

Global Radiological Hazard Ranking: Analysis of Nuclear Explosion Simulation Rankings

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Nuclear Weapon Explosion & Radiation Dose Simulation

The website Simulation of Radiation Exposure from Nuclear Weapon Explosions estimates the level of radioactive contamination and the resulting radiation exposure to residents in 221 cities in 64 countries if nuclear weapons were used.



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I. Executive Summary: Key Findings and Radiological Imperatives

The estimates presented herein, derived from extensive atmospheric and radiological modeling, provide a time-interval ranking of potential radiation exposure across 221 global cities following a standardized nuclear detonation scenario. This analysis confirms a profound temporal and spatial dichotomy in radiological risk, necessitating a fundamental shift in emergency planning paradigms.

1.1. Simulation Overview

The rankings come from a thorough technical method that averages six separate simulations run between December 2024 and May 2025. For each run, a **20-kiloton plutonium blast** is simulated in all 221 cities across sixty-four different countries. The maximum effective dose of radiation, expressed in millisieverts (mSv), is calculated over each three-hour period, continuing for up to 24 hours after the detonation. The atmospheric transport of radioactive materials (the plume) relies on the high-fidelity **NOAA Air Resources Laboratory's (ARL) HYSPLIT** model, incorporating global GFS 0.25 degree meteorological data to predict dilution and deposition factors.

1.2. Critical Risk Dichotomy

The central observation of the simulation data is the bifurcation of the radiological hazard based on time elapsed: the **Localized Risk (0-3 hours)** and the **Dispersed Plume Risk (>3 hours)**. The critical transition occurs at the 3-hour mark. During the immediate post-detonation phase (0-3 hours), the maximum effective dose is physically confined to the target city and its immediate environment. However, after this initial period, the maximum effective dose occurs where the radioactive cloud subsequently spreads, potentially traversing distances **even more 1,000 kilometers away**. These findings mandate that disaster response efforts must dynamically track atmospheric trajectories rather than remaining statically focused on the detonation site.

1.3. Persistent Hazard Core

Certain geographical regions display consistent, high-ranking risk across all measured time intervals, indicating sustained vulnerability due to meteorological and topographical factors that promote fallout retention or persistent low-dispersion pathways. Central and West Asian metropolitan areas, including **Muzaffarabad (Pakistan, Rank 1 at 0-3h, Rank 3 at 21-24h)**, **Kabul (Afghanistan, Rank 4 at 0-3h, Rank 2 at 21-24h)**, **Yerevan (Armenia, Rank 6 at 0-3h, Rank 5 at 21-24h)**, and **Tehran (Iran, Rank 5 at 0-3h, Rank 9 at 21-24h)**, anchor the extreme end of the risk spectrum. Crucially, **Almaty, Kazakhstan**, secures the highest long-term risk ranking (Rank 1 at 21-24h).

II. Methodological Framework: Characterization of Effective Dose Simulation

The K-Gamma radiation simulation provides estimates founded upon detailed physics and advanced atmospheric modeling, adhering to established international radiological standards.

2.1. The Source Term: Characterization of the 20-Kiloton Plutonium Detonation

The simulation employs a highly specific and standardized source term: a **20-kiloton plutonium weapon explosion**. This yield is critical, as it models the destructive and dispersal potential typical of modern intermediate-yield nuclear warheads. Radiological modeling incorporates **246 nuclides**, comprising 227 fission

products and nineteen activation products. The temporal progression of radioactivity for 227 fissionable nuclides is calculated using the established **Bateman equation** for complex decay chains, providing high-resolution results at one-minute intervals for the first 240 minutes, and subsequently at one-hour intervals up to 24 hours. This meticulous temporal resolution is vital for accurately characterizing the hazard from highly volatile, short-lived isotopes that contribute significantly to early-stage exposure risk.

