



Ending nuclear weapons before they end us: current challenges and paths to avoiding a public health catastrophe

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Abstract

The United Nations Treaty on the Prohibition of Nuclear Weapons (TPNW)—an important planetary health good—entered into legal force in January 2021. Evidence of the consequences of nuclear war, particularly the global climatic and nutritional effects of the abrupt ice age conditions from even a relatively small regional nuclear war, indicates that these are more severe than previously thought. None of the nine nuclear-armed states is disarming; instead, all invest enormously in new and more hazardous nuclear weapons. Nor has any of the 32 states claiming reliance on another state’s nuclear weapons yet ended such reliance. These factors, abrogation of existing nuclear arms control agreements, policies of first nuclear use and war fighting, growing armed conflicts worldwide, and increasing use of information and cyberwarfare, exacerbate dangers of nuclear war. Evidence-based advocacy by health professionals on the planetary health imperative to eliminate nuclear weapons has never been more urgent.

Keywords Treaty on the Prohibition of Nuclear Weapons · Nuclear disarmament · Nuclear winter · Nuclear famine · Existential risk

The Treaty on the Prohibition of Nuclear Weapons (TPNW) is now in legal force

This article reviews current evidence, challenges, and opportunities towards controlling the most acute existential threat facing humankind and the biosphere: growing danger of nuclear war. During the years 2020 and 2021, dramatic explosion of the COVID-19 pandemic and rapidly accelerating severity and frequency of extreme weather and disasters caused by global heating have painfully underscored the necessity for public

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policies to be firmly grounded in evidence, especially those related to catastrophic and existential risks. Sadly, in many jurisdictions this is inadequately the case, exacerbating adverse health effects and risks. For nuclear weapons, the gap between government policy and the evidence on consequences and risks is a gaping chasm in 41 nations that claim some unique right to threaten people worldwide with indiscriminate nuclear violence; or to assist others to do so. While the climate emergency from global heating is finally receiving substantial government, professional, and public attention worldwide, the more acute existential risk to the stable and hospitable climate needed for human and planetary health posed by nuclear weapons is not. Both demand urgent attention.

An article in these pages in 2018 titled: "The Treaty on the Prohibition of Nuclear Weapons: a planetary health good of the highest order" [1] described this new United Nations treaty, adopted in 2017 [2], the first to comprehensively and categorically prohibit the worst weapons of mass destruction. It discussed the role of public health evidence-based advocacy in its development. When Honduras ratified the treaty (hereinafter, TPNW) on 24 October 2020, the world achieved a milestone of 50 state ratifications, signalling their readiness to be legally bound by its provisions. This triggered the treaty's formal legal entry into force 90 days later, on 22 January 2021. From this date, nations are required to fulfil their obligations under the treaty, starting 90 days after each completed its procedure for joining the treaty, thereby becoming a "State Party" to it.

By 14 December 2021, 86 countries had signed the treaty and 57 had ratified it [3]. From 2014, 127 states joined the Austrian-initiated Humanitarian Pledge [4], committing to work collaboratively to fill a legal gap: nuclear weapons as the last and only weapon of mass destruction *not* prohibited by an international treaty. In 2016, more than 120 states supported the development and negotiation of the treaty at each step in the United Nations General Assembly (UNGA) that required voting, and adoption of the treaty in 2017, then again for subsequent UNGA resolutions supporting the treaty [5]. Despite many competing priorities and fierce opposition to the TPNW from states deploying nuclear weapons, many of the supportive but not yet signatory states are likely to sign. The 31 signatory states which have not yet ratified the treaty are very likely to do so. Thus, the number of States Parties will continue to grow, and with them the legal, political, and moral force of the treaty.

The regularly scheduled at least biennial meetings of States Parties, including review conferences at least every 6 years, to further implementation, promotion, and development of the treaty will begin with the first meeting currently planned for 22–24 March 2022 in Vienna, Austria. A one-day intergovernmental humanitarian conference will precede it to review research updates on the impacts of nuclear weapons and the risks of nuclear war.

Current evidence on the consequences of nuclear war

First WHO assessment, 1983

In 1983, the World Health Assembly considered the first report of an international committee of experts on the effects of nuclear war on health and health services. It



endorsed the committee's conclusion: "that it is impossible to prepare health services to deal in any systematic way with the catastrophe resulting from nuclear warfare, and that nuclear weapons constitute the greatest immediate threat to the health and welfare of mankind" [6]. The committee's report states: "It is obvious that no health service in any area of the world would be capable of dealing adequately with the hundreds of thousands of people seriously injured by blast, heat or radiation from even a single 1-megaton bomb." The committee concluded: "... the only approach to the treatment of the health effects of nuclear explosions is primary prevention of such explosions, that is, the primary prevention of atomic war" [7].

