UNDERSTANDING THE GLOBAL EFFECTS OF NUCLEAR CONFLICT IN THE 21st CENTURY: READING LIST

TABLE OF CONTENTS

The damaging effects of the light, heat, blast, and radiation caused by a nuclear explosion have been known to scientists since the end of the Second World War and the bombings of Hiroshima and Nagasaki. Predictions about the indirect effects of nuclear detonations, however, are less certain and less understood. While not exhaustive, this reading list provides an overview of relevant literature on the global, long-term nuclear effects on (i) the climate, agriculture, and food security; (ii) the global economy, trade, and development; and (iii) foreign policy and international governance. Not listed are articles that address the immediate effects of a nuclear detonation, including consequences for emergency response and public health preparedness. This reading list not only draws from the field of nuclear policy but includes articles from adjacent fields that teach a broader lesson about the vulnerabilities of our world, such as environmental and climate science, crop modeling, disaster management, critical infrastructure, and economics. The reading list (including abstracts) provides a basis for examining global nuclear effects in a way that reflects the interconnectedness of our societies, taking into account the catastrophic ripple effects that the use of nuclear weapons could cause in today's globalized world.

This document is intended as a living resource to bring together the body of research and thinking that has emerged on the global and long-term effects of nuclear war. It will be periodically updated. For suggested additions to this list, please email: jaworek@nti.org

Climate Change

Bardeen, Charles G. et al. "Extreme Ozone Loss Following Nuclear War Results in Enhanced Surface Ultraviolet Radiation." *JGR Atmospheres* 123 (2021).
Nuclear war would result in many immediate fatalities from the blast, heat, and radiation, but smoke from fires started by these weapons could also cause climate change lasting up to 15 years threatening food production. The authors simulate the effects on ozone chemistry and surface ultraviolet (UV) light caused by absorption of sunlight by smoke from a global nuclear war. This could lead to a loss of most

of our protective ozone layer taking a decade to recover and resulting in several years of extremely high UV light at the surface further endangering human health and food supplies.

Coupe, Joshua, Charles G. Bardeen, Alan Robock, Owen B. Toon. "Nuclear Winter Responses to Nuclear War Between the United States and Russia in the Whole Atmosphere Community Climate Model Version 4 and the Goddard Institute for Space Studies ModelE." JGR Atmospheres 124, no. 15 (2019): 8522-8543.
The authors simulate the climate response using the Community Earth System Model-Whole Atmosphere Community Climate Model version 4 (WACCM4) and compare the results to an older simulation conducted in 2007 with the Goddard Institute for Space Studies ModelE run at 4° × 5° horizontal resolution with 23 levels up to 80 km and constant specified aerosol properties and ozone. These are the only two comprehensive climate model simulations of this scenario. Despite having different features and capabilities, both models produce similar results. Nuclear winter, with below freezing temperatures over much of the Northern Hemisphere during summer, occurs because of a reduction of surface solar radiation due to smoke lofted into the stratosphere. WACCM4's more sophisticated aerosol representation removes smoke more quickly, but the magnitude of the climate response is not reduced. In fact, the higher-resolution WACCM4 simulates larger temperature and precipitation reductions than ModelE in the first few years following a 150-Tg soot injection. A strengthening of the northern polar vortex occurs during winter in both simulations in the first year, contributing to above normal, but still below freezing, temperatures in the Arctic and northern Eurasia.

Coupe, Joshua, Samantha Stevenson et al. "Nuclear Niño response observed in simulations of nuclear war scenarios." *Communications Earth & Environment* 2, no. 18 (2021)
The climate impacts of smoke from fires ignited by nuclear war would include global cooling and crop failure. Facing increased reliance on ocean-based food sources, it is critical to understand the physical and biological state of the post-war oceans. The authors use an Earth system model to simulate six nuclear war scenarios, showing that global cooling can generate a large, sustained response in the equatorial Pacific, resembling an El Niño but persisting for up to seven years. The El Niño following nuclear war, or Nuclear Niño, would be characterized by westerly trade wind anomalies and a shutdown of equatorial Pacific upwelling, caused primarily by cooling of the Maritime Continent and tropical Africa. Reduced incident sunlight and ocean circulation changes would cause a 40% reduction in equatorial Pacific phytoplankton productivity. These results indicate nuclear war could trigger extreme climate change and compromise food security beyond the impacts of crop failure.

Eden, Lynn. Whole World on Fire: Organizations, Knowledge, and Nuclear Weapons Devastation, (Cornell University Press, March 2006).
In her book, Eden asks two questions: Why has the US government seriously underestimated for more than a half-century the damage that nuclear weapons could cause? Why did it develop detailed knowledge about the blast damage, but fail to develop it about the even more devastating effects of mass fire damage? As a result, any US decision to use nuclear weapons almost certainly would be predicated on insufficient and misleading information. If nuclear weapons were used, the physical, social, and political effects could be far more destructive than anticipated.

Harrison, C. S., Rohr, T., DuVivier, A., Maroon, E. A., Bachman, S., Bardeen, C. G., et al. "A new ocean state after nuclear war." *AGU Advances* 3, no. 4 (2022).
Nuclear war would produce dire global consequences for humans and our environment. The authors simulate climate impacts of US-Russia and India-Pakistan nuclear wars in an Earth System Model and report on the ocean impacts. Like volcanic eruptions and large forest fires, firestorms from nuclear war would transport light-blocking aerosols to the stratosphere, resulting in global cooling. Surface cooling drives sea ice expansion, enhanced meridional overturning, and intensified ocean vertical mixing that is expanded, deeper, and longer lasting. Phytoplankton production and community structure are highly modified by perturbations to light, temperature, and nutrients, resulting in initial decimation of production, especially at high latitudes. A new physical and biogeochemical ocean state results,

characterized by shallower pycnoclines, thermoclines, and nutriclines, ventilated deep water masses, and thicker Arctic sea ice. In the largest US-Russia scenario (150 Tg), ocean recovery is likely on the order of decades at the surface and hundreds of years at depth, while changes to Arctic sea-ice will likely last thousands of years, effectively a "Nuclear Little Ice Age." Marine ecosystems would be highly disrupted by both the initial perturbation and in the new ocean state, resulting in long-term, global impacts to ecosystem services such as fisheries.

Helama, Samuli, et al. "Volcanic dust veils from sixth century tree-ring isotopes linked to reduced irradiance, primary production and human health." *Scientific Reports* 8, no. 1339 (2018).
The large volcanic eruptions of AD 536 and 540 led to climate cooling and contributed to hardships of Late Antiquity societies throughout Eurasia. A model based on sixth century isotopes reconstructs an irradiance anomaly for AD 536 and 541–544 of nearly three standard deviations below the mean value based on modern data. This anomaly can be explained by a volcanic dust veil reducing solar radiation and thus primary production threatening food security over a multitude of years. The authors offer a hypothesis that persistently low irradiance contributed to remarkably simultaneous outbreaks of famine and Justinian plague in the eastern Roman Empire with adverse effects on crop production and photosynthesis of the vitamin D in human skin and thus, collectively, human health. The article provides a hitherto unstudied proxy for exploring the mechanisms of 'volcanic summers' to demonstrate the post-eruption deficiencies in sunlight and to explain the human consequences during such years. The study offers important lessons about the parallels that could be drawn to the impact of "nuclear winter" on human health.