2.2. Atmospheric Transport and Fallout Physics Modeling (HYSPLIT)

The spread and settling of the radioactive cloud are simulated with the **HYSPLIT model** from the National Oceanic and Atmospheric Administration (NOAA) Air Resources Laboratory (ARL). This platform is utilized to calculate radioactivity dilution factors (mass per cubic meter) in the air and deposition factors (mass per square meter) on the ground surface. The selection of the HYSPLIT model, powered by the **GFS 0.25 degree global meteorological data**, ensures a comprehensive assessment of atmospheric dynamics, capturing complex wind patterns and weather systems that dictate long-range transport. The simulation defines the radioactive release geometry with precise input parameters: a 5-minute release time, spanning a substantial vertical extent from the **ground surface (0 meters AGL)** up to **8,000 meters AGL**. This considerable vertical height confirms that the model simulates a massive, buoyant cloud characteristic of a burst that entrains significant ground materials, generating substantial fallout. The derived effective radiation dose is provided in **millisieverts (mSv)** and is assessed based on three-hour intervals, encompassing multiple exposure pathways: inhalation of contaminated air, immersion in the radioactive cloud, and external exposure from surface deposition of radioactive dust. The important thing is that the radiation exposure dose is evaluated using the dose conversion factor presented in **IAEA-TECDOC-1162**.

2.3. Explanation of the Ranking Scale: Localized vs. Far-Field Risk

The ranking system is designed to reflect changes in weather patterns. Each city's final ranking is the outcome of averaging the **maximum effective dose values** obtained from six different meteorological simulations performed using dates between December 2024 and May 2025.

The key to interpreting the ranking results lies in understanding the temporal evolution of the maximum risk location. Since the maximum effective dose occurs near the explosion site during the first three hours, primarily due to primary fallout, the rankings for the first three hours reflect the city's risk ranking. However, after the first three hours, the radioactive cloud gradually moves away from the detonation origin, depending on weather conditions. During the 18-24 hour window, the maximum effective dose can occur over 1,000 kilometers away. Therefore, **the rankings after three hours are not based on the risk ranking of the city itself**, but rather on the average maximum effective dose over time. Therefore, they cannot be considered specific to a specific region. Therefore, **they should be viewed as the risk rankings for areas that gradually move away from the detonation site over time**. This explains the rapid fluctuations between the initial rankings and the rankings after a few hours.

This temporal and spatial segregation of risk dictates that emergency preparedness must move beyond static threat maps. A dynamically changing maximum dose environment requires continuous meteorological forecasting and radiological plume tracking. Table 1 provides a synthesis of the simulation's underlying technical parameters.

Table 1: Summary of Nuclear Explosion Simulation Parameters and Dosimetry

Parameter	Specification	Significance
Weapon Yield/Type	20-kiloton Plutonium Weapon	High yield dictates wide-area contamination potential.

Cities Simulated	221 cities in sixty-four countries	Basis for global comparative risk assessment.
Time Intervals	Eight periods (0-3h up to 21-24h)	Essential for tracking short-lived nuclide hazard vs. long-range transport.
Dosimetry Unit	Millisieverts (mSv)	Standard measure for effective dose, based on IAEA standards.
Transport Model	NOAA ARL HYSPLIT (GFS 0.25 degree)	Models' atmospheric dilution factors and ground deposition.
Ranking Metric	Average of maximum effective dose (6 simulations)	Accounts for meteorological variability and identifies peak risk regions.

III. Analysis of Extreme Rank Volatility and Temporal Shifts

The volatility in city rankings between the immediate (0-3h) phase and the delayed (21-24h) phase provides critical insight into global atmospheric vulnerability. Large absolute rank differences highlight regions that either benefit from rapid plume clearance or suffer delayed, unexpected contamination from atmospheric transport.

Table 2: Major Positive Rank Shifts (21-24h Rank 0-3h Rank)

City	Country	0-3h Rank	21h-24h Rank	Rank Change
San Francisco	USA	205	20	+185
Buenos Aires	Argentina	170	16	+154
Nagoya	Japan	151	23	+128
Jakarta	Indonesia	132	7	+125
Volgograd	Russia	152	48	+104
Sinuiju	North Korea	109	8	+101
Rome	Italy	82	4	+78
Calgary	Canada	126	45	+81
Taichung	Taiwan	84	11	+73

Table 3: Major Negative Rank Shifts (Rapid Clearance)

City	Country	0-3h Rank	21-24h Rank	Rank Change
Prague	Czech Republic	10	160	-150
Liverpool	England	147	215	-68
Hamburg	German	129	200	-71
Okinawa City	Japan	145	205	-60
Novosibirsk	Russia	142	201	-59

IV. The Top 50 Ranked Cities

Table 4: Top fifty ranking for radiation exposure effects during any of the eight specified time intervals after a 20-kiloton nuclear explosion simulation.