New evidence of climate impacts

In the decades since 1983 we have learned much about the multiplicity of impacts of nuclear explosions and war. The evidence grows ever clearer as to the catastrophic effects. The most important new evidence relates to climate impacts. Nuclear weapons are extremely efficient at igniting vast numbers of simultaneous fires over large areas. These would consume all flammable materials and coalesce into massive confluent fires within which no one could survive the > 800 °C heat, intense smoke, and oxygen depletion. Atmospheric scientists estimated that even the relatively small tactical size nuclear weapon exploded on Hiroshima (15 kilotonnes of high explosive equivalent) released about 1000 times as much energy in the fires it ignited as in the explosion itself [8]. In Hiroshima approximately 13 km² of the city burned completely. Detonation of the largest currently deployed nuclear weapons, up to five megatonnes in size, would result in a confluent megafire more than 45 km in diameter, 1600 km² in area [9].

Atmosphere and climate effects of regional nuclear war: the example of India–Pakistan

The scenario for regional nuclear war most often studied by atmospheric scientists is a war between India and Pakistan. This possibility is all too realistic, as the two nations have waged war four times since their independence in 1949, and mobilised up to 1,000,000 troops on two other occasions. They possess two of the world's three most rapidly growing nuclear arsenals. Both have policies which create high risks of nuclear escalation in a war between them. Violence erupts across their disputed border in Kashmir almost daily. The most recently updated scenario involves use of 250 nuclear weapons of 15, 50, or 100 kt in size [10]. These constitute less than 2% of the number of nuclear weapons worldwide; and amount to less than 1% of their explosive yield, because the average size of the 13,150 nuclear weapons is 200 kt [11].

Such a war would produce between 83 and 183 million acute casualties in cities across both nations, including 52 to 127 million deaths (depending on the size of the weapons used) [10]. Radioactive contamination, severe social and economic disruption, and people attempting to flee on an unprecedented scale would extend across South Asia and beyond. Such a war would also produce between 16 and 36 million



tonnes of black carbon in sooty smoke from burning cities [10]. This smoke would loft quickly into the upper stratosphere and mesosphere, beyond the reach of clouds and precipitation in the lower atmosphere (troposphere). The sun would heat the rising smoke by 50 to 80 °C. The carbon would blanket the Earth for over a decade. It would also reduce global average surface temperatures by 3 to 6 °C, well within the range of minimum temperatures during the peak of the last ice age 20,000 years ago, 3 to 8 °C colder than present. Unevenly distributed temperature declines of 8 to 15 °C would cover much of the large North American and Eurasian land masses.

Global precipitation would also decline by up to 35%, with particular disruption of the South Asian monsoon on which food production for 1.5 billion people critically depends. Scientists expect these drier conditions and colder temperatures to be associated with cold spells and shortened frost-free growing seasons in temperate regions. An unprecedented increase in ultraviolet flux (30–100% increases during summer outside the tropics) would exacerbate these changes [12]. Stratospheric ozone would be extensively depleted, with harmful effects on plant and animal development and health in both aquatic and terrestrial environments. Even a smaller India-Pakistan nuclear war releasing 5 million tonnes of soot would produce peak global ozone loss of 25%, and up to 55% loss at higher latitudes, with recovery taking 12 years and peak increase of 40% in the ultraviolet B wavelengths associated with DNA damage [13]. Most agricultural production would cease in higher latitude regions including Canada, northern areas of Europe, Russia, China, Korea, and Japan [14].

Radioactive fallout and toxic chemical contamination from destroyed pipelines and industrial and storage sites would affect large areas of agricultural land. Social, economic, transport and trade turmoil would disrupt global distribution of fertiliser, fuel, machinery and equipment, seeds, pesticides, food storage facilities, and transport on which modern agriculture, food stocks, and distribution depend. And the consequence? The climatic changes alone would cause a decline in net primary productivity (NPP) of between 10 and 20% in the oceans and between 15 and 40% on land over multiple years [10]. NPP is the net amount of carbon per square metre per year converted into plant matter after accounting for what plants use for their own respiration. This loss would be comparable to the total current annual human use of food and fibre. Scientists continue to discover new effects that would exacerbate the harm. Recent findings indicate that various nuclear war scenarios could induce an El Niño-like pattern of unprecedented magnitude across the Pacific, with associated reductions in equatorial Pacific phytoplankton productivity of about 40% [15]. Researchers recently identified large and abrupt exacerbations in global ocean acidification as consequences of nuclear conflict including potential inability for marine calcifying organisms like shellfish and corals to maintain their shells or skeletons in a corrosive environment [16].

