

RESTRAINING THE NEW NUCLEAR ARMS RACE

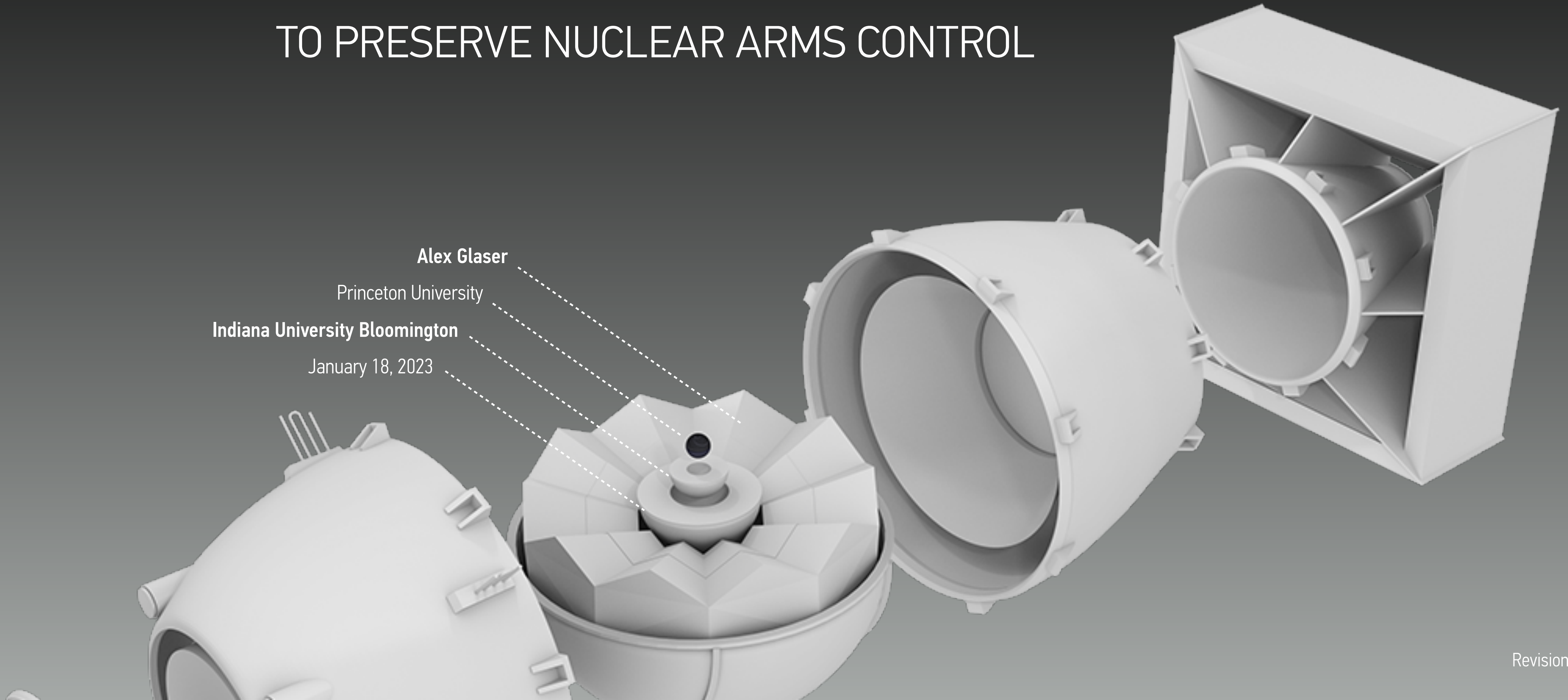
WHAT SCIENTISTS AND ENGINEERS CAN DO
TO PRESERVE NUCLEAR ARMS CONTROL


Alex Glaser

Princeton University

Indiana University Bloomington

January 18, 2023



The image features five flags of nuclear-armed states: the United States, China, France, and the United Kingdom, along with a partially visible Russian flag on the left. The flags are arranged in a cluster, set against a blue background with a faint world map. A semi-transparent dark blue banner is overlaid at the bottom, containing white text.

*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."

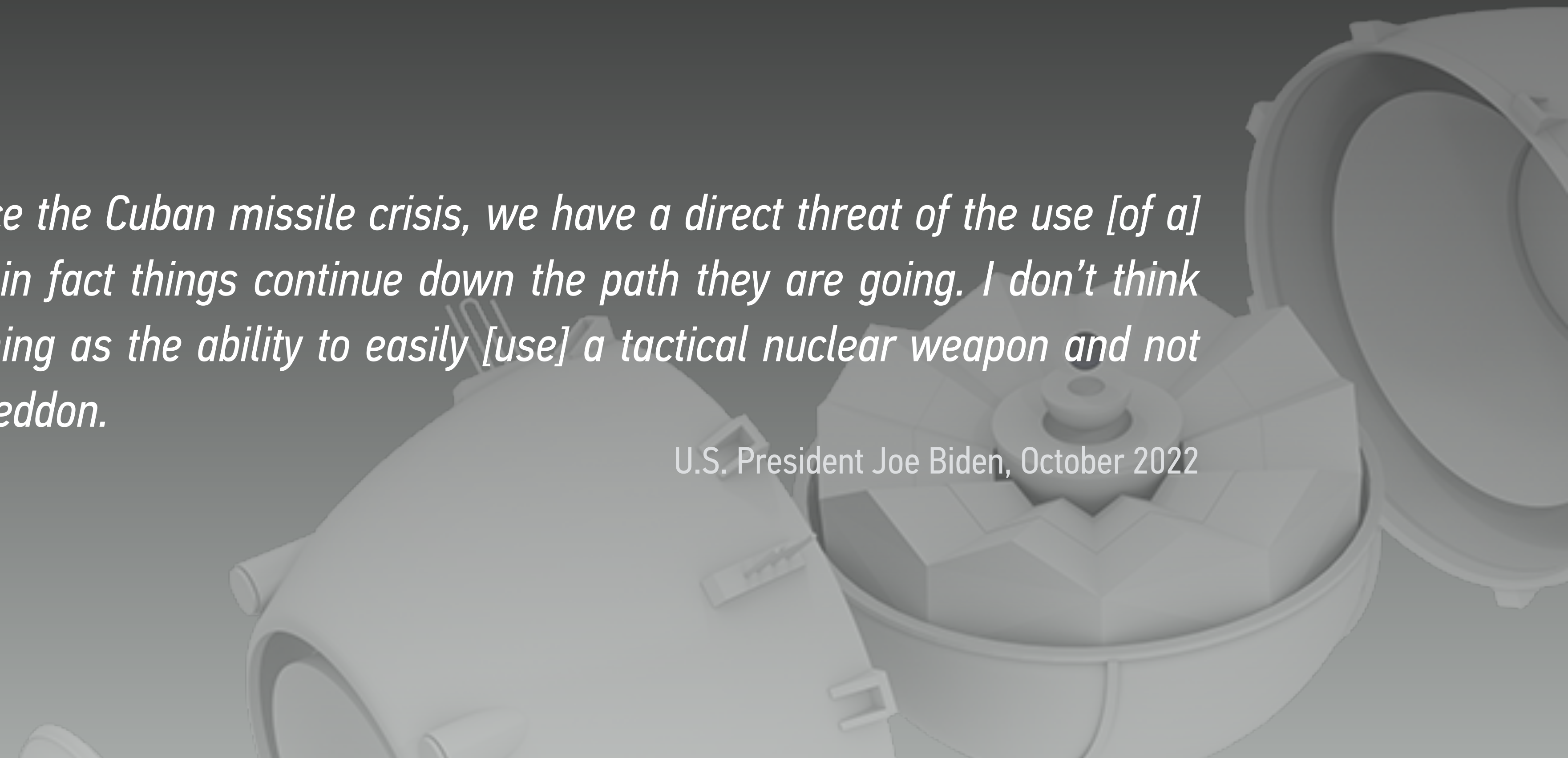
February 27, 2022: Putin orders the minister of defense and the chief of the general staff of the Russian armed forces to transfer the deterrence forces of the Russian army to a "special mode of combat duty."

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

PLAN A

HOW A NUCLEAR WAR
COULD UNFOLD

www.youtube.com/watch?v=2jy3JU-ORpo

2017/2020

CREDITS

Alex Wellerstein

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Sharon Weiner

Zia Mian

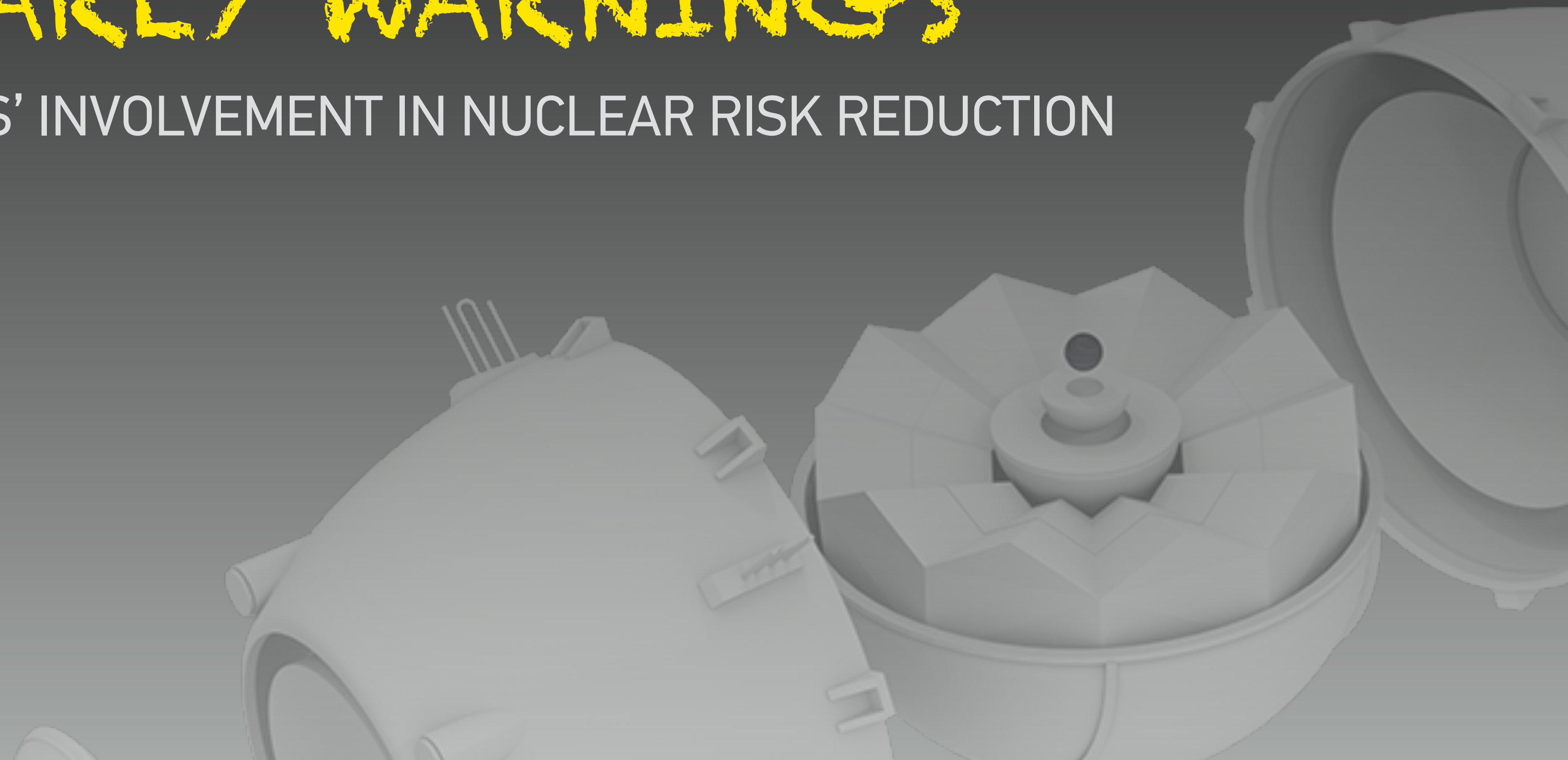
Pavel Podvig

Jeff Snyder (sound)

