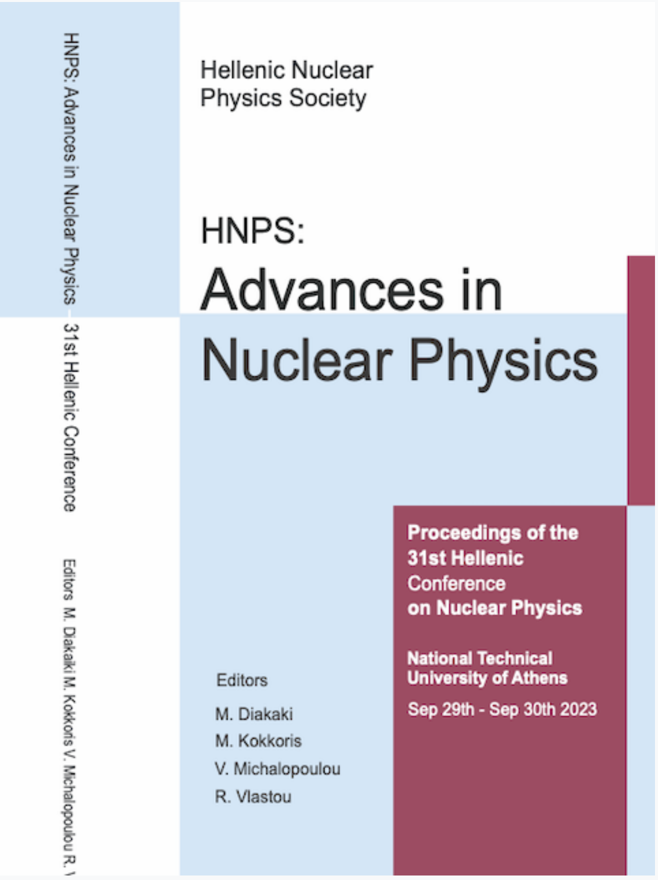
ePublishing

Annual Symposium of the Hellenic Nuclear Physics Society

Τόμ. 30 (2024)

HNPS2023



Atmospheric Dispersion Software Intercomparison Exercise and Sensitivity of Results

Nikos Salpadimos, Konstantinos Karfopoulos, Constantinos Potiriadis, Spyros Andronopoulos, Ioannis Seimenis

doi: [10.12681/hnpsanp.6204](https://doi.org/10.12681/hnpsanp.6204)

Copyright © 2024, Nikos Salpadimos, Konstantinos Karfopoulos, Constantinos Potiriadis, Spyros Andronopoulos, Ioannis Seimenis

Άδεια χρήσης Creative Commons Attribution-NonCommercial-NoDerivatives 4.0.

Βιβλιογραφική αναφορά:

Salpadimos, N., Karfopoulos, K., Potiriadis, C., Andronopoulos, S., & Seimenis, I. (2024). Atmospheric Dispersion Software Intercomparison Exercise and Sensitivity of Results . *Annual Symposium of the Hellenic Nuclear Physics Society*, *30*, 124–130. https://doi.org/10.12681/hnpsanp.6204

https://epublishing.ekt.gr | **e-Εκδότης:** EKT | **Πρόσβαση:** 15/12/2025 18:44:45

Atmospheric Dispersion Software Intercomparison Exercise and Sensitivity of Results

N. Salpadimos[1,*], K.L. Karfopoulos[1], I. Seimenis[2], C. Potiriadis[1], S. Andronopoulos[3]

[1] *Environmental Radiation Monitoring Department, Greek Atomic Energy Commission, 15310 Aghia Paraskevi, Athens, Greece*

[2] *Medical Physics Lab, Medical University of Athens (EKPA), 115 27 Goudi, Athens, Greece*

[3] *National Center for Scientific Research "Demokritos",* Institute *of Nuclear and Radiological Sciences and Technology, Energy and Safety, 153 10 Aghia Paraskevi, Athens, Greece*