Hess, G.D. "The Impact of a Regional Nuclear Conflict between India and Pakistan: Two Views." *Journal for Peace and Nuclear Disarmament* 4, no. 1 (2021): 163-175.
The severity of climatic effects of a regional nuclear conflict between India and Pakistan, involving the use of a hundred Hiroshima-scale nuclear weapons, is contested between two groups; Mills et al. from the National Center for Atmospheric Research (NCAR), University of Colorado, and Rutgers University conclude that a global Nuclear Winter would occur; Reisner et al. from Los Alamos National Laboratory (LANL) conclude that No Nuclear Winter would occur. This paper discusses the different assumptions that lead to the two different conclusions. Specifically, it highlights the use of different fuel loading and different input methods for the amount and initial location of black carbon (BC) into the climate models, and discusses some underlying reasons for these different choices, including the question of what kind of fire will occur in the aftermath of a nuclear weapon being dropped on a densely populated city. The paper also briefly discusses some physical phenomena that have not been considered by either group and lays out some questions for research before any definitive conclusion about the climatic effects of a limited nuclear war can be reached.

Raymond Jeanloz, "Environmental Effects of Nuclear War," in Andrei Sakharov, The Conscience of Humanity (S. D. Drell and G. P. Shultz, eds.), (Hoover Press, 2015), pp. 53-68.
Jeanloz summarizes the main developments in the research on the effect of soot from a nuclear conflict generating a 'nuclear winter.' After outlining several methodologies taken to evaluate the environmental impact of atmospheric soot, he supports the conclusion that the release of 3-5 Mt soot in the atmosphere could have significant and detrimental effects on the human population but reiterates that there remains significant uncertainty and remaining research in order to translate these findings to policymakers.

Lovenduski, Nicole S., Cheryl Harrison et al. "The Potential Impact of Nuclear Conflict on Ocean Acidification." Geophysical Research Letters 47, no. 3 (2020).
A regional nuclear conflict may have far-reaching effects on global ocean carbonate chemistry. These changes may have negative consequences for marine organisms, in particular for those that precipitate calcium carbonate shells (e.g., coccolithophores, pteropods, foraminifera, corals, molluscs, and echinoderms). The decrease in saturation state would exacerbate shell dissolution from anthropogenic ocean acidification.

Mills, Michael J. et al. "Massive global ozone loss predicted following regional nuclear conflict." *PNAS* 105, no. 14 (2008): 5307-5312.
This article uses new estimates of smoke produced by fires in contemporary cities to calculate the impact on stratospheric ozone of a regional nuclear war between developing nuclear states involving 100 Hiroshima-size bombs exploded in cities in the northern subtropics. The authors find ozone losses of more than 20% globally, 25–45% at midlatitudes, and 50–70% at northern high latitudes persisting for 5 years, with substantial losses continuing for 5 additional years. The resulting increases in UV radiation could impact the biota significantly, including serious consequences for human health.

Mills et al. "Multidecadal global cooling and unprecedented ozone loss following a regional nuclear conflict." *Earth's Future* 2, no. 4 (2014): 161-176.
Based on the scenario of a limited, regional nuclear war between India and Pakistan, this article predicts that global ozone losses of 20%–50% over populated areas, levels unprecedented in human history, would accompany the coldest average surface temperatures in the last 1000 years. Mills et al. calculate summer enhancements in UV indices of 30%–80% over midlatitudes, suggesting widespread damage to human health, agriculture, and terrestrial and aquatic ecosystems. Killing frosts would reduce growing seasons by 10–40 days per year for 5 years. Surface temperatures would be reduced for more than 25 years. The combined cooling and enhanced UV would put significant pressures on global food supplies and could trigger a global nuclear famine.

National Research Council. 1975. "Long-Term Worldwide Effects of Multiple Nuclear Weapon Detonations." Washington, D.C.: National Academy of Sciences.
The study examines the possible long-term worldwide effects of a 10,000-megaton (Mt) nuclear war, looking at radioactive fallout, photochemical effects, temperature effects, and climatic implications. Even though the understanding of climatological phenomena at that time was insufficient to come to definitive conclusions, the study finds that the injection of dust in the stratosphere could lead to significant climatological effects and that major global climate change cannot be excluded.

Pierazzo et al. "Ozone perturbation from medium-size asteroid impacts in the ocean." *Earth and Planetary Science Letters* 299, no. 3 and 4 (2010): 263-272.
The study is referenced by Mills et al. Pierazzo et al. present a review of the literature considering the effects of large increases on UV radiation on living organisms and note that the ozone loss could lead to DNA damage in crops, possibly passing it on to successive generations, and may alter the susceptibility of plants to insect attacks. It could also affect aquatic ecosystems and reduce phytoplankton that could result in a loss of up to 7 million tons of fish harvest per year, putting significant pressure on global food security.

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, 2752–2772.
This article finds that the effects on global surface temperatures are not uniform and are concentrated primarily around the highest arctic latitudes, dramatically reducing the global impact on human health and agriculture compared with that reported by earlier studies. The analysis demonstrates that the probability of significant global cooling from a limited exchange scenario as envisioned in previous studies is highly unlikely, a conclusion supported by examination of natural analogs, such as large forest fires and volcanic eruptions. Robock et al. responded to this article (see below).

Reisner et al. "Reply to Comment by Robock et al. on "Climate Impact of a Regional Nuclear Weapon Exchange: An Improved Assessment Based on Detailed Source Calculations." *JGR Atmospheres* 124, no. 23 (2019).
Robock et al. (2019) contend that the reasons for Reisner et al. (2018) simulations not producing enough black carbon (BC) in the upper atmosphere are as follows: (1) low fuel loads, (2) high surface

winds, (3) omission of latent heat release by cloud formation, and (4) short simulation. In this response to Robock et al.'s comment, Reisner et al. resolve (1) with additional simulations over a range of fuel loads, clarify (2) by noting that our surface winds of 2.4 m/s are below the firestorm threshold, agree that addressing (3) requires more research, and (4) short simulations are appropriate since this is when most of the BC emissions that can reach the upper atmosphere occur. While Reisner et al. agree with Robock et al. assessment that a firestorm was not produced, the authors demonstrate why a firestorm, according to their model, is unlikely in dense population centers found in India and Pakistan where concrete structures dominate.

Robock et al. "Nuclear winter revisited with a modern climate model and current nuclear arsenals: still catastrophic consequences." *Journal of Geophysical Research* 112 (2007).
In this article, Robock et al. use a modern climate model to reexamine the climate response to a range of nuclear wars, producing 50 and 150 Tg of smoke. This is the first time that an atmosphere-ocean general circulation model has been used for such a simulation and the first time that 10-year simulations have been conducted. The response to the 150 Tg scenario can still be characterized as "nuclear winter," but both produce global catastrophic consequences. The changes are more long-lasting than previously thought, however, because the new model is able to represent the atmosphere up to 80 km, and simulates plume rise to the middle and upper stratosphere, producing a long aerosol lifetime.

