

Nuclear Exchange Scenarios

Technical Report

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Abbreviations and Acronyms

cGy	centigray
DOSE	Global Data Set of Reported Sub-national Economic Output
DPRK	Democratic People's Republic of Korea
FEMA	Federal Emergency Management Agency
GHS-BUILT-V	Global Human Settlement Layer, built-up volume grid
GHS-POP	Global Human Settlement Layer, population grid
ISO	International Organization for Standardization; the ISO 3166-2 codes identify the principal subdivisions of a country
kt	kiloton
LD50	median lethal dose
mph	miles per hour
Mt	megaton
NATO	North Atlantic Treaty Organization
psi	pounds per square inch
SIPRI	Stockholm International Peace Research Institute
Tg	teragram
WGS84	World Geodetic System 1984, the reference ellipsoid distances are measured on

Executive Summary

This document specifies a library of state-to-state nuclear exchange scenarios in a form a consequence model consumes, together with the method by which casualties are to be estimated from it, and a worked instance of that method on one cell.

A scenario is stated as a tuple over eight axes: the belligerents, the initiating pathway, the target class employed, the number of weapons, their yield, the burst condition, how far the effects reach, and the point at which the exchange stops. The library holds 75 such cells across 16 theatres. Every cell carries a provenance class recording what the published literature supplies for it, and 38 of them are constructed, meaning that no source treats them and their parameters follow a stated rule rather than a publication.

Two properties of the library govern how its numbers may be used. First, the effects of a detonation divide into layers that are bounded by radius and layers that are not, and the two are never summed, because they describe different populations over different windows. Second, the unbounded layers rest on an atmospheric quantity that two published lineages estimate differently, the lower at about one sixth to one quarter of the higher, and a consensus assessment records the disagreement without adjudicating it. The library therefore carries that quantity as two bases rather than one number, and the indirect layer is read under each.

The estimation method is a chain of five steps from the scenario cell to country and metropolitan totals, using public inputs at every step. Its response function is calibrated to the published fatality totals of one theatre at three weapon yields; the split of those fatalities between the two belligerent countries, which the calibration does not fit, departs from the published one by a margin that widens as yield rises. Its injuries are an output of held fractions rather than a calibrated quantity, and they fall below the published figures, as the body reports. A second published case, for Israel and Iran, puts the chain's median below the published fatalities in twenty-five of twenty-six cases; a third, for France and the United Kingdom at 15 kt, puts it above, by 9.5 and 6.1 percent. The European countervalue rung, run at its published five and ten weapons on each of the thirty most populous cities of each side, gives 56.2 through 119.5 million casualties at 100 through 500 kt, a span that holds the source's 85.3 million at a yield the source does not state; and 50 weapons of 15 kt on each of India and Pakistan give 1.093 of that source's fatalities. A constructed case outside the library, a strike by Russia's missiles based in Kaliningrad on the three capitals of members of the North Atlantic Treaty Organization that lie within their range, is run on the same chain, with Latvia and Lithuania read through a correction of the grid to their censuses; Warsaw's median fatalities are the largest of the three under each composition and yield, while in money one weapon of the smaller yield destroys more by blast on Riga than on Warsaw. A second constructed case puts one weapon on the capital of each of the alliance's 30 European members, with Albania, North Macedonia, and Montenegro read through a correction of their own; one weapon on Paris gives the largest median fatalities of the 30 at both yields and destroys the most value by blast. The estimates are reported as intervals spanning the calibrated response function, together with the wider spread that calibrations on three other geometries of the zones give, which measures how far the totals move with the geometry.

The fallout layer is reported as a bound rather than an estimate: the count of residents inside the lethal-dose contour, on stated overstatements and under two stated conditions, the wind the relation assumes and an exposed population near the aimpoints. It exceeds the direct-layer count in every case computed. In the largest exchange computed, its ratio to that count is lower at the larger force than at a tenth of it, because the contours of neighboring aimpoints overlap where the

smaller blast zones do not; in the smallest, the ratio rises with the force. The count is attributed both to the side struck and to the country its residents live in, and the second attribution crosses borders: a contour reaches states that are party to neither side of the exchange.

The residents both layers count are composed by sex and age against the residents of the units they live in, on one construction for both. The exposed are of working age in a higher proportion than their units on the majority of struck sides in both layers, the share under 15 running the other way, and their sex composition follows that of their units. For the calibration theatre the analysis states a rate per resident of each level-1 unit of residence, conditional on the scenario: an exposure rate and a mortality rate that weights it by the zones' fatality fractions. The two order the units differently, since exposure concentrated in the outer ring carries a lower mortality than exposure in the inner one.

The same rings and a thermal disc give the property layers: the built-up volume each unit exposes to blast and to fire, and a conditional damage ratio for each. The value layer carries both into money as produced capital destroyed, by unit for the calibration theatre, by country across the theatres run, and by capital for the two constructed cases, with blast and fire reported apart and never summed.

1 Introduction

A nuclear exchange reaches people and property through several mechanisms that share no common unit. People die at the point of detonation within a radius set by weapon yield and burst height. People die downwind of a surface burst on a path set by the weather of the day. People die, over years and across states that were not party to the conflict, from the failure of the food system under a cooled and darkened atmosphere. These are not three severities of one event; they are three events with different geographies, different time constants, and different evidence behind them.

A library of scenarios is therefore the first object such an exercise needs, and it is not a list of narratives. It is a set of parameter tuples a model can read, each carrying the provenance of its parameters and the layers of consequence it triggers.

This document specifies that library, the method for turning each of its cells into casualty estimates by country and by metropolitan area, one worked cell, and the results of running that method on nine theatres, of which one carries a published record against which the response function is calibrated. Section 2 states the axes over which a scenario is defined and the two rules that govern how its layers combine. Section 3 reports what the published literature supplies, theatre by theatre, and what it does not. Section 4 sets the physical bounds every cell on the current force basis must respect, and records the basis of those that are not. Section 5 treats the unbounded layer and the disagreement over the quantity that drives it. Section 6 specifies the estimation chain, and Section 7 works one cell through it. Section 8 reports the chain run on nine theatres: on the calibration theatre the totals lie within five percent of the published case at three yields, as the calibration requires, while the split of fatalities between the two countries, which it does not fit, departs from the published one by a margin that widens with yield; the library's countervalue cells are run at their published compositions against their sources; the section closes with two constructed cases, the capitals within reach of Russia's missiles based in Kaliningrad and the capitals of the alliance's European members, each carried through the value layer of Section 14. Section 9 reports the fallout bound and the countries and territories its contours reach, and Section 10 the composition of the residents both layers count, by sex and age, against the units they live in. Section 11 states the exposure and conditional mortality rates by unit of residence for the calibration theatre. Section 12 states the property analog, a built-up-volume exposure and a conditional damage ratio by unit on the same rings; Section 13 adds the fire zone as a second property loss; and Section 14 carries both into money as a value destroyed by unit. The central finding of the coverage section is that quantified consequence and analytical depth sit in different theatres: the exchanges studied most closely for how they would start are the ones for which no published account of what they would do was located.

2 The scenario architecture

A cell of the library is a tuple over eight axes. The belligerents name who initiates and against whom. The pathway names how use arises, from conventional escalation through false warning to unauthorized release. The use mode names the target class, from a demonstration sited to cause no casualties, through battlefield, maritime, infrastructure, counterforce, and countercommand employment, to attacks on population as such (countervalue use) and general release, and to a high-altitude burst whose effect is electromagnetic rather than physical. The size band and yield band, or a span of adjacent yield bands, give the composition. The burst condition decides whether

a fallout layer exists at all. The footprint states how far effects reach, and the termination axis states where the exchange stops, which is what decides which layers attach.

Two rules govern the arithmetic.

The first is that radius-bounded and unbounded layers are never summed. Blast, thermal radiation, prompt radiation, and fallout are effects of location, and a casualty figure for them is a statement about people near the detonation or under its plume. The climatic and food-system layers are effects of the atmosphere, and a figure for them is a statement about a global population over a period of years. Adding a published direct fatality count to a published famine count produces a number describing no population at all.

The second is that provenance travels with the parameters. A cell whose composition and consequence a source publishes is not the same object as a cell whose parameters follow a construction rule because no source treats it. Of the 75 cells, 18 are published and quantified, 2 carry a published composition whose consequence the source does not state, 17 take composition from a rule while the pathway is published, and 38 are constructed in both respects. A constructed cell is a stress case of stated shape. It is not evidence that an exchange of those parameters is possible, and it is not cited downstream as though a source stood behind it.

3 Coverage

The library spans 16 theatres, listed in Table 1, which names the Democratic People's Republic of Korea (DPRK) by its abbreviation. They include every pairing for which a published treatment was located, the pairings for which none was, use against states holding no weapons, strikes on the territory of states that host an ally's facilities, and the acquisition or reconstitution of an arsenal by a state that holds none. One theatre rests on a premise rather than on an arsenal: every cell of the Middle East theatre carries the premise that Iran holds deliverable weapons, which is the scenario's assumption and no claim about the state of its program.

Figure 1 shows the cells by theatre and provenance class. The pattern is the finding. Quantified consequence concentrates in six theatres, those holding at least one cell whose composition and consequence a source publishes. Analytical depth concentrates in others, where the pathway literature is extensive and no published casualty figure was located at any rung. Three theatres, T09, T12, and T13, carry no published scenario treatment that was located; a theatre can hold only constructed cells in Figure 1 and still be treated in a literature that quantifies no scenario of it.

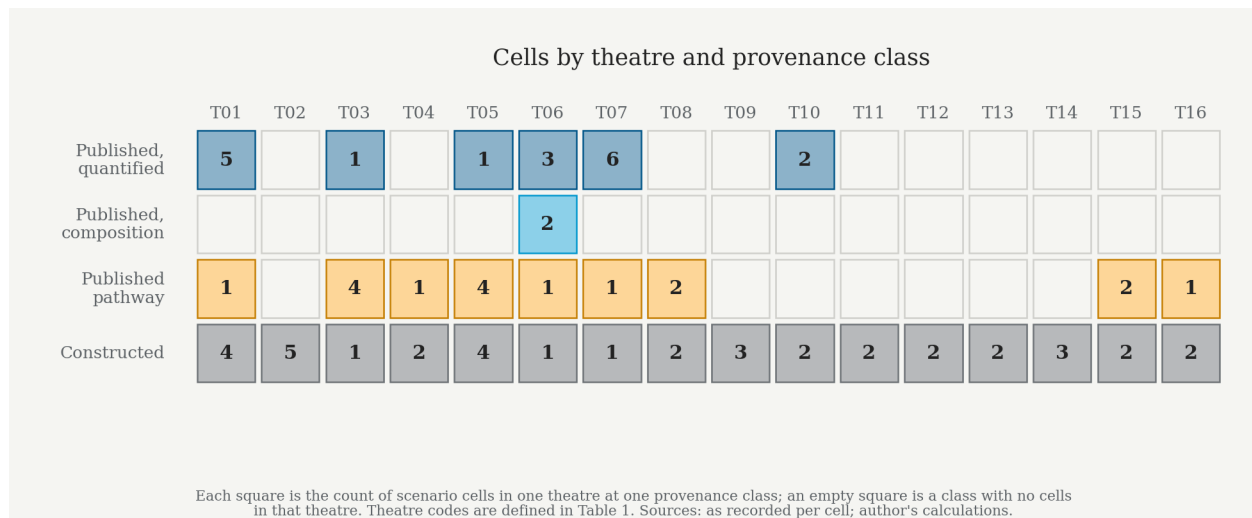


Figure 1: Count of scenario cells by theatre and provenance class. The horizontal axis is the theatre code of Table 1; the vertical axis is the provenance class. Fill hue encodes the class and the numeral gives the count; an outlined square with no fill is a class holding no cells in that theatre. Source: the scenario library; author's calculations.

Across the 9 states holding weapons there are 36 pairings, of which 8 carry a theatre here. The remainder are recorded with the reason: an alliance rather than an adversarial relation, or no published treatment located. Three of the pairings that carry no theatre share a land frontier: China and Pakistan, recorded as aligned; and Russia and the DPRK, and China and the DPRK, for which no published treatment was located.

Table 1: Theatres of the scenario library

Code	Theatre	Nuclear participants	Cells
T01	South Asia	India; Pakistan	10
T02	Himalayan frontier	China; India	5
T03	Korean Peninsula	DPRK; United States	6
T04	DPRK against the U.S. homeland	DPRK; United States	3
T05	Western Pacific	China; United States	9
T06	Europe	Russia; United States; United Kingdom; France	7
T07	Russia and the United States, homelands	Russia; United States	8
T08	Russia against a non-nuclear state	Russia	4
T09	Russia and China	Russia; China	3
T10	Middle East	Israel; Iran under the premise above	4
T11	Independent European deterrent	United Kingdom; France; Russia	2
T12	Third-party entry in South Asia	China; India; Pakistan	2
T13	Multi-theatre	Three or more	2
T14	Non-deliberate initiation	Actor-agnostic	3
T15	Host territory outside the belligerent states	The two belligerents; the host holds none	4
T16	Reconstitution and threshold states	None at the start; one or more by the end	3

4 Force basis

Every cell resting on the current inventory is bounded by it. At January 2026 the nine states held 12,187 warheads in total inventory, of which 9,745 were in military stockpiles and 4,012 were deployed with operational forces.¹ The stockpile rather than the inventory is the bound, since retired warheads await dismantlement and are not available for employment. Table 2 and Figure 2 give the distribution.

¹Hans M. Kristensen and Matt Korda, “World Nuclear Forces,” in Stockholm International Peace Research Institute, *SIPRI Yearbook 2026: Armaments, Disarmament and International Security* (Oxford: Oxford University Press, 2026), table 8A.1.

Table 2: Warheads by state and status, January 2026. A zero is SIPRI's nil or negligible; a dash is a figure SIPRI does not report. Source: SIPRI Yearbook 2026, table 8A.1.

State	Deployed	Stored	Military stockpile	Retired	Total inventory
United States	1,770	1,930	3,700	1,342	5,042
Russia	1,796	2,604	4,400	1,020	5,420
United Kingdom	120	105	225	0	225
France	280	10	290	80	370
China	34	586	620	0	620
India	12	178	190	–	190
Pakistan	0	170	170	–	170
North Korea	0	60	60	–	60
Israel	0	90	90	–	90
Total	4,012	5,733	9,745	2,442	12,187

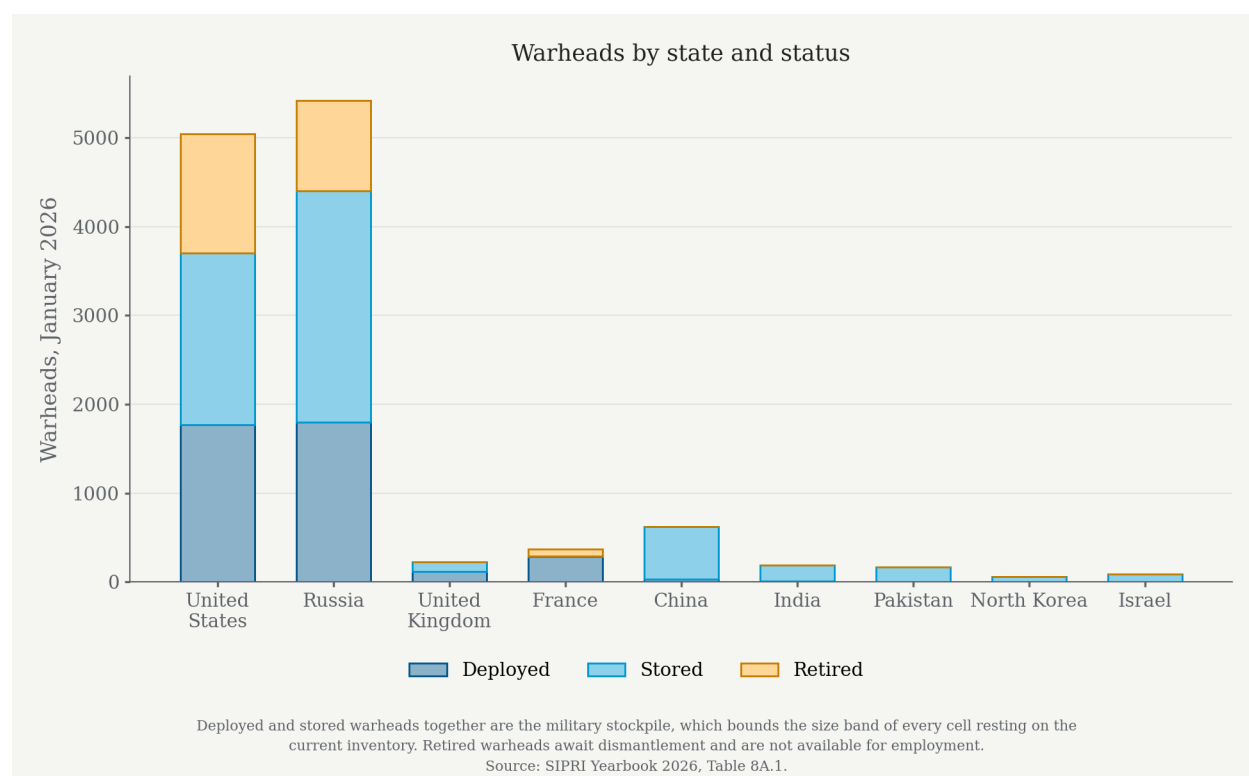


Figure 2: Warheads by state and status at January 2026, stacked as deployed, stored, and retired. Deployed and stored together are the military stockpile. Source: SIPRI Yearbook 2026, table 8A.1.

Yields are published for 4 states, in 21 entries by delivery system: the United States fields 0.3 through 455 kt, Russia 100 through 800 kt, the United Kingdom 100 kt, and France 150 kt, while two further entries, France's air-launched warhead on its two carriers, carry only the source's uncertain estimate of under 300 kt, which is not used here. Of the five states that remain, the source records for three, China, India, and Pakistan, that warhead yields are not known, and for the DPRK and Israel it gives none. A cell in a battlefield, maritime, or theatre-infrastructure mode draws on non-strategic warheads, whose yields the source gives for one state only, the United States, whose

non-strategic bomb lies inside its strategic range; for the others no range exists against which to test the cell.

Not every cell rests on the January 2026 inventory. 14 of them reproduce a published composition written against a different force basis: forces of 1979, arsenals projected for a year that has since passed, or the premise of a state that holds no weapons. Each such cell records its basis. Without that field, a composition of 500 weapons in South Asia would read as impossible against a combined stockpile of 360, when in fact its source wrote it against a projection that has not materialized at that level, which is a different statement.

5 The indirect layer

Above a threshold of burned urban area, an exchange injects soot into the stratosphere, where it absorbs sunlight, self-lofts, and persists for years. The published ladder of six cases runs from 5 through 150 Tg and carries, for each, an attack composition, a direct fatality count, and a count of people without food at the end of the second year.² Table 3 reproduces it, each case entered in the library as an overlay, coded OV-001 through OV-006.

Table 3: The published overlay ladder

Overlay	Soot (Tg)	Weapons	Yield (kt)	Direct fatalities	Without food, year two
OV-001	5	100	15	27,000,000	255,000,000
OV-002	16	250	15	52,000,000	926,000,000
OV-003	27	250	50	97,000,000	1,426,000,000
OV-004	37	250	100	127,000,000	2,081,000,000
OV-005	47	500	100	164,000,000	2,512,000,000
OV-006	150	4,400	100	360,000,000	5,341,000,000

The direct and famine columns are separate layers and are not summed. The famine column is stated against a population basis of 6,700.1 million, under an assumption set in which international trade ceases and half of livestock grain feed is converted to human consumption; two further published rows for the top case add household waste to food consumption, and give 5,081.2 million where all of it is added.

The soot masses themselves are contested. A detailed calculation of fuel loading and fire behavior reports much less material reaching the altitude at which it persists; the authors of the ladder have replied in print, and the authors of the calculation have answered.³ A consensus assessment published in 2025 reports agreement that lofted material of that quantity would cool the surface globally, disagreement over whether that much would be lofted that high, and states that it does not

²Lili Xia et al., “Global Food Insecurity and Famine from Reduced Crop, Marine Fishery and Livestock Production Due to Climate Disruption from Nuclear War Soot Injection,” *Nature Food* 3, no. 8 (2022): 586–596.

³Jon Reisner et al., “Climate Impact of a Regional Nuclear Weapons Exchange: An Improved Assessment Based on Detailed Source Calculations,” *Journal of Geophysical Research: Atmospheres* 123, no. 5 (2018): 2752–2772; and Alan Robock, Owen B. Toon, and Charles G. Bardeen, “Comment on ‘Climate Impact of a Regional Nuclear Weapon Exchange: An Improved Assessment Based on Detailed Source Calculations’ by Reisner et al.,” *Journal of Geophysical Research: Atmospheres* 124, no. 23 (2019): 12953–12958; and Jon Reisner, Eunmo Koo, Elizabeth Hunke, and Manvendra Dubey, “Reply to Comment by Robock et al. on ‘Climate Impact of a Regional Nuclear Weapon Exchange: An Improved Assessment Based on Detailed Source Calculations’,” *Journal of Geophysical Research: Atmospheres* 124, no. 23 (2019): 12959–12962.

connect employment scenarios to their outcomes, the uncertainty accumulating along the pathway from the one to the other; it publishes no casualty figure.⁴

The library therefore carries the soot mass as two bases rather than one number. The first takes each rung as published. The second applies a multiplier of 0.16, the detailed calculation's persisting soot over the ladder's injected mass at the rung where the two lineages treat the same exchange; its persisting soot over the ladder lineage's own persisting mass on that calculation's model gives 0.24, and the lower of the two is carried. That ratio is fixed at the one rung and applied at all six, across a soot mass running from 5 through 150 Tg. It is a ratio of persisting soot, and it carries both parts of the difference between the two lineages: the source term, the fuel loading and fire behavior that set how much soot is made and how high it is injected, and the lofting that decides how much of it persists. The basis is named for its lower lofted mass, which is the outcome of both. No published work gives it rung by rung, so the second basis is the first scaled by a constant rather than a second ladder, and it is read as that. Figure 3 shows both.

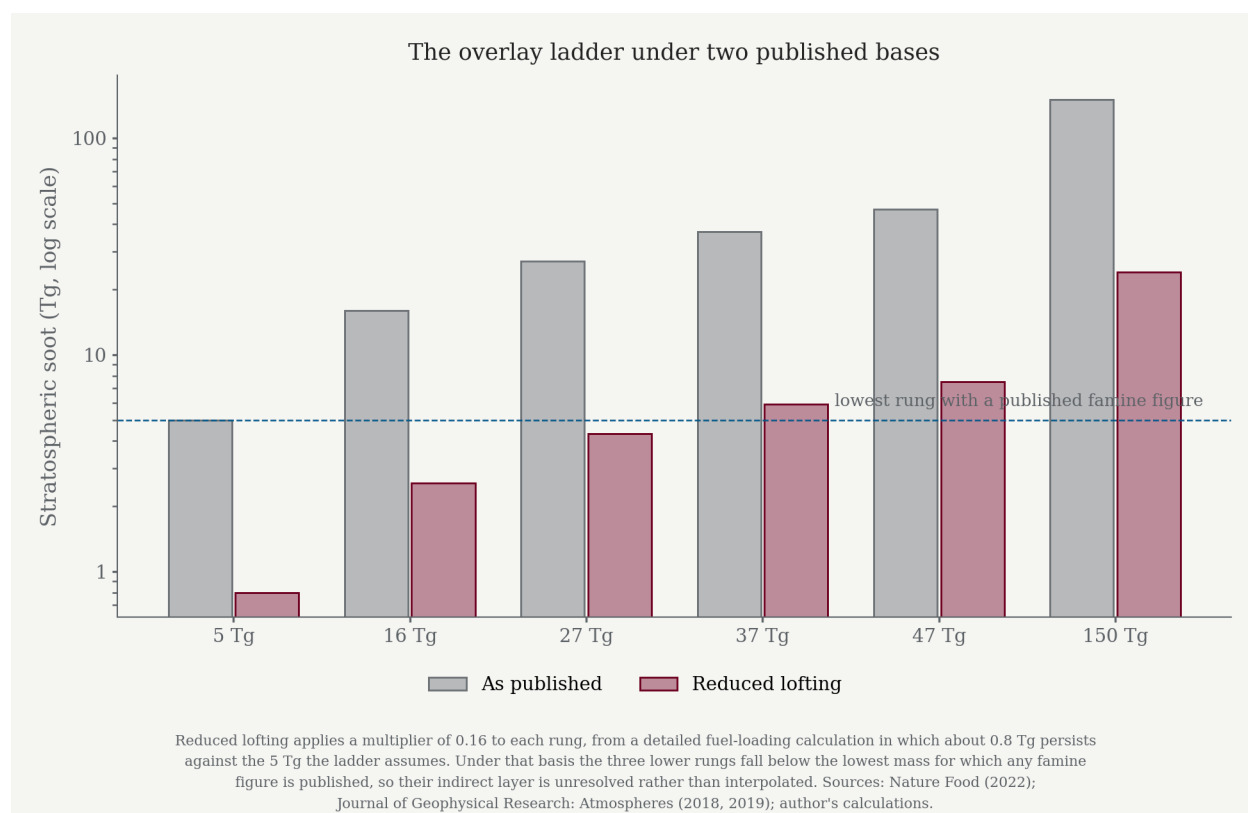


Figure 3: The six overlay rungs under the two bases, on a logarithmic vertical axis. Bars in gray give the soot mass as published; bars in maroon give the mass under the reduced-lofting basis. The dashed reference line marks 5 Tg, the lowest mass for which a famine figure is published. Sources: Nature Food (2022); Journal of Geophysical Research: Atmospheres (2018, 2019); author's calculations.