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

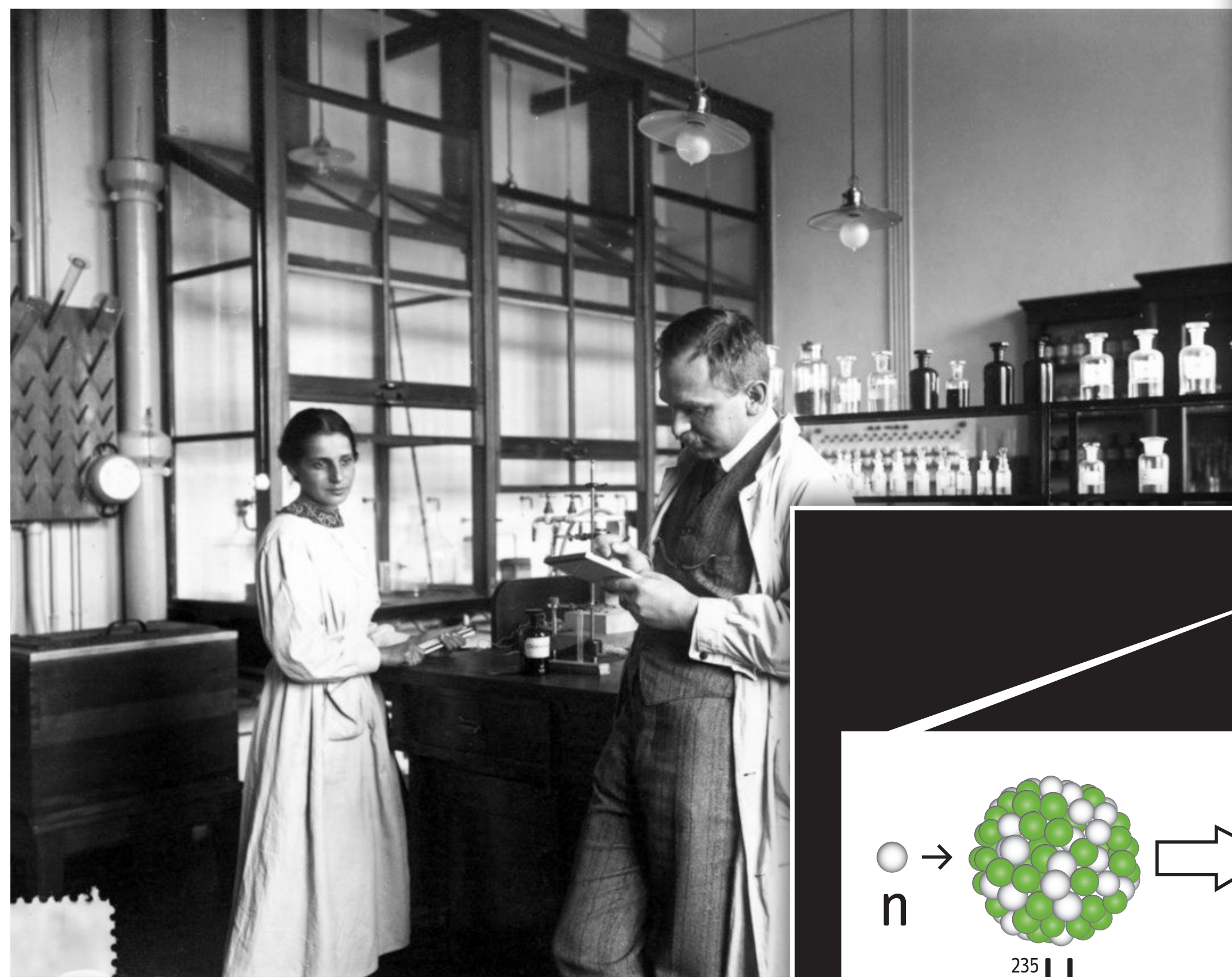
EARLY WARNINGS

PHYSICISTS' INVOLVEMENT IN NUCLEAR RISK REDUCTION



THE DISCOVERY OF NUCLEAR FISSION

(1938/1939)



Lise Meitner and Otto Hahn, Berlin, c. 1925

No. 3615, FEB. 11, 1939

NATURE

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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.

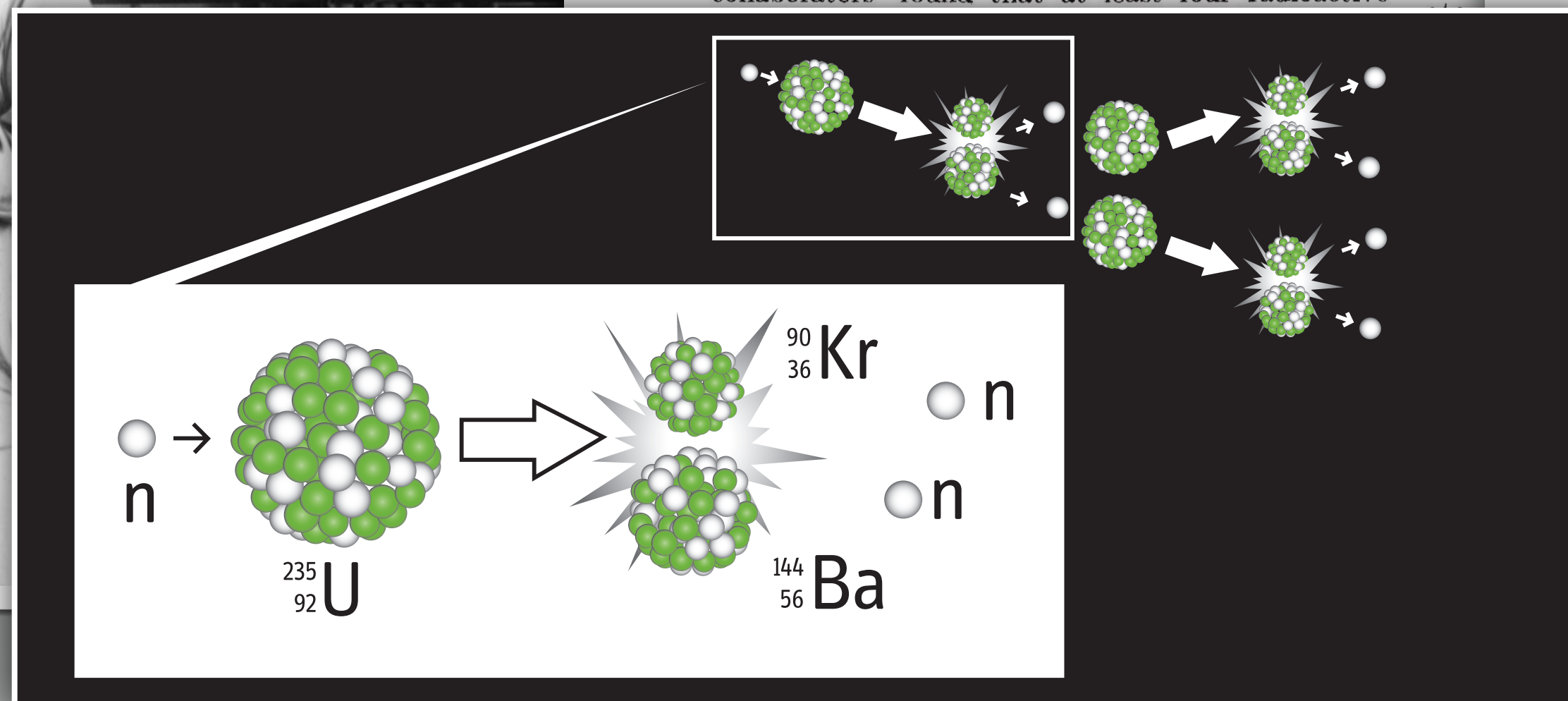
NOTES ON POINTS IN SOME OF THIS WEEK'S LETTERS APPEAR ON P. 247.

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 collaborators¹ found that at least four radioactive

that
dimi
show
with



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NATURE

It might be mentioned that the body with half-life 24 min.² which was chemically identified with uranium is probably really ^{238}U , and goes over into an eka-rhenium which appears inactive but may decay slowly, probably with emission of alpha particles. (From inspection of the natural radioactive elements, ^{238}U cannot be expected to give more than one or two beta decays; the long chain of observed decays has always puzzled us.) The formation of this body is a typical resonance process³; the compound state must have a life-time a million times longer than the time it would take the nucleus to divide itself. Perhaps this state corresponds to some highly symmetrical type of motion of nuclear matter which does not favour 'fission' of the nucleus.

LISE MEITNER.

Physical Institute,
Academy of Sciences,
Stockholm.

O. R. FRISCH.

Institute of Theoretical Physics,
University,
Copenhagen.
Jan. 16.

that Hahn and Strassmann were forced to conclude that isotopes of barium ($Z = 56$) are formed as a

two
chain

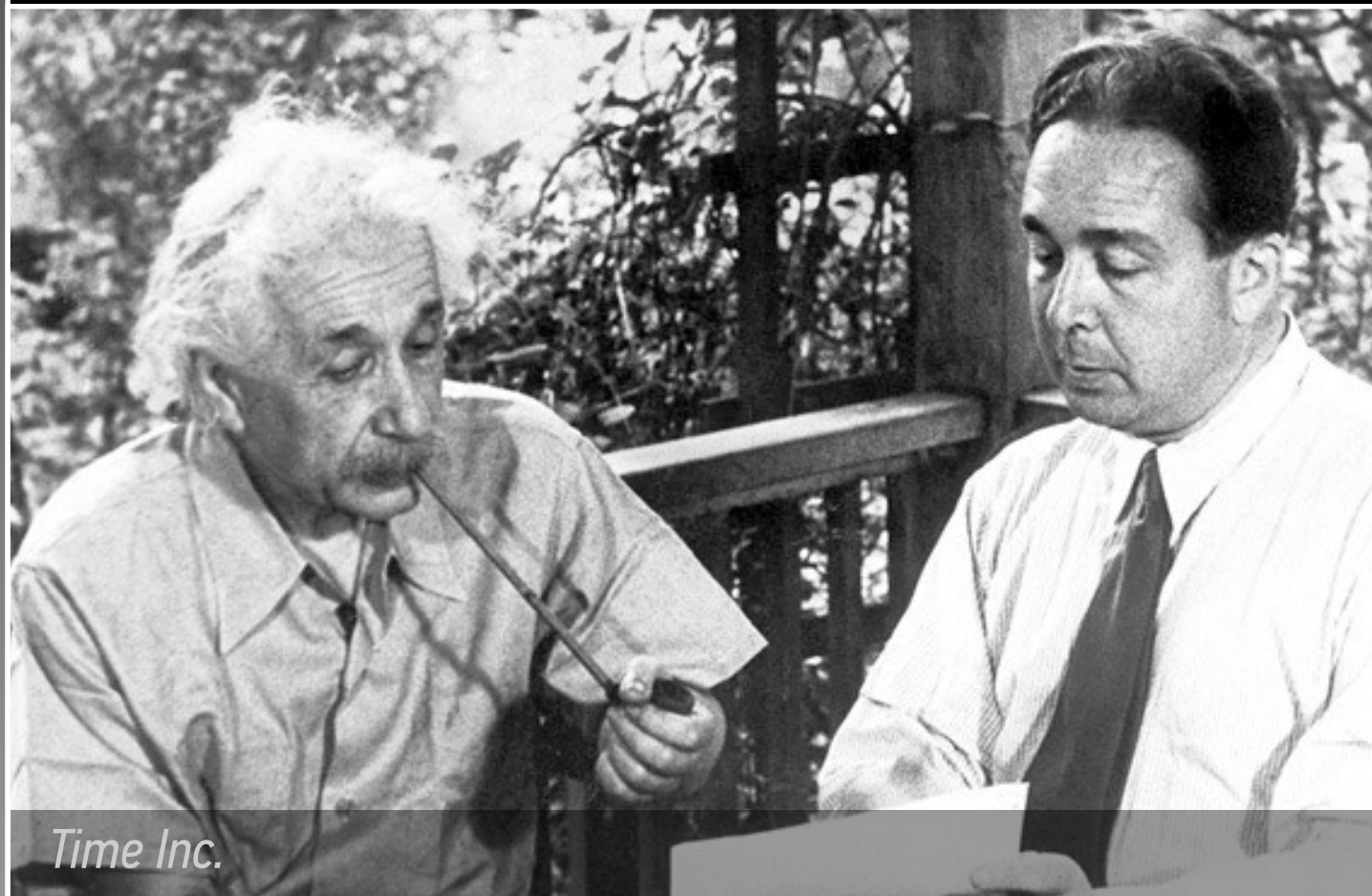
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EARLY INTERVENTIONS

