



# Nuclear Threat Reduction

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*Presentation developed within the framework of the APS Physicists Coalition for Nuclear Threat Reduction*

# Outline

Some technical aspects

- Bombs, the world arsenal, and their effects

Policy aspects

- The long peace and close calls

The current nuclear threat and how to reduce it

Engagement of the scientific community and the public in nuclear threat reduction

- Past efforts
- The APS Physicists Coalition for Nuclear Threat Reduction - <https://sgs.princeton.edu/physicistscoalition>



## Nuclear Threat Reduction

*The number of nuclear weapons is declining at a slow pace. The US, Russia, and the UK are reducing their nuclear arsenals, France and Israel have stable inventories, while China, Pakistan, India, and North Korea are developing new capabilities.*

Mikhail Gorbachev and Ronald Reagan after signing the Intermediate Range Nuclear Forces (INF) Treaty in 1987.

Figures depicting Vladimir Putin and Donald Trump breaking the INF Treaty during the Rosenmontag parade in Dusseldorf, 2019.

# The Discovery of Nuclear Fission

*Dual-use of nuclear energy started in the early days*

- August 2, 1939  
Albert Einstein sent a letter to President Roosevelt, advising him to fund research to explore the possibility of using nuclear fission as a weapon.
- October 21, 1939  
The Advisory Committee on Uranium budgeted \$6,000 for neutron experiments led by Fermi and Szilárd. The Manhattan project has officially started.



