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Effects of a Nuclear War:

Bridging Science, Policy, and Global Risk Governance

OCTOBER 2026



Pugwash-Carnegie Brief: Effects of a Nuclear War

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Table of Contents

Contributors.....4

Editor's note: **Bridging Science, Policy, and Global Risk Governance**.....5
Katariina Simonen and Monalisa Hazarika

Environmental and Human Nuclear Winter Risks in the Nordic Context.....8
Cheryl Harrison and William Faulkner

Irreversible Consequences of Nuclear Weapon Testing 19
Robert A. Jacobs

The Non-Nuclear Path to Nuclear War.....26
Dan Plesch and Manuel Galileo

The Lungs of Europe on the NATO-Russia Border.....42
Tarjia Cronberg

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BRIDGING SCIENCE, POLICY, AND GLOBAL RISK GOVERNANCE

EDITORS' NOTE

The consequences of nuclear war extend. far beyond the immediate destruction caused by nuclear detonations. They encompass cascading impacts on public health, food and energy systems, agriculture, the environment, trade, governance and societies across borders. Yet these wider consequences remain insufficiently integrated into contemporary discussions of nuclear policy and strategic stability. The Pugwash–Carnegie project on the Effects of a Nuclear War seeks address this gap by bringing scientific evidence across disciplines and policy perspectives into closer dialogue.

This collection of papers follows the multidisciplinary workshop ***Effects of a Nuclear War: Bridging Science, Policy, and Global Risk Governance***, convened in Stockholm on 12 June 2026 by the **Pugwash Conferences on Science** and **World Affairs and the SCRAP Weapons Project** at **SOAS University of London.** Held at a time of renewed concern over nuclear risks and the increasing militarization in the European security environment, the workshop brought together scientists, policy experts, diplomats, legal scholars, humanitarian actors, civil society representatives and early-career researchers.

The discussions identified a central challenge: nuclear war is too often approached as a military or strategic contingency, rather than as a global systems crisis with cascading consequences for health, food, climate, energy, trade, and governance. The workshop highlighted that global supply-chain fragility would amplify the direct effects of nuclear weapons use over a multi-year timeframe. In particular, nuclear winter effects of an atomic explosion could severely disrupt agriculture and fisheries worldwide, with Northern hemisphere high-latitude regions such as the Nordics facing especially acute risks.[1]

Fundamentally, advances in climate modelling and visualization were seen as opportunities to reframe nuclear danger and enhance public communication on the global and existential risks of nuclear weapons. Other discussions considered the implications for Nordic and European security policy, international humanitarian law, public preparedness and contemporary nuclear policy. Across these perspectives, participants identified a persistent disconnect between the growing body of scientific evidence and its integration into policy, strategic planning and public discourse.

[1] See https://pugwash.org/2026/06/17/stockholm-workshop-on-effects-of-a-nuclear-war/ for a report of the workshop.

The papers in this collection build on these discussions from interdisciplinary and regional perspectives. They do not seek to provide a single account of the consequences of nuclear war, but rather to contribute to a broader evidence base through which policymakers can better understand the scale, complexity and interconnectedness of these risks. From an environmental scientific perspective, **Harrison and Faulkner** discuss past cooling effects due to volcanic disruption while bringing the lessons learnt to today´s Nordic environment in case of a nuclear winter. History of nuclear technologies discussed by **Jacobs** through examples of global contamination of past nuclear detonations, with concrete proposals for remediation steps in Northern European sites. Technology and political science perspectives are introduced by **Plesch and Galileo**, discussing escalation pathways to nuclear use in the North. **Cronberg** narrows in on the Finnish-Russian border to explore Finally, through her background in medicine, **Juva** discusses the mental health of leaders and the risks this poses to our understanding of deterrence.

As international efforts, including the work of the United Nations Independent Scientific Panel on the Effects of Nuclear War, update the scientific assessment of nuclear war's consequences[2], there is a parallel need to ensure that this knowledge informs policy deliberations and risk-reduction efforts. This collection is offered as a contribution to that endeavour: strengthening the connection between science and policy, encouraging interdisciplinary and intergenerational dialogue, and supporting more comprehensive approaches to nuclear risk governance.



[2] See Nuclear war effects and scientific research: resolution / adopted by the General Assembly (2024), available at https://digitallibrary.un.org/record/4071347?ln=en&v=pdf.
Other notable works in the field include Glasstone and Dolan, The Effects of Nuclear Weapons (1977 3rd ed.); R.P. Turco, O.B. Toon, T.P. Ackerman, J.B. Pollack, and Carl Sagan, "Global Atmospheric Consequences of Nuclear War" Science (1983). Most recently, the USA National Academies of Sciences, Engineering, and Medicine published a comprehensive report, "Potential Environmental Effects of Nuclear War" 2025, https://doi.org/10.17226/27515.

ENVIRONMENTAL AND HUMAN NUCLEAR WINTER RISKS IN THE NORDIC CONTEXT

Cheryl Harrison and William Faulkner

1. Introduction

Understanding impacts of past cooling events, such as volcanic winter, can help us conceptualize how nuclear winter might affect different regions, both from the physical climate and sociological perspectives. The Nordic region in particular is rich with historical climate observations, as people in the region were early adopters of both temperature recordkeeping and noting linkages between climate and society (Collet et al., 2025). This exceptional recordkeeping, along with the marginality of agriculture and thus sensitivity to cooling, make the Nordic region an excellent case study to explore how history can inform understanding of potential future nuclear winter impacts. While a full treatment of this important topic is beyond the scope of this short paper, we hope to point the way for future investigations.

Expanding nuclear arsenals, the expiration of arms control treaties, and growing geopolitical stressors such as climate change are increasing the risk of intentional and unintentional nuclear conflict.[3] Beyond the immediate casualties of blast, heat, and radiation exposure, smoke from fires ignited by nuclear weapons could reach the stratosphere, where it would be transported globally in a matter of weeks, similar to large forest fires and volcanic eruptions (Toon et al., 2019). Smoke and aerosols in the stratosphere absorb and scatter incoming solar radiation, darkening the skies and leading to global cooling. Thus, smoke entering the atmosphere in one region, either from nuclear conflict or volcanic eruption, can cool countries across the world. The impacts do not remain local (Robock and Toon, 2012). For further information on and illustration of the mechanisms of nuclear winter see Harrison et al. (2026).

In this way volcanic eruptions have had a major impact on global climate variability throughout historical and geological time and so have been modeled extensively (Marshall et al., 2022). Building on this knowledge, we can use global Earth system models to project the climate impacts of nuclear conflict, which requires a similar modeling framework to modeling volcanic impacts (e.g., Otto-Bliesner et al., 2015; Toon et al., 2019).

[3] E.g. "It is now 85 seconds to midnight," 2026, https://thebulletin.org/doomsday-clock/2026-statement/.

Model simulations show that regional to global nuclear conflict is likely to cause a global cooling effect due to the stratospheric injection of black carbon (BC) from burning urban targets (Toon et al., 2019). Further, climate observations after volcanic events, both over the historical period as well as proxy records over longer timescales, can be used to help ground our understanding of environmental impacts of global cooling events seen in models (Collet et al., 2025; Sigl et al., 2022). We can also examine the human historical record to understand how climate events such as volcanic driven cooling and the associated impacts affected societies in different regions. As mentioned above, the Nordic countries are an excellent case study, and thinking along these lines can both drive motivation for avoiding nuclear war as well as societal preparedness for volcanic cooling events.

(a)

Soot load	Warring Nations	Δ Radiative Forcing ($W m^{-2}$)	Δ Temperature (°C)	Description
5 Tg	India and Pakistan	-10.9	-1.25	Lower-end regional conflict 100 15 kt weapons
16 Tg	India and Pakistan	-31.1	-2.5	250 15 kt weapons
27 Tg	India and Pakistan	-46.9	-4	250 50 kt weapons
37 Tg	India and Pakistan	-57.8	-5.5	High-end regional conflict 250 100 kt weapons
47 Tg	India and Pakistan	-68.7	-6.5	Upper-limit regional conflict 500 100 kt weapons
150 Tg	Russia and U.S.	-115.3	-10.5	Nuclear superpower conflict 4400 100 kt weapons

(b)

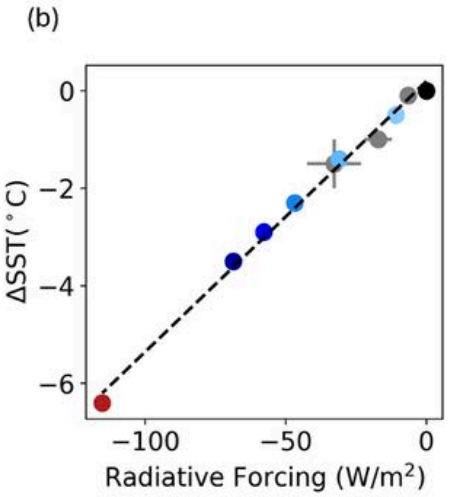


Figure 1. (a) Details of nuclear war scenarios from Toon et al. (2019) used in this paper, including mass of soot (black carbon) delivered to the stratosphere, warring nations, maximum global mean radiative forcing reduction (i.e. change in incoming energy from sunlight) at the Earth's surface, maximum global mean temperature reduction, and a description of the war scenario in terms of weapons used. (b) Change in global mean sea surface temperature (ΔSST) under each scenario (colored circles, Harrison et al. (2022)), as well as estimates for ocean cooling after the Pinatubo, Tambora and Samalas volcanic eruptions (grey circles, Chikamoto et al., 2016). Here the volcanic and nuclear driven cooling follow the same relationship between reduction of radiation and ocean cooling.