Two consequences follow. Under the second basis, three of the six rungs fall below the lowest mass for which any famine figure exists, so their indirect layer is unresolved rather than interpolated, and the top rung maps to 24.0 Tg, which sits between two published rungs and is bracketed

⁴National Academies of Sciences, Engineering, and Medicine, *Potential Environmental Effects of Nuclear War* (Washington, DC: The National Academies Press, 2025).

by them. The source supports multipliers from 0.16 to 0.24 on its own figures; the lowest is carried. And the direct layer does not move at all under either basis, since blast, thermal radiation, and fallout are computed from weapon effects and population location, which the disagreement does not touch.

Two bases are carried rather than a distribution over them, because no published work assigns weights between the lineages and a distribution would manufacture a weighting the literature does not supply.

The fire layer of Section 13 affords a check on the scaling of the assumed soot, since a fire zone and the soot the overlays assume rest on the same fires. The calibration theatre's exchange (Section 8) is exactly the ladder's regional composition—Pakistan's one hundred and fifty weapons against India's one hundred, for a total of two hundred and fifty⁵—so its burned built-up volume—the building volume the GHS-BUILT-V grid carries, inside the outer thermal disc within which thermal radiation ignites light fuels (Section 13), summed over the struck units—can be set against the ladder's assumed soot rung for rung. Dividing the one by the other gives the stratospheric soot the ladder implies per cubic meter of burned built-up volume, and that figure is nearly constant across the three yields: 0.89 through 1.13 kilograms per cubic meter, a mean of 0.97 with a coefficient of variation of 11 percent over the 3 rungs, though the soot mass itself more than doubles across them. The ladder's soot therefore scales with the burned volume the chain computes across the three yields. The check does not locate the disagreement between the lineages: built-up volume is not fuel mass, and both quantities grow with the thermal disc, so it speaks to how the soot scales and not to its level, which is where the lineages part.

The indirect layer is reported by country. Of 158 nations, 41 have at least 99 percent of their population without food at the end of the second year at the top rung under the as-published basis. Figure 4 gives the distribution. Canada stands at 99.7 percent, South Africa at 80.4 percent, and Australia at 0.0 percent, one of ten nations with no population without food at any rung. South Africa and Australia are belligerents in no cell of the library, and Canada only as a member of the North Atlantic Treaty Organization (NATO), whose cities are among the targets of the European theatre; the spread between the three in this layer does not follow from proximity to any exchange.

⁵Owen B. Toon et al., "Rapidly Expanding Nuclear Arsenals in Pakistan and India Portend Regional and Global Catastrophe," *Science Advances* 5, no. 10 (2019): eaay5478.

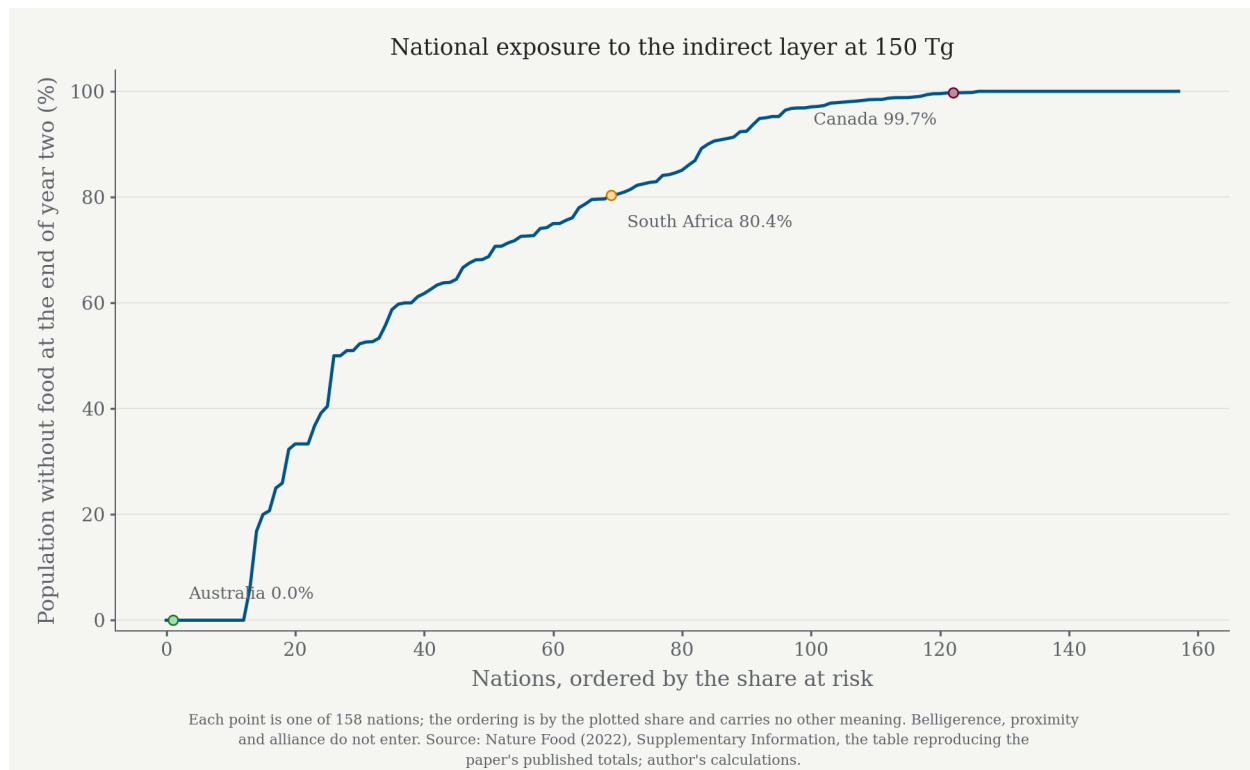


Figure 4: Share of national population without food at the end of the second year, at the 150 Tg rung under the as-published basis, for 158 nations ordered by that share. Markers identify three nations holding no weapons: South Africa and Australia, belligerent in no cell of the library, and Canada, belligerent only as a member of NATO. Source: Nature Food (2022), Supplementary Information; author's calculations.

6 The estimation method

Casualties are estimated per cell, per layer, by the chain in Figure 5. Every input is public; the section describes each step in turn before the worked instance of Section 7 and the results of Section 8 apply it.

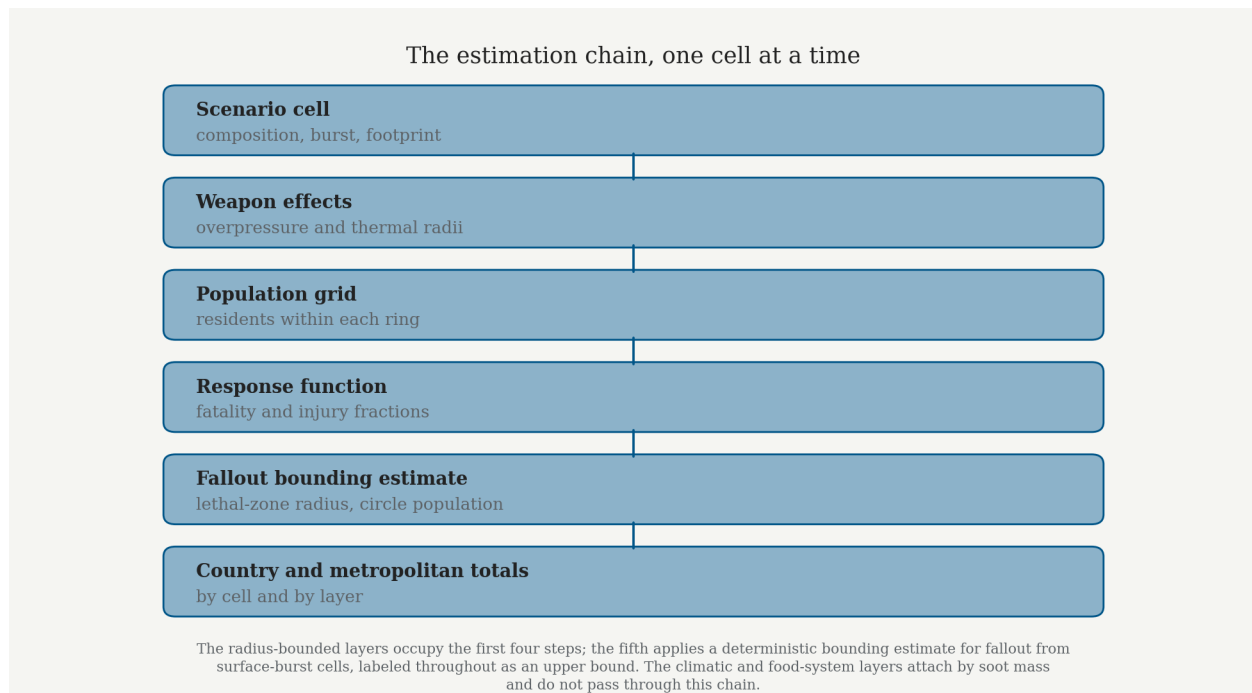


Figure 5: The estimation chain from a scenario cell to country and metropolitan totals. Boxes are steps and connectors run downward; the first four steps carry the radius-bounded layers, the fifth applies a deterministic bounding estimate for fallout from surface-burst cells (upper bound under three stated assumptions and two conditions; see Section 6.2), and the climatic and food-system layers attach by soot mass outside the chain. Source: author’s construction.

The cell supplies composition, burst condition, and footprint. Weapon effects convert yield to radii: blast radius scales as the cube root of yield, so the area within a given overpressure scales as the two-thirds power.⁶ The Global Human Settlement Layer population grid (GHS-POP), release R2023A, epoch 2025, at 100 m resolution, supplies residents within each ring at a resolution fine enough to resolve a metropolitan area. A response function converts exposure to a fatality and an injury fraction: a fraction per zone—severe, moderate, and light, the rings of the federal planning guidance for response to a nuclear detonation, whose radii Section 7 gives—applied to the residents the ring holds, with the zone radii carrying the cube-root scaling above. The fractions are calibrated against the published case in Section 8 rather than assumed, and the results span every pair of them the calibration admits.

For surface-burst cells, the chain’s fifth step is a deterministic bounding estimate under three stated assumptions described in Section 6.2. The transport-and-dose alternative—particle source term, atmospheric transport on archived analysis winds, integrated dose compared against a dose-response function, fatalities reported as a distribution over the weather of one year—has been demonstrated on public inputs and supplies the endpoint toward which the bounding estimate is an acknowledged simplification.⁷

⁶Samuel Glasstone and Philip J. Dolan, eds., *The Effects of Nuclear Weapons*, 3rd ed. (Washington, DC: U.S. Department of Defense and Energy Research and Development Administration, 1977), §§ 3.61–3.63.

⁷Sébastien Philippe and Ivan Stepanov, “Radioactive Fallout and Potential Fatalities from Nuclear Attacks on China’s New Missile Silo Fields,” *Science & Global Security* 31, nos. 1–2 (2023): 3–15.

6.1 The constructions

The steps above leave choices that move printed figures. Each is stated here once, with what it moves where that has been measured.

The population surface and its correction. The grid is GHS-POP R2023A, epoch 2025, at 100 m on the World Mollweide projection, corrected against national censuses in the countries where it disagrees with them. The audit is the same for every country holding a target: the reference is the national census by first-level unit, as the statistical office publishes it, for Japan and Korea that of 2025: Japan's census of 1 October 2025 as tabulated by its Statistics Bureau, and Korea's register-based census of 1 November 2025. The census figures are aggregated to the boundary source's units (Overture Divisions, stated below) where the two differ, and a unit that cannot be matched exactly is reported and left out of the test rather than approximated (three units of the 18 countries are). A unit's statistic is its GHS-POP count over its census count, divided by the same ratio taken over the matched national totals, so one means the grid places the unit's share of the country where the census does. A country fails when a unit holding at least 1 percent of the matched census total departs from one by more than 25 percent, and six of the 18 do: China, Iran, Japan, Pakistan, the Republic of Korea, and Turkey. The censuses the test rests on run from 2008 through 2025, and dividing by the national ratio is what makes the statistic a test of shares: a country whose units all carried the census shares would pass at any national total, so the audit does not test the level and the correction does not change it.

A failing country is corrected within itself, and its GHS-POP national total is kept, so every country stays on the grid's own totals; those totals stand at 0.986 through 1.132 times the census totals the correction reads, the higher end being Iran, a spread the years between each census and the grid's epoch produce. Its distribution is taken level by level from the source that is right at that level: the first-level unit totals from the census shares; within a unit, the one-kilometer distribution from whichever of GHS-POP and WorldPop 2020⁸ has the distribution that fits the census better at the finest level at which a census and its boundaries can be obtained, measured as the census-weighted mean of $|\log r|$ over the matched units, r being the statistic above taken within the first-level unit; and within a one-kilometer cell, the 100 m pattern from GHS-POP. The criterion selects at one kilometer, a scale no census reaches, so it is a proxy, stated here as one, measured as close to that scale as the censuses allow: Pakistan's census districts, China's prefecture-level units, Iran's counties, Japan's municipalities and Turkey's districts, and for the Republic of Korea the first level. A cell where GHS-POP holds nobody stays empty, so the correction places no resident on water or bare ground, and the residents so displaced are kept in the unit by its scaling and reported per unit. The criterion takes WorldPop 2020 within the unit in China, Iran, and Japan and GHS-POP in Pakistan, the Republic of Korea, and Turkey, Turkey's by the narrowest margin of the tests.

The choice decides more than a distribution. Measured at the first level, the criterion takes WorldPop within Pakistan's units; measured at the district, GHS-POP, which is the construction. The two are compared on the calibration theatre with the census totals held. With GHS-POP's distribution within Pakistan's units, and Pakistan's targets derived on the raster it gives, Pakistan's severe zone falls from the uncorrected grid by 3 percent at 15 kt and 4 percent at 100 kt; with WorldPop's, and the targets derived on its raster, by 46 and 40 percent. Calibrated on its own 394 admissible pairs (the pairs of zone fractions that meet every published total within 5 percent, as the

⁸WorldPop, *Global 1km Age/Sex Structures* (Southampton: University of Southampton, 2018), <https://doi.org/10.5258/SOTON/WP00654>; the age-sex rasters summed over their bands.

calibration grid below states), the WorldPop reading puts India at 1.16, 1.02, and 1.00 of its published figure and Pakistan at 0.74, 0.82, and 0.94, India above Pakistan at every yield, where the construction puts Pakistan above India at every yield (Section 8). The distribution within the units carries most of the difference and the targets it selects the rest: with GHS-POP's distribution and Pakistan's targets held at those derived on WorldPop's raster, the fall is 10 and 7 percent, so the within-unit source alone accounts for 79, 80, and 82 percent of the fall WorldPop's gives at 15, 50, and 100 kt, and on that reading's own 201 pairs India runs at 1.05, 0.93, and 0.92 and Pakistan at 1.01, 1.05, and 1.15, India above Pakistan at 15 kt and below it at the two higher yields. The sign of the country split at 50 and 100 kt therefore follows the within-unit source, which the census tests only down to its finest level; at 15 kt, where the construction puts the two countries 0.01 apart (the gap taken, here and below, between the unrounded ratios), it follows the targets as well.

The target derivation. Targets are derived from the corrected grid, not from a gazetteer. The 100 m grid is summed in blocks of 10 by 10 cells into a 1,000 m search grid aligned to its origin, each block's value the exact sum of its cells with no-data counting as zero. A search cell belongs to a country when its center lies inside one of that country's level-zero polygon parts in the boundary source, a part being kept when its bounding box covers at least 10,000 km²; cells outside carry no residents for the ranking, so a place near a border is ranked on the residents of its own side. A cell's score is the sum of the country's masked search cells whose centers lie within 3 km of its center, the cell included. The country's candidates are its masked cells with a positive score, taken in descending score with ties going to the lower global search row and then column, each taken only where its center lies at least 12 km from every candidate already taken, until 250 are taken. The target point is the center of the cell taken and its ranking figure is that cell's score. Because only positively scored cells are candidates, no coordinate on which nothing was scored can enter a list.

The distance metric. Every distance in the direct layer—the scoring disc, the minimum separation, the confinement, the zone radii, and the assignment of cells to aimpoints—is a distance on the World Geodetic System 1984 (WGS84) ellipsoid, computed by Vincenty's inverse formula and bracketed first by chord bounds, so that a pair whose bounds settle it is not resolved by the series. The grid is equal-area and not equidistant, and at the calibration theatre's targets a disc drawn on it is an ellipse on the ground of axis ratio up to 1.587, which a distance on the ellipsoid does not carry.

The placement rule and what it decides. A weapon detonates within 5 km of its target. Its aimpoint is the cell of the 100 m grid whose center lies within that confinement of the target point and which holds the most residents within the severe radius, searched exhaustively over the candidate cells, every cell in the confinement a candidate whether or not it holds residents; the objective carries no fitted fraction, so the placement does not depend on the fractions the calibration chooses; it does rest on the severe radius, the zone whose fraction the calibration holds at one rather than fitting. The aimpoint's own cell is counted in the severe zone, as it is in the fallout layer. The three zones are exclusive shells and not nested discs—a cell is severe where its distance is at most the severe radius, moderate where it exceeds that and is at most the moderate radius, light where it exceeds that and is at most the light radius—so each fraction applies to residents counted once. Where several weapons fall on one place, the search reaches the city scale, 15 km of the target point, rather than the confinement, and each weapon is placed in turn by the marginal residents it adds;

no neighboring place's weapons enter its search. Measured against the confinement applied to every weapon, on the rows of 300+300 weapons between Russia and the United States, the city scale moves 90 of the 200 aimpoints of places given two weapons at 100 kt and lowers the central fatalities (the median over the admissible pairs) of the Russian side by 11.7 percent and of the United States side by 11.3; at 1 Mt it moves 127 of 200 and lowers them by 6.5 and 7.3 percent. At five and ten weapons on each of the European rows' places at 100 kt it raises them instead, by 27.2 and 47.1 percent (Section 8.4).

The alternative reading of "within 5 km"—each weapon on its target, with no search—is the literal reading of the sentence, and it is carried as a sensitivity rather than left implicit. On the calibration theatre it widens the admissible set from 156 pairs to 661, and India's 100 kt interval from 85.9–90.3 to 87.3–96.6 million. The interval of Table 5 is therefore narrower than the one an unstated placement rule would leave, and the difference is the width the rule decides.

The rule decides more than a width. Under the alternative Pakistan falls at every yield and India rises at the two higher: India runs at 1.03, 0.96, and 0.95 of its published figure against 1.03, 0.93, and 0.91 as built, Pakistan at 0.97, 1.03, and 1.12 against 1.04, 1.06, and 1.15, and the gap between them goes from 0.01, 0.13, and 0.24 to 0.06, 0.07, and 0.17, India above Pakistan at 15 kt and below it at 50 and 100 kt. The alternative agrees with the published split better at the two higher yields; the placement of record was not chosen on its agreement with the split.

The confinement is measured the same way. Each target's residents are read from its window, a square of the grid centered on the target. Released to the largest radius the windows admit at each yield—21.9, 19.2, and 17.0 km at 15, 50, and 100 kt, beyond which an aimpoint's light ring would leave its window—the search moves 62, 50, and 46 aimpoints onto cores that neighboring targets already hold, where the assignment to the nearest aimpoint counts the overlap once. Recalibrated on its own 420 pairs, Pakistan runs at 0.96, 1.05, and 1.11 of its published figure and India at 1.06, 0.95, and 0.92, so the gap between them narrows at 50 and 100 kt, to 0.09 and 0.19, and at 15 kt reverses, to 0.11 with India above. The confinement does not produce the split the study reports.

The assignment and the calibration grid. Every populated cell is assigned to the nearest aimpoint across the whole struck set rather than within its own window, and ties break to the lowest aimpoint index, the aimpoints indexed in the order of the targets they belong to. Each side's strike is its own set, so a cell near a border can fall within the zones of an aimpoint on each side and be counted under each. It does not happen in this library: on every row that strikes two sides, no aimpoint of one struck side lies within twice the light radius of an aimpoint of the other, at any yield run, so no cell falls in both. The country mask of the derivation governs the ranking alone: neither the placement objective nor the zone count is masked, and a cell counts toward the strike whose aimpoint is nearest it whichever country it lies in. The response function is calibrated by searching a grid of fraction pairs: the moderate fraction on steps of 0.004 from zero through 1, the light on steps of 0.002 from zero through 0.2, with the severe fraction held at one. A pair is admissible when the chain's total is within 5 percent of the published total at each of 15, 50, and 100 kt. The count of 156 admissible pairs is a property of that grid as much as of the zone counts: halving both steps gives 581 pairs spanning 0.392 through 0.576 on the moderate zone and zero through 0.046 on the light, so the count scales with the grid, and the span of the fractions is the same at the precision printed.

The boundary source. Level-zero and level-one units are Overture Maps Foundation Divisions, release 2026-08-19.0,⁹ throughout—the country mask of the derivation, the attribution of Section 10, and the fallout attribution of Section 9—so no two stages of the chain read different borders. A grid cell belongs to one unit only, the first in the source’s order whose rasterized polygon holds it (the first-wins rule), the units lying wholly inside another unit of their country being excluded.

6.2 The fallout bounding estimate

Three stated overstatements each raise the count; under the two conditions stated at the close of this subsection, their product bounds the result from above. The bound is not added to the direct-layer count, since the populations it describes overlap with those inside the blast zones of the same detonations.

For a surface burst of yield W kilotons, $L(W)$ is the downwind distance at which the dose accumulated in the week after the fallout arrives reaches 450 centigray (cGy), the dose the Office of Technology Assessment gives as fatal to half of those exposed within a week, the median lethal dose (LD50).¹⁰ It is computed by Glasstone and Dolan’s own procedure.¹¹ The unit-time reference dose rate R_1 on the downwind axis is read from their idealized contours for a contact surface burst in an effective wind of 15 miles per hour (mph), whose downwind distances scale as $W^{9/20}$, and is interpolated between contours linearly in the logarithms of rate and distance; the fallout arrives at the distance over the wind speed, τ hours after the burst; and the week’s dose is

$$D = 5 R_1 \left[1/\tau^{1/5} - 1/(\tau + 168)^{1/5} \right] \text{ cGy}, \quad (1)$$

$L(W)$ being the distance at which D reaches 450. The reach is 36.2 km at 15 kt, 73.3 km at 100 kt, and 169.2 km at 1 Mt.