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

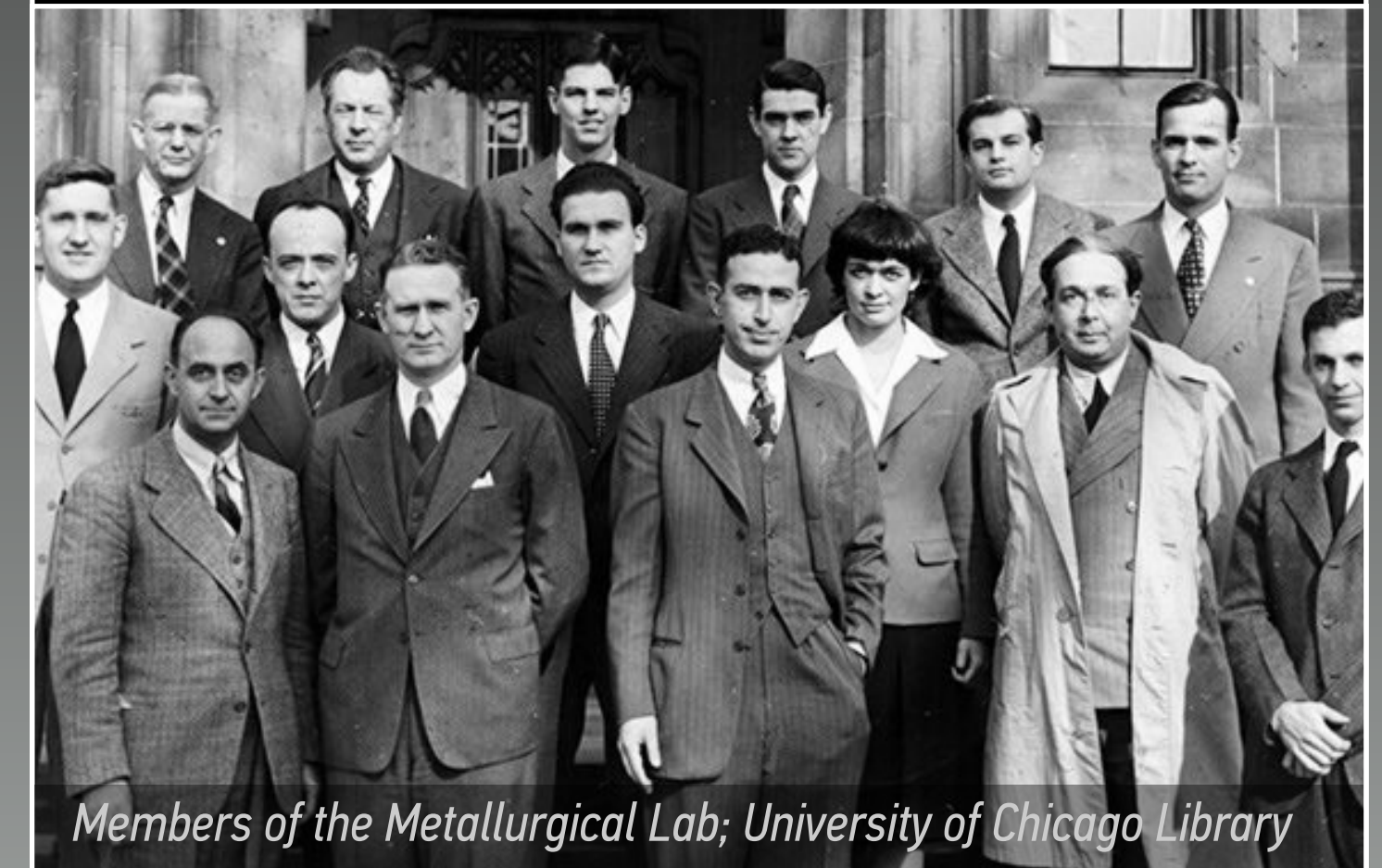
Niels Bohr advocates for not using the atomic bomb without first notifying Stalin, trying to lay the basis for post-war control of nuclear energy.



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, hpmuseum.jp

John Hersey, "Hiroshima," New Yorker, August 31, 1946, www.newyorker.com/magazine/1946/08/31/hiroshima

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,


A. Einstein.

**There is no
secret, and there
is no defense.**

*Albert Einstein on behalf of the
Emergency Committee of Atomic Scientists
Princeton, NJ, December 1946*

FROM KILOTONS TO MEGATONS

THE INVENTION OF THE H-BOMB, 1952



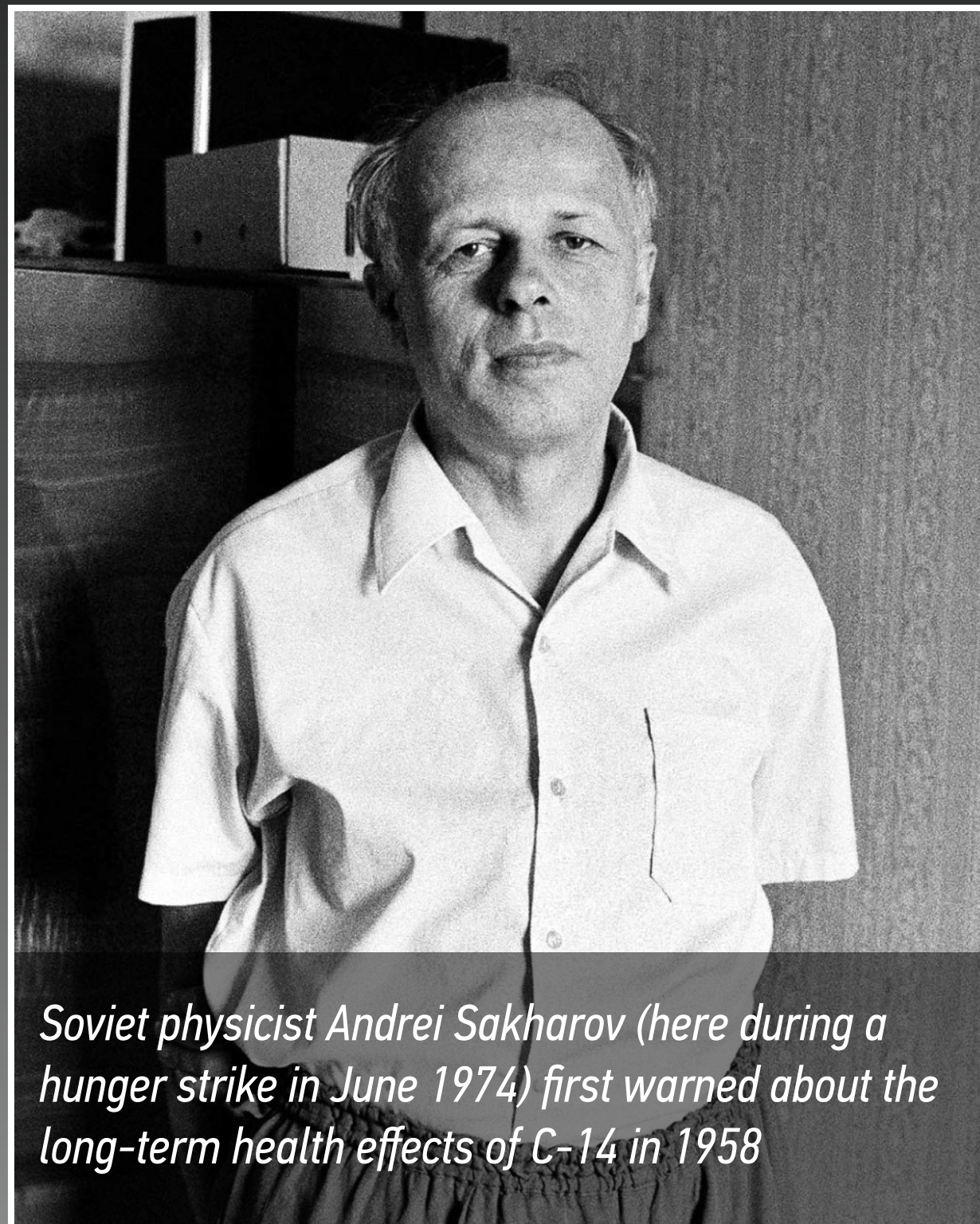
“Let it be clearly realized that this is a super weapon; it is in a totally different category from an atomic bomb. The reason for developing such super bombs would be to have the capacity to devastate a vast area with a single bomb. Its use would involve a decision to slaughter a vast number of civilians. 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

Photo: French thermonuclear test “Licorne” (914 kt, July 1970), Moruroa Atoll, South Pacific

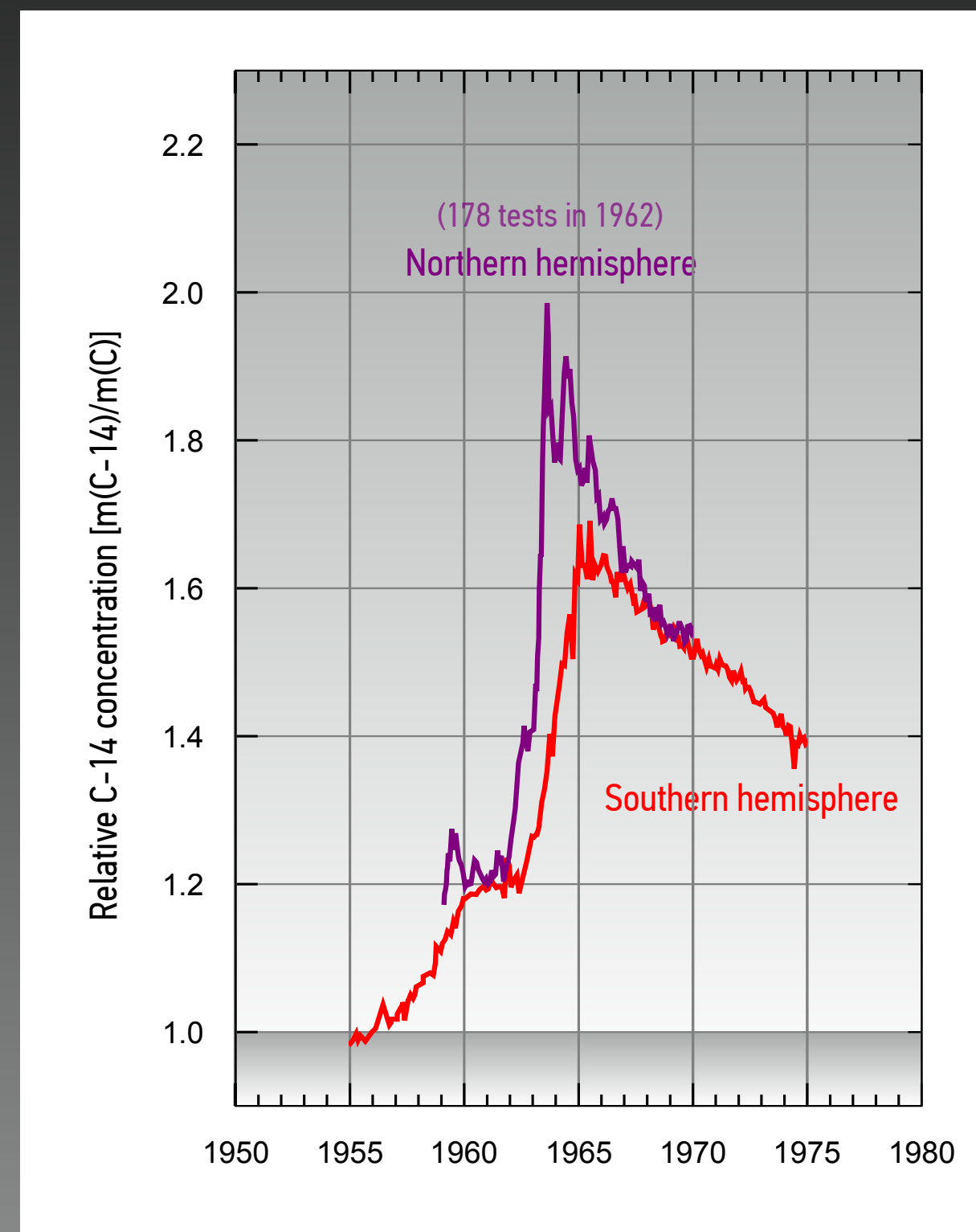
ENDING NUCLEAR TESTING IN THE ATMOSPHERE