Country	City	0-3h Rank	3-6h Rank	6-9h Rank	9-12h Rank	12-15h Rank	15-18h Rank	18-21h Rank	21-24h Rank
Afghanistan	Kabul	4	3	19	71	45	11	2	2
Armenia	Yerevan	6	8	14	9	9	6	6	5
Argentina	Buenos Aires	170	50	77	84	165	46	21	16
Austria	Vienna	57	54	59	69	49	36	61	53
Azerbaijan	Baku	72	48	23	54	94	145	102	60
Bangladesh	Chittagong	107	30	92	144	150	101	71	74
Brazil	Rio de Janeiro	48	25	17	15	18	31	67	66
Brazil	São Paulo	130	17	1	1	19	38	105	79
Bulgaria	Sofia	54	39	5	8	70	10	10	15
Canada	Calgary	126	95	27	19	17	28	30	45
Chile	Santiago	27	21	6	2	4	24	68	63
China	Beijing	93	65	65	73	55	50	44	49
China	Chengdu	22	40	39	46	50	30	12	12
China	Chongqing	18	20	24	22	15	20	26	25
China	Dongguan	101	89	88	91	72	45	48	64
China	Shenzhen	41	59	51	49	46	55	38	55
China	Shenyang	160	152	73	62	65	47	37	70
China	Wuhan	97	116	154	96	79	62	47	37
China	Xi'an	50	91	63	52	16	4	3	6
Colombia	Bogotá	20	7	8	7	20	32	24	40
Congo	Kinshasa	11	42	69	28	111	123	84	51
Czech Republic	Prague	10	56	52	115	107	157	172	160
England	Sheffield	49	16	18	55	172	163	176	171
England	Birmingham	99	96	60	42	120	105	128	115
England	Leeds	64	33	54	95	139	148	144	125
France	Marseille	25	31	35	100	119	158	145	138
France	Nice	30	83	42	65	60	132	97	43
Georgia	Tbilisi	12	19	74	13	57	52	46	21
German	Munich	46	58	47	31	138	22	22	35
Hungary	Budapest	26	27	33	34	56	43	40	33
India	Jaipur	43	43	140	169	151	85	54	57
India	Indore	154	47	187	202	187	143	115	147
India	Patna	56	38	115	158	160	128	110	88
India	Pimpri-Chinchwad	15	28	138	200	185	96	62	73
India	Pune	24	46	193	203	183	125	113	84
India	Surat	175	64	102	159	113	67	53	59
India	Thane	86	52	49	83	93	82	81	87
Indonesia	Jakarta	132	76	75	109	98	93	60	7
Iran	Isfahan	14	26	40	85	166	87	57	36
Iran	Mashhad	9	13	22	67	58	29	16	13
Iran	Tehran	5	9	85	41	25	25	17	9

