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COMPARATIVE ASSESSMENT OF THE POTENTIAL CONSEQUENCES OF A NUCLEAR DEVICE DETONATION EVENT

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Abstract. *The detonation of a nuclear device in proximity to the Romanian border constitutes a low-probability, extreme-consequence scenario that necessitates rigorous scientific quantification. Driven by the protracted conflict in Ukraine and the shifting nuclear signaling posture within the Black Sea basin, this study evaluates the hypothetical deployment of a state-origin tactical nuclear weapon (TNW) targeting Snake Island. Utilizing high-resolution modelling, we analyze the multi-vector impact: the initial prompt physical effects (blast, thermal, and ionizing radiation) and the subsequent atmospheric transport of the radioactive plume. The assessment quantifies cross-border radionuclide deposition and projected population doses within Romania under diverse, representative meteorological regimes. Our findings emphasize the critical sensitivity of fallout trajectories to synoptic-scale wind patterns and localized precipitation, which can drastically alter the radiological footprint. By contextualizing scientific uncertainties and modelling limitations, this research provides an evidence-based framework for regional preparedness, offering strategic insights for the protection of near-field populations and the resilience of critical infrastructure in a post-detonation environment.*

Keywords: tactical nuclear weapon (TNW), Snake Island; Black Sea, atmospheric dispersion, nuclear fallout, radiological protection.

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1. Introduction

The history of nuclear weapons began on July 16, 1945, with the first detonation of a nuclear device at the White Sands Proving Ground in New Mexico. The Trinity test, the first successful detonation of a nuclear device under the Manhattan Project, marked the birth of the nuclear age [1]. The event unveiled a force of unprecedented destructive magnitude, fundamentally altering the nature of global conflict and revealing a level of destructive power that fundamentally changed global security, a moment that J. Robert Oppenheimer would later describe through the famous line,

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"Now I am become Death, the destroyer of worlds" [2]. Only weeks later, the detonations over Hiroshima and Nagasaki provided the first large-scale empirical data on the combined effects of a nuclear explosion: thermal radiation, blast overpressure, and the long-term impact of ionizing radiation and fission product dispersal. These early events also showed how environmental conditions, detonation height, and local geography can influence the distribution of radioactive material, shaping the way nuclear effects are analyzed even today. In the decades that followed, global nuclear arsenals expanded rapidly, reaching their peak in the mid-1980s. Although the number of warheads has decreased since then, the remaining stockpiles have been modernized, with greater emphasis on variable yields, precision, and flexible deployment options [3]. This evolution introduced a clear distinction between strategic and tactical nuclear weapons. While strategic systems were designed for long-range deterrence, tactical nuclear weapons were developed for regional theatres, creating new types of risks for states located near potential conflict zones.

The conflict in Ukraine has brought nuclear rhetoric back to the forefront of international security. Tactical nuclear weapons, once considered marginal in Cold War planning, have returned strategic discussions through doctrinal statements and military exercises. As a result, nuclear signaling has shifted from a background deterrent to an active instrument of coercion, increasing uncertainty for neighboring states [4]. For countries on NATO's eastern flank, this shift is not theoretical but a direct strategic concern, underscoring the need for objective, data-driven assessments of nuclear risks, especially in sensitive maritime regions such as the Black Sea. Building on this renewed relevance, a nuclear blast close to the Romanian coast is not an abstract scenario but a serious issue that must be considered carefully and treated with the highest level of responsibility. The Black Sea region combines strategic military importance with complex meteorological behavior, making it an area where even a single detonation could generate significant uncertainty. Although a nuclear device has a known yield and predictable radiological characteristics, its interaction with a maritime-influenced environment introduces additional variables. The Black Sea's specific atmospheric dynamics can alter fallout transport, plume rise, and radionuclide deposition patterns, complicating the prediction of cross-border effects.

The renewed prominence of nuclear rhetoric in Eastern Europe makes such assessments essential. When tactical nuclear deployment is openly discussed as a possible strategic option, institutions such as the 'Horia Hulubei' National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH) and the National Commission for the Control of Nuclear Activities (CNCAN), whose mission is to ensure nuclear and radiological emergency preparedness and response, have the duty to provide clear, objective, and technically sound assessments of transboundary effects [5] [6]. Using two different dose-projection software tools [7], this study provides a high-resolution assessment of a hypothetical nuclear explosion on Snake Island, in the Black Sea region. It examines the prompt physical effects, the behavior of the radiological plume, and the potential for cross-border transport under selected meteorological scenarios. In addition, the comparative application of multiple modelling systems for the same event scenarios [8] makes it possible to see how differences in model design, parameter choices, and numerical methods affect the resulting dispersion patterns and dose estimates. Even if the physical principles are similar, each system handles the input parameters differently, which can lead to variations in the projected radiological consequences. By analyzing dose-rate projections and possible impacts on critical infrastructure, the research offers an evidence-based framework that links historical nuclear knowledge with modern modelling tools. The goal is to support national and regional preparedness by providing scientifically grounded estimates of the consequences [9] that a nuclear event in the Black Sea region could generate and, also, aims to contribute to that effort by offering a realistic and transparent analysis of a scenario that, although hypothetical, must be understood with precision and seriousness.

2. PROBLEM STATEMENT

2.1. Defining the event scenarios

This study focuses on a simulation of a nuclear event at Snake Island, in the Black Sea region. To provide a comprehensive evaluation of the potential consequences, two specific scenarios were considered: a nuclear blast using a tactical weapon and one using a strategic weapon. The characteristic parameters for both scenarios are presented in Table 1. The selection of these two scenarios is technically motivated by the need to capture the operational range of nuclear effects relevant to the Black Sea region. Tactical and strategic nuclear weapons differ substantially in yield, burst characteristics, and intended employment, which results in distinct source terms and radiological release profiles [10]. Evaluating both cases allows the modelling framework to account for variations in energy output, fireball formation, debris lofting, and plume rise dynamics, all of which directly influence atmospheric transport and dose distribution. By including a low-yield tactical detonation and a higher-yield strategic detonation, the analysis spans the lower and upper bounds of plausible radiological impact, ensuring that dispersion modelling, dose-rate estimation, and cross-border transport assessments remain robust across a representative spectrum of nuclear device parameters.

Table 1. Characteristic parameters for the two modeled detonation scenarios.

