Confronting the Threat of Nuclear Winter

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Abstract
Large-scale nuclear war sends large quantities of smoke into the stratosphere, causing severe global environmental effects including surface temperature declines and increased ultraviolet radiation. The temperature decline and the full set of environmental effects are known as nuclear winter. This paper surveys the range of actions that can confront the threat of nuclear winter, both now and in the future. Nuclear winter can be confronted by reducing the probability of nuclear war, reducing the environmental severity of nuclear winter, increasing humanity's resilience to nuclear winter, and through indirect interventions that enhance these other interventions. While some people may be able to help more than others, many people—perhaps everyone across the world—can make a difference. Likewise, the different opportunities available to different people suggests personalized evaluations of nuclear winter, and of catastrophic threats more generally, instead of a one-size-fits-all approach.

Keywords: catastrophic threats, global catastrophic risk, nuclear war, nuclear winter, risk reduction

1. Introduction

The explosion of nuclear weapons causes enormous fireballs, burning everything in the vicinity. Most of the ensuing smoke rises past the clouds, into the stratosphere, where it spreads around the world and remains for a time on the order of ten to twenty years. A large enough nuclear war would send up so much smoke that the global environment would be fundamentally altered. Surface temperatures and precipitation would decline, while ultraviolet radiation increases. The effects could be catastrophic, killing a large portion of the total human population and potentially threatening the long-term viability of human civilization.

Research on the global environmental consequences of nuclear war flourished in the 1980s, including such luminaries as Carl Sagan and Nobel laureate Paul Crutzen. (For a history, see Badash 2009.) The 1980s nuclear winter research garnered considerable attention, due in large part to Sagan's aggressive campaigning and high public profile. The term "nuclear winter" was coined by Sagan's colleague Richard Turco in order to avoid the political connotations of "nuclear war", ironically because "nuclear winter" itself became heavily politicized (Dörries 2011). In precise technical terms, nuclear winter refers specifically to a temperature decline following nuclear war that yields winter-like temperatures during summer. This paper will use "nuclear winter" to refer more generically to the full set of global environmental consequences of nuclear war, since the full set is of interest in the context of catastrophic threats to humanity.

Nuclear winter research quieted down around the end of the Cold War, but has been revived in recent years with new research led by climate scientists using advanced climate models developed for the study of global warming (Robock 2010; Stenke et al. 2013; Mills et al. 2014). Some research has studied post-nuclear winter agricultural declines (Xia and Robock 2012; Özdoğan et al. 2012) and corresponding famine (Helfand 2013). One paper has also studied

policy implications of nuclear winter for military force structures (Baum 2015). This recent nuclear winter research has strengthened the initial research's conclusion that nuclear winter could indeed be catastrophic for humanity and for natural ecosystems.

The purpose of this paper is to survey the breadth of intervention options to confront the threat of nuclear winter. Successful confrontation of nuclear winter is defined here as any outcome in which nuclear winter does not prevent the permanent collapse of human civilization. Permanent collapse includes human extinction. Success can thus occur if nuclear winter never happens, if it happens but civilization remains intact, or if civilization collapses but recovers. This definition is consistent with contemporary understanding of the ethics of global catastrophic risk (or, alternatively, existential risk), which emphasize avoiding catastrophes that cause permanent collapse or human extinction (Beckstead 2013; Bostrom 2013; Maher and Baum 2013), an understanding that has origins in the 1980s nuclear winter research (Sagan 1983).

As with other global catastrophic risks, nuclear winter might superficially seem like such a big issue that only a select few of elite insider scientists and policy makers can make a difference on it. It is certainly the case that some people can make more of a difference than others. However, there are options for a wide variety of people, perhaps even everyone on the planet. Motivated lay people can make a significant difference. This point holds for global catastrophic risks more generally and is well illustrated by the case of nuclear winter.

Nuclear winter is of note within the space of global catastrophic risks in that it can occur quickly and at any time.[1] Many nuclear weapons remain on hair-trigger alert, available for immediate use – many more than would be needed to cause severe nuclear winter. Some actions can help confront this present threat of nuclear winter. However (and despite the ongoing Ukraine crisis), most of the risk lies in the future. Even if the annual probability of nuclear war gradually declines to zero, it is still more likely that nuclear war, and in turn nuclear winter, will occur in some future year than at the present time. Likewise, many of the actions to confront the nuclear winter are largely oriented towards the future.

The paper is organized in chronological order following the unfolding of nuclear winter. Section 2 covers interventions to reduce the probability of nuclear war, making it less likely that nuclear winter happens in the first place. Section 3 covers interventions to reduce the severity of nuclear winter, such that human civilization will be more likely to remain intact or recover from it. Section 4 covers interventions to increase civilization's resilience to nuclear winter, again making civilization more likely to remain intact or recover. Finally, Section 5 covers several indirect interventions are considered, which can support the breadth of direct interventions. Section 6 concludes.

2. Reducing the Probability of Nuclear War

Nuclear winter cannot happen without a sizable nuclear war. A single nuclear weapon would not produce enough smoke to cause significant nuclear winter effects—hence there was no nuclear winter following the Hiroshima and Nagasaki bombings. A lower bound for the number of nuclear weapons needed to cause nuclear winter has not been established, and at any rate would depend on the weapons' yield and how much flammable material is in the vicinity of their detonation, among other factors. Recent research finds significant nuclear winter effects from an India-Pakistan nuclear war involving 100 weapons (50 per side) of 15 kiloton yield dropped on major cities (Mills et al. 2014). Until further research has been conducted, a lower bound of 50

[1] Pandemics, large asteroid or comet impacts, and volcano eruptions are other examples.

total weapons may be appropriate for ensuring a sufficiently small probability of permanent civilization collapse.[2]

In theory, nuclear winter could be caused by nuclear terrorism. In practice however, terrorists would have a difficult time accessing and detonating a single weapon (Bunn and Wier 2006) making it extremely difficult to procure the sizable arsenal needed to cause nuclear winter. Potentially this could change in the future if terrorists increase their capacity for nuclear weapons procurement. The most likely scenario might involve terrorists acquiring a larger arsenal from a nuclear weapon state, with Pakistan perhaps being the most likely candidate due to its instability and significant terrorist presence (Narang 2009). But for the foreseeable future, a focus on interstate nuclear war is reasonable. Regardless, many of the details discussed here also apply to nuclear terrorism.