Robock, Alan et al. "Climatic consequences of regional nuclear conflicts." *Atmospheric Chemistry and Physics* 7, no. 8 (2007): 2003-2012.
Robock et al. use a modern climate model and new estimates of smoke generated by fires in contemporary cities to calculate the response of the climate system to a regional nuclear war between emerging third world nuclear powers using 100 Hiroshima-size bombs on cities in the subtropics. They find significant cooling and reductions of precipitation lasting years, which would impact the global food supply. The climate changes are large and long-lasting because the fuel loadings in modern cities are quite high and the subtropical solar insolation heats the resulting smoke cloud and lofts it into the high stratosphere, where removal mechanisms are slow. While the climate changes are less dramatic than found in previous "nuclear winter" simulations of a massive nuclear exchange between the super-powers, because less smoke is emitted, the changes are more long-lasting because the older models did not adequately represent the stratospheric plume rise.

Robock, Alan et al. Comment on "Climate Impact of a Regional Nuclear Weapon Exchange: An Improved Assessment Based on Detailed Source Calculations" *JGR Atmospheres* 124 no. 23 (2019).
This article is a response to Reisner et al. who revisited a study Robock et al. had done modeling the climate impacts of a nuclear war between India and Pakistan. The Robock et al. article states that the fires started by 100 15-kt atomic bombs would produce 5 Tg of soot injected into the upper troposphere and would be subsequently lofted into the lower stratosphere. Robock et al. contradict Reisner et al. who say that there would be much less smoke. Reisner et al. chose a target area of suburban Atlanta that includes a golf course, playground, and individual houses with large yards, with little material to burn, which is not representative of densely populated cities in India and Pakistan. The fire Reisner et al. modeled is not typical of the type of mass fire likely to result from a nuclear attack on cities, using winds that are stronger than typical winds. Robock et al. also criticize that Reisner et al. used a fire model that they have not made available for other scientists to try to reproduce their work, and which has not been shown to accurately simulate firestorms observed in Hamburg, Dresden, and Hiroshima during World War II. Robock et al. state that Reisner et al. significantly underestimate the amount of smoke, and climate and agricultural impacts likely to occur after a nuclear war. Reisner et al. responded to this article (see above).

Robock, Alan and Brian Zambri. "Did Smoke From City Fires in World War II Cause Global Cooling?" *Journal of Geophysical Research: Atmospheres* 123 (2018).
Between 3 February and 9 August 1945, an area of 461 square kilometers in 69 Japanese cities, including Hiroshima and Nagasaki, was burned during the U.S. B-29 Superfortress air raids, and the Hiroshima and Nagasaki smoke was less than 5% of the total. The authors calculate how much smoke was emitted and how much climate change would have been expected. Although there was a small cooling, because of multiple uncertainties in smoke injected to the stratosphere, sunlight observations, and surface temperature observations, the authors find that it is not possible to say for sure that this was a cooling signal from World War II smoke. However, these results do not that much more massive smoke emissions from nuclear war would cause large climate change and impacts on agriculture.

Paul Rubinson, "Imagining the apocalypse: nuclear winter in science and the world." in *Understanding the Imaginary War: Culture, Thought and Nuclear Conflict, 1945-90*, eds. Matthew Grant and Benjamin Ziemann (Manchester, 2017).
This essay by Rubinson, a nuclear historian, shows how the indiscriminate effects of nuclear winter helped to galvanize a shared global ethos against nuclear weapons as a planetary issue. It details early reception of the nuclear winter theory by peers of Sagan and the TTAPS scientific movement in the early 1980s and outlines the obstacles Sagan and his colleagues faced when translating scientific findings for the public and defending scientific findings against politically motivated attacks.

Stenke, Andrea et al. "Climate and chemistry effects of a regional scale nuclear conflict." *Atmospheric Chemistry and Physics* 13 (2013): 9713-9729.
Stenke et al. used a different climate model to test the reliability of previous results (one that does not account for changing ocean circulation) which confirmed Robock's and Mill's research. The study finds that a nuclear conflict would lead to cold, dark, and dry environmental conditions by cooling the earth's surface, reducing global precipitation, and leading to ozone loss. The latter could result in significant UV enhancements (up to 40% in summer) which would have adverse effects on human health, plants, and the biosphere in general. The team of researchers further observed a strong increase in sea ice coverage over both hemispheres which could strongly impact shipping routes and, thus, global food and fuel supply.

Stothers, Richard B. "Volcanic Dry Fogs, Climate Cooling, and Plague Pandemics in Europe and the Middle East." *Climatic Change* 42 (1999): 713-723.
Dry fogs spawned by large volcanic eruptions cool the climate by partially blocking incident sunlight and perturbing atmospheric circulation patterns. The climatic and epidemiological consequences of seven intense volcanic dry fogs of the past 21 centuries, detected in Europe and the Middle East, are investigated by using historical reports, supplemented by tree-ring data and polar-ice acidity measurements. In four cases, the first winter following the eruption was exceptionally cold. The eruptions preceding these frigid first winters are known, or strongly suspected, to have occurred at high northern latitudes. Two of the other dry fogs are linked unambiguously to tropical eruptions, after each of which the first winter was comparatively mild. The following few years tended to be cooler on the average in all six of the instances that can be checked. Famine and disease pandemics ensued, with the epidemics in all cases reaching the Mediterranean area within 1 to 5 years after the eruptions.

Turco, R. P., O. B. Toon, T. P. Ackerman, J.B. Pollack, and C. Sagan. "Nuclear Winter: Global Consequences of Multiple Nuclear Explosions." *Science* 222 (1983): 1283-1292.
The potential global atmospheric and climatic consequences of nuclear war are investigated using models previously developed to study the effects of volcanic eruptions. Although the results are necessarily imprecise, due to a wide range of possible scenarios and uncertainty in physical parameters, the most probable first-order effects are serious. Significant hemispherical attenuation of the solar radiation flux and subfreezing land temperatures may be caused by fine dust raised in high-yield nuclear surface bursts and by smoke from city and forest fires ignited by airbursts of all yields.

For many simulated exchanges of several thousand megatons, in which dust and smoke are generated and encircle the earth within 1 to 2 weeks, average light levels can be reduced to a few percent of ambient and land temperatures can reach -15° to -25°C. When combined with the prompt destruction from nuclear blast, fires, and fallout and the later enhancement of solar ultraviolet radiation due to ozone depletion, long-term exposure to cold, dark, and radioactivity could pose a serious threat to human survivors and to other species.

Toon, Owen et al. "Atmospheric effects and societal consequences of regional scale nuclear conflicts and acts of individual nuclear terrorism." *Atmospheric Chemistry and Physics, European Geosciences Union* 7, no. 8 (2007) 1973-2002.
Toon et al. find that low yield weapons can produce 100 times as many fatalities and 100 times as much smoke from fires per kt yield as previously estimated in analyses for full scale nuclear wars using high-yield weapons, if the small weapons are targeted at city centers. Using a modern US climate model, the study finds that the soot from a nuclear detonation would rise to much higher altitudes than previously believed, which increases the time it would take for the soot to decompose causing a longer-lasting climate response. Megacities exposed to atmospheric fallout of long-lived radionuclides would likely be abandoned indefinitely, with severe national and international implications.

Agriculture and Food Security

Baum, Seth D., David Denkenberger, Joshua M. Pearce, Alan Robock and Richelle Winkler. "Resilience to global food supply catastrophes." *Environment Systems & Decisions* 35, no. 2 (2015)
In contrast to local catastrophes, global food supply catastrophes cannot be addressed via food aid from external locations. Three options for food supply resilience are identified: food stockpiles, agriculture, and foods produced from alternative (non-sunlight) energy sources including biomass and fossil fuels. Each of these three options has certain advantages and disadvantages. The optimal portfolio of food options will typically include some of each and will additionally vary by location as regions vary in population and access to food input resources. Furthermore, if the catastrophe shuts down transportation, then resilience requires local self-sufficiency in food. Food supply resilience requires not just the food itself, but also the accompanying systems of food production and distribution.