Scenario	*Scenario 1*	*Scenario 2*
Type	Tactical	Strategic (worst case)
Yield (kt)	50	150
Burst type	Airburst	Ground burst
Height of burst	**Optimal – maximizing blast coupling and reducing surface interaction**	**Ground (0 m) – maximizing surface interaction and fallout generation**
Intended effect	Maximize blast radius, minimize cratering	Maximize radiological output and particulate entrainment
Purpose in modelling	Localized infrastructure impact	Worst-case radiological source term for transboundary fallout

2.2. Site description

Snake Island is located approximately 40 km from the Romanian coastline and about 335 km from Bucharest (Figure 2). Positioned near NATO's eastern flank, major maritime routes, and several ecologically sensitive areas, the island holds strategic, environmental, and civil protection relevance. Any detonation in its vicinity would therefore require a clear understanding of both the immediate physical effects and the longer-term radiological implications for neighboring states. Economically, the surrounding waters form a key transit area for grain shipments linking Ukrainian ports to global markets, meaning that regional stability directly influences commercial navigation, energy infrastructure, and broader trade security. These combined factors make the island a critical point for strategic planning and economic resilience in the Black Sea region.

Fig. 2. Spatial position of Snake Island and reference distances to key Romanian points of interest.

2.3. The meteorological conditions

To ensure consistency across both scenarios, simulated meteorological conditions were applied throughout the assessment. This aspect is particularly important for Scenario 2 (*worst case*), where fallout transport and deposition are highly sensitive to atmospheric dynamics. Accordingly, a constant wind speed and direction toward the Romanian border, specifically toward Bucharest, was assumed, including an extremely-weather wind regime representative of the upper bound of plausible atmospheric conditions, and a no-precipitation setting was selected. This configuration ensures that the simulated plume and fallout patterns represent the highest plausible level of transboundary exposure.

2.4. Characteristics and Effects of Airburst and Ground Burst Nuclear Detonations

Nuclear detonations can occur as airbursts, ground bursts, underground bursts, or underwater bursts, each type produces distinct *mechanical, thermal, electromagnetic, and radiological effects*. A fundamental parameter governing all these phenomena is the *yield*, defined as the total energy released by detonation. Yield is expressed in *kilotons (kt)* or *megatons (Mt)* of TNT equivalent, and it directly influences fireball size, overpressure radius, thermal output, and fallout production. The sequence of events following a nuclear detonation occurs on extremely short timescales. Within the first *microseconds*, the weapon's core undergoes fission or fusion, releasing intense *prompt gamma and neutron radiation*. By *1–10 milliseconds*, the expanding *fireball* becomes visible, reaching millions of degrees and emitting a powerful flash of thermal radiation. Between *10–100 milliseconds*, the rapidly expanding fireball drives the formation of the *shockwave*, which propagates outward as the primary source of overpressure. Within *1–2 seconds*, the fireball begins to rise buoyantly, forming the characteristic *mushroom cloud*, while the shockwave continues to expand across the surface. As the scope of this study is limited to airburst and ground burst detonations, the discussion that follows focuses exclusively on the physical and radiological characteristics associated with these two scenarios.

In an *airburst*, the fireball remains above the ground, maximizing the horizontal propagation of *overpressure*, which can reach destructive thresholds such as 1 psi for window breakage, 5 psi for severe structural damage, and over 20 psi for near-total destruction [10] Thermal radiation spreads widely, producing strong heat flux and a high probability of ignition. Because the fireball does not contact the surface, *no crater is formed*, and the *source term* consists mainly of fine aerosols containing fission products. As a result, *local fallout is limited*, although fine particles may be transported long-range (Figure 3). The shockwave attenuates gradually with distance, and the absence of soil entrainment greatly reduces the radiological impact, making airbursts predominantly governed by mechanical and thermal effects. Airbursts also generate a strong *electromagnetic pulse (EMP)* due to gamma-ray interactions with the upper atmosphere, capable of disrupting unshielded electronics over large areas.

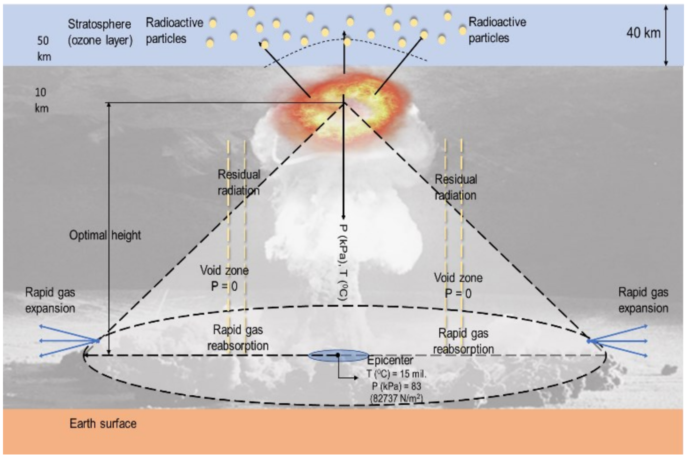

Fig. 3. Schematic representation of an atmospheric (airburst) detonation model.

In a *ground burst*, the fireball intersects the surface, vaporizing and ejecting soil, sediment, and debris. This produces a substantial *crater* and creates a dense, *particulate-rich source term* (Figure 4). This particulate loading generates an intense near-field radiological impact, as large, refractory particles settle rapidly and concentrate deposition close to ground zero. The combined effects of crater excavation and soil activation further strengthen the local source term, producing high dose rates shortly after detonation. These processes make ground bursts the main drivers of severe local fallout. The mechanical shock is extremely intense near ground zero, though it decays more rapidly with distance than in an airburst. Thermal effects are partially shielded by the ground, reducing their horizontal reach. The entrainment of large quantities of soil generates *heavy radioactive fallout*, dominated by coarse particles that settle rapidly. In strategic-yield detonations, the fallout plume is transported *strictly along the prevailing wind direction*, forming a narrow, elongated deposition pattern that can extend hundreds of kilometers downwind [10]. Meteorological conditions – wind speed, atmospheric stability, and precipitation – strongly influence plume geometry and deposition intensity.