Lise Meitner, Otto R. Frisch



Otto Hahn, Fritz Strassmann  
achieved fission in Berlin, 1938

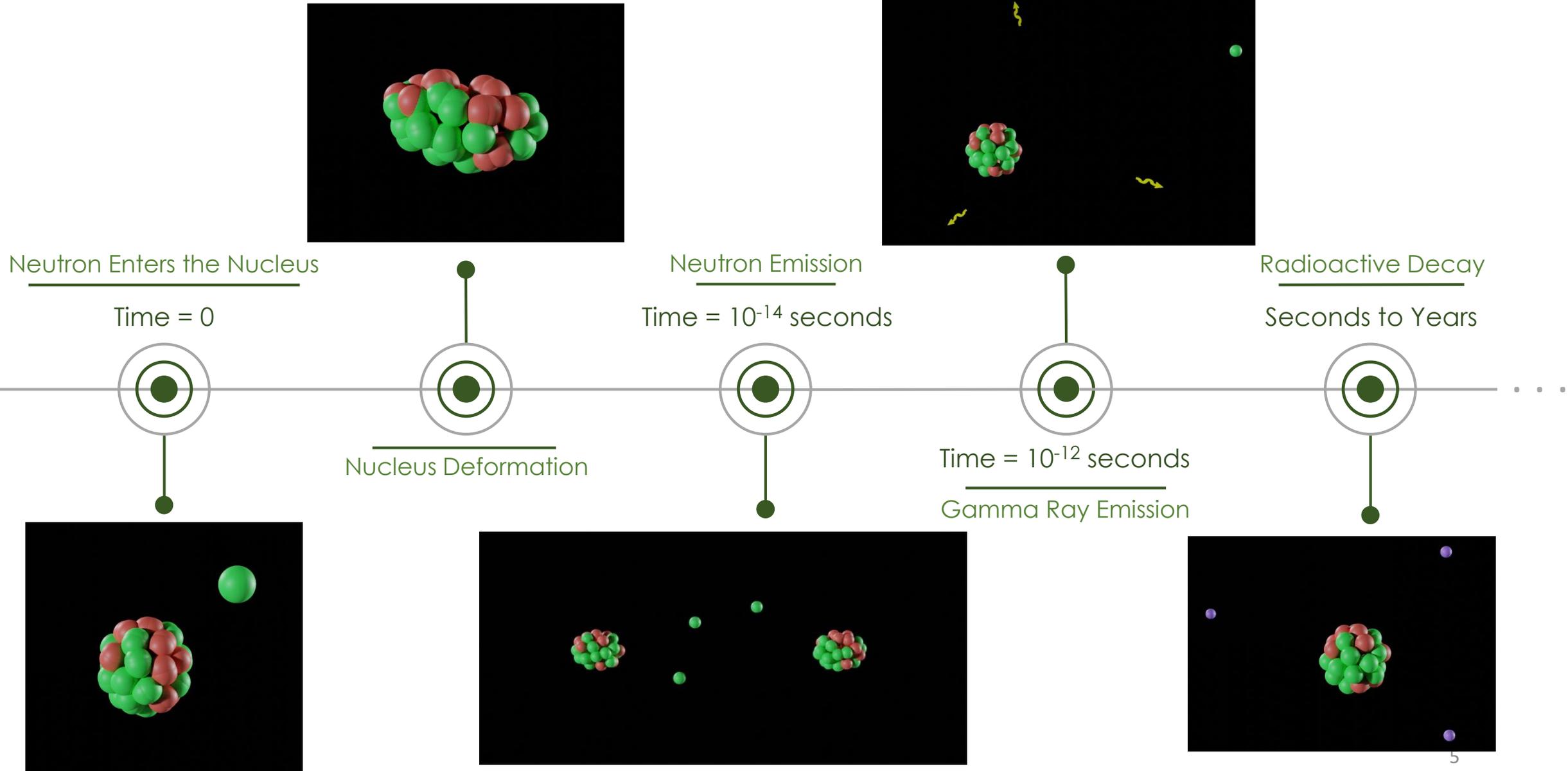


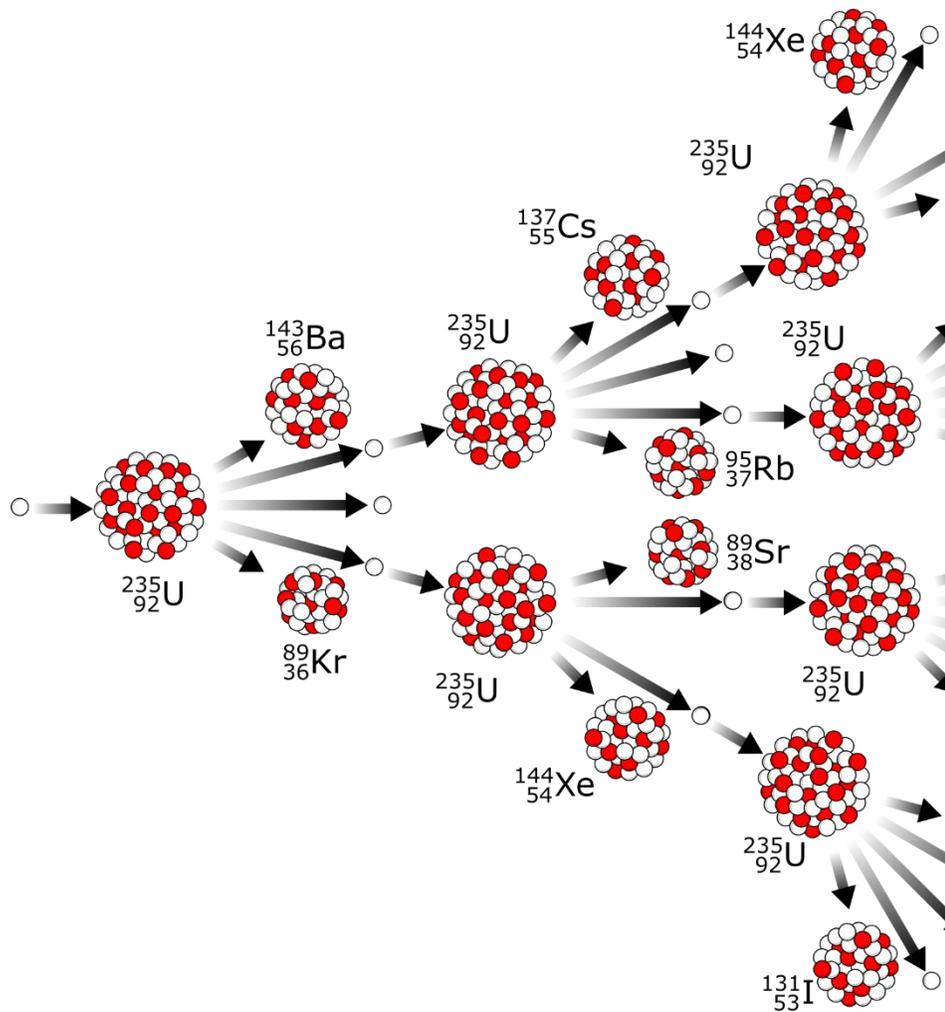
Enrico Fermi

Performed the first fission reaction of uranium with slow neutrons, 1932-33. Initially, he thought he had discovered two new transuranic elements.