2. Global cooling history and projections

Climatic impacts of volcanic eruptions over the last few thousand years have been well recorded, from extensive paleoproxy records in ice cores, tree rings and stalagmites, to direct observations over the historical and satellite eras (Marshall et al., 2022). Such global cooling has occurred, for example, after the relatively small Mt. Pinatubo eruption in 1991, with a global mean cooling of 0.5°C for a number of months (Parker et al., 1996), as well as after the Mt. Tambora eruption in 1815 that led to the "Year Without a Summer" across parts of the Northern Hemisphere, with summer temperatures around 2-4°C below normal in some regions of Europe and North America (Luterbacher and Pfister, 2015). When we study the historical volcanic record, we see a "dose response" in the climate impact magnitude depending on the aerosol load delivered to the stratosphere. In general, larger volcanic eruptions cause more severe climate effects, and the projections for nuclear conflict follow the same rule of thumb, with larger delivery of black carbon to the atmosphere leading to greater cooling (Fig. 1b).

There are, however, important distinctions between climate impacts of volcanic eruptions and nuclear conflict. Most importantly, the climatic changes driven by nuclear conflict are expected to last significantly longer. The dark color of black carbon helps it to absorb sunlight, heat the surrounding air, and thus self-loft much higher in the stratosphere than lighter-colored volcanic aerosols, increasing its residence time (Robock et al., 2007; Yu et al., 2019). Current research suggests the amount of soot in the stratosphere would be halved roughly every 5 years, as compared to 1 year for volcanic sulfur. The light reduction response from a nuclear conflict could therefore last a decade or more, as compared with 2-3 years for volcanic eruptions. Thus, when we imagine the connections between volcanic winter and nuclear winter, we need to consider an extension of the impact timescale and hence severity on ecological and human systems.

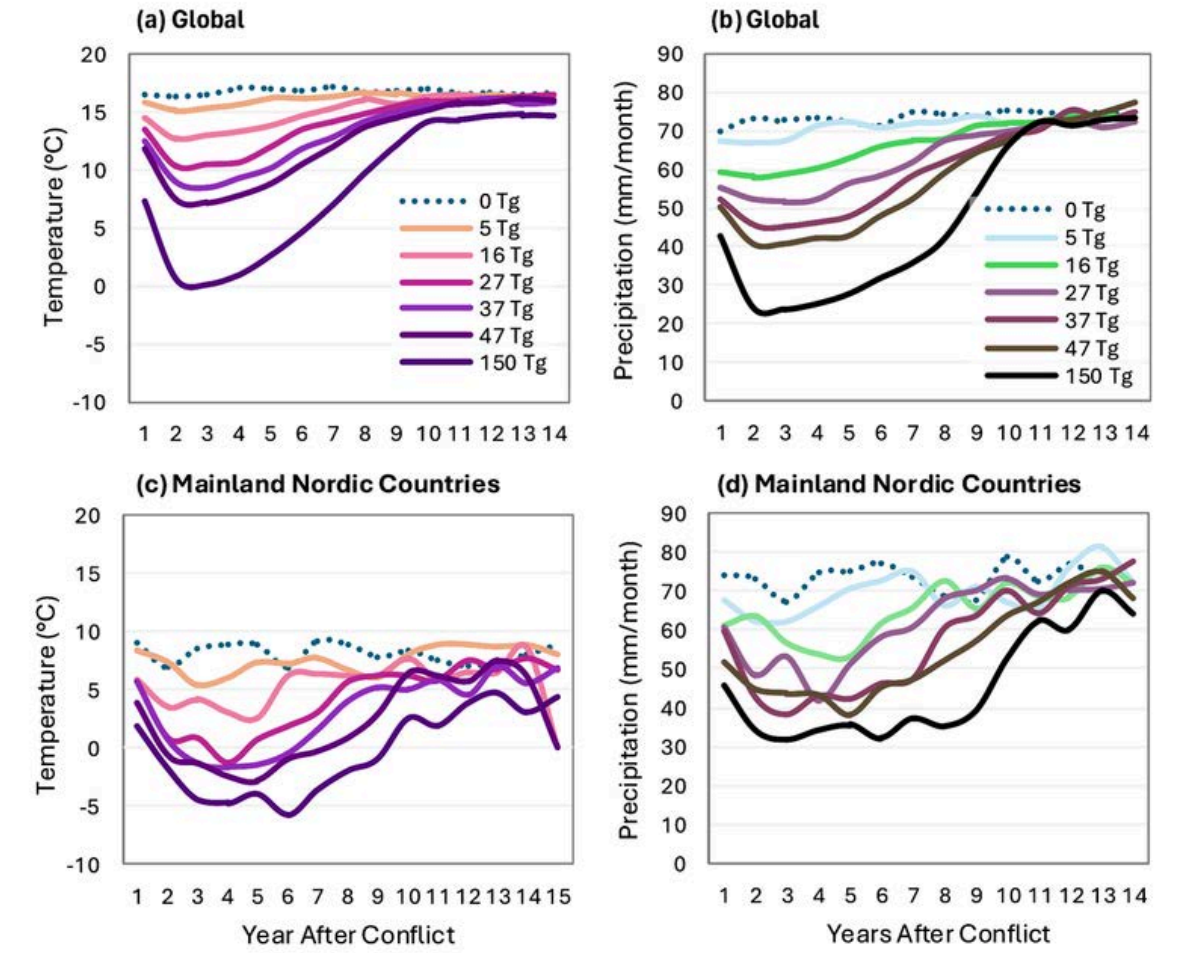


Figure 2: Post nuclear war temperature (a,c) and precipitation (b,d) changes over land for global (a,b) and mainland Nordic countries (c,d; Denmark, Sweden, Norway and Finland) for the nuclear winter scenarios in Fig. 1a. All means are weighted by country area. Data from Harrison et al. (2026).

Beyond global average temperature decline, there are regional impacts that would affect the Nordic region. In any global cooling event, the land loses heat more rapidly than the ocean and so is much colder, and the Northern Hemisphere cools off more due to the greater land mass. In particular, the interiors of large continents cool more because of their distance from the insulating properties of the ocean, and the Arctic cools more than other regions because of climate feedback effects, the so-called "Arctic amplification" (Coupe et al., 2019; Schneider et al., 2009).

This heightened northern cooling manifests in the mainland Nordic countries (Denmark, Sweden, Norway and Finland) as a larger cooling signal than the global average (Fig. 2ac). For example, the model projections for a moderate size nuclear conflict scenario, an India -Pakistan war delivering 27 teragrams (Tg)[4] of BC to the stratosphere (see Fig. 1a), the maximum temperature decline over the entire globe is over 4°C, and the decline over land is greater at 6°C, while the decline over this Nordic region peaks at over 10°C, with an average annual mean temperature below freezing at -1°C in the fourth year after the war. In this way the Nordic region is expected to experience disproportionally larger temperature impacts during global cooling events, while also starting from a colder baseline temperature.

3. Rainfall, food supplies and other environmental impacts

Global cooling slows the hydrologic cycle, on average reducing rainfall (D'Agostino et al., 2026; Toon et al., 2019). For example, in the 27 Tg nuclear war scenario (Fig. 1a), global mean rainfall over land is reduced by 30% in the third and fourth years after the conflict (Fig. 2bd). In the mainland Nordic countries precipitation decrease is more similar to the global amount than for temperature, but still greater at a 44% reduction, peaking in the fourth year. However, while the global average signal is that of drying, temporary or regional increases may occur due to changes in atmospheric circulation patterns (e.g., Toon et. al 2019. Fig. S7).

Both cooling and drying, combined with the reduction of light, will lead to secondary environmental effects, most notably reductions in agricultural yields (Xia et al., 2022). Historically, food shortages have been well noted after volcanic eruptions, resulting in famines across the globe, and farm abandonment in the Nordic countries (Büntgen et al., 2026; Collet et al., 2025). During nuclear winter, the projected reduction in agricultural production is much greater in the Nordic region than the global average (Fig. 3a). For example, the production of maize in mainland Nordic countries completely ceases for seven years after a 37 Tg nuclear conflict, and the production of wheat fails for the second and third year after the conflict, much greater than the global reductions of ~50% and ~30%, respectively.