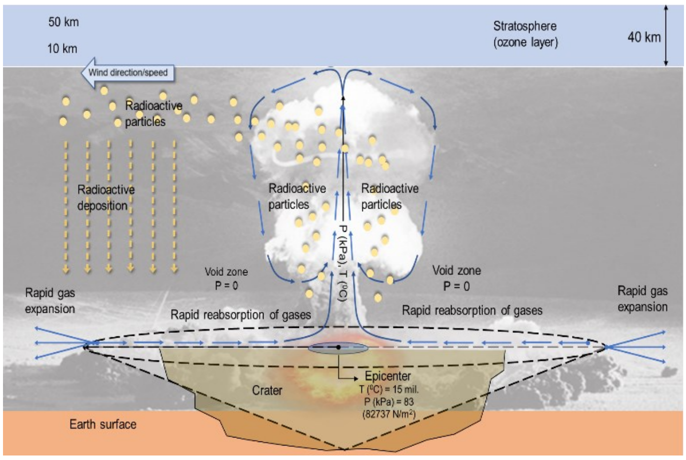

Fig. 4. Schematic representation of a surface (ground) burst detonation model.

Overall, airbursts maximize blast and thermal effects with limited local radiological impact, while ground bursts produce the most severe fallout hazards due to intense particulate formation and wind-driven downwind transport. The physical and radiological distinctions between airburst and ground burst are summarized in Table 2. These differences arise from the interaction of the fireball with the surface, the amount and size distribution of entrained material, the altitude at which radioactive products are injected into the atmosphere, and the prevailing meteorological conditions. Airbursts tend to disperse activity over larger areas with relatively low local deposition, whereas ground bursts concentrate deposition in narrower, high-intensity fallout zones. Understanding these distinctions, together with yield scaling and event timing, is essential for consistent scenario definition, model parametrization, and cross-border impact assessment.

Table 2. Principal physical and radiological distinctions between airburst and ground burst.

Parameter	*Airburst Detonation*	*Ground Burst Detonation*
Detonation height	Fireball remains above the surface	Fireball contacts ground or water
Overpressure distribution	Wide-area, efficient propagation; large destructive radius	Very high peak overpressure near ground zero; rapid decay with distance
Thermal effects	Extensive thermal radiation; high ignition probability	Reduced thermal reach due to ground shielding
Crater formation	None	Significant crater from vaporized/ejected soil
Source term	Mainly fine aerosols; low particulate mass	Heavy particulate loading; soil and debris entrainment

Fallout intensity	Minimal local fallout; long-range fine aerosol transport	Intense local and regional fallout; rapid deposition
Fallout directionality	Weakly influenced by surface winds	Strongly wind-driven; plume follows prevailing wind direction
EMP effects	Strong EMP due to gamma interactions at altitude	Weaker EMP; gamma energy absorbed by ground/low atmosphere
Operational purpose	Maximizes blast and thermal effects	Maximizes structural penetration and radiological impact

2.5. Software description

The assessment of these scenarios was performed using two distinct dose-projection software tools, each defined by its own modelling approach, computational assumptions, and output structure. Together, they provide a complementary basis for comparing radiological consequences. The tools used in this study are the CBRNE Software (Chemical, Biological, Radiological, Nuclear, Explosive Software Platform) [11] and NUKEMAP [12]. CBRNE Software is an in-house solution developed and maintained at IFIN-HH. The platform has been developed as part of a research project in the field of national security and safety [11] and represents a Modelling, Simulation and Visualization (MS&V) application designed for anticipatory, prognostic assessment of CBRNE events, comprising functions for diagnosis of effects and consecutive recommendation of response measures for an open and scalable variety of event scenarios.

NUKEMAP is an online visualization tool that models the physical effects of nuclear detonation on real-world geographic locations [12]. It uses unclassified Cold War–era effects equations to estimate blast overpressure, thermal radiation, prompt radiation, and simplified fallout patterns, displaying them as map overlays. Developed by historian Alex Wellerstein, the tool is intended for educational and illustrative purposes, helping users understand the scale and variability of nuclear weapon effects.

3. RESULTS AND DISCUSSION

The assessment of such an event focuses primarily on the potential impact on the environment and the exposed population. It integrates a selection of results illustrating the mechanical, thermal, and radiological effects associated with the assumed scenarios. The following elements are provided: (i) situational maps indicating the potential geographical area of influence of the event; and (ii) tables summarizing potential impacts on buildings and individuals, including degree of structural damage, overpressure (psi), estimated human casualties (%), and corresponding distances. Numerical outputs also include Early Fallout Reference Data, nominal values that can be further adjusted according to the Time of Entry of personnel into the contaminated area (hours after detonation) and their Residence Time (hours) within it, serving primarily as operational guidance for responders. The methodology underlying the results presented below combines validated models [13] [14] and data from international specialized institutions [15]. A comparative analysis of the outputs generated by the two software tools is also performed, both graphically and numerically.

3.1. CBRNE Software assessments results

In assessing these scenarios, the dedicated Nuclear Risks and Threats module, specifically the Improvised Nuclear Devices (INDs) application, was used. Although fully equipped to model standard fission-device detonations at optimal height, the application places particular emphasis on ground-level bursts and the corresponding modelling adjustments recommended in the literature. The output focuses on the radii associated with the mechanical, thermal, and radiological effects, both prompt and delayed, providing a structured basis for understanding the potential consequences of such an event.

3.1.1 Scenario 1. Tactical nuclear (airburst) assessment

In this scenario, it is important to note that nuclear fallout effects are considered negligible compared to direct physical effects (mechanical and thermal). The rapid, high-altitude rise of the fireball and plume prevents significant ground-level deposition in the vicinity of the detonation. The representative maps of the expected effects are shown in Figure 5, while resulting outputs mechanical, thermal, and radiological are summarized in Table 3.

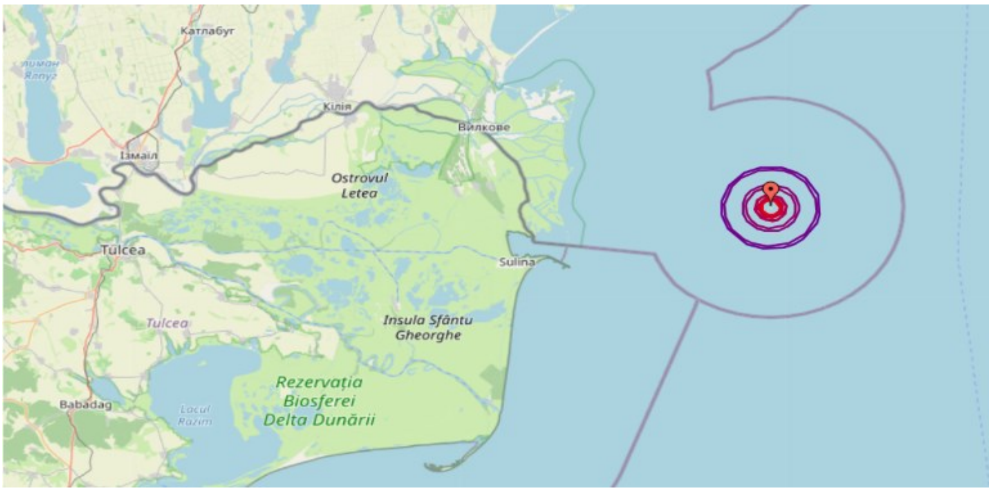

Fig. 5. Scenario 1. CBRNE – Tactical weapon situation maps.