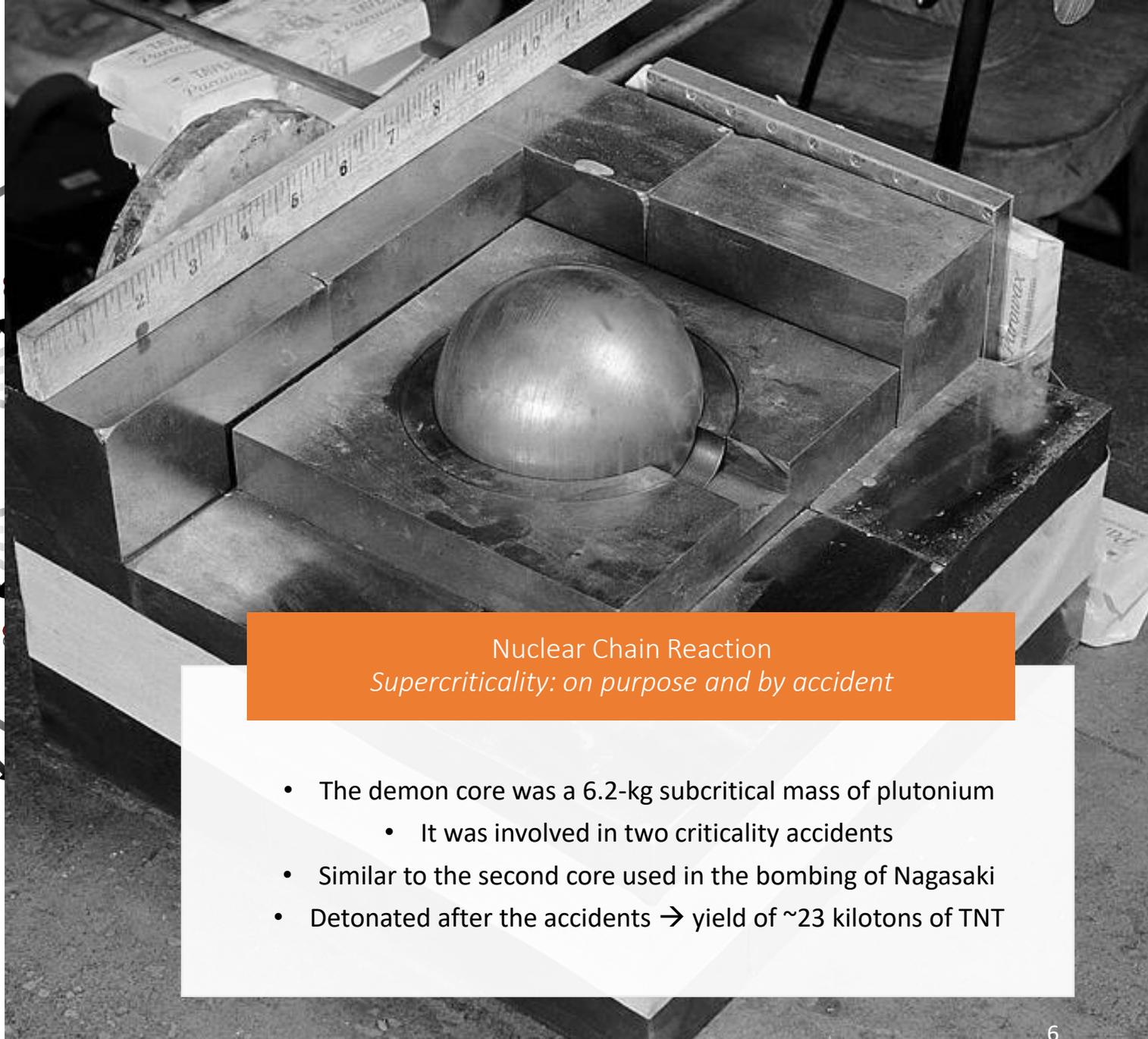
The map is not to scale

# Fission Timeline





80 generations fissions 1 kg of material,  
in 1 microsec, equivalent of approximately 15 ktoms  
TNT



Nuclear Chain Reaction  
*Supercriticality: on purpose and by accident*

- The demon core was a 6.2-kg subcritical mass of plutonium
  - It was involved in two criticality accidents
- Similar to the second core used in the bombing of Nagasaki
- Detonated after the accidents → yield of ~23 kilotons of TNT



Chicago Pile-1

<https://www.atomicheritage.org/history/chicago-pile-1>

## The First Self-sustained Nuclear Chain Reaction

*The dual-use of nuclear energy started in the early days*

December 2, 1942

- The first **self-sustained nuclear chain reaction** was achieved at the University of Chicago by Fermi and his team.

The United States government then encouraged the development of **nuclear energy for peaceful purposes.**

December 20, 1951

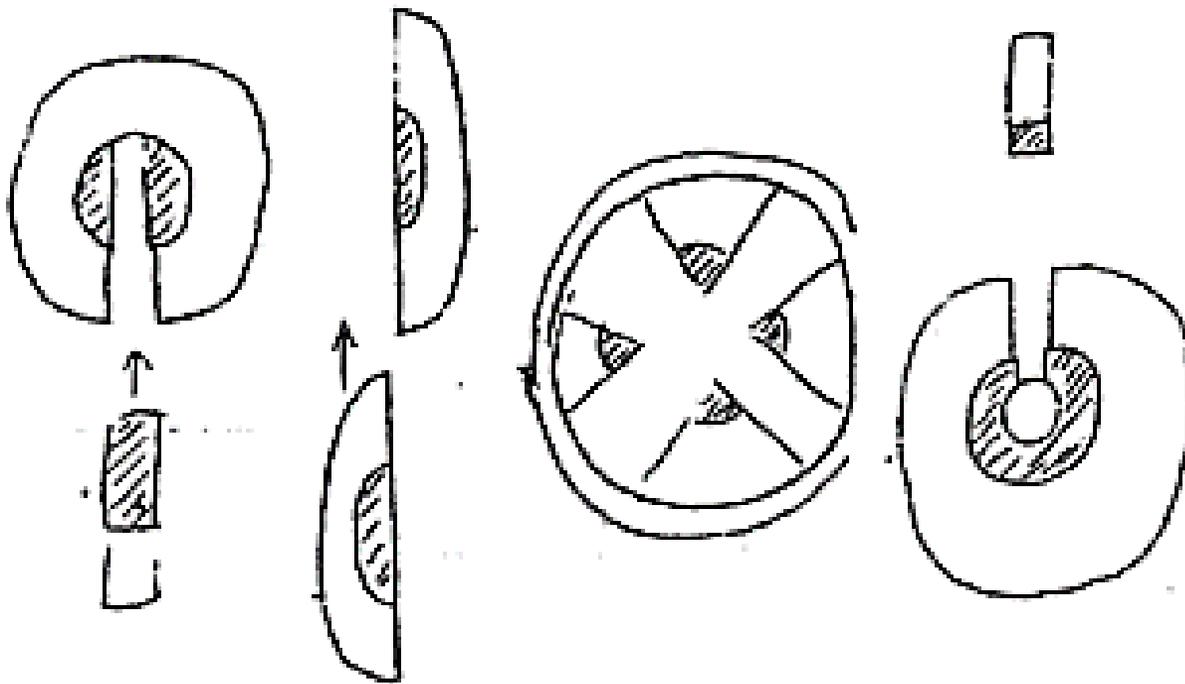
- The Experimental Breeder Reactor generated electricity from nuclear energy at a site in Idaho.