The ongoing probability of nuclear war is a topic of some debate. It is sometimes assumed that nuclear deterrence[3] is effectively perfect, rendering a zero or near-zero probability of nuclear war. Wilson (2013) criticizes this assumption as being inconsistent with historical deterrence cases. Hellman (2008) explains that even a small annual probability of nuclear war becomes alarmingly large over longer time periods. Barrett et al. (2013) analyze the annual probability of Russia-United States nuclear war occurring inadvertently, i.e. in response to a false alarm, finding significant sensitivity to uncertain underlying assumptions but with reasonable estimates of annual probabilities on the order of 0.1% to 1%. Lundgren (2013) retrospectively analyzes the probability of nuclear war over the preceding 66 years, finding a probability greater than 50%. Meanwhile, current world events offer reminders of the potential for nuclear war. At the time of this writing, Russia is hinting at its willingness to attack Ukraine with nuclear weapons if Ukraine tries re-annexing Crimea (Keck 2014).[4] Observing these events in light of the above-mentioned research, it is difficult to come to the conclusion that nuclear war has a zero or near-zero annual probability.

With that in mind, here are interventions capable of reducing the probability of nuclear war.

2.1 Diplomacy

Nuclear war, as with all war, typically involves a failure of diplomacy. The use of force to resolve disputes is commonly (though perhaps not universally) considered a measure of last resort. The use of nuclear weapons is further considered to be a last resort among military options, reserved only for extreme situations. Diplomacy serves to avoid disputes in the first place, to prevent disputes from escalating into crises and in turn into war, and to end wars before the damage gets out of hand.

Diplomacy is commonly understood as the province of professional diplomats working in official capacity on behalf of their states. Oftentimes, it is. This has been seen repeatedly throughout the history of nuclear war threats. For example, the 1962 Cuban missile crisis memorably saw Soviet leader Nikita Kruschev send a personal letter to US President John F.

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[2] On acceptable probabilities of global catastrophes, see Tonn (2009). The 50 weapon limit comes from Baum (2015). Prior studies suggested limits in the range of 100-300 weapons per state (Turco and Sagan 1989; Robock and Toon 2012).

[3] Nuclear deterrence is, in simple terms, the strategy of preventing attacks (often nuclear attacks) by an adversary by threatening the adversary with retaliation with nuclear weapons: “If you attack us, we will attack you back”.

[4] Such hints about nuclear weapons, whether made by Russia or other countries, could be interpreted as political posturing. However, they may not be mere posturing. Even if they are intended as posturing, they still make it more likely that nuclear weapons actually get used, by creating a public commitment to using them under certain circumstances.

Kennedy attempting to defuse the conflict and untie "the knot of war" (Kruschev 1962). Today, the Nuclear Non-Proliferation Treaty (originally signed in 1968) stands as an important means of reducing the number of states with nuclear weapons and, arguably to a lesser extent, in achieving nuclear disarmament (Potter 2010).

But diplomacy can be much more than that. Readers of this article may be keen to note that academics often serve in what is called "Track-II diplomacy", meeting with their counterparts from adversarial countries to build mutual understanding and explore possible conflict resolutions (Agha et al. 2003). Indeed, the 1980s nuclear winter research brought together American and Soviet researchers to inform policy debates in both countries (Rubinson 2013). A notable contemporary effort is the trilateral Deep Cuts Commission, composed of American, Russian, and German experts and sponsored by the German Federal Foreign Office, which works to identify steps need for the US and Russia to make deep cuts to their nuclear arsenals (Deep Cuts Commission 2014).

Lay citizens can also contribute to diplomacy, including by engaging with citizens from adversarial counties. A prominent recent example is the 2012 "Israel Loves Iran" and "Iran Loves Israel" social media campaign that had Israeli and Iranian citizens expressing mutual affections online in hopes of defusing conflict between their respective countries (Kuntsman and Raji 2012). While the efficacy of this particular campaign is unclear, more generally, this sort of citizen diplomacy can create political climates on both sides conducive to peaceful resolution of disputes.

Diplomacy is often summoned during immediate crises, but it can also be a good long-term investment towards avoiding and defusing future crises. Effective diplomacy benefits from interpersonal relationships and mutual understanding, both of which take time to build. For example, Kruschev's letter to Kennedy during the Cuban missile crisis built on interactions the two previously had, leading to Kruschev speaking more openly.[5] Diplomatic efforts today can thus contribute to reducing the probability of nuclear war for many years into the future.

2.2. Weapons Systems

While nuclear weapons can be perceived in even mythological terms (Wilson 2013), ultimately they are technological devices, embedded in broader technological systems, including systems to command and control the weapons and systems to deliver them to their detonation target. How these systems are configured can affect the probability of nuclear war occurring. Likewise, people capable of influencing nuclear weapon system configurations will often have opportunities to adjust the systems to reduce the probability of nuclear war. These people are generally engineers who design the systems and military officials who configure them, though outsiders (including researchers) can sometimes have some influence.

The role of nuclear weapon systems is perhaps most clearly seen in the case of inadvertent nuclear war (Barrett et al. 2013). Inadvertent nuclear war occurs when one side mistakenly interprets a false alarm as real and launches nuclear weapons in what it believes to be a counterattack, but is actually a first strike. Inadvertent nuclear war thus involves a failure in systems for monitoring incoming nuclear attacks. For example, in 1995, Russian radar detected a scientific weather rocket launched off the northern coast of Norway. The Russians initially believed that it was a nuclear weapon launch. The alarm reached all the way to then-President

[5] Specifically, Kruschev wrote "My conversation with you in Vienna gives me the right to talk to you this way" regarding his threat to retaliate with "the same that you hurl against us" in the event of a US attack on the Soviet Union.

Boris Yeltsin. Fortunately, Yeltsin and his associates correctly concluded that it was a false alarm and did not order a nuclear weapon launch in response (Forden et al. 2000). That this event, known as the Norwegian rocket incident, occurred after the Cold War during a time of relative calm between Russia and the US, speaks to the ongoing risk that exists.