Bachev, H. and F. Ito (2014) "Implications of Fukushima Nuclear Disaster for Japanese Agri-Food Chains." *International Journal of Food and Agricultural Economics* 2(1): 95-120.
This study presents the results of a study on the implications of the Fukushima nuclear disaster for Japanese agri-food chains. The authors assess immediate and short-term radiation effects, effects on nearby populations, safety regulation and inspection systems, market and consumer behavior, agricultural and food products, health, and economic impacts on farming and agri-businesses. The study also provides an estimate of the overall shorter and longer-term impacts on agriculture, food industries, and consumers in the Fukushima region, neighboring regions, and other parts of Japan.

Denkenberger, David et al., "Long term cost-effectiveness of resilient foods for global catastrophes compared to artificial general intelligence safety." *International Journal of Disaster Risk Reduction* 73 (2022): 102798.
Global agricultural catastrophes, which include nuclear winter and abrupt climate change, could have long-term consequences on humanity such as the collapse and nonrecovery of civilization. Using Monte Carlo (probabilistic) models, the authors analyze the long-term cost-effectiveness of resilient foods (alternative foods) - roughly those independent of sunlight such as mushrooms. Because the agricultural catastrophes could happen immediately and because existing expertise relevant to

resilient foods could be co-opted by charitable giving, it is likely optimal to spend most of the money for resilient foods in the next few years.

Helfand, Ira. "Nuclear Famine." In: "Unspeakable suffering – the humanitarian impact of nuclear weapons." Reaching Critical Will. January 2013.
Over the last several years, a number of studies have shown that a limited, regional nuclear war between India and Pakistan would cause significant climate disruption worldwide (see below). This article summarizes some of the more recent work on the climate and agricultural effects of nuclear conflict. It concludes that the decline in available food would be exacerbated by increases in food prices, which would make food inaccessible to hundreds of millions of the world's poorest. Even if agricultural markets continued to function normally, 215 million people would be added to the rolls of the malnourished over the course of a decade.

Helfand, Ira. "Nuclear Famine: Two Billion People at Risk?" IPPNW, 2013.
In April of 2012, the IPPNW released a report titled "Nuclear Famine: A Billion People at Risk" which examined the climatic and agricultural consequences of a limited, regional nuclear war. The report looked specifically at the declines in US maize and Chinese rice production that would result from the predicted climate disruption and concluded that even a limited nuclear conflict would cause extensive famine, mainly in the developing world, and put more than one billion people at risk of starvation. Since then, new research by Xia and Robock (see below) has shown that climate change caused by a limited nuclear war would affect Chinese maize production as severely as rice production and it would affect wheat production much more severely than rice output. Their new findings suggest that the original report may have seriously underestimated the consequences of a limited nuclear war. In addition to the one billion people in the developing world who would face possible starvation, 1.3 billion people in China would confront severe food insecurity. The prospect of a decade of wide-spread hunger and intense social and economic instability in the world's largest country has immense implications for the entire global community, as does the possibility that the huge declines in Chinese wheat production would be matched by similar declines in other wheat producing countries.

Hochman, Gal, Hainan Zhang, Lili Xia, Alan Robock et al. "Economic incentives modify agricultural impacts of nuclear war." *Environmental Research Letters* 17, no. 5 (2022).
A nuclear war using less than 1% of the current global nuclear arsenal could produce significant impacts on agricultural productivity and the economy. These effects would be most severe for the first five years after the nuclear war and may last for more than a decade. This paper calculates how food availability would change by employing the Environmental Impact and Sustainability Applied General Equilibrium model. Under a robust world trading system, global food availability would drop by a few percentage points. If the war would destabilize trade, it would magnify by several times the negative ramifications of land productivity shocks on food availability. If exporting countries redirect production to domestic consumption at the expense of importing countries, it would lead to the destabilization of international trade. The analysis suggests that economic models aiming to inform policymakers require both economic behavior analysis and biophysical drivers. Policy lessons derived from a crop model can be significantly nuanced when coupled with economic feedback derived from economic models.

Jägermeyr, Jonas, Alan Robock, et al. "A regional nuclear conflict would compromise global food security." *PNAS* 117, no. 13 (2020): 7071-7081.
Jägermeyr et al. conclude that a limited nuclear war would result in sudden global cooling of about 1.8 degrees Celsius for a period of 5 to 10 years which would be more harmful to global agriculture than the same amount of warming associated with anthropogenic climate change. Comparing these results with historic famines caused by volcanic eruptions, global cooling from a limited nuclear war would cause average losses in agricultural production of more than 11 percent globally and more than 18 percent in the US (up to 41 percent depending on the individual year in which the conflict occurs). The soot emissions from a limited nuclear war and subsequent climatic consequences could trigger a severe food production shock and depleting food reserves (which would last only for a year after the

conflict). Trade dependencies would propagate the disruption to the Global South, reducing food availability in 71 countries by more than 20 percent and globally by more than 13 percent. Such a food supply shock would have more severe societal implications than any other event documented in recent history – as major export countries would be hit hardest, these food supply disruptions could not be alleviated by global trade or food aid and would likely cause inflated food prices, exacerbating inequalities and social unrest (especially in developing countries).

Naylor, Rosamond L. and Walter P. Falcon. "Food Security in an Era of Economic Volatility." *Population and Development Review* 36, no. 4 (2010): 693-723.
This article analyzes international commodity price movements, assesses food policies in response to price fluctuations, and explores the food security implications of price volatility. It focuses specifically on measurements, causes, and consequences of recent food price trends, variability around those trends, and price spikes. Naylor highlights the new linkages between the agriculture-energy and agriculture-finance markets that affect the world food economy today. Even though the article does not relate to nuclear conflict, its findings suggest that critical spikes in global food prices could ensue such an event, considering that smaller production shocks are often associated with commodity price surges.

Özdogan, Mutlu, Alan Robock and Christopher Kucharik. "Impacts of a nuclear war in South Asia on soybean and maize production in the Midwest United States." *Climatic Change* 116 (2013): 373-387.
Crop production would decline in the Midwestern United States from climate change following a regional nuclear conflict between India and Pakistan. The authors calculate change in crop yield based on the decline in precipitation, solar radiation, growing season length and average monthly temperature predicted in Robock's studies. Despite the fact that certain significant factors such as UV radiation were not considered in this model, the study shows significant declines in both corn and soybean production, which, over 10 years, could decline by 10% on average.

Puma, Michael J. et al. "Assessing the evolving fragility of the global food system." *Environmental Research Letters* 10 (2015) 024007.
The world food crisis in 2008 highlighted the susceptibility of the global food system to price shocks. The article uses annual staple food production and trade data from 1992–2009 to analyze the changing properties of the global food system. The authors show that the global food system is relatively homogeneous (85% of countries have low or marginal food self-sufficiency) and increases in complexity, with the number of global wheat and rice trade connections doubling and trade flows increasing by 42 and 90%, respectively. The increased connectivity and flows within these global trade networks suggest that the global food system is vulnerable to systemic disruptions, especially considering the tendency for exporting countries to switch to non-exporting states during times of food scarcity in the global markets.