**EBR-I**  
WORLD'S FIRST  
NUCLEAR  
POWER PLANT  
ENTRANCE

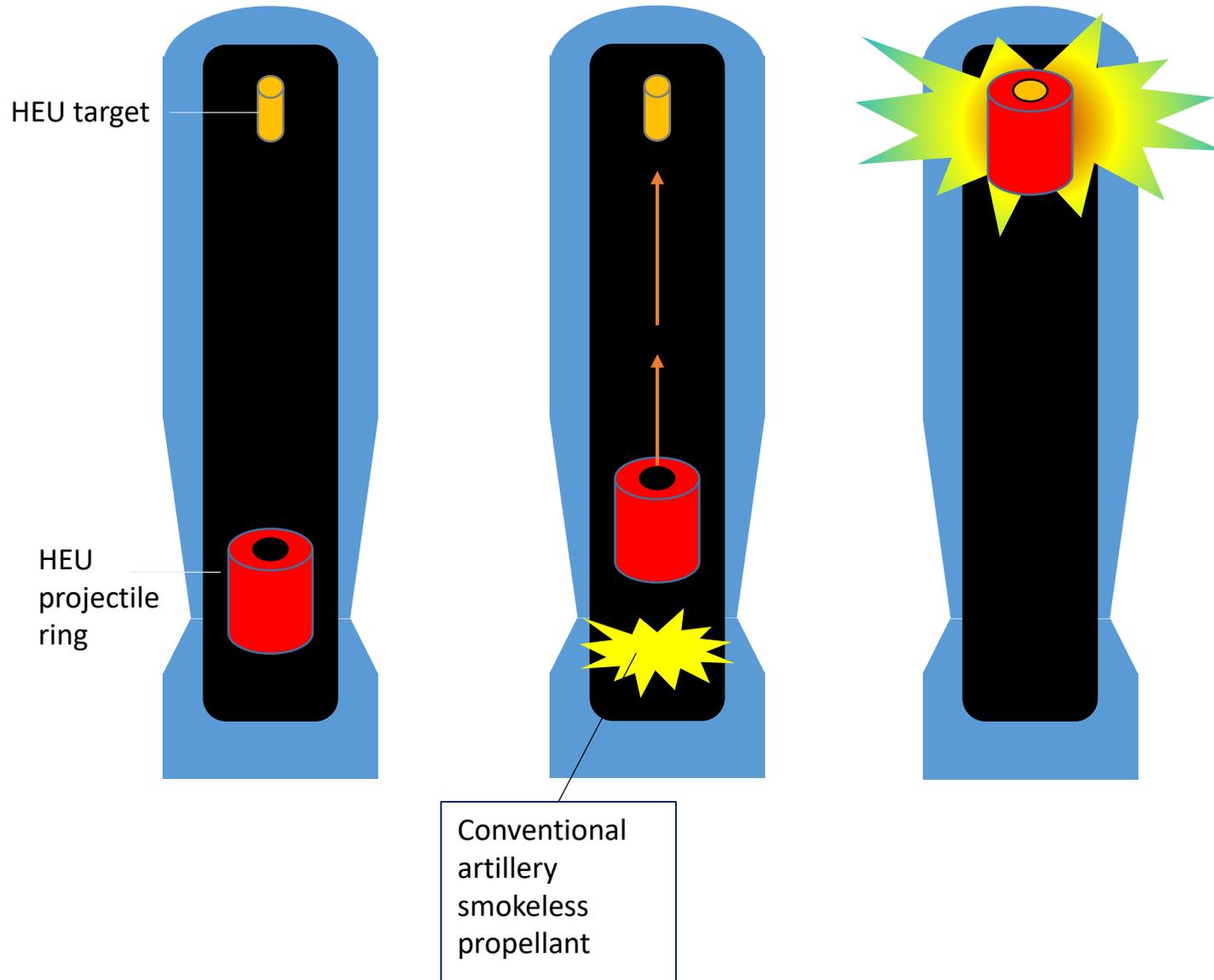
# Use of Fission Energy in Nuclear Weapons

## *From the “Los Alamos Primer” to actual design*



The figure shows fission bomb assembly methods described in the “**Los Alamos Primer**”.

The primer included a series of lectures on the principles of nuclear weapons and was given to new arrivals at the top-secret Los Alamos laboratory during the Manhattan Project.