Abstract The Greek Atomic Energy Commission (EEAE) is the national regulatory authority, competent for the control, regulation, and supervision in the fields of nuclear energy, nuclear technology, radiological and nuclear safety, and radiation protection. Within its mandate is to assess emergencies in or out of Greece, which may entail radiological risk for the country. To this end, studies based on atmospheric dispersion software, like JRodos, are performed [1]. To validate the performance of the software, EEAE recently participated in a JRodos intercomparison exercise. The exercise was conducted within the Rodos User Group (RUG) and was based on a hypothetical release from a nuclear icebreaker in Danish coastal waters. This work further evaluates its results on the basis of their sensitivity in the parameter of the atmospheric dispersion models. To this end, three atmospheric dispersion models: RIMPUFF [2], LASAT [3], and DIPCOT [4], were applied. Their results were compared in different timesteps in terms of the effective gamma-dose rate at the height of 1 m. It was found that results tend to differentiate immediately after the release due to the models' different approaches. However, all models yield similar results at the later phases of the release.

Keywords nuclear accident, emergency preparedness, atmospheric dispersion modeling

INTRODUCTION

In line with the fundamental safety principles of the International Atomic Energy Agency (IAEA), the primary goals of preparedness and response for a nuclear or radiological emergency include effective arrangements at local, regional, national, and international level [5]. The Greek Atomic Energy Commission is the regulatory body of Greece, competent for the control, regulation, and supervision in the fields of nuclear energy, nuclear technology, radiological and nuclear safety, and radiation protection. As such, potential radiation and nuclear emergency threats are to be identified, studied, and assessed. To this end, a specific national emergency preparedness and response plan has been established, in case of a severe accident originating from a nuclear installation neighboring Greece [6].

Nuclear emergency response systems have been established as crucial tools in nuclear emergency preparedness and response. These tools are widely used to evaluate the consequences of an accidental release of radionuclides, and to determine an optimal countermeasure strategy [7].

Numerous dedicated software has been established, which contain different models to accurately predict a hypothetical release. The software used in this work is JRodos, as this is the primary tool for emergency preparedness and response in many countries, including Greece [1]. JRodos, the redesigned

* Corresponding author e-mail: *nikos.salpadimos@eeae.gr*

Java version of Rodos, is a decision support system for off-site emergency management of radioactive material in the environment. JRodos contains different models and databases, for assessing, presenting, and evaluating the consequences of a nuclear accident. In detail, it contains numerous models for atmospheric dispersion, dose assessment, and evaluation of the countermeasure strategy both in the early and late phase of an event [8,9]. These models, use operational weather data to simulate the transport, deposition, and distribution of radionuclides in the environment [8]. The accuracy of the results depends on the reliability of the input parameters, namely the meteorological data, the source term, and the atmospheric dispersion models [7].

Previous studies have focused mainly on investigating the impact of source term on the meteorological data on the accuracy of modelling results. Thus, this work aims at conducting a sensitivity analysis of the atmospheric dispersion models included in JRodos. JRodos contains three atmospheric dispersion models, namely RIMPUFF [2], LASAT [3], and DIPCOT [4]. A well-established hypothetical scenario is applied, and the total effective gamma dose rates at the height of 1 metre above the ground are calculated. For this calculation, JRodos calculates the radionuclide concentration in the air and the radionuclide deposition based on the dry and wet deposition processes, and then applies the Cloudshine and Groundshine factors respectively for each radionuclide of interest. A previous work by Päsler-Sauer aimed at comparing the atmospheric models RIMPUFF, DIPCOT and ATSTEP [10], in terms of radionuclide concentration in the air [11]. Our work focuses on identifying how differences in models affect decision-making in case of a real emergency. As such, the applied countermeasures based on the measured value were also presented for each model's results.

MATERIALS AND METHODS

JRodos contains different model chains to simulate a hypothetical release. Each model chain emphasizes on different output results. In this work, the LSMC (Local Scale Model Chain) was applied. This model chain is an atmospheric dispersion model, coupled to a meteorological pre-processor. The meteorological pre-processor considers the fine-scale topography details on atmospheric flow [11]. The atmospheric model is able to simulate the transport and dispersion of radionuclides in the atmosphere, at a distance up to 800 kilometers from the emission point. Results are produced in terms of plume track and arrival time, air concentration, ground contamination, and dose rates [9]. All dose rates are given in terms of effective gamma dose rates at the height of 1 meter above the ground level (nSv/h) [12]. This value is constantly measured by the radiation monitoring network detectors, a network that many countries, including Greece utilize, not only as an early notification system, but also as a decision-making tool [13]. Thus, this work focuses on this parameter because it directly affects decision-making in case of a real emergency.

