

White Paper:

Cascading Disasters, Systemic Risks, and Nuclear War

Understanding Global Effects in an Interconnected World

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September 2026

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Introduction

Research on the consequences of the use of nuclear weapons has traditionally focused on the immediate physical effects of nuclear detonations. Over several decades, scientific research has produced a substantial body of knowledge on the destructive effects of nuclear explosions and their environmental consequences. This work has examined the effects of blast and thermal radiation on built environments and populations, the medical consequences of ionizing radiation exposure, and the climatic effects of large-scale nuclear detonations. One of the most significant findings of this research concerns the potential for nuclear winter. This is the phenomenon revealed through climate modeling whereby firestorms ignited by nuclear detonations could inject massive quantities of soot into the stratosphere, reducing incoming solar radiation and significantly lowering global surface temperatures, altering precipitation patterns and significantly affecting global food production systems.¹ These studies form the foundation of our contemporary understanding of the effects of nuclear war, but far less attention has been devoted to analyzing how such environmental and infrastructural disruptions caused by the detonation of a few, or many, nuclear weapons might spread through modern societies.

This reflects a deeper pattern in the production of knowledge about the effects of nuclear weapons to underestimate the consequences of nuclear detonations. Lynn Eden, for example, has shown that the U.S. Air Force produced nuclear targeting models that ignored the effects of fire and firestorms for more than half a century. This choice caused the destructive consequences of nuclear use to be dramatically understated in official assessments. There was a comparable omission in understanding the effects of the electromagnetic pulse (EMP) generated by a nuclear detonation.² These effects were recognized years before they were incorporated into nuclear planning and doctrine. The effects of nuclear winter were similarly ignored or rejected in military planning documents long after the scientific evidence had accumulated.

Closely related to this pattern of underestimation is the tendency to treat nuclear war as a survivable, and therefore manageable, event on the basis that escalation can be controlled and nuclear war kept in some meaningful sense “limited.” Historical evidence militates strongly against this view. Declassified government assessments from the early Cold War period such as the 1955 UK “Strath Report” concluded that the detonation of even a small number of thermonuclear weapons on major cities would effectively destroy the functioning of the state, overwhelm any conceivable civil defense, and produce casualties and infrastructure collapse from which recovery within any meaningful timeframe would be impossible.³ These assessments showed that nuclear weapons use substantially short of global thermonuclear could be catastrophic, and the cascading systemic effects analyzed here suggest that we continue to underestimate just how catastrophic.

¹ Lili Xia et al., “Global Food Insecurity and Famine from Reduced Crop, Marine Fishery and Livestock Production Due to Climate Disruption from Nuclear War Soot Injection,” *Nature Food* 3, no. 8 (2022): 586–96, <https://doi.org/10.1038/s43016-022-00573-0>.

² Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack, *Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack: Critical National Infrastructures* (Washington, DC: EMP Commission, 2008).

³ Home Defence Committee, *The Defence Implications of Fall-Out from a Hydrogen Bomb*, CAB 134-940 (London: The National Archives, March 17, 1955).

This report addresses what might be the latest instance of this pattern of ignoring the systemic effects of nuclear detonations and the limits of “control” in a nuclear war: the systemic cascading effects of nuclear weapons use on the interconnected societies and global infrastructure upon which human civilization now depends. These effects have not yet been systematically assessed.⁴ The argument of this report is that this absence is consequential and that correcting it changes how we should think about both the risks of nuclear use and the urgency of preventing it.

That said, there *is* a growing body of scholarship across several fields that has begun to examine how large-scale non-nuclear shocks propagate through complex societies. This scholarship is underpinned by the fact that contemporary societies are characterized by high levels of economic, infrastructural, and institutional interdependence. For example, global supply chains connect regions of agricultural production with distant markets, financial systems link national economies through dense networks of capital flows, energy systems, telecommunications networks, and transport infrastructures form tightly coupled systems whose functioning depends on continuous flows of resources and information, and so on. In systems characterized by such interdependence, disruptions rarely remain confined to the sector or location in which they originate. Instead, they can propagate through networks of dependency and generate cascading effects across multiple regional and global systems.

In particular, research on systemic risk and infrastructure interdependence has investigated how disruptions spread through networks of critical systems and generate cascading failures across multiple sectors.⁵ Scholarship on civilizational collapse has examined how societies depend on a limited number of critical functional systems whose failure can destabilize an entire social order.⁶ Research on the climate-conflict nexus and environmental security has given us empirical evidence of how environmental shocks affect livelihoods, migration patterns, governance capacity, and political stability.⁷ This scholarship is important because the environmental consequences of nuclear weapons use captured by the nuclear winter hypothesis can be understood as the *initiating systemic shock* from which broader cascading

⁴ For a first step, see Seth D. Baum and Anthony M. Barrett, *A Model for the Impacts of Nuclear War*, Working Paper 18-2 (New York: Global Catastrophic Risk Institute, 2018); and Michael J. Frankel, James Scouras, and George W. Ullrich, *The Uncertain Consequences of Nuclear Weapons Use*, NSAD-R-13-068 (Laurel, MD: Johns Hopkins Applied Physics Laboratory, 2013).

⁵ Steven M. Rinaldi, James P. Peerenboom, and Terrence K. Kelly, “Identifying, Understanding, and Analyzing Critical Infrastructure Interdependencies,” *IEEE Control Systems Magazine* 21, no. 6 (2001): 11–25; Gianluca Pescaroli and David Alexander, “Understanding Compound, Interconnected, Interacting, and Cascading Risks: A Holistic Framework,” *Risk Analysis* 38, no. 11 (2018): 2245–57.

⁶ Igor Linkov, Stefania E. Galaitsi, Benjamin D. Trump, Ekaterina Pinigina, Kyla Rand, Eric H. Cline, and Maxim Kitsak, “Are Civilizations Destined to Collapse? Lessons from the Mediterranean Bronze Age,” *Global Environmental Change* 84 (2024): 102792; Joseph A. Tainter, *The Collapse of Complex Societies* (Cambridge: Cambridge University Press, 1988); Jared Diamond, *Collapse: How Societies Choose to Fail or Succeed* (New York: Viking Penguin, 2005); Luke Kemp, *Goliath’s Curse: The History and Future of Societal Collapse* (London: Penguin Books, 2025).

⁷ Jon Barnett and W. Neil Adger, “Climate Change, Human Security and Violent Conflict,” *Political Geography* 26, no. 6 (2007): 639–55; Solomon M. Hsiang, Marshall Burke, and Edward Miguel, “Quantifying the Influence of Climate on Human Conflict,” *Science* 341, no. 6151 (2013): 1235367; Katharine J. Mach, Caroline M. Kraan, W. Neil Adger, Halvard Buhaug, Marshall Burke, James D. Fearon, Christopher B. Field, et al., “Climate as a Risk Factor for Armed Conflict,” *Nature* 571 (2019): 193–97; Stefano Michelini, “A Comprehensive Framework for the Relationship Between Organized Violence and Climate Change,” *Geopolitics* (2025): 1–35.

disruptions are likely to emerge. This is in the broader context of plausible pathways to nuclear detonations that have been well-documented.⁸

Although these bodies of scholarship developed largely independently, they share a common insight that the most severe consequences of large-scale shocks often arise from the secondary and tertiary disruptions that spread through interconnected systems and that are often amplified through feedback mechanisms, as well as from the initial event.

The purpose of this report is therefore to synthesize this scholarship on systemic risk, cascading disasters, civilizational stability, and climate-conflict dynamics in order to better understand how the effects of nuclear detonations could generate complex global crises extending far beyond their immediate physical impacts. Understanding these dynamics is important for assessing the full consequences of nuclear weapons use because the broader societal impacts of cascading disruptions will shape the global consequences of nuclear war.

⁸ Seth D. Baum, Richard de Neufville, and Anthony M. Barrett, *A Model for the Probability of Nuclear War*, Working Paper 18-1 (New York: Global Catastrophic Risk Institute, 2018), <https://ssrn.com/abstract=3137081>.

PART I

Conceptual Foundations: How Systemic Shocks Affect Societies

Understanding how the consequences of nuclear weapons use could propagate through global systems requires a conceptual framework that can explain how large shocks affect complex societies. Research on systemic risk and infrastructure interdependence has examined how disruptions spread through networks of critical systems and generate cascading failures across multiple sectors.⁹ Work on global systemic risks has explored how increasing interdependence within economic, technological, and governance systems can amplify the consequences of shocks.¹⁰ Studies of complex socio-technical systems have analyzed how tightly coupled networks can experience cascading failures and abrupt transitions under stress.¹¹ Finally, scholarship on civilizational collapse has examined how societies depend on a limited number of critical functional systems and that entire social orders can be destabilized when these fail.¹² Taken together, these literatures provide the conceptual foundations for analyzing nuclear war as a systemic global risk, in which environmental, infrastructural, economic, and political disruptions caused by nuclear detonations can interact to produce cascading crises across interconnected systems at a global and potentially civilizational scale.

Before summarizing these literatures, it is useful to set out some important definitions from the scholarship consulted for this report that are essential to understanding nuclear war as a systemic risk in the current global system.¹³

Systemic risk: This refers to the condition in which disruptions threaten essential societal functions across interconnected systems, often with transboundary spillover effects, feedback loops, deep uncertainty, and the possibility of tipping points. Systemic risk is the umbrella concept under which this analysis sits because it is about the vulnerability of a whole socio-technical order to the disruption of its core networks and about the way that vulnerability is partly generated by the normal functioning of highly optimized, tightly coupled systems.¹⁴

Cascading disasters: These are the processes through which systemic risk manifests. Cascading disasters occur when an initiating event triggers secondary and tertiary crises across interdependent systems that have consequences often exceeding the initial harm.

⁹ Rinaldi, Peerenboom, and Kelly, "Critical Infrastructure Interdependencies," 11–25; Pescaroli and Alexander, "Understanding Compound," 2245–57.

¹⁰ Miguel A. Centeno, Manoranjan Nag, Thayer S. Patterson, Andrew Shaver, and A. Jason Windawi, "The Emergence of Global Systemic Risk," *Annual Review of Sociology* 41 (2015): 65–85; Miguel A. Centeno, Peter Callahan, Paul Larcey, and Thayer S. Patterson, eds., *How Worlds Collapse: What History, Systems, and Complexity Can Teach Us About Our Modern World and Fragile Future* (Abingdon: Routledge, 2023).

¹¹ Dirk Helbing, "Globally Networked Risks and How to Respond," *Nature* 497 (2013): 51–59; Linkov et al., "Are Civilizations Destined to Collapse?" 102792.

¹² Tainter, *Collapse of Complex Societies*; Kemp, *Goliath's Curse*.

¹³ James Scouras, "Nuclear War as a Global Catastrophic Risk," *Journal of Benefit-Cost Analysis* 10, no. 2 (2019): 274–95.

¹⁴ Centeno et al., "Emergence of Global Systemic Risk," 65–85; Ortwin Renn, Michael Laubichler, Klaus Lucas, Wolfgang Kröger, Juergen Schanze, Roland W. Scholz, and Pia-Johanna Schweizer, "Systemic Risks from Different Perspectives," *Risk Analysis* 42, no. 9 (2022): 1902–20.

This means that the real drivers of escalating harms are the vulnerability pathways embedded in interconnected socio-technical systems. Vulnerability pathways are preexisting weaknesses or failures in governance, regulation, infrastructure, and institutional coordination that determine where cascades travel, how fast, and to what effect.¹⁵

Compound events: These are situations in which multiple drivers, hazards, or background conditions combine to produce an extreme impact. The core point is that the impact is generated by the interaction of hazards rather than by one alone. This means that moderate factors can produce severe outcomes when they coincide or happen in sequence. For example, a relatively small-scale nuclear war occurring during a global food supply shock or extreme climatic conditions could combine atmospheric effects, agricultural disruption, and existing supply constraints to produce far more severe food insecurity than any of these factors alone.¹⁶

Connected extreme events: Raymond and colleagues use this term to capture cases where hazards and societal systems become linked across time, space, and sector. Here, events that are geographically separate can become one crisis if they draw on the same emergency capacities, trade routes, fiscal resources, or governance institutions. In a nuclear context, a regional exchange might connect distant places through food prices, insurance withdrawal, humanitarian logistics, or panic in financial markets.¹⁷

Tipping points: These are critical thresholds beyond which systems can undergo rapid and sometimes irreversible change through reinforcing feedback processes that can abruptly shift a system into a new state rather than deteriorating gradually. Understanding why the effects of a nuclear war might escalate rapidly and become difficult to reverse depends on understanding this dynamic.