## Use of Fission Energy in Nuclear Weapons

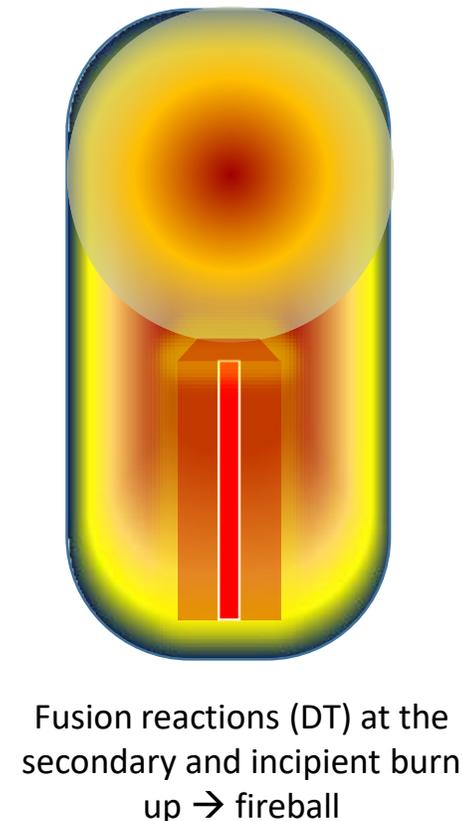
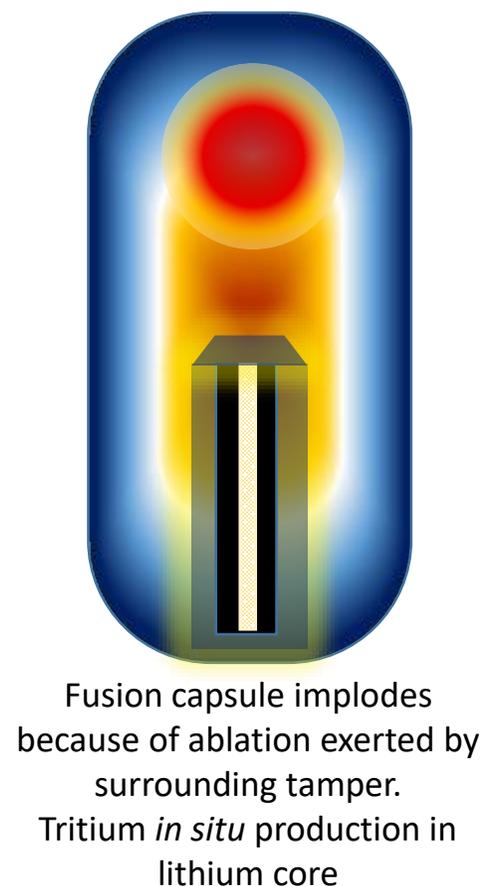
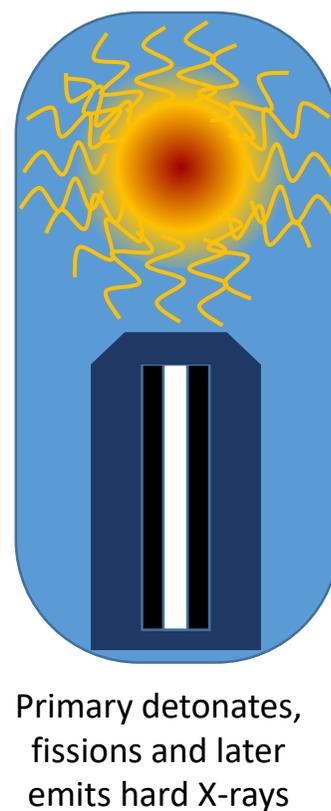
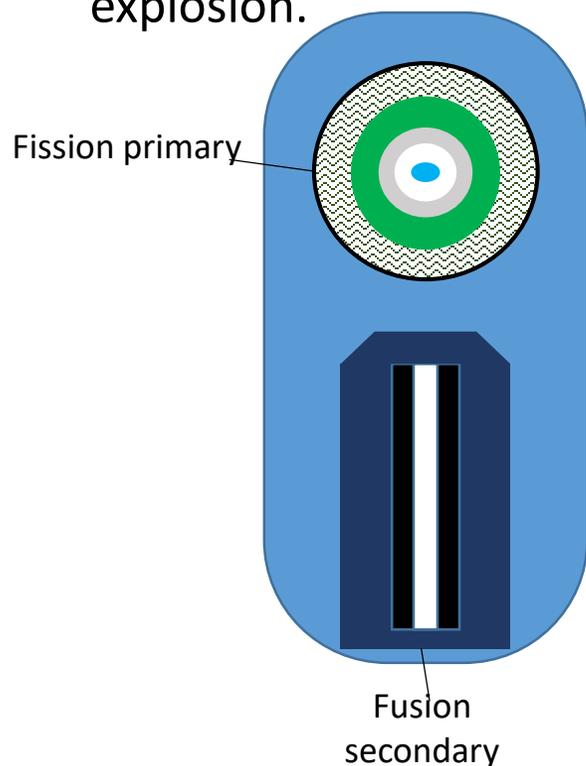
### *Gun-type fission weapon*

- "Little Boy", the atomic bomb dropped on the Japanese city of Hiroshima on 6 August 1945 during World War II had a similar, gun-type design.
- **It exploded with an energy of approximately 15 kilotons of TNT.**