Devastation of food production

The world is not well prepared to withstand sustained decline in food production of such magnitude. In July 2021, the Food and Agriculture Organisation (FAO) of the



United Nations estimated between 720 and 811 million people to be chronically malnourished in 2020, 118 million more than in 2019 [17]. Due to the COVID-19 pandemic, FAO estimated the number of people experiencing moderate or severe food insecurity in 2020 at 2.37 billion, 318 million more than the previous year. Their November 2021 forecast for the 2021–22 year for global cereal stocks is equivalent to 104 days of consumption [18]. We expect more detailed country specific estimates of impacts on food production to be published in coming months. Sustained declines in global food production of such magnitude threaten over 2 billion people with starvation [19]. Epidemics of various infectious diseases would inevitably accompany famine of such unprecedented magnitude, as well as conflict within and between nations over inadequate and diminishing food reserves. The combination would likely exacerbate the human toll substantially.

Human health effects and implications

Immediate localised destruction would cause catastrophic local health impacts. Widespread health impacts would be caused by dispersed radioactive fallout and potentially an electromagnetic pulse from a high-altitude nuclear explosion that would incapacitate all civilian electrical and electronic infrastructure on a continental scale. But the major cause of casualties worldwide from a nuclear war would be from an abrupt onset of a nuclear ice age and resultant mass starvation. The ice age induced starvation findings from even a localised regional nuclear war do not support the commonly claimed theoretical basis for *nuclear deterrence of mutually assured destruction*. Instead, they characterise nuclear weapons as risking *self-assured destruction* from what amount to global suicide bombs. Nuclear weapons overwhelmingly endanger the security of all peoples and render meaningless any concept of winning a nuclear war [20]. They have no legitimate or legal military purpose.

The current risk of nuclear war

Risks of a nuclear war are growing [21, 22]. No nuclear-armed state is currently disarming, nor engaged in nuclear disarmament negotiations. First the US, followed by Russia, abrogated hard-won treaties negotiated between them which were fruits of the end of the first Cold War, and which constrained nuclear weapons numbers and types. Together these two countries hold 90% of all nuclear weapons [11]. The treaties include the Anti-Ballistic Missile Treaty, the Intermediate Nuclear Forces Treaty (eliminated short and medium-range nuclear missiles from the Soviet, then from Russian and US arsenals), the Open Skies Treaty (increased nuclear transparency), and the more recent Joint Comprehensive Plan of Action (Iran nuclear deal that provided effective constraints on Iran's nuclear program until the Trump administration abrogated it). Were it not for the incoming Biden administration's quick agreement to extend the New START treaty just two days before it would otherwise



have expired, there would be no treaty restraints in force in 2021 on US and Russian nuclear weapons despite an effectively resurgent Cold War.

Modernising and expanding nuclear arsenals at enormous and escalating cost

All nine nuclear-armed states are investing massively in modernising and expanding their nuclear arsenals. Modernisation means new, faster, stealthier, more flexible and accurate capacities. A number can be armed with either conventional or nuclear warheads, indistinguishable until point of impact. These changes lower the overall threshold for use of nuclear weapons [23]. Both Russia and the USA, owning between them 90% of all nuclear weapons, are comprehensively replacing and modernising their warheads, missiles and launch platforms. They are also increasing the role of nuclear weapons in their military policies, and the range of circumstances in which they might be used, including against conventional and cyber attacks [24, 25]. Russia is testing and deploying entirely new types of nuclear weapons including nuclear-powered cruise missiles, hypersonic delivery vehicles atop ballistic missiles, and long-range nuclear torpedoes designed to explode in waters close to cities [25]. The US is producing new nuclear warheads for the first time in three decades, modernising all types of nuclear weapons—ballistic and cruise missiles, bombs delivered by aircraft, and the submarines, ships and aircraft that carry them [24]. It is also upgrading the nuclear weapons it provides to the UK and the nuclear bombs it stations in Belgium, Germany, Italy, Netherlands and Turkey [24].

Current estimates of global spending on development and production of nuclear weapons reached US\$72.6 billion in 2020, an increase of \$1.4 billion from 2019, even given constraints of the pandemic [26]. The total cost of nuclear weapons programs, including environmental clean-up and legacy costs, is far greater. The US spends the most on military and nuclear weapons: in FY 2021 its nuclear weapons-related costs reached US\$74.75 billion [27]. Military spending consumes half of all discretionary US government spending. In the US, nuclear warhead spending is currently at an all-time record high, with projected expenditures over the next three decades of over US\$2 trillion to comprehensively refurbish the nuclear arsenal and the facilities that produce nuclear weapons [23]. While Russia's military spending in 2020 (\$61.7 billion) was estimated to be only 8% of that of the US (\$778 billion) [26], the proportion it spends on nuclear weapons is more than 2.5 times as great as the US [28].