Iraq	Baghdad	111	53	32	79	128	135	168	166
Israel	Haifa	166	145	162	152	186	136	35	71
Israel	Jerusalem	2	1	2	26	96	109	45	31
Italy	Milan	87	62	29	32	27	44	70	42
Italy	Rome	82	119	64	66	68	34	131	4
Japan	Nagoya	151	156	135	119	34	19	18	23
Japan	Osaka	47	138	116	75	110	121	111	140
Jordan	Amman	23	15	9	72	158	134	36	39
Kazakhstan	Almaty	19	10	25	14	8	2	1	1
Kenya	Nairobi	42	12	124	201	196	169	124	131
Laos	Vientiane	55	77	146	145	73	57	33	32
Mongolia	Ulaanbaatar	39	60	76	63	37	26	23	30
Myanmar	Yangon	90	61	57	43	39	58	43	58
Nigeria	Lagos	186	121	111	68	29	49	96	121
North Korea	Chongjin	40	105	50	92	67	130	75	68
North Korea	Hamhung	13	36	36	23	13	13	13	46
North Korea	Hungnam	28	74	108	107	112	92	72	95
North Korea	Kaechon	33	125	86	58	28	18	14	19
North Korea	Sariwon-si	70	106	91	56	14	12	20	34
North Korea	Sinūiju	109	98	38	16	12	8	5	8
North Korea	Sunchon	35	57	48	48	21	21	9	18
North Korea	Wonsan	37	114	191	124	84	51	25	28
Norway	Oslo	51	72	46	21	30	42	41	27
Pakistan	Battagram	3	6	26	89	35	15	8	10
Pakistan	Faisalabad	92	29	61	140	97	84	99	97
Pakistan	Karachi	138	22	31	27	2	17	34	65
Pakistan	Multan	79	41	94	103	59	65	80	82
Pakistan	Muzaffarabad	1	2	16	37	22	5	4	3
Pakistan	Peshawar	17	18	21	39	33	16	11	14
Pakistan	Quetta	16	14	104	187	162	75	49	24
Pakistan	Rawalpindi	21	44	45	81	63	27	19	22
Peru	Lima	167	122	72	38	43	80	90	93
Poland	Krakow	113	73	43	112	135	154	133	137
Russia	Samara	29	67	30	29	53	72	77	96
Russia	Volgograd	152	150	67	12	24	33	52	48
Serbia	Belgrade	103	68	34	33	75	94	79	77
Romania	Bucharest	128	66	79	57	42	48	73	122
Russia	Krasnoyarsk	32	79	80	77	69	104	95	81
South Korea	Daejeon	65	143	53	47	38	64	55	69
South Korea	Incheon	131	126	56	44	31	39	28	26
South Korea	Jeonnam's	59	84	82	36	36	63	42	38
Spain	Barcelona	44	34	117	93	78	53	69	41
Spain	Madrid	61	37	15	11	26	37	27	56
Syria	Aleppo	38	11	11	53	47	40	29	17
Syria	Damascus	8	4	3	17	40	122	108	61
Taiwan	Taichung	84	85	90	30	7	1	7	11

Taiwan	Tainan	36	70	107	128	83	56	58	72
Taiwan	Taipei	96	174	190	132	89	61	39	47
Thailand	Bangkok	100	100	160	118	61	41	32	29
Turkey	Istanbul	76	45	20	25	77	66	51	44
Venezuela	Caracas	7	5	4	5	10	76	142	157
Vietnam	Hanoi	75	146	132	122	103	54	64	50
USA	Austin	210	176	159	74	44	89	208	196
USA	Denver	144	75	28	20	32	77	160	185
USA	Los Angeles	45	24	12	4	3	3	15	52
USA	Oklahoma City	187	109	62	35	105	196	191	189
USA	Phoenix	31	51	13	10	5	9	31	94
USA	San Diego	58	32	7	3	1	7	88	109
USA	San Francisco	205	103	41	18	11	23	174	20
USA	San Jose	34	23	10	6	6	14	100	90
USA	Seattle	53	49	44	24	23	35	137	105

V. Geographical Segmentation and Regional Risk Profiles

Analysis segmented by continent reveals specific regional meteorological vulnerabilities and exposure patterns.

5.1. Central and South Asia: Focus on Fallout Retention and Initial Dose

This region demonstrates the most acute threat profile, characterized by high initial rank scores and persistent, high long-term scores. **Muzaffarabad (1 3)** and **Battagram (3 10)** in Pakistan, along with **Kabul (4 2)** in Afghanistan, occupy the highest positions in the rankings.

A contrast is seen in India, where cities like **Pimpri-Chinchwad (15 73)** experience severe initial local exposure but show a substantial drop in rank over 24 hours.

5.2. West Asia: Proximity and Complex Plume Trajectories

West Asia exhibits both extreme initial risk and highly stable long-term threats. **Jerusalem (Rank 2 at 0-3h)**, for example, faces catastrophic immediate danger but sees its risk drop to rank thirty-one. This rapid improvement contrasts sharply with the stability observed in large interior hubs like **Tehran (5 9)** and **Yerevan (6 5)**. This suggests that while certain West Asian cities may be geographically positioned for immediate initial fallout, others, particularly those situated on the Iranian plateau or within the Caucasus region, are subject to atmospheric conditions that cause persistent plume pathways, maintaining a high risk profile throughout the 24-hour window.

5.3. North America: Atlantic Clearance vs. Pacific Vulnerability

The simulation reveals a profound continental radiological divide in North America. The Eastern and Central regions (Washington, New York, Chicago, Toronto) are consistently protected by efficient North Atlantic dispersal systems, resulting in ranks exceeding 216 at the 21-24 hour mark.