# Fission and *Fusion* Energy in Nuclear Weapons

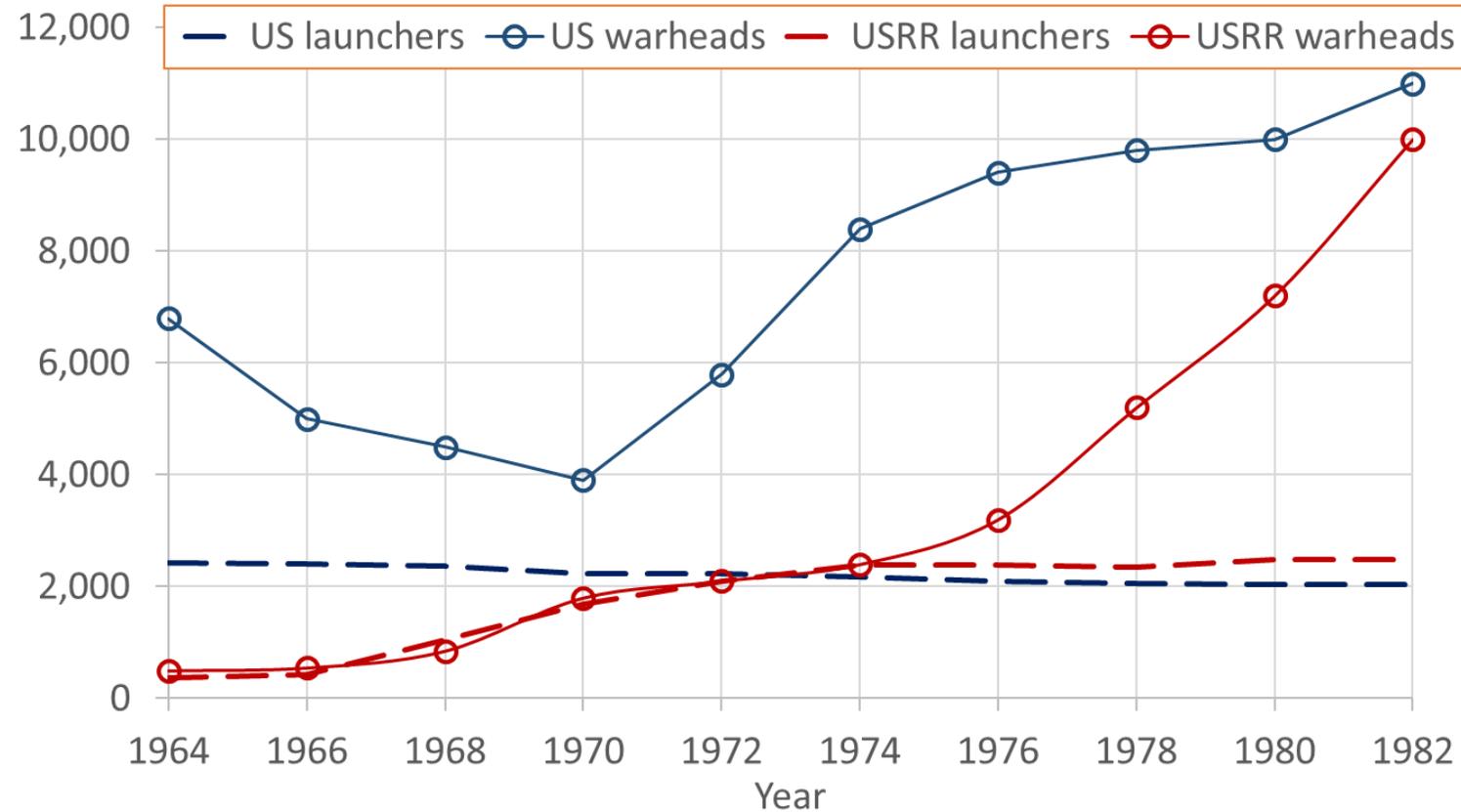
Mike shot of Operation Ivy yielded 10.4 Mtons using a new and more efficient design based on radiation implosion and the addition of a secondary stage.

The ignition of a large mass of thermonuclear fuel is made possible by a relatively small fission explosion.





1955 Soviet Aviation Day "Potemkin village"



## The Nuclear Arms Race

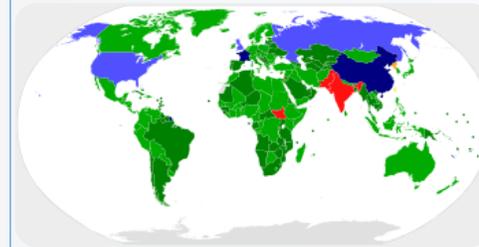
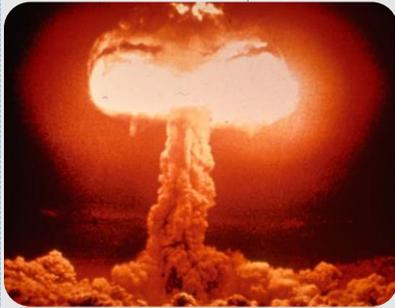
*Mutual Assured Destruction,  
deterrence, stability-  
instability paradox*

### The Strategic triad:

- Strategic bombers: long-range manned aircrafts carrying nuclear bombs;
- ICBMs: land-based intercontinental ballistic missiles with nuclear warheads;
- SLBMs: nuclear-powered submarines armed with nuclear ballistic missiles.