The bound rests on three overstatements. The first is the dose: every kiloton is treated as fission, where the source scales the dose rates by the weapon’s fission fraction; the ground is the smooth reference surface, where the source reduces the dose by a factor of about 0.7 over level ground; and nobody is sheltered. Each lengthens the reach.

The second is geometry: all population within a circle of radius $L(W)$ around each aimpoint is counted, not only the population under the plume. The source’s idealized pattern at the 450-cGy dose, a body of the reach’s length and the pattern’s greatest width with a semicircle upwind, covers between one part in 61 and one part in 27 of the circle’s area across the yields the layer uses, the smaller share at the smaller yields. That is an area reading, and it carries to population only where population is spread evenly over the circle. It is not: the aimpoints are population centers, so the circle is centered on the densest ground it holds, and on the radial profile of the calibration theatre’s own aimpoints 46 percent of the population inside the 36.2 km contour lies within ten kilometers of an aimpoint, where the area share is 8 percent. Population within the pattern’s upwind semicircle, about 0.8 km of the aimpoint at 15 kt and 4.5 km at 1 Mt, is under the pattern whichever way the wind sets, and the pattern is widest near the aimpoint, so the overstatement in people is smaller

⁹Overture Maps Foundation, *Divisions*, release 2026-08-19.0, Open Database License, <https://docs.overturemaps.org>.

¹⁰U.S. Congress, Office of Technology Assessment, *The Effects of Nuclear War*, OTA-NS-89 (Washington, DC: U.S. Government Printing Office, 1979), chap. 2, for the dose received within a short time, and p. 126 for the same dose received over one week.

¹¹Glasstone and Dolan, *Effects of Nuclear Weapons*, table 9.93, eq. 9.150.1, and the worked example that follows § 9.98.

than the overstatement in area. The third is mortality: one hundred percent of the population within the circle is treated as fatally exposed, where the dose inside the contour is above the median lethal dose and the share who would die is above one half, an overstatement of at most a factor of two. On the area reading the second and third together place actual fallout fatalities below the bound by a factor of between 27 and 122, by less than that to the extent population concentrates at the aimpoint, and by more for the first. The bound holds on three conditions: the wind the relation assumes; an exposed population near the aimpoints; and, where several weapons fall on one place, each weapon's contour counted on its own, the doses of separate weapons not being summed. Where a sustained wind carries the plume past $L(W)$ to population beyond it, the bound can fall below the fatalities, and against two published transport cases it did so for one at the chain's convention of one warhead each, and for the other's worst day without shelter (Section 9.1).

Two qualifications govern which cells produce a fallout figure. The bound requires aimpoints that match the population centers the derived targets mark: cells in the general-release and countervalue use modes meet this condition; cells in the counterforce and battlefield modes do not, because their aimpoints are remote facilities and fielded forces rather than population centers. The bound also requires a burst that puts fission products on the ground, since it rests on a surface burst's fallout: it is computed for a theatre whose library holds a general-release or countervalue cell with a surface or near-surface burst, which seven of the nine theatres run do, and not for a theatre whose countervalue cells burst in the air alone. In a theatre it admits, every weapon of every row is then treated as a surface burst at the row's aimpoints, including the rows whose composition is taken from a cell that bursts in the air, as the calibration theatre's rows are. The contour is read from the population grid itself in disjoint tiles, on the ground distance the direct layer uses, so no window bounds it; the windows the direct layer reads, whose half-widths run from 30.05 through 79.05 km across the five target sets (the South Asian, East Asian, Middle Eastern, and Russian and United States sets derived from the grid, and the European set drawn from a gazetteer), supply its aimpoints and nothing else, while L is already 56.7 km at 50 kt.

Two properties of the chain bear on how its results are read. The fallout bounding estimate does not vary with the weather, holding one wind, the effective wind of the relation; actual fallout from any surface burst varies with it, so the estimate does not carry the weather uncertainty the transport-and-dose chain would produce. And the population grid carries residents at their place of residence rather than occupants at their place of activity, so a detonation over a district whose daytime population differs from its resident population is estimated against a denominator that is too small in a commercial center by day and too large in a residential district by day. The cells do not carry a time of day, so the direction is not determined within a cell, and no correction is applied.

7 A worked cell

The single-weapon cell is worked here because it is the only single-weapon rung for which a published casualty range exists against a stated composition, so the chain can be run and its output compared.

The published zone geometry gives outer radii at a 10 kt reference of one half, one, and three miles for severe, moderate, and light damage.¹² At 1 Mt the cube-root relation scales each by 4.6416, giving the radii and areas of Table 4. Fatality fractions of 0.900, 0.439, and 0.0104 are applied by

¹²Federal Emergency Management Agency, *Planning Guidance for Response to a Nuclear Detonation*, 3rd ed. (Washington, DC: Federal Emergency Management Agency, 2022).

zone. They are the Office of Technology Assessment's response to overpressure, 98, 50, and 5 percent killed over 12 pounds per square inch (psi) of overpressure, from 5 to 12 psi, and from 2 to 5 psi, and none from 1 to 2 psi,¹³ averaged over the area of each zone on that source's own 1 Mt air burst. The zones are drawn by radius and the source's bands by overpressure, so a band's fraction does not carry to a zone unchanged; the 12 and 2 psi distances are interpolated between those the source tabulates, in the logarithms of distance and overpressure, and interpolated linearly instead they give 0.980, 0.474, and 0.0160.

Table 4: Zone geometry and weighted area at 1 Mt: the planning guidance's near-surface zones scaled by the cube root, with the response fractions of an air burst

Zone	Outer radius (km)	Area (km ²)	Fatality fraction	Weighted area (km ²)
Severe	3.73	43.8	0.900	39.4
Moderate	7.47	131.5	0.439	57.7
Light	22.41	1,402.4	0.0104	14.6
Total	–	1,577.7	–	111.7

The weighted area is 111.7 km². The published case reports 220,000 through 2,500,000 dead, a spread of 11.4 times. That range spans the case's variants as well as its conditions: the attacks it covers are a 1 Mt weapon on Detroit and on Leningrad, a 25 Mt weapon on Detroit, a 9 Mt weapon on Leningrad, and ten 40 kt weapons on Leningrad, and the source attributes the variation to the details of the attack and to conditions it names: time of day, time of year, weather, weapon size, height of burst, and the preparation of the population. Its own calculations hold the conditions fixed, at night, with no warning, in clear weather, so the range runs across the cities, the yields, and the burst type, and its lower end is the 1 Mt surface burst on Detroit.¹⁴ Dividing the range by the unrounded weighted area of the 1 Mt geometry gives implied uniform population densities of 1,969 through 22,371 residents per km² (1,724 through 19,588 on the linear interpolation). Those bracket the city-proper densities of the two cities the published case was drawn from, each population on its city's land area: 3,426 per km² for Detroit in 1980 and 7,954 for Leningrad in 1979, the latter on the land area stated in 1973, the nearest official statement found.¹⁵ The comparison is therefore an order-of-magnitude check on the geometry and the response fractions, not a reproduction of the published case: the endpoints belong to different cities, yields, and burst types, and the weighted area is the 1 Mt air burst's throughout.

The exercise establishes the chain's arithmetic and nothing more. A uniform density is not a population product: it understates casualties where the detonation is over a dense core and overstates them where it is not, and the error does not average out, because the weighting is by area within rings that are themselves centered on the densest point of the target. Replacing the uniform

¹³Office of Technology Assessment, *Effects of Nuclear War*, chap. 2, fig. 1 and table 3.

¹⁴Office of Technology Assessment, *Effects of Nuclear War*, summary of case 1.

¹⁵U.S. Bureau of the Census, *1980 Census of Population*, vol. 1, *Characteristics of the Population*, chap. A, *Number of Inhabitants*, pt. 1, *United States Summary*, PC80-1-A1 (Washington, DC: U.S. Government Printing Office, 1983), table 25; "Vsesoiuznaia perepis' naseleniia 1979 g.: Chislennost' gorodskogo naseleniia RSFSR, ee territorial'nykh edinit, gorodskikh poselenii i gorodskikh raionov po polu" [All-Union Census of Population of 1979: Urban population of the RSFSR by territorial unit, urban settlement, and urban district, by sex], *Demoskop Weekly*, accessed 29 September 2026, https://www.demoscope.ru/weekly/ssp/rus79_reg2.php, from the Russian State Archive of the Economy, f. 1562, op. 336, d. 5943–5951, table 1c, the city proper; *Bol'shaia sovetskaia entsiklopediia* [Great Soviet Encyclopedia], 3rd ed., vol. 14 (Moscow: Sovetskaia entsiklopediia, 1973), s.v. "Leningrad," the city proper less its inner waters.

density with the gridded product is what turns this arithmetic into an estimate, and it is the next step rather than a refinement of this one.

8 Results across nine theatres

The chain of Section 6 has been run on nine theatres. The South Asian theatre carries a published case¹⁶ and serves as the calibration, its country split as a check; the remaining eight theatres are extrapolations of the response function calibrated there, and they are labeled as such. The additional theatres are reported in Section 8.1; the chain is set against two further published cases in Sections 8.2 and 8.3, and the library's countervalue cells are run at their published compositions in Section 8.4; and two cases outside the library close the section, one constructed on the reach of Russia's missiles based in Kaliningrad (Section 8.5) and one on the capitals of the alliance's European members (Section 8.6), each with the value it destroys beside its fatalities.

Targets are derived from the population grid rather than from a gazetteer, by the derivation of Section 6.1. The gazetteer stops at 100,000 residents and supplied 35 Pakistani places against the 250 the published case uses; deriving them from the grid under a boundary mask removes that floor and yields 500 targets, none of which falls outside its own country.

The confinement and the assignment each change the count. Without the first, a weapon assigned to a small target beside a large city relocates into the city. Without the second, residents between two nearby targets are counted twice: at 100 kt that reached 14.2 percent of the Indian count and 30.1 percent of the Pakistani, against 1.2 and 4.0 percent at 15 kt, since 65 pairs of aimpoints lie closer than twice the outer radius at the higher yield.

The response function is calibrated against the published case rather than assumed. Within 5 percent of every published total there are 156 admissible pairs of zone fractions, spanning 0.392 through 0.576 on the moderate zone and 0.000 through 0.046 on the light, with the severe zone held at one. Two responses not used in the calibration come near it. The Office of Technology Assessment's response to overpressure, averaged over the zones on its own air burst (Section 7; the published case's weapons are air bursts too), gives the moderate zone 0.439 and the light 0.0104, each within its range on either interpolation, but not a pair of the set: with its severe fraction of 0.900, the calibration theatre's totals fall to 0.911, 0.851, and 0.863 of the published. The response that the second published case applies (Section 8.2) brackets the published totals at every yield under the two readings its table of rates admits: 0.925 through 0.983 under one and 1.094 through 1.130 under the other. Its rates for blast, mass fire, and burns are taken over the zones through the overpressure of a near-surface burst, at the heights that case states. Injuries take 0.210 of the moderate zone's survivors and 0.090 of the light zone's. The admissible set is fixed on the published fatality totals alone, so the injuries are an output of those held fractions rather than a fitted quantity: against the published casualties less their fatalities, they run 34 through 49 percent below.

The source also states its response in distance rather than in zones. Its supplement draws the probability of fatality and of any casualty against distance from ground zero at 15 and 100 kt, Gaussians fitted to Hiroshima and Nagasaki whose widths scale with the square root of yield; at 50 kt that rule applies, and the 100 kt curve scaled down to 50 kt gives the same figures as the 15 kt curve scaled up. Read from the figure's drawing and applied to this construction's aimpoints and residents, the fatality curve gives 1.05, 1.21, and 1.33 of the published totals at 15, 50, and 100 kt, above

¹⁶Toon et al., "Rapidly Expanding Nuclear Arsenals."

at every yield and by more as yield rises, and the casualty curve 1.20, 1.32, and 1.38 of the published casualties. Averaged over the zones, with this construction's residents as weights, the fatality curve takes 0.51, 0.61, and 0.68 of the moderate zone, above the admissible range at 50 and 100 kt, and 0.05, 0.11, and 0.17 of the light zone, above the admissible range at every yield. The calibrated set thus holds the light zone, and at the two higher yields the moderate, below the source's own curve, and that is how it meets published totals which the curve, on this construction, exceeds.

The source does not publish its targets, but it states the rule that chose them: each cell of its population data scored by the residents within a few kilometers of it, the most populous such regions taken in turn with no two overlapping, the search radius scaled with yield. Rebuilt by that rule on the data it names, LandScan 2016,¹⁷ and summed through its curve, the scenario's targets give fatalities 4 through 8 percent above the published totals at the three yields, and at 15 kt 149 of India's first 250 ranks and 161 of Pakistan's lie within 10 percent of the source's per-target figures, read from the markers of its supplement's second figure. Of the rebuilt targets the scenario strikes, 147 of India's 150 and 99 of Pakistan's 100 lie within 12 km of one of this study's places, at a median distance of 3.8 and 3.7 km. The targets are the same cities, but a median offset of that size is not small against the zones' radii, so the difference between the source's curve on this construction and the source's own figures is not separated among the targets, the population surface, and the construction, which this study adopts. Table 5 reports the resulting fatalities as the interval spanned by that set, and the injuries at its median, each country's injuries taken over the pairs on their own; the injury fractions apply to the survivors of each zone, the residents the fatality fraction leaves. Each column spans the set on its own: its ends are the least and the greatest value that country's fatalities take over the 156 pairs, and the two columns' ends need not fall on one pair, since the two countries weight the moderate zone against the light differently. Adding the columns' upper ends therefore does not give the greatest total the set admits, and at 15 kt it exceeds it, 54.8 million against 54.5, the greatest total the admissible set gives.

Table 5: Direct-layer fatalities and injuries, in millions, by country

Cell	Yield (kt)	India, fatalities	India, injuries	Pakistan, fatalities	Pakistan, injuries
NX-T01-06	15	36.2–37.8	14.9	16.4–17.0	5.7
NX-T01-07	50	65.0–67.4	19.7	27.1–28.1	6.9
NX-T01-08	100	85.9–90.3	21.3	34.9–36.8	7.4

8.1 The eight additional theatres

Table 6 extends the South Asian results to the eight additional theatres estimated, every row under the construction of the calibration theatre, with the departure stated below for a place given more than one weapon: one weapon per target on the struck country's most populous derived targets, each aimpoint within five kilometers of its target, every populated cell assigned to the nearest aimpoint across the whole struck set, and the admissible fraction set of Table 5 applied unchanged. Two of the additional rows, the two ends of one cell's weapon band, take their composition from a cell of the library, and the rest are constructed at the weapon counts the table states, as recorded below; the theatre code places each row in Table 1. Two departures from the calibration theatre's inputs are stated here. The European targets are the thirty most populous cities of Russia and of

¹⁷Edward Bright et al., *LandScan Global 2016* (Oak Ridge, Tennessee: Oak Ridge National Laboratory, 2017), <https://doi.org/10.48690/1524211>.

the NATO members from a gazetteer, the form in which the published case for that theatre states its countervalue rung, while every other target set is derived from the grid. And where a side's weapons exceed the derived targets listed for the struck country, as with 300 weapons on 250 places, the surplus takes the most populous places a second time, searched within the city scale; no place takes more than two weapons. No target of any set is set aside as a coordinate defect. The derivation of Section 6.1 takes a country's candidates from its masked search cells with a positive score, so a coordinate on which nothing was scored cannot enter a list; none of the 2,429 places of the five target sets has an empty window. The response function is extrapolated beyond its calibration theatre; the direction of that extrapolation error is established against two published cases, in the Middle Eastern theatre, where the chain runs below (Section 8.2), and on French and British cities at 15 kt, where it runs above (Section 8.3); the European countervalue rung, whose yield its source does not state, lies within the span the chain gives across the yields tested (Section 8.4); and both the calibration gap and the extrapolation caveat are stated on the face of the table. One cell of the library is run at its own stated composition: NX-T12-01, third-party entry in South Asia, places between two and ten weapons of 10 kt on India, and the two ends of that weapon band are the T12 rows, on the calibration theatre's own Indian target set. The cell's mode is battlefield use; its composition is run here on countervalue aimpoints, which is what admits its rows to the fall-out bound of Section 9. The library's other countervalue cells with a published composition put several weapons on each city, between five and ten per city in the European case; they are run at those compositions beside the table, against their sources, in Section 8.4, and the constructed rows keep their own. Two further limits of the extrapolation are stated. The rows at 1 Mt apply fractions calibrated at 15 through 100 kt to zones whose radii are 2.15 times larger, an extrapolation in yield as well as in theatre. And the per-weapon toll of the 300+300 rows is below that of the 30+30 rows at each yield: the larger force reaches places further down each side's ranking, and where a place takes a second weapon it is placed within the city scale, 15 km, of a target whose first weapon's light zone spans 22.4 km at 1 Mt. The rows read as the toll of the places struck rather than of the weapons counted.

Table 6: Direct-layer fatalities and injuries, in millions, across nine theatres. Theatre is the code of Table 1; Struck names the countries whose targets are hit, in the order of the Weapons column, which gives each side's weapons. Fatalities span the 156 admissible fraction pairs calibrated on the South Asian case and injuries are at the set's median, an interval whose ends agree at the displayed precision printing as one value. The admissible set is fixed on the published fatality totals alone, so the injury column is an output of held fractions rather than a calibrated quantity and falls below the published figures; calib. marks the calibration theatre and extra. an extrapolation of its response function. Sources: GHS-POP, release R2023A, epoch 2025; author's calculations.

Theatre	Struck	Weapons	Yield (kt)	Fatalities (m)	Injuries (m)	Basis
T01	India; Pakistan	150+100	15	52.6–54.5	20.5	calib.
T01	India; Pakistan	150+100	50	92.2–95.6	26.6	calib.
T01	India; Pakistan	150+100	100	120.8–127.1	28.7	calib.
T06	Russia; NATO members	30+30	100	13.6–15.0	6.8	extra.
T07	Russia; United States	30+30	100	13.8–14.4	5.2	extra.
T07	Russia; United States	30+30	1000	36.5–39.0	6.8	extra.
T07	Russia; United States	300+300	100	54.1–55.8	13.9	extra.
T07	Russia; United States	300+300	1000	118.4–125.9	16.0	extra.
T02	India; China	30+30	15	23.7–26.0	11.6	extra.
T02	India; China	30+30	100	60.3–62.4	20.1	extra.
T05	United States; China	30+30	100	34.1–35.3	12.3	extra.
T05	United States; China	30+30	1000	89.6–94.5	17.5	extra.
T09	Russia; China	30+30	100	35.7–36.9	12.3	extra.
T09	Russia; China	30+30	1000	91.0–96.7	16.0	extra.
T03	DPRK; Republic of Korea	26+16	15	6.2–6.3	1.9	extra.
T03	DPRK; Republic of Korea	26+16	100	12.1–12.5	2.9	extra.
T03	Japan	16	100	5.6–5.9	2.7	extra.
T10	Israel	20	15	1.4	0.4	extra.
T10	Israel	20	100	3.0–3.2	0.7	extra.
T10	Iran	20	15	1.6–1.9	1.1	extra.
T10	Iran	20	100	4.9–5.1	1.9	extra.
T12	India	2	10	1.6–1.8	0.8	extra.
T12	India	10	10	5.1–5.7	2.7	extra.

The Middle East rows illustrate a point that applies to every asymmetric theatre in the table: the same weapon count striking two different countries gives different casualty figures because it strikes different population distributions, not because either side is more or less vulnerable in any strategic sense. Twenty weapons on Iran give 1.2 times the central fatalities of twenty weapons on Israel at 15 kt and 1.6 times at 100 kt, which follows from the residents within the zones of Iran's twenty most populous derived targets exceeding those within Israel's. The ratio is a property of the two countries' urban geography as this chain measures it, not a finding about either country's vulnerability, and it is not comparable across theatres without accounting for the underlying population distributions each theatre's targets draw on.

Three properties of these numbers govern how they may be read.

The first property is that the totals are fitted to the published case and the country split is not, and does not agree with it. Figure 6 shows the ratio of chain to published for each country at each yield. The totals lie within five percent throughout, as the admissible set requires, but Pakistan runs above its published figure at every yield and India below it at the two higher: India 1.03 and Pakistan 1.04 at 15 kt, India 0.91 and Pakistan 1.15 at 100 kt, so the two countries diverge from the published split as yield rises. Three constructions bear on the divergence. The first counts once a resident within the rings of two neighboring targets; it moves the levels and leaves the split in place. The population correction of Section 6.1 is the second: it leaves India, which passes the census audit, unchanged to the resident, and with the within-unit source of record it lowers Pakistan's severe zone by 3 percent at 15 kt and 4 percent at 100 kt. The split turns on the within-unit source: with WorldPop's inside Pakistan's units the fall is 46 and 40 percent and India runs above Pakistan at every yield, 1.16 and 0.74 at 15 kt and 1.00 and 0.94 at 100 kt, and GHS-POP's was selected on the census test at district level (Section 6.1). The depth of the ranking is the third: spreading each country's weapons evenly over its 250 ranked places rather than its most populous ones moves the India-to-Pakistan ratio to 2.73, 3.03, and 3.14 at 15, 50, and 100 kt against the published 2.25, 2.73, and 3.10, further from the published one at 15 kt and nearer at the two higher yields, but under it no pair of fractions meets the published totals. The source's targets, rebuilt from its stated rule, lie within a few kilometers of this study's, as stated above; the remaining divergence is not separated among the targets' placement within that offset, the population surface below the census's finest level, and the construction, which nothing in hand tests further.

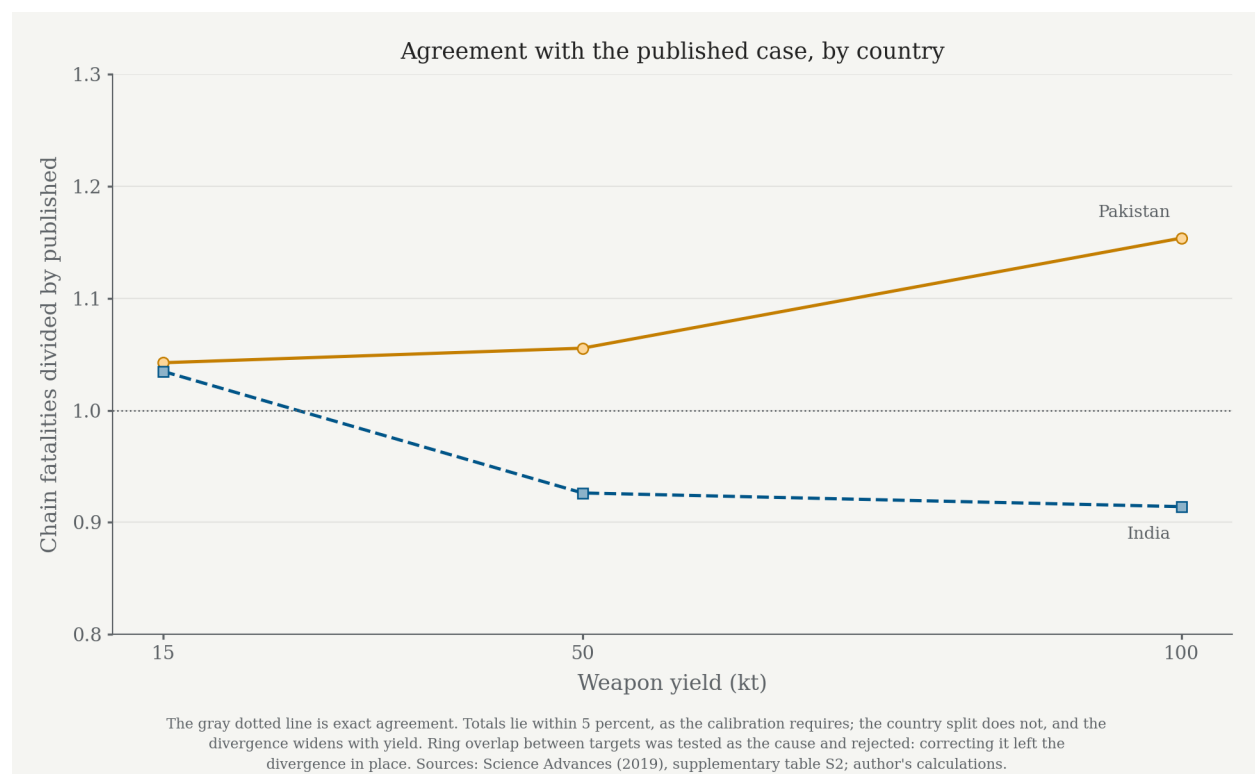


Figure 6: Chain fatalities divided by the published figure, by country, at three yields. Markers are the two countries in their assigned hues; the dashed line is exact agreement. Sources: Science Advances (2019), supplementary table S2; author's calculations.