The probability of inadvertent nuclear war can be reduced through several adjustments to nuclear weapon systems. One adjustment is to increase the amount of time between the alarm sounding (i.e., the signal of a potential incoming nuclear weapon being noticed) and the might-be-a-nuclear weapon reaching its target. This gives decision makers more time to discern whether the alarm is real and thus whether "counterattack" should be aborted. Decision time can be increased, for example, by each side relocating their nuclear weapon submarines farther from each others' coasts, increasing the flight time for nuclear missiles launched from the submarines. Another adjustment is to improve the quality of the alarm signal, which can be achieved by installing multiple detection systems, such as RADAR and satellite. Recent reports of the malfunction of a Russian satellite in geostationary orbit above the US suggest an increase in the risk of inadvertent nuclear war (GSN 2014); recent reports of low morale in US nuclear forces (Hennigan 2014) could suggest an increase as well, though the effect here is more ambiguous.

Nuclear weapon systems can also influence the probability of intentional nuclear war, which occurs when both sides accurately understand the state of affairs and decide to launch nuclear weapons. In a crisis, a country whose nuclear weapons are vulnerable to attack may be more likely to launch its weapons first, a situation of "use it or lose it". For example, some recent scholarship has suggested that the US could take out Russia's and China's nuclear arsenals in a first strike attack (Lieber and Press 2006). New US missile defense systems raise the additional concern that, even if a first strike would leave some weapons intact, retaliation would fail (Steff 2013). Systems that protect nuclear weapons from being taken out, such as mobile missile launchers, nuclear submarines, and decoys to thwart missile defense, make it easier for countries to hold off on launch decisions during crises.

Shifts in nuclear weapon systems can help with both immediate and future nuclear war risks. Indeed, shifts in the status of existing systems (e.g. relocating submarines) are among the few rapid means of reducing nuclear war risk. Future-oriented nuclear weapon systems shifts include the design of new technologies and the procurement of new infrastructure.

2.3. Doctrine

Nuclear weapons doctrine is the protocol or guidelines that countries create to govern their use of nuclear weapons. The doctrines—or at least portions of them—are typically published publicly so that allies and adversaries alike will know which actions could provoke a nuclear attack. For example, US publicly declared nuclear doctrine can be found in its Nuclear Posture Review (US DoD 2010). This establishes core principles and outlines broad contours of US doctrine. More specific details, including war fighting plans, are contained in the classified Operations Plan (OPLAN; Kristensen 2010). Nuclear doctrine plays a crucial role in determining which crises end in nuclear war, with some doctrines lowering the probability of nuclear war.

One doctrine that, if universally followed, could significantly reduce the risk of nuclear war or even eliminate the risk entirely, is the doctrine of no-first-use. In this doctrine, countries pledge to not be the first country to use nuclear weapons in a conflict. The doctrine reserves the possibility of launching retaliatory second-strike attacks, which makes deterrence of nuclear attacks the main role of nuclear weapons. No-first-use is most closely associated with China, which has followed an unconditional no-first-use doctrine since the beginning of its nuclear

weapons program; India has a similar doctrine (Peng and Rong 2009). The US does not have a no-first-use doctrine, but it has been encouraged to adopt one (Sagan 2009). In theory, if all countries follow no-first-use, then nuclear weapons will never be used. In practice, nuclear war could start inadvertently under no-first-use doctrine.

US nuclear doctrine states that the US "would only consider the use of nuclear weapons in extreme circumstances to defend the vital interests of the United States or its allies and partners" (US DoD 2010:ix). The US has been steadily shifting military capabilities from nuclear weapons towards advanced high precision conventional weapons ("prompt global strike") and missile defense systems, which permit the US to reduce the role of nuclear weapons. Other countries with nuclear weapons may follow in this direction but lag in these technologies. With an eye to the future, these changes in weapon systems could render nuclear weapons irrelevant, permitting radical shifts in nuclear doctrine. Such shifts may even already be possible. Noting the military preference for precision weapons with minimal collateral damage, Wilson (2012:27) writes that "Increasingly, nuclear weapons look like dinosaurs: really large and frightening creatures that were destined to die out because they could not adapt".

2.4. Complete and Permanent Disarmament

Nuclear war cannot happen if nuclear weapons no longer exist, and it is less likely to happen if fewer countries have nuclear weapons. Complete and permanent disarmament is the surest guarantee that nuclear winter will not harm the long-term success of human civilization, or harm anything else for that matter. But it is easier said than done. None of today's nuclear weapons countries appear set to go to zero weapons, and many have plans to modernize their weapons systems, suggesting that they will retain their arsenals for decades. Still, several interventions can help promote working towards a world without nuclear weapons.

There are two basic perspectives on how to achieve zero nuclear weapons. One is to pursue gradual disarmament, starting with Russia and the US (which still have over 90% of all nuclear weapons) but eventually including other countries. This is the approach favored by countries with nuclear weapons and some of their allies. It can be seen in, for example, the New START treaty reducing US and Russian nuclear arsenals, or in Barack Obama's famous 2009 Prague speech, in which he said: "So today, I state clearly and with conviction America's commitment to seek the peace and security of a world without nuclear weapons. I'm not naive. This goal will not be reached quickly—perhaps not in my lifetime" (Obama 2009). The Deep Cuts Commission and the nongovernmental organization Global Zero also follow this gradual disarmament approach, pushing countries to pick up the pace of disarmament and helping troubleshoot the issues that arise along the way. Global Zero's plan would have a world without nuclear weapons in 2030 (Global Zero, undated).

The other perspective is to pursue complete and immediate disarmament. This is the approach favored by many countries that do not have nuclear weapons, which are frustrated at the glacial pace of disarmament. This approach has accelerated in recent years with a new initiative to shift nuclear weapons discourse from military to humanitarian terms, possible en route to a new treaty banning nuclear weapons, an initiative that follows in the footsteps of successful recent initiatives to ban landmines and cluster munitions (Borrie and Caughley 2013; Borrie 2014). Nongovernmental organizations active in this new "humanitarian consequences initiative" include the International Committee of the Red Cross and the International Campaign to Abolish Nuclear Weapons (ICAN). Discussions about a ban treaty are active and it would not be surprising for such a treaty to be signed within the next five years or so. Initially, the treaty

would likely not be signed by any countries with nuclear weapons, but instead would put pressure on them to disarm. Meanwhile, by highlighting the severe humanitarian consequences of nuclear weapons use, including nuclear winter (e.g., Helfand 2013), the initiative reminds nuclear weapons countries why nuclear weapons should not be used, potentially reducing the probability of nuclear war even before complete disarmament has been achieved.