# The path to the Treaty on the Non-Proliferation of Nuclear Weapons (NPT)

1. Prevent the spread of nuclear weapons and related technology
2. Promote nuclear disarmament
3. Promote the peaceful use of nuclear energy



**1957**

The IAEA is created

**1960**

France tested the first nuclear weapon.

**1961**

The UN General Assembly unanimously approved the **Irish resolution**.

**1962**

Declaration on the denuclearization on Latin America.

**1964**

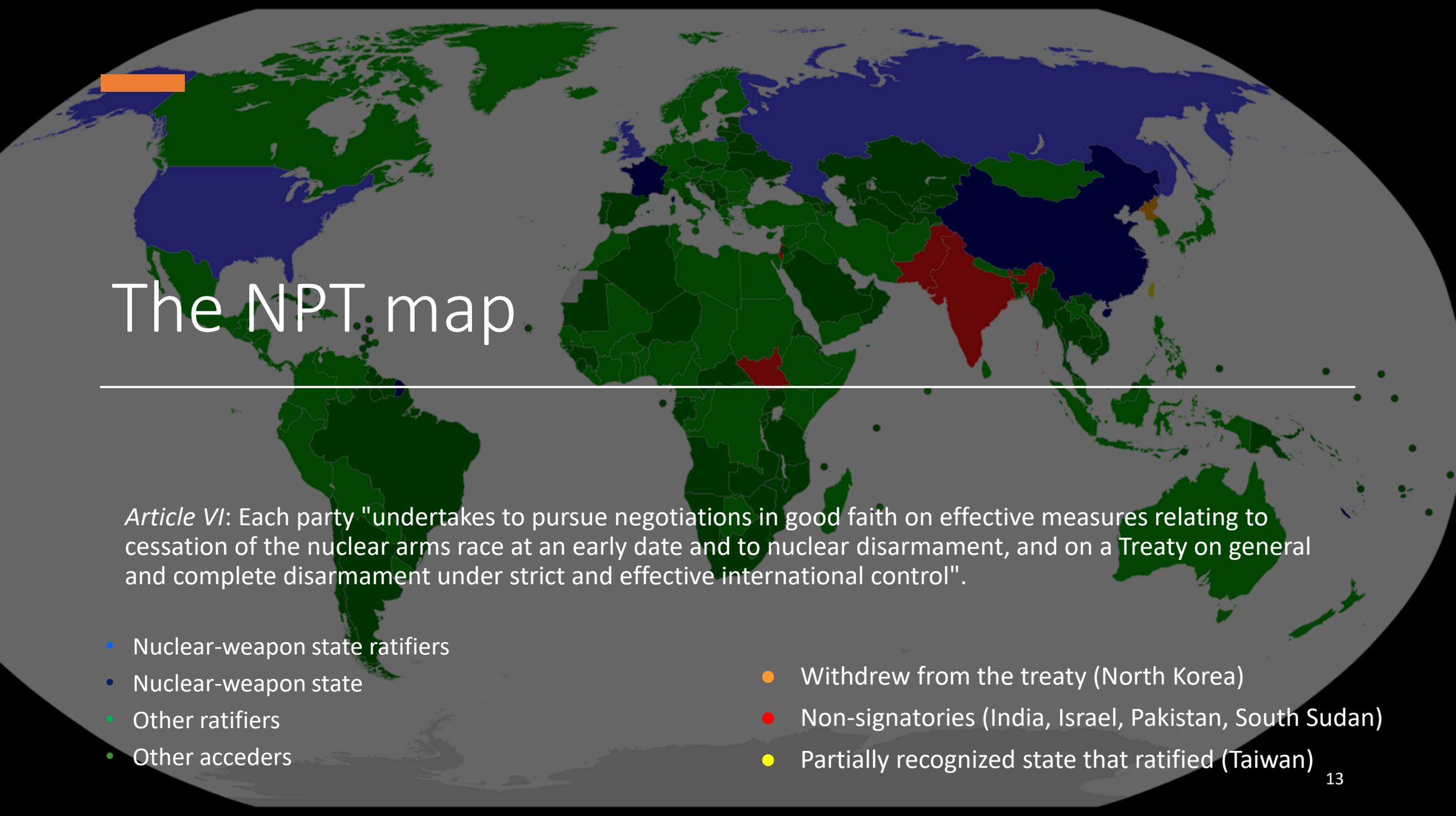
China tested a pure-fission U-235 implosion device for the first time, it was named "596".

**1967**

Tlatelolco Treaty.

**1968**

The NPT was opened for signature.

A world map where countries are color-coded based on their status regarding the Nuclear Non-Proliferation Treaty (NPT). The map shows the following categories: Nuclear-weapon state ratifiers (dark blue), Nuclear-weapon state (medium blue), Other ratifiers (green), Other acceders (light green), Withdrew from the treaty (orange), Non-signatories (red), and Partially recognized state that ratified (yellow).

# The NPT map

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*Article VI:* Each party "undertakes to pursue negotiations in good faith on effective measures relating to cessation of the nuclear arms race at an early date and to nuclear disarmament, and on a Treaty on general and complete disarmament under strict and effective international control".