Scherrer, Kim N., Cheryl S. Harrison et al. "Marine wild-capture fisheries after nuclear war." PNAS 117, no 47 (2020): 29748–29758.
The effects of nuclear war on marine wild-capture fisheries, which significantly contribute to the global animal protein and micronutrient supply, remain unexplored. The authors simulate the climatic effects of six war scenarios on fish biomass and catch globally, using a state-of-the-art Earth system model and global process-based fisheries model. They also simulate how either rapidly increased fish demand (driven by food shortages) or decreased ability to fish (due to infrastructure disruptions), would affect global catches, and test the benefits of strong prewar fisheries management. The study finds a decade-long negative climatic impact that intensifies with soot emissions, with global biomass and catch falling by up to 18 ± 3% and 29 ± 7% after a US–Russia war under business-as-usual fishing—similar in magnitude to the end-of-century declines under unmitigated global warming.

Seekell, David et al. "Resilience in the global food system." *Environmental Research Letters* 12 (2017) 025010.
The article states that ensuring food security requires that food production and distribution systems function despite potential disruptions. The ability of a food system to respond and adapt to disruptions, while maintaining its function, describes the system's resilience. Local, global, and cross-scale interactions must be included when evaluating resilience within the increasingly globalized food system. Seekell et al. consider three main dimensions of resilience: the ability to access food which is based on social and economic factors; biophysical capacity to increase food production; and the magnitude and diversity of domestic food production. The article finds that very few countries have exclusively high or low values for all three dimensions. It also creates a national-scale index that creates the opportunity for global comparisons of food resilience between nations.

Webb et al. "Medium to Long-Run Implications of High Food Prices for Global Nutrition." *Journal of Nutrition* 140, no. 1 (2010): 140-147.
Drawing from data received through the Özdogan et al. study, Webb et al. examine the effects of a regional nuclear war on food prices. They conclude that a one-year 20 percent decline in crop yield would cause prices to rise by 19.7 percent globally – with an uneven distribution across the world. In East Asia the rise would amount to over 20 percent and in south Asia to over 30 percent. Over 10 years a total of 215 million people could become malnourished. Webb notes that these numbers could even be exacerbated as the economic model operates with normally behaving markets, which in the aftermath of a nuclear war, would most likely not be the case. Rather, we would need to expect market reactions such as hoarding, as exporting nations would most likely suspend exports leading to grave disturbances of normal market conditions that could increase prices to an even larger extent (such market disturbances have also occurred during the COVID-19 pandemic). A limited nuclear war therefore not only poses an existential threat to those who are already malnourished but also those in countries that are import-dependent (such as North Africa, South Korea, and countries in the Middle East).

Xia, Lili and Alan Robock. "Impacts of a nuclear war in South Asia on rice production in Mainland China." *Climatic Change* 116 (2013): 357-272.
A regional nuclear war between India and Pakistan with a 5 Tg black carbon injection into the upper troposphere would produce significant climate changes for a decade, including cooling, reduction of solar radiation, and reduction of precipitation, which are all important factors controlling agricultural productivity. Xia/Robock find that rice production would decline by an average of 21 % for the first 4 years after soot injection and would slowly recover in the following years. Different regions are expected to respond differently to climate changes from nuclear war. Rice production in northern China was damaged severely, while regions along the south and east coasts showed a positive response to regional nuclear war.

Xia, Lili et al. "Decadal reduction of Chinese agriculture after a regional nuclear war." Earth's Future 3 (2015): 37-48.
Using a crop simulation model forced by three global climate model simulations, the authors investigate the impacts of a nuclear war between India and Pakistan on agricultural production in China, the largest grain producer in the world. In the first year after the regional nuclear war, a cooler, drier, and darker environment would reduce annual rice production by 30 megaton (Mt) (29%), maize production by 36 Mt (20%), and wheat production by 23 Mt (53%). With different agriculture management simulated national crop production reduces 16%–26% for rice, 9%–20% for maize, and 32%–43% for wheat during 5 years after the nuclear war event. This reduction of food availability would continue, with gradually decreasing amplitude, for more than a decade. Assuming these impacts are indicative of those in other major grain producers, a nuclear war using much less than 1% of the current global arsenal could produce a global food crisis and put a billion people at risk of famine.

Global Economy, Trade, and Development

Acheson, Ray. "Wider consequences – impact on development." in "Unspeakable Suffering", Reaching Critical Will, 2013.
Acheson explores how the use of nuclear weapons—whether a single detonation or a nuclear war—could exacerbate poverty and inequalities and undermine the achievement of the Millennium Development Goals (MDGs). The article relies on data from other disasters, including natural disasters, the Chernobyl and Fukushima nuclear disasters, and nuclear testing in the Marshall Islands, in order to extrapolate possible implications of the use of nuclear weapons on development. It explains how disasters gravely exacerbate development challenges from reducing poverty to building infrastructure to promoting gender equality and suggests how the use of nuclear weapons could have such effects.

Albert, Réka, István Albert, and Gary L. Nakarado. "Structural vulnerability of the North American power grid." *Physical Review E* 69, 025103(R) (2004).
The magnitude of the August 2003 blackout affecting the United States has put the challenges of energy transmission and distribution into the limelight. Despite all the interest and concerted effort, the complexity and interconnectivity of the electric infrastructure for a long time precluded researchers from understanding why certain events happened. This paper studies the power grid from a network perspective and determines its ability to transfer power between generators and consumers when certain nodes are disrupted. It finds that the power grid is robust to most perturbations, yet disturbances affecting key transmission substations greatly reduce its ability to function. The authors emphasize that the global properties of the underlying network must be understood as they greatly affect local behavior.

Article 36. "Economic impacts of a nuclear weapon detonation." International Campaign to Abolish Nuclear Weapons, Briefing Paper, 2015.
This briefing paper states that the world has become more urbanized, globalized and more heavily dependent on infrastructure that relies on electricity and electronics. The economic impact of a nuclear detonation in an urban area would be caused by the enormous loss of human and physical capital: About 65 percent of the world's economically active population works in industry and services which are, to a high extent, located in urban areas. About 80 percent of the world's GDP is generated in cities which would mean that an urban nuclear attack would most likely destroy key sectors of a national economy, disrupting supply chains and product distribution (leading to bottlenecks elsewhere), as well as quality educational facilities, and hospitals. A nuclear attack would further significantly disturb the modern economy's dependence on functioning infrastructures, such as communication, transport, water, electricity, and fuel networks as well as electrical grids more broadly. This is crucial, as even a short electricity network disruption can have considerable economic costs (the cost of the "Northeast Blackout" in 2003 that affected the U.S. and Canada and lasted only a few hours, incurred economic costs in the amount of 10 billion USD). Response and recovery would place a heavy burden on public finances in the long-term – the Chernobyl nuclear power plant accident still affects government spending in Ukraine, with 5-7 percent each year still devoted to related benefits and programs (including social benefits).

Bram et al. "Measuring the Effects of the September 11 Attack on New York City." *FRBNY Economic Policy Review* (2002): 5–6.
The analysis presented in this article provides a basis for the Dumas/Nelson article listed below. It evaluates the short-term economic consequences of the attack on Manhattan and the four other boroughs that make up New York City, looking at the effects of the attack on the inputs to the production process: labor and capital. The article finds that the attack led to an idling and underutilization of labor not only in the World Trade Center area, but also in other parts of the city. The analysis of capital covers the destruction of commercial space and infrastructure.