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

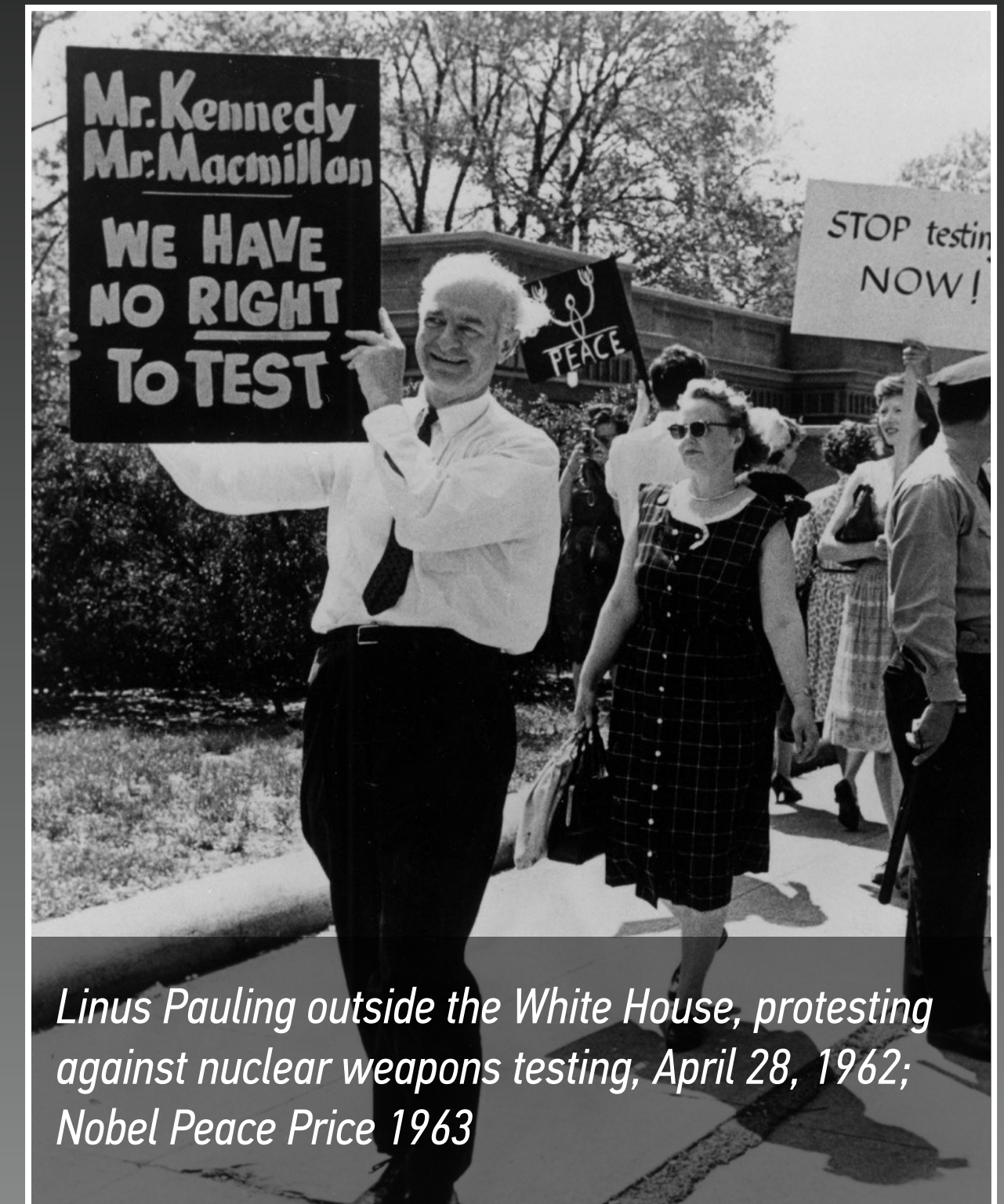


Soviet physicist Andrei Sakharov (here during a hunger strike in June 1974) first warned about the long-term health effects of C-14 in 1958

Source: Anonymous



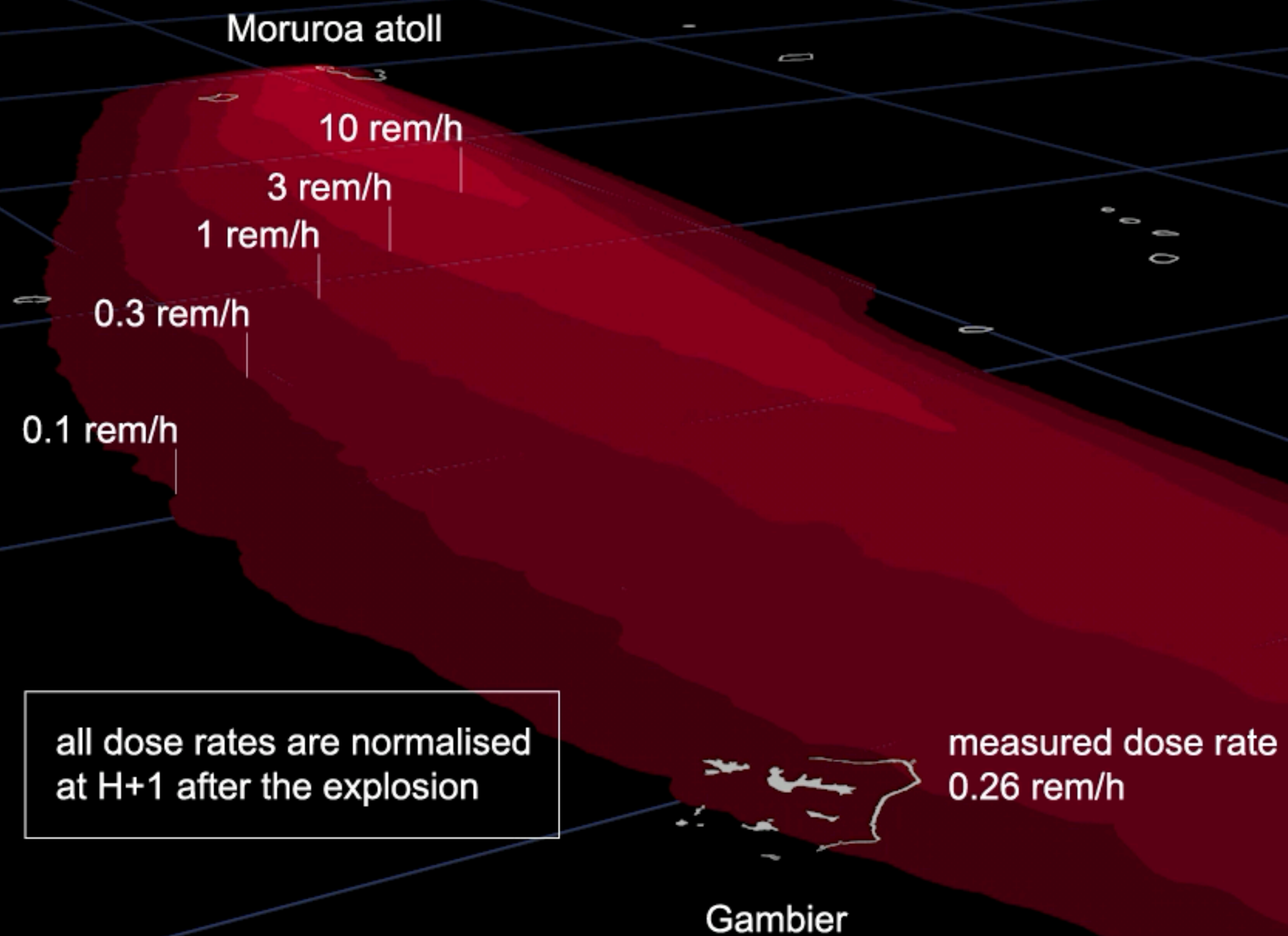
Source: Adapted from CDIAC/ORNL



Linus Pauling outside the White House, protesting against nuclear weapons testing, April 28, 1962; Nobel Peace Prize 1962

Source: AIP Emilio Segre Visual Archives

Frank von Hippel, "The Long-Term Global Health Burden from Nuclear Weapon Test Explosions in the Atmosphere: Revisiting Andrei Sakharov's 1958 Estimates," *Science & Global Security*, 30 (2), 2022, doi.org/10.1080/08929882.2022.2119716



*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*

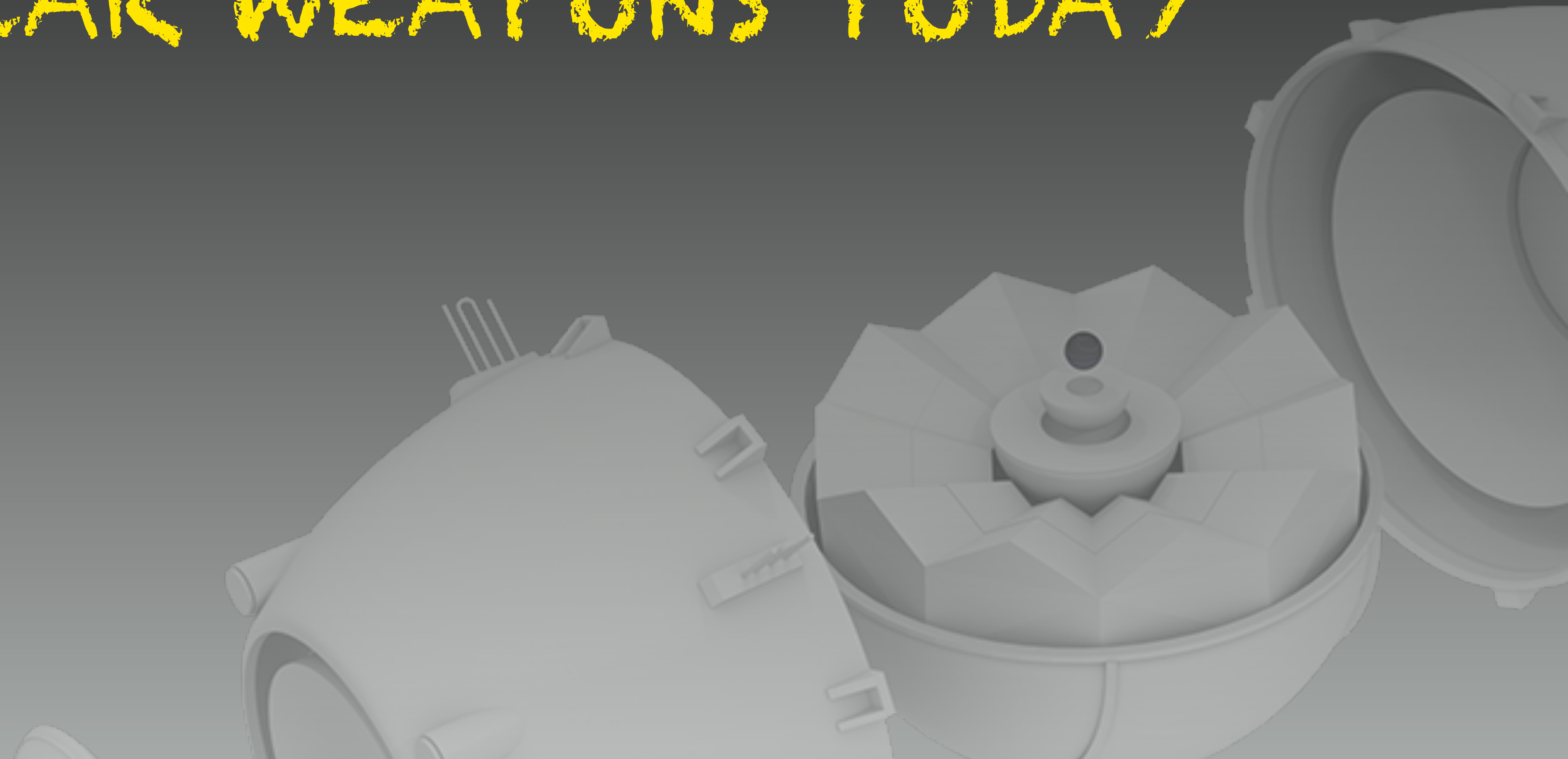
S. Philippe, S. Schoenberger, and N. Ahmed, scienceandglobalsecurity.org/archive/sgs30philippe.pdf

ALDEBARAN

03 July

03:40

NUCLEAR WEAPONS TODAY



USA
5,500



U.S. Nuclear Weapon

Russia
6,000



United Kingdom
215



France
300



Israel
80



Pakistan
135



India
125



China
350



North Korean Nuclear Weapon

North Korea
15

***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



Primary
Typically 3–4 kg of
plutonium

Secondary
Typically 15–25 kg of
enriched uranium

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***

MOAB
(11 tons of TNT, Ø 0.1 miles)