The second property is that the interval in Table 5 is narrower than the uncertainty it represents. Spanning the admissible set gives a width of up to about 5 percent, conditional on the geometry being correct. The response function has also been calibrated, on the same three published totals, on three other geometries of the zones: aimpoints unconfined with each target's window counted on its own, aimpoints confined within five kilometers with the windows counted apart, and cells assigned to the nearest aimpoint across the windows. Read on the present zone counts, the three calibrations give totals spanning a factor of 1.22 through 1.24, which measures how far the totals move with the geometry of the zones and which the admissible interval, conditional on one geometry, does not carry.

The third property is that the indirect layer for these cells is unchanged by any of the above, since it is taken from the published soot ladder of Section 5 and not from the chain's direct counts.

8.2 A second published case

A second published case states both its compositions and its fatalities city by city: a study of an exchange between Israel and Iran¹⁸ whose table of results gives, for twenty-one cities in twenty-seven cases, the weapons, their yield, and the fatalities its model counts. The chain is run on each case as it runs on a theatre, and nothing in it is fitted to the source. Each city is mapped to the nearest place of the Middle Eastern derived targets, every city lying within 7.4 km of one; the city's weapons are placed on that place by the construction of record, one weapon confined and several searched within the city scale; the residents are counted on the windows of the Middle East rows of Table 6, re-clipped from the population grid to a reach of 32.8 km so that the city scale holds at the largest yield the source uses (the reach of the windows of record is 27.4 km, and on every place the wider window agrees with the narrower one cell for cell); and fatalities are taken over the 156 admissible pairs calibrated on the South Asian case. One case, Ahvaz, places two weapons of different yields, a composition the counting does not take, and is printed without a chain figure.

Table 7 sets out the comparison. The chain's median lies below the source in twenty-five of the twenty-six cases run, and so does the upper end of the admissible range in twenty-five; the one case above is Tel Aviv's two weapons of 15 kt. The ratio of the chain's median to the source's fatalities has a median of 0.520 over the twenty-three Iranian cases, spanning 0.208 through 0.916, and of 0.923 over the three Israeli cases, spanning 0.536 through 1.092. Summed over the cases run, the chain's fatalities are 0.569 of the source's.

The comparison is between two models rather than between a model and an observation, and what it establishes is a direction, not a calibration: in the Middle Eastern theatre, the response function calibrated in South Asia runs below this source, by about half on Iranian cities and by little on Israeli ones. It does not separate the causes. The source counts thermal burns, mass fire, and fallout among its fatalities, which the three zones reach only through the calibrated fractions, and it bursts its weapons at heights it states. Its population is LandScan 2007, an ambient surface averaged over the day, which the source describes as daytime population, against this study's 2025 residential grid: where a city has grown since 2007 the later grid moves the chain up against the source, and an ambient surface's weighting of city cores by day moves the source up against the chain, and nothing in the comparison separates either from the response function. Nor does it separate the mapping, which takes each city to the nearest core of the population grid rather than to the city's named point. The direction stands for this theatre and this source. For the Russian

¹⁸Cham E. Dallas et al., "Nuclear War between Israel and Iran: Lethality beyond the Pale," *Conflict and Health* 7, no. 1 (2013): 10.

and United States cities of the other theatres no published case in hand states fatalities city by city, and there the direction is not established.

Table 7: The chain against the second published case, city by city. Source fatalities are the source's table of results as it prints them; the chain's median and admissible range are taken over the 156 admissible fraction pairs of Table 5, and the ratio is the chain's median over the source's fatalities. Ahvaz's two weapons are of different yields. Sources: Conflict and Health (2013), table 4; GHS-POP, release R2023A, epoch 2025; author's calculations.

City	Country	Weapons $\times$ yield (kt)	Source fatalities	Chain fatalities		Ratio
				Median	Admissible range	
Beer Sheva	Israel	1×15	105,510	56,598	55,781–58,343	0.536
Haifa	Israel	1×15	69,420	64,062	62,900–65,306	0.923
Tel Aviv	Israel	2×15	229,330	250,445	243,479–254,722	1.092
Arak	Iran	1×250	387,600	170,253	163,410–177,030	0.439
Ardabil	Iran	1×500	428,120	350,959	328,727–367,062	0.820
Hamadan	Iran	1×250	362,400	245,149	236,028–254,582	0.676
Karaj	Iran	1×15	157,960	64,950	60,905–71,575	0.411
Karaj	Iran	1×50	325,860	130,852	122,621–144,197	0.402
Karaj	Iran	1×100	508,030	194,805	183,397–212,595	0.383
Karaj	Iran	1×250	744,100	333,167	314,172–363,360	0.448
Karaj	Iran	1×500	891,190	517,165	493,919–545,664	0.580
Kerman	Iran	1×500	510,850	220,662	207,659–231,604	0.432
Qazvin	Iran	1×100	423,200	88,096	86,429–89,903	0.208
Rasht	Iran	1×500	482,940	221,061	216,660–224,984	0.458
Reza Iyeh	Iran	1×500	545,450	288,231	277,433–300,347	0.528
Yazd	Iran	1×250	326,610	193,282	189,409–200,393	0.592
Zahedan	Iran	1×500	578,950	530,409	487,533–559,001	0.916
Ahvaz	Iran	500 and 250	852,140	not run: the weapons differ in yield		
Bandar Abbas	Iran	3×100	438,240	199,315	188,958–207,245	0.455
Esfahan	Iran	2×500	1,510,050	590,489	580,146–605,224	0.391
Kermanshah	Iran	3×250	718,480	507,084	480,342–526,347	0.706
Mashad	Iran	3×500	2,178,020	1,668,737	1,576,381–1,741,901	0.766
Shiraz	Iran	2×500	1,037,170	518,435	503,662–536,259	0.500
Tabriz	Iran	2×500	1,220,250	864,033	815,870–904,163	0.708
Tehran	Iran	5×100	3,615,350	1,878,265	1,827,566–1,909,197	0.520
Tehran	Iran	5×250	5,594,200	2,967,029	2,867,011–3,084,186	0.530
Tehran	Iran	5×500	7,127,800	4,252,749	3,989,230–4,459,117	0.597

8.3 A third published case

A third published case states a composition and its fatalities for France and for the United Kingdom: fifty weapons of 15 kt, air burst, on each country's most densely populated places, a target being the cell with the most residents within 3 km and the targets lying at least 6 km apart, on LandScan's ambient population of 2003.¹⁹ The chain is run on that composition with nothing fitted to the source. The targets are derived from the population grid by the rule of Section 6.1 at the source's

¹⁹O. B. Toon et al., "Atmospheric Effects and Societal Consequences of Regional Scale Nuclear Conflicts and Acts of Individual Nuclear Terrorism," *Atmospheric Chemistry and Physics* 7 (2007): 1973–2002, tables 4, 6 and 7.

separation of 6 km and, beside it, at the derivation's own 12 km, fifty places in each country. Each place takes one weapon, placed by the construction of record or, as a sensitivity, at the target's own cell, and fatalities are taken over the admissible pairs each placement calibrates, 156 and 661. Every resident within the zones is counted whatever country holds the cell, as the source counts; the share on cells outside the struck country is at most 0.20 percent. One level below the census test of Section 6.1, against France's departments and the United Kingdom's regions and county and unitary authorities, the grid's shares pass the same test, the units farthest from one being Paris at 1.0903 and London at 1.0920.

Table 8 sets out the comparison. On the source's composition the chain's median lies above the source, by 9.5 percent for France and 6.1 percent for the United Kingdom, and so does the lower end of the admissible range for both. At the derivation's separation the chain lies below the source for both countries under either placement; at the source's separation with the weapons at the targets it lies above for both. One weapon on the first-ranked place gives 0.919 and 1.034 of the source's figure for one weapon on the country's highest-density city. The chain's injuries, held fractions of the zones' survivors, are 0.366 and 0.466 of the source's severe and slight injuries.

The comparison is again between two models, and it establishes a direction for this source: on French and British cities at 15 kt the chain runs above it, where on Iranian and Israeli cities it runs below the second case. It does not separate the causes. The two population surfaces differ in year and in kind, residents in 2025 against an ambient average over the day in 2003; the source's fatality curve is a normal distribution of stated width, against the chain's three zones; and the separation at which the targets are taken moves the chain's figure by more than its difference from the source.

Table 8: The chain against the third published case. Source fatalities are the source's tables as it prints them, for fifty weapons of 15 kt, air burst, and for one weapon on the highest-density city; the chain's median and admissible range are taken over the admissible pairs each placement calibrates, and the ratio is the chain's median over the source's fatalities. Sources: Atmospheric Chemistry and Physics (2007), tables 4 and 6; GHS-POP, release R2023A, epoch 2025; author's calculations.

Targets	Placement	Source fatalities	Chain median	Admissible range	Ratio
France					
6 km apart	of record	3,509,000	3,842,865	3,794,488–3,953,067	1.095
6 km apart	at the target	3,509,000	3,563,259	3,351,558–3,701,086	1.015
12 km apart	of record	3,509,000	3,268,472	3,167,631–3,327,307	0.931
12 km apart	at the target	3,509,000	3,084,289	2,849,880–3,271,088	0.879
first-ranked place	one weapon, of record	269,000	247,268	229,602–278,288	0.919
United Kingdom					
6 km apart	of record	2,891,000	3,067,947	2,959,490–3,162,547	1.061
6 km apart	at the target	2,891,000	3,123,600	2,831,982–3,412,558	1.080
12 km apart	of record	2,891,000	2,851,055	2,720,894–3,036,842	0.986
12 km apart	at the target	2,891,000	2,602,575	2,288,847–3,024,516	0.900
first-ranked place	one weapon, of record	126,000	130,275	118,750–151,530	1.034

8.4 The library's countervalue cells at their published compositions

Two countervalue cells of the library state a composition and a casualty figure that no row of Table 6 runs at its composition. The countervalue rung of the European escalation chain of Plan A, a simulation by Princeton University's Program on Science and Global Security, puts five through ten weapons on each of the thirty most populous cities of Russia and of the alliance and counts about 85.3 million casualties, dead and injured together, in forty-five minutes, at a yield the source does not state.²⁰ And the source of the calibration theatre restates, on its 2016 population data, the composition of its authors' earlier study, 50 weapons of 15 kt on each of India and Pakistan, at 27 million fatalities and 45 million casualties.²¹ Each is run beside the table, as the published cases above are, on the construction of record and with nothing fitted to the source; a casualty is a fatality or an injury, and the chain's casualties are its fatalities and its injuries summed at each of the 156 admissible pairs.

The European rung is run on the thirty places of each side of Table 6's European rows, each side's weapons on the other's places: five a place, 150 a side, and ten a place, 300 a side, air burst at 100, 250, and 500 kt. A place given several weapons is searched within the city scale, so the windows are clipped again from the population grid to a reach of 32.8 km, the city scale and the light radius at 500 kt, against the 27.4 km of the windows of record; each of the wider windows, cut to the narrower's half width, equals it cell for cell, and at 100 kt both compositions give the same zones and aimpoints on either. Table 9 sets out the result. At five weapons a city the chain's median lies below the source's figure at 100 and 250 kt and above it at 500 kt, where the whole admissible range lies above; at ten weapons a city it lies below at 100 kt and above at 250 and 500 kt. The source's figure therefore lies inside the span that the stated composition and the yields tested give: between the chain's figures at 250 and 500 kt for five weapons a city, and between those at 100 and 250 kt for ten. Doubling the weapons on each city multiplies the median casualties by 1.408 at 100 kt, 1.319 at 250 kt, and 1.277 at 500 kt. The alliance's struck cities carry 64.4 through 69.3 percent of the casualties in every composition and yield.

The rule for several weapons on one place is measured here beyond two weapons a place. At 100 kt the search within the city scale puts 172 of the 300 aimpoints at five weapons a city and 383 of the 600 at ten more than five kilometers from their places' points, none beyond the city scale. Against the five-kilometer confinement applied to every weapon, it raises the median fatalities by 27.2 percent at five weapons a city, from 37.5 million to 47.6, and by 47.1 percent at ten, from 47.9 million to 70.4; at two weapons a place, on the rows between Russia and the United States, it lowers them (Section 6.1).

The South Asian case is run on the first 50 places of each country's derived targets, one weapon each. The chain's median fatalities are 29.5 million, spanning 28.5 through 30.4 over the admissible set, 1.093 of the source's figure; India's struck side carries 18.6 million and Pakistan's 10.9. The median casualties are 42.7 million, 0.949 of the source's, the injuries being an output of held fractions here as in the calibration. The source and the response function are the calibration's; the composition is not, and at it the chain's fatalities lie within ten percent of the source's.

The European comparison is again between two models, and with the yield unstated it places the source's figure within the chain's span rather than testing the chain at one composition; it does

²⁰ Program on Science and Global Security, Princeton University, "Plan A" (simulation, 2019), <https://sgs.princeton.edu/the-lab/plan-a>; the program states that its fatality estimates are limited to the acute deaths of the explosions.

²¹ Toon et al., "Rapidly Expanding Nuclear Arsenals," the text on its figure 2.

not separate the source's response from the chain's, nor its population data from the residential grid of 2025.

Table 9: The European countervalue rung at its published composition: thirty cities on each side, every city taking five or ten weapons, air burst. Fatalities and casualties are in millions, the medians and the range taken over the 156 admissible fraction pairs of Table 5, a casualty being a fatality or an injury; the ratio is the chain's median casualties over the source's 85.3 million. Sources: Program on Science and Global Security, Princeton University (2019); GHS-POP, release R2023A, epoch 2025; author's calculations.

Weapons a city	Yield (kt)	Fatalities, median	Casualties, median	Casualties, admissible range	Ratio
five	100	47.6	56.2	55.7–57.1	0.659
five	250	66.3	76.4	75.5–77.5	0.896
five	500	82.7	93.6	92.5–94.9	1.097
ten	100	70.4	79.2	78.1–80.4	0.928
ten	250	91.6	100.8	99.5–102.0	1.181
ten	500	109.9	119.5	118.2–120.8	1.401

8.5 A constructed case: the Kaliningrad reach

Russia's Iskander-M short-range ballistic missile has a maximum range of 500 km and has been deployed permanently in Kaliningrad since 2018.²² Measured on the WGS84 ellipsoid from the city of Kaliningrad, the capitals of three members of NATO lie within that range: Warsaw at 277.6 km, Vilnius at 307.4 km, and Riga at 336.0 km; the nearest member's capital beyond it is Copenhagen, at 517.1 km. No source consulted states a composition for a strike on these capitals, so the case is constructed, and it models Russia's strike alone. Each missile carries one warhead, burst in the air at 10 or at 100 kt, the two ends of the yield a published estimate of Russia's forces gave the missile in 2022; the estimate of January 2026 states no yield for Russia's non-strategic systems.²³ Two compositions are run on each capital. In the first, one weapon falls on the capital's first-ranked place. In the second, one weapon falls on each place the derivation of Section 6.1 takes inside the capital's own unit at its separation of 12 km, with no limit on the count: four in the county of Warsaw, three in the city municipality of Vilnius, and four in the state city of Riga. The windows, the zones, and the admissible pairs are those of the construction of record.

The census test of Section 6.1 is run on the three countries,²⁴ at the first level of Overture Divisions and, for Poland and Lithuania, also at the level below it; Latvia is tested at its first level alone. Poland passes at its voivodeships and at its counties. Latvia, whose first level is its 42 state cities and municipalities, fails there: three municipalities adjoining Riga stand between 0.6763 and 0.7215. Lithuania passes at its counties and fails at its municipalities, where the district municipality of Šiauliai stands at 1.2537; the city municipality of Šiauliai, at 0.7640, lies inside the test's tolerance.

²²Center for Strategic and International Studies, Missile Defense Project, "9K720 Iskander (SS-26)," *Missile Threat*, last modified 23 April 2024, accessed 14 October 2026, <https://missilethreat.csis.org/missile/ss-26-2/>.

²³Hans M. Kristensen and Matt Korda, "Russian Nuclear Weapons, 2022," *Bulletin of the Atomic Scientists* 78, no. 2 (2022): 98–121, table 1; Kristensen and Korda, "World Nuclear Forces," table 8A.3.

²⁴Statistics Poland, Local Data Bank, National Population and Housing Census 2021, resident population by voivodeship and by county; Statistics Lithuania, 2021 Population and Housing Census, population by county and by municipality; Central Statistical Bureau of Latvia, Official Statistics Portal, table IRS031, population at the beginning of 2021 by state city and municipality; each accessed 13 October 2026.

Each of the two countries is corrected for this case alone, by the rule of that section, at the level where it fails, and the within-unit distribution is GHS-POP's in both: its census-weighted mean of $|\log r|$ stands at 0.0682 against WorldPop's 0.0762 over Latvia's units, and at 0.0772 against 0.2036 over Lithuania's municipalities.

Table 10 sets out the fatalities over the 156 admissible pairs and the injuries. One weapon of 100 kt on Warsaw's first-ranked place gives a median of 252,463 fatalities, and the four weapons of the second composition give 675,718. Warsaw's median exceeds Vilnius's and Riga's under both compositions at both yields. Its fatalities also exceed theirs under every admissible pair, with one exception: with one weapon of 10 kt, Warsaw's exceed Riga's under 93 of the 156 pairs, Warsaw's light zone holding more residents than Riga's and its moderate zone fewer. In every case the median fatalities on cells outside the struck country number fewer than one. The correction puts Riga's medians at 0.994 through 0.997 of their values on the uncorrected grid, and Vilnius's at 0.968 through 0.969, the places held at those taken on the corrected grid; in Vilnius the uncorrected grid gives the same places. The fallout bound of Section 6.2 is not computed for the case, since it rests on a surface burst and these weapons burst in the air.

Table 10: The constructed case of the Kaliningrad reach. For each capital, one weapon on its first-ranked place and one weapon on each of its places, burst in the air. Fatalities are the median and the range over the 156 admissible pairs, and injuries the median. Riga and Vilnius are read through the correction of Latvia and Lithuania to the census, and the ratio is the median fatalities over the median on the uncorrected grid at the same places; Warsaw's grid is not corrected. Sources: Statistics Poland and Statistics Lithuania, censuses of 2021; Central Statistical Bureau of Latvia, population at the beginning of 2021; GHS-POP, release R2023A, epoch 2025; author's calculations.

Weapons	Yield (kt)	Fatalities, median	Admissible range	Injuries, median	Ratio
Warsaw					
1	10	71,175	65,175–82,336	53,023	—
1	100	252,463	239,890–270,554	140,184	—
4	10	222,230	212,636–234,364	109,178	—
4	100	675,718	657,312–697,779	162,021	—
Vilnius					
1	10	52,887	51,633–53,762	20,607	0.969
1	100	142,058	139,705–146,032	37,991	0.969
3	10	74,022	72,365–75,041	26,318	0.969
3	100	185,819	182,100–191,014	43,368	0.968
Riga					
1	10	70,058	68,349–70,999	26,610	0.994
1	100	159,503	156,320–161,249	44,469	0.995
4	10	113,867	110,735–115,590	43,743	0.995
4	100	288,900	274,780–299,975	45,159	0.997

Table 11 carries the case through the value layer of Section 14. Each level-1 unit of residence a blast ring reaches enters with its whole produced capital, and the value destroyed is that capital times the unit's damage ratio. Warsaw's unit is the Masovian Voivodeship and Vilnius's is Vilnius County, each valued on its share of its country's non-agricultural output; Latvia's units are valued on their share of Latvia's built-up volume, the output data holding no year in which every Latvian region carries its output and population. One weapon of 10 kt destroys more value by blast on Riga

than on Warsaw, 8.4–18.0 billion 2017 U.S. dollars at purchasing-power parity against 6.4–14.4, although Warsaw’s median fatalities are the larger. Warsaw’s unit loses more built-up volume, 31.1–70.0 million cubic meters against Riga’s 19.9–42.9, but its capital at risk comes to 205 dollars a cubic meter of its built-up volume against 420 in Riga, and the voivodeship’s damage ratio is 0.010–0.022 against the state city’s 0.075–0.162. Warsaw’s blast value exceeds Riga’s at both ends of the interval only with every place struck at 100 kt. With one weapon of 100 kt the lower end of Riga’s interval lies above Warsaw’s and its upper end below, and with every place struck at 10 kt the two lower ends agree at the precision shown and Warsaw’s upper end lies above Riga’s.

Table 11: The value layer of the constructed case of the Kaliningrad reach, in billions of 2017 U.S. dollars at purchasing-power parity. For each capital, one weapon on its first-ranked place and one weapon on each of its places, burst in the air: the count of level-1 units of residence the blast rings reach, their capital at risk, and the value destroyed by blast and by fire, each an interval over the bounds of Sections 12 and 13 and conditional on the case. Capital at risk is the nation’s Penn World Table capital stock apportioned to the unit by its share of national non-agricultural output, or by its share of national built-up volume where the output data do not reach the unit, as in Latvia; each unit reached enters whole. The fire value is the unattenuated upper bound, reported apart and not summed with the blast. Sources: Penn World Table 10.01 (cn); DOSE version 2.14; GHS-BUILT-V, release R2023A, epoch 2025; Overture Maps Foundation, Divisions, release 2026-08-19.0, admin level 1; author’s calculations.

Weapons	Yield (kt)	Units	Capital at risk	Blast	Fire
Warsaw					
1	10	1	648.9	6.4–14.4	1.2–15.0
1	100	1	648.9	21.0–44.7	7.1–96.5
4	10	1	648.9	15.1–32.5	3.0–35.7
4	100	1	648.9	45.6–82.3	16.5–154.0
Vilnius					
1	10	1	148.6	6.1–13.0	1.3–16.0
1	100	1	148.6	17.9–32.5	6.6–57.7
3	10	1	148.6	9.4–18.6	2.0–22.5
3	100	1	148.6	25.0–42.7	8.9–77.0
Riga					
1	10	1	111.7	8.4–18.0	1.7–19.3
1	100	6	141.0	22.9–42.4	8.3–85.8
4	10	6	140.4	15.1–32.2	3.0–38.0
4	100	8	152.9	43.2–71.4	17.0–109.3

8.6 A constructed case: the capitals of the alliance’s European members

A document Russia sent to NATO in September 2026 warned of “Russian strikes against decision-making centres in the alliance’s member states” in response to an attempt by the alliance to isolate the Kaliningrad region.²⁵ No source consulted names the centers or states a composition for such a strike, so the case is constructed: one weapon falls on the capital of each of the alliance’s 30 European members, the capital as the GeoNames gazetteer records it, and Russia’s strike alone is modeled. Each weapon is burst in the air at 100 kt, the upper end of the yield the estimate of

²⁵Henry Foy and Max Seddon, “Russia Threatens Nuclear Strikes on Nato Countries over Kaliningrad,” *Financial Times*, 30 September 2026.

2022 gives the Iskander-M, or at 200 kt, the yield the estimate of January 2026 gives the cruise missiles carried by Russia's strategic bombers.²⁶ The weapon's place is the highest-scored place the derivation of Section 6.1 takes in the capital's country within its separation of 12 km of the capital's coordinate. For 24 of the capitals that place is the country's first-ranked; for the other six, Ankara, Berlin, Bratislava, Madrid, Rome, and Sofia, a place elsewhere in the country ranks above it. The places lie 0.4 through 8.1 km from the capitals' coordinates. Luxembourg, no part of which has a bounding box of 10,000 km², takes its largest part as the geography the derivation searches. The windows, the zones, and the admissible pairs are those of the construction of record, and no two capitals' places lie within twice the light radius at 200 kt, so the strike on all 30 capitals counts each resident in one capital's zones and its totals are the sums of the single weapons'.