Table 3. Scenario 1 – Summary of the assessed effects and their associated distance.

Effect type and description	*Distance (m)*
Shockwave effects	
Severe damage; steel-reinforced structures damaged; 12 psi overpressure; 98% dead, 2% injured	1492
Moderate damage; wood/masonry structures destroyed; 5 psi overpressure; 50% dead, 40% injured	2578
Minor damage; wood/masonry structures damaged; 2 psi overpressure; 2% dead, 5% injured	4752
Light damage; windows shattered; 1 psi overpressure; ~25% injured	7828
Thermal effects	
Fatal skin burns; ignition of most flammable materials (20 cal/cm²)	2651
Severe skin burns; ignition of easily flammable materials (8 cal/cm²)	4171
First-degree skin burns; equivalent to sunburn (2 cal/cm²)	8343
Prompt irradiation effects	
Radiation sickness, 100% fatal; 800 rad	1649
Radiation sickness lethal threshold; approx. 5% fatalities; 300 rad	1799
Radiation sickness lower threshold; mild symptoms; 70 rad	2049

The situational map shows that, for a 50 kt airburst, neither the blast nor prompt radiation reaches the Romanian mainland, as the ~40 km maritime buffer fully absorbs the immediate effects. The results indicate that the effects produced by the tactical airburst decrease rapidly with distance but follow distinct attenuation patterns. Shockwave effects dominate the overall affected area, with severe structural damage occurring within roughly 1.5 km and light damage, such as window breakage, extending to nearly 8 km. Thermal effects remain significant but diminish more quickly, with fatal burns expected up to about 2.6 km and first-degree burns reaching approximately 8.3 km. Prompt radiological effects are confined to the smallest zone, with lethal doses limited to around 1.6 km and mild symptoms extending only to about 2 km. While the land border remains outside the impact zone, the Sulina–Snake Island maritime corridor falls within the lethal radius, requiring the establishment of exclusion zones. Overall, the distribution reflects the characteristic behavior of an airburst optimized for mechanical effects, where blast and thermal impacts define the primary hazard footprint, while prompt radiation contributes only within a relatively restricted radius.

3.1.2 Scenario 2. Strategic nuclear (ground burst) assessment

This scenario focuses on quantifying the fallout plume under a deliberately conservative, *worst-case* meteorological configuration. The analysis emphasizes the large-scale entrainment of radioactive particulates generated by the ground-burst, which represents the dominant transboundary hazard. To isolate the maximum plausible impact, simulated meteorology with a stable, unidirectional wind field was applied, ensuring continuous downwind transport toward the Romanian sector. Under these conditions, the plume maintains coherence over long distances, allowing for sustained deposition beyond the immediate detonation zone. The representative spatial patterns are illustrated in Figure 6, while the corresponding mechanical, thermal, and radiological outputs are summarized in Table 4.

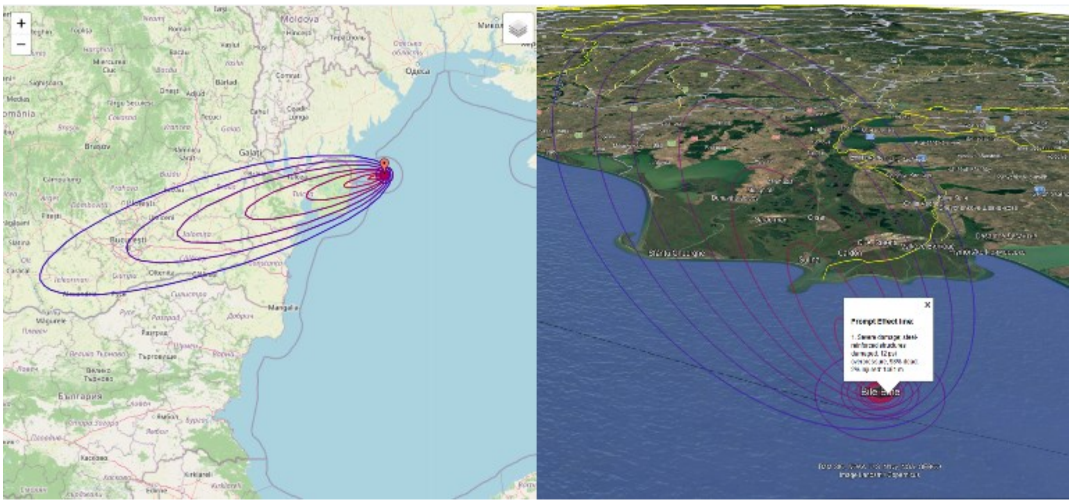

Fig. 6. Scenario 2. CBRNE – Strategic weapon situation maps.
Overview of the affected area (left) and 3D terrain perspective on Google Earth (right)

Early Fallout Reference Data are also provided as nominal values, intended to guide responders and to be further adjusted according to the Time of Entry into the contaminated area and the Residence Time within it (Figure 7). By applying the matrix, first responders can determine the integrated dose for deployed personnel and strictly regulate stay-times to ensure compliance with national occupational exposure limits. A delayed entry markedly reduces the corresponding multiplication factor, underscoring the operational advantage of shelter-in-place measures during the initial high-activity phase of the fallout The maps show that, in this scenario, the response must shift from maritime exclusion zones to broader civil protection actions, including potential sheltering or evacuation in the eastern counties. The modelling demonstrates that increasing the yield to 150 kt and using a ground-burst configuration removes the “maritime shield” seen in the tactical case, producing a direct and severe transboundary impact.

Table 4. Scenario 2 – Summary of the assessed effects and their associated distance.