200 kt
(47.8 square miles)
Area destroyed by mass fire

200 kt
(5.7 square miles)
Area destroyed by air blast

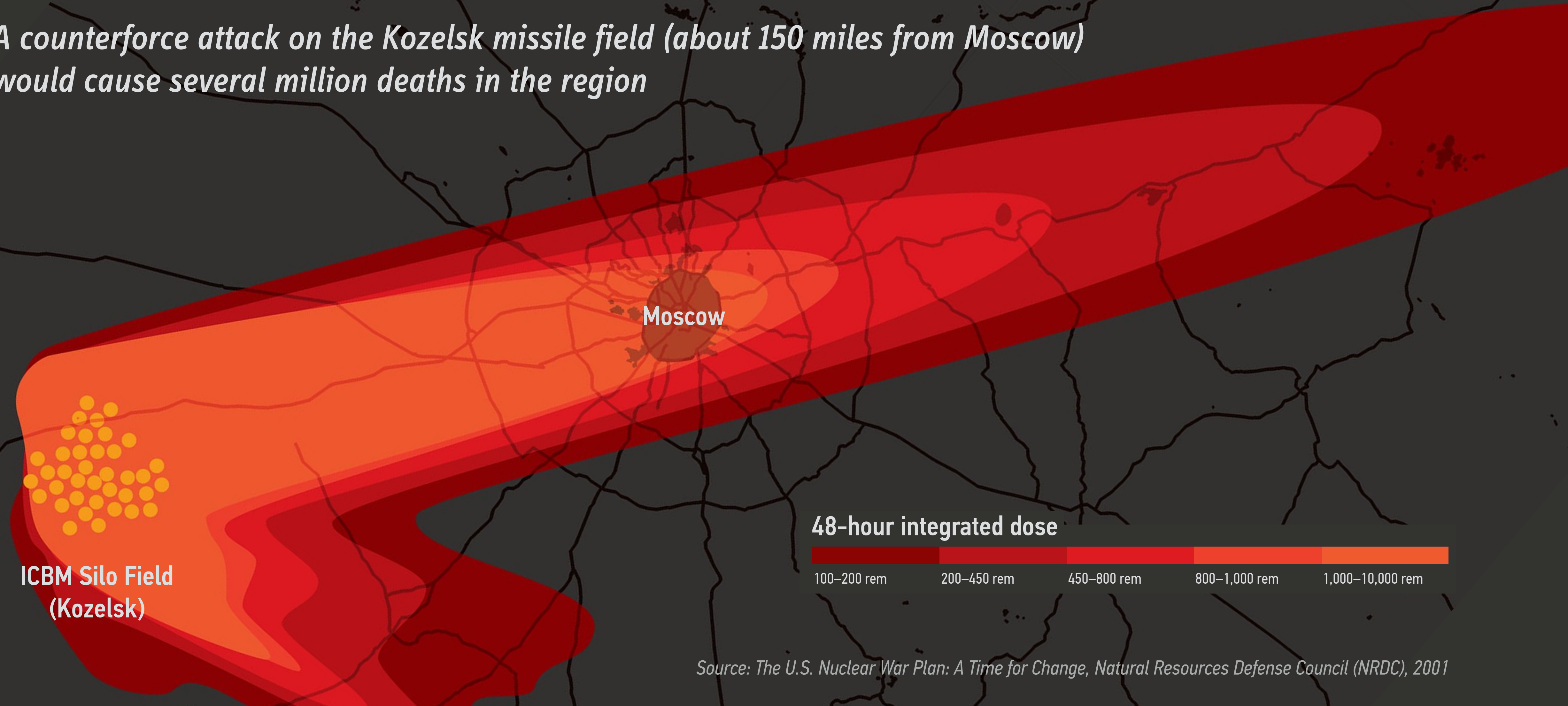
16 kt
Hiroshima-sized
explosion
(1.1 square miles)

New York City

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

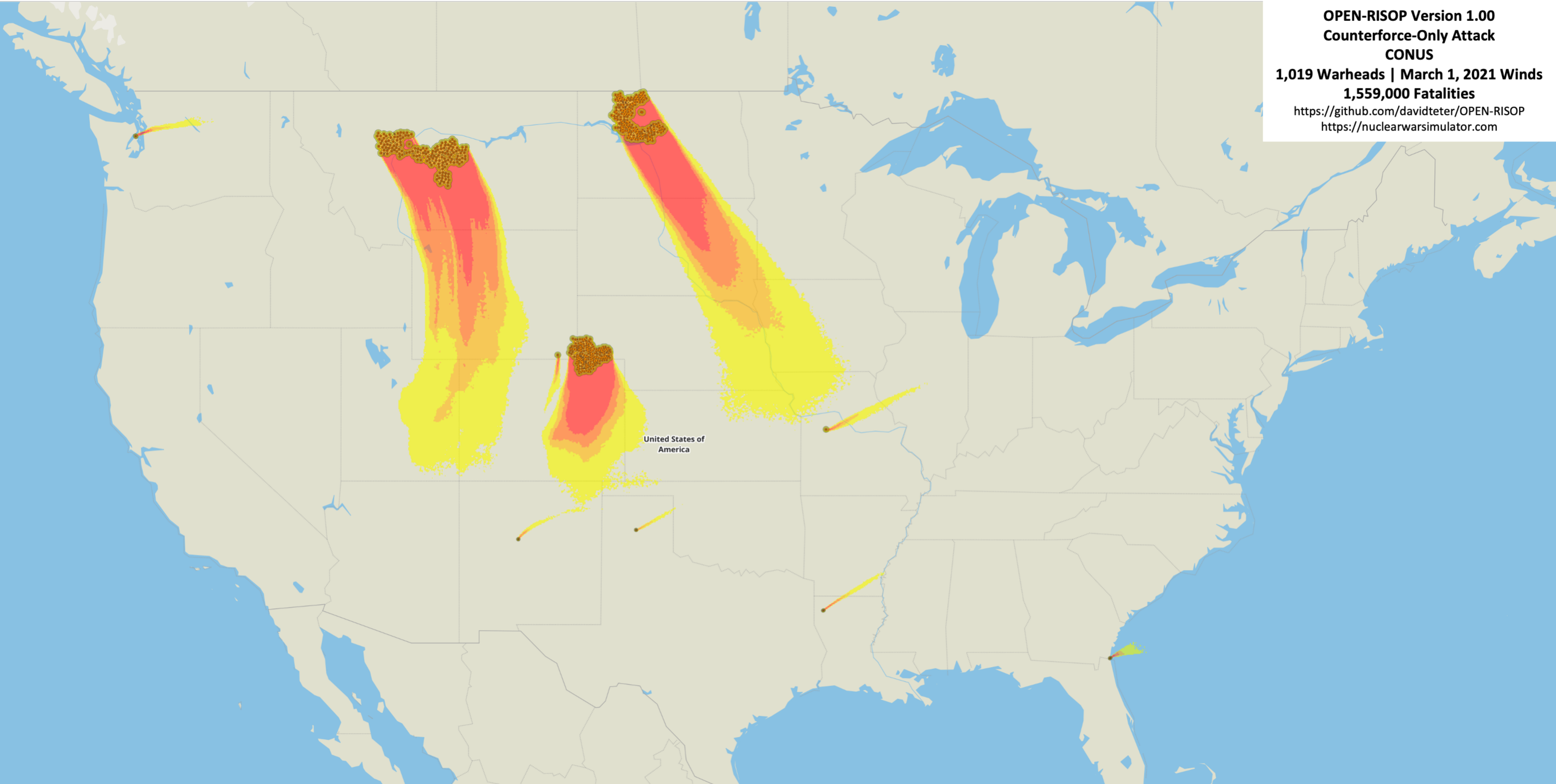
The catastrophic effects of nuclear weapons are not limited to the intended target

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



Source: *The U.S. Nuclear War Plan: A Time for Change*, Natural Resources Defense Council (NRDC), 2001

OPEN-RISOP Version 1.00
Counterforce-Only Attack
CONUS
1,019 Warheads | March 1, 2021 Winds
1,559,000 Fatalities
<https://github.com/davidteter/OPEN-RISOP>
<https://nuclearwarsimulator.com>

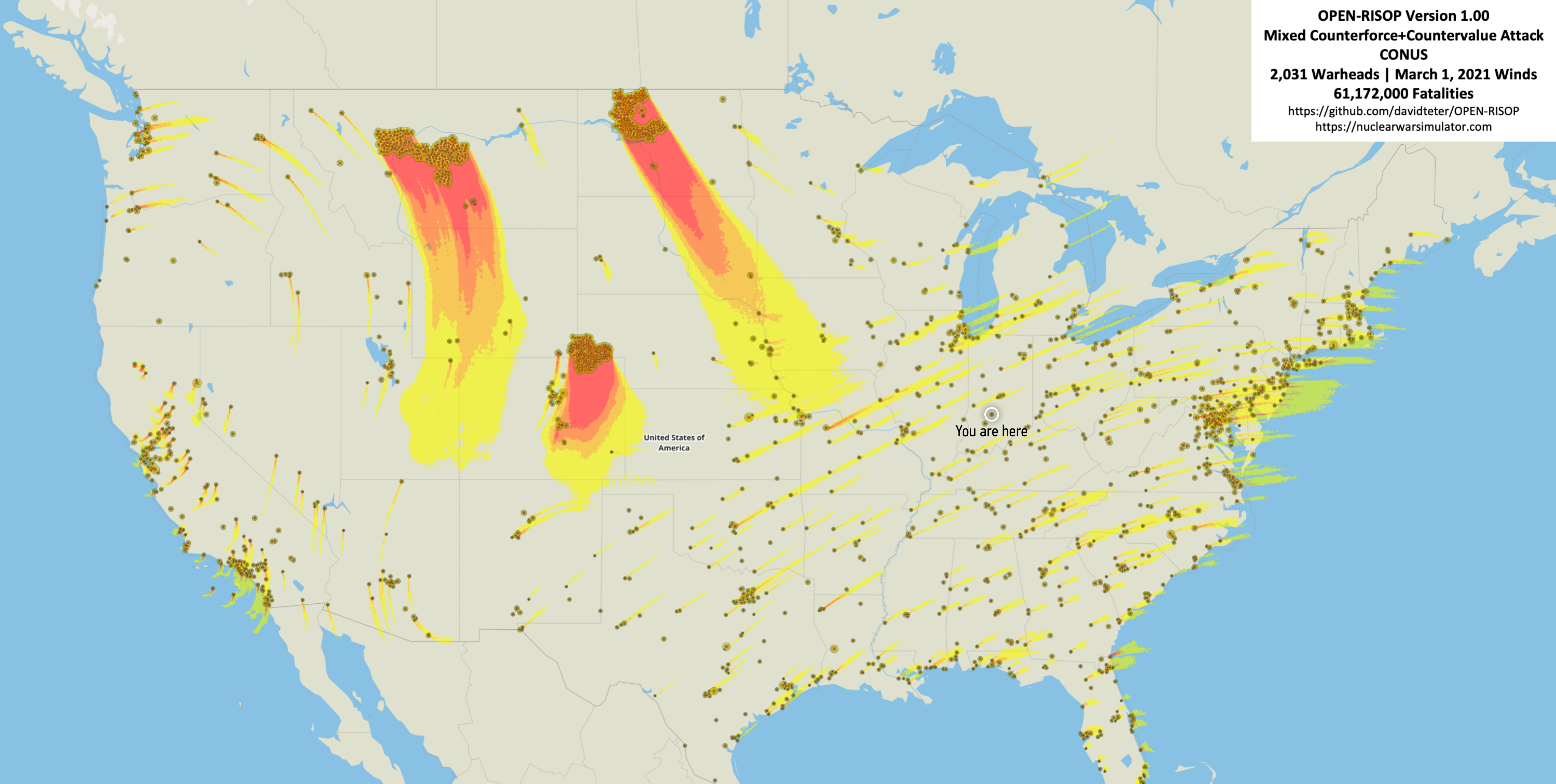


Fallout Radiation Effects

- 100 Roentgen Integrated Dose – Mild Radiation Sickness
- 500 Roentgen Integrated Dose – ~60% Deaths
- 1,000 Roentgen Integrated Dose – ~95% Deaths
- 5,000 Roentgen Integrated Dose – ~100% Deaths

Source: David Teter
github.com/davidteter/OPEN-RISOP/

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>



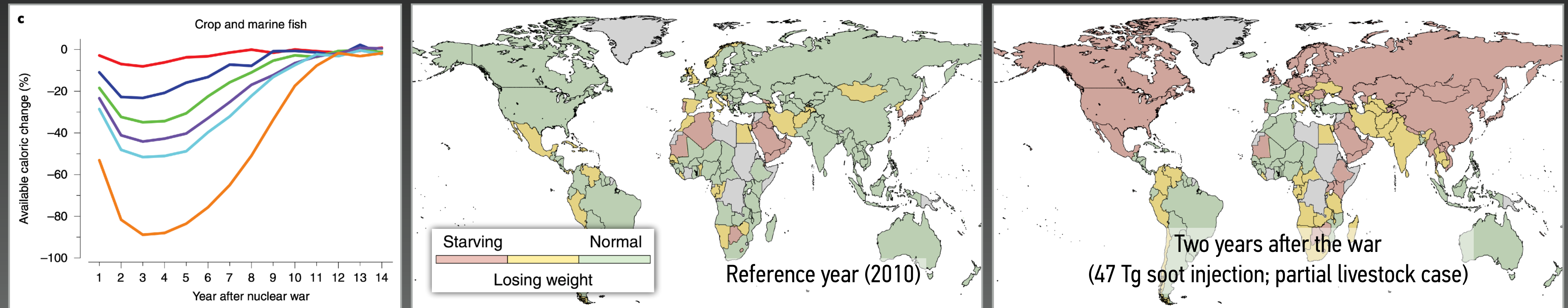
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- 5,000 Roentgen Integrated Dose – ~100% Deaths

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

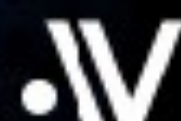


AVAILABLE ON META QUEST

ON THE MORNING YOU WAKE (TO THE END OF THE WORLD)



ARCHER'S MARK



Novelab.