The census test of Section 6.1 has been run on seven of the members in the construction of record and on three in Section 8.5. The other 20 are tested here, at the first level of Overture Divisions,²⁷ with the census counts aggregated to the boundary source's units where the two differ; Finland's Åland, which the boundary source holds apart from Finland's regions, is left out of Finland's test. 17 of the 20 pass. Albania fails at four of its 12 prefectures, which stand between 0.5692 and 1.2784. North Macedonia fails at five of the 21 of its 71 municipalities that hold at least 1 percent of its census total, the City of Skopje counted as one, between 1.2535 and 1.5628. Montenegro fails at one of the 19 of its 25 municipalities so tested, Zeta, at 1.3271. Each of the three is corrected for this case alone, by the rule of that section, at its first level. The within-unit distribution is WorldPop's in Albania, its census-weighted mean of $|\log r|$ standing at 0.1095 against GHS-POP's 0.1954, and GHS-POP's in North Macedonia and Montenegro, at 0.1096 and 0.1006 against WorldPop's 0.2114 and 0.2273.

Table 12 sets out the fatalities over the 156 admissible pairs and the injuries. One weapon on Paris gives the largest median of the 30 at both yields, 751,402 fatalities at 100 kt and 1,086,355 at 200 kt, and one on Reykjavík the smallest, 74,327 and 97,481. The 30 weapons together give a median of 8,444,468 fatalities at 100 kt and 11,555,139 at 200 kt, 1.368 times as many. Over the admissible pairs the strike's fatalities run from 8,182,961 through 8,615,889 at 100 kt and from 11,297,159 through 11,704,568 at 200 kt, and its median injuries are 3,454,469 and 4,044,131. The corrections put Tirana's medians at 0.681 through 0.720 of their values on the uncorrected grid, Skopje's at 1.115 through 1.117, and Podgorica's at 0.959 at both yields, the places held at those taken on the corrected grid. Every resident in a zone is counted, whatever country holds the cell. Cells inside another country's polygons in the boundary source carry at most 0.8 percent of a capital's median fatalities, Bratislava's at 200 kt. Cells whose centers lie inside no country's polygon carry up to 5.9 percent, Helsinki's at 100 kt, and more than one percent in the cases of Helsinki, Oslo, Reykjavík, and Stockholm. The fallout bound of Section 6.2 is not computed for the case, since it rests on a surface burst and these weapons burst in the air.

²⁶Kristensen and Korda, "Russian Nuclear Weapons, 2022," table 1; Kristensen and Korda, "World Nuclear Forces," table 8A.3.

²⁷Eurostat, 2021 Population and Housing Censuses, census hub, population by region, for the 17 members whose census it carries; Institute of Statistics of Albania, *Albania Population and Housing Census 2023: Main Results*, table 6; State Statistical Office of North Macedonia, *Census of Population, Households and Dwellings 2021*, total resident population by municipality; Statistical Office of Montenegro, "The 2023 Census of Population, Households, and Dwellings: Population of Montenegro by Sex and Age," 15 October 2024, table 1; each accessed 14 October 2026.

Table 12: The constructed case of the capitals of the alliance's European members. One weapon on the place taken for each capital, burst in the air. Fatalities are the median and the range over the 156 admissible pairs, and injuries the median. Tirana, Skopje, and Podgorica are read through the correction of Albania, North Macedonia, and Montenegro to their censuses. Sources: Eurostat, 2021 Population and Housing Censuses; Institute of Statistics of Albania, census of 2023; State Statistical Office of North Macedonia, census of 2021; Statistical Office of Montenegro, census of 2023; GHS-POP, release R2023A, epoch 2025; author's calculations.

Capital	100 kt			200 kt		
	Fatalities, median	Admissible range	Injuries, median	Fatalities, median	Admissible range	Injuries, median
Amsterdam	285,035	280,748–293,423	87,389	379,898	371,237–391,414	92,911
Ankara	590,660	575,502–599,115	211,006	785,953	765,239–805,791	254,052
Athens	448,556	429,565–467,473	231,561	620,825	602,844–628,312	256,491
Berlin	280,837	264,222–306,874	173,611	390,784	371,155–418,950	220,616
Bratislava	98,864	96,079–103,383	27,894	112,831	109,733–118,083	30,220
Brussels	349,337	342,193–355,254	123,297	595,517	551,542–629,604	132,438
Bucharest	428,294	418,510–435,600	163,730	586,786	574,902–605,061	164,513
Budapest	323,912	313,578–333,986	126,418	427,119	418,331–433,037	142,897
Copenhagen	354,134	341,555–367,894	92,959	431,216	421,681–443,409	94,633
Helsinki	157,536	154,209–159,425	45,773	202,516	196,309–211,894	65,707
Lisbon	223,095	213,308–237,281	106,770	288,645	273,486–315,220	144,813
Ljubljana	126,696	120,136–132,210	26,029	165,059	156,374–171,945	28,889
London	445,109	412,495–498,108	326,358	614,754	567,993–695,894	449,719
Luxembourg	105,915	101,936–109,346	16,962	131,672	129,240–134,365	18,422
Madrid	714,661	694,841–726,733	314,409	969,862	954,562–994,742	344,796
Oslo	181,043	176,944–182,976	61,577	255,565	250,937–262,975	68,824
Paris	751,402	715,605–796,946	406,078	1,086,355	1,043,204–1,128,655	527,412
Podgorica	104,571	98,703–108,784	12,979	129,193	122,929–133,551	11,615
Prague	247,027	239,390–252,024	100,976	334,622	328,662–340,835	111,693
Reykjavík	74,327	71,280–77,307	17,746	97,481	91,599–102,026	17,431
Riga	159,503	156,320–161,249	44,469	210,263	205,356–216,383	46,415
Rome	311,974	295,000–339,780	169,068	439,876	423,987–455,699	193,742
Skopje	172,600	169,198–177,669	43,930	229,083	220,761–237,096	46,797
Sofia	220,126	213,275–224,610	90,596	308,534	302,816–318,552	97,575
Stockholm	279,887	272,624–283,582	102,094	387,233	378,787–390,556	120,916
Tallinn	128,061	126,160–129,863	34,372	168,514	166,580–172,184	37,641
Tirana	276,522	261,448–289,338	61,837	368,710	345,862–385,716	59,133
Vilnius	142,058	139,705–146,032	37,991	186,012	182,182–191,119	41,246
Warsaw	252,463	239,890–270,554	140,184	371,924	359,758–379,542	162,211
Zagreb	191,402	188,181–197,120	56,046	256,968	247,713–266,453	59,780

Table 13 carries the case through the value layer. The blast rings reach 74 level-1 units at 100 kt and 82 at 200 kt, the second set holding the first and no unit lying in two capitals' rings. Of the 82, 37 are valued on their share of national non-agricultural output and 45 on their share of national built-up volume: the units of Albania and Latvia, for which the output data hold no year in which every region carries its output and population; those of Iceland, Luxembourg, and Montenegro, which the data do not hold; and, in North Macedonia, Slovenia, Finland, Norway, and Portugal, units that are neither a region of the data nor a union of its regions, the municipalities of the first two, Uusimaa, Akershus, and the districts of Lisbon and Setúbal. One weapon on Paris destroys the most value by blast at both yields, 147.5–374.6 billion 2017 U.S. dollars at 100 kt and 226.3–551.9

at 200 kt. The 30 weapons together put 36,506.6 billion of capital at risk at 100 kt and destroy 1,423.6–3,002.2 billion of it by blast and, apart and not summed, 529.6–6,131.6 by fire; at 200 kt they put 38,558.0 billion at risk and destroy 1,987.1–3,974.0 by blast and 874.3–8,802.6 by fire. On a clear day, at a visibility of twenty kilometers, the fire value falls to 347.8–3,315.5 billion at 100 kt and 524.0–4,609.1 at 200 kt. With every unit valued on its share of national built-up volume, the blast value is 782.4–1,639.5 billion at 100 kt and 1,083.8–2,167.8 at 200 kt.

A unit enters the capital at risk whole once a blast ring reaches it, so the capital at risk follows the extent of the unit as well as the strike. London's unit is England, with 12,262.7 billion of capital at risk, and at 200 kt the light ring of the weapon on Luxembourg reaches France's Grand Est, which adds 1,137.1 billion to that strike's capital at risk and at most 9.1 million to its blast value. Built-up volume in the rings on cells in no first-level unit is reported and not valued; it comes to at most 3.2 percent of a capital's built-up volume in the rings, Helsinki's at 100 kt. Such cells lie in no country's polygon, in the Holy See, for which the Penn World Table carries no capital series and whose 1.98 million cubic meters lie in Rome's light ring at both yields, or, in Denmark, Iceland, and Portugal, inside the country's polygon and outside every one of its first-level units.

Table 13: The value layer of the constructed case of the capitals of the alliance's European members, in billions of 2017 U.S. dollars at purchasing-power parity. One weapon on the place taken for each capital, burst in the air. Capital at risk is the produced capital of the level-1 units the blast rings reach, each entering whole: the nation's Penn World Table capital stock apportioned to the unit by its share of national non-agricultural output, or of national built-up volume where the output data do not reach the unit. Blast and fire value destroyed are that capital times the unit's damage ratios, each an interval over the bounds of Sections 12 and 13, conditional on the case, and reported apart and not summed; the fire value is the unattenuated upper bound. The last row is the strike on all 30 capitals, the sum of the single weapons. Sources: Penn World Table 10.01 (*cn*); DOSE version 2.14; GHS-BUILT-V, release R2023A, epoch 2025; Overture Maps Foundation, Divisions, release 2026-08-19.0, admin level 1; author's calculations.

Capital	100 kt			200 kt		
	Capital at risk	Blast	Fire	Capital at risk	Blast	Fire
Amsterdam	1,389.7	50.3–101.9	19.1–191.5	1,389.7	68.5–132.1	28.8–279.5
Ankara	1,014.7	62.2–128.8	21.4–232.5	1,014.7	88.3–175.5	34.2–399.5
Athens	1,143.7	77.5–185.8	29.5–418.8	1,143.7	108.1–244.3	51.9–635.7
Berlin	1,320.9	61.0–145.2	22.8–312.5	1,320.9	84.7–192.3	39.2–488.0
Bratislava	669.8	17.5–34.0	5.7–76.1	744.1	20.7–39.8	9.5–97.3
Brussels	2,269.3	98.5–198.1	41.3–424.4	3,078.8	163.4–284.9	75.3–478.4
Bucharest	480.0	69.0–143.6	26.7–317.2	491.4	94.0–178.2	44.9–390.2
Budapest	668.3	62.4–131.1	22.3–273.6	668.3	83.3–166.4	37.1–387.8
Copenhagen	614.4	58.6–119.8	22.9–227.5	614.4	76.0–145.7	33.6–305.4
Helsinki	377.9	26.1–45.7	8.2–70.8	377.9	35.5–62.0	11.5–119.2
Lisbon	623.5	32.8–65.8	11.6–112.3	623.5	46.1–85.3	16.1–184.4
Ljubljana	84.9	18.4–31.9	7.4–51.7	88.2	23.9–39.7	9.7–57.6
London	12,262.7	44.5–117.2	16.8–256.9	12,262.7	65.6–168.8	31.4–438.9
Luxembourg	197.7	30.8–48.9	10.4–73.1	1,334.8	39.0–59.5	13.0–85.6
Madrid	2,251.5	112.9–246.4	44.3–507.5	2,251.5	156.2–318.8	71.6–721.4
Oslo	573.6	80.4–149.2	29.5–300.6	573.6	112.5–197.9	50.0–368.6
Paris	5,327.8	147.5–374.6	55.5–812.1	5,327.8	226.3–551.9	103.7–1,386.0
Podgorica	16.8	6.3–9.5	2.2–12.7	16.8	8.0–11.2	2.5–14.0
Prague	830.7	82.9–168.9	30.9–347.7	830.7	111.0–210.5	47.7–467.1
Reykjavík	55.8	12.6–23.0	5.1–43.3	55.8	16.6–28.7	7.9–48.2
Riga	141.0	22.9–42.4	8.3–85.8	152.9	30.2–53.2	13.4–106.2
Rome	1,949.8	55.0–124.7	19.3–268.7	1,949.8	72.7–161.3	32.2–414.2
Skopje	35.0	6.3–11.8	2.5–22.3	35.0	8.8–15.4	3.8–27.3
Sofia	206.3	23.6–48.3	8.7–109.7	210.3	32.1–61.8	15.9–136.6
Stockholm	748.9	58.7–107.6	19.1–200.9	748.9	75.4–139.0	30.3–277.5
Tallinn	134.1	14.2–27.5	5.2–55.9	134.1	19.7–35.7	9.0–71.8
Tirana	90.2	14.6–25.0	5.6–40.3	90.2	19.1–30.2	7.6–45.3
Vilnius	148.6	17.9–32.5	6.6–57.7	148.6	24.0–41.2	9.4–73.7
Warsaw	648.9	21.0–44.7	7.1–96.5	648.9	29.0–58.8	12.1–142.7
Zagreb	230.2	37.1–68.2	13.9–131.0	230.2	48.6–83.8	20.9–154.3
All 30	36,506.6	1,423.6–3,002.2	529.6–6,131.6	38,558.0	1,987.1–3,974.0	874.3–8,802.6

9 The fallout layer

This section reports the bounding estimate of Section 6 run on the rows of Table 6 in the theatres its burst condition admits, together with the attribution of the residents it counts to the countries and territories they live in.

A unit is one row of Table 6, which fixes a composition and a yield. Its figure is the number of residents whose grid cell lies within $L(W)$ of the nearest aimpoint of the strike that row states, on the aimpoints the direct layer uses for the same row. The count runs at the population grid's own 100 m resolution, on ground distance on the WGS84 ellipsoid between cell centers, the distance the direct layer uses, and ties in the nearest-aimpoint rule break to the lowest aimpoint index. The grid is read in disjoint tiles, so every cell is counted once and no window bounds the contour, which at one megaton reaches 169.2 km.

The bound is computed for the nineteen rows in the theatres its burst condition admits. The four rows of Table 6 striking the Korean peninsula, Japan, and the NATO members carry no fallout figure: no general-release or countervalue cell of their two theatres bursts at or near the ground, so the bound does not apply to them. Their absence follows from the library's burst condition and not from the population data.

The bound is not added to the direct-layer count. A resident inside a blast zone is also inside the fallout contour of the same detonation, so the two counts describe overlapping populations, and their sum describes neither. They are read as a ratio instead. The residents the bound counts are not fatalities: the three overstatements stated in Section 6.2 place actual fallout fatalities below the bound under the wind the relation assumes and with the exposed population near the aimpoints, conditions whose failure Section 9.1 examines. A blast zone sits inside the contour of its own detonation, but the contour holds more residents than the zones: across the nineteen units of Table 14, between 38 and 75 percent of the residents inside the contour lie outside every blast ring, above sixty percent in fourteen of them. Those residents enter no direct-layer count at any fraction. The direct-layer totals of Table 6 therefore carry no fallout fatality, and in sixteen of the nineteen units the population that would bear one is in the majority beyond the zones they count.

Table 14: The fallout bound, by unit. Each row is one row of Table 6, identified by the same Theatre, Struck, and Weapons columns. L is the lethal-dose radius at that yield, the distance at which equation 1 gives 450 cGy. Residents is the count of residents inside the contour, in millions; Direct is the direct layer's central fatality estimate for the same cell, the median over the admissible pairs, in millions, whose interval Table 6 reports; Ratio is the first divided by the second, taken on the unrounded values. Residents inside the contour are a count that bounds fallout fatalities from above, not an estimate of them, and are not added to the direct layer. Sources: GHS-POP, release R2023A, epoch 2025; author's calculations.

	Theatre Struck	Weapons	Yield (kt)	L (km)	Residents (m)	Direct (m)	Ratio
T01	India; Pakistan	150+100	15	36.2	784.9	54.0	14.5
T01	India; Pakistan	150+100	50	56.7	1,086.9	93.2	11.7
T01	India; Pakistan	150+100	100	73.3	1,270.1	123.5	10.3
T07	Russia; United States	30+30	100	73.3	161.3	14.2	11.4
T07	Russia; United States	30+30	1000	169.2	228.1	37.8	6.0
T07	Russia; United States	300+300	100	73.3	352.6	54.7	6.4
T07	Russia; United States	300+300	1000	169.2	459.2	122.5	3.7
T02	India; China	30+30	15	36.2	489.5	24.7	19.8
T02	India; China	30+30	100	73.3	859.6	61.4	14.0
T05	United States; China	30+30	100	73.3	531.5	35.0	15.2
T05	United States; China	30+30	1000	169.2	1,007.1	91.9	11.0
T09	Russia; China	30+30	100	73.3	480.2	36.5	13.1
T09	Russia; China	30+30	1000	169.2	949.4	94.0	10.1
T10	Israel	20	15	36.2	14.9	1.4	10.5
T10	Israel	20	100	73.3	24.5	3.1	7.9
T10	Iran	20	15	36.2	31.5	1.7	18.6
T10	Iran	20	100	73.3	36.9	5.0	7.4
T12	India	2	10	31.1	29.2	1.7	17.2
T12	India	10	10	31.1	113.1	5.3	21.2

The bound exceeds the direct-layer estimate in every unit, by factors running from 3.7 through 21.2. Two constructions produce that: the contour radius at a given yield exceeds the radii of the blast zones, and every resident inside the contour is counted, where the direct layer applies a fatality fraction below one outside the severe zone.

In T07 the ratio falls as the force grows. T07 and T12 are the two theatres in the table run at two force sizes. At 30+30 weapons the bound is 11.4 times the direct layer at 100 kt and 6.0 times at 1 Mt; at 300+300 weapons the same two ratios are 6.4 and 3.7. Ten times the weapons do not put ten times the residents inside a contour: the contours of neighboring aimpoints overlap, and their union approaches the population the strike can reach, while the direct layer's smaller zones go on accumulating. What binds the bound at that force size is where people live rather than how many weapons arrive. In T12, at two and ten weapons of 10 kt, the ratio rises instead, from 17.2 to 21.2.

A fallout contour does not stop at a border. The attribution by entity of residence is computed for every unit at the level-1 administrative grain of the boundary source and rolled up to the entity the source places each unit in; it reaches 38 countries and territories, and Table 15 reports three units. A territory the source records as disputed is not adjudicated here: where the source carves

it out as an entity of its own, it takes its own line with its claimants named, and the readings under each claimant are stated in this paragraph. The Israeli row at 100 kt puts 24.5 million residents inside the 73.3 km contour, of whom 37.9 percent live in Israel, 14.9 percent in the West Bank, and 8.3 percent in the Gaza Strip, the rest in Jordan, Syria, Lebanon, and Egypt. With the West Bank counted to Israel, Israel's share is 52.8 percent; with both territories counted to Palestine, the Palestinian share is 23.1 percent. Of the disputed level-1 units the source places inside a country, the largest in the three reported units is Jammu and Kashmir, at 1.09 percent of the T01 unit at 100 kt, placed in India and claimed by Pakistan. It is the one such unit that reaches the one-percent line, and it stays on the line of the country it is placed in, as every such unit does; its share is stated here so that a reader can move it. In the calibration theatre at the same yield, 34.48 million of the residents inside the contours live in Bangladesh, which is party to neither side. At the largest force in the table, 15.12 million residents of Canada, 8.00 million of Ukraine, and 7.48 million of Mexico lie inside contours cast by weapons on Russia and the United States.

Table 15: Residents inside the lethal-dose contour by entity of residence, for three units of Table 14. Residents are in millions and shares are percentages of the unit's own total, so each block partitions its unit. Entities below one percent of a unit are pooled on its Other entities line, with the count; Unattributed is residents on cells no level-1 polygon covers. A level-1 unit rolls up to the entity the boundary source places it in; a disputed territory the source carves out as its own entity has its own line with its claimants named, and the assignment is the reader's. Country names not used elsewhere in this document are Natural Earth's. Sources: GHS-POP, release R2023A, epoch 2025; Overture Maps Foundation, Divisions, release 2026-08-19.0, admin level 1; author's calculations.

Entity of residence	Residents (m)	Share of unit (percent)
T01, India; Pakistan, 150+100 weapons at 100 kt		
India	997.82	78.6
Pakistan	233.62	18.4
Bangladesh	34.48	2.7
Other entities (4)	4.03	0.3
Unattributed	0.20	0.0
T07, Russia; United States, 300+300 weapons at 1000 kt		
United States	276.78	60.3
Russia	137.14	29.9
Canada	15.12	3.3
Ukraine	8.00	1.7
Mexico	7.48	1.6
Other entities (14)	13.81	3.0
Unattributed	0.85	0.2
T10, Israel, 20 weapons at 100 kt		
Israel	9.28	37.9
Jordan	6.83	27.9
West Bank (claimed by Palestine and Israel)	3.64	14.9
Gaza Strip (claimed by Palestine)	2.03	8.3
Lebanon	1.28	5.2
Syria	1.20	4.9
Other entities (1)	0.15	0.6
Unattributed	0.07	0.3

The boundary source carries Hong Kong and Macao as entities of their own, so the units that strike Chinese targets report them as entities of residence in their own right. Across the layer, 0.07 percent of residents fall on cells no level-1 polygon covers, worst in the T10 row of 20 weapons at 15 kt, at 0.3 percent. The source's land polygons end at the shoreline, so a cell the population grid places on the coast can fall on no polygon; on the one window where the source's maritime polygons were measured beside its land polygons, the two classes together left no resident uncovered, which on that window places the residue in the class boundary rather than in the source. A second part of it is entity coverage: the source carries disputed areas a window meets—the Golan and Iturup among them—that the set of land polygons used here does not hold, so their residents have no polygon to fall on either. Both parts are reported on their own line rather than folded into a neighboring entity.

9.1 The bound against two published transport cases

Two published cases resolve fallout by transport on the archived weather of every day of one year, on the population source this study uses, and publish the range of fatalities across those days: an attack on the United States' 450 missile silos with one 800 kt warhead each,²⁸ and an attack on China's three new silo fields with two 300 kt warheads on each of 270 silos.²⁹ Silos lie away from population, so their fatalities are almost wholly fallout carried downwind, and neither case is a countervalue cell to which the chain applies the bound. They test the bound where its second condition, a population near the aimpoints, fails. It was counted around the silos' own coordinates, the United States' from public lists of the launch facilities of the three missile wings³⁰ and China's from the dashboards of the Federation of American Scientists that the source cites,³¹ which hold 297 silo positions where the source counts 270.

The United States' published figures assume that people shelter in place for at least four days, where the bound assumes that nobody is sheltered. Against them the bound is 4.23 times the published average and 1.29 times the worst day, so it bounds the sheltered range, though by a smaller factor than the area reading's 27 or more: around a remote silo the population does not concentrate at the aimpoint, and the plume carries the dose to it. The source states that without appropriate shelter the toll could be twice as high; on that reading the bound is 2.12 times the average and 0.64 of the worst day, so it bounds the unsheltered average and not the unsheltered worst day. For China, at the chain's convention, it falls below the published figures: counting each warhead on its own, as the chain does for several weapons on one place, the bound is 0.60 of the published average with protection factors and 0.15 of the average without; summing the two warheads' week doses at every distance, which reach the median lethal dose at 154.8 km, raises it to 1.76 times the protected average, still 0.58 of the worst day and 0.45 of the unprotected average. The fields in western and northern China lie upwind of populations beyond $L(W)$, which the transport reaches and the circle does not. The comparison is between the bound and a transport model rather than an observation, and it does not test the bound at the countervalue aimpoints of Table 14, where the exposed population is near the aimpoint; those figures remain conditional on the wind the relation assumes. It

²⁸Sébastien Philippe, "Who Would Take the Brunt of an Attack on U.S. Nuclear Missile Silos?" *Scientific American*, 1 December 2023.

²⁹Philippe and Stepanov, "Radioactive Fallout."