3. Reducing the Severity of Nuclear Winter

The discussions in this section and the following one are more grim. This section assumes that a nuclear war will occur, and explores how to make the nuclear war less horrible. The following section assumes that a nuclear war has already occurred and caused some degree of nuclear winter, and explores how to make the aftermath less catastrophic for survivors. Neither of these are happy stories, but they are important ones, and working through them points to opportunities to save many lives and potentially even tip the balance towards the long-term success of human civilization.

The severity of nuclear winter is mainly a function of the amount of smoke that enters the stratosphere. The amount of smoke in turn depends on the number of nuclear weapons used in the war, the weapons' yield, and their targets. Note that the focus in this section is strictly on the severity of the environmental change; the severity of human impacts is discussed in the following section.

3.1 Targeting

Changes in targeting is perhaps the simplest intervention that countries with nuclear weapons can take to reduce the severity of nuclear winter following a nuclear war. Targeting is changed simply by pointing nuclear weapons in different locations. By pointing nuclear weapons away from with more flammable material in the vicinity, the same number of nuclear detonations will produce less smoke, thereby reducing the severity of nuclear winter. For this reason, Robock and Toon (2012:72) recommend "an immediate agreement to not target cities and industrial areas". Targeting fewer cities and industrial areas, and with lower-yield weapons, would also help, albeit to a lesser extent.

A shift in targeting policies away from cities would not just reduce the severity of nuclear winter—it would also reduce the number of people killed by the initial nuclear explosions. The amount of smoke produced is roughly proportional to population density (Toon et al. 2008). Reducing the amount of smoke produced thus means reducing the number of people killed in explosions, and the number of people injured. Reducing the explosions' humanitarian destruction is a rather large ancillary benefit of reducing the severity of nuclear winter. A "no-cities" targeting policy may be in order.

There is an additional, legal aspect to targeting cities. International humanitarian law calls for armed conflicts to avoid targeting or otherwise harming civilians. Weapons with wide, indiscriminate effects are likely to harm civilians in significant number, especially when aimed at targets near civilian populations. This reasoning has motivated bans on biological and chemical weapons, landmines, and cluster munitions, and currently motivates the initiative to ban nuclear weapons (Borrie 2014). In 1996, the International Court of Justice issued an advisory opinion on the Legality of the Threat or Use of Nuclear Weapons. A split court reached the following decision:

> It follows from the above-mentioned requirements that the threat or use of nuclear weapons would generally be contrary to the rules of international law applicable in armed

> conflict, and in particular the principles and rules of humanitarian law; However, in view of the current state of international law, and of the elements of fact at its disposal, the Court cannot conclude definitively whether the threat or use of nuclear weapons would be lawful or unlawful in an extreme circumstance of self-defence, in which the very survival of a State would be at stake.

Use of nuclear weapons is thus expected to follow the same humanitarian law as the use of any other weapons. This makes targeting cities unacceptable under most circumstances. Indeed, the Report on Nuclear Employment Strategy of the United States specifically states that "all plans must be consistent with the fundamental principles of the Law of Armed Conflict. Accordingly, plans will, for example, apply the principles of distinction and proportionality and seek to minimize collateral damage to civilian populations and civilian objects. The United States will not intentionally target civilian populations or civilian objects." (US DoD 2013:4-5). The fact that targeting cities would worsen nuclear winter, further harming civilians, including in non-belligerent countries, makes targeting cities even harder to justify under international humanitarian law.

However, no-cities targeting comes with a significant possible downside: It could increase the probability of nuclear war. In security jargon, targeting cities is associated with "countervalue" targeting. Countervalue is contrasted with "counterforce" targeting, in which the targets are military forces, including the adversary's nuclear weapons. Countervalue targeting can cause significantly more humanitarian harm, but it does not harm the adversary's ability to retaliate, arguably making it less likely that the weapons would be used in the first place. Additionally, states are often more averse to losing their cities than their militaries; thus if their cities are targeted, they may show more restraint. In contrast, counterforce targeting increases pressure on states to launch during crises. With their weapons systems targeted, they may find themselves in a "use it or lose it" situation (Section 2.2; see also e.g. Lieber and Press 2006; Kristensen et al. 2009). Kristensen et al. (2009) propose a no-cities, countervalue targeting scheme, emphasizing critical economic infrastructure as targets. Schemes along these lines may find a better balance of reducing both the probability and severity of nuclear war, and likewise are worth pursuing further.

There are thus roles for a variety of actors in influencing targeting policies. Policy formulation would benefit from further research clarifying the relationship between targets and nuclear winter (more on research interventions below). International humanitarian law experts can help build the case for no-cities targeting. Citizens can draw attention to the issue (more on awareness raising interventions below). And military officials (including civilian political leadership) can order and make the actual targeting changes.

3.2 Partial Disarmament

Complete and permanent nuclear disarmament would eliminate the possibility of nuclear war. Partial disarmament would not, but it could at least reduce the severity of nuclear war, and the ensuing nuclear winter. In this regard, partial disarmament functions like targeting shifts, reducing the number of weapons aimed at flammable targets. The key distinction is that disarmament is more difficult to implement and to reverse.

Partial disarmament is an ongoing process. Today's arsenal of around 16,000 nuclear weapons is several times lower than the Cold War peak of around 70,000. Delivery systems

including missiles and airplanes have also been reduced.[6] But the remaining arsenal is still plenty large enough to cause very severe nuclear winter. Recall from above that catastrophic nuclear winter could potentially follow from nuclear war with as few as around 50 total nuclear weapons. Disarmament has a long way to go before it would eliminate concerns about nuclear winter. Meanwhile, a variety of opportunities exist to promote disarmament. Many are discussed in Section 2.4.