Effect type and description	*Distance (m)*
Shockwave effects	
Severe damage; steel-reinforced structures damaged; 12 psi overpressure; 98% dead, 2% injured	1461
Moderate damage; wood/masonry structures destroyed; 5 psi overpressure; 50% dead, 40% injured	2390
Minor damage; wood/masonry structures damaged; 2 psi overpressure; 2% dead, 5% injured	3799
Light damage; windows shattered; 1 psi overpressure; ~25% injured	6216
Thermal effects	
Fatal skin burns; ignition of most flammable materials (20 cal/cm²)	3303
Severe skin burns; ignition of easily flammable materials (8 cal/cm²)	5205
First-degree skin burns; equivalent to sunburn (2 cal/cm²)	10349
Prompt irradiation effects	
Radiation sickness, 100% fatal; 800 rads.	2288
Radiation sickness lethal threshold; approx. 5% fatalities; 300 rad	2038
Radiation sickness lower threshold; mild symptoms; 70 rad	1888

The ground-burst configuration produces a markedly different distribution of effects compared to an airburst, with a sharper attenuation of the shockwave and a pronounced expansion of the thermal and radiological footprints. Mechanical damage remains significant near the detonation point, with severe structural failure confined to roughly 1.5 km and moderate destruction extending to about 2.4 km, reflecting the energy lost into crater formation and soil coupling. In contrast, thermal effects dominate the mid-range, with fatal burns projected out to more than 10 km, substantially farther than the blast wave, highlighting the enhanced surface-level heating characteristic of ground-level detonations. Prompt radiation also reaches larger distances than in an airburst, with lethal doses extending to approximately 2.3 km due to the reduced shielding from altitude. Overall, the results confirm that a ground burst shifts the hazard profile toward intense local destruction, extended thermal injury zones, and significantly increased radiological impact, forming the basis for the large-scale fallout plume assessed in Scenario 2.

1 – Nominal Unit Time Reference Dose Rate (rad/hr) for total yield
2 – Actual Unit Time Reference Dose Rate (rad/hr) on contour, fission yield considered
3 – Downwind path (miles)
4 – Upwind radius (miles)
5 – Crosswind stretch, maximum(miles)
6 – Crosswind stretch at ground zero(miles)

1	2	3	4	5	6	
2999	2999	8.44882497	0.47575051	0.56617926	0.47575051	~
1000	1000	16.0011415	1.04357404	1.62230258	1.04357404	~
300	300	40.0028538	2.21591859	3.5494706	2.21591859	~
100	100	79.1167553	3.19906405	7.68136411	3.19906405	~
30	30	142.232369	4.13497879	12.5725884	4.13497879	~
10	10	213.348554	5.3052558	19.9276645	5.3052558	~
3	3	266.685692	6.94364362	26.9443872	6.94364362	~
1	1	355.580923	11.7027701	36.5626567	11.7027701	~

UNIT DOSE-RATE MULTIPLYING FACTORS

.	Exposure time														
Entry time	6'	12'	30'	1hr	2hr	4hr	8hr	1d	2d	4d	2wk	2mn	6mn	25y	
. hours	0.1	0.2	0.5	1	2	4	8	24	48	96	336	1440	4320	219000	
0.1	0.8	1.5	2.0	2.6	3.25	3.75	4.1	5.0	5.5	6.0	6.5	6.7	6.9	7.00	^
0.2	0.5	0.8	1.45	1.9	2.6	3.0	3.4	4.0	4.7	5.0	5.5	6.0	6.4	6.80	^
0.4	0.22	0.4	0.7	1.4	1.7	2.1	2.7	3.1	3.6	4.0	4.6	4.9	5.2	5.50	^
0.7	0.13	0.25	0.5	0.8	1.3	1.5	2.0	2.5	2.8	3.0	3.25	3.9	4.7	5.00	^
1	0.08	0.17	0.4	0.6	0.95	1.4	1.55	2.3	2.4	2.5	3.5	3.9	4.0	4.10	^
2	0.04	0.08	0.16	0.25	0.45	0.8	1.25	1.75	2.0	2.25	3.0	3.5	3.65	3.80	^
4	0.016	0.035	0.08	0.15	0.3	0.5	0.7	1.4	1.5	1.75	2.25	3.0	3.4	3.50	^
7	0	0.02	0.04	0.085	0.16	0.3	0.5	0.9	1.3	1.5	2.0	2.2	2.4	2.50	^
10	0	0.015	0.03	0.055	0.115	0.2	0.395	0.7	1.0	1.25	1.6	2.0	2.2	2.30	^
20	0	0	0.016	0.026	0.05	0.1	0.2	0.4	0.69	0.85	1.4	1.75	1.9	2.00	^
40	0	0	0	0.011	0.0225	0.05	0.1	0.225	0.39	0.55	0.9	1.4	1.65	1.75	^
70	0	0	0	0	0.015	0.0235	0.05	0.14	0.201	0.35	0.69	1.0	1.3	1.50	^
100	0	0	0	0	0	0.0175	0.025	0.075	0.15	0.275	0.50	0.85	1.1	1.30	^
200	0	0	0	0	0	0	0.015	0.04	0.07	0.14	0.3	0.55	0.85	1.00	^
400	0	0	0	0	0	0	0	0.015	0.03	0.065	0.15	0.4	0.69	0.75	^
700	0	0	0	0	0	0	0	0	0.015	0.03	0.1	0.28	0.5	0.60	^
1000	0	0	0	0	0	0	0	0	0	0.02	0.07	0.2	0.4	0.50	^
2000	0	0	0	0	0	0	0	0	0	0	0.035	0.13	0.225	0.25	^
4000	0	0	0	0	0	0	0	0	0	0	0.015	0.05	0.1	0.15	^
7000	0	0	0	0	0	0	0	0	0	0	0	0.015	0.03	0.07	^
10000	0	0	0	0	0	0	0	0	0	0	0	0	0	0.04	^

Fig. 7. Scenario 2 – Screenshot of the Early Fallout Reference Data.

The detailed outputs of the 150 kt scenario enable a precise assessment of threat levels at two critical reference points: the immediate detonation area and the national capital, Bucharest. The most significant finding of the simulation concerns the capital city. Although located approximately 335 km from ground zero, Bucharest remains aligned with the modelled fallout axis under worst-case meteorological conditions. The situational map indicates a residual dose rate of approximately 3 rad/hr., a value characteristic of long-range, highly diluted late fallout transported under extreme-weather wind conditions (Figure 8). Such levels are consistent with the expected attenuation of particle concentration over large distances and do not imply the potential for acute radiological effects.