Opportunity costs: weapons versus United Nations and related programs

Such vast expenditures on weapons that create a hazardous legacy even in their production have enormous social, environmental, and public health opportunity costs. Estimates by the Sustainable Development Solutions Network place average total annual investment required between 2019 and 2030 to fully finance achievement of the Sustainable Development Goals (SDGs) agreed by all nations at US\$1011 billion [29]. That amounts to about half of annual military expenditures, US\$1981 billion in 2020—2.6% higher than in 2019 [26]. That increase occurred despite the



COVID-19 pandemic and the associated severe economic downturn, increase in poverty and food insecurity. The combined annual budgets of the World Health Organization (WHO), UNICEF, the United Nations itself, the UN High Commissioner for Refugees, the International Committee of the Red Cross, and the UN Office of Disarmament Affairs amount to less than 30% of direct spending on nuclear weapons [30]. Operating an F-35 nuclear-capable combat aircraft for one-hour costs as much as a nurse earns in a year (OECD average); the cost of one Virginia Class nuclear submarine could fund 9180 fully equipped ambulances; the cost of one Trident II nuclear missile could buy 17 million facemasks [30]. By September 2021, at least one dose of COVID-19 vaccine had reached fewer than 3% of people in low-income countries and the WHO fell short by US\$900 million in funds they needed to cover the period till March 2022 for their essential role in ending the acute phase of the pandemic—1.2% of annual direct nuclear weapons spending [31].

Doomsday clock reflects growing insecurity

Leaders of all nuclear-armed states have, in recent years, issued specific nuclear threats, with military leaders confirming their active planning to fight nuclear war [32]. In 2020, the Bulletin of the Atomic Scientists moved its authoritative Doomsday Clock to 100 s to midnight, further forward than it has ever been before, explaining that: "the international security situation is now more dangerous than it has ever been, even at the height of the Cold War." [33] In 2021 the clock hands remained in the same position, as: "the potential to stumble into nuclear war—ever present—has grown." [22] In 2019, the United States intelligence community's annual assessment to Congress of worldwide threats warned that the effects of climate change and environmental degradation increase stress on communities around the world and intensify global instability and the likelihood of conflict, increasing the danger of nuclear war [34]. Over the last decade, the number of armed conflicts has steadily grown, particularly the number of "internationalised intrastate" conflicts—within a state but involving at least one nation (disproportionately nuclear-armed nations) outside the state in conflict [35].

Cyberwarfare increases vulnerability of nuclear arms systems

Another major area of increasing risk of use of nuclear weapons is growing use of cyberwarfare by both states and non-state actors. Attacks on civilian and military nuclear facilities included extensive hacking in December 2020 of the US National Nuclear Security Administration which maintains US nuclear weapons [36]. Complex global systems of early warning, command, control, communications, and intelligence are related to nuclear weapons. They are complex, dispersed, and interlinked—and vulnerable to cyberattack. As General James Cartwright, former head of US Strategic Command stated, it: "might be possible for terrorists to hack into Russian or American command and control systems and launch nuclear missiles, with a high probability of triggering a wider nuclear conflict." [37]



British, French, Russian, and US authorities keep 2000 nuclear warheads on high alert, all mounted on delivery vehicles and ready for use within minutes of a launch order [11]. These warheads are particularly vulnerable to digital sabotage and inadvertent or unauthorised launch. Many states, including China, Iran, Israel, North Korea, Russia, and the US, engage in offensive cyber operations [38]. Buyers may include governments, government proxies, and terrorist organisations. Frequently buyers find tools in a lucrative global black and grey market offering hacking tools, especially 'Zero-day exploits'. These tools exploit software or hardware flaws and vulnerabilities for which no corrective patch yet exists [38]. Government staff, as part of their work, or moonlighting staff, or government contractors can develop offensive digital tools. Individual or organised hackers and cybercriminals, or private for-profit companies can also produce them almost anywhere. Targets of hacking and digital sabotage to date include banking and health systems, Sony Corporation, electricity grids, water treatment facilities, airports, electoral systems, oil company computer systems, uranium enrichment centrifuges, and nuclear power plants. Increasing digital sophistication of nuclear weapons and delivery systems may increase their vulnerability to digital sabotage [38].