One intervention opportunity specific to partial disarmament is promoting and enacting the doctrine of minimum deterrence. This doctrine seeks to identify and deploy the minimum nuclear force (including weapons, delivery vehicles, and command and control systems) necessary to deter adversaries from attacking. While the precise arsenal size needed for minimum deterrence is not well known (and could vary from situation to situation), it is generally believed to require far fewer than the thousands of nuclear weapons still held by the US and Russia, and thus would require partial disarmament for these countries, and potentially for other countries too. China and India's doctrines both have strong elements of minimum deterrence, and it has sometimes been advocated for the US; in all three countries, advocacy for minimum deterrence is often associated with technical weapons experts familiar with bomb attributes (e.g., Robert Oppenheimer) instead of with political officials (Lewis 2008).

On first glance, it would appear that minimum deterrence would still leave a severe nuclear winter, since China has about 250 nuclear weapons and India 100 (FAS 2014). Upon closer inspection, the situation is more promising. China in particular, with its no-first-use policy, expects that a significant portion of its nuclear weapons will be destroyed in a first strike, with a relatively small number of weapons surviving to provide "assured retaliation" (Fravel and Medeiros 2010). The exact makeup of such a retaliation, and thus its contribution to nuclear winter, is not publicly known, but potentially it could be consistent with a relatively mild nuclear winter, or could be shifted to make it consistent with relatively little difficulty, especially as compared to the Russian and US arsenals.

3.3 Nuclear War Timing

In some circumstances, it is possible to reduce the severity of nuclear winter by adjusting the timing of nuclear war. If there is already significant smoke in the stratosphere, then it would be advantageous to postpone the war until after the smoke clears out. This would mean avoiding the simultaneous outbreak of multiple nuclear wars and avoiding nuclear war after large volcano eruptions and asteroid impacts. Noting that it would take several years for the smoke to clear out, it is difficult to imagine leaders postponing nuclear war long enough unless they have a firm understanding of nuclear winter and commitment to reducing its severity. This intervention is included in this paper largely for the sake of completeness.

4. Increasing Resilience to Nuclear Winter

Now, the paper turns to human life during and after nuclear winter. While the severity of nuclear winter is important, the human dimension is the bottom line, at least in terms of the long-term success of civilization. If civilization is able to remain largely intact during nuclear winter, or recover sometime thereafter, then nuclear winter would be a much smaller problem—still horrible, but not the astronomical horror of the permanent collapse of civilization.

[6] The START (Strategic Arms Reduction Treaty) treaties have played a major role in achieving this disarmament, a testament to the efficacy of diplomacy (Section 2.1).

The overall resilience of human civilization to nuclear winter has not yet been studied in any detail. To my knowledge, the only paper considering the issue is Maher and Baum (2013), which does not reach clear conclusions on this.[7] But resilience is the right framing. Resilience is the capacity of a system to withstand a disturbance without being transformed into a fundamentally different state. The question here is whether human civilization can withstand the disturbance of nuclear winter without being transformed into a collapsed non-civilization. The answer to this question is of course that nobody knows, since nothing like nuclear winter has ever hit civilization. Still, there are several interventions that could increase civilization's resilience, making it more likely that civilization stays intact or recovers.

4.1 Resource Stockpiles

A variety of resources could help keep people alive and civilization intact through nuclear winter. These resources could be stockpiled ahead of time for the benefit of survivors (Maher and Baum 2013). With enough of the right resources, anyone not directly hit by the nuclear explosions has a chance of surviving and even living comfortably until environmental conditions return to normal.

Food is the most obvious resource to stockpile, given the agricultural declines already identified as consequences of nuclear winter (Xia and Robock 2012; Özdoğan et al. 2012; Helfand 2013). Water may also be needed in at least some areas, given that the hydrological cycle will be slowed by the lower temperatures. Sunscreen or other protection from the increased ultraviolet radiation could help. Fuel stockpiles could help provide basic services and quality of life. Extra medical supplies and peacekeeping forces may be needed given the potential for weakened conditions to lead to disease outbreaks and conflicts (Helfand 2013). Other resources may also be critical; this is not intended as an exhaustive list.

Stockpiles could be extremely expensive for pre-catastrophe populations. Nuclear winter could last for ten or twenty years. If agriculture, manufacturing, and shipping will be down for a comparable period of time, then stockpiles will needed for this time. Producing such stockpiles may be prohibitively expensive even for the wealthiest countries. This limits the potential for stockpiles to increase civilization's resilience to nuclear winter.

Alternatively, stockpiles could be provided for only part of a population. This approach is essentially the logic of "lifeboat ethics" (Hardin 1974): without enough resources for everyone, some people are "pushed off the boat" to die in order to ensure that some people survive through to the end. Deciding who lives and who dies is not an enviable task, nor is enforcing such a decision on the desperate, dying masses. The worst tragedies in human history may pale in comparison. But, in the absence of enough resources to go around, this approach may increase civilization's overall resilience to nuclear winter.

Despite the challenges and limitations of resource stockpiles, this is an intervention that a wide range of actors are capable of performing, from national governments to private citizens. Indeed, many citizens already do, often under the rubric of survivalism or prepping. Governments at all scales also often stockpile basic resources for a variety of local and global catastrophes. This is one attractive feature of resource stockpiles: they can help for a lot more than just nuclear winter (Maher and Baum 2013).

[7] The US and Soviet Union both published civil defense guides describing how citizens might survive nuclear war (e.g., US OCD 1951; Kuzmenko et al. 1986). However, these guides focus on people in the vicinity of nuclear explosions and did not discuss nuclear winter.

4.2 Refuges

An even more extreme solution than stockpiles for only part of the population is to build isolated refuges for a select few. Refuges are facilities that provide basic needs for inhabitants such that they are able to survive through catastrophes. Jebari (2014) proposes isolated, self-sufficient, continuously inhabited underground refuges as a means of protecting civilization against a range of known and unknown catastrophic threats (see also Hanson 2008; Sandberg et al. 2008; Beckstead 2014; Baum et al. 2015). These refuges have parallels to the bunkers built in the Cold War era for continuity of government through nuclear war (McCamley 2007). Assuming such a facility can be built, and a suitable population can be persuaded to move in, this could ensure some population surviving through to the end of nuclear and potentially going on to rebuild civilization.