[4]One teragram is equivalent to one million metric tons, or roughly twice the mass of the world's current tallest building, the Burj Khalifa in Dubai.

Cooling and light reduction also leads to a reduction in marine primary production in most regions, in turn reducing fisheries production that could be potentially used to offset declines in agricultural production (Harrison et al., 2022; Scherrer et al., 2020). On the global scale, for the 27 Tg case under a business-as-usual fishing scenario, an over 10% decline in fish catch is projected, lasting for six years (Fig. 3b); for the mainland Nordic countries, the decline in projected fish catch is over 40%, with declines lasting for ten years (Fig. 3c). In an intensified fishing scenario that could be initiated by food insecurity, the fishery production is not enough to keep up with fishing pressure, and any catch gain crashes after just a few years; however, managing fisheries for higher biomass before the cooling event could offset this crash, a form of passive emergency food storage (Scherrer et al., 2020). Limited scholarship is available linking historical volcanic records and fish catch records, though for the Nordic region it is likely these are both available.

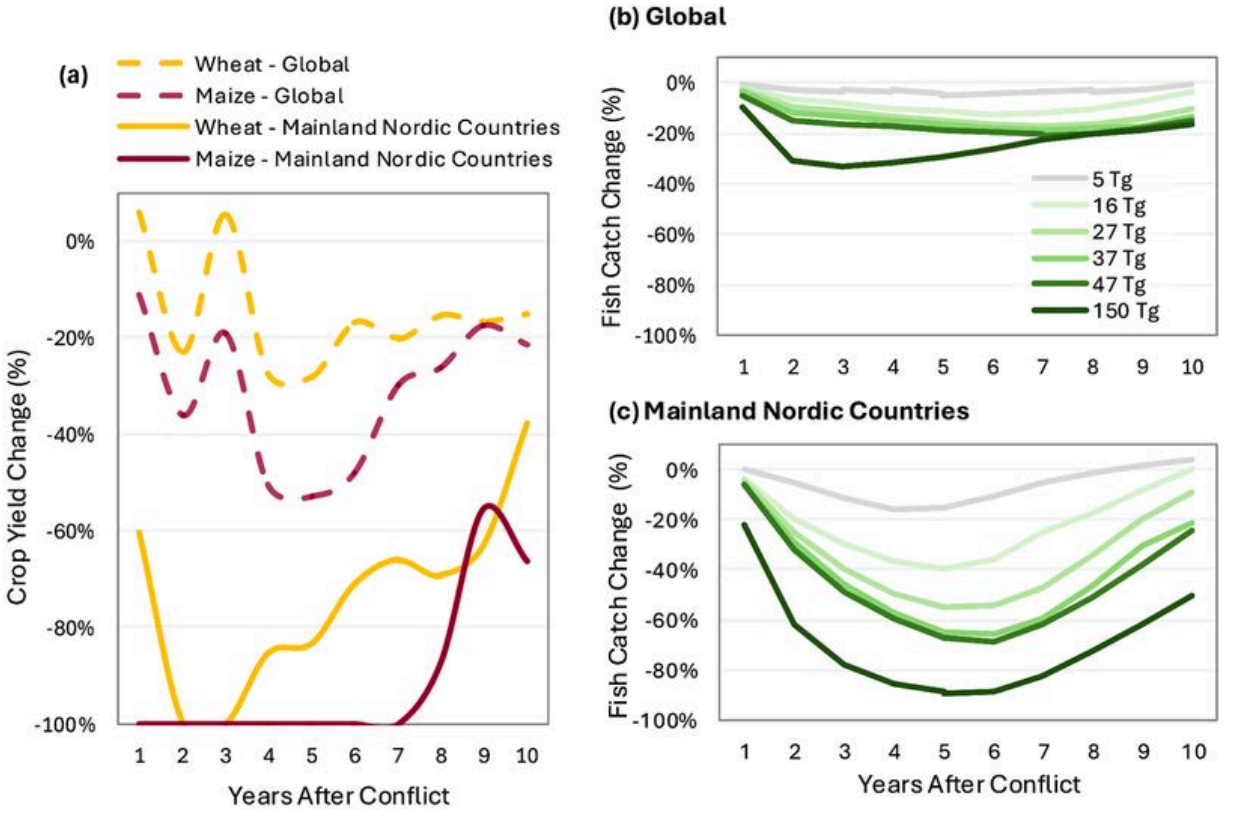


Figure 3. Plot of crop yields (a) for the 37 Tg scenario (see Fig. 1a) and fish catch changes for global ocean Exclusive Economic Zones (EEZs; b) and mainland Nordic EEZs (c). Reduction in both agricultural and fish catch after a nuclear war is greater in the mainland Nordic region than in the global mean, indicating a higher risk of food insecurity (see Fig. 4). Crop yields are measured in metric tons per hectare and are weighted by the mean annual harvest yield (2000-2020). Fish catch is measured in tons of wet biomass and weighted by EEZ area. Data from Harrison et al. (2026).

It has been reported that the majority of fatalities after volcanic eruptions have been due to famine (Tanguy et al., 1998), and this is also projected for nuclear winter (Fig. 4; Toon et al., 2019; Xia et al., 2022). For the Nordic region, which has historically been dependent on fish as an important diet component (Collet et al., 2025), a coincident reduction of fish catch with agriculture would combine to increase the risk of famine. Across the six nuclear war scenarios studied here, the mainland Nordic countries are projected to have much greater starvation rates than the global population (Fig. 4); for example, in the 37 Tg case over 95% of the population is starving in the second year after the war, compared with 28% of the global population.

Other secondary effects would work to compound environmental stress. For example, heating in the stratosphere from material absorbing radiation can also lead to ozone loss, producing more ultraviolet radiation at the surface (Marshall et al., 2022; Mills et al., 2014), which can have negative impacts on humans, plants and phytoplankton (Coupe et al., 2025; Neale et al., 2023; Shi et al., 2025). Many such secondary effects are understudied.

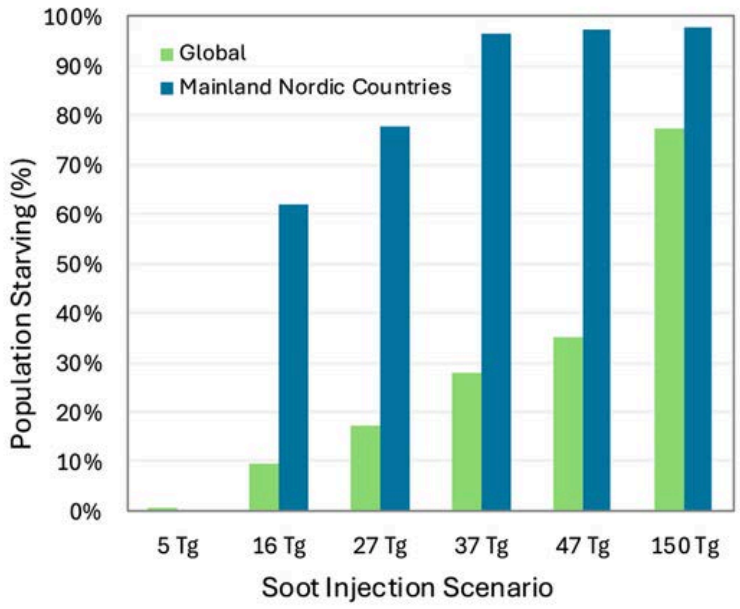


Figure 4. Percent of population starving in the second year after nuclear war for global (green) and mainland Nordic countries (blue) across soot injection scenarios (Fig. 1a). In this scenario international trade is assumed to continue and 50% of livestock feed is redirected for human consumption (see Xia et al., 2022). Means are weighted by the 2010 country population. Data from Harrison et al. (2026).

4. Conclusions and Discussion

The results from this workshop highlighted that the Nordic region is disproportionately susceptible to consequences of nuclear winter and that a greater scientific understanding of the myriad consequences of nuclear weapons is needed for informed policy development. This requires integration of climate, political and social science, with a foundation on humanitarian and security needs, taking a "system of systems" approach (NASEM, 2025). This critical work is currently significantly underfunded and is perhaps overshadowed by concerns about climate and AI, despite that these stressors are likely increasing the risk of nuclear war (Johnson, 2021; Liska et al., 2017).

