RESTRAINING THE NEW NUCLEAR ARMS RACE

WHAT SCIENTISTS AND ENGINEERS CAN DO

to preserve nuclear arms control

Alex Glaser
Princeton University
Indiana University Bloomington
January 18, 2023
We affirm that a nuclear war cannot be won and must never be fought. [...] We also affirm that nuclear weapons— for as long as they continue to exist—should serve defensive purposes, deter aggression, and prevent war.”

Joint Statement of the Leaders of the Five Nuclear-Weapon States on Preventing Nuclear War and Avoiding Arms Races, January 2022
www.whitehouse.gov/briefing-room/statements-releases/2022/01/03/p5-statement-on-preventing-nuclear-war-and-avoiding-arms-races/
February 24, 2022 [Day of Russia’s invasion of Ukraine]: Putin warns other countries that any attempt to interfere would lead to “consequences you have never seen in history.” Adding, “we are ready for any outcome.”

February 27, 2022: Putin orders the minister of defense and the chief of the general staff of the Russian armed forces to transfer the deterrence forces of the Russian army to a “special mode of combat duty.”

In the background: Valery Gerasimov (Chief of the General Staff of the Russian Armed Forces, left) and Sergei Shoigu (Minister of Defense, right)
Even a single use of a nuclear weapon could lead to an all-out nuclear war

[The] first time since the Cuban missile crisis, we have a direct threat of the use [of a] nuclear weapon if in fact things continue down the path they are going. I don’t think there’s any such thing as the ability to easily [use] a tactical nuclear weapon and not end up with Armageddon.

U.S. President Joe Biden, October 2022
How do you think it ends?
It ends the same way every time. It does.
It ends bad. And the bad meaning it ends with global nuclear war.

General John E. Hyten (Commander, U.S. Strategic Command, 2016–2018) on the outcome of the annual Global Thunder Exercise

www.stratcom.mil/Media/Speeches/Article/1577239/the-mitchell-institute-triad-conference
With the aim of inhibiting the other side's recovery, Russia and NATO each target the other's 30 most populated cities and economic centers, using 5–10 warheads on each city depending on population size.

Immediate casualties:

<table>
<thead>
<tr>
<th>Number of immediate casualties, including fatalities</th>
<th>Number of immediate casualties, including injuries</th>
</tr>
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<tbody>
<tr>
<td>34.1 million</td>
<td>57.4 million</td>
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</table>

Deaths from nuclear fallout and other long-term effects would significantly increase this estimate.

Watch the four-minute video: [https://youtu.be/2jy3JU-ORpo](https://youtu.be/2jy3JU-ORpo)

**CREDITS**

Plan A was originally produced as part of a small exhibition at Princeton University that opened in November 2017.

- Alex Wellerstein
- Tamara Patton
- Moritz Kütt
- Alexander Glaser
- Bruce Blair
- Sharon Weiner
- Zia Mian
- Pavel Podvig
- Jeff Snyder (sound)
Letters to the Editor

The Editor does not hold himself responsible for opinions expressed by his correspondents. He cannot undertake to return, or to correspond with the writers of, rejected manuscripts intended for this or any other part of Nature. No notice is taken of anonymous communications.

NOTES ON POINTS IN SOME OF THIS WEEK'S LETTERS APPEAR ON P. 247.
CORRESPONDENTS ARE INVITED TO ATTACH SIMILAR SUMMARIES TO THEIR COMMUNICATIONS.

Disintegration of Uranium by Neutrons: a New Type of Nuclear Reaction

On bombarding uranium with neutrons, Fermi and collaborators found that at least four radioactive elements were produced in the second place. These elements have now been identified as krypton and barium. The results of this experiment are of fundamental importance, for they provide evidence that the nucleus of the atom is not stable and that it can be split up into smaller particles.

O. R. FRISCH

Physical Institute, Academy of Sciences, Stockholm.
Jan. 16.

The Editor suggests that the results of this experiment be published in full in a subsequent issue of Nature.

NATURE
EARLY INTERVENTIONS

EINSTEIN’S LETTER
August 1939

Szilard and Einstein inform President Roosevelt about the feasibility of a uranium bomb and recommend speeding up experimental work on nuclear fission.

