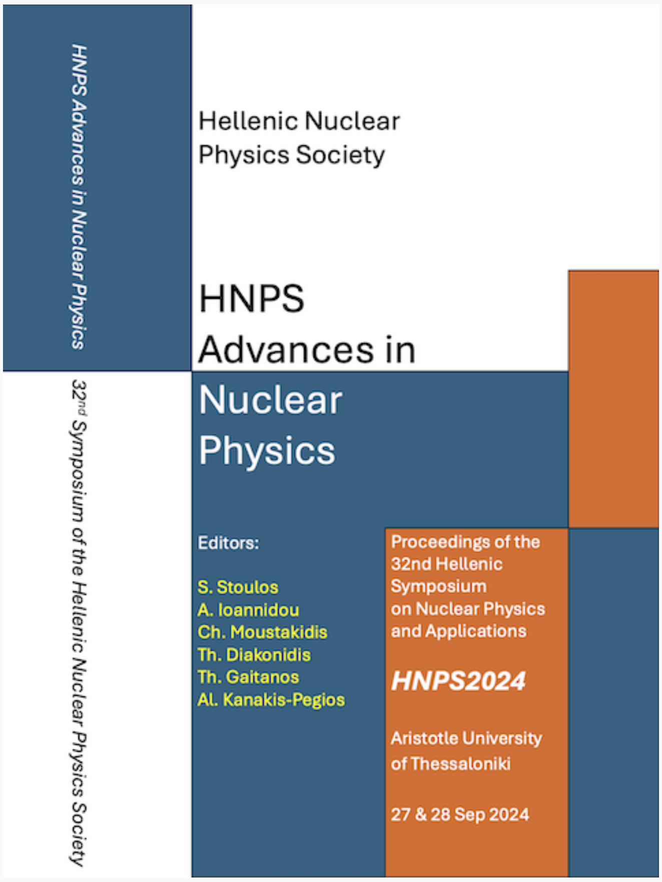


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# Assessment of the Total Effective Dose to the Representative Person in Greece, after a Hypothetical Release from a Nuclear Power Plant

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**Abstract** The Greek Atomic Energy Commission (EEAE), as the national regulatory authority, is responsible for ensuring radiological protection and nuclear safety. To this end, EEAE focuses on the assessment of nuclear or radiological emergencies, which may entail radiological risk for the country. As part of the risk assessment studies conducted by EEAE, a total of 40 worst-case release scenarios from a neighboring nuclear power plant were identified and studied in depth, using atmospheric dispersion software Hysplit and decision support system JRodos.

This work focuses on further analyzing the consequences of these release scenarios, by calculating the total effective dose to the representative person. The representative person is defined as a hypothetical individual, located in the areas within Greece that exhibit the highest radionuclide deposition and dose rates, and engaged to activities leading to potential exposure. The main exposure pathways were identified, while agricultural and livestock data provided by the Hellenic Statistical Authority were incorporated into the analysis. The total effective dose was calculated by applying appropriate dose coefficients. The results were compared to the dose limits which are defined in the Greek legislation. The analysis concluded that, even for the critical groups of the population, the calculated dose remained below the established limits. It was also evident that compliance with recommended countermeasures would significantly reduce the total effective dose, further enhancing public safety.

**Keywords** nuclear accident, emergency preparedness, atmospheric dispersion modeling

## INTRODUCTION

The fundamental safety principles of the International Atomic Energy Agency (IAEA) set the primary goals of preparedness and response for a nuclear or radiological emergency [1]. The Greek Atomic Energy Commission, as the regulatory body of Greece, oversees nuclear safety and radiation protection. To this end, potential radiation and nuclear emergency threats have been identified, studied, and assessed [2].

Previous works have focused on identifying and studying possible nuclear emergency scenarios which may impact the country and its population [3,4]. To achieve this, atmospheric dispersion software and decision support systems such as JRodos [5] were applied to simulate the transport and deposition of radionuclides in the environment.

This work aims at assessing the health risk of the affected population, after a nuclear emergency originating from a nuclear power plant neighboring Greece. Its aim is to optimize the countermeasure strategy, while ensuring compliance with the annual dose limit of 20 mSv for public exposure [6]. In alignment with the recommendations of the International Commission on Radiological Protection (ICRP), the concept of the representative person was applied to properly perform dose assessment to the public [7,8]. The representative person is defined as an individual that receives a dose that is representative of the more highly exposed individuals in the population and refers to the average member of the critical group

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[7,9].

The total effective dose was calculated for different groups of the population, and over varying time periods. The findings indicate that critical groups of the population residing both in urban and agricultural areas remain within the dose limits defined in the legislation**.** However, there is potential for further dose reduction in agricultural areas, where the primary pathway of exposure is the consumption of leafy vegetables**.** By implementing restrictions on the consumption of leafy vegetables, the total dose for those critical groups can be significantly reduced, ensuring compliance with the 20 mSv dose limit while improving public safety.