Together, these five concepts—**systemic risk, cascading disasters, compound events, connected extreme events, and tipping points**—provide the analytical vocabulary through which the scholarship reviewed in this report can be applied to nuclear war.

From this starting point it is important to consider the timescales over which the consequences of nuclear detonations can unfold through global systems in terms of immediate-, medium-, and long-term effects:

- An immediate **acute** phase: This covers days to weeks is dominated by immediate casualties, infrastructure outages, fire, contamination, and emergency response overload.
- A medium-term **cascading disruption**: This phase covers weeks to months when interdependencies become decisive, for example as electricity loss disables water and health services, transport disruption undermines food distribution, workforce

¹⁵ David Alexander and Gianluca Pescaroli, “What Are Cascading Disasters?,” *UCL Open Environment* 1 (2019): e001; Gianluca Pescaroli and David Alexander, “Critical Infrastructure, Panarchies and the Vulnerability Paths of Cascading Disasters,” *Natural Hazards* 82, no. 1 (2016): 175–92.

¹⁶ Michael Leonard, Seth Westra, Amit Phatak, Martin Lambert, Bart van den Hurk, Kathleen McInnes, James Risbey, Stefan Schuster, Debbie Jakob, and Mark Stafford-Smith, “A Compound Event Framework for Understanding Extreme Impacts,” *WIREs Climate Change* 5, no. 1 (2014): 113–28; Jakob Zscheischler, Seth Westra, Bart J. J. M. van den Hurk, et al., “Future Climate Risk from Compound Events,” *Nature Climate Change* 8 (2018): 469–77.

¹⁷ Colin Raymond, Horton R. M., Jakob Zscheischler, et al., “Understanding and Managing Connected Extreme Events,” *Nature Climate Change* 10 (2020): 611–21.

dislocation hinders repair, financial uncertainty interrupts trade and the liquidity of financial institutions, and so on.

- A long-term **systemic reorganization**: This phase stretching from months to decades is when the issue becomes whether systems recover, simplify, fragment, or become irrevocably scarred.¹⁸

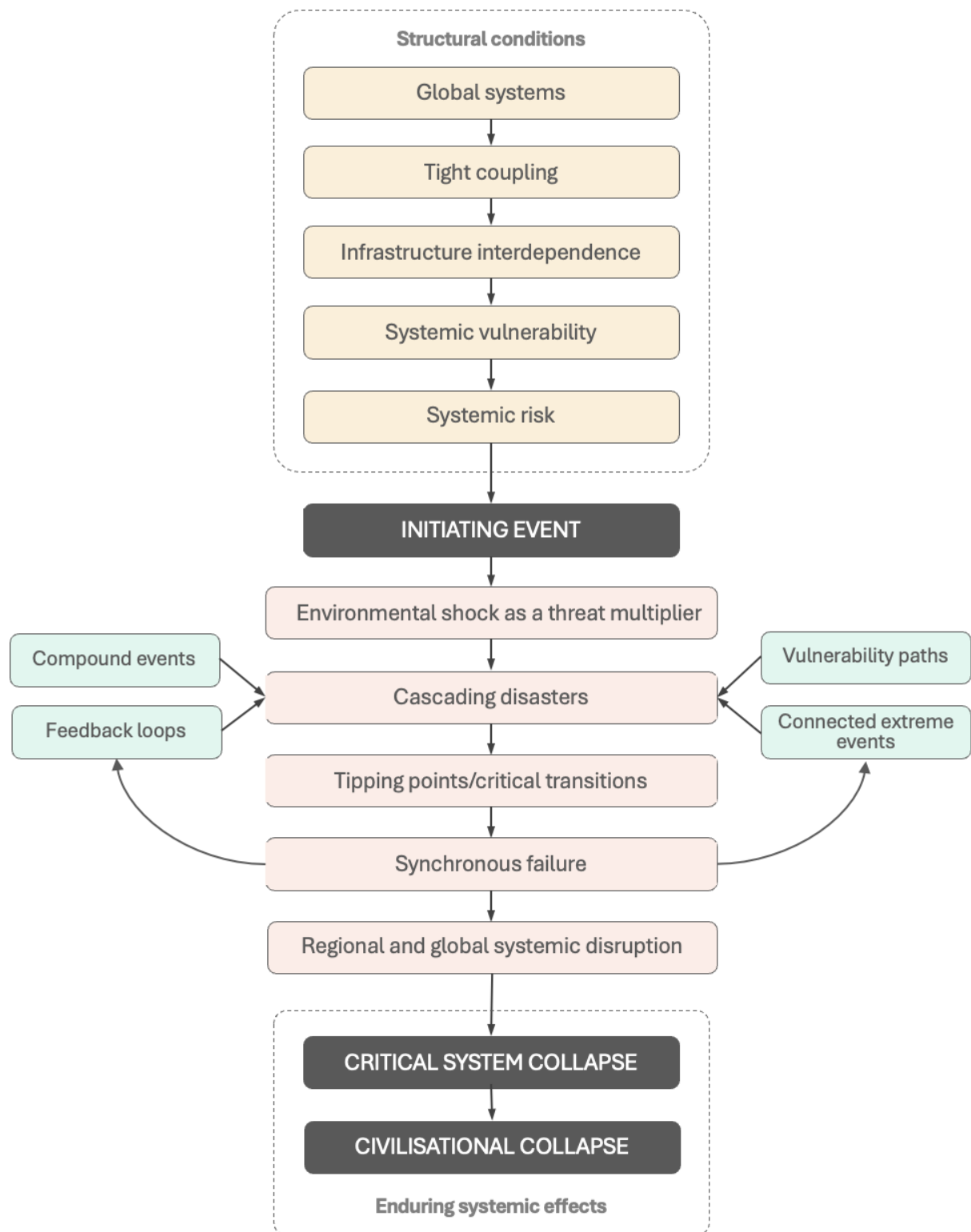
The framework outlined in Figure 1 shifts our analytical focus to asking which essential social functions are likely to fail in a nuclear war, for how long, in which places, with what substitution options, and under what governance conditions.¹⁹

¹⁸ Pescaroli and Alexander, “Critical Infrastructure,” 175–92; Nathan Chandler, *Pathways from Climate Change to Conflict in U.S. Central Command Regions*, RAND Research Report (Santa Monica, CA: RAND Corporation, 2023).

¹⁹ Richard G. Little, “Controlling Cascading Failure: Understanding the Vulnerabilities of Infrastructures,” *Journal of Urban Technology* 9, no. 1 (2002): 109–23.

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“civilisational” to “civilizational”

Figure 1. Essential Social Functions Likely to Fail in a Nuclear War



Systemic Risk and Cascading Disasters

Modern societies depend on dense networks of infrastructures and institutions that support the functioning of economic production, communication, governance, and everyday life (e.g., the ways in which electricity systems power telecommunications networks, transport infrastructures support global supply chains, financial systems coordinate economic exchange, and digital networks enable the operation of modern administrative and technological systems (financial systems, hospital records, logistics, and command systems, and so on)). These systems do not operate independently but form highly interconnected networks, or a system of systems, whose functioning depends on continuous flows of resources, information, and services.²⁰

The key takeaway from this body of research is that the consequences of shocks depend on the structure of the networks through which disruptions propagate, as well as the magnitude of the initial disturbance. Systems characterized by a dense level of connectivity and tight coupling can enable rapid propagation of failures across different sectors.

Centeno and colleagues show that contemporary societies are characterized by unprecedented levels of connectivity across economic, technological, and social systems.²¹ Globalization has produced dense networks of production systems, financial markets, supply chains, and communication infrastructures. These connections have developed through, and enable, economic growth and technological innovation, but they have also created new forms of *systemic vulnerability*. This is because modern infrastructures, supply chains, and digital systems are designed for efficiency, speed and optimization, often at the cost of redundancy and resilience. Increasing connectivity, global integration, and rapid technological change are drivers of systemic fragility because they reduce buffers that might otherwise absorb shocks.²²

This means that disturbances affecting key nodes within interconnected networks can propagate rapidly across global systems and produce crises that extend far beyond their points of origin. For example, studies show how global trade and financial systems depend on highly concentrated nodes and chokepoints whose disruption can propagate disturbances widely.²³

This is supported by research on interdependent network systems, which demonstrates that networks that appear robust when analyzed individually can become highly vulnerable when there are dependency links between networks. The failure of nodes in one network can then trigger failures in dependent networks and generate cascading collapse across interconnected systems.²⁴ This can happen through different escalation routes, such as “hazard cascades” where one hazard triggers another, or “snowball cascades” where multiple pathways interact and accelerate escalation.²⁵ These dynamics are characterized as global systemic risks because disruptions propagate across multiple interconnected systems

²⁰ Pescaroli and Alexander, “Critical Infrastructure,” 175–92; Alexander Fekete, “Critical Infrastructure and Flood Resilience: Cascading Effects Beyond Flood-Prone Areas,” *WIREs Water* 6, no. 1 (2019): e1370.

²¹ Centeno et al., “Emergence of Global Systemic Risk,” 65–85.

²² Helbing, “Globally Networked Risks,” 51–59.

²³ Centeno et al., “Emergence of Global Systemic Risk,” 65–85.

²⁴ Sergey V. Buldyrev, Roni Parshani, Gerald Paul, H. Eugene Stanley, and Shlomo Havlin, “Catastrophic Cascade of Failures in Interdependent Networks,” *Nature* 464 (2010): 1025–28.

²⁵ Fekete, “Critical Infrastructure and Flood Resilience,” e1370.

simultaneously and crises emerge from interactions between complex global networks rather than from isolated events.²⁶

It is in this context that Pescaroli and Alexander argue that disasters *increasingly* take the form of cascading processes, in which initial disturbances trigger chains of failures affecting multiple sectors. They show that many modern disasters unfold as cascading disasters characterized by sequences of interacting disruptions that propagate through infrastructure networks, supply chains, and governance systems, rather than a single catastrophic event.²⁷

This body of research has explored how cascading disruptions can generate infrastructure failure that can lead to the collapse of core services.²⁸ Rinaldi, Peerenboom, and Kelly identify several forms of *infrastructure interdependence* that can transmit disruptions across systems and thereby generate such failures:

- Physical interdependencies are when infrastructures require material inputs from other systems, such as electricity required to operate water treatment plants;
- Cyber interdependencies are when infrastructures rely on information and control systems for monitoring and operation;
- Geographic interdependencies are when infrastructures are co-located in ways that expose them to common hazards; and
- Logical interdependencies are when financial, institutional, or policy relationships link different systems.²⁹

Linkov and colleagues also analyze how infrastructure networks behave under stress. They show how highly interconnected systems can experience abrupt systemic failures once cascading disruptions begin to spread.³⁰ Conversely, systems with greater redundancy or “modularity”³¹ have a greater chance of containing disruptions and preventing cascading crises. The vulnerability of modern societies to systemic risk therefore arises not only from exposure to hazards but also from the architecture of interconnected infrastructures and institutions. This is what Pescaroli and Alexander define as “vulnerability paths”: preexisting weaknesses in governance, regulation, infrastructure maintenance, and institutional coordination that determine where cascades travel and how fast. Since vulnerability paths will be different in different societies, the same physical shock can produce very different systemic consequences.³²

From this perspective, the societal consequences of nuclear weapons use cannot be understood solely in terms of the direct destruction caused by nuclear detonations. The broader impacts of nuclear war would likely unfold through cascading disruptions across interconnected systems in ways that traditional nuclear effects analysis does not capture. This is precisely the condition defined as systemic risk where an entire socio-technical order is vulnerable to networked disruption whose scale is determined by the architecture of the

²⁶ Centeno et al., *How Worlds Collapse*.

²⁷ Pescaroli and Alexander, “Understanding Compound,” 2245–57.

²⁸ Little, “Controlling Cascading Failure,” 109–23.

²⁹ Rinaldi, Peerenboom, and Kelly, “Critical Infrastructure Interdependencies,” 11–25.

³⁰ Linkov et al., “Are Civilizations Destined to Collapse?,” 102792.

³¹ Modularity refers to the degree to which a system is divided into relatively self-contained units that can fail or be disrupted independently of one another, i.e., the opposite of tight coupling. Lance H. Gunderson and C. S. Holling, eds., *Panarchy: Understanding Transformations in Human and Natural Systems* (Washington, DC: Island Press, 2002), 39–50.