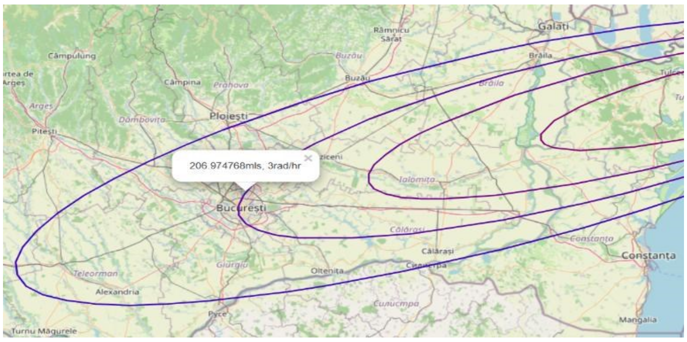

Fig. 8. Scenario 2 – Residual fallout dose rate of 3 rad/hr in the Bucharest area.

While the dose rates at this range are markedly lower than those observed along the coast, they still exceed established thresholds for mandatory radiological monitoring and may necessitate protective measures for vulnerable populations. These results demonstrate that a detonation on Snake Island cannot be characterized as a localized maritime event, but rather as a radiological incident with nationwide operational relevance.

3.2. NUKEMAP assessments results

To strengthen the cross-validation of the institutional simulations, the study incorporates results generated with NUKEMAP version 2.75. Unlike CBRNE, which relies on complex meteorological integration, NUKEMAP is based on a scaling-law modelling approach [5] [14]. Using both methods ensures that the transboundary risk assessment is supported simultaneously by modern atmospheric transport codes and by empirically validated nuclear-effects scaling relationships. Incorporating NUKEMAP provides a conservative baseline grounded in decades of atmospheric testing data [16], ensuring that the projected physical effects on Romanian territory remain consistent with established nuclear weapons effects physics.

3.2.1 Scenario 1. Tactical nuclear (airburst) assessment

In this scenario, the NUKEMAP simulation models a nuclear airburst by applying empirically derived scaling laws for blast overpressure, thermal radiation, and prompt ionizing radiation [5] [14]. The tool automatically optimizes the height of burst to maximize the radius of structural damage, reflecting standard strategic planning assumptions. Based on these parameters, the model delineates the zones of severe blast effects, thermal injury thresholds, and prompt radiation lethality, projecting their spatial extent over the Snake Island region. Because fireballs do not intersect the surface, the simulation focuses exclusively on the immediate physical effects of the detonation, providing a standardized and conservative representation of an airburst's impact envelope. The representative maps of the expected effects are shown in Figure 9, while resulting outputs mechanical, thermal, and radiological are summarized in Table 5.

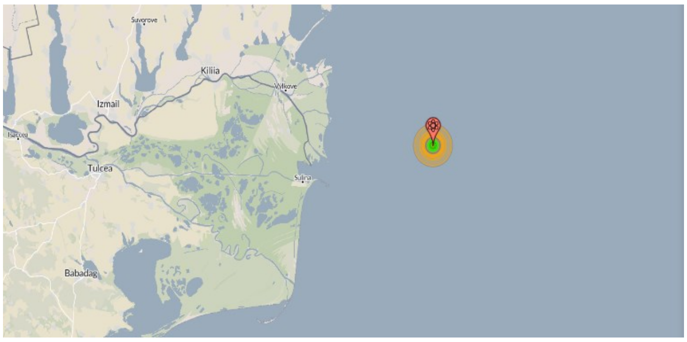

Fig. 9. Scenario 1. NUKEMAP – Tactical weapon situation maps.

The situation maps shows that all modeled effect radii remain well below the distance to Romanian territory, and none of the blast, thermal, or radiation effects extend far enough to impact Romania under this scenario.

Table 5. Scenario 1 – Summary of the assessed effects and their associated distance.

Effect type and description	*Distance (m)*
Shockwave effects	
Severe blast; 12 psi overpressure; near-total fatalities; collapse of reinforced structures	1510
Moderate blast; 5 psi overpressure; widespread fatalities/injuries; residential collapse; high fire ignition risk	2590
Minor blast; 2 psi overpressure; injuries; structural compromise; standing buildings prone to fire spread	4700
Light blast; 1 psi overpressure; window breakage; glass-related injuries; flash-to-blast delay increases exposure	7280
Thermal effects	
3rd-degree burns; 9.46 cal/cm²; full-thickness skin destruction; nerve damage; infection risk; fatal without treatment	3200
2nd-degree burns; 5.27 cal/cm²; deep dermal injury; intense pain; blistering; fluid loss; scarring; grafting often required	4330
1st-degree burns; ~2 cal/cm²; superficial epidermal injury; pain, redness; heals in 5–10 days; similar to severe sunburn	7000
Prompt irradiation effects	
Lethal radiation; 8 Sv; fatal dose; death within weeks; high ARS severity	1320
Severe radiation; 3 Sv; acute radiation sickness; vomiting, fatigue; possible fatalities	1560
Low radiation; 0.7 Sv; mild symptoms; increased long-term cancer risk	1910

The results show a clear separation between the dominant effects: blast lethality is confined to the inner zone, thermal injuries dominate the mid-range, and prompt radiation is significant only close to the detonation point. Severe blast pressures capable of collapsing reinforced structures extend out to approximately 1.5 km, while moderate to light structural damage progresses outward through the 2.6 km and 4.7 km contours, reaching the outer limit of the blast field at roughly 7.3 km. Thermal radiation produces a much wider casualty footprint than the shockwave. Third-degree burns occur up to 3.2 km, second-degree burns to 4.3 km, and first-degree burns to 6.1 km, indicating that thermal exposure affects a far larger population than structural collapse. Prompt radiation remains restricted to the inner 1–1.7 km, with lethal doses only within 1 km. Beyond that, radiation contributes primarily to long-term health risks rather than immediate incapacitation. It should be emphasized that the separation between the outermost significant hazard contour and the nearest Romanian population location is fully consistent with these findings, reinforcing the conclusion that the prompt physical destruction associated with a 50 kt tactical airburst remains confined to a localized maritime footprint. Overall, the scenario is characterized by localized blast lethality, broad thermal injury potential, and limited-range radiation effects, reflecting the typical distribution of hazards for an airburst of this yield.

3.2.2 Scenario 2. Strategic nuclear (airburst) assessment

For this scenario, NUKEMAP treats the detonation as a true ground-level burst, redistributing a significant fraction of the explosive energy into the surface. This results in crater formation, reduced atmospheric blast propagation, and enhanced entrainment of soil and debris into the rising cloud. In this configuration, fallout becomes the dominant hazard driver, with population exposure estimated by overlaying deposition fields onto global demographic datasets. The representative spatial patterns are illustrated in Figure 10, while the corresponding mechanical, thermal, and radiological outputs are summarized in Table 6.