Cochrane, Hal and Dennis Mileti, "The Consequences of Nuclear War: An Economic and Social Perspective." in: The Medical Implications of Nuclear War, ed. by F. Solomon and RQ Marsten (National Academies Press, 1986).
The economic infrastructure which is left intact after the attack would play a key role in determining the length of time during which such life-threatening conditions might persist. The survivors would face the critical task of rebuilding a viable economy capable of rapidly reallocating undamaged capital and distributing uncontaminated foodstuffs. The tools available to researchers are based on historic patterns of production and institutional arrangements. However, these are likely to change during the period of reconstruction. It is highly unlikely that the social order, for example, would remain static. There may be insufficient reserves of domestic oil and gas to meet the needs of both reconstruction and production of essential consumer items and trading patterns may not return to their prewar state.

Comes, T., & Van de Walle, B. "Measuring disaster resilience: The impact of hurricane sandy on critical infrastructure systems." 2014.
Modern critical infrastructure (CI) systems are tightly coupled, resulting in unprecedented complexity and difficulty to predict, limit and control the consequences of disruptions caused by hazards. Therefore, a paradigm shift in disaster risk management is needed: instead of focusing on predicting events, resilience needs to be improved as a basis for adequate response to any event. This paper starts from a definition of CI resilience that provides a basis for quantitative and qualitative decision support. For the quantitative modelling approach, which aims at measuring the resilience of individual CIs, we focus on two CIs of fundamental importance for disaster response: transportation and power supply. The qualitative framework details relations between CIs. The results of this research are illustrated by a case study that analyses the impact of Hurricane Sandy. The findings highlight the need for a framework that combines qualitative and quantitative information from heterogeneous sources to improve disaster resilience.

Dixon, Peter B. et al. "The Economic Effects of a Hypothetical Nuclear Attack on Downtown LA." Multi-regional Dynamic General Equilibrium Modeling of the U.S. Economy, p. 211-227.
Dixon et al. use economic modeling of hypothetical adverse events which was developed by the Department of Homeland Security (DHS) in order to assist in emergency response planning. The article concludes that evacuation expenses would reach almost 4 billion USD and decontamination costs would amount to 70 billion USD in the first and second year after the attack. Evacuation policies and immediate deaths would reduce available capital and employment of about 20 percent – leading to permanent depression after the attack.

Dumas, Lloyd J. and Teresa D. Nelson. "Estimating the economic consequences of a nuclear weapons explosion: Critical factors." in "Unspeakable Suffering", Reaching Critical Will, 2013.
Based on an analysis of economic costs incurred by the 9/11 attack by Bram et al. (2002), Dumas/Nelson estimate that a comparable nuclear attack would amount to more than 30 billion USD in lost earnings from the victims alone which would be accompanied by an increase in regional and potentially even national unemployment levels, depending on the industries affected by the detonation. Worker productivity would suffer significantly in the aftermath of the detonation, due to the effects on the physical and mental health of survivors – which could be exacerbated by a lack of accessible health care services – adding to associated economic costs. Additional economic costs would arise out of the physical destruction from the detonation which would far exceed the damage incurred by a regular terrorist attack or a natural disaster, adding decontamination costs.

Folga, Stephen et al. "Literature Review and Synthesis for the Natural Gas Infrastructure." Argonne National Laboratory.
The U.S. energy infrastructure fuels the economy of the 21st century. Without a stable energy supply, health and welfare are threatened, and the U.S. economy cannot function. Presidential Policy Directive 21 identifies the Energy Sector as uniquely critical because it provides an "enabling function" across all critical infrastructure sectors

Katz, Arthur and Sima R. Osdoby. "The Social and Economic Effects of Nuclear War." Cato Institute. April 21, 1982.
This paper finds that the effects of nuclear war on a complex, technical/industrial society are not evaluated adequately in the development of strategic policies. If the full range of economic, social, and political effects, as well as casualty projections, of fighting various types of proposed nuclear war were to be examined realistically, our strategic goals and weapons requirements would change, in some cases significantly. The study finds that casualties, evacuation, and land denial would create severe national and local economic dislocations. A major evacuation would leave the regional economy in a shambles. Because of economic interdependence, the problem of „bottlenecking" -- serious disruption of the national economy -- would be likely. Even modest reductions in capacity of basic, pivotal industries can have severe, widespread effects on the economy. This disruption could easily last several months, and in a post-attack stalemate with the possibility of future attack requiring prolonged urban evacuation, it would become worse.

Kerber, Samuel W., Gilbert, Alexander Q., Deinert, Mark R., and Bazilian, Morgan D., 2021. "Understanding the nexus of energy, environment and conflict: An overview." *Renewable and Sustainable Energy Reviews*, Elsevier, vol. 151(C).
Energy, environment, and conflict are each the subject of significant research efforts. However, their nexus has received relatively little attention, and even less when climatic shifts are considered. The authors examine existing literature on these individual areas, their overlaps, and elucidate the fundamental gaps in understanding their nexus. Past work has shown that energy and the environment can both be the cause of conflict, or be used as tools in it. Importantly, while many databases have been developed to track conflict, these resources often fail to contain information on the root cause, or target of conflict events. Further work in this complex space could help inform decisionmakers working on reducing conflicts at the local, national, and regional levels.

Lynn, Barry. "Built to Break: The International System of Bottlenecks in the New Era of Monopoly." *Challenge* 55, no. 2 (2012): 87-107.
The study shows that global economic disruption can be immense even after events that occur in only one country because the impact of any major disaster would today be magnified by the fact that the global economy has grown more dependent on fewer sources of supply – a fact that has been observed after natural disasters. Disruption in the energy sector, such as US fuel production and processing industry, would be particularly harmful. The world is far more susceptible than ever before to industrial disruption, and even crashes, due to events in only one country.

Meade, Charles and Roger Molander. "Considering the Effects of a Catastrophic Terrorist Attack." RAND, 2006.
Meade/Molander conduct a detailed scenario analysis of a hypothetical attack involving a nuclear detonation in the Port of Long Beach and use strategic gaming to explore the longer-term implications. As detailed by the scenario analysis, the attack would devastate much of the Los Angeles region. Results indicate that the consequences could easily spread to national and international scales. This work is the first to illuminate the critical economic contingencies driven by decision-making in the extended period after a catastrophic attack. Given the pressing policy concerns involving critical infrastructure and the vulnerability to terrorism, the authors believe there is a need for continued investigations of the longer-term economic effects of catastrophic events.

Medalia, John. "Port and Maritime Security: Potential for Terrorist Nuclear Attack Using Oil Tankers." CRS Report for Congress. December 7, 2004.
The terrorist attacks of September 11, 2001, heightened interest in port and maritime security. Much of this interest has focused on cargo container ships because of concern that terrorists could use containers to transport weapons into the United States, yet only a small fraction of the millions of cargo containers entering the country each year is inspected. Some observers fear that a container-

borne atomic bomb detonated in a U.S. port could wreak economic as well as physical havoc. Such an attack could lead to a halt to container traffic worldwide for some time, bringing the world economy to its knees.