³⁰Wikipedia, "90th Missile Wing LGM-30 Minuteman Missile Launch Sites," "91st Missile Wing LGM-30 Minuteman Missile Launch Sites," and "341st Missile Wing LGM-30 Minuteman Missile Launch Sites," accessed 28 September 2026, <https://en.wikipedia.org>.

³¹Federation of American Scientists, "Yumen Missile Silo Field Over Time," "Hami Missile Silo Field Over Time," and "Ordos Missile Silo Field Over Time," Tableau Public, accessed 28 September 2026, <https://public.tableau.com/app/profile/kate.kohn>.

does limit what the bound can be called. Blast adds little at either silo set: residents within the light zone’s outer radius are 3.6 percent of the bound in the United States and 0.25 percent in China.

Table 16: The fallout bound around missile silos against two published transport cases. The bound is the residents within $L(W)$ of the nearest silo. Published deaths are over every day of 2021, the United States’ with shelter in place and China’s with protection factors. Sources: Scientific American (2023); Science & Global Security (2023); Federation of American Scientists; GHS-POP, release R2023A, epoch 2025; author’s calculations.

Silo fields	Aimpoints	$L(W)$ (km)	Bound (residents)	Published deaths, average and worst day	Bound over average
United States, 800 kt	450	156.2	5,924,750	1,400,000; 4,600,000	4.23
China, 300 kt a warhead	297	109.6	2,771,690	4,609,300; 13,906,100	0.60
China, two doses summed	297	154.8	8,106,270	4,609,300; 13,906,100	1.76

10 The age-sex composition of the exposed

This section reports who the residents the two layers count are, by sex and by age, against the residents of the level-1 units they live in. The question it answers is whether the population a strike reaches differs in composition from the population of the regions it falls in, which is what placing the counts of Sections 8 and 9 against a population of known age and sex structure requires.

The construction is one construction on both sides of the comparison. Each 100 m cell the attribution assigns to a level-1 unit of residence receives the sex and age-band shares of the 1 km WorldPop cell that holds its center, from the 2020 unconstrained age-sex rasters, applied to the GHS-POP residents of the cell; the source’s own bands are kept—the first year of life, ages one through four, and five-year bands through 80 and over. Its shares supply no totals. The exposed population of a struck side is the residents the layer counts on that side, summed over its zones and its units of residence. The reference population is the residents of those same units over their whole extent, from the same raster, the same rasterizer, and the same shares, so that a difference between the two is a property of where the strikes fall and not of the sources. Two classes of residents enter no share: those on cells no level-1 polygon covers, who have no unit and so no reference (0.07 percent of the residents the layers count), and those on 1 km cells the age-sex raster leaves unpopulated, who are carried as a count with no band (0.02 percent). Every share below is over the residents with a known band.

Tables 17 and 18 report the direct layer, split after the T02 rows, and Table 19 the fallout layer, one line per struck side of every unit, each share of the exposed beside the same share of the reference. Figure 7 draws the calibration theatre at 100 kt at the source’s own grain.

Table 17: The direct layer's exposed residents by sex and age against the units they live in, one line per struck side of each row of Table 6 through T02. Yield is in kilotons; residents are the exposed on level-1 units, in millions; each share is a percentage of residents with a known band, the exposed before the slash and the residents of the units reached over their whole extent after it, for ages under 15, 15 through 64, and 65 and over, and for females. Sources: GHS-POP, release R2023A, epoch 2025; WorldPop 1 km unconstrained age-sex rasters, 2020; Overture Maps Foundation, Divisions, release 2026-08-19.0, admin level 1; author's calculations.

Theatre Struck		Weapons	kt	Exposed (m)	Under 15	15–64	65+	Female
T01	India	150+100	15	181.8	24.1 / 26.8	69.6 / 66.7	6.2 / 6.5	47.5 / 48.2
T01	Pakistan	150+100	15	70.5	32.6 / 34.3	63.1 / 61.2	4.3 / 4.5	47.8 / 48.3
T01	India	150+100	50	249.8	23.9 / 26.8	69.8 / 66.7	6.2 / 6.5	47.5 / 48.2
T01	Pakistan	150+100	50	91.4	32.6 / 32.9	63.1 / 62.2	4.3 / 4.9	47.8 / 48.1
T01	India	150+100	100	281.3	24.0 / 26.8	69.8 / 66.7	6.2 / 6.5	47.5 / 48.2
T01	Pakistan	150+100	100	102.5	32.7 / 32.9	63.0 / 62.2	4.3 / 4.9	47.8 / 48.1
T06	Russia	30+30	100	27.0	17.0 / 17.6	67.0 / 66.6	16.0 / 15.8	54.6 / 54.5
T06	NATO members	30+30	100	55.1	17.1 / 17.9	65.8 / 64.8	17.0 / 17.3	51.4 / 51.1
T07	Russia	30+30	100	32.7	15.8 / 17.2	67.8 / 66.7	16.4 / 16.0	54.6 / 54.6
T07	United States	30+30	100	31.7	17.6 / 18.7	67.5 / 65.1	14.9 / 16.1	51.7 / 51.0
T07	Russia	30+30	1000	40.8	16.0 / 17.2	67.6 / 66.7	16.4 / 16.0	54.7 / 54.6
T07	United States	30+30	1000	55.7	18.1 / 18.9	67.0 / 65.2	14.9 / 15.9	51.4 / 51.0
T07	Russia	300+300	100	75.4	17.6 / 17.1	66.6 / 68.1	15.8 / 14.8	54.5 / 53.5
T07	United States	300+300	100	109.0	19.1 / 18.9	66.4 / 65.0	14.5 / 16.1	51.2 / 51.0
T07	Russia	300+300	1000	91.3	17.7 / 17.1	66.6 / 68.1	15.8 / 14.8	54.5 / 53.5
T07	United States	300+300	1000	164.6	19.3 / 18.9	66.2 / 65.0	14.5 / 16.1	51.2 / 51.0
T02	India	30+30	15	76.0	22.8 / 26.5	71.2 / 66.9	6.0 / 6.6	46.9 / 48.0
T02	China	30+30	15	65.3	11.6 / 17.3	77.1 / 70.5	11.3 / 12.1	48.9 / 48.8
T02	India	30+30	100	130.3	22.7 / 26.5	71.3 / 66.9	6.0 / 6.6	47.0 / 48.0
T02	China	30+30	100	122.1	11.5 / 17.3	77.3 / 70.5	11.2 / 12.1	48.7 / 48.8

Table 18: The direct layer's exposed residents by sex and age against the units they live in, continued: the rows of Table 6 from T05. Columns as in Table 17. Sources: GHS-POP, release R2023A, epoch 2025; WorldPop 1 km unconstrained age-sex rasters, 2020; Overture Maps Foundation, Divisions, release 2026-08-19.0, admin level 1; author's calculations.

Theatre Struck		Weapons	kt	Exposed (m)	Under 15	15–64	65+	Female
T05	United States	30+30	100	31.7	17.6 / 18.7	67.5 / 65.1	14.9 / 16.1	51.7 / 51.0
T05	China	30+30	100	122.1	11.5 / 17.3	77.3 / 70.5	11.2 / 12.1	48.7 / 48.8
T05	United States	30+30	1000	55.7	18.1 / 18.9	67.0 / 65.2	14.9 / 15.9	51.4 / 51.0
T05	China	30+30	1000	191.9	11.8 / 17.3	77.5 / 70.6	10.7 / 12.1	48.4 / 48.8
T09	Russia	30+30	100	32.7	15.8 / 17.2	67.8 / 66.7	16.4 / 16.0	54.6 / 54.6
T09	China	30+30	100	122.1	11.5 / 17.3	77.3 / 70.5	11.2 / 12.1	48.7 / 48.8
T09	Russia	30+30	1000	40.8	16.0 / 17.2	67.6 / 66.7	16.4 / 16.0	54.7 / 54.6
T09	China	30+30	1000	191.9	11.8 / 17.3	77.5 / 70.6	10.7 / 12.1	48.4 / 48.8
T03	DPRK	26+16	15	9.1	19.1 / 14.2	71.2 / 74.0	9.8 / 11.8	53.2 / 50.5
T03	Republic of Korea	26+16	15	15.7	13.2 / 13.2	72.8 / 71.6	13.9 / 15.2	51.0 / 51.1
T03	DPRK	26+16	100	11.4	19.1 / 14.3	71.2 / 73.8	9.7 / 12.0	53.2 / 50.6
T03	Republic of Korea	26+16	100	28.3	13.1 / 13.2	73.0 / 71.1	14.0 / 15.7	51.1 / 51.1
T03	Japan	16	100	32.2	12.2 / 12.7	62.0 / 61.3	25.8 / 26.0	51.1 / 51.2
T10	Israel	20	15	5.6	28.2 / 30.1	60.0 / 59.8	11.8 / 10.1	50.6 / 50.3
T10	Israel	20	100	9.1	28.4 / 29.6	60.1 / 60.3	11.5 / 10.1	50.5 / 50.3
T10	Iran	20	15	12.9	21.1 / 23.4	72.3 / 70.4	6.6 / 6.2	50.0 / 49.9
T10	Iran	20	100	22.8	21.1 / 23.4	72.4 / 70.4	6.5 / 6.2	50.0 / 49.9
T12	India	2	10	9.7	20.6 / 23.8	73.3 / 69.9	6.0 / 6.3	46.0 / 48.0
T12	India	10	10	32.5	21.0 / 26.2	73.1 / 67.3	5.9 / 6.5	46.4 / 47.7

Table 19: The fallout layer's residents inside the lethal-dose contour by sex and age against the units they live in, one line per struck side of each unit of Table 14. Columns as in Table 17. Sources: GHS-POP, release R2023A, epoch 2025; WorldPop 1 km unconstrained age-sex rasters, 2020; Overture Maps Foundation, Divisions, release 2026-08-19.0, admin level 1; author's calculations.

Theatre Struck		Weapons	kt	Exposed (m)	Under 15	15–64	65+	Female
T01	India	150+100	15	590.5	25.8 / 27.3	67.8 / 66.4	6.4 / 6.2	47.8 / 48.3
T01	Pakistan	150+100	15	194.1	33.6 / 32.1	61.9 / 62.7	4.5 / 5.2	48.2 / 48.0
T01	India	150+100	50	856.9	26.4 / 27.4	67.2 / 66.4	6.4 / 6.2	47.9 / 48.3
T01	Pakistan	150+100	50	229.6	33.8 / 32.1	61.6 / 62.8	4.6 / 5.2	48.3 / 48.0
T01	India	150+100	100	1,025.7	26.6 / 27.4	67.0 / 66.4	6.5 / 6.2	48.0 / 48.3
T01	Pakistan	150+100	100	244.0	33.8 / 32.1	61.6 / 62.7	4.6 / 5.2	48.2 / 48.0
T07	Russia	30+30	100	55.0	16.4 / 17.2	67.2 / 66.4	16.4 / 16.4	54.7 / 54.7
T07	United States	30+30	100	105.9	18.9 / 18.8	66.3 / 65.0	14.8 / 16.2	51.2 / 51.0
T07	Russia	30+30	1000	85.0	17.2 / 17.5	66.4 / 66.1	16.4 / 16.4	54.7 / 54.7
T07	United States	30+30	1000	142.4	18.8 / 18.7	65.7 / 65.0	15.5 / 16.3	51.1 / 51.0
T07	Russia	300+300	100	121.8	17.9 / 16.5	66.3 / 68.9	15.8 / 14.6	54.5 / 53.1
T07	United States	300+300	100	230.0	19.2 / 19.0	65.6 / 65.1	15.2 / 15.9	51.1 / 51.0
T07	Russia	300+300	1000	158.7	17.9 / 16.5	66.4 / 69.2	15.8 / 14.3	54.3 / 52.6
T07	United States	300+300	1000	299.4	18.8 / 19.0	65.2 / 65.0	16.0 / 16.0	51.1 / 51.0
T02	India	30+30	15	235.7	24.0 / 27.6	70.0 / 66.1	6.0 / 6.4	47.2 / 48.0
T02	China	30+30	15	253.6	12.2 / 17.2	76.9 / 70.7	10.9 / 12.1	48.5 / 48.8
T02	India	30+30	100	434.1	26.0 / 27.3	68.0 / 66.3	6.0 / 6.4	47.5 / 48.1
T02	China	30+30	100	425.0	13.4 / 17.2	75.2 / 70.7	11.4 / 12.1	48.5 / 48.8
T05	United States	30+30	100	105.9	18.9 / 18.8	66.3 / 65.0	14.8 / 16.2	51.2 / 51.0
T05	China	30+30	100	425.0	13.4 / 17.2	75.2 / 70.7	11.4 / 12.1	48.5 / 48.8
T05	United States	30+30	1000	142.4	18.8 / 18.7	65.7 / 65.0	15.5 / 16.3	51.1 / 51.0
T05	China	30+30	1000	863.8	15.6 / 17.2	72.3 / 70.8	12.1 / 12.1	48.7 / 48.8
T09	Russia	30+30	100	55.0	16.4 / 17.2	67.2 / 66.4	16.4 / 16.4	54.7 / 54.7
T09	China	30+30	100	425.0	13.4 / 17.2	75.2 / 70.7	11.4 / 12.1	48.5 / 48.8
T09	Russia	30+30	1000	85.0	17.2 / 17.5	66.4 / 66.1	16.4 / 16.4	54.7 / 54.7
T09	China	30+30	1000	863.8	15.6 / 17.2	72.3 / 70.8	12.1 / 12.1	48.7 / 48.8
T10	Israel	20	15	14.9	31.0 / 31.6	59.7 / 60.3	9.3 / 8.2	50.2 / 49.9
T10	Israel	20	100	24.4	31.9 / 32.0	60.6 / 61.2	7.5 / 6.8	49.7 / 49.6
T10	Iran	20	15	31.5	21.6 / 25.3	72.1 / 68.7	6.3 / 6.0	49.9 / 49.6
T10	Iran	20	100	36.9	22.0 / 25.3	71.7 / 68.7	6.3 / 6.0	49.9 / 49.6
T12	India	2	10	29.1	21.0 / 23.8	72.5 / 69.9	6.5 / 6.3	47.0 / 48.0
T12	India	10	10	113.1	21.8 / 25.5	72.5 / 67.9	5.8 / 6.6	46.6 / 47.9

The exposed are of working age in a higher proportion than the residents of the units they live in on the majority of struck sides in both layers: the share aged 15 through 64 is above the reference on 34 of the 39 struck sides of the direct layer and below it on 5, and above it on 25 of the 32 sides of the fallout layer and below it on 7. The share under 15 moves the other way, below the reference on 32 sides of the direct layer and 22 of the fallout layer. The share aged 65 and over is below the reference on 28 direct-layer sides and above it on 11, with none printing alike. The direction is the one the target sets imply: the aimpoints are the most populous places of each side, and the blast

zones around them hold a population of working age in a higher proportion than the provinces and states around them.

In the calibration theatre the direct layer carries the working-age excess on both sides at every yield, and the fallout layer does not: inside the contours cast on Pakistan, the share aged 15 through 64 is below that of the units the contours reach at every yield, since a contour of 73.3 km at 100 kt runs past the cities into the districts around them, while inside the contours cast on India it stays above. Figure 7 shows the two profiles at every band. On the Indian side of the direct layer the exposed sit above the reference in every band from 20 through 59 and below it in every band under 20; in the fallout layer the two Indian profiles differ by less than half a point in every band. On the Pakistani side the two profiles differ by less than one point in every band, in both layers.

The sex composition of the exposed follows that of the units they live in. The female share is above the reference on 19 sides of the direct layer and below it on 17, with 3 printing alike, and the largest difference in either layer, taken between the unrounded shares, is 2.6 points, on the DPRK side of T03 at 100 kt in the direct layer.



Figure 7: The age-sex composition of the exposed against the residents of the units they live in, T01 at 100 kt, for each struck side in each layer. The horizontal axis is the share of the population in each WorldPop band by sex, females to the left of zero and males to the right, in percent of residents with a known band; filled bars are the exposed residents and outlined bars the reference. Sources: GHS-POP, release R2023A, epoch 2025; WorldPop 1 km unconstrained age-sex rasters, 2020; Overture Maps Foundation, Divisions, release 2026-08-19.0; author's calculations.

Three limits of the construction hold for every number in this section. The age-sex shares are those of the 1 km cell, applied uniformly to the 100 m cells inside it, so a difference in composition at a finer grain than 1 km is not observed. The shares are for 2020 and the residents for 2025, from two sources whose totals differ; the shares are used as shares and the residents as residents, and no total is taken from the age-sex source. And the reference is the units the layer reaches, not the country: a unit reached by a single contour cell enters the reference whole, so the reference of a side with many small units near its border weighs those units by their whole population, which is stated here rather than adjusted for.

11 Mortality rates by unit of residence

Sections 8 through 10 report the exchange in residents and in their composition. This section states the quantity that keys to a life: a rate per resident of a unit of residence, conditional on the scenario. It is reported for the calibration theatre, whose totals are fitted to a published case, at 100 kt, and at the finest boundary grain the analysis carries, the level-1 unit of residence, identified by its International Organization for Standardization subdivision code (ISO 3166-2).

Two rates are stated for each unit. The exposure rate is the share of the unit's residents inside the direct zones—the severe, moderate, and light rings, which are exclusive and add—and is at most one. The mortality rate weights that exposure by the zones' fatality fractions, the severe ring at one and the moderate and light rings at one of the 156 admissible fraction pairs of Section 8, and is reported as the interval those pairs span, no pair averaged and no corner of the set a member. Both rates are conditional on the scenario: they carry no frequency, which the analysis does not supply and the reader does. The fallout contour is a count that bounds fallout fatalities, not an estimate of them, and is weighted by no fatality fraction, so it is not a mortality rate and is not stated here.

Table 20 reports the ten units of the Indian side and the seven of the Pakistani side that hold the most residents in the direct zones, 81.6 and 100.0 percent of each side's zone residents, ordered by the mortality rate. One unit of the Pakistani side lies in Afghanistan: Kandahar, across the border from Quetta, whose residents fall in the zones of a Pakistani target, since a cell counts toward the strike whose aimpoint is nearest it whichever country it lies in; for the same reason a unit of India, Punjab, is reached from the Pakistani side, at an exposure rate below the table's floor. Figure 8 draws the same units.

Table 20: Exposure and conditional mortality rates by level-1 unit of residence, T01 at 100 kt. The exposure rate is the share of the unit's residents inside the direct zones; the mortality rate is that exposure weighted by the zones' fatality fractions, as the interval over the 156 admissible pairs. Both are per resident and conditional on the scenario. Units are the ten of each struck side with the most residents in the direct zones, among those whose exposure rate is at least 0.05 percent, or every such unit of a side that holds fewer, ordered by the mortality rate, and are labeled by ISO 3166-2 code and subdivision name; exposed residents are in millions. Sources: GHS-POP, release R2023A, epoch 2025; Overture Maps Foundation, Divisions, release 2026-08-19.0, admin level 1; author's calculations.

ISO 3166-2	Unit of residence	Exposed (m)	Exposure rate	Mortality rate
<i>India struck by Pakistan</i>				
IN-DL	Delhi	20.4	0.916	0.217–0.226
IN-GJ	Gujarat	21.4	0.288	0.109–0.119
IN-MH	Maharashtra	44.2	0.337	0.108–0.114
IN-WB	West Bengal	26.0	0.251	0.083–0.087
IN-KL	Kerala	11.9	0.258	0.070–0.073
IN-UP	Uttar Pradesh	47.9	0.197	0.064–0.066
IN-KA	Karnataka	17.6	0.239	0.062–0.065
IN-TN	Tamil Nadu	17.6	0.209	0.050–0.052
IN-MP	Madhya Pradesh	11.0	0.124	0.037–0.039
IN-BR	Bihar	11.6	0.087	0.033–0.034
<i>Pakistan struck by India</i>				
PK-SD	Sindh	28.7	0.510	0.173–0.184
PK-PB	Punjab	54.3	0.421	0.146–0.154
PK-BA	Balochistan	3.7	0.248	0.113–0.118
PK-IS	Islamabad	1.7	0.711	0.105–0.115
PK-KP	Khyber Pakhtunkhwa	13.3	0.322	0.098–0.102
PK-JK	Azad Jammu and Kashmir	0.7	0.157	0.082–0.086
AF-KAN	Kandahar	0.1	0.039	0.000–0.002

The two rates order the units differently, because a unit's exposure can fall mostly in the light ring, whose fatality fraction is near zero, or mostly in the severe ring, whose fraction is one. On the Pakistani side Islamabad carries the highest exposure rate, 0.711, and a mortality rate of 0.105 through 0.115, while Sindh, exposed at 0.510, carries the highest mortality rate, 0.173 through 0.184: the more-exposed unit is not the deadlier one. The mortality interval is narrow throughout—0.173 through 0.184 for the widest of the printed units—because the severe ring, at fatality one, fixes the greater part of the rate and only the moderate and light rings vary across the pairs.



Figure 8: Exposure rate and conditional mortality rate by level-1 unit of residence, T01 at 100 kt, for each struck side. Units are keyed by ISO 3166-2 code, with the subdivision names in Table 20, and ordered by the mortality rate. The blue marker is the exposure rate and the maroon marker the mortality rate, whose interval over the 156 fraction pairs is narrow enough to read as a point. Both rates are per resident and conditional on the scenario. Sources: GHS-POP, release R2023A, epoch 2025; author's calculations.

Three properties of the rate bound its use. It is conditional on the scenario and carries no frequency, so it is not an annual rate; a reader multiplies it by a scenario probability the analysis does not supply. It is a level-1 rate, an average over the hit and unhit parts of a state or province, so a population located finer than the level-1 unit reads a rate coarser than its own grain. And the rate is stated per unit and not by age or sex: the exposed carry the age-sex composition of the unit they live in to within the differences Section 10 reports, which arise within the unit, the blast zones holding a population of working age in a higher proportion than the units around them, and a population whose age and sex composition differs from the unit's is matched at the grain Section 10 reports.

12 Damage ratios by level-1 unit

Section 11 keys a rate to a life. This section keys a damage ratio to a structure: the built-up volume destroyed in the direct zones over the built-up volume the unit holds, conditional on the scenario. The exposure surface is the built-up volume of the Global Human Settlement Layer, GHS-BUILT-V, release R2023A, epoch 2025, on the same 100 m World Mollweide grid as the population surface,

so the property layer re-weights the severe, moderate, and light rings the casualty layers already use, with built-up volume in place of residents and a per-ring damage fraction in place of a fatality fraction. The measure is physical—built-up volume in cubic meters, all use classes, not a monetary value—so a reader who wants a currency figure applies a cost per cubic meter the analysis does not supply.

The ring damage fractions are bounds, not a fit. The severe ring loses 0.90 through 1.00 of its built-up volume, the moderate ring 0.30 through 0.70, and the light ring 0.03 through 0.15, judgment bounds on the qualitative damage descriptions of the planning guidance's second edition³² and the Glasstone–Dolan overpressure–damage relations, neither of which states a fraction of volume destroyed. Unlike the fatality fractions of Section 8, which are identified by reproducing a published fatality aggregate, no published property-loss aggregate exists to calibrate against, so the loss is carried as the interval those independent bounds span, which is wider than the fatality set's for that reason rather than from any added uncertainty in the exposure. The loss is blast only: fire is a separate upward bound the analysis does not add here, and fallout denies use without destroying structure and is not carried.

Across the 39 direct-layer scenario sides the library runs, the built-up volume in the direct zones is 1,010 billion cubic meters, and the volume destroyed is 207 through 383 billion cubic meters over the damage-fraction bounds. Table 21 reports the calibration theatre at the level-1 unit of residence, the ten units of the Indian side and the seven of the Pakistani side with the most built-up volume in the direct zones, 74.8 and 100.0 percent of each side's zone volume, ordered by the damage ratio. Figure 9 draws the same units.

³²National Security Staff Interagency Policy Coordination Subcommittee for Preparedness and Response to Radiological and Nuclear Threats, *Planning Guidance for Response to a Nuclear Detonation*, 2nd ed. (Washington, DC: Federal Emergency Management Agency, 2010).