BOHR’S ADVOCACY
July 1944

Niels Bohr advocates for not using the atomic bomb without first notifying Stalin, trying to lay the basis for post-war control of nuclear energy.

CHICAGO SCIENTISTS’ PETITION
July 1945

“The United States shall not resort to the use of atomic bombs in this war unless the terms which will be imposed upon Japan have been made public ...”

See www.atomicarchive.com/resources/documents/manhattan-project for a collection of documents
Copy of Kenichi Nakano, Whole City a Sea of Fire. Hell. Hell on Earth, Hiroshima Peace Memorial Museum, hpmmuseum.jp
Dear Friend:

I write to you and other friends for help.

Through the release of atomic energy, our generation has brought into the world the most revolutionary force since prehistoric man’s discovery of fire. This basic power of the universe cannot be fitted into the outmoded concept of narrow nationalisms. For there is no secret and there is no defense; there is no possibility of control except through the aroused understanding and insistence of the peoples of the world.

We scientists recognize our inescapable responsibility to carry to our fellow citizens an understanding of the simple facts of atomic energy and its implications for society. In this lies our only security and our only hope - we believe that an informed citizenry will act for life and not for death.

We need $1,000,000 for this great educational task. Sustained by faith in man's ability to control his destiny through the exercise of reason, we have pledged all our strength and our knowledge to this work. I do not hesitate to call upon you to help.

Faithfully yours,

[Signature]

Albert Einstein on behalf of the Emergency Committee of Atomic Scientists
Princeton, N.J., December 1946

There is no secret, and there is no defense.
"Let it be clearly realized that this is a super weapon; it is in a totally different category from an atomic bomb. The reason for developing such super bombs would be to have the capacity to devastate a vast area with a single bomb. Its use would involve a decision to slaughter a vast number of civilians. We are alarmed as to the possible global effects of the radioactivity generated by the explosion of a few super bombs of conceivable magnitude. If super bombs will work at all, there is no inherent limit in the destructive power that may be attained with them. Therefore, a super bomb might become a weapon of genocide."

Excerpt from the Majority Annex of the U.S. General Advisory Committee Report on the “Super” (October 1949), chaired by J. R. Oppenheimer
ENDING NUCLEAR TESTING IN THE ATMOSPHERE

1-3 MILLION ESTIMATED CANCER CASES, MOST OF THEM STILL IN THE FUTURE

Fallout from the “Aldebaran” Nuclear Test, July 2, 1966, French Polynesia
Simulations by Sébastien Philippe, 2021/2022

The study showed that 90% of Polynesian population could have received doses > 1 mSv in a given year, making them eligible for government compensation; moruroa-files.org

NUCLEAR WEAPONS TODAY
There remain almost 13,000 nuclear weapons in the world today.

77 YEARS OF NUCLEAR WEAPONS
SMALLER, LIGHTER, MORE DESTRUCTIVE

U.S. W80-4 cruise missile warhead
Source: NNSA/Sandia National Laboratory

North Korean two-stage weapon
Source: KCNA
A modern nuclear weapon has a destructive power tens to hundreds of times greater than the Hiroshima bomb.

New York City

A 200-kt nuclear explosion would immediately kill more than 1,300,000 people in New York City and the surrounding areas. Fallout effects would significantly increase this number.

The catastrophic effects of nuclear weapons are not limited to the intended target.

A counterforce attack on the Kozelsk missile field (about 150 miles from Moscow) would cause several million deaths in the region.

OPEN-RISOP Version 1.00
Mixed Counterforce+Countervalue Attack
CONUS
2,031 Warheads | March 1, 2021 Winds
61,172,000 Fatalities
https://github.com/davidteter/OPEN-RISOP
https://nuclearwarsimulator.com

Source: David Teter
github.com/davidteter/OPEN-RISOP/
GLOBAL FAMINE DUE TO CLIMATE DISRUPTION

FOLLOWING A NUCLEAR WAR

Bombs targeted on cities and industrial areas start firestorms, injecting large amounts of soot into the upper atmosphere, rapidly cooling the planet

Uses climate, crop, and fishery models to estimate the impacts of six war scenarios

The study finds that more than 2 billion people could die from nuclear war between India and Pakistan, and more than 5 billion could die from a war between the United States and Russia

Lili Xia, Alan Robock, Kim Scherrer, et al., “Global Food Insecurity and Famine from Reduced Crop, Marine Fishery and Livestock Production Due to Climate Disruption from Nuclear War Soot Injection,” Nature Food, 3, 2022, doi.org/10.1038/s43016-022-00573-0
ON THE MORNING YOU WAKE (TO THE END OF THE WORLD)
HOW DID I GET INTO THIS? (NEUTRONICS!)