Reichmuth et al. "Economic Consequences of a Rad/Nuc Attack: Cleanup Standards Significantly Affect Cost." Conference presentation.
Reichmuth et al. conducted an analysis for the Pacific Northwest National Laboratory of the economic consequences of a single nuclear weapon attack, particularly addressing decontamination costs. Their estimates ranged from 93 million USD per square kilometer for farm or range land to 2.7 billion per square kilometer for high density urban areas – depending on cleaning standards.

Rosoff and D. von Winterfeldt. "A Risk and Economic Analysis of Dirty Bomb Attacks on the Ports of Los Angeles and Long Beach." *Risk Analysis* 27, no. 3 (2007): 533-546.
The costs of disruption vary depending on how the area struck fits into the local, national, and global economic network. An economic analysis of a "dirty bomb" attack on the ports of Los Angeles and Long Beach, the third busiest port in the world, conducted by Rosoff/Winterfeldt shows that the economic consequences from a shutdown of the harbors due to contamination could result in significant losses in the tens of billions of dollars, including the decontamination costs and the indirect economic impacts due to the port shutdown. Even a relatively small-scale terrorist attack with a "dirty bomb" could cause an entire shutdown of operations of the ports for up to a year resulting in a loss of over 250 billion USD.

Sastry, Anjali, Joseph J. Romm, and Kosta Tsipis, "Nuclear Crash – The U.S. Economy After a Small Nuclear Attack," Massachusetts Institute of Technology, June 1987; Broad, William J. "Economic Collapse Tied to Atom War." New York Times. 1987.
The study concludes that, in 1987, a limited attack on the United States, involving only 1 percent of the Soviet strategic nuclear arsenal, could set off a collapse of the American economy that would last for decades. The study found that an attack aimed only at liquid fuels and their distribution points could cripple transportation, energy production and key industries, damaging the economy so thoroughly that most of the population would die of starvation in months. The survivors, it said, would be reduced to ''near-medieval levels of existence'' for decades.

Schweikert, A. E., G. F. L'Her, and M. R. Deinert. "Simple method for identifying interdependencies in service delivery in critical infrastructure networks." *Applied Network Science* 6, no. 1 (2021): 1-13
Critical infrastructure failures from natural hazard events affect the economic and social well-being of communities. This is particularly true in lower income countries, where infrastructure may be less resistant to natural hazards and disaster recovery is often limited by available resources. The interconnectivity of these systems can strongly affect the services they deliver, and the failure of one infrastructure system can result in cascade failures with wide-reaching consequences. Unfortunately, interconnectivity has been particularly difficult to measure. The authors present a method for identifying service-oriented interdependencies in interconnected networks. The approach uses well-established methods for network analysis and is demonstrated for healthcare services in the Commonwealth of Dominica, a small island state in the Caribbean.

Schweikert, Amy and Mark R. Deinert. "Vulnerability and resilience of power systems infrastructure to natural hazards and climate change." WIREs Climate Change 12, no. 5 (2021).
The value of critical infrastructure rests in the services they provide. Electricity in particular underpins the operation of hospitals, schools, financial systems, transportation assets, telecommunications, and water treatment, and affects many other aspects of daily life. There is an emerging recognition of power systems as complex adaptive systems and a proliferation of work on how to make them more resilient in the face of natural hazards and climate change. Understanding infrastructure vulnerability and risk are key components of resilient power system assessments. However, differentiating

vulnerability from functional resilience (service delivery even when components fail) can help identify gaps in data, modeling and decision making.

U.S. Department of Homeland Security, Protective Security Division. "Characteristics and Common Vulnerabilities." Infrastructure Category: Petroleum Refineries." September 22, 2003.
Preventing terrorism and reducing the nation's vulnerability to terrorist acts requires understanding the common vulnerabilities of critical infrastructures, identifying site-specific vulnerabilities, understanding the types of terrorist activities that likely would be successful in exploiting those vulnerabilities, and taking preemptive and protective actions to mitigate vulnerabilities so that terrorists are no longer able to exploit them. This report characterizes and discusses the common vulnerabilities of United States (U.S.) petroleum refineries, which produce and handle large quantities of inherently hazardous materials and manufacture final and intermediate products that are fundamental elements of other economic sectors.

U.S. Government Accountability Office. "Critical Infrastructure Protection. Actions Needed to Address Significant Weaknesses in TSA's Pipeline Security Program Management." December 2018.
More than 2.7 million miles of pipeline transport and distribute oil, natural gas, and other hazardous products throughout the United States. Interstate pipelines run through remote areas and highly populated urban areas, and are vulnerable to accidents, operating errors, and malicious physical and cyber-based attack or intrusion.

Zhang, Hui. "Bounce Forward: Economic Recovery in Post-Disaster Fukushima." Sustainability 11, no. 6736 (2019): 1-24.
After the cascading disaster—earthquake, tsunami, and nuclear accident—in Fukushima on 11 March 2011, the Fukushima region is facing a significant reconstruction challenge. Based on field surveys of the affected areas and unstructured interviews with key informants such as local residents, government officials, and local businesses, this study analyses economic recovery in Fukushima which according to the author depends on how the region can overcome contamination, economic downturn, depopulation, labor shortage, a damaged reputation, and public distrust. By exploring four key "pillar" areas of Fukushima's economic recovery—renewable energy, manufacturing, agriculture, and tourism—this paper gives an overview of how to rebuild industry in the shadow of nuclear pollution. The results show how the economic recovery in Fukushima has required adaptation and innovation by the local people, and the economic downturn has been reversed and subsequently improved.

Society, Governance, and Policy

Arguello, Irma and Emiliano J. Bius. "Terror Unleashed. An assessment of global and national impacts of a nuclear terrorist attack." Latin American and Carribean Leadership Network (LALN). 2016.
Based on a comparison to the 9/11 terrorist attacks, the LALN report states that a terrorist attack with nuclear weapons would trigger both a national security and national defense response in the target country, involving the use of armed and security forces to facilitate an immediate response to the event as well as maintain high-alert status and protect the territory and national interests from additional attacks. Notions of proportionality would be highly at risk. Depending on whether the terrorist attack was conducted with or without support of a sponsor state, the situation could either escalate uncontrollably into nuclear conflict or strengthen cooperative relations between UNSC permanent members in alignment against global (nuclear) terrorism. Other short-term measures would most likely include the installation of comprehensive monitoring measures and prioritize defense spending over other national needs and long-term economic recovery which could be achieved only slowly. The risk of escalation would be kept high due to a simultaneous setback in nuclear disarmament efforts, and current modernization efforts as well as signs of a new arms race

would be accelerated. In addition, certain negative security assurances could be revoked, increasing the risk of nuclear conflict.

Baum, Seth. "Winter-Safe Deterrence: The Risk of Nuclear Winter and Its Challenge to Deterrence." *Contemporary Security Policy* 36, no. 1 (2015): 123-148.
A new line of nuclear winter research shows that even small, regional nuclear wars could have catastrophic global consequences. However, major disarmament to avoid nuclear winter goes against the reasons nuclear weapon states have for keeping their weapons in the first place, in particular deterrence. To reconcile these conflicting aims, this paper develops the concept of winter-safe deterrence, defined as military force capable of meeting the deterrence goals of today's nuclear weapon states without risking catastrophic nuclear winter. This paper analyses nuclear winter risk, finding a winter-safe limit of about 50 nuclear weapons total worldwide. This paper then evaluates a variety of candidate weapons for winter-safe deterrence. Non-contagious biological weapons (such as anthrax or ricin), neutron bombs detonated at altitude, and nuclear electromagnetic weapons show the most promise. Each weapon has downsides, and the paper's analysis is only tentative, but to the author winter-safe deterrence does appear both feasible and desirable given the urgency of nuclear winter risk.