Three different atmospheric dispersion models can be utilized when applying LSMC model chain; LASAT [3], RIMPUFF [2], and DIPCOT [4]. LASAT (Lagrangian Simulation of Aerosol-Transport) is a three-dimensional Lagrangian particle model. It utilizes the random walk process to simulate the dispersion and transport of a representative sample of trace particles [3]. RIMPUFF (Risø Mesoscale PUFF model) is a Gaussian-like trajectory puff model which is able to consider meteorological data which change temporally and spatially. At each time step the model/code advects, diffuses and deposits the individual puffs according to local meteorological parameter values and calculates the gamma-radiation dose components from puffs and deposited radionuclides [2]. DIPCOT (DIsPersion over COmplex Terrain) is a Lagrangian Puff / Particle model that has been implemented in RODOS to simulate radionuclides atmospheric dispersion over complicated terrain. As such, a certain number of fictious puffs/particles are utilized and are assumed to move with the mean wind flow, plus a random velocity component to simulate turbulent diffusion. Also, the calculation of gamma dose rates considers the inhomogeneous 3-dimensional cloud shape [4].

The scenario used in this study was a well-established hypothetical scenario obtained from the 2nd JRodos User Group (RUG) exercise. The exercise was organized on November 2022 by the JRodos team ITES (KIT), and 30 organizations from 24 countries participated. It featured an accident on nuclear powered ship near the Danish coastal waters on the 17th November of 2022. A collision led to severe hull damage, which in turn resulted into a radioactive release 24 hours after the initial event. The duration of the release was 3 hours, and the height of release was assumed at 10 meters above the ground. The source term, which was derived from the NKS-139&390 Reports, consisted mainly of Xenon isotopes, and also ^{131}I and Cesium isotopes, as well as other aerosols [14, 15]. The total source term is presented in Table 1.

Table 1. Source term of hypothetical release

Radionuclide	Half life (d)	Release to atmosphere (Bq)	Release to atmosphere relative to the inventory (%)
Sr-90	10512	4.4E+13	0.5
Ru-106	373.6	1.6E+13	0.3
I-131	8.05	3.4E+15	8
Te-132	3.204	5.5E+16	3
Xe-133	5.243	1.0E+17	80
Xe-135	0.3808	2.6E+16	80
Cs-134	754	7.1E+15	4
Cs-137	10976	8.8E+15	4
Ba-140	12.752	9.3E+16	0.5
Pu-239	8.80015×10^6	7.5E+11	0.04

The meteorological data were obtained by NOAA’s National Centers for Environmental Information (NCEI) and imported into the JRodos. The data started at 18/11/2022 at 00:00 UTC, with 0.25-degree grid resolution and 6 hours update period (Grib2). For each model run, atmospheric dispersion was monitored for 96 hours after the release (i.e., 16 updates of meteorological data were considered) and the value of the total effective gamma dose rate for a height of 1 meter above the ground within this 96-hour span was obtained for each geographical grid cell, with a time-step of one hour. In the set of runs for the present work, the selected calculation distance was 800 km. The grid size was 2 kilometers near the emission point and increases up to 32 kilometers, depending on the distance from the emission point, to achieve more detailed results where doses are expected to be higher.

RESULTS AND DISCUSSION

To study the aforementioned scenario, a separate run was performed, each time applying a different atmospheric dispersion model, and studying the effect on the total effective gamma-dose rate at the height of 1m above the ground, and hence at suggested countermeasures. The results were compared at different timesteps, at 3 hours and 24 hours after the release.

Table 2 presents the comparison of median values of gamma dose rates within all atmospheric dispersion models, in terms of percentage difference.