From the climate side, while there are many known impacts of global cooling, as outlined above, there are many yet to be examined. Many open physical questions revolve around "fuel loading", i.e. the distribution and types of combustible material in urban areas, the properties of the fires that develop, and how efficiently they loft smoke into the stratosphere (NASEM, 2025). In terms of human impacts, how governments, communities, and individuals would react and adapt to the combination of reduced temperatures, limited food, and other stressors, on top of global or regional conflict, needs sustained, focused study. For example, food insecurity and cold temperatures together might increase susceptibility to illness, as after volcanic eruptions (Büntgen et al., 2026). For the interested reader, we list a number of open questions in a recent publication of accessible data for studying the impacts of nuclear winter (Harrison et al., 2026), and hope that this dataset will increase further investigation, and in particular help researchers outside climate science answer questions like those brought up in this workshop.

A major conclusion of this workshop is that country and region level assessments of combined impacts, including the initial bombing casualties, the longer-term climate impacts, and the resulting food, medical, humanitarian and political impacts, are needed to help both political decisionmakers and the general public understand the full breadth of consequences of nuclear conflict, including in what are often labeled 'limited' scenarios. This incipient study program will require the coordination and cooperation of experts from across disciplines. Facilitating the development of a sustainable, diverse research community should be a top priority.

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IRREVERSIBLE CONSEQUENCES OF NUCLEAR WEAPON TESTING

Robert A. Jacobs

1. Introduction

Nuclear weapon detonations are among the most profound things that have ever happened on Earth. The United States conducted two nuclear attacks against the people of Hiroshima and Nagasaki in 1945, killing and maiming hundreds of thousands of people; an attack that had both instantaneous and deep time impacts.

Nuclear weapon detonations are understood to have three primary effects: blast, heat and radiation. All three are forms of energy radiating outward from the epicentre of a detonation, setting free a tremendous impulse of energy lasting only less than a second. This fireball creates a flash of light, heat, radiation and an expanding blast wave. Prompt radiation (gamma and neutrons) is extraordinarily intense and results in damaging the health of living creatures and any organic material.

Radioactive waves are a form of energy that passes through the body, not unlike an x-ray. After the burst, the wave dissipates and the radiation is gone, however, while it passes through the body it can damage cells, organs and DNA. In Hiroshima a two-year-old girl named Sadako Sasaki was 1.6km from ground zero when the nuclear weapon was detonated. She was seemingly unhurt by the attack but ten years later the radiological damage her body suffered eventuated in leukaemia, which killed her at 12 (Sasaki).

Harm from radioactive particles occurs differently. Since these are chemical isotopes, they have a radioactive lifespan and trajectory of their own that continues after the explosion. Unlike the waves that penetrate, dissipate and are gone, the radionuclides stick around and present an ongoing threat after the attack. These particles are primarily dangerous when they are internalized, usually through swallowing or inhalation. The body then understands the radionuclide as a chemical, for example, when we consume food containing iodine, the body puts it in the thyroid gland. If that iodine happens to be the radioactive isotope of iodine, iodine-131, the body will still put it in the thyroid gland. Once deposited inside of the body, these particles will continue to irradiate the cells around them 24 hours a day. The energy of these particles is lower than that of the radioactive waves, however the amount of time that we are exposed to them is often far longer, especially if we are carrying them around inside of our bodies.

2. Past detonations teach us about irreversible consequences

The weapons used in the attacks on the people of Hiroshima and Nagasaki are now considered mini-bombs – battlefield nuclear weapons – we have vastly larger weapons for use against fixed targets and cities. During the Cold War the nuclear weapon states manufactured more than 100,000 nuclear weapons and detonated more than 2,000. We can easily understand some of the irreversible consequences of nuclear weapons usage by looking at the history of nuclear testing during the last 80 years, which began eleven months after Hiroshima. Nuclear weapons were detonated at dozens of sites, on ocean atolls, and on every continent except for South America and Antarctica, which both did have radiological disasters unrelated to weapons. We tend to think of the Cold War as a period in which nuclear weapons were not used; however, statistically a nuclear explosion took place every 8.6 days during the Cold War (Jacobs 2022: 5-6).

During these tests, the blast, heat and gamma waves of a nuclear explosion could largely be contained to the test sites, but the radioactive fallout could not. Mushroom clouds, laden with radioactive particles, would drift downwind as the fallout contaminated communities, farms and pastureland, drinking and fishing waters. Because the remaining radiation of the fallout particles are radioactive for a long time, the risk of internalizing these into your body and developing a radiogenic disease endures after their deposition. Particles of Cesium-137 have a short half-life time of approximately 30 years. This means that after 300 years 0.1% of the released radioactive Cesium is still radiating, at which point it blends into safe background levels. Plutonium-239 particles will remain dangerous for 240,000 years.

Millions of people lived downwind from these atmospheric test sites, often colonial, postcolonial or minority populations selected specifically for their political powerlessness (Jacobs 2013: 1257-177). Weapons were tested in the atmosphere until 1980, and each explosion lifted radioactive fallout particles in the sky where they were carried into downwind communities. Many in these communities suffered a range of ingestion cancers and immune disorders. Studies have tracked these radiogenic illnesses and tracked the migration of various fallout particles in soils and waters of downwinders. Additionally, since many of the particles have half-lives longer than human lives, they await each new generation born in the community, creating a unique and existential risk faced not just by oneself, but by generations of one's descendants.

This happened to, and is still happening to, millions of people. A 2007 IAEA assessment of the human impact of decades of Soviet testing Nevaya Zemlya concluded that, "The critical group for exposure is indigenous peoples of the Far North (reindeer herdsmen). They consume daily, on the average, about 250g of reindeer meat Moreover, an additional dose (about 10%) due to the daily use of snow for obtaining drinking water and cooking, consumption of freshwater fish and meat of ptarmigans for food. This critical group numbers 30,000 people." As participants in the ecosystem, these people came to mirror the contamination of their food source: "The seasonal dependence of caesium-137 content in the body of reindeer herdsmen who eat freshly slaughtered reindeer meat corresponds to the level in the reindeer: at the end of summer, the minimum is recorded, and at the end of spring, the maximum" (IAEA 2004:17).

3. Global distribution of fallout

But it got worse. By the mid-1950s we developed thermonuclear weapons, or H-bombs. These use an entirely different principle to release energy, and can be made to almost any size, allowing for weapons that were thousands of times larger than earlier atomic bombs to become mass produced by the 1960s. Thermonuclear weapons don't just release more energy than fission bombs but also significantly more radioactive fallout and because of the size of the explosions, the mushroom clouds carry fallout up into the troposphere and stratosphere allowing for a much wider distribution.

The Bravo test at Bikini Atoll in the Marshall Islands on March 1, 1954, tested a thermonuclear weapon that was small enough to be delivered to a target by an airplane. It was the largest weapon ever detonated by the United States at 14MT, roughly 1,000 times larger than the Hiroshima bomb. The fallout cloud from the Bravo test spread across hundreds of miles of the central Pacific, engulfing inhabited atolls and hundreds of fishing boats. Several Marshallese communities were forcibly dispossessed from their home atolls because of radiological contamination, which included of their bodies. The radio operator on one of the Japanese tuna fishing boats exposed to the fallout died six months later, revealing that one could be almost 200km away from the explosion of an H-bomb and it could still kill you. The way it killed Aikichi Kuboyama was with fallout (Homei 2012: 212-232).

Meteorologists working for the United States Atomic Energy Commission published a map tracking the global distribution of fallout specifically from the Bravo test in Science magazine in 1956. It shows the particles circling the Earth for years before descending back to the surface, resulting in a global distribution of Bravo fallout particles (Matcha et al. 1956: 474-477). We have found radionuclides from hydrogen bomb tests on every continent and in every significant body of water; it is this global distribution of transuranic radionuclides that is often suggested as the golden spike marker of the proposed Anthropocene. The global ubiquity of fallout has even become a tool to determine forgeries: paintings sold as from the 19th century were revealed to be forged because of traces of fallout in the oils and fibres; new wine placed in old bottles to be sold at inflated prices has also been detected by tracing cesium-137 (Jacobs 2022: 72-73).

A demonstration of how this can work in someone's life can be seen in a 2021 study examining the presence of cesium-137 particles originating in nuclear tests in Nevada during the 1950s, in honey samples from the east coast of the United States (Ogasa 2021). Researchers found such particles in more than 50% of the samples, yet I would venture that no one who internalized one of these particles and suffered a subsequent radiogenic illness would think, "maybe this has something to do with those nuclear tests conducted 60 years ago on the other side of the continent." We are simply all together now, living in the ecosystem we have augmented with our transuranic and fallout radionuclides.

During the Cold War, millions were irradiated, food sources were contaminated, whole communities forcibly displaced, and virtually no one compensated: this was violence. I see the Cold War as a limited nuclear war: limited targets, politically powerless populations under the control of the nuclear weapon states, and limited weapon effects, just fallout. However, fallout was strategized to be the primary means of killing the enemy in the long planned and feared global thermonuclear war that was the marque threat of the Cold War. Thermonuclear explosions are how you kill millions of people, the fallout from thermonuclear explosions is how you kill tens of millions of people.