Source materials for nuclear weapons are not under adequate control

Vast stocks of fissile materials, the highly enriched uranium and plutonium from which nuclear weapons can be built, persist in civilian and military stockpiles in tens of countries. There are no effective international constraints on the production of these materials. Every state with a civilian nuclear industry is also capable of producing fissile materials; and any state that can enrich uranium to reactor grade can enrich it to weapons grade. Nuclear reactors inevitably convert some of the uranium in the fuel into plutonium. The average modern nuclear weapon contains around 4 kg of plutonium and/or 15 kg of highly enriched uranium (HEU) [39]. With the global fissile material stockpile at the start of 2020 estimated by the International Panel on Fissile Materials to contain 1330 tonnes of HEU and 540 tonnes of separated plutonium, [40] this equates to more than 225,000 nuclear weapon equivalents of material [39]. Apart from removal of relatively modest quantities of highly enriched uranium from civilian stockpiles in 34 countries plus Taiwan [41], the challenges of ceasing production of these materials, eliminating them where possible, and keeping the remaining quantities in consolidated storage in the safest possible form at the highest possible levels of security, remain largely unaddressed.

The TPNW provides our best path to control our worst weapons

The importance and urgency to eliminate nuclear weapons and to reduce the constant risk of their deliberate, inadvertent, or accidental use has never been greater. The Treaty on the Prohibition of Nuclear Weapons provides the most substantial positive development. It is firmly rooted in evidence of real consequences, costs, and dangers of nuclear weapons; it categorically and comprehensively prohibits these weapons; it contains the first treaty-based obligations for states to assist victims of



nuclear weapons use and testing; and it obligates them to assist in remediation of environments so contaminated. This treaty is helping to drive divestment by responsible financial institutions from companies that profit from manufacturing the worst, and now illegal, weapons of mass destruction [42].

The treaty also contains the only internationally agreed and codified framework for the elimination of nuclear weapons. The treaty provides flexible pathways for nuclear-armed states to disarm before or after joining the treaty. It specifies plans for time-bound dismantlement of the weapons and the facilities that produce and maintain them. It is subject to verification by a competent international authority. Thus, the treaty provides the most promising pathway for all states to fulfil their obligations to negotiate in good faith to achieve nuclear disarmament. Many health and humanitarian organisations, including the World Federation of Public Health Associations, the Red Cross and Red Crescent movement, the World Medical Association, the International Council of Nurses, and the International Federation of Medical Student Associations have joined with International Physicians for the Prevention of Nuclear War (IPPNW) to welcome the entry into force of the treaty. These organisations urge all nations to join and faithfully implement it [43].

The role of scientists and health professionals

Escalating urgency to eliminate nuclear weapons

Fundamental questions shadow everyone alive in our nuclear era: Will humanity eradicate weapons that pose the most acute existential threat to human and biosphere health and survival? And will we do so in time—before anyone uses them again, setting off indiscriminate nuclear violence that will bring about the end of us? Too few citizens and leaders worldwide realise and act on this recognition: the stable and hospitable climate needed for our living world requires protection from rampant global heating and from an abrupt nuclear ice age. Planetary health depends on both.

Health evidence and advocacy can be powerful

Effective evidence-based advocacy by expert custodians of scientific and health evidence has enabled much of the progress towards constraining the nuclear arms race. Prominent, respected figures including Dr. Albert Schweitzer and paediatrician Dr. Benjamin Spock drew attention to evidence of markedly increasing levels of strontium-90 in children's deciduous teeth from atmospheric nuclear weapons testing in the 1950s and 60s. Their efforts played an important role in the Partial Test Ban Treaty of 1963 that ended Soviet and US atmospheric nuclear testing [19]. Soviet general secretary Mikhail Gorbachev and US president Ronald Reagan understood the catastrophic effects of nuclear war. Their attention to growing evidence of the cataclysmic consequences of a nuclear winter led them to declare jointly in 1985 that "A nuclear war cannot be won and must never be fought". In 1986 they came



tantalisingly close to agreeing to eliminate their nuclear arsenals entirely over 15 years [44].

Partnerships and coalitions are vital

What played the decisive role in the Humanitarian Initiative on nuclear weapons? It was evidence of the catastrophic consequences of any use of nuclear weapons, the impossibility of any effective health or humanitarian response, growing dangers of nuclear war, and severe global impacts likely from even a relatively small scale regional nuclear war—coupled with the powerful testimony of the *hibakusha* and nuclear test survivors who experienced ongoing devastation of nuclear weapons firsthand [1, 45]. This project of governments and global civil society, from 2010, led to adoption of the TPNW. It was an organisation of health professionals, International Physicians for the Prevention of Nuclear War, that established the International Campaign to Abolish Nuclear Weapons (ICAN). This campaign coalition became the major civil society partner with governments in development of the TPNW, a role resulting in award of the Nobel Peace Prize to ICAN in 2017.