Table 2. Median values of the percentage difference over the set of grids, between the atmospheric dispersion models

Median Dose Rates 10 m		
Models	**Percentage Difference (3H)**	**Percentage Difference (24H)**
Rimpuff-Lasat	25%	136%
Rimpuff-Dipcot	185%	59%
Lasat-Dipcot	199%	121%

It is evident that RIMPUFF and LASAT are mainly in agreement for the shorter timeframe, while their results tend to differentiate at the 24-hour timestep. This is explained by the fact that LASAT primarily specializes in computing the transport of radionuclides in the regional scale, up to approximately 200km. The plume from the studied scenario has traveled far beyond that distance on the 24h timestep, thus leading to these differentiations. Moreover, DIPCOT results significantly differentiate from the other models at the 3h timestep, mostly due to the calculation processes involved. ATSTEP and RIMPUFF use wind velocity data close to the ground -or averaged in the vertical direction up to a certain level- while DIPCOT uses the fully three-dimensional wind velocity field, which varies with height [11]. According to previous studies, when tested under complex meteorological conditions together with real topographic data, DIPCOT accounts for the strong directional wind shift with height, by dispersing a fraction of the released particles into shifted directions [11]. As a result, the particle model DIPCOT has been found to yield more accurate results than the puff models [11]. However, at larger distances, the RIMPUFF and DIPCOT results tend to converge. It is also noted that percentage difference below 100% are not considered as huge deviations for this study, given that the uncertainties in modeling such scenarios are already substantial, mainly due to the uncertainties induced by the meteorological data input. Figures 1 to 3 present the models' results differences, in terms of total effective gamma dose rate at the height of 1m, by using the percentage difference metric. The presented results correspond to the 3-hour timestep, because higher dose rates are expected, as well as differences between models, which may result in inconsistent countermeasure strategies. The 24-hour timestep results are included in supplemental material.

According to the presented results, it is concluded that the atmospheric dispersion models' results converge near the center of the plume (percentage difference < 100%), but as the plume spreads, the results tend to differentiate, as the percentage difference is within 100% and 1000%. It is also important to note that, as seen in the figures, different models' results lead to different locations of transport of the plume, as depicted in black coloring. Those differences are attributed to the processes followed by each model. RIMPUFF is a puff model, while LASAT and DIPCOT are particle models. ATSTEP and RIMPUF use wind velocity data close to the ground -or averaged in the vertical direction up to a certain level. On the other hand, DIPCOT uses the fully three-dimensional wind velocity field, which varies with height. When tested under complex meteorological conditions together with real topographic data, DIPCOT accounts for the strong directional wind shift with height, by dispersing a fraction of the released particles into shifted directions. To this end, it has been established that the particle model DIPCOT yields more accurate results than the puff models, especially under complex conditions [10]. Such differences should be considered by the modeler in case of a real event, and the worst-case scenario ought to be considered to protect the public.