These frontline test site communities remain fundamentally uncompensated for their losses, and their lands remain radiologically contaminated. Bear in mind that this is what happens when we work consciously to minimize and hide the ecological and human impacts, imagine when we are angry and burn each other's cities down. Northern European nations became nuclear frontline communities when a significant portion of the initial plumes from the Chernobyl explosion and fire blew directly towards Scandinavia, and a vast swath of fallout was deposited across Finland, Sweden and Norway. Nations outside of the Soviet Union first became aware of the Chernobyl accident when this plume was registered by monitors at the Forsmark nuclear site in Sweden several days after the incident. Studies have detailed a range of harms resulting from the substantial deposition of fallout radionuclides from Chernobyl in Northern Europe. From the well-known contamination of the reindeer and subsequent impacts of those contaminations in Sami communities in several countries, even the test scores of children in urban settings in Sweden were found to have been negatively affected by the radionuclides over time (Almond et al. 2007).

4. The deep-time legacy of spent nuclear fuel

There are vast ecological consequences simply from the manufacture of nuclear weapons, even if they are never used in warfare: whole landscapes of high-level radioactive waste that must be actively managed for centuries or millennia. Uranium mining and milling to fashion nuclear fuel for reactors has left behind mountains of uranium tailings that will present health risks to living creatures for millions of years. These are largely abandoned and unmanaged and strewn around the world. The manufacturing of plutonium has been a radiological and toxic nightmare at multiple sites in the nuclear weapon states. In my country, the United States, the current administration seeks to reduce the funding for the Hanford site, America's primary plutonium production complex where some high-level liquid waste sits in 177 leaking tanks (Cary 2026). However the current funding battles are resolved, it is difficult to imagine that all nuclear weapon states will continue to fund these obligations through the decades of economic, political and ecological crises that the next century could easily bring rather than abandoning them like a pile of uranium tailings.

Deeper into time and toxicity are the tens of thousands of metric tons of spent nuclear fuel rods from manufacturing plutonium in reactors, which we intend to place into what is euphemistically called, “permanent” disposal. These spent fuel rods will remain dangerous to living creatures for more than a hundred thousand years. Whatever your view of various disposal methods, the idea that thousands of generations of human beings can only have a relationship of risk and avoidance with material that was manufactured to benefit just one or two generations (if you believe in deterrence theory) is being bad ancestors.

If we assume that all, or a significant amount of our spent nuclear fuel does make it into deep geological storage, sites such as Onkalo or Forsmark may well become plutonium mines where future societies, or militaries, obtain plutonium for their own nuclear weapons. Why go to the time consuming and expensive process of manufacturing plutonium when we have already done it for them? Unlike uranium-235, plutonium does not need to be enriched and is ready for weapon use as is and will remain weapons viable for thousands of years. What we call the permanent disposal of spent nuclear fuel may turn out to be proliferation into the future.

The ecological, financial and ethical tentacles and entanglements of our choices and actions stretch out for millennia, beyond the functional capacities of any government, or the ethical system of any religion or society.

5. Conclusion

We can learn from this. We have done a lot of damage to living creatures and released a lot of long-lived radionuclides into the ecosystem. But we can stop here. We can limit this damage to what has already been done, to harm we inflicted while performing competence during our nuclear weapon stockpiling, testing and deployment. We need to learn how to see the damage we have already done to keep us from more reckless and permanent acts. Beyond the necessities of nuclear deescalation and abolition, we can move away from generating more spent nuclear fuel, militarily and industrially, until we have actual waste mediation and not simply storing in potential plutonium mines. However, most immediate and essential is to insist that governments that have pursued or regulated nuclear industries must commit to fully funding all required safety and remediation steps at former production sites and contamination sites.

In Northern Europe this would include the Sellafield (former Windscale) site in the UK, the submarine reactor waste of the former Soviet Union scattered on and alongside the Kola Peninsula, and multiple sites on Novaya Zemlya. The costs of managing these radiological wounds deep into the future must be accept and structured into the budgeting of these nuclear nations for centuries. International treaties can be passed that insist that any national or corporate entity that manufactures radiological materials is fiscally responsible for any harm they cause, and for their ultimate containment of such materials. Laws can be passed and funding streams insisted upon that contribute to mediating the harm that will long follow in the wake of our shoddy nuclear production histories.

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THE NON-NUCLEAR PATH TO NUCLEAR WAR: *ENTANGLEMENT, CONVENTIONAL COUNTERFORCE, AND THE ESCALATION PATHWAYS TO NUCLEAR USE IN THE NORTH* [5]

Dan Plesch and Manuel Galileo

This paper takes the Stockholm workshop's question, the consequences of a nuclear war, and asks how such a war would begin (Pugwash, 2026). Our answer is that the most likely opening is conventional, and that the European and Arctic North, where the modelled consequences are easiest to identify, is where conventional and nuclear systems are most thoroughly tangled together.

1. A pathway that begins without nuclear weapons

Missiles and delivery systems already in service are amalgamating conventional and nuclear forces so closely that adversaries can no longer distinguish them. That blurring is termed *entanglement*, and it is rewriting the logic of deterrence between the United States, Russia, and China. Through the Cold War, deterrence rested on concealment and mutual vulnerability: a state that could hide its weapons and survive a first strike forced its adversary to assume it could still retaliate. Three dynamics now undermine that thesis. Permanent surveillance erodes the concealment on which mobile forces depend. Entanglement blends conventional and nuclear capabilities across hardware, geography, and command systems. Speed shrinks the time a leader has to decide, and compressed decision time is where miscalculation lives. Senior officials have said so openly. General James Cartwright, then commanding U.S. Strategic Command, observed in December 2005 that precision had cut the yield needed for a given effect, remarking of one target that he had "always held this at risk with a nuclear weapon for some reason" (Cartwright, 2005). Xi Jinping warned in 2014 that U.S. global rapid-strike capabilities would "fundamentally change the traditional pattern of offensive and defensive warfare," and Vladimir Putin argued in 2015 that high-precision, long-range non-nuclear arms "in effect" allow a disarming first strike (Beauchamp-Mustafaga, 2025; Plesch and Galileo, 2026).

[5] This paper was presented at the Pugwash workshop "Effects of a Nuclear War: Bridging Science, Policy, and Global Risk Governance," held at SIPRI, Stockholm, on 12 June 2026, and has been revised to reflect the discussion there; for the workshop report see https://pugwash.org/2026/06/17/stockholm-workshop-on-effects-of-a-nuclear-war/. It draws on the authors' report Masters of the Air: Strategic Stability and Conventional Strikes (SOAS University of London, 2024), https://scrapweapons.com/wp-content/uploads/2024/09/Report-Masters-of-the-Air-.pdf.

Accuracy, not yield, destroys the other side's weapons, and missile technology has delivered that accuracy across nuclear and non-nuclear means alike (Lieber and Press, 2006, 2017). Within days of each other in October 2025, all three major powers rehearsed the opening moves of a nuclear war. Russia's Grom exercise combined land-based missiles, a submarine launch, and bombers firing cruise missiles that come in near-identical conventional and nuclear versions, with the chief of the general staff saying it would practice the procedures authorizing nuclear use (Podvig, 2025; Rostampour, 2025); NATO's Steadfast Noon flew the F-35 at the head of the strike package as a dual-capable aircraft for the first time (NATO Allied Air Command, 2025); and Global Thunder 26 rehearsed the less visible task of exercising nuclear command and control (USSTRATCOM, 2025). The regime that once made these forces countable is gone: the INF Treaty ended in 2019, Russia suspended New START inspections in 2023, and New START expired on 5 February 2026 with nothing to replace it, while China declines to join at all (Liang, 2026). Exercises are now the closest thing left to a confidence-building measure, a thin thread on which to hang strategic stability.

2. Three forms of entanglement

Entanglement operates in three forms. The first is hardware: the same system does the conventional job and the nuclear one. Russian strategic bombers carry the conventional Kh-101 and the nuclear Kh-102, identical on the wing; China places nuclear and conventional warheads on identical DF-26 launcher trucks, so a satellite watching a DF-26 unit cannot tell which it sees; and the American F-35 flies a conventional strike one day and carries the B61-12 the next, from the same squadron at the same base (NATO Allied Air Command, 2025; U.S. Department of Defense, 2024). The starkest case is Russia's Oreshnik, first used against Dnipro in November 2024 with non-nuclear warheads and moved into Belarus in December 2025, minutes' flight from NATO territory, with no way to read the warhead until it lands (CSIS, 2026; Defense News, 2025).

The second form is geographic: Talmadge (2017) has shown that in a U.S.–China war over Taiwan, conventional strikes on radars, command posts, and missile units would degrade China's nuclear forces by co-location rather than design, confronting Beijing with a choice between using its weapons and losing them. The third form is the least discussed.