³² Pescaroli and Alexander, “Critical Infrastructure,” 175–92.

system rather than by the initiating shock alone. Moreover, the scholarship also shows that any meaningful humanitarian response to nuclear detonations would rapidly be overtaken by the demands created by the failure of infrastructure itself. Infrastructure failure is therefore not just a background condition for any response, but a central driver of an escalating crisis.³³

Complex Systems, Tipping Points, and Non-Linear Change

A closely related body of scholarship examines how complex systems behave under conditions of stress. Research on complex systems shows that systems composed of many interacting components often exhibit non-linear dynamics. This means that the relationship between cause and effect is not proportional such that small changes can produce minimal consequences under some conditions but trigger rapid and far-reaching systemic change under others.³⁴

One of the most important insights from this literature is the existence of *tipping points*, which are thresholds beyond which systems can undergo rapid and sometimes irreversible change.³⁵ Renn and colleagues argue that global systemic risks are characterized by complexity, uncertainty, and cascading effects that cannot be understood through traditional linear risk models.³⁶ Scheffer and colleagues show that before a tipping point is reached a system can appear relatively stable even when underlying stresses are increasing. However, once stresses exceed a critical level then reinforcing feedback processes can push the system into a new state. Centeno et al. emphasize that global systems “tend to evolve through adaptation to a critical zone that lies at the border between order and chaos” and that systems operating at the “edge of chaos” are particularly prone to “sudden, non-linear transitions from one state to another” once critical thresholds are crossed.³⁷

Research on *critical transitions* demonstrates that these dynamics occur across a wide range of natural and social systems from lakes and coral reefs to financial markets and social networks, challenging the assumption that systems respond gradually to increasing pressures. A key mechanism driving critical transitions is the presence of positive feedback loops whereby changes within a system reinforce further changes in the same direction. For example, declining agricultural productivity increases food prices that destabilizes economies and governance systems that further undermine agricultural production and distribution. In such cases, feedback processes amplify the effects of initial disturbances and accelerate systemic change.

Seminal work by Homer-Dixon and colleagues examines the possibility of *synchronous failure*, in which disruptions affecting multiple interconnected systems interact to produce large-scale systemic instability. They, too, argue that modern societies have become

³³ Gianluca Pescaroli and Ilan Kelman, “How Critical Infrastructure Orients International Relief in Cascading Disasters,” *Journal of Contingencies and Crisis Management* 25, no. 2 (2017): 56–67.

³⁴ Didier Wernli, Lucas Böttcher, Frederik Vanackere, Yuliya Kaspiarovich, Mumtaz Masood, and Nicolas Levrat, “Understanding and Governing Global Systemic Crises in the 21st Century: A Complexity Perspective,” *Global Policy* 14, no. 2 (2023): 207–28.

³⁵ Marten Scheffer et al., “Anticipating Critical Transitions,” *Science* 338, no. 6105 (2012): 344–48.

³⁶ Ortwin Renn, Klaus Lucas, Armin Haas, and Carlo Jaeger, “Things Are Different Today: The Challenge of Global Systemic Risks,” *Journal of Risk Research* 22, no. 4 (2017): 401–15.

³⁷ Centeno et al., “Emergence of Global Systemic Risk,” 67–68.

increasingly vulnerable to such dynamics because of rising complexity, growing interdependence, and declining resilience within core systems driven by technological innovation and economic growth.³⁸ Kemp and colleagues also emphasize the possibility of synchronous failures when multiple systems experience breakdown simultaneously due to shared stressors, feedback loops, and interacting disruptions. When such stresses occur concurrently across multiple sectors, societies can experience crises that exceed the capacity of individual systems to respond.³⁹ These dynamics are closely linked to the concept of *polycrisis*, which describes situations in which multiple interacting crises reinforce and amplify one another through feedback loops across sectors and regions that intensify instabilities.⁴⁰

The key takeaway from research on complex systems, tipping points, and non-linear change is therefore that crises can escalate rapidly once critical thresholds are crossed. Systems can absorb disturbances for extended periods while appearing relatively stable, but once underlying stresses exceed certain limits then reinforcing feedback processes can trigger abrupt and sometimes irreversible systemic change. The consequences of shocks can therefore be disproportionately large relative to the initial disturbance.⁴¹

Critical Social Systems and Civilizational Collapse

Research on civilizational collapse has investigated the conditions under which societies lose the capacity to sustain the economic, political, technological, and social systems upon which they depend based on similar processes of cascading disasters. This aligns closely with the scholarship on systemic risk because it emphasizes how cascading disruptions across interconnected socio-technical systems can transform severe shocks into long-term societal decline rather than a temporary crisis.⁴²

A central insight from this scholarship is that complex societies depend on a relatively small number of critical systems whose functioning underpins social stability. These systems include food production and distribution, energy systems, economic exchange and trade networks, governance institutions, and public health systems. Societies can experience rapid and destabilizing transformations when multiple core systems fail simultaneously. Collapse in this context refers to the loss of organizational complexity and the breakdown of the institutions that sustain coordinated social activity but don't necessarily lead to the eradication of a society.⁴³

Tainter argues in his study of societal collapse that complex societies develop increasingly elaborate administrative, economic, and infrastructural systems in order to solve problems

³⁸ Thomas Homer-Dixon, Brian Walker, Reinette Biggs, Anne-Sophie Crépin, Carl Folke, Eric Lambin, Garry D. Peterson, et al., "Synchronous Failure: The Emerging Causal Architecture of Global Crisis," *Ecology and Society* 20, no. 3 (2015): art. 6; Thomas F. Homer-Dixon, *Environment, Scarcity, and Violence* (Princeton, NJ: Princeton University Press, 1999).

³⁹ Luke Kemp, Chi Xu, Joanna Depledge, Kristie L. Ebi, Timothy A. Gibbins, Timothy A. Kohler, Johan Rockström, et al., "Climate Endgame: Exploring Catastrophic Climate Change Scenarios," *Proceedings of the National Academy of Sciences* 119, no. 34 (2022): e2108146119.

⁴⁰ Michael Lawrence, Thomas Homer-Dixon, Scott Janzwood, Johan Rockström, Ortwin Renn, and Jonathan F. Donges, "Global Polycrisis: The Causal Mechanisms of Crisis Entanglement," *Global Sustainability* 7 (2024): e6.

⁴¹ Helbing, "Globally Networked Risks," 51–59.

⁴² Tainter, *Collapse of Complex Societies*; Kemp, *Goliath's Curse*; Diamond, *Collapse*.

⁴³ Tainter, *Collapse of Complex Societies*.

and maintain stability. Over time, however, maintaining such systems requires increasing investments of energy and resources. As societies grow more complex, the costs of sustaining core institutions can rise faster than the benefits they provide. As a result, external shocks or internal stresses can increase the burden on already strained systems to the point of collapse because a society can no longer sustain the institutions required to maintain coordinated its core economic and political systems. Societal collapse in this sense often emerges through the interaction of multiple stresses affecting key societal functions simultaneously rather than from a single catastrophic event.⁴⁴

Diamond's comparative analysis of historical societies also argues that societal collapse often results from a combination of environmental stress, resource depletion, economic disruption, and governance failure.⁴⁵ He argues that environmental and economic stresses can cascade into broader societal instability when a society's institutions are unable to adapt effectively to challenges that require coordinated responses across multiple sectors. For example, if failures in food production trigger economic crises and political unrest, energy disruptions affect industrial production and transportation networks, governance failures undermine the capacity of institutions to coordinate responses, and so on. Such interactions can produce systemic breakdowns that can destabilize entire societies. Today's highly interconnected global systems characterized by urbanization, concentration of populations, globalized networks, and centralized governance systems have created complex societies capable of unprecedented levels of economic productivity by coordinating flows of goods, energy, capital, and information across large geographic scales are particularly susceptible to such instabilities.⁴⁶

The key risk that civilizational collapse research identifies is therefore the possibility of simultaneous multi-system failure affecting a society's critical systems. In relation to the consequences of nuclear war, this body of research suggests that the most consequential risks arise not only from the direct physical effects of nuclear detonations but from the potential loss of core societal functions across interconnected systems on a global scale. Nuclear war would likely disrupt agricultural production and global food trade, destroy and disrupt core infrastructure and energy systems, disrupt economic coordination and financial flows, weaken governance systems through public health crises, and displacement and political instability could weaken governance systems. The capacity of societies to maintain basic functions if faced with major disruptions like these that interact across multiple sectors would likely degrade quite rapidly and risk cascading systemic failure. Collapse therefore becomes plausible when interacting disruptions prevent recovery and lead to a sustained loss of complexity and coordination within a society and potentially at the level of our global technological civilization. Understanding nuclear war therefore requires analyzing it not only as a military or environmental event but also as a potential trigger for systemic disruptions that undermine the core functions upon which complex societies depend.

Environmental Stress as a Systemic Shock

Climate-conflict and environmental security scholarship provide further sources of empirical evidence about the relationships between environmental shocks and social and political

⁴⁴ Tainter, *Collapse of Complex Societies*.

⁴⁵ Diamond, *Collapse*.

⁴⁶ Diamond. *Collapse*.

systems.⁴⁷ This is especially important given the environmental effects of nuclear war. This literature examines how climatic variability, environmental degradation, and resource pressures influence patterns of economic stability, migration, governance capacity, and conflict. Most contemporary research in this area emphasizes that environmental pressures interact with existing social, economic, and political vulnerabilities to produce complex outcomes, rather than presenting environmental disruption as a direct cause of violence or instability.⁴⁸ In fact, studies show that the relationship between climate variability and conflict is highly context-dependent and mediated by economic, political, and institutional factors.⁴⁹ Empirical research has explored these dynamics across various contexts and shows that factors such as economic inequality, governance capacity, demographic pressures, and political institutions strongly influence whether environmental disruptions translate into instability or violence.⁵⁰

In that context, one of the most widely cited concepts emerging from this literature is that environmental change often functions as a *threat multiplier*.⁵¹ Research has shown that environmental change does not typically generate conflict directly but amplifies existing stresses and conflict dynamics through multiple pathways.⁵² Environmental disruptions such as droughts, flooding, and extreme heat can undermine agricultural productivity, reduce water availability, and disrupt livelihoods in communities that are dependent on natural resources. These disruptions can have wide-ranging effects, for example by intensifying economic hardship, increasing competition over scarce resources, causing widespread displacement and placing pressure on governance institutions that are responsible for managing crises.

These sorts of effects can then undermine the economic and social foundations upon which societies depend. For example, disruptions to rainfall patterns can reduce agricultural yields and income for rural communities, declining agricultural productivity can increase food prices in domestic and international markets, and rising food prices can generate economic stress for urban populations and increase political pressure on governments responsible for maintaining economic stability.⁵³

One of the most significant mechanisms through which environmental stress affects societies is through livelihood disruption. In many regions of the world, economic activity remains closely tied to agriculture, fisheries, and pastoral lifestyles that are sensitive to ecological changes. This means that large-scale or repeated climate disruption can undermine the economic stability of entire communities because of the effects on income, employment, and economic hardship. These sorts of livelihood disruptions can increase vulnerability to food insecurity and poverty, prompt migration to urban areas or across

⁴⁷ Kemp et al., "Climate Endgame," e2108146119.

⁴⁸ Barnett and Adger, "Climate Change, Human Security and Violent Conflict," 639–55; Mach et al., "Climate as a Risk Factor," 193–97.

⁴⁹ Mach et al., "Climate as a Risk Factor," 193–97.

⁵⁰ Solomon M. Hsiang and Marshall Burke, "Climate, Conflict, and Social Stability: What Does the Evidence Say?," *Climatic Change* 123, no. 1 (2014): 39–55.

⁵¹ This idea does a lot of political work on national security thinking. Rebecca Cullum, "Making a World of Climate Insecurity: The Threat Multiplier Frame and the US National Security Community," *Global Studies Quarterly* 4, no. 4 (2024): ksae085.

⁵² Barnett and Adger, "Climate Change, Human Security and Violent Conflict," 639–55; Michelini, "A Comprehensive Framework," 1–35.