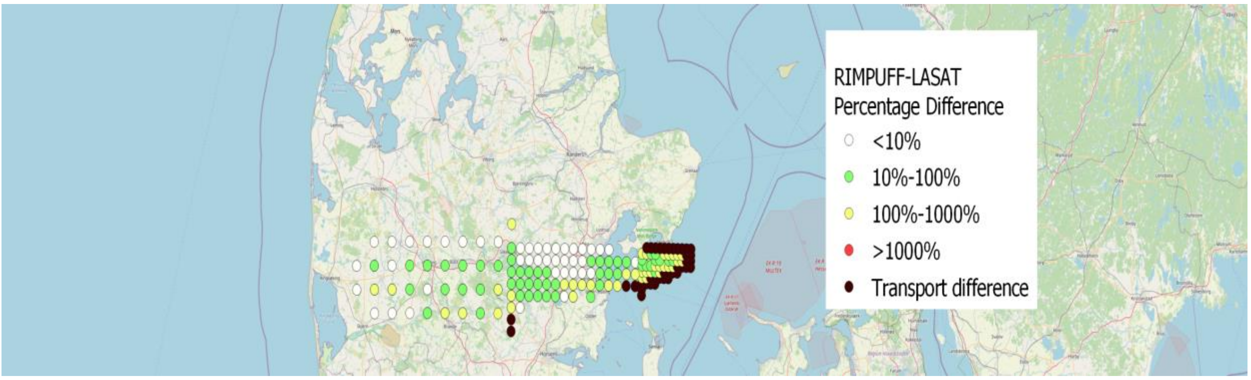


Figure 1. *RIMPUFF and LASAT comparison in terms of percentage difference*

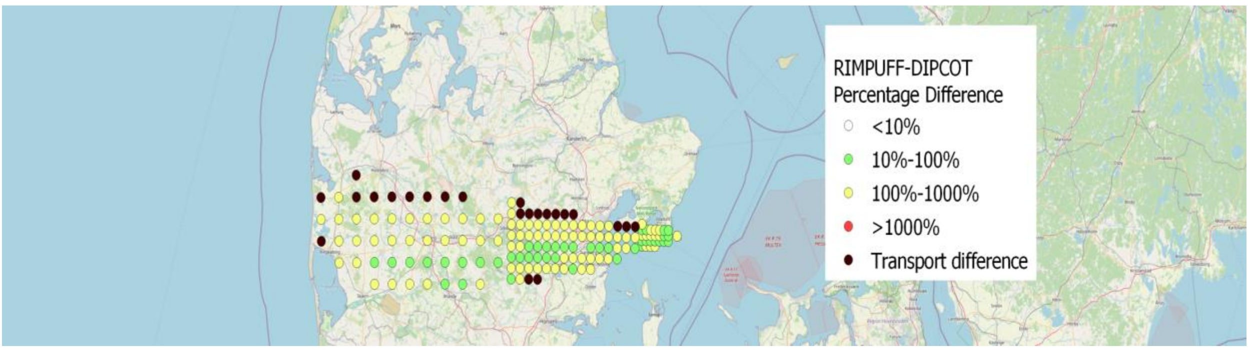


Figure 2. *RIMPUFF and DIPCOT comparison in terms of percentage difference*

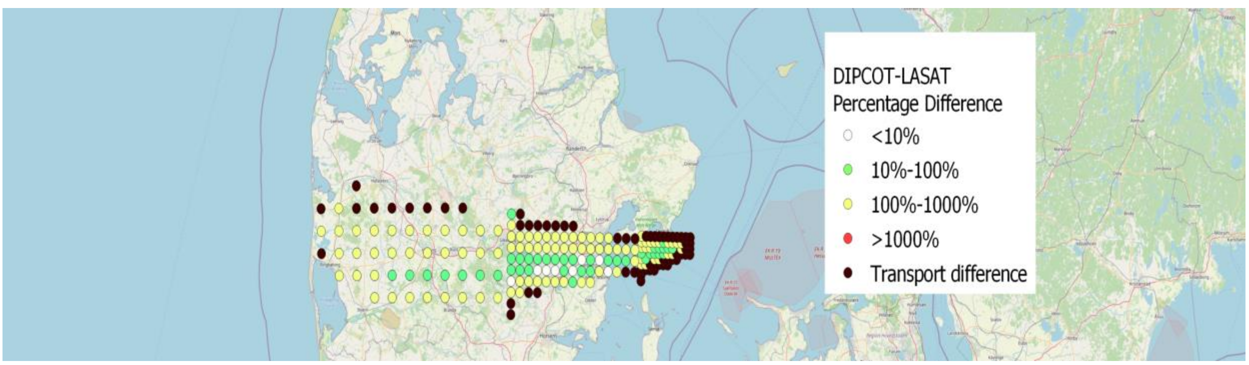


Figure 3. *LASAT and DIPCOT comparison in terms of percentage difference*

Due to the significant differences observed, this work also focuses on how the presented results affect decision-making. To this end, figures 4 to 6 present the total effective gamma dose rate for each atmospheric dispersion model. Each interval depicted in the legend, and presented with a different color in the figure, corresponds to a different countermeasure, based on IAEA' operational intervention levels [16]. In detail, total effective dose rate at the height of 1m below 1 μSv/h corresponds to no countermeasure applied based on this value. For dose rates above 1μSv/h the foodstuff and feedstuff in those areas would be investigated for possible contamination. At dose rates above 15 μSv/h sheltering is advised. Evacuation would be justified at dose rates above 100 μSv/h. The 0.5 μSv/h interval has also been included to perform a more detailed analysis.