4.3 Space colonies

It is sometimes noted that if humanity has populated, self-sufficient colonies in outer space, then it will have great capacity to survive through a variety of catastrophes on Earth (Abrams et al 2007; Shapiro 2009). Space colonies would indeed provide a high degree of protection. However, space colonies are criticized for being far more expensive than refuges on Earth, suggesting that they should not be the first option to pursue (Sandberg et al. 2008; Baum 2009). On the other hand, space missions are already being pursued for other reasons, in particular for political, scientific, and economic reasons; space colonies for surviving Earth catastrophes could "piggyback" on these missions (Baum et al. 2015). However, by the time technology develops enough that space colonization is technologically and economically feasible, even with piggybacking, nuclear disarmament may have long since ended the threat of nuclear winter. (One should hope.) Thus, space colonies are mentioned here largely for the sake of completeness.

4.4 Alternative Food

A novel proposal put forth by Denkenberger and Pearce (2014) is to produce food through alternative means during a food crisis such as nuclear winter. The idea here is that even in the complete absence of agriculture, it may be possible to keep humans alive for extended periods of time, i.e. multiple years or even longer. Denkenberger and Pearce identify options including (1) covert trees and other biomass to food using mushrooms; (2) grow crops indoors using artificial lights powered by fossil fuels; and (3) making tea from decaying leaves. Denkenberger and Pearce's initial analysis suggests that it may be technically feasible to keep most people alive through a nuclear winter and a variety of other food crises. While many questions about this new proposal remain unanswered, it does hold some promise, at least as a measure of last resort to keep people alive and civilization intact during the most desperate of circumstances.

5. Indirect Interventions

The three preceding sections all discuss interventions that directly influence some aspect of the impact of nuclear winter on human civilization: whether nuclear winter occurs in the first place, how severe it is, and how well civilization can survive it. This section covers indirect interventions, aimed at influencing and improving the direct interventions. These indirect interventions can support the full breadth of direct interventions, though will often be more helpful for some direct interventions than others.

5.1 Research

Research can help inform decisions on a wide variety of issues, certainly including nuclear winter. Several factors make nuclear winter a particularly worthy research topic: the urgency and complexity of nuclear winter, the dearth of prior research especially on certain aspects of nuclear winter, and the uncertainty about a variety of interventions to confront nuclear winter. The most valuable research will reduce uncertainties about interventions and thus improve the overall quality of the interventions. This can include basic science, but will often involve engineering and policy design as well.

Some important nuclear winter science questions remain. Nuclear winter research to date has focused on one nuclear war scenario, an India-Pakistan nuclear war with 100 weapons (Mills et al. 2014). A wider range of scenarios would help inform decisions about reducing the severity of nuclear winter, clarifying which targeting practices and which levels of disarmament to aim for —or rather, how to balance nuclear winter against other factors when making decisions about targeting and disarmament. Additionally, a much more thorough social science of nuclear winter is needed to understand the human consequences. Some topics begging for attention include the human impacts of increased ultraviolet radiation, secondary effects such as disease outbreaks and conflicts, and the overall resilience of civilization.

Policy research can also be helpful. Can nuclear winter be reconciled with doctrines of no-first-use, no-cities, or minimum deterrence?[8] Would countries with nuclear weapons be willing to support such doctrines, or other efforts to confront nuclear winter? Is there a case for nuclear winter to be considered within international humanitarian law? Would countries with nuclear weapons be willing to sponsor resource stockpiles, alternative food programs, or other programs to help civilization endure nuclear winter? These are among the worthy policy research questions to explore.

5.2 Raising Awareness

Action on nuclear winter often benefits from more people being aware of nuclear winter, nuclear war, and related topics, and having a more detailed awareness. Efforts to raise awareness can help confront the threat of nuclear winter by getting more people involved, by motivating those already involved to take more actions, and by educating people about how to take better educations.

Extensive efforts were made to raise awareness about nuclear winter in the 1980s (Badash 2009; Rubinson 2013). These efforts were boosted by enthusiastic contributions from Carl Sagan, who took this issue on at the height of his pubic popularity. Popular media portrayals such as the BBC film *Threads* (1984) and the book Planet Earth in Jeopardy (Dotto 1986) further heightened awareness. Nuclear winter became a household term, and policymakers took notice. Perhaps the biggest effect was on Mikhail Gorbachev, who later wrote: “The environment has been greatly damaged by the nuclear arms race. Models made by Russian and American scientists showed that a nuclear war would result in a nuclear winter that would be extremely destructive to all life on Earth; the knowledge of that was a great stimulus to us, to people of honor and morality, to act in that situation” (Hertsgaard 2000).

But raising awareness is not only the province of elites like Sagan. Indeed, it is something everyone is able to do. Organizations like Global Zero and ICAN are among the many organizations out there that provide citizens with opportunities and resources for speaking up about nuclear weapons issues in general, often with attention to nuclear winter. And many of the

[8] Baum (2015) is one policy research effort in this direction.

organizations would likely welcome the opportunity to say more about nuclear winter, if someone was motivated to make that happen. The organizations often emphasize that even a single use of nuclear weapons would be catastrophic, which is true, although it would not be a civilization-threatening global catastrophe. Still, raising awareness to prevent any use of nuclear weapons will also help prevent nuclear winter.

5.3 Providing Funding

Many of the various efforts to confront nuclear winter would benefit from additional funding. Likewise, providing such funding would help advance this work. Indeed, for some people, providing funding may be among the best contributions they can make to confronting nuclear winter, or confronting catastrophic threats to humanity more generally. An argument can be made that people today, especially in affluent countries, do not donate as much money to charity as they should (Singer 2009). While this argument has typically focused on donating to reduce poverty, an even stronger argument can be made for donating to confront catastrophic threats to humanity, given the astronomical scale of the values at stake.

It is worth noting that not all efforts to confront nuclear winter benefit from additional funding. Shifts in nuclear doctrine, diplomatic ventures, and raising awareness are among the efforts that can sometimes be obtained essentially for free. Many government initiatives likewise do not accept direct private donations. Furthermore, some efforts would even save money. For example, nuclear disarmament would require an up-front expense but then would save money over the long run, i.e. the cost of maintaining nuclear weapons. Likewise organizations sometimes cite the cost of nuclear weapons in their efforts to promote disarmament (e.g. Ploughshares 2014).