SCIENCE &
GLOBAL SECURITY
PRINCETON UNIVERSITY



vr for good

arte



HOW DID I GET INTO THIS? (NEUTRONICS!)

PLUTONIUM DISPOSITION

1990s

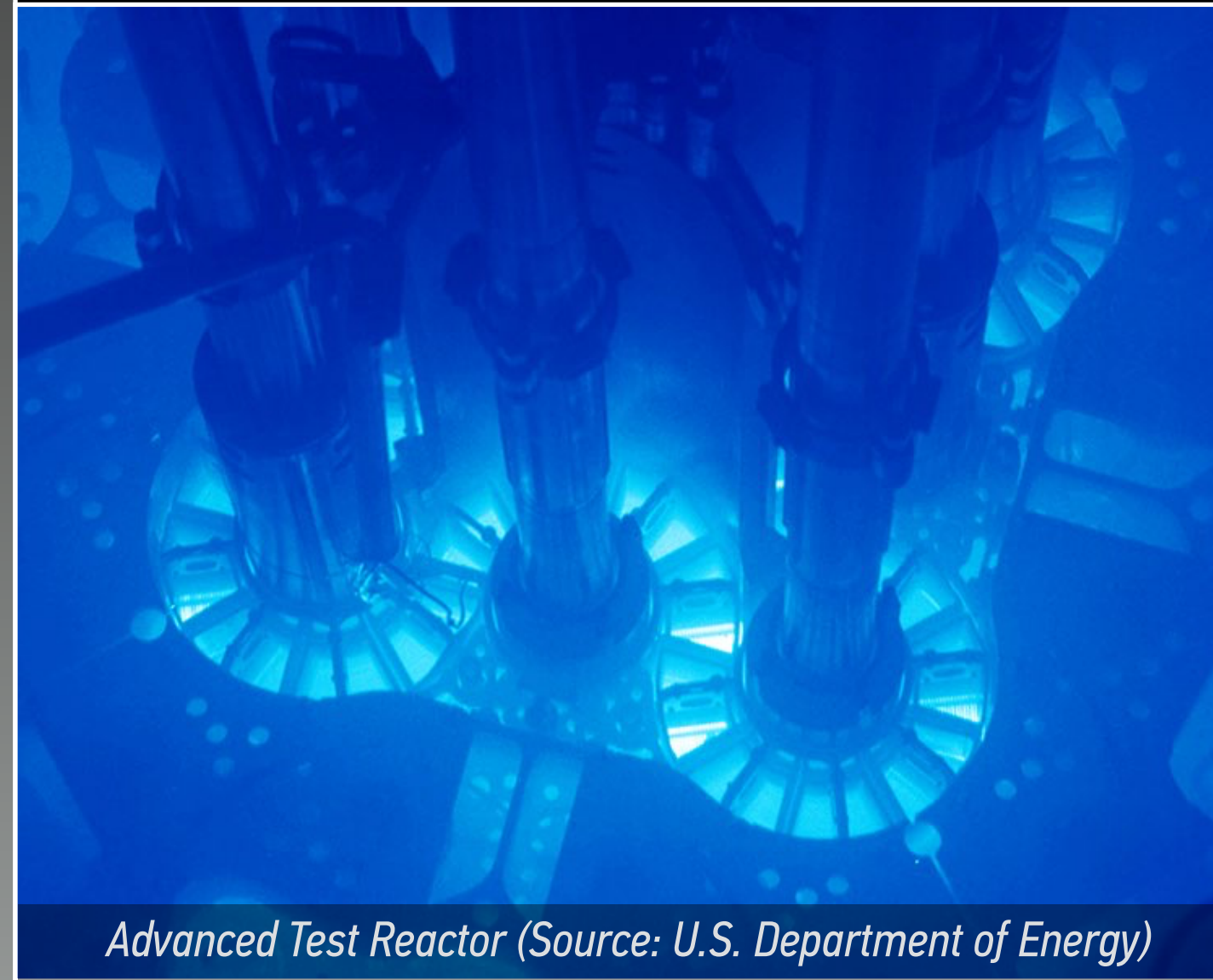
Can one eliminate or irreversibly dispose
50–100 tons of excess weapons plutonium?



REACTOR CONVERSION

2000s

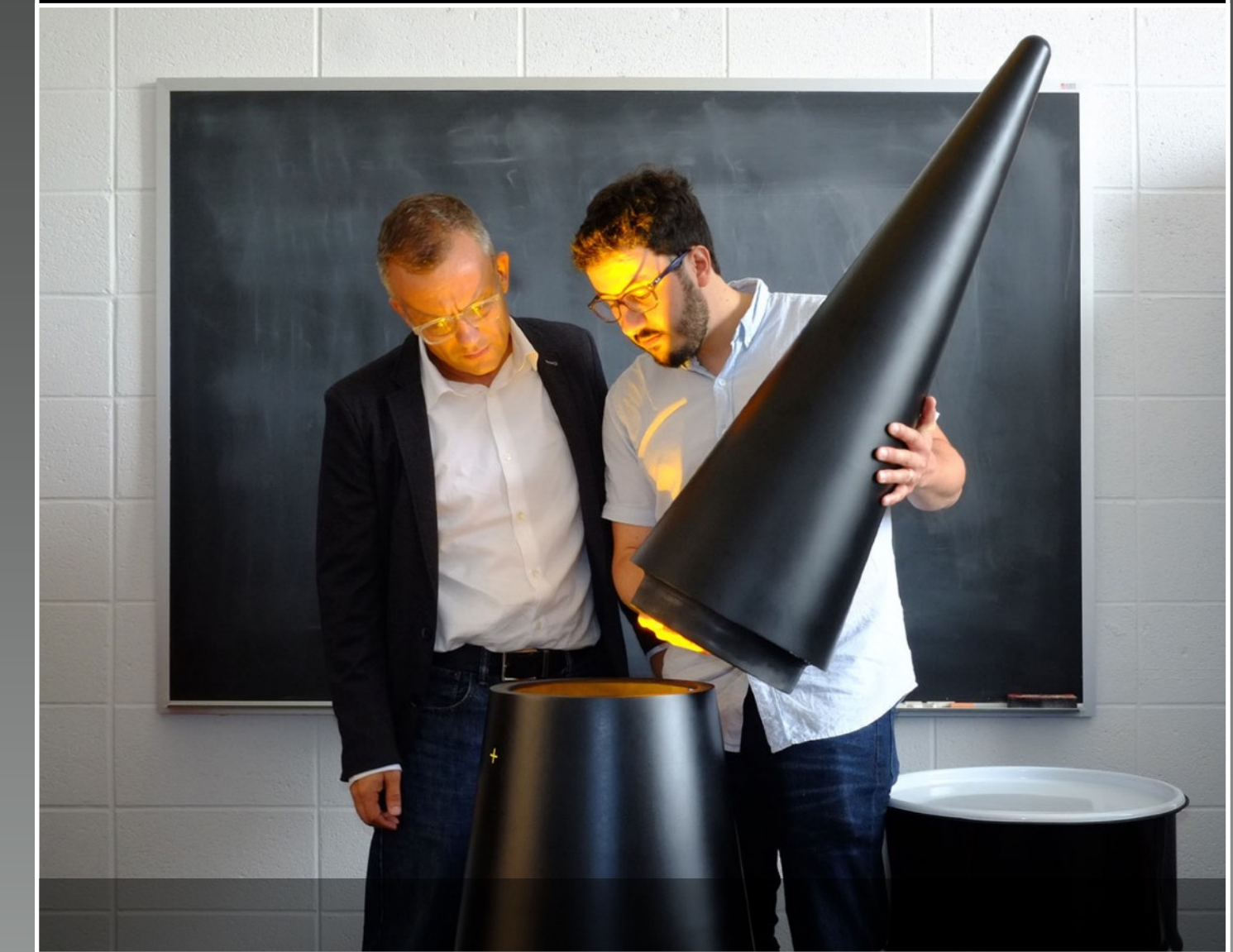
Can one use low-enriched uranium in
research reactors without performance loss?



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

1340 tons of highly enriched uranium (HEU)

520 tons of separated plutonium

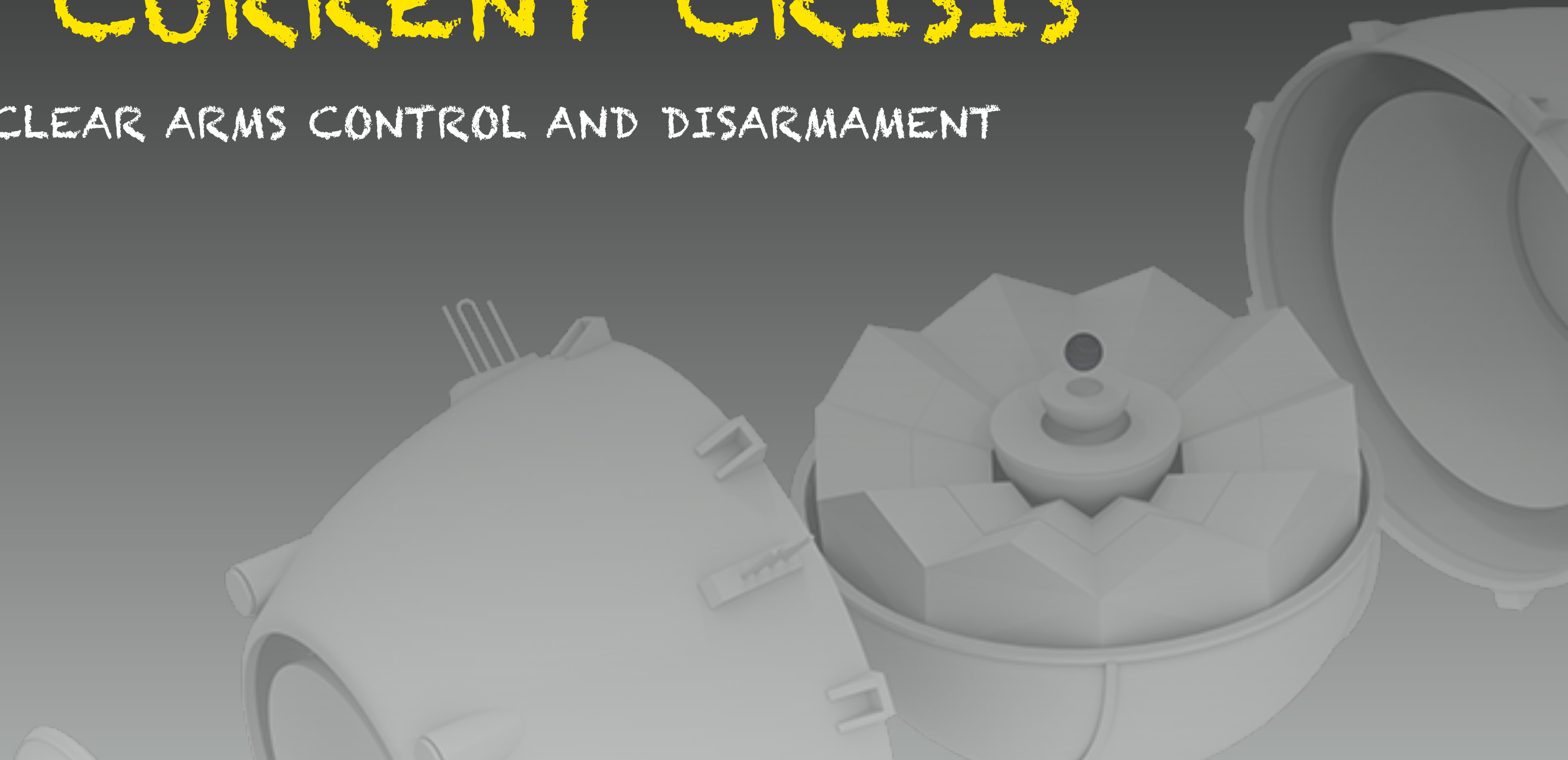


*Each block corresponds to 12 kg of HEU, the amount necessary to
make a fission bomb; about 111,670 bombs-worth total*

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

THE CURRENT CRISIS

IN NUCLEAR ARMS CONTROL AND DISARMAMENT



LANDMARK NUCLEAR ARMS CONTROL TREATIES

ANTI-BALLISTIC MISSILE TREATY

(1972–2002)



Source: U.S. Missile Defense Agency

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

The United States withdrew in 2002

INTERMEDIATE NUCLEAR FORCES

(1988–2019)



Source: www.defenseimagery.mil

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

START & New START

(1994–2009, 2011–2026)



Source: Alexander Zemlianichenko, Associated Press

START and New START requires the United States and Russia to reduce and limit their deployed strategic weapons