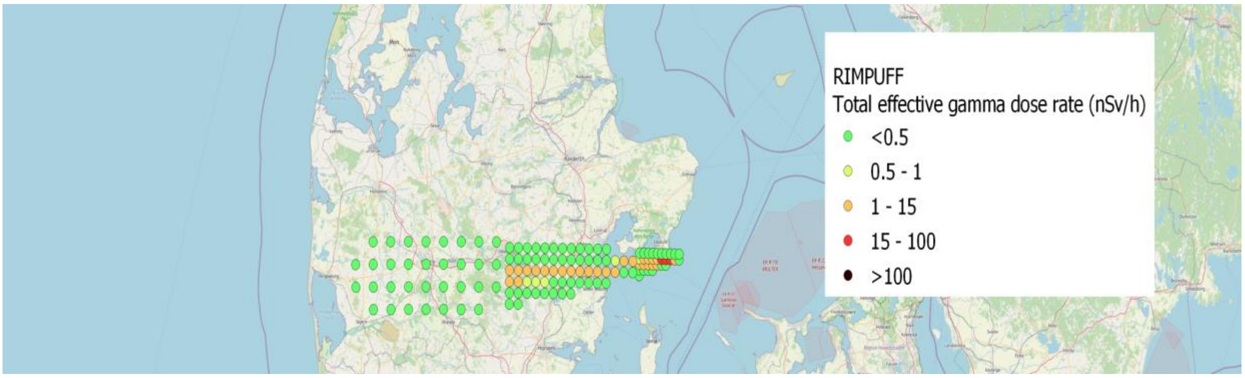


Figure 4. *Total effective gamma dose rate at the height of 1 m with RIMPUFF*

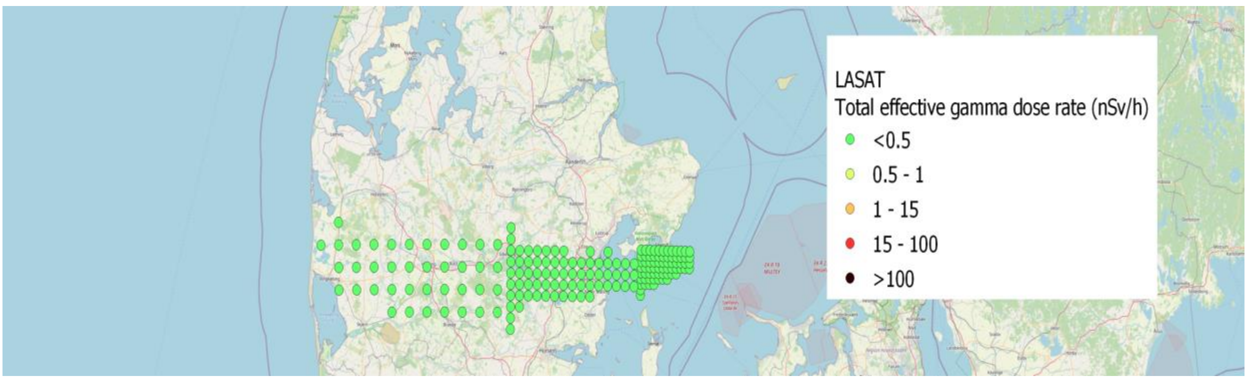


Figure 5. *Total effective gamma dose rate at the height of 1 m with LASAT*

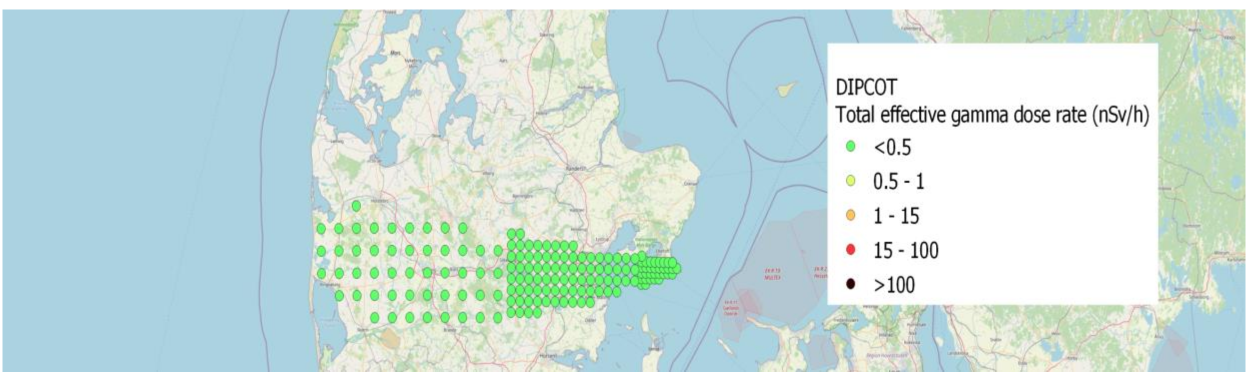


Figure 6. *Total effective gamma dose rate at the height of 1 m with DIPCOT*

While LASAT and DIPCOT agree in terms of recommended countermeasures, RIMPUFF justifies the application of sheltering in this scenario and possibly evacuation for a range of 2 km from the emission point. All three models indicate that foodstuff and feedstuff may be contaminated and suggest no further countermeasures to be applied. However, it is noted that the measurand value (total effective gamma dose rate at the height of 1m) cannot be used to justify the uptake of potassium iodide pills.

CONCLUSION

In this work, the atmospheric dispersion models contained in JRodos were applied in a hypothetical nuclear accident scenario. The differences between the models were investigated and quantified, in terms of the total effective gamma dose rate at the height of 1m. Moreover, the results of each model were used to establish a countermeasure strategy based on IAEA recommendations. It was established that considerable differences between the models' results might lead to different countermeasures. Thus, it would be important to apply every model and account for the worst-case scenario.

References