Table 21: Built-up-volume exposure and conditional damage ratio by level-1 unit of residence, T01 at 100 kt. The exposure is the share of the unit's built-up volume inside the direct zones; the damage ratio is the volume destroyed over the unit's whole built-up volume, as the interval over the ring damage-fraction bounds. Both are conditional on the scenario. Units are the ten of each struck side with the most built-up volume in the direct zones, among those whose exposure is at least 0.05 percent, or every such unit of a side that holds fewer, ordered by the damage ratio, and are labeled by ISO 3166-2 code and subdivision name; built-up volume in zones is in billion cubic meters. Sources: GHS-BUILT-V, release R2023A, epoch 2025; Overture Maps Foundation, Divisions, release 2026-08-19.0, admin level 1; author's calculations.

ISO 3166-2	Unit of residence	In zones (bn m ³)	Exposure	Damage ratio
<i>India struck by Pakistan</i>				
IN-DL	Delhi	2.55	0.892	0.142–0.292
IN-MH	Maharashtra	5.47	0.307	0.070–0.126
IN-UP	Uttar Pradesh	5.78	0.269	0.064–0.111
IN-WB	West Bengal	2.68	0.312	0.049–0.101
IN-GJ	Gujarat	2.99	0.260	0.053–0.100
IN-TN	Tamil Nadu	2.93	0.229	0.038–0.077
IN-PB	Punjab	1.65	0.210	0.039–0.076
IN-TS	Telangana	1.62	0.273	0.031–0.074
IN-MP	Madhya Pradesh	1.53	0.164	0.037–0.067
IN-KA	Karnataka	2.02	0.193	0.034–0.066
<i>Pakistan struck by India</i>				
PK-SD	Sindh	2.38	0.512	0.131–0.225
PK-IS	Islamabad	0.46	0.730	0.095–0.216
PK-BA	Balochistan	0.32	0.418	0.138–0.214
PK-PB	Punjab	7.38	0.441	0.123–0.204
PK-KP	Khyber Pakhtunkhwa	1.80	0.386	0.098–0.167
PK-JK	Azad Jammu and Kashmir	0.13	0.170	0.077–0.108
AF-KAN	Kandahar	0.01	0.095	0.003–0.014

Exposure and damage ratio order the units differently, for the same reason the two rates of Section 11 do: a unit's volume can fall mostly in the light ring, whose damage fraction is 0.03 through 0.15, or mostly in the severe ring, whose fraction approaches one. On the Pakistani side Punjab holds the most built-up volume in the zones, at a damage ratio of 0.123 through 0.204, while Sindh carries the highest upper end of the damage ratio, 0.131 through 0.225; on the Indian side Uttar Pradesh holds the most volume and Delhi, the capital territory, the highest damage ratio, 0.142 through 0.292, on an exposure of 0.892. The loss interval is wider than the mortality interval of Section 11, chiefly because the moderate and light rings' damage fractions span 0.30 through 0.70 and 0.03 through 0.15, wider than the spread of the fatality fractions over the admissible pairs.



Figure 9: Built-up-volume exposure and conditional damage ratio by level-1 unit of residence, T01 at 100 kt, for each struck side. Units are keyed by ISO 3166-2 code, with the subdivision names in Table 21, and ordered by the damage ratio. The blue marker is the exposure and the maroon marker the damage ratio, drawn as its interval over the ring damage-fraction bounds. Both are conditional on the scenario. Sources: GHS-BUILT-V, release R2023A, epoch 2025; author's calculations.

The damage ratio bounds its use as the mortality rate does. It is conditional on the scenario and carries no frequency. It is a level-1 fraction, an average over the hit and unhit parts of a unit, so property concentrated finer than the level-1 unit reads a ratio coarser than its own grain. And it is a fraction of physical volume, not of value: where a unit's cost per cubic meter departs from the unit average—a central business district against its hinterland—the value damage ratio departs from the volume damage ratio, and a reader with a cost surface applies it in place of the flat assumption here.

13 The fire zone

Section 12 is blast only. Thermal radiation is the other mechanism that destroys built stock, and above roughly a hundred kilotons its reach can rival the blast rings. This section adds the fire zone as a second property loss, on the same built-up-volume surface and the same units, reported beside the blast loss and never summed with it, since the two mechanisms destroy overlapping stock, as the close of this section states.

The fire zone is a disc set by a thermal-fluence threshold. 35 percent of an airburst's yield is released as thermal radiation, and the radiant exposure falls with the square of distance, so the radius to a fixed fluence follows from energy conservation; the analysis uses it unattenuated, which makes it an upper bound, since atmosphere only shrinks it, as the close of this section measures. The threshold is carried as a bound, from light-kindling ignition at the outer edge, 5 calories per square centimeter, to heavier-fuel ignition at the core, 20, the range of Glasstone and Dolan's ignition exposures,³³ so the disc is an interval. Within it the fire damage ratio runs from the isolated-fire regime, 0.20 of the built-up volume in the disc, to the mass-fire regime, 0.90, judgment bounds and not a fit; whether a mass fire develops bears on how much burned material is lofted, one of the questions behind the soot debate of Section 5, and the interval is stated rather than resolved.

Across the 39 direct-layer scenario sides, the built-up volume within the outer fire disc is 843 billion cubic meters, and the volume the fire would destroy is 91 through 758 billion cubic meters over the extent and severity bounds. The interval is wider than the blast layer's 207 through 383 billion, because both the disc's extent and the fire's severity are uncertain where the blast rings' radii are fixed; its upper end exceeds the blast layer's, because the mass-fire fraction applies to the whole of the outer disc. Table 22 reports the calibration theatre at the level-1 unit, the ten units of the Indian side and the seven of the Pakistani side with the most built-up volume in the fire disc, 74.8 and 100.0 percent of each side's disc volume, ordered by the fire damage ratio.

³³Glasstone and Dolan, *Effects of Nuclear Weapons*, table 7.40.

Table 22: Built-up-volume share in the fire disc and conditional fire damage ratio by level-1 unit of residence, T01 at 100 kt. The share is the unit's built-up volume inside the outer fire disc over its whole built-up volume; the fire damage ratio is the volume destroyed over the whole, as the interval from the inner disc times the isolated-fire fraction to the outer disc times the mass-fire fraction. Both are conditional on the scenario and are the fire mechanism alone, not summed with the blast loss of Table 21. Units are the ten of each struck side with the most built-up volume in the fire disc, among those whose share in the disc is at least 0.05 percent, or every such unit of a side that holds fewer, ordered by the fire damage ratio. Sources: GHS-BUILT-V, release R2023A, epoch 2025; Glasstone and Dolan; Overture Maps Foundation, Divisions, release 2026-08-19.0, admin level 1; author's calculations.

ISO 3166-2	Unit of residence	In fire disc	Fire damage ratio
<i>India struck by Pakistan</i>			
IN-DL	Delhi	0.696	0.054–0.627
IN-MH	Maharashtra	0.255	0.026–0.230
IN-WB	West Bengal	0.219	0.018–0.198
IN-UP	Uttar Pradesh	0.218	0.022–0.196
IN-GJ	Gujarat	0.216	0.020–0.194
IN-KL	Kerala	0.212	0.019–0.191
IN-PB	Punjab	0.172	0.015–0.155
IN-TN	Tamil Nadu	0.170	0.014–0.153
IN-KA	Karnataka	0.147	0.012–0.132
IN-MP	Madhya Pradesh	0.139	0.014–0.125
<i>Pakistan struck by India</i>			
PK-IS	Islamabad	0.534	0.038–0.480
PK-SD	Sindh	0.438	0.048–0.394
PK-BA	Balochistan	0.374	0.046–0.337
PK-PB	Punjab	0.373	0.043–0.335
PK-KP	Khyber Pakhtunkhwa	0.306	0.034–0.275
PK-JK	Azad Jammu and Kashmir	0.143	0.023–0.129
AF-KAN	Kandahar	0.069	0.000–0.062

Fire and blast do not order the units alike, and neither dominates everywhere. In Delhi, the Indian capital territory, the fire damage ratio runs 0.054 through 0.627 against the blast layer's 0.142 through 0.292: the isolated-fire floor sits below the blast loss, while the mass-fire ceiling rises above it. That is the general shape—fire's lower bound is the gentler of the two and its upper bound the more severe—and it is why the two are carried apart. The combined structural loss, were a reader to form it, is in each cell at least the larger of the two mechanisms and at most their sum, so per unit it lies between the greater single-mechanism loss and their sum; the analysis states that bound rather than adding the layers into one number.



Figure 10: Built-up-volume share in the fire disc and conditional fire damage ratio by level-1 unit of residence, T01 at 100 kt, for each struck side. Units are keyed by ISO 3166-2 code, with the subdivision names in Table 22, and ordered by the fire damage ratio. The blue marker is the share of the unit's built-up volume in the fire disc and the maroon marker the fire damage ratio, drawn as its interval from the isolated-fire to the mass-fire regime. Both are conditional on the scenario. Sources: GHS-BUILT-V, release R2023A, epoch 2025; Glasstone and Dolan; author's calculations.

The fire damage ratio carries the same cautions as the blast one and three of its own. It is conditional on the scenario and a level-1 average. Its radius is an unattenuated upper bound, so the disc is at its widest, and atmospheric attenuation narrows it. And its severity interval is wide by construction, spanning a regime question—whether isolated fires merge into a mass fire—that the literature has not closed; the width is what that question leaves open, not a defect of the measure. Two constants the disc rests on are held fixed where the source varies them, and both err toward a larger disc. The thermal share is the air-burst 35 percent for every row, where Glasstone and Dolan give a contact surface burst an effective share about half as large,³⁴ which would shorten the unattenuated radius by about three tenths for cells that burst at the surface; and the ignition thresholds are held at every yield where the source's rise with it, so at a megaton the outer disc is wider than the source would draw it.

The atmosphere absorbs and scatters thermal radiation, so the fluence at range is the unattenuated value times a transmittance below one, and the fire radius that meets an ignition threshold is

³⁴Glasstone and Dolan, *Effects of Nuclear Weapons*, chap. 7.

smaller than the energy-conservation radius. A clear-day reference, at a visibility of twenty kilometers, is carried beside the unattenuated radius, the transmittance taken as the Koschmieder visual-band extinction fixed by that visibility.³⁵ Because the visual band attenuates a thermal source more than its near-infrared content is attenuated in fact, the attenuated radius understates the footprint and is a lower bound, and the true extent lies between it and the unattenuated disc. The effect grows with range: at a megaton the outer disc falls from about twenty-four kilometers unattenuated to about nine at the clear-day floor, while at fifteen kilotons it draws in only from under three kilometers to a little above two. Both radii are reported. The fire figures of this section's tables and of Section 14 are the unattenuated ceiling, and Section 14.1 states the clear-day floor beside it for the envelope total.

14 A value denominated in money

Sections 12 and 13 report a physical loss—built-up volume destroyed—and a damage ratio of a unit's built-up volume. What is at stake is value, not volume. This section carries the physical loss into money.

The value destroyed in a unit is the built-up volume destroyed there times the value of a cubic meter of built stock, summed over the unit. With the cost per cubic meter held flat within a level-1 unit, the per-unit value damage ratio equals the volume damage ratio the property and fire sections already report—the cost cancels—so what money adds is the absolute value destroyed and the aggregation across units by capital at risk. The construction reduces to one line: the value destroyed in a unit is the nation's produced capital, apportioned to the unit by its share of national non-agricultural output, times the unit's damage ratio. The national built-up volume a cost-per-cubic-meter surface would need cancels from this form: such a surface prices a unit at national capital over national volume times the unit's volume, which is national capital times the unit's share of national volume, the form above on the volume basis.

The national produced capital is the Penn World Table's capital stock (the variable *cn*, at current purchasing-power parities, for 2019): 34.10 trillion 2017 U.S. dollars for India and 1.67 trillion for Pakistan. The output shares are each unit's manufacturing-plus-services output over its country's, from DOSE, the Global Data Set of Reported Sub-national Economic Output, on the construction's assumption that non-agricultural output tracks built capital more closely than total output, whose agricultural part is land- rather than building-based. Two properties of the measure are stated rather than assumed. It is a net stock of produced capital at current cost, written down by depreciation and so below its replacement cost new—all fixed assets, broader than built structures. And it is denominated at purchasing-power parity, which sits above the market-exchange cost of rebuilding in a lower-income economy, so a reader converting at market rates would scale it down.

Table 23 reports the calibration theatre at the level-1 unit, booking each unit's value to its own country. On the Indian units the value destroyed by blast is 1,712.9 through 3,241.4 billion 2017 U.S. dollars across the 24 matched units, against a capital at risk of 33.40 trillion, a value-weighted blast damage ratio of 0.051 through 0.097. On the Pakistani units the blast value is 206.0 through 345.7 billion across 4 units, on 1.67 trillion of capital at risk, a value-weighted damage ratio of 0.123 through 0.207—above India's, because the Pakistani units struck lose a larger fraction of their built-up volume to blast (Table 21). The fire value is reported apart and never summed with

³⁵Harald Koschmieder, "Theorie der horizontalen Sichtweite," *Beiträge zur Physik der freien Atmosphäre* 12 (1924): 33–53, 171–181.

the blast: 632.9 through 6,250.5 billion on the Indian units and 72.9 through 580.4 billion on the Pakistani, the wider interval and higher ceiling the fire section set out.

Table 23: Capital at risk and conditional value destroyed by level-1 unit of residence, T01 at 100 kt, in billions of 2017 U.S. dollars at purchasing-power parity. Capital at risk is the unit's produced capital—the nation's Penn World Table capital stock apportioned by the unit's share of national non-agricultural output. Blast and fire value destroyed are that capital times the unit's damage ratio of Tables 21 and 22, conditional on the scenario, reported apart and not summed. The blast value is given on both share bases: the output basis, which is the one applied to India and Pakistan, and the built-up-volume basis the same unit would take if output data did not reach it, the two bracketing the effect of the basis. The capital at risk and the fire value are on the applied basis. Units are the ten of each country with the most blast value destroyed, or every valued unit of a country that holds fewer, booked to their own country. Sources: Penn World Table 10.01 (*cn*); DOSE version 2.14; GHS-BUILT-V, release R2023A, epoch 2025; author's calculations.

ISO 3166-2	Unit of residence	Capital at risk (bn 2017 U.S.\$)	Blast value lost		Fire value lost (bn 2017 U.S.\$)
			Output basis (bn 2017 U.S.\$)	Volume basis (bn 2017 U.S.\$)	
India					
IN-MH	Maharashtra	4,911.4	345.9–619.6	246.8–442.2	128.1–1,128.8
IN-DL	Delhi	1,604.7	228.4–467.8	80.2–164.2	87.2–1,005.6
IN-UP	Uttar Pradesh	2,716.0	174.9–301.9	273.3–471.8	60.0–532.6
IN-GJ	Gujarat	2,650.7	141.6–266.0	121.1–227.4	54.1–515.2
IN-TN	Tamil Nadu	3,262.0	123.6–250.5	95.8–194.0	47.2–499.4
IN-WB	West Bengal	1,951.3	96.5–196.9	83.9–171.1	35.6–385.4
IN-KA	Karnataka	2,943.1	99.8–195.6	70.2–137.6	36.5–389.7
IN-KL	Kerala	1,541.5	81.8–154.1	58.4–110.1	29.8–294.3
IN-TS	Telangana	1,574.4	49.3–116.1	36.6–86.2	18.2–272.4
IN-MP	Madhya Pradesh	1,101.0	40.7–73.5	68.0–122.8	15.3–137.5
Pakistan					
PK-PB	Punjab	825.2	101.4–168.2	121.4–201.3	35.6–276.7
PK-SD	Sindh	560.1	73.5–126.3	36.0–61.9	26.6–220.6
PK-KP	Khyber	205.1	20.1–34.3	26.9–45.9	7.0–56.4
PK-BA	Pakhtunkhwa	79.4	11.0–17.0	6.3–9.8	3.6–26.7
	Balochistan				

The calibration theatre leaves 4 struck units without a value figure: Kandahar, Puducherry, Islamabad, and Azad Jammu and Kashmir. Kandahar lies in Afghanistan, which the Penn World Table does not carry; Puducherry is absent from the subnational output data at India's year, the source carrying it through 2014 only, and Islamabad and Azad Jammu and Kashmir lie outside its four-province coverage of Pakistan; their physical loss still stands in the property and fire sections. The four provinces' output shares sum to one, so the output of the two uncovered units is carried by the provinces, whose capital at risk is overstated by that output's share of the country. The data do not give it; on built-up volume the two hold 2.2 and 2.6 percent of the country. Pakistan's output shares are the most recent complete year the data holds for it, 2004, against India's 2019; the shares are within-country weights applied to 2019 capital, so the older distribution is an approximation, not a mixing of price levels across years.

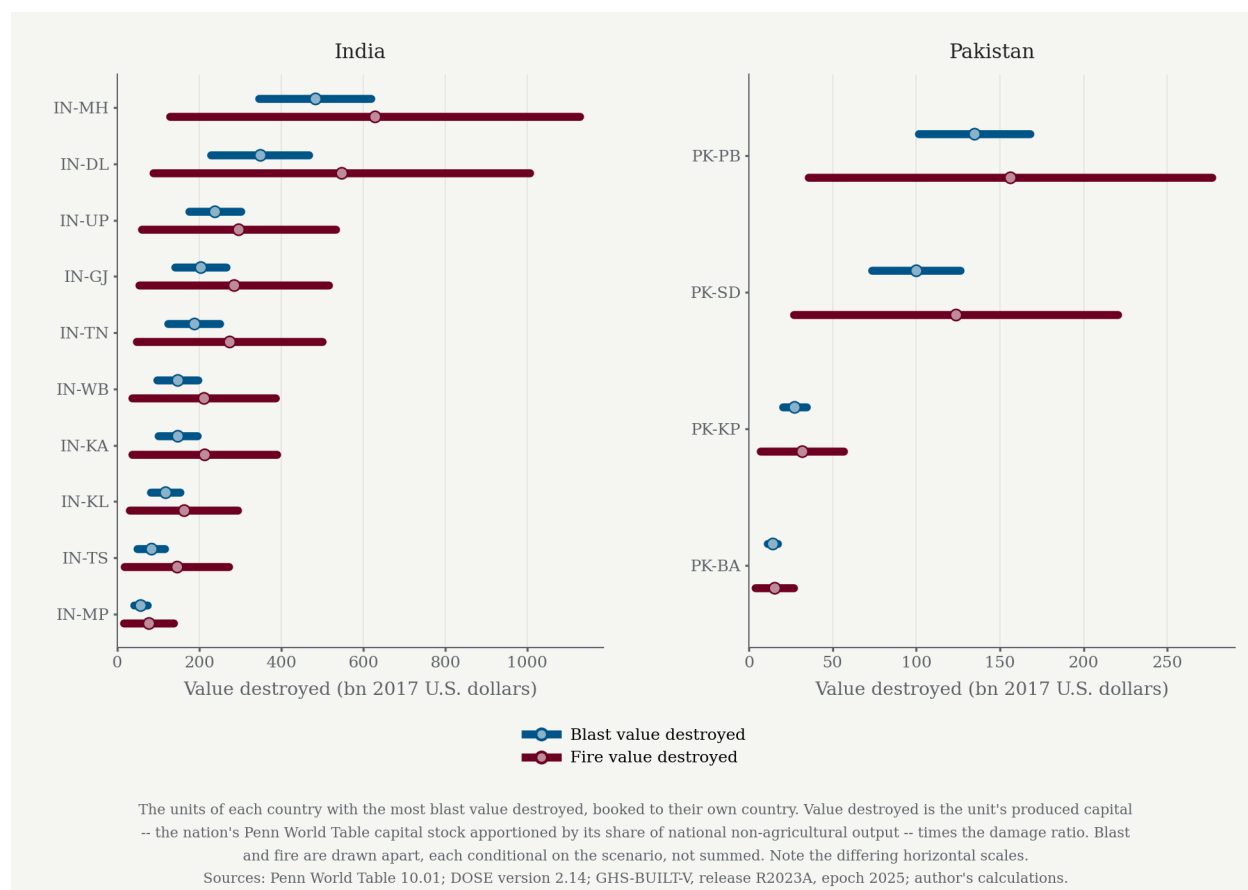


Figure 11: Conditional value destroyed by level-1 unit of residence, T01 at 100 kt, in billions of 2017 U.S. dollars at purchasing-power parity, for each country. Units are keyed by ISO 3166-2 code, with the subdivision names in Table 23, ordered by the blast value destroyed. The blue interval is the blast value and the maroon the fire value, each conditional on the scenario and reported apart. Sources: Penn World Table 10.01 (cn); DOSE version 2.14; GHS-BUILT-V, release R2023A, epoch 2025; author's calculations.

14.1 Across the theatres

The same construction reaches every struck country with a capital series. Where DOSE reaches, a unit's share is its non-agricultural output over the nation's; where it does not, the share is a unit's built-up volume over the country's whole built-up volume, which places capital where building is and needs no output data. That whole-country built-up volume is already in hand: the property denominator was tiled over every level-1 unit, struck or not, so a partly struck country takes its struck units' true share of national capital and leaves the unstruck remainder out of the zones. On that basis Israel, Lebanon, Hong Kong, and Bangladesh, which DOSE does not hold, enter on built-up volume, as do Ukraine and Canada, for which DOSE holds no year in which every region carries non-agricultural output, and Russia, whose DOSE regions do not match its level-1 units one for one—including where only part of a country is struck, as in Hong Kong, whose northern districts are reached while its dense core is not, and in Canada, whose two struck provinces hold three fifths of its built-up volume. DOSE holds a region for each of those Canadian provinces but no year in which every Canadian region carries the population data its output figure needs, so the nation's total cannot be formed from it without an assumption; Canada's other-basis figure takes the twelve

regions that carry data, Newfoundland and Labrador lacking it. Because value is a capital stock and not a per-scenario flow, each unit is counted once at its worst modeled strike, the worst taken by blast value—the envelope of capital at risk, not a sum across hypothetical exchanges. A unit's fire column is then the fire value of that same strike rather than of its own worst, so a country's fire figure here can sit below the figure a single theatre gives it.

Table 24 reports the 23 struck countries so reached, 238 units in all. The capital at risk across them is 283.41 trillion 2017 U.S. dollars at purchasing-power parity; the value destroyed is 23.56 through 40.48 trillion by blast and, apart and not summed, 10.68 through 78.92 trillion by fire. The most value destroyed is carried by the United States and the most capital at risk held by China: a strike across the provinces that hold most of a large economy's capital puts a large capital stock at risk and destroys a small fraction of it, where a denser or more heavily struck country loses a larger share of a smaller base. The fire figure is the unattenuated upper bound; the atmosphere absorbs and scatters thermal radiation, so on a clear day, at a visibility of twenty kilometers, the fire value destroyed falls to 6.41–45.43 trillion, a fraction 0.58 of the unattenuated ceiling at the upper bound (Section 13). The two bracket the atmospheric uncertainty. Capital at risk is the produced capital of the struck units, not the value destroyed: the second is the first times the damage ratio, and the gap between them is what the terms of a particular application and the scenario's severity decide.

The two share bases do not agree, so the table carries both. They part company on metropolitan ground: where a level-1 unit is a city, its output share runs several times its built-volume share, output per cubic meter of built stock standing above the country's average there, while a large province takes much the same share either way. Every struck unit the other source reaches is therefore priced on that basis too, which is exact rather than approximate, the value being linear in the share, except Canada's, whose output share is taken over twelve of its thirteen regions. Of the 238 units, 220 carry both bases and 18 carry one, those last holding 1 percent of the blast value at the upper end; 17 of the 23 countries carry a figure on both, and the 6 that do not are Bangladesh, Hong Kong, Israel, Lebanon, Russia, and Ukraine.

Across the envelope the choice is worth this much. Read with every country on built-up volume, the blast value destroyed falls from 23.56–40.48 to 20.38–34.65 trillion, 14 percent below; with every unit the output source reaches put on output, Russia's among them, it rises to 23.95–41.27 trillion, 2 percent above. The table as built sits near the upper of those, the countries on the output basis carrying most of the value. The gradient of Section 14.2 narrows the spread to 12 percent below and 0 percent above, because weighting a unit's cost by its own built-up-volume density lifts the same metropolitan ground the output basis lifts: the two corrections raise the same units, and applying either leaves less for the other to raise. Table 25 sets both readings under its envelope total, so the basis and the gradient can be read together.