Scientific and health evidence-based communication and advocacy on impacts and risks of nuclear war continue to play vital roles for citizens, leaders, and governments. Key factors that have prevented nuclear war to date include informed understanding of nuclear weapons dangers by key leaders, widespread revulsion by citizens worldwide of indiscriminate radioactive violence that nuclear war would unleash, and pressure from mobilised citizens [46]. Policies that justify nuclear weapons flow from primitive thinking, not facts and evidence. Evidence shows that nuclear weapons cannot make anyone more secure; instead, they pose an existential threat to the security of all people. If not eliminated before being used again, a nuclear war with catastrophic consequences will be inevitable. As growth in divestment from nuclear weapons producers encouraged by the TPNW demonstrates, powerful military, government, and corporate inertia and vested interests that drive the massive nuclear weapons enterprise are formidable, but not immovable [42].

Treaties work

Experience with treaties prohibiting other types of inhumane and indiscriminate weapons shows that they often influence even states that oppose and have not signed on to the treaty. Biological and chemical weapons, landmines and cluster munitions are now less often justified, produced, sold, deployed, and used after their prohibition—even by states not having joined the respective bans [45].

Lessons from COVID

The worst global pandemic in a century challenged leaders to learn and effectively apply lessons of this pandemic. We must find the silver linings in a dark cloud and build on them. COVID-19 should puncture any delusions of mastery of the



natural world or complacent omnipotence about pathogens. COVID-19 has caught even the wealthiest nations inadequately prepared. Some that invest obscene sums in nuclear weapons that must never be used proved unable to provide the most basic of protective equipment for many frontline health professionals. COVID-19 is a timely reminder of threats to security for the world's people for which massive military arsenals and the worst weapons of mass destruction offer only a useless distraction.

COVID-19 highlights our highly interconnected vulnerabilities, ones requiring cooperative solutions. The pandemic has shown how quickly ideology, exceptionalist hubris, and arrogant leaders cause monumental failures of leadership and vast numbers of readily preventable deaths. The pandemic has laid bare a vital lesson: effective policy and governance depend on respect for truth and evidence and deference to its expert custodians. Measures previously deemed unthinkable, including rapid vaccine development and large-scale social support, can rapidly come to fruition. And the pandemic has confirmed that female leaders are generally more sensible and reliable in a crisis; we need more of such leadership.

Enormous investments by many countries in economic stimulus and support during the pandemic provide a tremendous if still poorly used opportunity to achieve greater social equity and capital with more equitable access to renewable energy. All of these can promote healthier and less polluting cities and infrastructure and prepare us much better for the next pandemic. COVID-19 should motivate leaders and citizens to take an evidence-based, preventive approach and work assiduously to eliminate the global health threats that are within our control, foremost among them nuclear weapons. An increasingly climate-stressed world is even more dangerous and unsustainable for arsenals of doomsday weapons. Effective and coordinated evidence-based advocacy by scientists and public health professionals on the planetary health imperative to eliminate nuclear weapons has never been more urgent.

Declarations

Conflict of interest The author states that there is no conflict of interest.

References

1. Ruff TA. The Treaty on the Prohibition of Nuclear Weapons: a planetary health good of the highest order. (The Federation's Pages—World Federation of Public Health Associations). *J Public Health Pol.* 2018;39:382–7. <https://doi.org/10.1057/s41271-018-0128-x>.
2. UN General Assembly. Treaty on the Prohibition of Nuclear Weapons. A/CONF.229/2017/8. 2017. <http://undocs.org/A/CONF.229/2017/8>.
3. United Nations Office for Disarmament Affairs. Treaty on the Prohibition of Nuclear Weapons. Status of the treaty. <https://treaties.unoda.org/tpnw>.
4. Europe Integration and Foreign Affairs Federal Ministry, Republic of Austria. Humanitarian Pledge. Vienna Conference on the Humanitarian Impacts of Nuclear Weapons. 9 Dec 2014. https://www.bmeia.gv.at/fileadmin/user_upload/Zentrale/Aussenpolitik/Abruestung/HINW14/HINW14vienna_update_pledge_support.pdf.
5. Kmentt A. The treaty prohibiting nuclear weapons. How it was achieved and why it matters. New York: Routledge; 2021.