⁵³ Homer-Dixon, *Environment, Scarcity, and Violence*.

international borders, which in turn can place pressure on urban infrastructure, employment, and governance institutions. Analysis of climate-induced migration shows that environmental degradation and resource scarcity can generate substantial population movements that affect political stability and social cohesion in precisely these ways.⁵⁴

Scholars have also emphasized the role of governance capacity in mediating the societal consequences of environmental stress.⁵⁵ This is because the effects of environmental shocks are filtered through the ability of institutions to manage them.⁵⁶ Environmental shocks can be manageable and the political legitimacy of governance systems can be sustained if they are able to provide basic services, stabilize markets, and manage population movements. In contrast, environmental shocks can increase the risk of political unrest and conflict if governance capacity is weak or fragmented.⁵⁷

Taken together, the climate-conflict scholarship demonstrates that environmental stresses can function as a systemic shock by affecting multiple sectors simultaneously. In the context of nuclear war, this suggests that the societal consequences of climatic disruption depend not only on the scale of environmental effects, but also on the capacity of political and institutional systems to manage the resulting pressures across food, economic, and social systems *and* how climatic disruption and ecological damage interacts with existing environmental and economic pressures and conflict dynamics.⁵⁸

⁵⁴ Rafael Reuveny, "Climate Change-Induced Migration and Violent Conflict," *Political Geography* 26, no. 6 (2007): 656–73.

⁵⁵ Tobias Ide, *Catastrophes, Confrontations, and Constraints: How Disasters Shape the Dynamics of Armed Conflicts* (Cambridge, MA: MIT Press, 2023).

⁵⁶ Mach et al., "Climate as a Risk Factor," 193–97; Nicholas P. Simpson et al., "A Framework for Complex Climate Change Risk Assessment," *One Earth* 4, no. 4 (2021): 489–501.

⁵⁷ Hsiang, Burke, and Miguel, "Quantifying the Influence of Climate," 1235367.

⁵⁸ David D. Zhang, Peter Brecke, Harry F. Lee, Yan-Qing He, and Jane Zhang, "Global Climate Change, War, and Population Decline in Recent Human History," *Proceedings of the National Academy of Sciences* 103, no. 51 (2006): 19214–19; Vaclav Smil, *Harvesting the Biosphere: What We Have Taken from Nature* (Cambridge, MA: MIT Press, 2013); Kemp et al., "Climate Endgame," e2108146119.

PART II

Mechanisms of Cascading Disruption Relevant to Nuclear War

The previous section unpacked a set of concepts for analyzing the systemic consequences of nuclear war as a large-scale shock that would propagate through complex societies. These are *systemic risk*, *cascading disasters*, *compound and connected events*, *tipping points*, *vulnerability paths*, *critical social systems*, *threat multipliers*, and *governance capacity and resilience*. This section applies those concepts and analytical tools to the specific mechanisms through which nuclear weapons use could generate cascading disasters and disruption.

This has not yet been done in a systematic way. The global catastrophic risk scholarship identifies nuclear war as a systemic global risk and highlights key global mechanisms such as climatic disruption and food insecurity (summarized in the next section), but it has not yet systematically analyzed the multi-domain cascading pathways through which disruption would likely propagate across interconnected socio-technical systems.⁵⁹ The climate-conflict nexus scholarship also “remains detached from nuclear weapons”⁶⁰ with the “conflict” part assumed to be fought with conventional weapons, even though the India-Pakistan nuclear relationship, for example, could be severely destabilized through environmental changes, not least by changes to Indus River flows.⁶¹ Finally, a body of work in the United States has examined the effects of the detonation of a 10 kiloton improvised nuclear device in a large metropolitan area following the attacks of September 11, 2001. This scholarship looked at how the medical community would be able to deal with victims, how the population of a city would react, the impacts of destruction and disruption of critical infrastructure, mass displacement of people, the costs of the decontamination and rebuilding, and some of the long-term impacts on society.⁶² But this work and its methodologies have not been expanded to the effects of a wider nuclear exchange.

⁵⁹ Nick Bostrom, “Existential Risk Prevention as Global Priority,” *Global Policy* 4, no. 1 (2013): 15–31; Toby Ord, *The Precipice: Existential Risk and the Future of Humanity* (New York: Hachette Book Group, 2020); Seth D. Baum, Stuart Armstrong, Timoteus Ekenstedt, Olle Häggström, Robin Hanson, Karin Kuhlemann, Matthijs M. Maas, et al., “Long-Term Trajectories of Human Civilization,” *Foresight* 21, no. 1 (2019): 53–83.

⁶⁰ Stephen van Buuren, Thomas Fraise, and Benoît Pelopidas, “Existential Silos: The Compartmentalization of the Futures of Environmental Change and the Nuclear Threat,” *Futures* 173 (2025): 103650.

⁶¹ Zia Mian, “Kashmir, Climate Change, and Nuclear War,” *Bulletin of the Atomic Scientists*, December 7, 2016, <https://thebulletin.org/2016/12/kashmir-climate-changeand-nuclear-war/>.

⁶² Nisha Parikh, Hemant G. Hayatnagarkar, Richard J. Beckman, et al., “A Comparison of Multiple Behavior Models in a Simulation of the Aftermath of an Improvised Nuclear Detonation,” *Autonomous Agents and Multi-Agent Systems* 30, no. 6 (2016): 1148–74; John Hick, Dan Weinstock, Courtney Coleman, Dan Hanfling, Stephen Cantrill, Irwin Redlener, et al., “Health Care System Planning for and Response to a Nuclear Detonation,” *Disaster Medicine and Public Health Preparedness* 5, no. S1 (2011): S73–S88; Frederick M. Burkle and Cham E. Dallas, “Developing a Nuclear Global Health Workforce Amid the Increasing Threat of a Nuclear Crisis,” *Disaster Medicine and Public Health Preparedness* 10, no. 1 (2016): 129–44; Tener Goodwin Veenema, Frederick M. Burkle, and Cham E. Dallas, “The Nursing Profession: A Critical Component of the Growing Need for a Nuclear Global Health Workforce,” *Conflict and Health* 13, no. 1 (2019): 9; William C. Bell and Cham E. Dallas, “Vulnerability of Populations and the Urban Health Care Systems to Nuclear Weapon Attack—Examples from Four American Cities,” *International Journal of Health Geographics* 6 (2007): 5; Michael 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): 143–50; M. Mitchell

We begin here with the framework of *hazard, exposure, and vulnerability* developed in the systemic risk and disaster response literatures and used by the International Panel on Climate Change (IPCC). This framework understands disaster as the product of these three interacting elements: an initiating hazard, exposure, and vulnerability conditions.⁶³ Analyzing nuclear war through this framework clarifies both the scale of the initiating shock and the reasons why its consequences would extend far beyond immediate physical destruction.

The initiating **hazards** in a nuclear-use scenario include blast and thermal destruction, prompt radiation, and radioactive contamination, and in some scenarios EMP or cyber-physical disruption. If urban firestorms produce significant soot injection into the upper atmosphere, the hazard field expands to include climatic disruption affecting temperature, precipitation, ocean states, and food growing conditions. These are not sequential events because they could interact simultaneously and compound one another across affected regions.

Exposure refers to the extent to which the populations, infrastructures, markets, institutions, and ecosystems could be exposed to direct damage or to secondary disruption, even when located far beyond the detonation zone. Exposure is highly networked in a complex global society through ports, cloud-computing hubs, refinery complexes, grain-export corridors, undersea cable landing stations, payment systems, logistics nodes, and the rest. This networked exposure is what could transform even a limited regional nuclear war into a potential systemic global event.

Vulnerability encompasses things like social inequality, weak healthcare systems, limited governance capacity, dependence on imports, just-in-time inventories, infrastructural redundancy, fiscal headroom, and political legitimacy. Thomas, Jang, and Scandlyn's *CHASMS model* (Cascading Hazards to disasters that are Socially constructed eMerging out of Social Vulnerability) is especially useful here because it shows how cascades are enabled by preexisting inequalities and different levels of access to the resources needed to respond, adapt, and survive. The key point here is that the effects of nuclear detonations would not hit a blank social slate but would interact with already uneven capacities to absorb and recover from a major shock.⁶⁴ The same pattern of nuclear harm could produce radically different cascading consequences depending on the baseline of a society's institutional strength, economic resilience, and the distribution of vulnerabilities across affected populations.

The sections that follow examine the specific pathways through which cascading disruptions might unfold using this hazard, exposure, and vulnerability framework and the scholarship on global system risks, complex societies, civilization collapse, and the climate-conflict nexus summarized above. In this context, nuclear detonations are the initiating shock that triggers

Waldrop, "What If a Nuke Goes Off in Washington, D.C.? Simulations of Artificial Societies Help Planners Cope with the Unthinkable," *Science*, April 12, 2019, <https://www.science.org/content/article/what-if-nuke-goes-washington-dc-simulations-artificial-societies-help-planners-cope>.

⁶³ Christopher B. Field, Vicente Barros, Thomas F. Stocker, Dahe Qin, David Jon Dokken, Kristie L. Ebi, Michael D. Mastrandrea, et al., eds., *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (Cambridge: Cambridge University Press, 2012); Leonard et al., "Compound Event Framework," 113–28; Zscheischler et al., "Future Climate Risk," 469–77.

⁶⁴ Deborah S. K. Thomas, Su-Yeul Jang, and Lois Scandlyn, "The CHASMS Conceptual Model of Cascading Disasters and Social Vulnerability: The COVID-19 Case Example," *International Journal of Disaster Risk Reduction* 51 (2020): 101828.

cascading dynamics that could expose an entire socio-technical order to networked disruption and collapse.

Environmental Disruption as the Initiating Systemic Shock

Research on nuclear weapons effects demonstrates that large-scale nuclear detonations could produce severe environmental disruptions extending far beyond the immediate areas affected by blast damage. In addition to the destruction of urban infrastructure and the direct humanitarian consequences of nuclear explosions, nuclear war could generate atmospheric and climatic changes capable of affecting global environmental systems. The possibility that nuclear detonations could produce large-scale climatic disruption was first explored in studies of nuclear winter in the 1980s.⁶⁵ Early research suggested that firestorms triggered by nuclear explosions in cities could generate massive quantities of smoke and soot that would be injected into the upper atmosphere. These particles could absorb solar radiation and reduce the amount of sunlight reaching the earth's surface, producing significant global cooling.⁶⁶

Subsequent advances in climate modeling refined our understanding of these processes through modeling the effects of global heating, volcanic eruptions, and massive wildfires. More recent research using modern climate models has examined how soot produced by urban firestorms could enter the stratosphere and remain there for extended periods, reducing solar radiation and altering atmospheric circulation patterns. Studies have modeled the scenario of a nuclear war between India and Pakistan in which each state detonates 50 Hiroshima-sized bombs with an explosive yield of 15 kilotons (kt). This scenario is estimated to produce 5 teragrams (Tg) of soot (1 teragram is 1 million tons). Later work examined a U.S.-Russia nuclear war in which each state uses 2,200 weapons releasing 150 Tg of soot.⁶⁷ The efficacy of these models has been rigorously tested.⁶⁸

One of the most significant environmental effects identified in this research is the potential for large-scale sunlight reduction. These studies suggest even a "limited" India-Pakistan nuclear war would cause substantial reduction in sunlight reaching the earth's surface in the years following a nuclear conflict, particularly if many cities were affected by firestorms. Reduced sunlight would directly affect photosynthesis and agricultural productivity and disrupt food production systems across large regions.⁶⁹

This would also cause a significant decline in temperature with average surface temperatures declining by several degrees Celsius for extended periods in some scenarios.

⁶⁵ Paul J. Crutzen and John W. Birks, "The Atmosphere After a Nuclear War: Twilight at Noon," *Ambio* 11, no. 2/3 (1982): 114–25.

⁶⁶ Richard P. Turco, Owen B. Toon, Thomas P. Ackerman, James B. Pollack, and Carl Sagan, "Nuclear Winter: Global Consequences of Multiple Nuclear Explosions," *Science* 222, no. 4630 (1983): 1283–92.

⁶⁷ Owen B. Toon, Alan Robock, and Richard P. Turco, "Environmental Consequences of Nuclear War," *AIP Conference Proceedings* 1596, no. 1 (2014): 65–73; Alan Robock, Luke Oman, Georgiy L. Stenchikov, Owen B. Toon, Charles G. Bardeen, and Richard P. Turco, "Climatic Consequences of Regional Nuclear Conflicts," *Atmospheric Chemistry and Physics* 7, no. 8 (2007): 2003–12; Francesco S. R. Pausata, Jonas Lindvall, Annica M. L. Ekman, and Gunilla Svensson, "Climate Effects of a Hypothetical Regional Nuclear War: Sensitivity to Emission Duration and Particle Composition," *Earth's Future* 4, no. 11 (2016): 498–511.