New START will expire in 2026

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

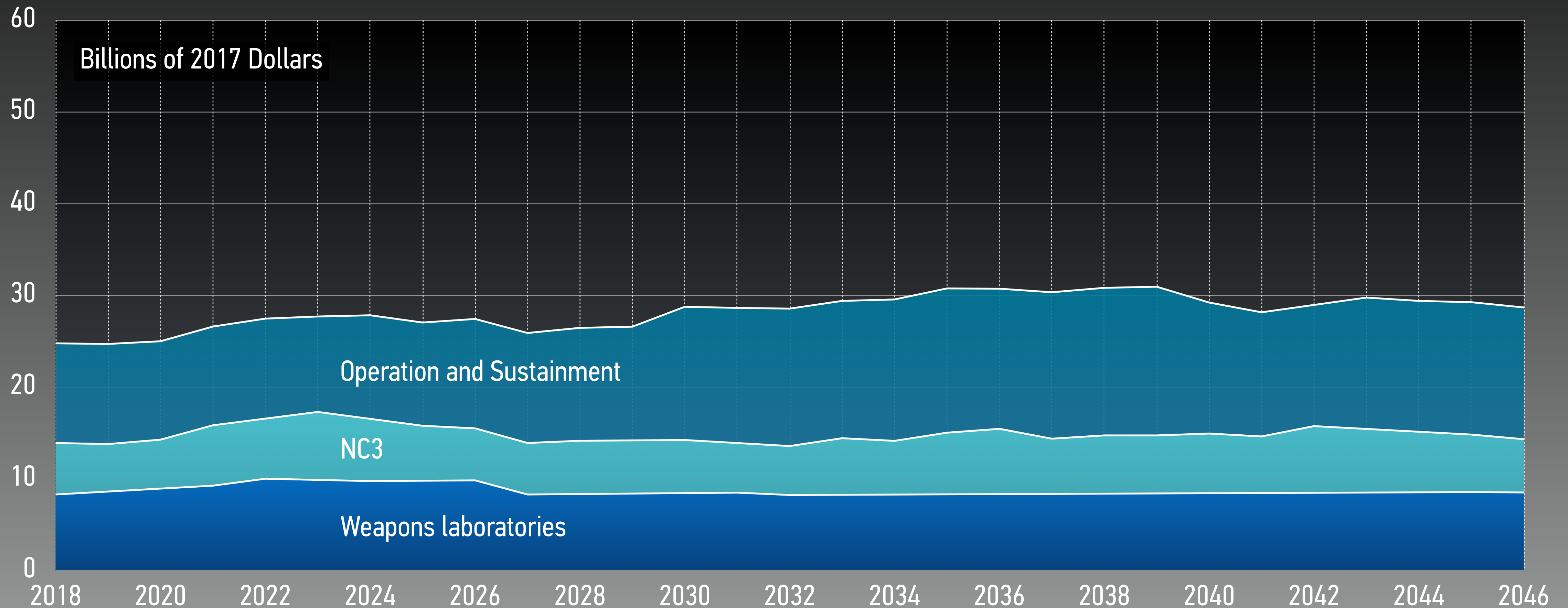
SO WHAT

WHAT IS NEW HERE AND WHY SHOULD I CARE?



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

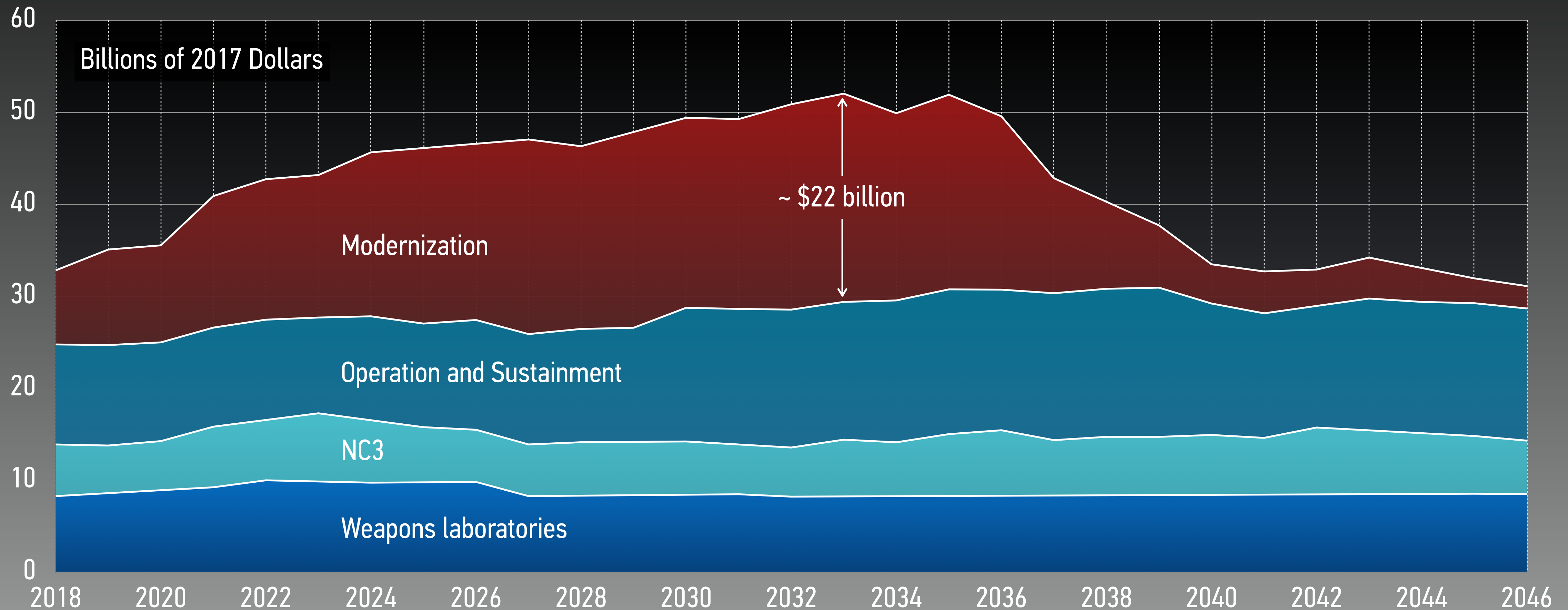
AND THE MODERNIZATION “BOW WAVE”



Source: *Approaches for Managing the Costs of U.S. Nuclear Forces, 2017 to 2046*, Congressional Budget Office, October 2017, www.cbo.gov/publication/53211

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

AND THE MODERNIZATION “BOW WAVE”



Source: *Approaches for Managing the Costs of U.S. Nuclear Forces, 2017 to 2046*, Congressional Budget Office, October 2017, www.cbo.gov/publication/53211

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

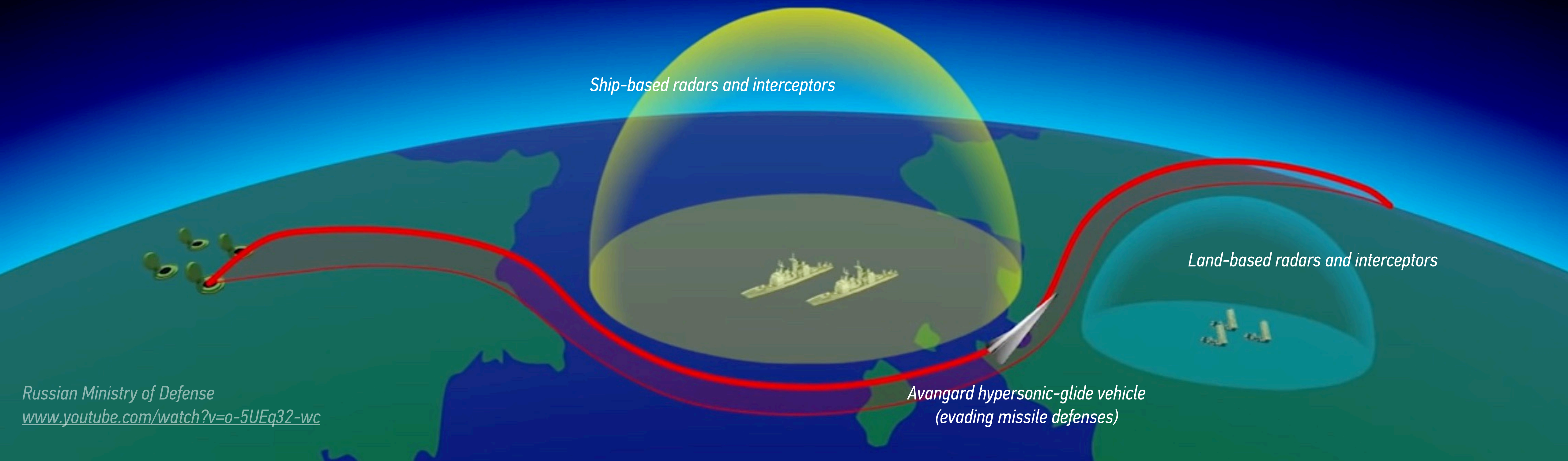


RUSSIA

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



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)

~ 4 km

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/

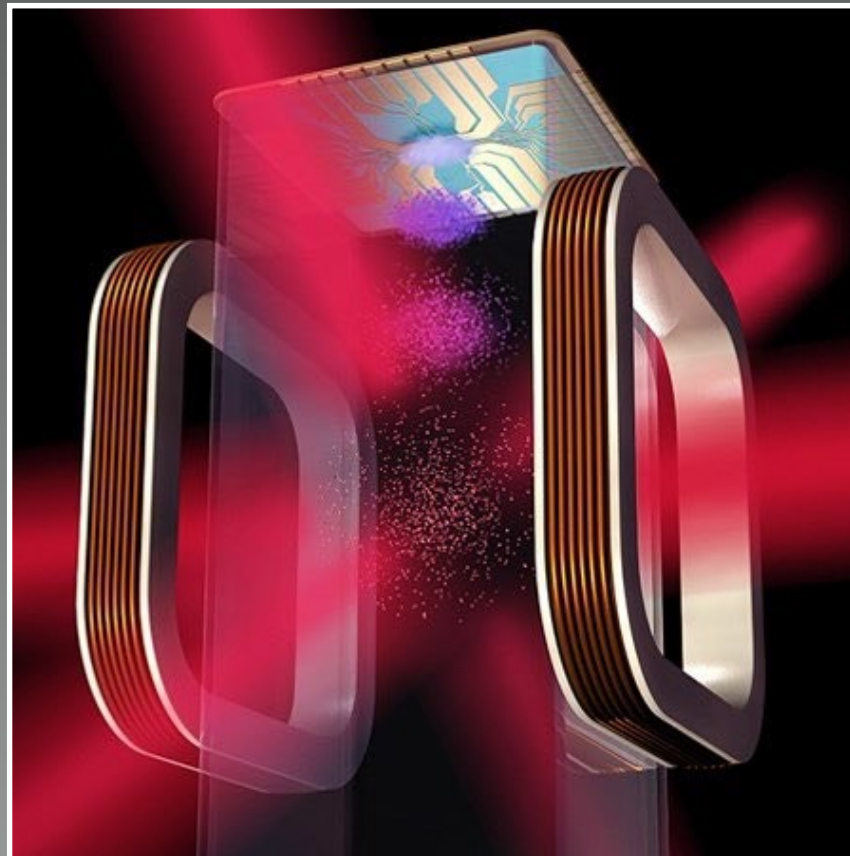
20 km (~ 12 miles)

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



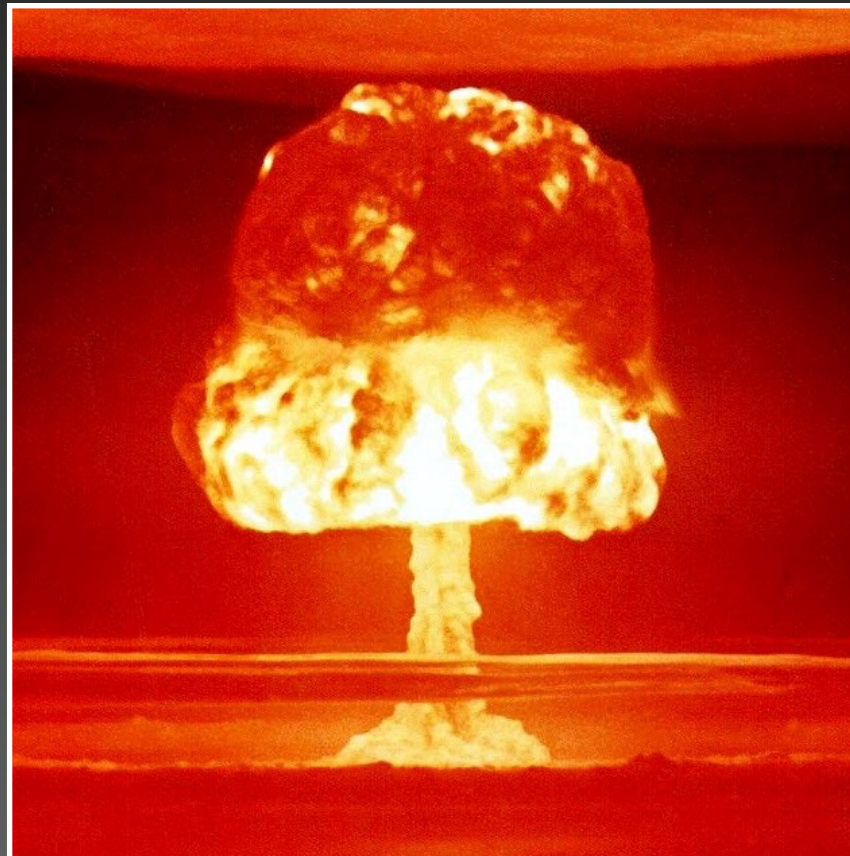
NEXT-GENERATION (“EMERGING”) TECHNOLOGIES