[1] C. Landman et al., The Risks of Nuclear Energy Technology, Science Policy Reports. Heidelberg, Germany: Springer-Berlin, 337–348 (2014), doi: 10.1007/978-3-642-55116-1_21
[2] Thykier-Nielsen S et al., Report RODOS(WG2)-TN (98)-02, (1999)
[3] U. Janike, Dispersion Model LASAT (2007)
[4] S. Andronopoulos et al., RODOS(RA2)-TN (09)-01, (2009)
[5] IAEA, Fundamental safety principles, Safety fundamentals, IAEA safety standards N° SF-1 STI/PUB/1273, (2006)
[6] ESARPEA, Special Response Plan to Radiological or Nuclear Emergency from a Nuclear Installation Outside the Borders of Greece, EEAE (2021)
[7] S.J. Leadbetter et al., Radioprotection 55, 51 (2020); doi: 10.1051/radiopro/2020012
[8] I. Ievdin et al., Int. J. Energy Clean Environ. 13, 179 (2012); doi: 10.1615/InterJEnerCleanEnv.2013006151
[9] Leung et al., J. Env. Rad. 183, 27 (2018)
[10] J. Päsler-Sauer, Radioprotection 45, 89 (2010); doi: 10.1051/radiopro/2010018
[11] S. Andronopoulos et al, Radioprotection 45, 77 (2010); doi: 10.1051/radiopro/2010017
[12] Ievgen Ievdin et al., JRODOS Result Guide- Version 2.1, 43 (2017)
[13] IAEA, Internation Radiation Monitoring Information System, IRMIS Version 3.0.0, (2019)
[14] O. Reistad, et al., NKS 139 - Inventory and source term evaluation of russian nuclear power plants for marine applications, (2006)
[15] Inger Margrethe H. et al., NKS-390- COASTEX Scenario Report: nine maritime accident scenarios Report no. 1 from the NKS-B COASTEX activity, (2017)
[16] IAEA, Preparedness and Response for a Nuclear or Radiological Emergency: IAEA Safety Standards Series No. GSR Part 7, (2015)