⁶⁸ Seth D. Baum, "Winter-Safe Deterrence: The Risk of Nuclear Winter and Its Challenge to Deterrence," *Contemporary Security Policy* 36, no. 1 (2015): 127–48.

⁶⁹ Robock et al. Climatic consequences of regional nuclear conflicts; Xia et al. Global food insecurity and famine.

Such temperature changes would affect staple crop production on a global scale by shortening growing seasons and damaging crops across multiple agricultural regions.⁷⁰ Research also indicates that atmospheric changes associated with nuclear winter could alter global circulation systems and reduce rainfall in many regions. Changes in precipitation patterns could affect both rain-fed and irrigated agricultural systems and exacerbate existing water scarcity.⁷¹ Studies suggest two billion people would be at risk of starvation in the India-Pakistan nuclear war scenario.⁷² These simultaneous effects of reduced sunlight, temperature decline, and altered precipitation interacting across affected agricultural regions are precisely what the compound events framework describes: multiple drivers combining to produce an extreme impact that none would generate alone.

Studies also show severe depletion of the ozone layer over populated areas with increased ultraviolet (UV) radiation damaging terrestrial and oceanic plants, producing skin cancer, eye damage, and other health effects in humans and animals. The increase in UV-B radiation would damage aquatic ecosystems, including amphibians, shrimp, fish, and phytoplankton, which provide food for a wide range of fish and jellyfish.⁷³ More recent studies also suggest a collapse in the summer monsoon in Southern Asia,⁷⁴ an increase of ocean acidification affecting marine life and food chains,⁷⁵ significant losses in global fish catch and biomass,⁷⁶ and a complete disruption of the normal circulation pattern of the equatorial Pacific Ocean.⁷⁷ Studies further suggest the ocean would enter a new “biogeochemical and ecosystem state” as a result of global cooling resulting in an expansion of sea ice into populated coastal areas and decimation of ocean marine life.⁷⁸

Because global food production systems are highly interconnected through international trade and supply chains, disruptions affecting major agricultural regions would likely

⁷⁰ Lili Xia, Alan Robock, Michael Mills, Andrea Stenke, and Ira Helfand, “Decadal Reduction of Chinese Agriculture After a Regional Nuclear War,” *Earth’s Future* 3, no. 2 (2015): 37–48; Jonas Jägermeyr, Alan Robock, Joshua Elliott, Christoph Müller, Lili Xia, et al., “A Regional Nuclear Conflict Would Compromise Global Food Security,” *Proceedings of the National Academy of Sciences* 117, no. 13 (2020): 7081–86.

⁷¹ Toon, Robock, and Turco, “Environmental Consequences of Nuclear War,” 65–73.

⁷² Ira Helfand, *Nuclear Famine: Two Billion People at Risk?*, 2nd ed. (Boston: International Physicians for the Prevention of Nuclear War, 2013), <https://psr.org/wp-content/uploads/2018/04/two-billion-at-risk.pdf>; Xia et al., “Global Food Insecurity and Famine,” 586–96.

⁷³ Michael J. Mills, Owen B. Toon, Julia Lee-Taylor, and Alan Robock, “Multidecadal Global Cooling and Unprecedented Ozone Loss Following a Regional Nuclear Conflict,” *Earth’s Future* 2, no. 4 (2014): 161–76; Charles G. Bardeen, Douglas E. Kinnison, Owen B. Toon, Michael J. Mills, Francis Vitt, Lili Xia, et al., “Extreme Ozone Loss Following Nuclear War Results in Enhanced Surface Ultraviolet Radiation,” *Journal of Geophysical Research: Atmospheres* 126, no. 18 (2021): e2021JD035079.

⁷⁴ Joshua Coupe, Charles G. Bardeen, Alan Robock, and 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,” *Journal of Geophysical Research: Atmospheres* 124, no. 15 (2019): 8522–43.

⁷⁵ Nicole S. Lovenduski, Cheryl S. Harrison, Jessica Olivarez, Charles G. Bardeen, Owen B. Toon, Joshua Coupe, Alan Robock, Tyler Rohr, and Samantha Stevenson, “The Potential Impact of Nuclear Conflict on Ocean Acidification,” *Geophysical Research Letters* 47, no. 3 (2020): e2019GL086246.

⁷⁶ Kim J. N. Scherrer, Cheryl S. Harrison, Ryan F. Heneghan, Eric Galbraith, Charles Bardeen, et al., “Marine Wild-Capture Fisheries After Nuclear War,” *Proceedings of the National Academy of Sciences* 117, no. 47 (2020): 29748–58.

⁷⁷ Joshua Coupe, Samantha Stevenson, Nicole S. Lovenduski, et al., “Nuclear Niño Response Observed in Simulations of Nuclear War Scenarios,” *Communications Earth & Environment* 2 (2021): art. 18.

⁷⁸ Cheryl S. Harrison, Tyler Rohr, Alice DuVivier, Elizabeth A. Maroon, Scott Bachman, Charles G. Bardeen, et al., “A New Ocean State After Nuclear War,” *AGU Advances* 3, no. 4 (2022): e2021AV000610.

propagate through global markets and affect food availability in regions distant from the nuclear war. These findings highlight an obvious but important feature of nuclear weapons effects: that the environmental consequences extend far beyond the areas directly affected by explosions. Nuclear war would not only destroy cities and infrastructure but could also disrupt the planetary systems that regulate climate and ecological processes.

From the perspectives set out in Part I of this report, these environmental disruptions can be understood as an initiating systemic shock. Environmental changes affecting sunlight, temperature, and precipitation would destabilize the ecological and agricultural systems that support human societies. Because food production systems are closely linked to economic markets, trade networks, and governance institutions, disruptions in environmental conditions would likely cascade through these interconnected systems. Climate-conflict research provides empirical evidence of how environmental shocks can generate cascading societal effects through such pathways. Environmental disruptions affecting agricultural productivity would likely undermine rural livelihoods, increase food prices, place pressure on economic systems and governance institutions, increase migration pressures as populations move in search of more stable conditions, create severe governance challenges and increase the risk of social unrest, political instability, and breakdown.⁷⁹ These dynamics suggest that the environmental consequences of nuclear war would propagate through interconnected societal systems in ways similar to those observed in climate-related crises, but on a far larger scale.

A further dimension of environmental and infrastructural disruption that has received insufficient attention in assessments of the consequences of nuclear war is the vulnerability of civilian nuclear power infrastructure. Nuclear power plants are potential targets in a nuclear conflict, whether struck deliberately or through collateral damage from attacks on nearby military or industrial sites. Research has documented how strikes on reactor facilities would release large quantities of radioactive material and produce zones of intense contamination that could render agricultural land, river systems, and groundwater sources unusable for years or decades.⁸⁰ In the context of the cascading disaster framework in this report, the destruction of nuclear power facilities compounds the initiating hazard in several ways simultaneously: it would take out essential electricity generation capacity at precisely the moment when the resilience of the grid would be most critical; it would produce long-term contamination of water catchments and agricultural systems that would amplify the food and water disruption pathways analyzed below; it would overwhelm the radiation medicine and public health capacity of affected regions; and it would create exclusion zones adding another layer of disruption to transport, supply chains, and population movement in ways that interact with the migration and governance stress pathways analyzed below.⁸¹ Moreover, the number of potential facilities whose destruction could trigger these cascading effects is increasing as the global share of electricity generated by nuclear power plants grows.

⁷⁹ Halvard Buhaug and Nina von Uexkull, "Vicious Circles: Violence, Vulnerability, and Climate Change," *Annual Review of Environment and Resources* 46 (2021): 545–68; Michelini, "A Comprehensive Framework," 1–35.

⁸⁰ Steve Fetter and Kosta Tsepis, "Catastrophic Releases of Radioactivity," *Scientific American* 244, no. 4 (1981): 41–47.

⁸¹ Bennett Ramberg, *Nuclear Power Plants as Weapons for the Enemy: An Unrecognized Military Peril* (Berkeley: University of California Press, 1985).

The scale of these consequences reflects both the networked exposure of modern economies and institutions to environmental disruption extending well beyond blast zones, and the uneven vulnerability of populations whose capacity to absorb and recover from shocks is shaped by existing inequalities in institutional capacity, infrastructure redundancy, and economic resilience. These are the conditions that determine how an initiating hazard translates into cascading societal harm.

Clean Water Disruption

Access to clean water is often discussed as a secondary effect of infrastructure disruption rather than as a critical cascade pathway in its own right even though it is essential to complex societies. This is important because water is implicated in virtually every dimension of cascading disruption analyzed in this report, not least because agricultural systems in many of the world's most productive regions depend heavily on irrigation from rivers, aquifers, and reservoirs. The climatic disruption associated with nuclear winter would alter precipitation patterns, reduce snowpack and glacial melt that feeds major river systems, and affect the hydrological cycles upon which agriculture depends.⁸²

Nuclear detonations that damage or destroy water treatment and distribution infrastructure in urban areas, such as pumping stations, treatment plants, reservoir management systems, and so on, would make populations that are dependent on safe water supplies very vulnerable within days, well before food insecurity could become the dominant emergency. In conflict scenarios involving strikes on nuclear power facilities, as noted above, radiological contamination of river systems and groundwater could make water supplies unusable for extended periods across large areas. Research on the effects of nuclear weapons use on urban populations has documented how failure of power, water, and waste facilities would rapidly compound casualties and mortality beyond the effects of the initial blasts.⁸³

The governance and public health dimensions of water disruption are equally significant because the risk of waterborne disease outbreaks increases when treatment and sanitation systems fail, particularly in the context of large-scale displacement and urban overcrowding from migration (see below). The historical record of conflicts and disasters consistently shows that infectious diseases resulting from displacement, overcrowding, destruction of water and sanitation infrastructure, and malnutrition can cause death rates equal to or exceeding those from direct violence.⁸⁴

Research modeling the cascading public health consequences of nuclear crises similarly identifies the collapse of *protective infrastructure*, such as water, sanitation, and healthcare, as the primary driver of indirect mortality in disaster settings. Modeling suggests this would account for 60 to 90 percent of total mortality and morbidity over the course of a crisis.⁸⁵ What makes this particularly urgent is that water systems are under growing stress from

⁸² Robock et al., "Climatic Consequences," 2003–12; Toon, Robock, and Turco, "Environmental Consequences of Nuclear War," 65–73; Benjamin F. Hobbs, "Water Supply Impacts of Nuclear Fall," *Journal of the American Water Resources Association* 25, no. 3 (1989): 611–22; Institute of Medicine, *The Medical Implications of Nuclear War* (Washington, DC: National Academy Press, 1986).

⁸³ Bell and Dallas, "Vulnerability of Populations," 5.

⁸⁴ Ahmad Khalil, Fadi Tanios, Maya Kaddoura, et al., "Conflicts in Gaza and Around the World Create a Perfect Storm for Infectious Disease Outbreaks," *eClinicalMedicine* 69 (2024): 102476.

⁸⁵ Burkle and Dallas, "Developing a Nuclear Global Health Workforce," 129–44.

trends that have nothing to do with nuclear conflict. The expansion of nuclear energy generation places significant demands on river and reservoir systems for reactor cooling.⁸⁶ The rapid growth of data centers to support artificial intelligence infrastructure adds a further burden because of their water-intensive cooling requirements that compete directly with agricultural, municipal, and ecological water needs in already water-stressed regions.⁸⁷ These trends mean that the baseline resilience of water systems in terms of their capacity to absorb disruption and continue to function is declining. Water should therefore be treated as a critical system in its own right, alongside food, energy, and economic infrastructure, and its vulnerability should be a central consideration in both systemic risk assessment and risk reduction policy.