A nuclear force has a nervous system, the satellites, radars, and command links known as NC3, and that nervous system is now shared with conventional operations, so a strike on a radar or satellite that a commander believes serves a purely conventional battle can blind the other side's nuclear early warning at the same moment; Acton (2018) calls this escalation through entanglement. Russia has written its answer into law, in a doctrine signed in November 2024 providing that a large non-nuclear attack backed by a nuclear power counts as a joint attack on Russia and may be met with nuclear weapons (President of the Russian Federation, 2024). Set that beside the Oreshnik and the elements assemble themselves: a missile launched in a crisis, minutes to react, an unreadable warhead, and a rule already on the books permitting a nuclear reply (Arbatov, 2016).

The three forms occur together in the European and Arctic North. On the Kola Peninsula, a few hundred kilometres from the Norwegian and Finnish borders, Russia bases the submarines carrying the larger part of its assured retaliatory capability and defends them through a bastion concept that pushes conventional air, naval, and coastal missile forces into the Barents and Norwegian Seas (CSIS, 2020). Almost any conventional engagement in that space touches nuclear-relevant assets, and an adversary striking the bastion's outer layer cannot demonstrate that it is not reaching for the strategic weapons inside it. Russia's re-establishment of the Leningrad Military District in 2024, framed as a response to Finnish and Swedish accession to NATO, put nuclear and conventional forces under a single command on land as had already happened at sea and in the air (Barents Observer, 2024). The command layer completes the picture. The Globus complex at Vardø stands roughly sixty kilometres from the Russian border, and where Norway describes it as space surveillance Moscow reads it as a node in American missile defence, warning in 2019 that it would respond (Barents Observer, 2019); further west, the radars at Pituffik and Fylingdales watch the polar approaches over which Russian intercontinental missiles would fly (U.S. Space Force, 2026). These are the assets most dangerous and most tempting to strike in a conventional war, and they stand on Nordic, Greenlandic, and British ground.

3. The instruments: reach, sight, and defence

None of this hardware is a procurement project; it is already deployed. Rapid Dragon, demonstrated by the U.S. Air Force in late 2022, rolls palletized long-range cruise missiles out the back ramp of unmodified C-17 and C-130 transports with targeting supplied from a remote node, so a transport and a bomber now look the same on radar, the category of nuclear-capable aircraft loses its meaning, and the number of launch platforms multiplies overnight (Trevithick, 2026; U.S. Air Force, 2022). Snyder (2024) finds that conventional cruise missiles with few-meter accuracy achieve single-shot kill probabilities against Russian and Chinese silos comparable to nuclear ballistic missiles. Nor is the idea new: the Conventional Trident Modification, proposed in 2006 and identified by the Pentagon's commissioned assessment as the most viable prompt-strike option, lost its dedicated funding in Congress but not the broader prompt global strike category (National Research Council, 2008; Woolf, 2014). The same entanglement is spreading through Europe, where Germany will purchase Tomahawk cruise missiles and ground-based Typhon launchers, reported at up to 400 rounds, for stationing on German soil, and where the Typhon also fires the SM-6, at once an air-defence interceptor and a strike weapon (Defense News, 2026). For the North the asymmetry runs both ways, since the German-based Typhon and the stand-off weapons carried by allied aviation hold the Kola command nodes at risk from Western Europe, and it is the bastion, not the Baltic, that Moscow will read those weapons as targeting.

Strike capability matters only against found targets, and finding is the domain changing fastest. Mobile missiles are losing that game to persistent satellite coverage and machine processing, and even a buried silo gives itself away through its portals and the trucks and crews around it. The competition is old, since the United States held Soviet submarines and mobile forces at greater risk during the Cold War than the theoretical literature assumed (Long and Green, 2015); what is new is scale and persistence. Submarines remain the hardest to find, but improved sonar and the same pattern-finding software are exposing them to detection before launch (Zhao, 2018), and open-source investigation extends a version of these capabilities to non-state analysts (Wilson et al., 2024).

Even where tracking remains imperfect, the perception that concealment is failing is destabilizing, and that erosion will be felt first in the Barents and Norwegian Seas, where Russian ballistic missile submarines operate under bastion protection and where allied anti-submarine warfare is most concentrated. A bastion that begins to look transparent pushes Russian planners toward earlier alert, wider dispersal, and pre-delegated authority.

Missile defence converts a damaged arsenal into a potentially 'interceptable' one. Aegis warships with SM-3 interceptors and Aegis Ashore sites in Romania and Poland are already fielded, an SM-3 Block IIA destroyed an ICBM-class target in a controlled test in November 2020, and Moscow has stated that the Polish site raises the overall nuclear danger (NATO Allied Air Command, 2024; Reuters, 2024; U.S. Navy, 2020). Boost-phase defence sharpens the problem, because a missile is easiest to kill in its first minutes but interception then requires sensors and interceptors close to the adversary's launch sites, increasingly in space, and such a defence looks, from where you stand, exactly like a weapon aimed at your ability to hit back (Sankaran, 2025). Polar geography places the North at the centre: the sensors that would see Russian missiles flying over the Arctic sit at Pituffik, Fylingdales, and Vardø, and any space-based layer would be positioned over the Barents and the Kola, so Nordic, Greenlandic, and British territory hosts the infrastructure of the shield without having chosen the strategy it implies. A missile fired on a depressed trajectory compounds the effect, skimming below early-warning radars' best view and cutting warning time from half an hour to a handful of minutes (Gronlund and Wright, 1992). Each dynamic is manageable alone; stacked together they drain the same resource, the few minutes a leader has to read the situation.

4. Decapitation and the command layer

Counterforce is usually discussed as an attack on weapons. The shorter path is an attack on the people and the systems that authorize their use. A state need not destroy an arsenal it can prevent from being ordered into action, and the target set is small: national leadership, the command posts they would use, the links that carry a release order, and the sensors that tell them an attack is underway. Precision conventional weapons have brought that set within reach without crossing the nuclear threshold, which makes decapitation a conventional problem rather than a nuclear one.

Chinese analysts read American planning in exactly these terms, and Beauchamp-Mustafaga (2025) documents a People's Liberation Army literature preoccupied with a United States decapitation strike on Chinese leadership, including a classified 2004 textbook for the missile forces that identifies medium- or high-intensity conventional strikes against the Chinese capital among the circumstances warranting nuclear signalling.

What matters for stability is not whether such a strike would succeed but what states do in anticipation of one. Every available answer is corrosive: pre-delegation of release authority to subordinate commanders, launch-on-warning postures, dispersal of leadership, and semi-automated retaliation of the kind built into the Soviet-era Perimeter system, which Russia has never disowned (Blair, 1993; Hoffman, 2009). Each measure is designed to guarantee that retaliation survives the loss of the leadership, and each achieves that by removing human judgment from the moment when human judgment matters most. Entanglement compounds the problem, because the assets an adversary must strike to blind early warning are the same assets serving conventional operations, so a conventional campaign against air defence, satellites, and command nodes reproduces the opening moves of a decapitation attempt whether or not that was the intent.

The warning from history is Able Archer, the 1983 NATO exercise that Soviet forces came close to reading as preparation for a real attack, and which was contained in part by the restraint of one American officer. Leonard H. Perroots, then assistant chief of staff for intelligence at U.S. Air Forces in Europe and later Director of the Defense Intelligence Agency, declined to raise American alert levels when signals intelligence showed Soviet air forces preparing for the immediate use of nuclear weapons, a judgment he later described as instinct rather than informed guidance. On retiring in 1989 he asked what might have happened had the United States begun a precautionary generation of forces in reply, and the President's Foreign Intelligence Advisory Board concluded in 1990 that Washington may inadvertently have placed relations with the Soviet Union on a hair trigger (Jones, 2016; National Security Archive, 2025). The safeguard that worked was an individual judgment made by someone who still had time to make it, and that breathing room is what this technology is taking away.

In the North, the installations at Vardø, Fylingdales, and Pituffik are the assets whose loss would be read as the first move against the ability to see and to answer, so any Western strike on the bastion's command layer will be assessed in Moscow against the possibility that it opens a decapitation campaign rather than a local engagement, and no declaration of intent will settle that question inside the flight time available.

5. The limits of the argument

A serious body of opinion holds the opposite of our conclusion, resting on the eight decades deterrence has held, on a record of nuclear close calls thinner than popular accounts suggest (Tertrais, 2017), and on the substitution of precision conventional weapons for nuclear ones in missions once assigned to warheads, which was the original rationale for prompt global strike. Our disagreement concerns which variable to watch: the probability of a deliberate nuclear attack may well be falling, while the probability of an inadvertent one, reached through misread conventional operations against entangled forces under compressed timelines, moves independently of it, and workshop participants concluded that this risk is not understood by politicians and publics alike, which is to say that it is unpriced rather than absent (Pugwash, 2026). A Nordic version of the optimistic case reads Finnish and Swedish accession as having removed the ambiguity that made the region dangerous; clarity about alignment is not clarity about warheads.