But even these efforts can often benefit indirectly from funding. Shifts in doctrine can benefit from funding new doctrinal research and new events to educate policymakers about the research. Diplomatic ventures can benefit from providing resources to bring people from different countries together. Raising awareness can benefit from hiring full time advocates. Disarmament can even benefit from certain public-private ventures, such as that of the Nuclear Threat Initiative. And so providing funding can indirectly help advance a wide range of efforts to confront nuclear winter.

6. Conclusion

Nuclear winter—or, more precisely, the global environmental consequences of nuclear war—poses a severe threat to global human civilization. The full human consequences of nuclear winter are deeply uncertain and poorly studied, but at this point one cannot rule out the possibilities of the permanent collapse of human civilization or even human extinction. While nuclear winter can happen at any time, it is more likely to happen sometime in the future. Actions to confront nuclear winter can thus be of high value for confronting present and future catastrophic threats to humanity.

A variety of public and private actors can make constructive contributions to confronting the threat of nuclear winter. These interventions can affect the full sequence of nuclear winter events, from the onset of nuclear war, to the environmental severity of nuclear winter, to humanity's ability to survive and rebuild civilization. There are also indirect interventions that can enhance these other interventions. Collectively, these interventions can significantly reduce the overall risk from nuclear winter.

The breath of interventions demonstrates the breadth of actors that are capable of making a difference on nuclear winter risk. Experts on select research topics, military officers involved in nuclear weapon systems, and policy makers working on foreign policy are among the insider elite with relatively rare opportunities to make a difference. However, perhaps everyone in the world is capable of contributing productively. Lay citizens can influence policy both in their individual capacity and through a variety of nongovernmental organizations. Citizens in countries with and without nuclear weapons alike have helpful roles to play. Even citizens who are disconnected from policy processes can still contribute by donating money or increasing their resilience to nuclear winter. While some actions may do more to reduce the risk than others, all of these actions can contribute to an overall effective response to the threat of nuclear winter. Similarly, a one-size-fits-all approach to evaluating nuclear winter is inappropriate, because different actions will be best for different actors. These points hold for other catastrophic threats as well, not just for nuclear winter. Given a goal of confronting the threats, and not just characterizing the risk, these are important points to keep in mind.

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References

Abrams. S. et al., 2007. Phoenix: Final Report. International Space University, Strasbourg, France.

Agha, H., Feldman, S., Khalidi, A., Schiff, Z., 2003. Track-II Diplomacy: Lessons from the Middle East. MIT Press, Cambridge, MA.

Badash, L., 2009. A Nuclear Winter's Tale: Science and Politics in the 1980s. MIT Press, Cambridge, MA.

Barrett, A.M., Baum, S.D., Hostetler, K.R., 2013. Analyzing and reducing the risks of inadvertent nuclear war between the United States and Russia. Science and Global Security 21(2), 106–33.

Baum, S.D., 2009. Cost–benefit analysis of space exploration: Some ethical considerations. Space Policy 25(2), 75-80.

Baum, S.D., 2015. Winter-safe deterrence: The risk of nuclear winter and its challenge to deterrence. Contemporary Security Policy 36(1), 123-148.

Baum, S.D., Denkenberger, D.C., Haqq-Misra, J., 2015. Isolated refuges for surviving global catastrophes. Futures, forthcoming, doi: 10.1016/j.futures.2015.03.009.

Beckstead, N., 2013. On The Overwhelming Importance Of Shaping The Far Future. Doctoral Dissertation, Department of Philosophy, Rutgers University.

Beckstead, N., 2014. Improving disaster shelters to increase the chances of recovery from a global catastrophe. Effective Altruism Blog, 19 February. http://www.effective-altruism.com/improving-disaster-shelters-to-increase-the-chances-of-recovery-from-a-global-catastrophe

Borrie, J., 2014. Humanitarian reframing of nuclear weapons and the logic of a ban. International Affairs 90(3), 625–646.

Borrie, J., Caughley, T. (Eds.), 2013. Viewing Nuclear Weapons through a Humanitarian Lens. United Nations Institute for Disarmament Research, Geneva.

Bostrom, N., 2013. Existential risk prevention as a global priority. Global Policy 4(1), 15–31.

Bunn, M., Wier, A., 2006. Terrorist nuclear weapon construction: How difficult? Annals of the American Academy of Political and Social Science 607(1), 133-149.
Deep Cuts Commission, 2014. Preparing for Deep Cuts: Options for Enhancing Euro-Atlantic and International Security.
Denkenberger, D.C., Pearce, J.M., 2014. Feeding everyone: Solving the food crisis in event of global catastrophes that kill crops or obscure the sun. Futures, in press, doi:10.1016/j.futures.2014.11.008.
Dörries, M., 2011. The politics of atmospheric sciences: "Nuclear winter" and global climate change. Osiris 26(1), 198-223.
Dotto, L., 1986. Planet Earth in Jeopardy: Environmental Consequences of Nuclear War. Wiley, Chichester.
FAS (Federation of American Scientists), 2014. Status of World Nuclear Forces, April 30, http://fas.org/issues/nuclear-weapons/status-world-nuclear-forces.
Forden, G., Podvig, P., Postol, T.A., 2000. False alarm, nuclear danger. IEEE Spectrum 37(3), 31-39.
Fravel, M.T., Medeiros, E.S., 2010. China's search for assured retaliation: The evolution of Chinese nuclear strategy and force structure. International Security 35(2), 48-87.
Global Zero, undated. The Road to Zero. http://www.globalzero.org/get-the-facts/timeline.
GSN (Global Security Newswire), 2014. Russia loses another one of its early-warning satellites. June 26, http://www.nti.org/gsn/article/russia-loses-its-last-early-warning-satellite-raising-risk-strategic-miscalculation.
Hanson, R., 2008. Catastrophe, social collapse, and human extinction, in: Bostrom, N., Cirkovic, M. (Eds.), Global Catastrophic Risks, Oxford University Press, Oxford, pp. 363-377
Hardin, G., 1974. Lifeboat ethics. Psychology Today, September.
Helfand, I., 2013. Nuclear famine: Two billion people at risk. International Physicians for the Prevention of Nuclear War, http://www.ippnw.org/pdf/nuclear-famine-two-billion-at-risk-2013.pdf.
Hellman, M., 2008. Risk analysis of nuclear deterrence. The Bent of Tau Beta Pi, Spring, 14–22.
Hennigan, W.J., 2014. Major overhaul of nuclear force planned to improve security and morale. Los Angeles Times, 14 November.
Hertsgaard, M., 2000. Mikhail Gorbachev explains what's rotten in Russia. Salon.com, 7 September, http://www.salon.com/2000/09/07/gorbachev.
Jebari, K., 2014. Existential risks: Exploring a robust risk reduction. Science & Engineering Ethics, forthcoming, doi:10.1007/s11948-014-9559-3.
Keck, Z., 2014. Russia threatens nuclear strikes over Crimea. The Diplomat, July 11, http://thediplomat.com/2014/07/russia-threatens-nuclear-strikes-over-crimea.
Kristensen, H.M., 2010. Obama and the Nuclear War Plan. Federation of American Scientists Issue Brief, February.
Kristensen, H.M., Norris, R.S., Oelrich, I., 2009. From Counterforce to Minimal Deterrence: A New Nuclear Policy on the Path Toward Eliminating Nuclear Weapons. Federation of American Scientists Occasional Paper No. 7, April.
Kruschev, N., 1962. Department of State Telegram Transmitting Letter From Chairman Khrushchev to President Kennedy, October 26, 1962. Accessed from John F. Kennedy Presidential Library and Museum, http://microsites.jfklibrary.org/cmc/oct26/doc4.html.