Food System Disruption

Food production and distribution systems represent one of the most critical foundations of societal stability. Human societies ultimately depend on reliable access to food and disruptions to food systems can therefore generate far-reaching economic, political, and social consequences. Modern global food systems operate through complex networks that connect agricultural production, transportation infrastructure, energy systems, financial markets, and international trade. Essential components of agricultural systems such as fertilizers, energy, and irrigation systems support food production and transportation networks, and global markets coordinate the distribution of food across regions. Damage or stress in any one of these domains would amplify disruptive effects in others.⁸⁸ Disruptions affecting agricultural productivity in one region can therefore propagate through global supply chains and affect food availability and prices elsewhere. Research on environmental security and climate-conflict dynamics consistently identifies food systems as a key pathway through which environmental disruptions propagate through networks to generate broader societal instability.⁸⁹

We know that agricultural productivity depends on climatic conditions, including temperature, precipitation, and sunlight, and that changes in these conditions can directly affect crop yields and agricultural output. An immediate consequence of the disruption of agricultural productivity is the potential for crops to fail and for global food production to decline substantially. Climate modeling studies suggest that global food systems are particularly vulnerable to synchronous disruptions affecting major agricultural regions. This is because global food production is concentrated in a relatively small number of highly productive regions, such that environmental shocks that affect these areas would have a disproportionate impact on global food supply. Research shows us that environmental disruptions that affect agricultural production often translate rapidly into food price volatility

⁸⁶ International Atomic Energy Agency, *Efficient Water Management in Water Cooled Reactors*, IAEA Nuclear Energy Series NP-T-2.6 (Vienna: IAEA, 2012); Ennio V. Giusti and Edward Meyer, *Water Consumption by Nuclear Power Plants and Some Hydrological Implications*, U.S. Geological Survey Circular 745 (Washington, DC: U.S. Geological Survey, 1977).

⁸⁷ Pengfei Li, Jianyi Yang, Mohammad A. Islam, and Shaolei Ren, "Making AI Less 'Thirsty': Uncovering and Addressing the Secret Water Footprint of AI Models," arXiv, 2023, arXiv:2304.03271; David Mytton, "Data Centre Water Consumption," *npj Clean Water* 4 (2021): art. 11.

⁸⁸ Raymond et al., "Connected Extreme Events," 611–21; Kemp et al., "Climate Endgame," e2108146119.

⁸⁹ Homer-Dixon, *Environment, Scarcity, and Violence*; Jürgen Scheffran, Michael Brzoska, Jasmin Kominek, P. Michael Link, and Janpeter Schilling, "Climate Change and Violent Conflict," *Science* 336, no. 6083 (2012): 869–71.

as reduced supply pushes up global food prices. This can have significant knock-on economic and political consequences, particularly in countries where a large proportion of household income is spent on food so that a price shock can quickly become a nutrition shock.⁹⁰

Research on the political consequences of food price volatility highlights the potential for food system disruptions to generate economic instability and social unrest. Studies of the 2007–2008 global food price crisis show how rising food prices contributed to political instability and protests in multiple regions. Buhaug and von Uexkull, for example, show that environmental shocks affecting agricultural productivity can contribute to conflict risk through the economic effects on livelihoods and governance systems.⁹¹

This illustrates the concept of connected extreme events where a shock to a food system in one region becomes linked to instability in distant regions through shared trade routes, commodity markets, and financial systems. This can produce what the scholarship calls a multiple breadbasket failure: a single global food crisis as the aggregated effect of geographically dispersed agricultural disruptions that causes economic instability.⁹² The literature also warns against treating food insecurity as an isolated phenomenon because undernutrition, displacement, public health deterioration, and conflict are all linked. Kemp and colleagues, for example, describe famine, disease, and conflict as interlocking pathways through which systemic stress can lead to mass mortality.⁹³

For analysis of the effects of nuclear war, the key implication is that modeling food systems should not stop at the loss of agricultural production, but encompass effects on trade and prices, import dependence, rural incomes, shipping chokepoints, social protection, nutrition shocks, and constraints on humanitarian responses. Without this, the indirect and transboundary consequences are likely to be systematically underestimated.⁹⁴

Economic and Trade Network Disruption

The first part of the report noted that modern societies depend on complex networks of economic exchange that coordinate the production, distribution, and consumption of goods and services across global markets. Industrial production relies on global supply chains that connect the extraction of raw materials to manufacturing, transport infrastructure, financial systems, markets, industries and consumers. These networks enable the international coordination of economic activity across national borders and, in doing so, they underpin the functioning of contemporary economies and the global economic system.

However, these same networks that enable economic efficiency also create systemic vulnerabilities. This is because modern supply chains exemplify two dynamics. First, global production systems rely on highly specialized supply networks with different stages of production across multiple countries. This allows firms to optimize production efficiency but it

⁹⁰ Thomas, Jang, and Scandlyn, “CHASMS Conceptual Model,” 101828; RAND Corporation, *Global Catastrophic Risk Assessment* (Santa Monica, CA: RAND Corporation).

⁹¹ Buhaug and von Uexkull, “Vicious Circles,” 545–68.

⁹² Raymond et al., “Connected Extreme Events,” 611–21.

⁹³ Kemp et al., “Climate Endgame,” e2108146119.

⁹⁴ Page Stoutland, Paul Jaworek, and Isabelle Williams, *Global Nuclear Effects: Economic and Financial Fallout of Nuclear Use* (Washington, DC: Nuclear Threat Initiative, 2025); Raymond et al., “Connected Extreme Events,” 611–21.

also increases vulnerability to disruptions that affect key nodes in global supply chains. Disruption to transport networks, energy systems, or manufacturing facilities can therefore propagate through supply networks and affect production across multiple sectors and regions. Second, interruptions in supply chains can quickly propagate across production networks because many industries rely on just-in-time production systems, which means they carry limited inventories of materials and components. Firms that are dependent on specific components can be forced to halt production when components become unavailable, and this can cause ripple effects across entire industries.⁹⁵ Linkov and colleagues argue that highly interconnected systems exhibit both efficiency *and* fragility because the density of supply chain connections can facilitate rapid coordination and high productivity under normal conditions but enable failures to propagate rapidly when disruptions occur.⁹⁶

Financial systems represent another important pathway through which economic disruptions can propagate. Modern financial markets link banks, private markets, investment institutions, and corporations through networks of credit, investment, debt and trade. These networks enable the circulation of capital that supports economic activity, but they also create channels through which financial crises can spread. Disruptions affecting economic production or trade can therefore affect financial markets leading to a decline in investment, credit shortages, and economic contraction. NTI's paper on financial fallout establishes the basic point that globalization since the 1990s has produced deep integration in trade, capital flows, data infrastructure and payment systems. The authors note that major financial hubs, cloud-computing clusters, and data centers are concentrated in states that possess nuclear weapons or depend on nuclear alliances and could be subject to immediate destruction or disruption in a nuclear war.⁹⁷

The hyperconnected interdependence between financial systems and real economic activity means that disruptions affecting one domain can rapidly propagate into the other and that a severe shock to one or more key nodes would have consequences far beyond national borders. For example, disruptions to industrial production or supply chains can affect corporate revenues and employment, which in turn can affect financial institutions and investment markets. Financial instability can then propagate through credit systems and investment networks with widespread effects on employment, welfare provision, political legitimacy, and international cooperation that amplify the economic consequences of the initial disruption.⁹⁸

The literature on financial crises suggests at least four mechanisms that enable this. First, market panic through the repricing of risk, sell-offs, hoarding liquidity (holding onto cash and liquid assets rather than lending them out), and payment uncertainty. Second, disruptions that are mediated through infrastructure, for example damage to data centers, communications links, power supply, transport hubs, cloud services, and so on can interrupt

⁹⁵ Yossi Sheffi, *The Resilient Enterprise: Overcoming Vulnerability for Competitive Advantage* (Cambridge, MA: MIT Press, 2005); Daron Acemoglu, Vasco M. Carvalho, Asuman Ozdaglar, and Alireza Tahbaz-Salehi, "The Network Origins of Aggregate Fluctuations," *Econometrica* 80, no. 5 (2012): 1977–2016.

⁹⁶ Linkov et al., "Are Civilizations Destined to Collapse?," 102792.

⁹⁷ Stoutland, Jaworek, and Williams, *Global Nuclear Effects*.

⁹⁸ Tim Benton, Neil Morisetti, and Ollie Brown, "Cascading and Systemic Risks from Environmental Change," in *Climate Change, Conflict and (In)Security: Hot War*, ed. Tim Clack, Ziya Meral, and Louise Selisny (Abingdon: Routledge, 2023), 35–54; Simpson et al., "Complex Climate Change Risk Assessment," 489–501.

the operation of financial systems. Third, the seizing up of trade and supply chains when firms cannot pay for, insure, ship, or source components, leading to widespread production interruptions. Fourth, governance and institutional stress as states face fiscal collapse, emergency spending, and external financial pressures all at the same time.⁹⁹ This means supply chain disruptions could affect industrial production in regions far removed from the site of nuclear detonations and cause a decline in production, trade, investment, and credit leading to economic contraction across national economies.

These propagation dynamics illustrate how nuclear war could generate connected and extreme events in the economic domain with detonations concentrated in specific regions causing economic contraction far beyond those regions through the shared infrastructure of global supply chains, financial networks, and trade systems.¹⁰⁰ A full understanding of the effects of nuclear war therefore requires economic modeling of effects on payment systems, trade finance, insurance, logistics, debt sustainability, and the governance of markets under conditions of physical destruction, uncertainty, and conflict escalation. These are the systemic economic, financial, and trade pathways by which a regional nuclear event could become a global economic crisis.¹⁰¹

Migration and Demographic Pressures

Environmental disruptions that affect food production, people's livelihoods, and economic stability can generate significant population movements as individuals and communities try and find more secure living conditions. Migration therefore represents an important pathway through which environmental and economic shocks can propagate through social and political systems. Research on environmental migration and climate-conflict dynamics emphasizes that population displacement often emerges as a secondary effect of environmental disruption rather than as a direct response to environmental change itself.¹⁰² Specifically, migration can become an adaptive response for populations affected by environmental shocks that have undermined their livelihoods and economic stability. This can unfold through several interconnected mechanisms, such as reduced incomes in rural communities that are dependent on farming or pastoral livelihoods as agricultural productivity declines; increasing vulnerability of households and reduced access to basic necessities through food shortages; and reduced employment through wider economic instability. Under conditions like these, migration can become one of the few available strategies that people and communities have to try and maintain a livelihood.

Analysis of climate change-induced migration shows how environmental degradation and resource scarcity can generate population movements that can have a significant effect on political stability and social cohesion.¹⁰³ This is because large-scale movements of people can create pressures within receiving communities by increasing competition for housing, employment, land, and public services, especially in urban areas that are often the main destination for environmentally displaced people. Rapid migration from rural areas to urban

⁹⁹ Helbing, "Globally Networked Risks," 51–59; Wernli et al., "Understanding and Governing Global Systemic Crises," 207–28.

¹⁰⁰ Raymond et al., "Connected Extreme Events," 611–21.

¹⁰¹ Stoutland, Jaworek, and Williams, *Global Nuclear Effects*; Helbing, "Globally Networked Risks," 51–59.

¹⁰² Reuveny, "Climate Change-Induced Migration," 656–73; Scheffran et al., "Climate Change and Violent Conflict," 869–71.

¹⁰³ Reuveny, "Climate Change-Induced Migration," 656–73.

centers can increase pressure on housing markets, water supply systems, sanitation infrastructure, schools, welfare systems and other public services. In many cities, particularly in developing regions, governance institutions already face challenges in providing adequate infrastructure and services. This means that large-scale migration often exacerbates existing vulnerabilities within urban systems, particularly when governance institutions lack the capacity to manage rapid demographic change.¹⁰⁴

Studies also show how climate vulnerability and political violence can reinforce one another through vicious cycles that link environmental stress, disruption of livelihoods, and instability.¹⁰⁵ For example, violent conflict can destroy infrastructure, disrupt markets, displace populations and thereby increase vulnerability to environmental shocks. At the same time, environmental stress can undermine livelihoods and increase the likelihood of social unrest or violence. The interaction between migration and public health systems represents an important additional dimension because large-scale displacement can increase vulnerability to disease outbreaks and put a significant strain on health infrastructure in receiving regions through overcrowded living conditions, inadequate sanitation, and limited access to healthcare. Here, Lasater and colleagues analyze evidence linking climate change, displacement, and public health risks in vulnerable regions by highlighting how environmental disruptions can generate cascading humanitarian crises that affect food security, migration patterns, and health systems simultaneously.¹⁰⁶

The relevance of these dynamics becomes particularly significant in the context of nuclear war. If environmental disruptions associated with nuclear winter significantly reduce agricultural productivity across large regions, then declining food production and economic instability is likely to undermine livelihoods for populations dependent on agriculture and related economic sectors. Simultaneous agricultural failures across multiple regions could limit the capacity of unaffected areas to absorb displaced populations. In such circumstances, migration pressures could affect multiple regions simultaneously, placing strain on urban infrastructure, governance systems, and humanitarian response capacities.