PLUTONIUM DISPOSITION
1990s
Can one eliminate or irreversibly dispose 50–100 tons of excess weapons plutonium?

REACTOR CONVERSION
2000s
Can one use low-enriched uranium in research reactors without performance loss?

WARHEAD VERIFICATION
2010s
Can one dismantle a nuclear warhead without learning anything about its design?
There is enough nuclear explosive material in the world to make over 200,000 nuclear weapons

- 1,340 tons of highly enriched uranium (HEU)
- 520 tons of separated plutonium

Each block corresponds to 12 kg of HEU, the amount necessary to make a fission bomb, about 111,670 bombs-worth total.

Each block corresponds to 4 kg of plutonium, the amount necessary to make a fission bomb, about 130,000 bombs-worth total.

There is enough nuclear explosive material in the world to make over 200,000 nuclear weapons.
THE CURRENT CRISIS
IN NUCLEAR ARMS CONTROL AND DISARMAMENT
LANDMARK NUCLEAR ARMS CONTROL TREATIES

ANTI-BALLISTIC MISSILE TREATY
(1972–2002)

The ABM Treaty barred the United States and Russia from deploying nationwide defenses against strategic ballistic missiles. The United States withdrew in 2002.

Source: U.S. Missile Defense Agency

INTERMEDIATE NUCLEAR FORCES

The INF Treaty required the United States and Russia to eliminate all ground-launched ballistic and cruise missiles with ranges between 500 and 5,500 kilometers.

Source: www.defenseimagery.mil

START & New START

START and New START requires the United States and Russia to reduce and limit their deployed strategic weapons. New START will expire in 2026.

Source: Alexander Zemlianichenko, Associated Press

For details, see www.armscontrol.org/factsheets/USRussiaNuclearAgreements
SO WHAT

WHAT IS NEW HERE AND WHY SHOULD I CARE?
COSTS OF U.S. NUCLEAR FORCES, 2018–2046

AND THE MODERNIZATION “BOW WAVE”

COSTS OF U.S. NUCLEAR FORCES, 2018–2046

AND THE MODERNIZATION “BOW WAVE”


~ $22 billion
UPGRADING THE ARSENALS
(ALONG WITH THE UNITED STATES, FRANCE, AND THE UNITED KINGDOM)

CHINA
About 100 road-mobile missile launchers and possibly up to 200 ICBM silos under construction; weapons program likely constrained by fissile material inventory

NORTH KOREA
North Korea conducted numerous missile tests in 2021 and 2022 (including cruise missiles, SLBMs and ICBMs, up to 13,000 km range) and revealed the Hwasong-8 hypersonic glide vehicle

RUSSIA
Several new weapon systems under development, most of them aimed at neutralizing possible U.S. missile defense capabilities; concerns about low-yield use in Ukraine

Source: Xinhua/Tao Liang (top), KCNA (middle), tass.com/defense/1099659 (bottom)
RUSSIA HAS BEEN DEVELOPING NEW WEAPONS SYSTEMS
LARGELY IN RESPONSE TO U.S. WITHDRAWAL FROM ABM TREATY IN 2002

Ship-based radars and interceptors

Land-based radars and interceptors

Avangard hypersonic-glide vehicle (evading missile defenses)
After decades of a “minimum deterrence” posture, China appears to be embarking on a massive expansion of its nuclear arsenal (mirroring many decisions made by the United States and Russia during the Cold War).

ICBM silo field, under construction; Copernicus Sentinel Data, January 2, 2023, 42.273 N 92.682 E fas.org/blogs/security/2021/07/china-is-building-a-second-nuclear-missile-silo-field/
NEW TECHNOLOGIES

NEW TYPES OF DELIVERY SYSTEMS

In addition to rebuilding the entire nuclear triad, for the time up to 2100, new types of weapons and delivery systems are being introduced by the United States and others; these include, in particular, hypersonic weapons and various “exotic” Russian systems.