Table 24: Capital at risk and conditional value destroyed by struck country, each unit at its worst modeled strike, in 2017 U.S. dollars at purchasing-power parity. The share basis is a unit's non-agricultural output over the nation's (output) or its built-up volume over the country's (volume, where the struck units span the territory, or over the whole country where they do not). Blast and fire are reported apart and not summed. A dagger marks a country the other source does not reach in every valued unit; it is carried on volume and prints no other-basis figure. Three entities the strikes reach are absent: the DPRK and Afghanistan for want of a capital series, and the West Bank, whose capital two national accounts share along a line the boundary source does not draw; the physical loss of all three stands in the property and fire records. Two units of valued countries take no value figure either: Korea's Sejong, which the output data carry only after Korea's latest complete year, and Iran's Kurdistan, for which they hold no region. Sources: Penn World Table 10.01 (cn); DOSE version 2.14; GHS-BUILT-V, release R2023A, epoch 2025; author's calculations.

Struck country	Share basis	Capital at risk (tn 2017 U.S.\$)	Blast value lost		Fire value lost (bn 2017 U.S.\$)
			Applied (bn 2017 U.S.\$)	Other basis (bn 2017 U.S.\$)	
United States	output	63.14	9,826.1– 16,562.6	8,207.0– 14,102.0	5,023.7– 31,305.2
Russia [†]	volume	17.76	5,497.4– 7,528.5	—	1,903.7– 10,173.9
China	output	92.92	3,011.6–5,784.6	2,593.3– 4,909.3	1,772.6– 14,790.8
India	output	33.40	1,712.9–3,241.4	1,559.7– 2,898.6	632.9–6,250.5
Japan	output	13.27	925.8–2,043.1	506.8–1,158.1	380.0–4,796.7
South Korea	output	9.84	841.4–1,657.6	668.0–1,312.2	299.2–3,559.5
Iran	output	2.87	262.6–539.1	217.1–430.8	100.3–1,271.8
Israel [†]	volume	1.16	244.5–398.1	—	82.3–663.3
Spain	output	4.45	187.2–396.1	105.9–221.4	73.2–809.8
France	output	5.33	147.5–374.6	54.2–137.6	55.5–812.1
Pakistan	output	1.67	206.0–345.7	190.6–318.8	72.9–580.4
Turkey	output	4.13	147.7–330.3	75.4–169.6	52.0–636.4
Germany	output	5.98	132.8–281.9	94.0–195.2	47.0–567.3
Italy	output	5.82	123.0–277.1	96.4–216.9	44.4–593.6
Greece	output	1.14	77.5–185.8	49.3–118.2	29.5–418.8
Canada	volume	5.08	77.5–165.0	76.4–161.5	27.2–320.9
Mexico	output	1.04	76.8–147.3	78.5–152.1	42.3–358.0
Hong Kong [†]	volume	1.25	26.5–116.7	—	29.7–786.5
United Kingdom	output	12.26	38.4–102.9	36.9–98.7	13.6–227.3
Bangladesh [†]	volume	0.52	0.1–0.4	—	0.0–0.6
Ukraine [†]	volume	0.28	0.0–0.0	—	0.0–0.0
Kazakhstan	output	0.04	0.0–0.0	0.0–0.0	0.0–0.0
Lebanon [†]	volume	0.06	0.0–0.0	—	0.0–0.0

Three limits travel with the table. Coverage is a country's struck share of its own capital, not a claim on the whole: a country whose struck units hold a small part of its capital shows a small capital at risk, whatever the count of units struck. The two bases are not identical—output weights toward services and manufacturing, volume toward where building concentrates—so a country's figure carries the basis it was built on. And the DPRK and Afghanistan, without a published capital

series, and the West Bank, whose capital two national accounts share, take no value figure rather than a filled one; their physical loss stands in the property and fire records.

14.2 The sub-unit cost gradient

Apart from the comparison anticipated in Section 14.1, every value figure to this point weights each cubic meter of a unit's built-up volume equally: the damage ratio is the volume destroyed over the unit's whole volume, and a strike that lands on a provincial capital counts the capital's fabric no more heavily than the periphery's. Capital is not spread evenly across a unit; it concentrates where building concentrates, and a strike aimed at a city lands on the concentration. A cost gradient that lifts the weight of denser ground raises the value destroyed by a strike that finds the core and lowers it for one that spares it.

The gradient is formed without a new data source. Each raster cell is assigned a cost weight proportional to its own built-up volume—dense ground costs more per cubic meter—so a cell's value is its volume squared, and the density-weighted damage ratio is the sum of the squared built-up volumes of the cells in the struck zones over the same sum on the unit's whole extent,

$$\text{damage ratio}_{\text{density}} = \frac{\sum_{\text{zones}} f_{\text{zone}} (\sum v^2)_{\text{zone}}}{(\sum v^2)_{\text{unit}}}, \quad (2)$$

with v the cell's built-up volume and f_{zone} the same ring or disc damage fractions as before. It introduces no fitted parameter, its exponent of two being the assumption stated below, and is computed on the same cells by the same rasterizer as the volume-flat fraction; the identity holds for any per-cell cost weight, so another proxy—night-time radiance, a gridded product—can take the place of built-up volume. The construction is unit-preserving: the unit's capital at risk, national capital times the unit's share, is untouched; only the damage ratio gains a concentration-sensitive companion.

The two fractions are reported as a band, not one in place of the other, because neither is the truth. The volume-flat fraction treats core and periphery alike, so it understates a strike that finds the core and overstates one that spares it; the density-weighted fraction lifts the core, so it does the reverse. What the two support is that the value destroyed lies between them, and the support holds on a condition: the flat weight makes a cell's value proportional to its built-up volume and the density weight to the square of it, so the two bracket the concentration effect for a cost weight whose exponent in that volume lies between one and two, provided a unit's damage ratio moves in one direction as the exponent rises. That holds where the cells the strike reaches are all denser, or all less dense, than the rest of the unit, and need not hold where the two interleave; whether any unit is of the second kind is not measured. The exponent is an assumption, not a measurement. It would sit above two if capital per cubic meter rose faster than density itself—a central business district's fit-out, plant, and buried services against a suburb's—and below one if the dense ground were the cheaper per cubic meter, which neither the literature nor this construction asserts. Outside that range the pair is a pair of bounds in one direction rather than a bracket, and the band is read accordingly. Across the envelope, weighting by density raises the blast value destroyed from 23.56–40.48 to 35.94–58.44 trillion 2017 U.S. dollars—a factor of 1.44 at the upper bound—and the fire value from 10.68–78.92 to 15.09–103.24 trillion, a factor of 1.31. The gradient is carried for every one of the 238 units, each with its sum of squared volumes on its whole extent, so the density totals and the volume-flat totals run over the same units. Table 25 sets the two side by side, country by country.

Table 25: The sub-unit cost gradient: value destroyed under the volume-flat damage ratio and under the density-weighted damage ratio, by struck country, each unit at its worst modeled strike. The density weight is built-up-volume density (a cell's cost proportional to its own built-up volume), so the two bracket the concentration effect rather than assert a point estimate. The two rows beneath the envelope total read the same envelope with every country on one share basis and then on the other, so the table carries both axes of the construction: where capital sits within a country, and how it is weighted within a unit. The fire density column carries no entry on those rows. Country rows are in billions of 2017 U.S. dollars at purchasing-power parity; the envelope-total rows are in trillions. Blast and fire are reported apart and not summed. Sources: Penn World Table 10.01 (*cn*); DOSE version 2.14; GHS-BUILT-V, release R2023A, epoch 2025; author's calculations.

Struck country	Blast value lost		Fire value lost	
	Volume-flat (bn 2017 U.S.\$)	Density (bn 2017 U.S.\$)	Volume-flat (bn 2017 U.S.\$)	Density (bn 2017 U.S.\$)
United States	9,826.1– 16,562.6	13,767.4– 22,021.0	5,023.7– 31,305.2	6,453.5– 37,406.2
Russia	5,497.4–7,528.5	7,942.4– 10,392.4	1,903.7– 10,173.9	2,523.1– 12,496.9
China	3,011.6–5,784.6	6,096.3– 10,485.6	1,772.6– 14,790.8	3,123.1–21,666.1
India	1,712.9–3,241.4	3,297.0–5,905.0	632.9–6,250.5	1,174.2– 10,987.0
Japan	925.8–2,043.1	1,101.0–2,368.2	380.0–4,796.7	447.4–5,485.3
South Korea	841.4–1,657.6	1,040.8–1,948.2	299.2–3,559.5	356.6–4,086.6
Iran	262.6–539.1	312.7–626.5	100.3–1,271.8	116.9–1,468.8
Israel	244.5–398.1	296.3–459.6	82.3–663.3	96.2–735.1
Spain	187.2–396.1	309.9–610.9	73.2–809.8	119.6–1,189.2
France	147.5–374.6	251.6–606.6	55.5–812.1	100.1–1,360.6
Pakistan	206.0–345.7	364.3–594.2	72.9–580.4	129.9–973.8
Turkey	147.7–330.3	192.7–410.2	52.0–636.4	68.4–754.2
Germany	132.8–281.9	235.8–444.6	47.0–567.3	81.0–835.5
Italy	123.0–277.1	236.0–490.1	44.4–593.6	86.0–1,026.5
Greece	77.5–185.8	111.2–251.3	29.5–418.8	43.7–537.5
Canada	77.5–165.0	199.6–362.2	27.2–320.9	69.8–613.2
Mexico	76.8–147.3	102.0–191.9	42.3–358.0	55.8–445.8
Hong Kong	26.5–116.7	23.0–109.1	29.7–786.5	27.4–791.2
United Kingdom	38.4–102.9	61.5–162.0	13.6–227.3	22.3–382.1
Bangladesh	0.1–0.4	0.0–0.2	0.0–0.6	0.0–0.2
Ukraine	0.0–0.0	0.0–0.0	0.0–0.0	0.0–0.0
Kazakhstan	0.0–0.0	0.0–0.0	0.0–0.0	0.0–0.0
Lebanon	0.0–0.0	0.0–0.0	0.0–0.0	0.0–0.0
Envelope total	23.56–40.48	35.94–58.44	10.68–78.92	15.09–103.24
every country on volume	20.38–34.65	31.70–51.17	9.26–66.74	—
every country on output	23.95–41.27	35.73–58.52	10.98–80.05	—

the envelope-total rows are in trillions of 2017 U.S. dollars

The gradient adds to the reading of the cross-theatre table rather than replacing it. It leaves capital at risk unchanged, moves no first-moment figure, and raises the envelope above its volume-flat total. For the blast value it runs the other way for five countries of the table, Bangladesh, Hong Kong, Kazakhstan, Lebanon, and Ukraine, where the ground the strikes reach is less dense than the unit's average; for Kazakhstan, Lebanon, and Ukraine the difference is below the precision the

table prints. Where the two figures are close, the ground the strikes reach is about as dense as the unit's average; where the density figure is the higher, it is denser.

15 Conclusion

The library specified here holds 75 scenario cells across 16 theatres, of which 37 rest in some part on published work and 38 are constructed against stated rules. It is bounded by the January 2026 force inventory wherever a cell claims that basis, and it records a different basis wherever a published composition assumes one.

Its two governing rules are what make it usable. Keeping radius-bounded and unbounded layers apart prevents the arithmetic that would otherwise produce a single headline number describing no population. Carrying provenance with every parameter keeps a constructed stress case from acquiring, through repetition, the standing of a published result.

The direct and indirect layers' ranges have different sources. The direct layer's interval comes from the admissible pairs of zone fractions applied to one population count. The indirect layer's comes from the atmospheric quantity its published figures rest on, which is disputed between two lineages, the lower estimate about one sixth to one quarter of the higher; a consensus assessment has declined to adjudicate between them and states that it does not connect employment scenarios to their outcomes. Carrying two bases is what that state of the evidence supports. It also changes the shape of the answer: the indirect layer becomes a range whose lower end leaves the published grid for the three lowest rungs, while the direct layer stays where it was under either basis.

The country distribution of the indirect layer is the result that reaches furthest beyond the parties to the exchange. It runs from nations with effectively their whole population without food at the top rung to nations with none, and, as the three nations of Section 5 show, a country's position in it need not follow from proximity to the exchange.

The chain is run on nine theatres. In the calibration theatre the totals are fitted to the published case within five percent, and the country split, which is not fitted, departs from it. In the eight extrapolation theatres the checks are published models: a second, for the Middle Eastern theatre, against which the chain runs below in every case but one; a third, for French and British cities at 15 kt, puts the chain above, by 9.5 percent for France and 6.1 percent for the United Kingdom; and the European countervalue rung, run at its published composition, gives a span across the yields tested that holds the source's 85.3 million casualties, the source stating no yield. Elsewhere the calibration error and the extrapolation error combine in a direction that is not established. Both limitations are stated with the results. A constructed case outside the library, the reach of Russia's missiles based in Kaliningrad, is run on the same chain on Warsaw, Vilnius, and Riga, with Latvia and Lithuania corrected to their censuses for that case, and Warsaw's median fatalities are the largest of the three under both compositions and at both yields; valued in money, one weapon of the smaller yield destroys more by blast on Riga than on Warsaw. A second constructed case puts one weapon on the capital of each of the alliance's 30 European members, with Albania, North Macedonia, and Montenegro corrected to their censuses for that case, and one weapon on Paris gives the largest median fatalities of the 30 at both yields and destroys the most value by blast.

The fallout layer is computed for nineteen of the rows of Table 6 and reported in Section 9, as a bound, under the two conditions it states, that exceeds the direct layer in every unit, by a factor that in the largest exchange falls as the force grows. Both layers are composed by sex and age in

Section 10, against the units their residents live in, and Section 11 states, for the calibration theatre, the exposure and conditional mortality rates by unit of residence, so that a population can be placed against the counts at the grain of its own residence and age structure. The mortality rate is conditional on the scenario and carries no frequency; the analysis stops where the frequency of a nuclear exchange begins.³⁶ The present study prices the consequence, not the rate. What remains for it is the fallout of the four rows striking the Korean peninsula, Japan, and the NATO members, whose theatres hold no general-release or countervalue cell that bursts at or near the ground; a figure there would need a burst condition the library does not state. Cells whose belligerents or targets are stated as a class rather than as states also remain: the multi-theatre, non-deliberate, host-territory, non-nuclear-state, and reconstitution cells name an actor-agnostic initiator, a facility rather than a population, or a state that holds no arsenal at the outset, so no target set follows from the cell as written. And two theatres whose countervalue cells name both sides are not run here: the DPRK against the United States homeland, and an independent European deterrent against Russia. None of these is a refinement of what is here. Each is a layer or a coverage extension this document does not carry.

³⁶For the empirical record of that dimension, the dataset compiled by Melanie W. Sisson, *Nuclear Credibility in Theory and in Practice: What 81 Years of Nuclear Crises Reveal about Arsenal Size, Posture, and Deterrence* (Washington, DC: The Brookings Institution, 2026), counts thirty-six nuclear crises involving the United States across the nuclear age—militarized confrontations in which a nuclear threat was made explicit or implicit—of which none became a detonation. The count is drawn on here as a record of frequency, independent of the study’s own analysis of it.

A Data sources

The analysis rests on four gridded datasets and one set of vector boundaries, on two tabular economic datasets for the value layer, and on the published effects and force references of the Bibliography. Each dataset is named here with the release, resolution, projection, and license it was used under, and the role it plays.

Population. GHS-POP, the Global Human Settlement Layer population grid of the European Commission's Joint Research Centre,³⁷ release R2023A, epoch 2025, at 100 m resolution on the World Mollweide equal-area projection (map code 54009), under a Creative Commons Attribution 4.0 license. It supplies the residents of the direct and fallout layers and, tiled over each unit's whole extent, their denominators. In the six countries where it disagrees with a national census it is read through the corrected raster of Section 6.1, which keeps each country's own GHS-POP total and redistributes it as that subsection states; in the constructed case of Section 8.5, Latvia and Lithuania are read through a correction of their own, made by the same rule, and in that of Section 8.6, Albania, North Macedonia, and Montenegro.

Built-up volume. GHS-BUILT-V, the built-up volume grid of the same layer and producer, release R2023A, epoch 2025, at 100 m on the same World Mollweide grid and under the same license. It carries built-up volume in cubic meters across all use classes and is the property layer's exposure surface. Because it shares the population grid's release, epoch, resolution, and projection, a window's built-up volume reads cell-for-cell off it at the window's own grid offset, with no projection inverse, no redistribution, and no resampling.

Administrative boundaries. Overture Maps Foundation, Divisions, release 2026-08-19.0, at the country level and the first subdivision level. The geometry is published under the Open Database License and conflates OpenStreetMap; each file records its own per-record source and license. These boundaries define the level-1 units of residence and the first-wins rule by which the layers assign a cell to a unit, so the population, built-up-volume, and age-sex layers all partition on the same units. Country names in the tables that the document does not use elsewhere are Natural Earth's.³⁸

Age and sex structure. WorldPop unconstrained age and sex rasters, 2020 vintage, at 1 km.³⁹ The sex and age-band shares of the WorldPop cell holding a population cell's center are applied to that cell, giving the age-sex composition of the exposed that Section 10 reports. The same rasters, summed over their bands, supply the within-unit distribution of the population correction of Section 6.1 in three of the corrected countries, China, Iran, and Japan.

³⁷Martino Pesaresi et al., "Advances on the Global Human Settlement Layer by Joint Assessment of Earth Observation and Population Survey Data," *International Journal of Digital Earth* 17, no. 1 (2024): 2390454.

³⁸Natural Earth, *Admin 0 – Countries*, public domain, <https://www.naturalearthdata.com>.

³⁹WorldPop, *Global 1km Age/Sex Structures*.

The source's population data. LandScan Global 2016, Oak Ridge National Laboratory, at thirty arc-seconds, the ambient population averaged over the day, under a Creative Commons Attribution 4.0 license. It is the population data the cited source names, and it is read only to rebuild the source's targets by the source's own rule (Section 8); no figure of the chain rests on it.

Weapon effects. The overpressure thresholds of the severe, moderate, and light damage rings, and the ranges the ring damage fractions bound, are from the planning guidance's second edition of 2010, which states the overpressure at each zone's boundaries, the third edition giving the zones' radii without them, and from Glasstone and Dolan, all in the Bibliography. The property damage ratios are the ranges those descriptions bound, carried as an interval rather than fitted, because no published property-loss aggregate exists to calibrate them against.

National capital. The Penn World Table, version 10.01,⁴⁰ variable *cn*—the capital stock at current purchasing-power parities, in millions of 2017 U.S. dollars—for the observation year 2019, the national produced capital of the value layer. The release's countries are economies with national accounts of their own, Hong Kong among them, which the boundary source also files as an entity of its own; its struck districts therefore take their share of Hong Kong's capital and none of China's, and the tables list it as a struck country on that basis. Each series covers its country as that country's national accounts define it, which can differ from the country the boundary source draws: Ukraine's accounts exclude Crimea and Sevastopol and, for 2014–2019, a part of the Donetsk and Luhansk regions,⁴¹ all of which the boundary source files under Ukraine; Russia's statistical service states that its data exclude the Lugansk and Donetsk People's Republics and the Kherson and Zaporozhye Regions,⁴² and names no exclusion of Crimea and Sevastopol, so the source consulted does not say whether its series counts them. A unit's share of its country's capital is taken within the country as the boundary source draws it, for every country alike. The variable is produced capital over the release's nine asset types—residential buildings, other structures, information technology, communication technology, other machinery, transport equipment, software, other intellectual property products, and cultivated assets—with land and inventories omitted,⁴³ so it is broader than built structures; the table carries it for twenty-three of the countries the library's strikes reach and not for the DPRK or Afghanistan. The West Bank takes no value figure, for a reason of measurement rather than of status. As in the fallout attribution of Section 9, a disputed territory the boundary source carves out keeps its own line and is assigned to no claimant; a value, in addition, needs the capital of the unit from a national account that measures it, and the West Bank's is measured in two. The State of Palestine's national accounts, the series the Penn World Table carries for the

⁴⁰Robert C. Feenstra, Robert Inklaar, and Marcel P. Timmer, "The Next Generation of the Penn World Table," *American Economic Review* 105, no. 10 (2015): 3150–3182; the release is Robert C. Feenstra, Robert Inklaar, and Marcel P. Timmer, *Penn World Table version 10.01* (Groningen: Groningen Growth and Development Centre, 2023), <https://doi.org/10.34894/QT5BCC>.

⁴¹State Statistics Service of Ukraine, "Social and Economic Development of Ukraine," accessed 28 September 2026, https://www.ukrstat.gov.ua/operativ/infografika/2020/soc_ek_r_Ukr/soc_ek_r_Ukr_2019_e.pdf.

⁴²Federal State Statistics Service, data under the International Monetary Fund's Special Data Dissemination Standard, note 1, accessed 9 October 2026, <https://eng.rosstat.gov.ru/folder/160366>.

⁴³Robert Inklaar, Pieter Woltjer, and Daniel Gallardo Albarrán, "The Composition of Capital and Cross-country Productivity Comparisons," *International Productivity Monitor* 36 (2019): 34–52, at 41–42; version 10.0 keeps the nine assets as the lowest level of its investment detail (Robert Inklaar, Ryan Marapin, and Pieter Woltjer, "What Is New in PWT 10.0?," Groningen Growth and Development Centre, January 2021, the section on nominal investment).

West Bank and Gaza, exclude “Jerusalem J1,”⁴⁴ while Israel’s statistics are “supplied by and under the responsibility of the relevant Israeli authorities” and are published by the OECD “without prejudice to the status of the Golan Heights, East Jerusalem and Israeli settlements in the West Bank,”⁴⁵ and the boundary source draws no line between the two accounts’ territories within the West Bank, so neither account’s capital can be apportioned to it. Version 10.01 is the release the figures rest on; version 11.0, published on 7 October 2025, is the current one. Version 11.0 states the same variable in 2021 U.S. dollars where 10.01 states it in 2017, so adopting it re-denominates every money figure in this document rather than revising magnitudes within a fixed base; across the valued countries the total moves by a factor of 1.19, of which the larger part is the base year. A country’s share of that total is invariant to the base and so isolates what the release revises: the median country moves by 0.97 times, Russia by 1.34 and Turkey by 0.77. Because the value identity is linear in national capital, a reader who prefers the newer release can carry any country’s figure across by its own ratio without re-running a layer.

Subnational output. DOSE, the Global Data Set of Reported Sub-national Economic Output, version 2.14,⁴⁶ the source of the within-country output shares that apportion national capital across units in the value layer. It carries, per first-level subdivision and year, gross regional product and population, with the agricultural, manufacturing, and services parts split out; the value layer uses the manufacturing-plus-services share, called non-agricultural here; where the source’s three parts do not sum to its gross product, as for Japan’s prefectures, the two differ, and the sum of the two parts is the one used. India’s most recent complete year is 2019 and Pakistan’s is 2004, a vintage difference the value section states.

Force basis. The January 2026 warhead inventory that bounds a cell claiming that basis is from the Stockholm International Peace Research Institute yearbook in the Bibliography; a cell that states a different basis records it, and its provenance travels with the cell.

⁴⁴World Bank, *West Bank and Gaza Poverty Assessment 2025: Poverty, Conflict and the Erosion of Palestinian Livelihoods* (Washington, DC: World Bank, 2025), fig. 5, note: “National accounts data exclude Jerusalem J1.”

⁴⁵Organisation for Economic Co-operation and Development, “Information on the Data for Israel Appearing in OECD Documents and Publications,” accessed 27 September 2026 and 9 October 2026, <https://oecdcode.org/disclaimers/israel.html>.

⁴⁶Leonie Wenz et al., “DOSE—Global Data Set of Reported Sub-national Economic Output,” *Scientific Data* 10 (2023): 425.

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