## MATERIALS AND METHODS

In line with [4], an accidental release from a nuclear power plant neighboring Greece was assumed. A conservative source-term for a 3000 MWh LWR reactor was applied, as presented in Table 1, and different release scenarios were produced and studied. A worst-case scenario was selected regarding the meteorological data leading to a fast transport of radionuclides in the Greek territory. The decision-support system JRodos was applied to simulate the transport and dispersion of radionuclides in the atmosphere, at a distance up to 800 km from the emission point. The meteorological data imported into JRodos were obtained by NOAA's National Centers for Environmental Information (NCEI). The data started at 21/02/2020 at 00:00 UTC, with a 0.25-degree grid resolution and 6 hours update period. The scenario was studied for a total of 30 days, with 1-hour timesteps, and a spatial resolution of 16 km in the northern part of Greece and 32 km in the rest of the country. The modeling was conducted by applying the atmospheric dispersion model RIMPUFF, which produces Gaussian puffs continuously in time, which evolve temporally and spatially according to the meteorological data. The concentration of radionuclides in the air and the ground deposition were calculated. Transfer factors, which are specific for each radionuclide considered and for each type of plant, were applied to calculate the concentration of radionuclides in the plants and subsequently in the food chain [10].

**Table 1.** *Source term of hypothetical release*

| Radionuclide | Inventory (Bq) |
|---|---|
| Sr-89 | 3.50E+16 |
| Sr-90+ | 1.40E+15 |
| Ru-103+ | 4.10E+16 |
| Ru-106+ | 9.30E+15 |
| Te-129m+ | 2.00E+16 |
| Te-132+ | 2.40E+17 |
| I-131 | 3.20E+17 |
| I-133 | 6.30E+17 |
| Cs-134 | 2.80E+16 |
| Cs-136 | 1.10E+16 |
| Cs-137+ | 1.70E+16 |
| Ba-140+ | 5.90E+16 |

Two critical groups of the population were selected to calculate the dose to the representative person. Both critical groups were chosen to be residents of the area near the town of Komotini, in the northern part of Greece. According to the study performed in [4], this is one of the higher-risk areas of Greece in case of the event of a transboundary nuclear emergency, given the high probability of plume transfer and the high dose rates observed. As such, two critical groups were selected: a farmer residing in an agricultural area near the city of Komotini and a town resident in Komotini.

A total of four main exposure pathways were identified for the two critical groups of the population. Cloudshine (external irradiation from the concentration of radionuclides in the air), Groundshine (external irradiation from deposited radionuclides), inhalation and ingestion. To accurately perform dose assessment for all considered pathways, behavioral and lifestyle data were incorporated. Four important parameters were identified and studied: The time spent outdoors, the type of work -which affects breathing rates-, the house types, and the consumption of local foodstuff. According to data obtained from the Hellenic Statistical Authority [11] it was found that the farmer spends 12 hours on average outdoors, while the town resident spends 3 hours outdoors daily. The farmer's work was considered a combination of light and heavy work (4:1 ratio), while the town resident's work was considered mostly sedentary. Thus, suitable breathing rates were considered according to ICRP recommendations [12]. Moreover, a worst-case scenario was assumed for housing, where farmers reside in wooden houses and town residents in two-floor apartments. According to studies performed after the Fukushima release [13], which involved a similar range for air dose rates, the reduction factor was considered to be approximately 0.38 for wooden houses and 0.5 for concrete buildings or multi-store apartments.

Food consumption was categorized into five groups: milk, meat, vegetables, fruit, and cereal. Town residents were assumed to rely exclusively on packaged food, while farmers predominantly consumed locally produced food. To refine the assessment, each category was subdivided into specific food types (e.g. cow, goat, and sheep milk). Consumption patterns for each type were derived using data from the Hellenic Statistical Authority [11] and the Food and Agriculture Organization (FAO) [14]. Regional production data were normalized to calculate weighting factors for each food type, enabling the estimation of average monthly consumption.

## RESULTS AND DISCUSSION

This study utilized JRodos to model the aforementioned nuclear emergency scenario and calculate the air concentration in terms of $Bq/m^3$, ground deposition in terms of $Bq/m^2$ and concentration of radionuclides in foodstuff in terms of Bq/kg. The highest air concentrations in the area of interest were observed for iodine and tellurium isotopes and ranged between a few hundred up to a few thousand $Bq/m^3$. The deposition values ranged from a few hundred $Bq/m^2$ up to approximately 50 $kBq/m^2$ for iodine isotopes and remained below 10 $kBq/m^2$ for cesium isotopes.