NEXT-GENERATION (“EMERGING”) TECHNOLOGIES

Pinpoint accuracy without relying on global navigation satellite systems (GNSS).

Space-based military weapons systems are “back” (Space Policy Directive-4).

Autonomous weapons systems, conventional for now ... but potentially dual capable.

Source: U.S. Department of Defense (top) and NASA/JPL-Caltech (bottom)
NEW TECHNOLOGIES: RISKS & VULNERABILITIES

**NUCLEAR WEAPONS MAY BE PERCEIVED AS “MORE USABLE”**

Nuclear weapons with lower yield (5–7 kt) delivered with “pinpoint” accuracy

Belief that missile defenses may be effective against an adversary’s retaliatory strike

2018 Nuclear Posture Review expanded conditions for possible nuclear weapons use

**CYBER VULNERABILITIES**

Nuclear weapons and related systems predate digital electronics and are “tightly coupled”

Several types of systems may be exposed to attack (via network, supply chain, etc.)

Modern cyber threats further increase the risk of miscommunication and miscalculation

Source: Castle Bravo (top) and [wikimedia.org/pdphoto.org](http://wikimedia.org/pdphoto.org) (bottom)
CALL TO ACTION
WHO SHOULD HAVE NUCLEAR WEAPONS?

WHICH STATEMENT COMES CLOSEST TO YOUR VIEW?

- No countries should be allowed to have nuclear weapons
- Only the United States and its allies should be allowed to have nuclear weapons
- Only countries that already have nuclear weapons should be allowed to have them
- Any country that is able to develop nuclear weapons should be allowed to have them

July 2–19, 2020 | n = 2,111
Chicago Council Surveys

website: www.thechicagocouncil.org/commentary-and-analysis/blogs/americans-want-nuclear-free-world
WHERE DO WE GO FROM HERE?

WE NEED PUBLIC REENGAGEMENT
The public needs to reengage with nuclear weapon issues; in the United States, Congress needs to know their constituents care; public engagement and pressure was key to major threat reduction efforts.

WE NEED NEW IDEAS
Our existing ideas about deterrence and arms control have failed to prevent a new arms race or a major conflict involving nuclear weapon states; new Biden NPR has embraced the status quo.

WE NEED TECHNICAL ANALYSIS
Scientists and physicists can play an important role in advising the public, Congress, and the executive branch; can be both from inside or from outside the bureaucracy.

Source: Giancarlo Impiglia (top), Author (middle), and Matt Stanley (bottom)
Multi-year project, founded in 2020 with a startup grant from the American Physical Society’s Innovation Fund

Education and community-building effort to re-engage the physics community

Help inform the public, Congress, and other stakeholders on arms-control issues and opportunities for nuclear risk reduction

As of the end of 2022, almost 1000 scientists and engineers have joined

Colloquia and webinars at more than 120 U.S. universities

Position papers, letters to government officials, and policy briefs
COALITION NEXT-GENERATION FELLOWSHIP

FOR GRADUATE STUDENTS AND EARLY-CAREER SCIENTISTS

The one-year fellowship offers opportunities to gain exposure and experience at the intersection of science and policy: Learn about nuclear weapons policy and train in policy communication, advocacy, and partnership building; get hands-on experience in advocacy and outreach to Congress; and participate in the annual Princeton School on Science and Global Security.
“We state unequivocally that any threat to use nuclear weapons, at any time and under any circumstances, is extremely dangerous and totally unacceptable. We call on all people and governments everywhere to clearly condemn all nuclear threats, explicit or implicit, and any use of such weapons.”
With the aim of inhibiting the other side's recovery, Russia and NATO each target the other's 30 most populated cities and economic centers, using 5–10 warheads on each city depending on population size. Immediate casualties

| Number of immediate casualties, including fatalities (34.1 million) and injuries (57.4 million), resulting from the series of nuclear exchanges. |
|Deaths from nuclear fallout and other long-term effects would significantly increase this estimate. |

There never has been a moment’s justification for having the capability to destroy humanity.

Daniel Ellsberg

Acknowledgements: Physicists Coalition on Nuclear Threat Reduction Team, with special thanks to Sébastien Philippe and Chris Rostampour