6. World Health Assembly. The role of physicians and other health workers in the preservation of peace as the most significant factor for the attainment of health for all. WHA36.28. Geneva: WHO. 1983. http://apps.who.int/iris/bitstream/10665/160590/1/WHA36_R28_eng.pdf.
7. World Health Organization. Effects of Nuclear War on Health and Health Services. Geneva: WHO. 1984. https://apps.who.int/iris/bitstream/handle/10665/159417/WHA36_12_eng.pdf?sequence=1&isAllowed=y.
8. Toon O, Turco R, Robock A, Bardeen C, Oman L, Stenichkov G. Atmospheric effects and societal consequences of regional scale nuclear conflicts and acts of individual nuclear terrorism. *Atm Chem Phys*. 2007;7:1973–2002.
9. Ruff TA. The health consequences of nuclear explosions. In: Fihn B, editors. *Unspeakable suffering—the humanitarian impact of nuclear weapons*. Geneva/New York: Reaching Critical Will, Women’s International League for Peace and Freedom. 2013:14–27. <https://www.reachingcriticalwill.org/images/documents/Publications/humanitarian-impact-nuclear-weapons-2nd-edition.pdf>.
10. Toon OB, Bardeen CG, Robock A, Xia L, Kristensen H, McKinzie M, Peterson RJ, Harrison CS, Lovenduski NS, Turco RP. Rapidly expanding nuclear arsenals in Pakistan and India portend regional and global catastrophe. *Sci Adv* 2019; eaay5478. <https://advances.sciencemag.org/content/5/10/eaay5478>.
11. Kristensen HM, Korda M. Status of world nuclear forces. Federation of American Scientists. 7 October 2021. <http://fas.org/issues/nuclear-weapons/status-world-nuclear-forces/>.
12. Mills M, Toon O, Lee-Taylor J, Robock A. Multi-decadal global cooling and unprecedented ozone loss following a regional nuclear conflict. *Earth Fut*. 2015;2:161–76. <https://doi.org/10.1002/2013EF000205/full>.
13. Bardeen CG, Kinnison DE, Toon OB, Mills MJ, Vitt F, Xia L, Jägermeyr J, Lovenduski NS, Scherrer KJN, Clyne M, Robock A. Extreme ozone loss following nuclear war results in enhanced surface UV radiation. *J Geophys Res: Atmos*. 2021;126:e2021JD035079. <https://doi.org/10.1029/2021JD035079>.
14. Jägermeyr J, Robock A, Elliott J, Müller C, Xia L, Khabarov N, Folberth C, et al. A regional nuclear conflict would compromise global food security. *PNAS*. 2020;117(13):7071–7–81. <https://doi.org/10.1073/pnas.1919049117>.
15. Coupe J, Stevenson S, Lovenduski NS, Rohr T, Harrison CS, Robock A, Olivarez H, Bardeen CG, Toon OB. Nuclear Niño response observed in simulations of nuclear war scenarios. *Commun Earth Environ*. 2021;2:18. <https://doi.org/10.1038/s43247-020-00088-1>.
16. Lovenduski NS, Harrison CS, Olivarez H, Bardeen CG, Toon OB, Coupe J, et al. The potential impact of nuclear conflict on ocean acidification. *Geophys Res Lett*. 2020;47:e2019GL086246. <https://doi.org/10.1029/2019GL086246>.
17. FAO, IFAD, UNICEF, WFP and WHO. The state of food security and nutrition in the World 2021. Transforming food systems for food security, improved nutrition and affordable healthy diets for all. Rome: FAO; 2021. <https://doi.org/10.4060/cb4474en>.
18. Food and Agriculture Organisation of the United Nations. FAO Cereal Supply and Demand Brief. 4 November 2021. <http://www.fao.org/worldfoodsituation/csdb/en/>.
19. Helfand I, Haines A, Ruff T, Kristensen H, Lewis P, Mian Z. The growing threat of nuclear war and the role of the health community. *World Med J*. 2016;62(3):86–94.
20. Robock A, Toon OB. Self-assured destruction: the climate impacts of nuclear war. *Bull At Sci*. 2012;68(5):66–74. <https://doi.org/10.1177/0096340212459127>.
21. United Nations. Our common agenda—report of the Secretary General. New York: United Nations; 2021. p. 59.
22. Science and Security Board, Bulletin of the Atomic Scientists. This is your COVID wake-up call: It is 100 seconds to midnight. 2021 Doomsday Clock Statement. 27 January 2021. <https://thebulletin.org/doomsday-clock/current-time/>.
23. Women’s International League for Peace and Freedom. Assuring destruction forever: 2020 edition. New York. 2020. <https://reachingcriticalwill.org/resources/publications-and-research/publications/14711-assuring-destruction-forever-2020-edition>.
24. Kristensen HM, Korda M. United States nuclear weapons, 2021. *Bull At Sci*. 2021;77(1):43–63. <https://doi.org/10.1080/00963402.2020.1859865>.
25. Kristensen HM, Korda M. Russian nuclear weapons, 2021. *Bull At Sci*. 2021;77(2):90–108. <https://doi.org/10.1080/00963402.2021.1885869>.
26. Stockholm International Peace Research Institute. Trends in world military expenditure, 2020. SIPRI Fact Sheet. Solna: SIPRI, April 2021. <https://sipri.org/publications/2021/sipri-fact-sheets/trends-world-military-expenditure-2020>.
27. Dodge R. PSR-LA’s nuclear weapons community costs program. <https://www.psr-la.org/nuclear-costs>.