Our assessment rests deliberately on worst-case assumptions, and the empirical record is more nuanced. China's tunnel complexes date to the 1980s, the new Chinese and Russian silo fields appear configured to absorb nuclear rather than isolated conventional attack (Zhang, 2012), and the most ambitious conventional counterforce campaign to date, the Israeli–U.S. operations against Iran's missile forces since June 2025, degraded those forces heavily without eliminating them (Dubowitz and Ben Taleblu, 2026). Our claim is therefore not that conventional weapons can reliably disarm a nuclear power, but that their accuracy, range, and ISR integration have advanced far enough to generate powerful incentives for worst-case planning in Beijing and Moscow. China's silo program is the proof: roughly 320 new silos across three desert fields, more than 600 warheads in 2024 on a track toward 1,000 by 2030, and fast, low-flying systems such as the DF-17 and DF-27 that compress warning time (Kristensen et al., 2025; U.S. Department of Defense, 2024).

Because the three powers are coupled, reassurance offered to Moscow over the Barents cannot be ring-fenced from Beijing's reading of the same American systems in the Pacific, which is why measures in the Nordic-Arctic space must be designed as regional measures rather than as pieces of a global bargain that will not be struck.

6. Where the pathway leads: effects in the North

The workshop's central finding was that nuclear weapons use constitutes a global systems crisis rather than a localized military event, with cascading consequences for health, food, climate, energy, trade, and governance (Pugwash, 2026). Xia et al. (2022) estimate that a soot injection of 27 teragrams, well within the range of a regional exchange, would cut crop production by more than half across the mid-to-high latitudes of the Northern Hemisphere and reduce fish catches by 20 to 30 percent, while the 150-teragram case of a large U.S.–Russia exchange produces roughly 90 percent crop loss in the third and fourth years and more than five billion deaths from famine. Ocean modelling finds a shift to a new ocean state rather than a temporary perturbation, with marine primary productivity depressed for years and wild-capture fisheries unable to compensate for terrestrial losses (Harrison et al., 2022; Scherrer et al., 2020); Harrison and Faulkner set out the Nordic case in detail in a companion paper in this series.

Three features of the Northern case follow from the escalation analysis rather than from the climate models alone. The region's food system is exposed at the short end of the growing season, where a two-week loss is the difference between a harvest and none, which is why high-latitude losses in the models are so much steeper than global averages. Its substitute food source is the sea, and the ocean modelling removes it. And it depends on long, thin supply lines for pharmaceuticals, fuel, and imported calories, with workshop participants noting the case of ports freezing where prolonged sub-zero temperatures are unfamiliar, so that the means of relief fail at the moment relief is needed. The loss is compounding rather than additive, and it falls on societies whose civil preparedness is calibrated to storms and outages rather than to a five-year agricultural failure. The region that would host the misreading is the region least able to absorb its result.

Finland's parliament voted in June 2026 to amend the Nuclear Energy Act and the Criminal Code, removing the statutory bar on nuclear weapons on its territory, and Sweden, having declared on accession that it saw no reason to host nuclear weapons in peacetime, now signals openness to deployment in wartime; both have taken a place in the pathway while polling indicates majorities in both countries opposed to nuclear deployment on their soil (Euronews, 2026; Gotkowska, 2026; Höller, 2026; ICAN, 2026). That gap is not a communications problem but an unexamined transfer of risk. The UN General Assembly established an Independent Scientific Panel on the Effects of Nuclear War in resolution 79/238 of December 2024, reporting in 2027 (UN General Assembly, 2024). No comparable body examines how such a war would start. Effects research without escalation research yields a vivid picture of an outcome with no account of the route to it, and escalation research without effects research debates stability while omitting what instability costs.

7. Policy implications

Nuclear-only diplomacy cannot stabilize an entangled system. The comprehensive answer treats nuclear weapons, conventional strike, and their delivery systems as a single problem, which is the approach of the Strategic Concept for the Removal of Arms and Proliferation (SCRAP Weapons) at SOAS University of London, whose draft treaty framework for general and complete disarmament has been put before UN member states and the First Committee (SCRAP Weapons, 2024). That framework is not presently negotiable. The four steps below do not require it, each is compatible with it, and each has an immediate Northern European application (Plesch and Galileo, 2024).

First, turn the annual nuclear exercises into confidence-building measures and open them to the civil agencies that would manage the consequences. Grom, Steadfast Noon, and Global Thunder are the most informative recurring signals each side sends about its nuclear posture, and with New START gone they are read without any agreed framework for interpreting them. The precedent is durable: the 1988 agreement on notification of ballistic missile launches runs through the Nuclear Risk Reduction Centers, is of unlimited duration, stands independent of START, and outlived the suspension of New START inspections; the Hague Code of Conduct extends the same prelaunch logic to some 145 states; and in August 2026 forty-one governments called for notification of every intercontinental, submarine-launched, and space launch no less than twenty-four hours in advance (HCoC, 2020; United States and Union of Soviet Socialist Republics, 1988; U.S. Department of State, 2026).

Extending that principle from launches to exercises, through advance notification, published scenario parameters, and reciprocal observation, would convert an ambiguous signal into a deliberate one without touching capability, and the Vienna Document offers a model for the observation arrangements. Steadfast Noon and Grom are the obvious first pair. The second half of the measure is domestic and can be taken unilaterally. Nuclear exercises rehearse command, release procedures, and strike execution; they do not rehearse the multi-year agricultural failure that the effects literature identifies as the dominant consequence. Ministries of agriculture, fisheries, food security, health, and energy should be written into national exercise play with tasks rather than observer seats: measuring grain, seed, and fertilizer reserves against the soot-injection scenarios rather than against a bad harvest, testing import dependence and port function under prolonged sub-zero conditions, and rehearsing allocation when substitution from the sea is unavailable. Each cycle should open with a standing briefing to those ministries and their ministers on current nuclear winter and food-system modelling, for which the UN Panel's 2027 report is the natural authority. The gap is measurable: Finland, whose security of supply system is the most developed in Europe, holds statutory emergency grain reserves equivalent to roughly six months of consumption and has been raising them toward eight and a half, while the models it would be briefed on describe crop losses that run for years (National Emergency Supply Agency, 2022). The machinery already exists inside Nordic total defence structures, which is why this step requires no negotiation with anyone.

Second, build transparency and notification measures for long-range conventional systems. Advance notice of certain missile tests, geographic clarification of deployments, and selective data exchanges on missile defence architecture would reduce ambiguity without constraining capability. A regional measure is available now: notification of dual-capable intermediate-range deployments covering the Oreshnik in Belarus and the Typhon and Tomahawk deployments in Germany on the same terms, with Barents and Norwegian Sea activity in the same package.

Third, advance mutual reassurance and make the command layer its first object. States should privilege postures oriented to retaliation rather than counterforce primacy, supported by declaratory restraint on targeting nuclear forces, their command systems, and the sensors that provide early warning. Because the fear of decapitation drives pre-delegation, launch-on-warning, and automated retaliation, restraint here buys more stability per unit of concession than any measure applied to the weapons themselves. In the North, that means explicit restraint regarding Vardø, Pituffik, Fylingdales, and their Russian counterparts on the Kola, and a reciprocal statement that these are not targets in a conventional conflict costs neither side a capability it relies on.

Fourth, establish a conventional strategic risk dialogue and give the Nordic states a place in convening it. A standing trilateral or parallel bilateral channel would clarify perceptions of capability and doctrine at the intersection of conventional strike, missile defence, ISR, and nuclear command and control, without committing states to constraints they will not yet accept, supported by Track 1.5 and 2 engagement that maps escalation pathways before a crisis tests them. The first product should be a Nordic scenario set in which the initiating event is a conventional strike on bastion-related or early-warning assets rather than a stylized countervalue exchange, run through the crop, fishery, and supply-chain models presented at Stockholm. Sweden, Finland, Norway, and Denmark have the standing, they carry the consequences, and they hold a professional record in arms control; supporting the UN Panel's 2027 report with national data would be a concrete first contribution.

8. Conclusion

The likeliest road to nuclear use runs through conventional weapons, and our argument brings together two literatures that have grown up apart. Effects research models what a nuclear war would do but takes the war itself as given, while escalation research explains how one might start but stops at the moment of first use. Conventional counterforce is where the two meet, because it is the mechanism most likely to produce the exchange that the scientists model, and it is largely absent from Western debate while sitting at the centre of strategic thinking in Beijing and Moscow.

It also disposes of limited nuclear war as a category, since an exchange reached through entanglement could not be limited by design, nothing about it having been designed. The Nordic and Arctic region hosts the bastion, the radars, the dual-capable aviation, and the intermediate-range systems that make the escalation pathway short, and it sits at the latitudes where the models show the deepest and longest losses. The states that would host the misreading are the states that would pay for it, and that gives them both the strongest interest in the escalation question and the standing to raise it.