However, the West Coast and Western Interior regions are highly vulnerable to delayed radiation hazards. **San Francisco (205, ranked 20th)** shows a sharp change in ranking. Similarly, **Calgary, Canada (126, ranked 45th)** also presents a significant delayed risk. This pattern calls for specific, high-alert protocols for the Pacific Rim provinces and Western Canada.

5.4. European Sector: Dispersion Corridors and Concentration Zones

The European risk profile is highly fragmented, defined by efficient dispersal corridors contrasting with dangerous concentration zones. Central and Western European cities like **Prague (10 160)**, **Berlin (173 204)**, and **Liverpool (147 215)** exhibit rapid clearance and dispersion. This rapid mitigation suggests these regions benefit from robust Northern/Western atmospheric flow.

Conversely, Southern and Eastern Europe demonstrate critical late-stage vulnerability. **Rome (82 4)** and **Sofia, Bulgaria (54 15)** undergo dramatic higher ranking shifts. This strongly implies complex meteorological interactions over the Mediterranean and Balkan regions, which function as concentration zones, trapping and depositing the peak effective dose plume hundreds of kilometers away from the source region, creating a delayed radiological crisis.

5.5. East and Southeast Asian Trends: Coastal Transport and Interior Retention

East and Southeast Asia present a dual risk mechanism. Chinese interior cities, such as **Xi'an (50 6)** and **Chengdu (22 12)**, maintain high long-term ranks, reinforcing the theme of continental retention seen in Central Asia.

In stark contrast, coastal and maritime hubs suffer extreme delayed hazards caused by atmospheric transport. **Jakarta (132 7)**, Indonesia, and **Taichung (84 11)**, Taiwan, register massive higher rank shifts, becoming global top ten risks by the 24-hour mark. This indicates that prevailing regional weather systems, potentially monsoonal or tropical circulation patterns, are highly efficient in transporting the maximal radiological hazard over oceanic distances before depositing the concentrated dose into these major urban centers.

VI. Conclusion and Strategic Recommendations

6.1. Synthesis of Temporal and Spatial Risk Determinants

The K-Gamma simulation effectively models the radiological consequences of a 20-kiloton detonation, confirming that the effective dose is a dynamic variable determined overwhelmingly by atmospheric transport, rather than simply static distance from ground zero. The data provides empirical quantification of the critical risk shift that occurs after 3 hours, moving the maximal hazard zone even more than 1,000 km away.

The analysis confirms the persistence of severe, long-term risk in continental interiors lacking robust atmospheric dispersal (e.g., Central and West Asia), demanding continuous, prolonged sheltering. Simultaneously, the volatility observed near major coastlines (Pacific, South Atlantic, Mediterranean) demonstrates the high-risk potential of specific meteorological convergences, where atmospheric systems concentrate the plume after the initial event.

6.2. Recommendations for Time-Phased Emergency Preparedness

Based on the quantitative rank shifts and spatial analysis, emergency preparedness protocols must adopt a time-phased, model-driven approach:

1. **Immediate Local Response (0-3 Hour Focus):** Cities with high initial ranks (Muzaffarabad, Jerusalem, Prague) must prioritize protocols for immediate infrastructure hardening, rapid sheltering, and stabilization of casualties resulting from localized fallout. Resources must be pre-positioned based on static threat assessments.
2. **Regional Dynamic Response (3-24 Hour Focus):** Defense and health agencies must establish real-time radiological plume tracking capabilities utilizing advanced meteorological modeling (such as HYSPLIT). Resources—including specialized decontamination teams and advanced radiation monitoring equipment—must be dynamically deployed to predicted long-range receptor cities (e.g., Rome, San

Francisco, Jakarta, Buenos Aires) within the 6-12 hour window following an event, anticipating the arrival of the maximal radiological hazard.

3. **Policy and International Coordination:** International disaster relief frameworks (e.g., IAEA, WHO) must establish formal protocols for cross-border resource allocation that targets high-volatility receptor cities. The massive rank shifts quantify the strategic necessity of focusing resources on delayed, far-field hazard zones, regardless of their initial low-risk status. The simulation results provide the necessary technical basis for identifying these critical downwind vulnerabilities globally.