Baum, Seth and Anthony Barrett. "A Model for the Impacts of Nuclear War." Global Catastrophic Risk Institute Working Paper 18, no. 2 (2018).
This paper presents a model for calculating the total impacts of nuclear war. The model includes physical, infrastructural, and social impacts as they affect human lives. The model has five main branches corresponding to the five main types of effects of nuclear weapon detonations: thermal radiation, blast, ionizing radiation, electromagnetic pulse, and human perceptions. Model branches contain extensive detail on each of these effects, including interconnections between them and connections to other major risks including global warming and pandemics. The paper also includes background information on impacts analysis and modeling to help readers understand how to think about the impacts of nuclear war, including discussion of important attributes of nuclear war such as the number and yield of weapons detonated and the location of their detonation.

Borrie, John and Tim Caughley. "An illusion of safety: Challenges of nuclear weapon detonations for United Nations humanitarian coordination and response." UNIDIR, 2014.
This report underlines that different UN agencies are not sufficiently prepared to respond to specific challenges and humanitarian consequences arising from a nuclear weapon detonation event. Humanitarian operations in the aftermath of a nuclear weapon attack would face severe obstacles caused by the security-driven responses of the target countries and allies, such as the widespread suspension of flight, port operations, and routine government activities. Not only do UN agencies heavily rely on states to provide personnel and assets, the primary responsibility for humanitarian assistance after an emergency further lies with each state, which is why the skills, capacities and materiel needed to provide effective humanitarian assistance currently do not exist in the UN system. Even the personnel of the WHO and IAEA is not mandated and/or equipped and trained to assist in the field after a nuclear detonation. Radiation effects and nuclear fallout create additional risks for first responders which exacerbates the problem of delivering swift and effective care.

Gao, Chaochao, Francis Ludlow, John A. Matthews et al. "Volcanic climate impacts can act as ultimate and proximate causes of Chinese dynastic collapse." *Communications Earth & Environment* 2, no. 234 (2021).
State or societal collapses are often described as featuring rapid reductions in socioeconomic complexity, population loss or displacement, and/or political discontinuity, with climate thought to contribute mainly by disrupting a society's agroecological base. The authors use a state-of-the-art multi-ice-core reconstruction of explosive volcanism, representing the dominant global external driver of severe short-term climatic change, to reveal a systematic association between eruptions and dynastic collapse across two millennia of Chinese history. The study employs a 1,062-year

reconstruction of Chinese warfare as a proxy for political and socioeconomic stress to reveal the dynamic role of volcanic climatic shocks in collapse and finds that smaller shocks may act as the ultimate cause of collapse at times of high preexisting stress, whereas larger shocks may act with greater independence as proximate causes without substantial observed pre-existing stress.

Intondi, Vincent. "Reflections on Injustice, Racism, and the Bomb." Arms Control Today, July/August 2020.
The article explores the intersectionality of the nuclear weapons issue and highlights connections among race, climate, and poverty in the fight to abolish nuclear weapons.

Micheal Meit et al., "Rural and Suburban Population Surge Following Detonation of an Improvised Nuclear Device: A New Model to Estimate Impact." *Disaster Medicine and Public Health Preparedness* 5, no. 1 (2011): 143-150
The study suggests that suburban and rural communities could be overwhelmed by evacuees from their center city following an IND detonation. It predicts that even in some communities located far from Manhattan (used for the case study), arriving evacuees would increase the population needing services by 50% to 150%. The study highlights the urgency of educating and communicating with the public about radiation hazards to mitigate panic and hysteria, anticipating the ways in which a mass exodus may disrupt or even cripple rescue and response efforts, and devising creative ways to exercise and drill for an event about which there is great denial and fatalism.

Mian, Zia and Benoit Pelopidas. "Producing Collapse: Nuclear Weapons as Preparation to End Civilization." To appear in: Multidisciplinary Perspectives on Historical Collapse, eds. Miguel Centeno, Peter W. Callahan, Paul Larcey, and Thayer Patterson (Routledge, 2022)
The possibility of an end of humankind has always existed, in fact and in the imagination. The focus of the chapter is what has changed over the last seventy-five years with the coming of nuclear and thermonuclear weapons, their structures of governance, the contentious politics around them and over the human future, in short, the nuclear age.

Research Center for Nuclear Weapons Abolition, Nagasaki University (RECNA), Asia Pacific Leadership Network (APLN) & Nautilus Institute. "Pandemic Futures and Nuclear Weapon Risks: The Nagasaki 75th Anniversary pandemic-nuclear nexus scenarios final report." *Journal for Peace and Nuclear Disarmament* 4 (2021): 6-39.
This report is an outcome document of the Nagasaki 75th Anniversary Pandemic-Nuclear Nexus Scenarios Project, an international initiative aimed at exploring how the far-reaching effects of the COVID-19 pandemic (and future pandemics) could alter the landscape for nuclear risk and disarmament. The goals of the workshop were to (1) develop an analytical understanding of the interrelated nature of the co-occurring existential threats of nuclear weapons and global pandemics; (2) explore potential levers and pathways to influence the future under various conditions; and (3) identify concrete strategies to reduce the risk of nuclear war and resume nuclear disarmament by state and non-state actors, particularly in the Northeast Asia region.

Sanders-Zakre, Alicia, Michaele de Verdier, and Josefin, Lind. „No place to hide: Nuclear weapons and the collapse of health care systems." International Campaign to Abolish Nuclear Weapons, 2022.
Nuclear-armed states may prepare to use nuclear weapons but they can never adequately prepare for the humanitarian consequences of their use. Examining the existing health infrastructure available to respond to the explosion of a moderately-sized nuclear weapon over nine cities in nuclear-armed states and one non-nuclear armed state's capital makes this point tragically clear. A nuclear war would realistically involve many nuclear weapons targeting many cities in a country, creating an enormous humanitarian catastrophe impossible for any health care system to deal with - one that could potentially lead to the end of civilization as we know it. But if even just one average-sized nuclear weapon were to be detonated over a major city today, the immediate health impact would be disastrous beyond the ability of any nation to effectively respond.

James Scouras, *On Assessing The Risk Of Nuclear War*, The Johns Hopkins University Applied Physics Laboratory, 2021.
This edited volume attempts to establish a methodological and rigorous basis for answering the question "What is the risk of nuclear war?" in order to clarify the extent to which this question is researchable and to explore promising analytical approaches. The text uses four complementary approaches to likelihood assessment: historical case studies, expert knowledge, probabilistic risk assessment, and complex systems theory. Two chapters (Ch. 6 and 7) evaluate the state of knowledge for assessing the physical and intangible (economic, social, political, and psychological) consequences of nuclear weapons use.

Waldrop, Mitchell. „What if a nuke goes off in Washington, D.C.? Simulations of artificial societies help planners cope with the unthinkable." *Science*, April 12, 2018.
Instead of following fixed story lines and predictions about the consequences of a nuclear war assembled ahead of time, the article explores the use of computers that test "what-if" scenarios with a constructed, artificial society: an advanced type of computer simulation called an agent-based model.