Migration therefore represents a core pathway through which environmental disruption can generate cascading societal consequences when population displacement amplifies the effects of the disruption of food systems and economic instability and places additional pressure on governance institutions responsible for managing crises. The interaction between migration, public health, and governance capacity further illustrates the complexity of cascading disruptions where each pathway interacts with others and the combined effects can exceed the capacity of societies to manage them. From the perspective developed in this report, understanding these dynamics helps us to see how environmental shocks associated with nuclear war could propagate through demographic systems and contribute to broader patterns of societal instability.

¹⁰⁴ Scheffran et al., “Climate Change and Violent Conflict,” 869–71.

¹⁰⁵ Buhaug and von Uexkull, “Vicious Circles,” 545–68.

¹⁰⁶ Molly E. Lasater, Grace Prager, Youngji A. Choi, Tine Groteclaes, Deepthi Rao, Sarah P. Kamps, Chiara Altare, and Paul B. Spiegel, “Understanding Relationships Among Climate Change, Conflict, Migration/Displacement and Health in Humanitarian Settings: A Scoping Review,” *Conflict and Health* 19, no. 1 (2025): art. 73.

Governance Stress and Institutional Fragility

The severity of systemic crises depends not only on the magnitude of shocks affecting societies but also on the capacity of governance institutions to manage those shocks. Societies can often absorb significant environmental and economic disruptions when governance systems are functioning effectively and they are able to perform essential tasks such as coordinating responses to crises, managing the distribution of resources to those affected, maintaining public order, and managing economic stability.

However, the capacity to perform these tasks can decline when institutions are overwhelmed by simultaneous crises, which can then increase the risk of systemic instability. Research on environmental security has long emphasized the importance of governance capacity in managing the societal consequences of environmental change.¹⁰⁷ States are much better placed to mitigate the impacts of environmental shocks when their governance institutions are strong, but environmental disruptions can contribute to instability and insecurity if they are weak or overstretched.

Governance institutions can face increasing demands for coordinated intervention during crises when shocks affect several sectors simultaneously, especially agriculture, infrastructure, and economic systems. The scholarship on disaster studies shows how cascading crises often overwhelm the governance infrastructure of humanitarian response systems as information degrades, conditions shift rapidly, and cascading effects overwhelm the ability of centralized institutions to manage it all.¹⁰⁸ Moreover, systems for responding to crises and shocks are themselves dependent on the infrastructures that could be destroyed or put under severe stress in a violent conflict. For example, a humanitarian response without fuel, communications, road access, payment capacity, and public legitimacy could be impossible.¹⁰⁹ This would certainly be the case in areas directly affected by nuclear detonations.¹¹⁰

Analysis of the relationship between climate disasters and armed conflict also suggests that environmental shocks can affect political stability through the impact on governance systems.¹¹¹ Chandler, for example, shows that climate change and environmental disruption can reveal the fragility of governance systems that rely on complex coordination across multiple sectors and at scale.¹¹² Environmental crises require governments to manage a range of interactions between environmental systems, economic systems, and social systems simultaneously. However, institutional responses can struggle to keep pace with evolving crises when these interactions become too complex or occur too rapidly. Governments that are having to deal with multiple crises simultaneously can therefore struggle to maintain their authority and legitimacy, all of which can lead to institutional fragility. For example, environmental shocks can reduce economic activity and tax revenues, which then limits resources available for crisis response; infrastructure damage can disrupt

¹⁰⁷ Barnett and Adger, "Climate Change, Human Security and Violent Conflict," 639–55.

¹⁰⁸ Arjen Boin, Allan McConnell, and Paul 't Hart, *Governing After Crisis: The Politics of Investigation, Accountability and Learning* (Cambridge: Cambridge University Press, 2008).

¹⁰⁹ Pescaroli and Kelman, "Critical Infrastructure," 56–67.

¹¹⁰ Simon Bagshaw, "Responding to the Detonation of Nuclear Weapons: A United Nations Humanitarian Perspective," in *Viewing Nuclear Weapons Through a Humanitarian Lens*, ed. John Borrie and Tim Caughley (Geneva: UNIDIR, 2013), 118–30.

¹¹¹ Ide, *Catastrophes, Confrontations, and Constraints*.

¹¹² Chandler, *Pathways from Climate Change to Conflict*.

administrative and logistical systems, which then constrains effective responses; and population displacement can rapidly increase demands on social services.

The international dimensions of environmental crises further complicate governance responses because many environmental disruptions have cross-border effects that require coordination among multiple states, which can be difficult at the best of times.¹¹³

Environmental disruption that weakens the capacities of state in vulnerable regions can therefore increase the risk of instability spilling across borders through migration flows, regional economic disruption and political tensions.

In extreme cases, the breakdown of governance systems and institutions can amplify other systemic disruptions by significantly reducing the effectiveness of food distribution systems, disaster response efforts, and economic stabilization policies leading to food shortages, widespread economic stress, public dissatisfaction, unemployment, population displacement, collapse of public services, and social unrest. A serious decline in institutional capacity can also undermine the rule of law and the legitimacy of governance institutions, all of which can increase the risk of political violence or conflict. These feedback processes can accelerate systemic crises if governments face growing difficulties in maintaining social stability and coordinating responses across multiple sectors as pressures pile up from cascading effects.¹¹⁴ For nuclear war, this dynamic would be particularly acute where governance institutions faced extraordinary demands at precisely the moment when infrastructure damage and economic disruption severely reduced institutional capacity.

This is the governance dimension of tipping point dynamics where compounding demands from food insecurity, economic disruption, and population displacement accumulate beyond the capacity of governance institutions. This then accelerates rather than contains the cascading crisis as responses become increasingly ineffective. This underscores a broader point about the nature of nuclear war as a systemic risk, which is that it is not the scale of any single disruption that determines the ultimate consequences, but the interaction of multiple disruptions across interconnected systems whose combined effects can overwhelm the institutions responsible for managing them.

Composite Shock

These six pathways of environmental disruption, clean water disruption, food system disruption, economic and trade network disruption, migration and demographic pressure, and governance stress interact as a connected system in which disruptions in each pathway amplify disruptions in the others. These interactions can produce **compound events** as defined above such that a catastrophic outcome is not generated by any single pathway but by the combination of multiple disruptions arriving simultaneously and reinforcing one another through feedback processes.

They can also produce **connected extreme events** as disruptions that are geographically or sectorally separate, such as agricultural failure in one region, financial contagion in another,

¹¹³ Caitlin E. Werrell and Francesco Femia, "Climate Change, the Erosion of State Sovereignty, and World Order," *Brown Journal of World Affairs* 22, no. 2 (2016): 221–35.

¹¹⁴ Robert I. Rotberg, "Failed States, Collapsed States, Weak States: Causes and Indicators," in *State Failure and State Weakness in a Time of Terror*, ed. Robert I. Rotberg (Washington, DC: Brookings Institution Press, 2003), 1–25.

governance breakdown in a third, become linked into a single systemic crisis through shared trade networks, humanitarian logistics, financial systems, and governance institutions. The result can be a cascading disaster whose scale is determined by the vulnerability paths that are already embedded in the global systems through which that shock propagates, rather than by the magnitude of the initiating shock like the detonation of nuclear weapons.¹¹⁵

Through the lens of the **hazard-exposure-vulnerability** framework, we can see that the **hazard** is not a single event but a composite shock when nuclear detonations initiate a set of interacting processes that include physical destruction, disruption of infrastructure and, in many scenarios, atmospheric and climatic change. What matters here is the way these effects combine and unfold across different temporal and spatial scales in ways that extend the initial hazard beyond the immediate site of destruction and into the systems that sustain global food production, ecological stability, and core societal functions.

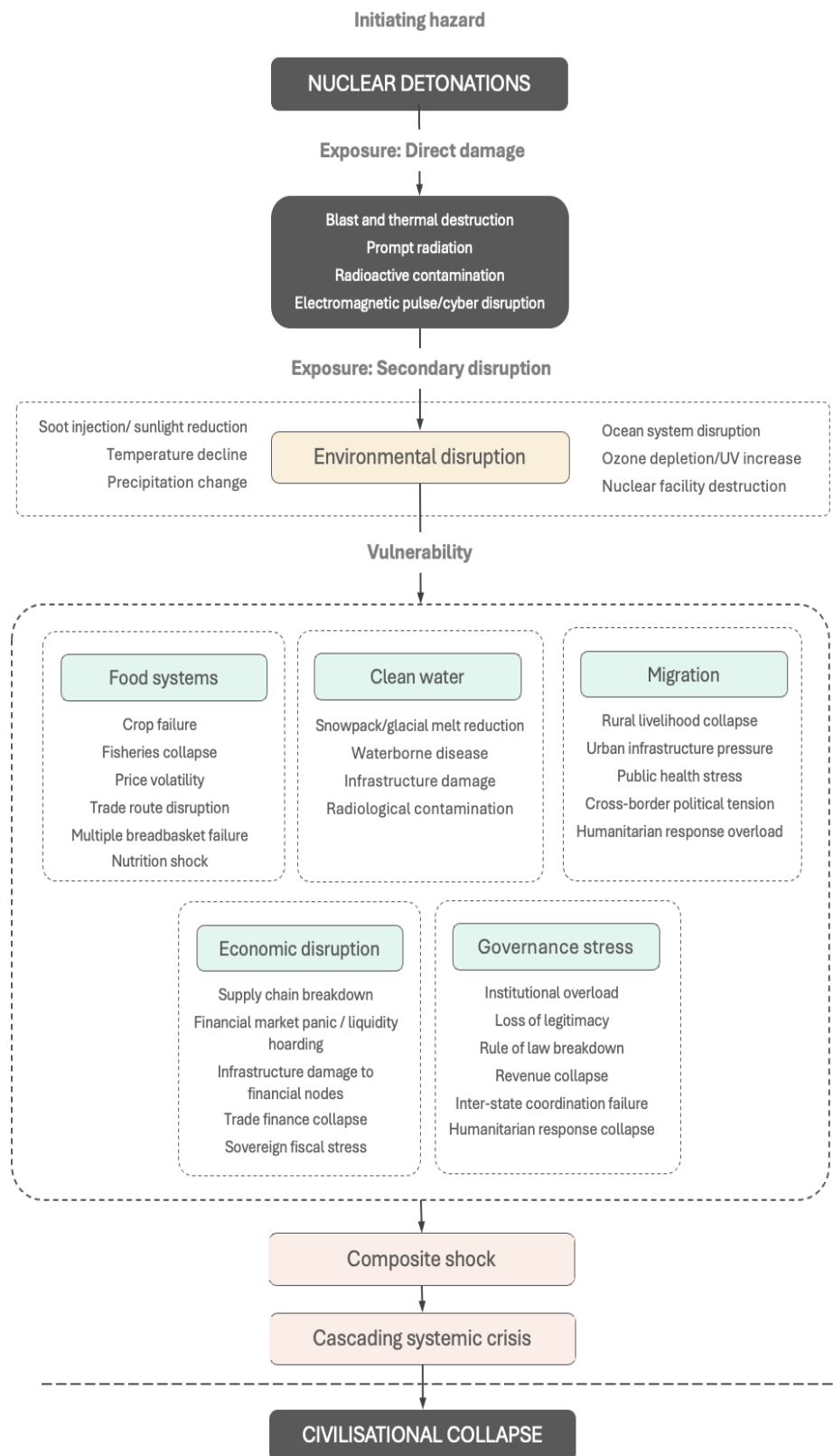
This analysis highlights the ways in which **exposure** is structured through the organization of contemporary societies. The pathways analyzed here show that exposure is not primarily local but networked: food systems depend on geographically concentrated production zones and globally distributed trade networks; economic activity relies on tightly coupled supply chains, financial systems and infrastructure nodes; population distributions and migration routes connect vulnerable regions to urban and transnational systems; and governance institutions are exposed through their limited capacities to manage multiple interdependent systemic disruptions simultaneously.

We can also see how **vulnerability** determines how these disruptions propagate and whether they remain contained or become systemic. The scholarship shows that vulnerability is embedded in the structure of these systems, notably through the where production is concentrated, the lack of redundancy in supply chains, dependence on imports, the limited ability of governments to raise revenue, uneven access to resources, and the fragility of governance institutions under stress. Across the four pathways, vulnerability is what links environmental shock to food insecurity, food insecurity to economic instability, economic disruption to migration pressures, and then how these dynamics combine to undermine governance institutions. It is therefore the configuration of vulnerability across systems, rather than the scale of any single disruption, that shapes the trajectory from an initial nuclear shock to a cascading crisis.