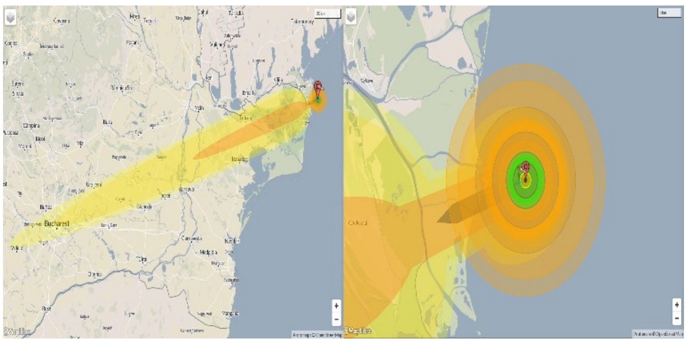

Fig. 10. Scenario 2. NUKEMAP – Strategic weapon situation maps.
Overview of the affected area (left) and effect radii at ground zero (right)

Table 6. Scenario 2 – Summary of the assessed effects and their associated distance.

Effect type and description	*Distance (m)*
Shockwave effects	
Severe blast; 12 psi overpressure; near total fatalities; collapse of reinforced structures	1520
Moderate blast; 5 psi overpressure; widespread fatalities/injuries; residential collapse; high fire ignition risk	2430
Minor blast; 2 psi overpressure; injuries; structural compromise; standing buildings prone to fire spread	4140
Light blast; 1 psi overpressure; window breakage; glass related injuries; flash to blast delay increases exposure	9910
Thermal effects	
3rd degree burns; 10.1 cal/cm^2; full thickness skin destruction; nerve damage; infection risk; fatal without treatment	3390
2nd degree burns; 5.63 cal/cm^2; deep dermal injury; intense pain; blistering; fluid loss; scarring; grafting often required	5220
1st degree burns; 2.83 cal/cm^2; superficial epidermal injury; pain, redness; heals in 5–10 days; like severe sunburn	9910
Prompt irradiation effects	
Lethal radiation; 8 Sv; fatal dose; death within weeks; high ARS severity	1830
Severe radiation; 3 Sv; acute radiation sickness; vomiting, fatigue; possible fatalities	2050
Low radiation; 0.7 Sv; mild symptoms; increased long term cancer risk	2380

The results show that for a 150 kt surface burst, a coherent distribution of blast, thermal, prompt radiation and fallout effects. Severe structural destruction is confined to the inner 1.5 km, with major damage extending to roughly 2.4 km and moderate structural compromise reaching about 4 km, while light damage and widespread window breakage extend to nearly 10 km, coinciding with the outer limit of first-degree thermal burns. Thermal radiation produces third-degree burns within approximately 3.4 km and second-degree burns up to about 5.2 km, consistent with the energy partitioning characteristic of a surface detonation. Prompt radiation remains restricted to the inner 2–2.4 km, with lethal and sub-lethal doses overlapping the zones of severe blast damage. Beyond the prompt-effect region, the surface burst generates a significant quantity of local fallout, with the resulting plume extending downwind according to the imposed meteorological conditions. Under the assumed constant wind direction toward Bucharest and an extremely-weather wind regime representative of upper-bound atmospheric conditions, the fallout plume reaches long-range distances and produces a continuous deposition footprint along the transport axis. In the Bucharest area, the model yields a residual dose rate of approximately 3 rad/h, consistent with long-range, highly diluted late fallout transported over large distances (Figure 11). This underscores that the primary transboundary hazard of a strategic ground burst is not the immediate blast, but the previously modelled 150 kt fallout plume.

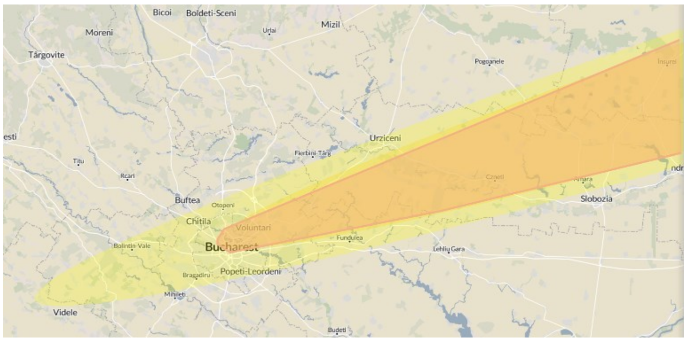

Fig. 11 Scenario 2 – Residual fallout dose rate of 3 rad/hr in the Bucharest area. Estimated fallout-radiation intensity contours and the corresponding area coverage for a 150 kt surface burst one hour after detonation are presented in Table 7.

Table 7. Scenario 2 – Fallout-radiation contours and area coverage (150 kt, 1-hour).

Dose rate (rad/h)	*Maximum downwind fallout distance (km)*	*Maximum contour width (km)*	*Approximate area affected (km²):*
1000	14.4	2.52	53
100	149	13.4	1,970
10	257	26.8	6,090
3	314	33.9	9,150
1	365	40.3	12,480

Beyond the prompt effects, the estimated fallout-radiation contours, together with the prevailing meteorological conditions directing the plume toward the Romanian coast, demonstrate the potential for long-range radioactive contamination extending far beyond the immediate damage footprint. While the scaling model uses a simplified version of atmospheric conditions, these figures provide a necessary "worst-case" guideline for responders. The penetration of the 100 rad/h and 10 rad/h contours into Romanian territory confirms that a strategic event on Snake Island would necessitate immediate and large-scale radiological protection measures for the coastal population.

3.2.3 Comparison of results

The combined use of the CBRNE Software platform and the NUKEMAP scaling model provides a coherent, cross-validated assessment of the potential consequences of an event on Snake Island. This integrated synthesis highlights three critical dimensions of the resulting threat profile, each informed by the complementary strengths of the two modelling approaches.

For Scenario 1, both CBRNE and NUKEMAP indicate a broadly similar overall footprint of influence, with the outer damage limits extending to approximately 8.3 km and 7.3 km respectively (Figure 12). Within this common envelope, for blast effects, the two platforms match remarkably well across all overpressure thresholds where contours differ by only a few tens of meters, while a modest divergence appears at 1 psi, where CBRNE extends the light-damage radius slightly farther than NUKEMAP. Thermal effects show a similar pattern of partial convergence: both models produce closely matching radii for third- and second-degree burns, but diverge at the first-degree threshold, where CBRNE predicts a larger thermal footprint. Radiological effects display the greatest variability, with CBRNE estimating larger radii for lethal and severe doses, while NUKEMAP extends the mild-dose contour slightly farther. The corresponding numerical values are summarized in Table 8. Overall, these results indicate that both modelling systems generate a broadly consistent representation of the physical consequences of the detonation, with differences concentrated primarily in the low-intensity thermal and radiological zones where modelling assumptions exert the strongest influence.