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THE LUNGS OF EUROPE ON THE NATO-RUSSIA BORDER

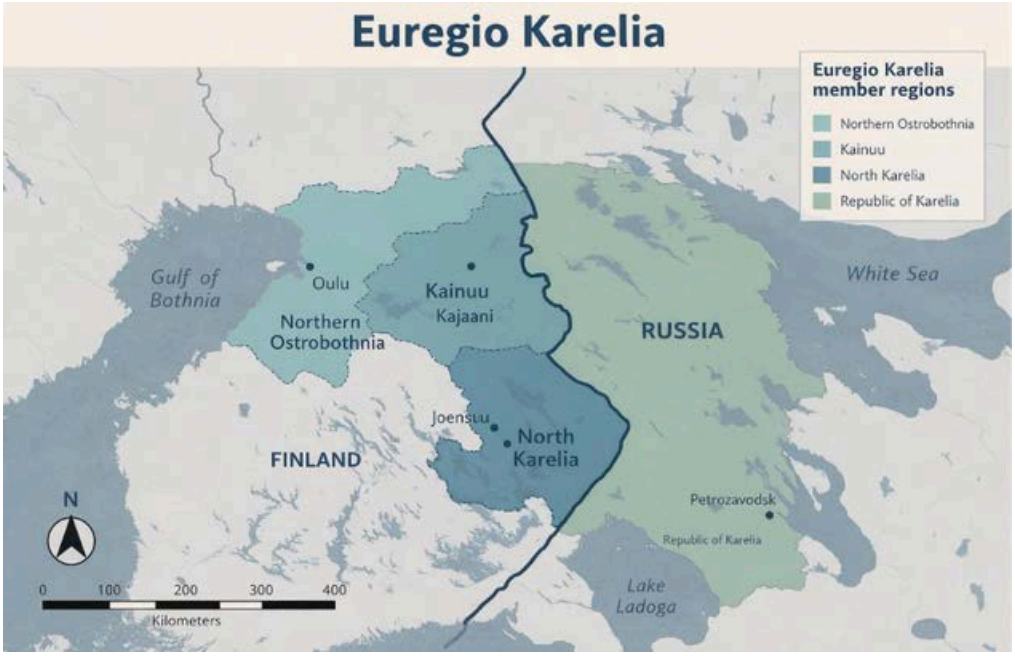
Tarja Cronberg

NATO Secretary General Mark Rutte and several Western intelligence services have warned that if current military rearmament continues Russia could have the capability to launch a larger conflict with NATO before 2030 (Cronberg 2026). The assumption is that Russia might want to test NATO´s resolve by attacking a NATO-state not only by conventional arms but also by a tactical nuclear weapon.

Finland is one of the possible target areas, implying a limited nuclear or conventional war to be fought on the territory of the Republic of Karelia on the Russian side and the border regions on the Finnish side with consequences for the environment.

1. The Republic of Karelia

The Republic of Karelia is located in the northwestern Russia bordering the Murmansk, Arkhangelsk, Vologda and Leningrad regions. It has a state border with Finland. The area is covered by wide untouched forest areas, a result of the Soviet era border policies of not to develop the border areas.



The Republic of Karelia is often referred to as "the lungs of Europe" because over half of its 180,500 km^2 territory is blanketed in untouched taiga and tundra forests. This massive boreal ecosystem acts as a critical natural carbon sink, purifying the air and supplying oxygen across the continent.

There are about 27,000 rivers in the region, over 61,000 lakes and about 6,500 swamps. The available capacity of local water reservoirs is 18.5 km^3. A total of 23% of the republic's territory is covered with water. Over one million hectares of land, or 5.6% of the total area of the republic, are specially protected natural areas. As an example of the biodiversity in the region the flora includes 1200 wild vascular plant species, of which over 300 species are classed as rare and to various degrees endangered.

These environmental conditions create a unique experimental area for research, especially taking into account the transformation on Finnish side: here, the forests have been subject to cultivation, the swamps have been dried out and reforested and, consequently, plant diversity has been radically reduced.

2. The Finnish-Russian Border

Until the war in Ukraine in 2022 and after the collapse of the Soviet Union, the Finnish-Russian border area was one of cooperation and dialogue in accordance with the European Union´s policy of Europe without divides (Cronberg 2006; Poporov 2004). European funds together with Finnish and Russian national funds were allocated to open new border crossings, to cooperation in environmental protection, to encourage cooperation between the regional administrations and to enable people-to-people contact across the border area.

A regional zone of cooperation, applying the European model of "Euroregions", the "Euregio Karelia" was established as a framework for future cooperation and to create "a soft border" among former enemies (Cronberg 2000). This model worked for 20 years, increasing the knowledge base of not only the economic but also the environmental situation on both sides of the border, as neighbouring universities cooperated on forestry and biodiversity. A warning system for situations such as forest fires was operational, as occasionally the smoke from fires in the forests on the other side spread over the Finnish landscape. In these cases the regional fire departments worked closely together to tame the flames.

Since Finland joined NATO in 2023, the border has been closed and a fence is being built, symbolizing the new hostile environment on the NATO-Russian border. Institutional contacts between universities on both sides are prohibited, as European universities have agreed to exclude all cooperation between European and Russian universities. The universities of Eastern Finland and the University of Petrozavodsk had a number of common projects, in economics, natural protection and communication, often funded by EU, to document the development in the regions on both sides of the border. Today, no contacts are allowed (O'Malley 2022).

3. Militarizing the Borderlands

Finnish security policy has, since the Second World War, always included a policy of neutrality and a capacity for the country to defend itself at the same time as the country, together with Sweden, had formed a buffer zone between NATO and the Soviet Union. Finland has today one of the largest conventional armies in Europe and the will to defend the country is one of the highest in Europe (Cronberg 2001). Relying on conscription, its military expenditure has historically been well below the NATO recommendation of 2% of the GDP. Given the new targets of NATO, Finland has increased its yearly military expenditure and is committed to reach 3,2% by 2030 (Reuters 2026).

As a member of NATO, Finland is today under the U.S. nuclear umbrella (Article 5 of the NATO treaty). Finland has, until now, had a nuclear energy law ('ydinenergialaki' in Finnish) which has prohibited any activities related to fissile material and nuclear weapons on Finnish soil. During the spring of 2026, the law was changed to allow for exceptions related to the defence of the country and/or defence cooperation. Furthermore, in parallel to its NATO membership, Finland has approved a bilateral defence cooperation agreement (DCA) with the USA, which allows for 15 American bases on Finnish soil.

These activities, while intended to improve Finnish defence in relation to Russia, also increase Finnish vulnerability to not only hybrid war and conventional aggression, but also for testing NATO resolve with a tactical nuclear weapon (BRICS Chain 2026). Correspondingly, rearmament is also taking place on the Russian side. Russia is massively expanding its military infrastructure along the Finnish border, both in the Karelian republic and the Leningrad military region, in response to Finland's accession to NATO (Military Watch 2026).

Intelligence agencies report that Russia is developing bases to eventually station up to 80,000 troops and reactivating Soviet-era garrisons to counter the Nordic alliance. Furthermore, the Russian leadership has placed Finland on its list of potential nuclear targets after the country adjusted its above-mentioned law to potentially permit nuclear weapons on its soil (Manuel 2026).

4. A Theatre of War?

In the current security environment, these developments pose an urgent risk. If the tension between NATO and Russia escalates, the Finnish-Russian border will be either the first target of Russian military aggression or Finland will be drawn into the expected NATO-Russia conflict either in the Baltic states or in Poland, increasing the probability of a military aggression also on the Russian-Finnish border. The vulnerability of the biodiversity of the forests of the Karelian Republic should be seen as one of the reasons to de-escalate the conflict in order to save the "lungs of Europe" from military devastation and forest fires. As pointed out by Harrison and Faulkner in this collection, smoke does not respect fenced borders. Environmental devastation on the Finnish-Russian border will be felt throughout the Nordic region. A common Nordic project as proposed by the two authors should also include the Russian side of the border.

5. Conclusion

Isolating countries creates problems not only for researchers but also reduces our knowledge of what is happening only a few hundred kilometres away. Cooperation on environmental questions should be allowed across the border, between the universities of neighbouring regions in order to better understand the environmental consequences and the impact on climate change in general but also those specific of potential military conflicts.

There are currently discussions between European leaders, among them the Finnish president, who have started talking about breaking Russian isolation. This is a long-term proposal at this time when escalation is taking place between NATO and Russia. Nevertheless, the European Union could reconsider its prohibition of institutional contacts between European and Russia universities in the environmental field. As a first step, there could been a special application procedure where individual cross-border projects would be evaluated in relation to their environmental urgency.

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