Kuntsman, A., Raji, S., 2012. “Israelis and Iranians, get a room!”: Love, hate, and transnational politics from the “Israel Loves Iran” and “Iran Loves Israel” Facebook campaigns. Journal of Middle East Women’s Studies 8(3), 143-154.
Kuzmenko, E., Korolev, O., Zemitan, V., 1986. Гражданская оборона (Civil Defence), Fifth ed. Vissaja School, Kiev.
Lewis, J., 2008. Minimum deterrence. Bulletin of the Atomic Scientists 64(3), 38-41.
Lieber, K.A., Press, D.G., 2006. The end of MAD? The nuclear dimension of US primacy. International Security 30(4), 7-44.
Lundgren, C., 2013. What are the odds? Assessing the Probability of a Nuclear War Nonproliferation Review 20(2), 361-374, doi: 10.1080/10736700.2013.799828.
Maher, T.M. Jr., Baum, S.D., 2013. Adaptation to and recovery from global catastrophe. Sustainability 5(4), 1461-1479, doi:10.3390/su5041461.
McCamley, N., 2007. Cold War Secret Nuclear Bunkers. Pen and Sword, South Yorkshire.
Mills, M.J., Toon, O.B., Lee-Taylor, J., Robock, A., 2014. Multi-decadal global cooling and unprecedented ozone loss following a regional nuclear conflict. Earth’s Future 2(4), 161-176, doi:10.1002/2013EF000205.
Narang, V., 2009. Pakistan’s nukes are safe. Maybe. Foreign Policy, 13 August.
Obama, B., 2009. Remarks by President Barack Obama, Hradcany Square, Prague, Czech Republic, 5 April. http://www.whitehouse.gov/the_press_office/Remarks-By-President-Barack-Obama-In-Prague-As-Delivered
Özdoğan, M., Robock, A., Kucharik, C., 2012. Impacts of a nuclear war in South Asia on soybean and maize production in the Midwest United States. Climatic Change 116, pp. 373-387.
Peng, G., Rong, Y., 2009. Nuclear no-first-use revisited. China Security 5(1), 78-87.
Ploughshares, 2014. Nuclear Budget. Ploughshares Blog, http://www.ploughshares.org/blog/topic/nuclear-budget.
Potter, W.C., 2010. The NPT & the sources of nuclear restraint. Daedalus 139(1), 68-81.
Robock, A., 2010. Nuclear winter. Wiley Interdisciplinary Reviews: Climate Change 1, 418–427.
Robock, A., Toon, O.B., 2012. Self-assured destruction: The climate impacts of nuclear war. Bulletin of the Atomic Scientists 68(5), 66-74.
Rubinson, P., 2013. The global effects of nuclear winter: Science and antinuclear protest in the United States and the Soviet Union during the 1980s. Cold War History 14(1), 47–69.
Sagan, C., 1983. Nuclear war and climatic catastrophe: Some policy implications. Foreign Affairs 62, 257–292.
Sagan, S.D., 2009. The case for No first Use. Survival 51(3), 163-182.
Sandberg, A., Matheny, J.G., Ćirković, M.M., 2008. How can we reduce the risk of human extinction? Bulletin of the Atomic Scientists, September 9, http://thebulletin.org/how-can-we-reduce-risk-human-extinction.
Shapiro, R., 2009. A new rationale for returning to the Moon? Protecting civilization with a sanctuary. Space Policy 25(1), 1-5
Singer, P., 2009. The Life You Can Save: Acting Now to End World Poverty. Random House, New York.
Steff, R., 2013. Cooperative ballistic missile defence for America, China, and Russia. Contemporary Security Policy 34(1), 99-102.

Stenke, A., Hoyle, C. R., Luo, B., Rozanov, E., Gröbner, J., Maag, L., S. Brönnimann, Peter, T., 2013. Climate and chemistry effects of a regional scale nuclear conflict. Atmospheric Chemistry and Physics 13(19), 9713-9729.
Tonn, B.E., 2009. Obligations to future generations and acceptable risks of human extinction. Futures 41(7), 427–435.
Toon, O.B., Robock, A., Turco, R.P., 2008. Environmental consequences of nuclear war. Physics Today 61(12), 37-42.
Turco, R., Sagan, C., 1989. Policy implications of nuclear winter. Ambio 18(7), 372-376.
Wilson, W., 2012. The pennyfarthing H-bomb. The World Today, October & November, 26-27.
Wilson, W. 2013, Five Myths About Nuclear Weapons. Houghton Mifflin, Boston.
US DoD (United States Department of Defense), 2010. Nuclear Posture Review Report.
US DoD (United States Department of Defense), 2013. Report on Nuclear Employment Strategy of the United States Specified in Section 491 of 10 U.S.C.
US OCD (United States Office of Civil Defense), 1951. Survival Under Atomic Attack. Government Printing Office.
Xia, L., Robock, A., 2012. Impacts of a nuclear war in South Asia on rice production in mainland China. Climatic Change 116, 357–372.