The radionuclide concentrations in various local food categories were calculated for each isotope of interest, focusing on those critical during a nuclear emergency. Leafy vegetables and milk were identified as key contributors to radiation exposure due to their high potential to accumulate radionuclides. Among the isotopes analysed, cesium and iodine are expected to have the most significant impact on the total effective dose. However, all relevant radionuclides were included in the dose assessment to ensure comprehensive evaluation. The analysis revealed that iodine isotopes can reach maximum concentrations of approximately 1,000,000 Bq/kg in leafy vegetables and 320 Bq/kg in cow milk. For cesium isotopes, the maximum concentrations were approximately 25,000 Bq/kg in leafy vegetables and 60 Bq/kg in cow milk. These findings underscore the importance of monitoring and managing the consumption of these foodstuffs during and after a nuclear emergency to minimize public exposure to radiation.

To properly perform dose assessment to the critical groups of the population, the simulation results were combined with appropriate weighting factors to consider habits data and then radionuclide specific dose coefficients were applied, according to ICRP [15]. The total effective dose from the first month, integrated over one year was calculated for every exposure pathway, for the representative person residing in the city and the representative person in the village. The results are presented in Table 2.

**Table 2.** *Total annual effective dose for the representative persons of the two critical groups from the first month, integrated over one year.*

| | **City** | **Village** |
|---|---|---|
| External Ground Dose | 0.092 | 0.116 |
| External Cloud Dose | 0.003 | 0.005 |
| Inhalation | 0.180 | 0.503 |
| Ingestion | 0.000 | 13.8 |
| **Total (mSv)** | 0.275 | 14.4 |

It is evident that for the representative person residing in the city, the total effective dose from the first month integrated over one year is calculated as less than 1 mSv and thus remains well below the annual dose limit of 20 mSv of emergency exposure for the public. The total effective dose from the first month integrated over one year for the representative person residing in the village was calculated as 14.4 mSv. While below the annual dose limit, the dose is not insignificant, and thus there is room for optimization. As per Table 2, the main pathway of exposure is ingestion. To this end, the calculation was performed again, after prohibiting the consumption of leafy vegetables, which were found to be the main contributor to the dose from the ingestion pathway. The optimized total effective dose from the first month integrated over one year for the representative persons of both critical groups is presented in Table 3.

**Table 3.** *Optimized total effective dose for the representative persons of the two critical groups from the first month, integrated over one year.*

| | **City** | **Village** |
|---|---|---|
| External Ground Dose | 0.092 | 0.116 |
| External Cloud Dose | 0.003 | 0.005 |
| Inhalation | 0.180 | 0.503 |
| Ingestion | 0.000 | 0.041 |
| **Total (mSv)** | 0.275 | 0.665 |

The total effective dose from the first month, integrated over one year remains the same for the person residing in the city, as a best-case scenario under which their diet relies solely on packaged food was considered. On the contrary, the total effective dose from the first month, integrated over one year for the representative person residing in the village is reduced from 14.4 to less than 1mSv after imposing restrictions on the consumption of leafy vegetables. Thus, decision-making was optimized.

**Table 4.** *Total effective gamma dose from the first year, integrated over the lifetime of the representative persons.*

| | **City** | **Village** |
|---|---|---|
| External Ground Dose | 0.22 | 0.27 |
| External Cloud Dose | 0.003 | 0.005 |
| Inhalation | 0.18 | 0.5 |
| Ingestion (banned vegetables) | 0.0 | 0.041 |
| **Total (mSv)** | 0.4 | 0.82 |

Finally, due to some radionuclides' long half-lives, the calculation was performed again, by considering the total effective dose from the first year, integrated over the lifetime of the representative persons. To perform the calculation, each radionuclide's half-life as well as deposition parameters were considered, as well as the radionuclide-specific lifetime dose coefficients provided by ICRP [15]. The results are presented in Table 4.

It is evident that the external ground dose is approximately doubled for both the representative person residing in the city and the one residing in the village. External ground dose becomes the main pathway of exposure for the critical group in the city, while inhalation remains the dominant pathway of exposure for the critical group in the village, assuming that the consumption of foodstuff is restricted. The difference is attributed to the enhanced breathing rates of the critical group of farmers, due to their type of work. In both cases, the lifetime dose remains well-within 1 mSv.

## CONCLUSION

In this work, a worst-case scenario involving an accidental release from a nuclear power plant neighboring Greece was produced and studied using JRodos. The modelling results were applied to perform dose assessment to the representative persons of two critical groups: a city resident in Komotini and a farmer in a nearby agricultural area. It was found that, while the total annual effective dose remains below the limit of 20 mSv, there is room for optimization, especially regarding the representative person residing in the agricultural area. Ingestion of contaminated foodstuff, and more specifically leafy vegetables was found to be the main pathway of exposure for the farmer. To this end, after prohibiting the consumption of leafy vegetables the annual effective dose was limited from 14.4 to less than 1 mSv for this critical group. Thus, the results of this study were used to further optimize the decision-making strategy.

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