The consequences of nuclear weapons use are therefore not simply the sum of their immediate effects, but the product of how an extreme, multi-dimensional hazard interacts with deeply interconnected systems and unevenly distributed vulnerabilities (see Figure 2).

¹¹⁵ Raymond et al., “Connected Extreme Events,” 611–21.

Figure 2. Effects of Cascading Destruction Initiated by Nuclear Detonations



Implications for Risk Reduction

The implication of this analysis is that preventing nuclear catastrophe must be understood in terms of both preventing any initial use of nuclear weapons *and* in terms of reducing the probability that any use escalates into a systemic global crisis through cascading disruption. This reflects a broader insight from the research on systemic risks set out above that the consequences of shocks are shaped as much by system structure and interdependence as by the initiating event itself. This shifts the focus of near- to mid-term nuclear risk reduction in three important ways.

First, it reinforces the importance of preventing escalation if nuclear weapons *are* used because the difference between a small number of detonations and larger exchanges is not linear but systemic. As the research outlined above shows, once a disruption crosses critical thresholds *which we are very unlikely to know in advance*, cascading effects can accelerate rapidly through feedback processes.¹¹⁶ Measures that reduce the risk of escalation *after* initial use therefore have *systemic* significance because they could mitigate that type of multi-system disruption capable of generating global cascading crises that could scale all the way up to civilizational collapse. These include crisis communication mechanisms, operational practices that reduce pressures for rapid follow-on use of nuclear weapons, and de-escalation processes.

The central challenge here is that meaningful control of escalation in a conflict once nuclear weapons have been used is likely to be illusory in practice. Classical deterrence theory has long acknowledged the difficulty of controlling escalation once nuclear use begins, because signalling becomes ambiguous, outcomes rapidly become unpredictable, and a logic of preemption can take hold under the pressure of compressed decision-making time.¹¹⁷ Virtual reality simulations of nuclear strike decisions have shown that human decision-making defaults toward further escalation once nuclear weapons use has been authorized because of factors like cognitive stress, time compression, and the irreversibility of choices made early on in a nuclear crisis.¹¹⁸ The entanglement of nuclear and conventional systems, including shared command-and-control and early warning infrastructures, further compresses decision timescales and creates structural pressures for follow-on use before those systems are themselves destroyed.¹¹⁹ Scholarship on decision-making under crisis conditions also highlights how time pressure, uncertainty, and organizational dynamics can further undermine the conditions required for successful de-escalation.¹²⁰

Second, it highlights the need to reduce the vulnerability of critical infrastructure nodes within global systems that underpin the functioning of modern societies. The research on cascading infrastructure failure outlined above shows that disruption to key nodes can trigger

¹¹⁶ Scheffer et al., “Anticipating Critical Transitions,” 344–48; Centeno et al., “Emergence of Global Systemic Risk,” 65–85.

¹¹⁷ Thomas C. Schelling, *Arms and Influence* (New Haven, CT: Yale University Press, 1966), 92–125.

¹¹⁸ Sarah Scoles and Clara Moskowitz, “In Deciding to Launch a Nuclear Strike, Humans Are Shockingly Suggestible,” *Scientific American*, June 5, 2025, <https://www.scientificamerican.com/article/nuclear-weapon-strike-decisions-could-come-down-to-human-suggestibility/>.

¹¹⁹ James M. Acton, “Escalation through Entanglement: How the Vulnerability of Command-and-Control Systems Raises the Risks of an Inadvertent Nuclear War,” *International Security* 43, no. 1 (2018): 56–99.

¹²⁰ Robert Jervis, *Perception and Misperception in International Politics* (Princeton, NJ: Princeton University Press, 1976); Rose McDermott and Reid Pauly, “The Psychology of Nuclear Brinkmanship,” *International Security* 47, no. 3 (2023): 9–51.

cascading effects across interdependent systems in tightly coupled networks. However, in the context of even the “limited” use of nuclear weapons, the direct protection of such nodes is often not realistic because the scale of physical destruction caused by nuclear detonations combined with the speed of cascading failures would likely overwhelm many forms of resilience and civil defense, as historical experience suggests.¹²¹ From a systemic risk perspective, the more plausible objective is reducing systemic *fragility* in order to slow cascading propagation through measures that increase redundancy and diversification, reduce dependence on highly concentrated nodes, and support the maintenance of minimal core functions under conditions of extreme disruption.

A useful illustration of this dynamic can be found in global food systems. Contemporary food supply depends on a relatively small number of highly productive agricultural regions and a limited set of trade corridors, shipping routes, and export infrastructures. Disruption to these nodes can propagate rapidly through global markets and generate price spikes and supply shortages far beyond the affected region.¹²² Risk reduction in this context is about reducing systemic fragility by diversifying sources of supply, maintaining strategic reserves, and avoiding dependence on a small number of export regions or transport chokepoints.

What’s important here is that these sorts of measures are not specific to the risk of nuclear war, but to building a degree of resilience to the effects of a much broader set of systemic risks that operate across environmental, economic, and infrastructural systems and to which modern societies are increasingly exposed, not least the ecological crisis. From this perspective, nuclear war represents an extreme case of a broader class of systemic risks, for which efforts to reduce systemic vulnerability and enhance resilience to cascading disruption are necessary in any case. Their relevance to nuclear risk reduction lies in their capacity to limit the scale and propagation of cascading crises should extreme nuclear shocks occur.

Third, the research outlined in this report underscores the importance of maintaining the capacity to sustain basic societal functions under conditions of cascading disruption. We have seen that the severity of systemic crises is shaped by underlying vulnerabilities, including inequality, governance capacity, and access to vital resources. For policy purposes, the critical issue is how these vulnerabilities translate into the loss of the core societal functions such as access to food, water, energy, and healthcare, as well as the ability of political administration to coordinate some sort of response. In this context, risk reduction is about sustaining a minimum operational capacity in key systems, including the ability to distribute food, maintain basic health services, coordinate emergency response, and manage population movement under crisis conditions. Measures like these are unlikely to prevent cascading disruption, but they can shape whether it escalates into widespread social and political instability or remains partially containable.

Understanding what this might mean in practice requires detailed modeling of impact chains, which are structured representations of how initiating hazards propagate through systems via exposure and vulnerability to cause systemic consequences over time. This would develop a small set of scenarios that stress different cascade mechanisms to map the dominant pathways through which disruption propagates through critical systems. This might

¹²¹ Lawrence J. Vale, *The Limits of Civil Defence in the USA, Switzerland, Britain and the Soviet Union: The Evolution of Policies Since 1945* (London: Palgrave Macmillan, 1987).

¹²² Zscheischler et al., “Future Climate Risk,” 469–77; Homer-Dixon et al., “Synchronous Failure”.

focus on a core set of critical systems to assess how and when social functions are lost and how quickly substitution becomes impossible (e.g., food and agriculture, energy and electricity, water and sanitation, healthcare, communications and data, transport and logistics, finance and payments, governance and humanitarian access, and ecosystems).¹²³ This would draw on impact chain analysis in disaster and risk studies.¹²⁴

However, mapping cascading effects from multiple nuclear detonations is a major analytical challenge. Comfort, Boin and Demchak argue that understanding the effects of cascading disasters is complicated by three core issues: first, societies are complex systems and different societies will adapt to extreme events in different ways and at different rates; second cascading disasters are global phenomena that can have “highly variable consequences in different locations, depending upon the initial conditions and the community’s capacity to act”¹²⁵; and third, cascading disasters can have multiple triggers and multiple pathways that require a broad range of knowledge to understand and model.¹²⁶

Schweizer and Juhola frame the analytical challenge in terms of complexity, uncertainty and ambiguity. For them, complexity is a major challenge because systemic risks emerge within complex adaptive systems that are made up of diverse interconnected components linked through feedback loops. Complexity means that uncertainty is a major challenge. This is because causal relationships in complex systems are difficult to establish since outcomes depend on initial conditions and non-linear dynamics. Systemic risks often involve tipping points that cannot be predicted reliably and for which historical data can only provide limited guidance for what would be an unprecedented crisis. Uncertainty can therefore run deep if reliable probabilistic models are unavailable and expert disagreement is widespread. As a result, ambiguity is a major challenge because the same data can support competing risk management strategies as well as serious disagreement on ethical judgments about trade-offs between security, freedom, equity, or economic stability under conditions of acute uncertainty and very high stakes.¹²⁷

¹²³ International Organization for Standardization, *Risk Management: Risk Assessment Techniques*, ISO/IEC 31010:2019 (Geneva: ISO, 2019); Gianluca Pescaroli et al., *Understanding and Mitigating Cascading Crises* (London: UCL, 2020).

¹²⁴ Fekete, “Critical Infrastructure and Flood Resilience,” e1370; Alexander and Pescaroli, “What Are Cascading Disasters?,” e001.

¹²⁵ Louise K. Comfort, Arjen Boin, and Chris C. Demchak, “Resilience Revisited: An Action Agenda for Managing Extreme Events,” in *Designing Resilience: Preparing for Extreme Events*, ed. Louise K. Comfort, Arjen Boin, and Chris C. Demchak (Pittsburgh, PA: University of Pittsburgh Press, 2010), 275.

¹²⁶ Ibid., 275.

¹²⁷ Pia-Johanna Schweizer and Sirkku Juhola, “Navigating Systemic Risks: Governance of and for Systemic Risks,” *Global Sustainability* 7 (2024): e38.

Conclusion

Research on the environmental consequences of nuclear weapons use has established that nuclear detonations could generate severe climatic disruption extending far beyond the immediate areas affected by explosions. Studies of nuclear winter indicate that firestorms triggered by nuclear detonations could inject soot into the upper atmosphere, reducing sunlight, lowering global temperatures, and disrupting precipitation patterns. Such environmental changes could significantly affect agricultural productivity and global food systems. The environmental effects of nuclear war are therefore relatively well established within the scientific literature.

However, understanding the full consequences of nuclear weapons use requires examining not only these environmental effects themselves but also how they might propagate through modern societies. Contemporary societies are characterized by dense networks that link infrastructure systems, economic production, global trade, governance institutions, and demographic systems. Disruptions affecting one part of these networks can therefore propagate across others and generate cascading consequences far beyond the initial shock.

Scholarship on systemic risk and cascading disasters provides an important framework for analyzing these dynamics. Research on infrastructure interdependence demonstrates how failures can propagate across interconnected systems and generate cascading disruptions affecting multiple sectors simultaneously. Studies of global systemic risk highlight how increasing interdependence within economic and technological networks can amplify the consequences of disruptions and shocks. Research on complex systems further shows that crises may escalate rapidly once interacting stresses push systems beyond critical thresholds. The scholarship on civilizational collapse also emphasizes the importance of critical societal systems that sustain complex societies, notably food production, energy systems, economic exchange networks, governance institutions, and public health systems that form the foundations of modern societies. When multiple systems like these experience disruption simultaneously, societies could face cascading instability that exceeds the capacity of their institutions to respond effectively.

Climate-conflict and environmental security research provides empirical evidence of how environmental shocks propagate through social systems. In particular, environmental disruptions can undermine livelihoods, generate migration pressures, destabilize economic systems, and place significant strain on governance institutions. These pathways interact through feedback processes that can amplify the consequences of environmental stress and generate cascading societal disruptions extending far beyond the initial disruption.

Applying these insights to the use of nuclear weapons suggests that the consequences of nuclear war would unfold through similar systemic pathways: environmental disruption associated with nuclear winter could destabilize global food production systems; food shortages could generate economic instability and migration pressures; economic disruption could propagate through global trade and financial networks; and governance institutions responsible for managing crises could face increasing strain as multiple systems experience disruption simultaneously. These interacting disruptions could generate cascading crises across interconnected societal systems at regional and global scales, with feedback processes amplifying instability and accelerating systemic crises once multiple systems begin to fail simultaneously. As a result, the most severe consequences of nuclear war may arise from the complex interactions among environmental, economic, demographic, and

governance systems rather than emerging solely from the direct destruction caused by nuclear detonations, which itself would be brutal.

Understanding nuclear detonations as a potential trigger for cascading systemic disruption therefore provides an important perspective on the global consequences of nuclear war. Analyzing nuclear war through the lens of systemic risk and cascading disasters therefore helps illuminate pathways through which the use of nuclear weapons could generate complex global crises extending far beyond immediate physical destruction and potentially extending to civilizational collapse.