28. International Campaign to Abolish Nuclear Weapons. Complicit: 2020 global nuclear weapons spending. Geneva. June 2021. https://www.icanw.org/complicit_nuclear_weapons_spending_increased_by_1_4_billion_in_2020.
29. Sustainable Development Solutions Network. SDG costing and financing for low-income developing countries. September 2019. https://resources.unsdsn.org/sdg-costing-financing-for-low-income-developing-countries?_ga=2.215601623.1575324682.1629814308-1550314391.1629814308.
30. International Peace Bureau. Global Campaign on Military Spending. Infographics and materials. https://demilitarize.org/resources_categories/infographics_materials/.
31. World Health Organization. WHO SPRP September update: an urgent call to fund the emergency response. September 2021. <https://www.who.int/publications/m/item/who-preparedness-and-response-progress-september-update>.
32. Steinbuch Y. Admiral warns of 'real possibility' of nuclear war with Russia, China. New York: New York Post. 3 February 2021. <https://nypost.com/2021/02/03/admiral-warns-of-possibility-of-nuclear-war-with-russia-china/>.
33. Science and Security Board, Bulletin of the Atomic Scientists. Closer than ever: It is 100 seconds to midnight. 2020 Doomsday Clock Statement. <https://thebulletin.org/doomsday-clock/2020-doomsday-clock-statement/>.
34. US Congress. H.Res.302 - Embracing the goals and provisions of the Treaty on the Prohibition of Nuclear Weapons. 116th Congress (2019–2020). Introduced 10 April 2019. <https://www.congress.gov/bills/116/congress-house/resolution/302/text>.
35. Uppsala Conflict Data Program. Armed conflict by type, 1946–2020. Uppsala: Uppsala University. 2021. <https://ucdp.uu.se/downloads/charts/>.
36. Bertrand N, Wolff E. Nuclear weapons agency breached amid massive cyber onslaught. Arlington: Politico. 17 Dec 2020. <https://www.politico.com/news/2020/12/17/nuclear-agency-hacked-officials-inform-congress-447855>.
37. Cirincione J. What happens when our nuclear arsenal is hacked? San Francisco Chronicle. 17 June 2015. <https://www.sfchronicle.com/opinion/openforum/article/What-happens-when-our-nuclear-arsenal-is-hacked-6333739.php>.
38. Perlroth N. This is how they tell me the world ends. The cyber weapons arms race. London: Bloomsbury Publishing; 2021.
39. Norwegian Peoples' Aid. Nuclear weapons ban monitor 2020. Oslo. Jan 2021. <https://banmonitor.org>.
40. International Panel on Fissile Materials. Fissile material stocks. 4 September 2021. <https://fissilematerials.org>.
41. International Panel on Fissile Materials. Materials: Highly enriched uranium. 29 April 2021. <http://fissilematerials.org/materials/heu.html>.
42. PAX, International Campaign to Abolish Nuclear Weapons. Perilous profiteering. Utrecht: November 2021. https://d3n8a8pro7vhm.cloudfront.net/ican/pages/2331/attachments/original/1637141262/2021_Perilous_Profitteering_Final.pdf?1637141262.
43. ICRC, ICN, IFMSA, IPPNW, WEPHA, WMA. International health and humanitarian organisations welcome the entry into force of the Treaty on the Prohibition of Nuclear Weapons. 21 January 2021. <https://www.ippnw.org/wp-content/uploads/2021/01/FINAL-English-Global-Health-Statement.docx.pdf>.
44. Forrow L, Ruff T, Thurlow S. The 2017 Nobel Peace Prize and the Doomsday Clock—the end of nuclear weapons or the end of us? *New Engl J Med*. 2018;378:2258–61.
45. Ruff TA. Negotiating the UN Treaty on the Prohibition of Nuclear Weapons and the role of ICAN. *Glob Change Peace Secur*. 2018;30(2):233–41.
46. Wittner LS. *Confronting the bomb*. Stanford: Stanford University Press; 2009.

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