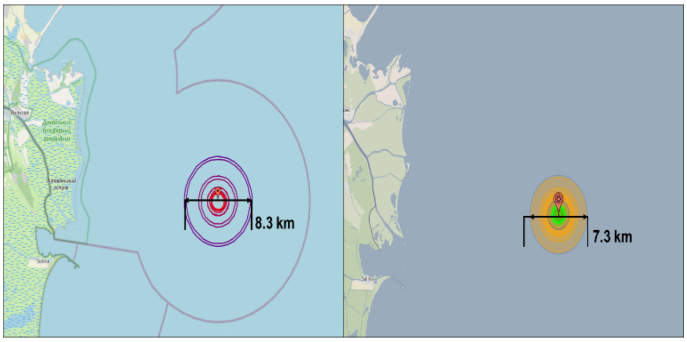

Fig. 12. Scenario 1 – Comparative situation maps.
CBRNE representation (left) and NUKEMAP representation (right)

Table 8. Comparison of results for Scenario 1.

Summary of prompt effects and their corresponding distances.

Effect	*Parameter*	*Value*	*Distance (m)*	
			CBRNE	*NUKEMAP*
Shockwave	Overpressure	12 psi	1492	1510
		5 psi	2578	2590
		2 psi	4752	4700
		1 psi	7828	7280
Thermal	Burn degree	3rd-degree;	2651	3200

		2nd-degree	4171	4330
		1st-degree	8343	7000
Radiological	Dose	Lethal	1649	1320
		Severe	1799	1560
		Mild	2049	1910

In Scenario 2 (150 kt surface burst), the fallout distances predicted are broadly similar across both software tools, indicating a consistent assessment of the downwind radiological footprint despite their methodological differences (Figure 13).

Building on this alignment, the prompt-effect analysis shows strong agreement in the high-intensity regime, where both models converge closely at the 12 psi and 5 psi overpressure thresholds, producing nearly identical estimates for zones of severe and moderate structural damage.

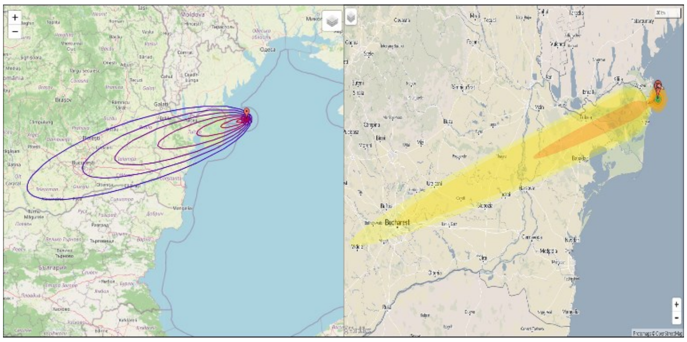

Fig. 13. Scenario 2 – Similar fallout distances across both software. CBRNE representation (left) and NUKEMAP representation (right)

Variations become more apparent at lower blast intensities, with NUKEMAP extending the 1 psi contour considerably farther than CBRNE, reflecting different treatments of long-range shockwave attenuation. Thermal effects exhibit the strongest convergence: both models generate nearly identical radii for third- and second-degree burns, with only a modest difference at the first-degree threshold, where CBRNE predicts a slightly more extended thermal footprint. Prompt radiation estimates remain closely aligned for lethal and severe doses, but the tools diverge at lower exposure levels, where NUKEMAP projects a widely affected area. The fallout predictions also show a high degree of consistency, including the identical value of 3 rad/hr. over the Bucharest area obtained by both models. The corresponding numerical values are summarized in Table 9.

Overall, these results indicate that both modelling platforms provide a coherent and mutually reinforcing representation of the physical and radiological consequences of a surface burst, with discrepancies that remain within the expected variability of independent modelling frameworks.

Table 9. Comparison of results for Scenario 2.

Summary of prompt effects and their corresponding distances.

Effect	*Parameter*	*Value*	*Distance (m)*	
			CBRNE	*NUKEMAP*
Shockwave	Overpressure	12 psi	1461	1520
		5 psi	2390	2430
		2 psi	3799	4140
		1 psi	6216	9910
Thermal	Burn degree	3rd-degree;	3303	3390
		2nd-degree	5205	5220
		1st-degree	10349	9910
Radiological	Dose	Lethal	2288	1830
		Severe	2038	2050
		Mild	1888	2380

It should be noticed that the difference in units reflects the underlying modelling conventions of the two tools. The CBRNE Software platform reports prompt radiation in rad, a legacy unit traditionally used in operational CBRN response models to express absorbed dose in a form compatible with older military and civil-protection tables. NUKEMAP, by contrast, uses sieverts (Sv), the modern SI unit that incorporates radiation weighting factors to represent the biological effectiveness of the absorbed dose. In practical terms, both units describe the same phenomenon, but rad expresses the physical energy deposited in tissue, whereas sieverts express the expected biological impact. The two scales are directly convertible (1 Sv ≈ 100 rad), and the difference in units does not affect the comparability of the underlying physical effects.

4. Conclusion

Taken together, the evaluations performed across both scenarios demonstrate that the two dose-projection tools provide a coherent and mutually reinforcing picture of the radiological and physical consequences associated with nuclear detonation events. Their consistent behavior in modelling high-intensity effects, coupled with broadly similar fallout predictions, including identical dose-rate estimates over the Bucharest area, supports a strong level of methodological validation and increases confidence in the robustness of their underlying assumptions.

Beyond the technical alignment, these results carry direct public-safety implications: reliable dose-projection outputs are essential for timely protective-action decisions, resource allocation, and communication with authorities and the population during radiological emergencies.

At the institutional level, the ability to operate, compare, and interpret multiple modelling platforms strengthens analytical capability, enhances preparedness, and ensures that response organizations can base their decisions on convergent, cross-validated evidence rather than on a single modelling source. In this context, the demonstrated modelling performance and operational coherence confirm that our institutions possess the analytical readiness, response capacity, and technical resilience required to support effective preparedness and response to nuclear or radiological emergencies of any nature.

Acknowledgements

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