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

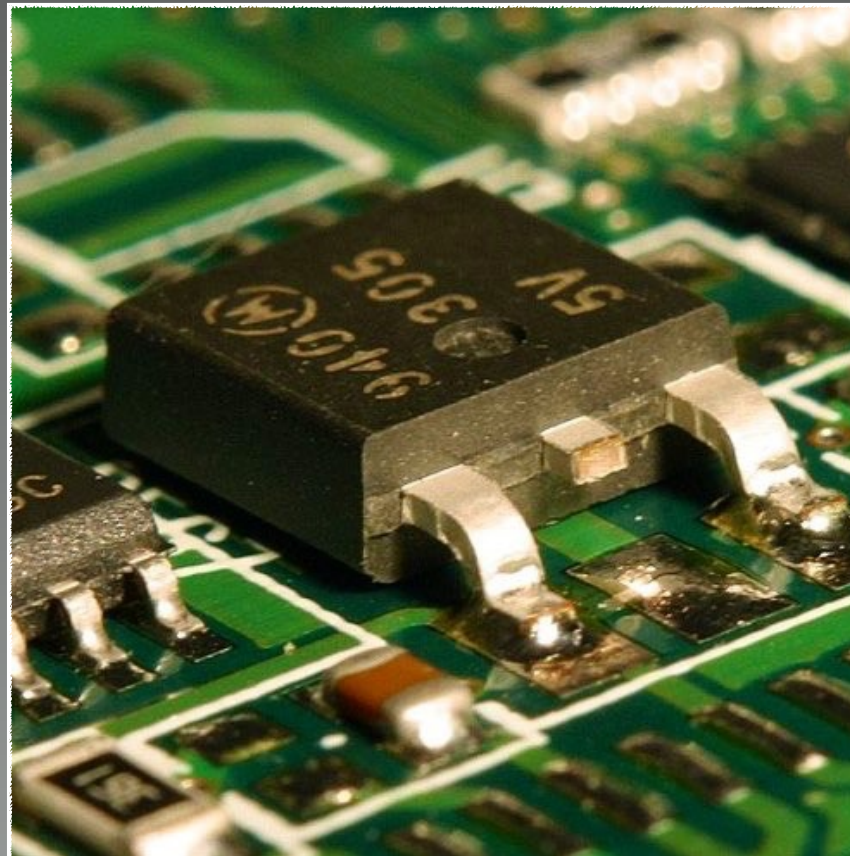
risks & vulnerabilities



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



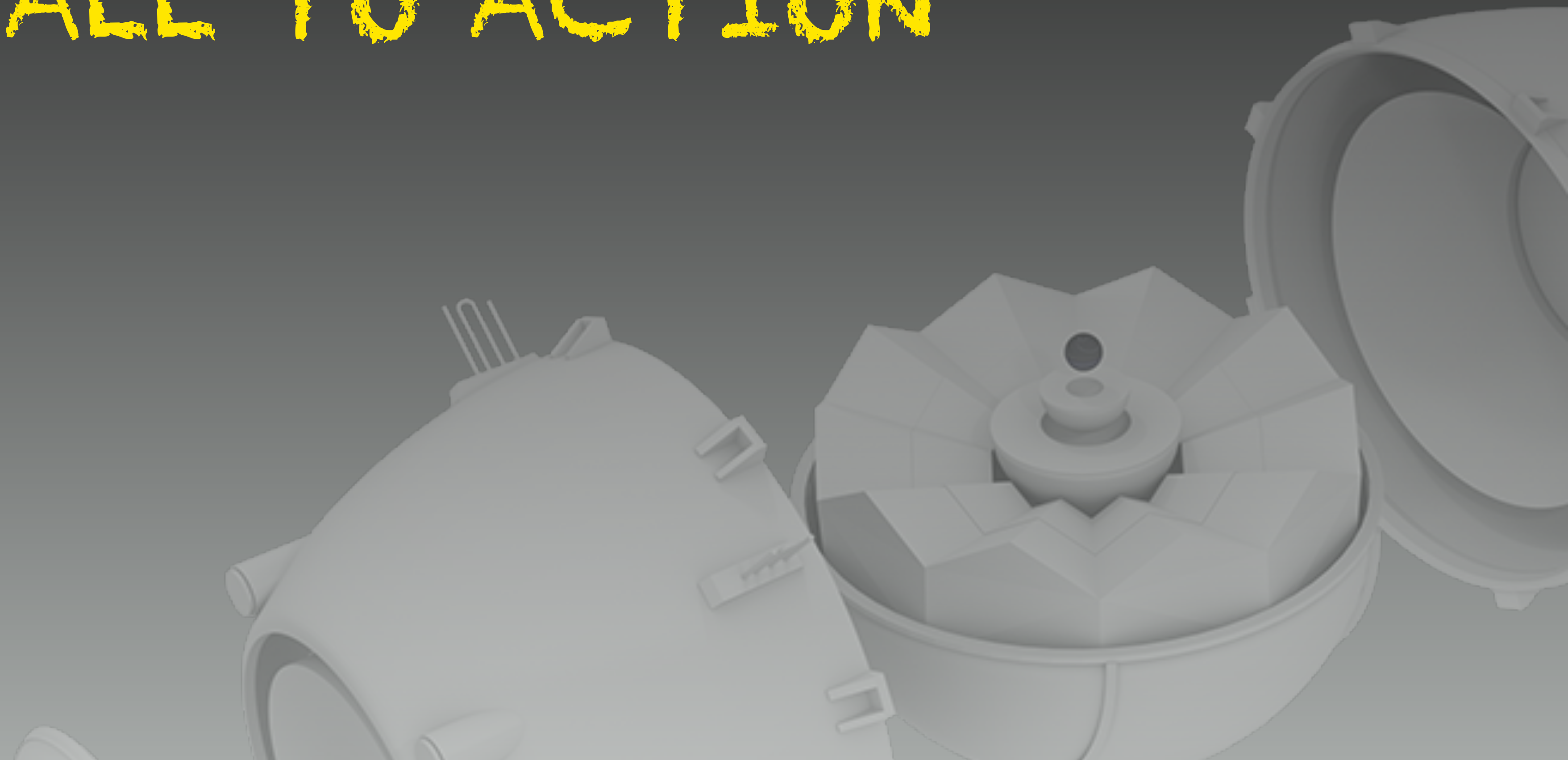
CYBER VULNERABILITIES

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

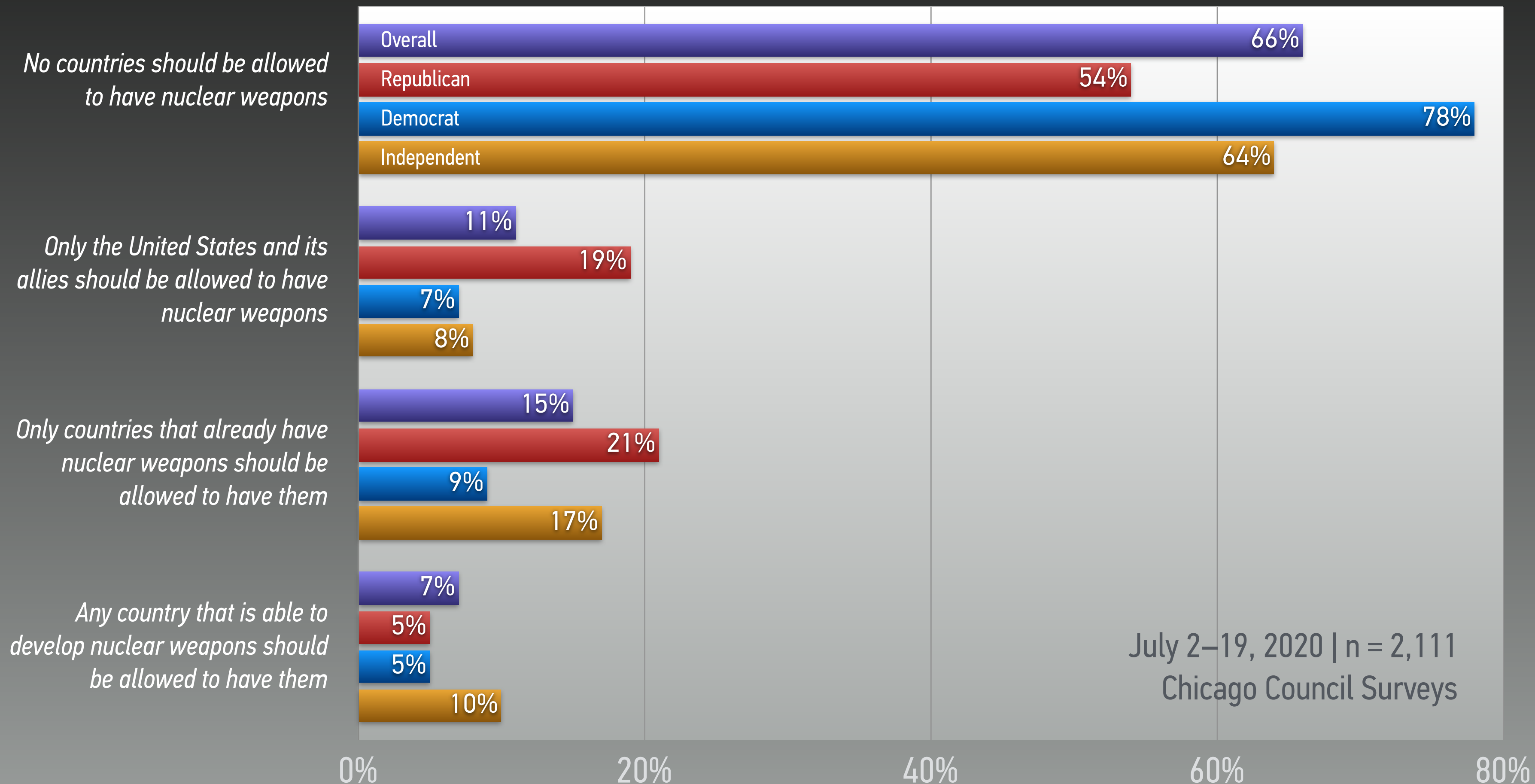
Source: Castle Bravo (top) and [wikimedia.org/pdphoto.org](https://commons.wikimedia.org/wiki/File:Microchip.jpg) (bottom)

CALL TO ACTION



WHO SHOULD HAVE NUCLEAR WEAPONS?

WHICH STATEMENT COMES CLOSEST TO YOUR VIEW?



www.thechicagocouncil.org/commentary-and-analysis/blogs/americans-want-nuclear-free-world

WHERE DO WE GO FROM HERE?



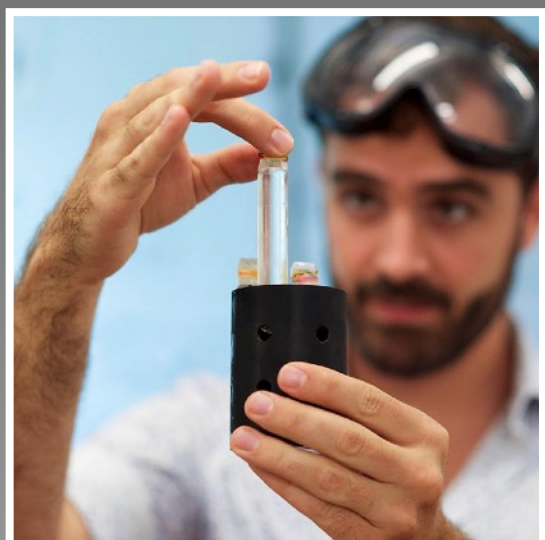
WE NEED PUBLIC REENGAGEMENT

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)

PHYSICISTS COALITION FOR NUCLEAR THREAT REDUCTION

www.physicistscoalition.org

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

“CONDEMNING ALL THREATS TO USE NUCLEAR WEAPONS”

A STATEMENT FROM SCIENTISTS, JANUARY 2023

“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.”

physicistscoalition.org/take-action



***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