- Nuclear-weapon state ratifiers
- Nuclear-weapon state
- Other ratifiers
- Other acceders
- Withdrew from the treaty (North Korea)
- Non-signatories (India, Israel, Pakistan, South Sudan)
- Partially recognized state that ratified (Taiwan)

Iron Magnetic pole

## Did the NPT regime and the strategy of deterrence work?

- Covert nuclear weapon program in Iraq.
- The IAEA seized components of the electromagnetic isotope separation (EMIS) plant at Tarmiya in 1991.
- Iraqi admitted their clandestine enrichment program.
- ---
- Ground-Based Midcourse Defense infrastructure in the US since 2001 did not discourage North Korea from testing long-range missiles.

Ring-shaped Electromagnetic coil



1 - No military use

2 - Freedom of scientific investigation

3 - Free exchange of scientific plans and data

4 - Any territorial claims put on hold

5 - Nuclear free zone

6 - Applies to land but not seas

7 - All stations open to inspection by other nations

8 - National laws apply to citizens not to areas

9 - The treaty may be modified at any time, requires unanimous agreement of treaty nations

10 - All treaty nations to ensure no-one carries out acts against the treaty

The Antarctic Treaty  
Main Points



## Treaties Banning Nuclear Weapons

- 1959 Antarctic Treaty
- 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space
- 1972 Treaty on the Prohibition of the Emplacement of Nuclear Weapons and Other Weapons of Mass Destruction on the Sea-bed and the Ocean Floor and in the Subsoil Thereof

First underground nuclear explosion at Pokhran in Rajasthan



Bhabha Atomic Research Centre at Trombay, the Indian equivalent to Los Alamos.



## Export Control

- 1974 Indian nuclear test showed how nuclear technology, though not developed for military applications, could be used to build weapons
  - Need further limitations to the export of nuclear equipment
- 1971-1974 Zangger Committee (People's Republic of China is a member)
- 1974 Nuclear Suppliers Group – Export control guidelines → INFCIRC/254

# Nuclear Weapon Free Zones & Nuclear Weapon Ban Treaty

The Treaty on the Prohibition of Nuclear Weapons (TPNW), the Nuclear Weapon Ban Treaty, prohibits the development, testing, production, stockpiling, transfer, use and threat of nuclear weapons.

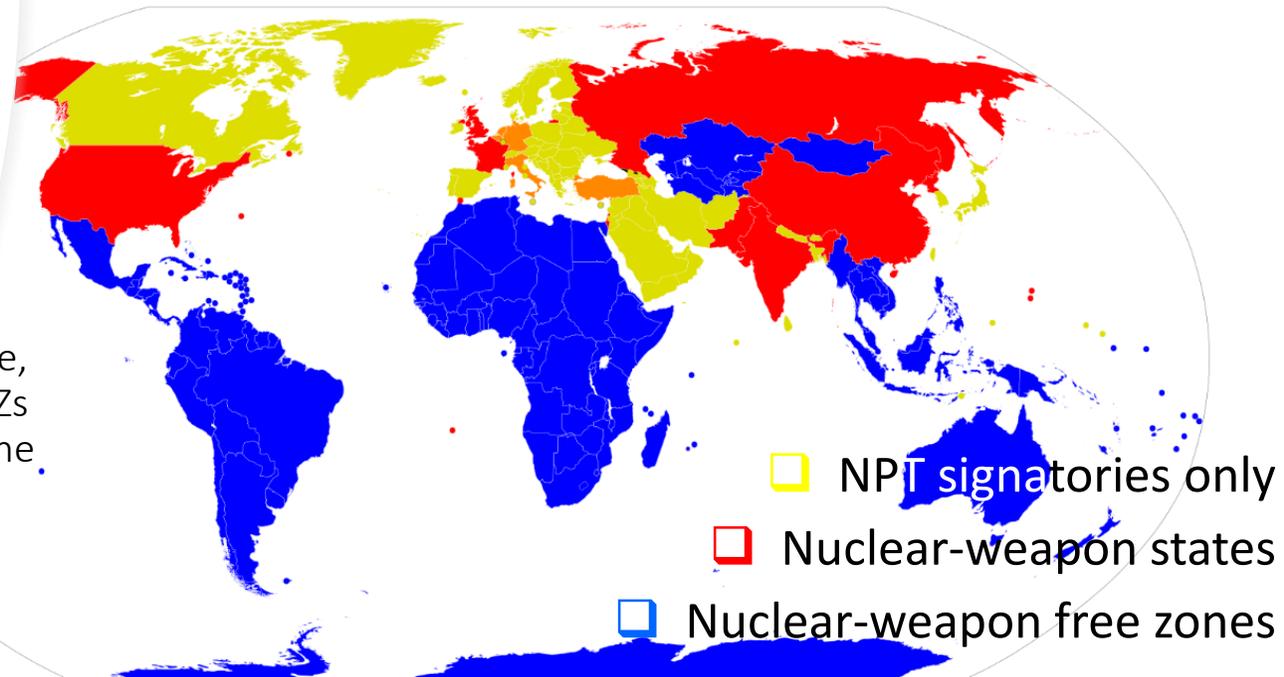
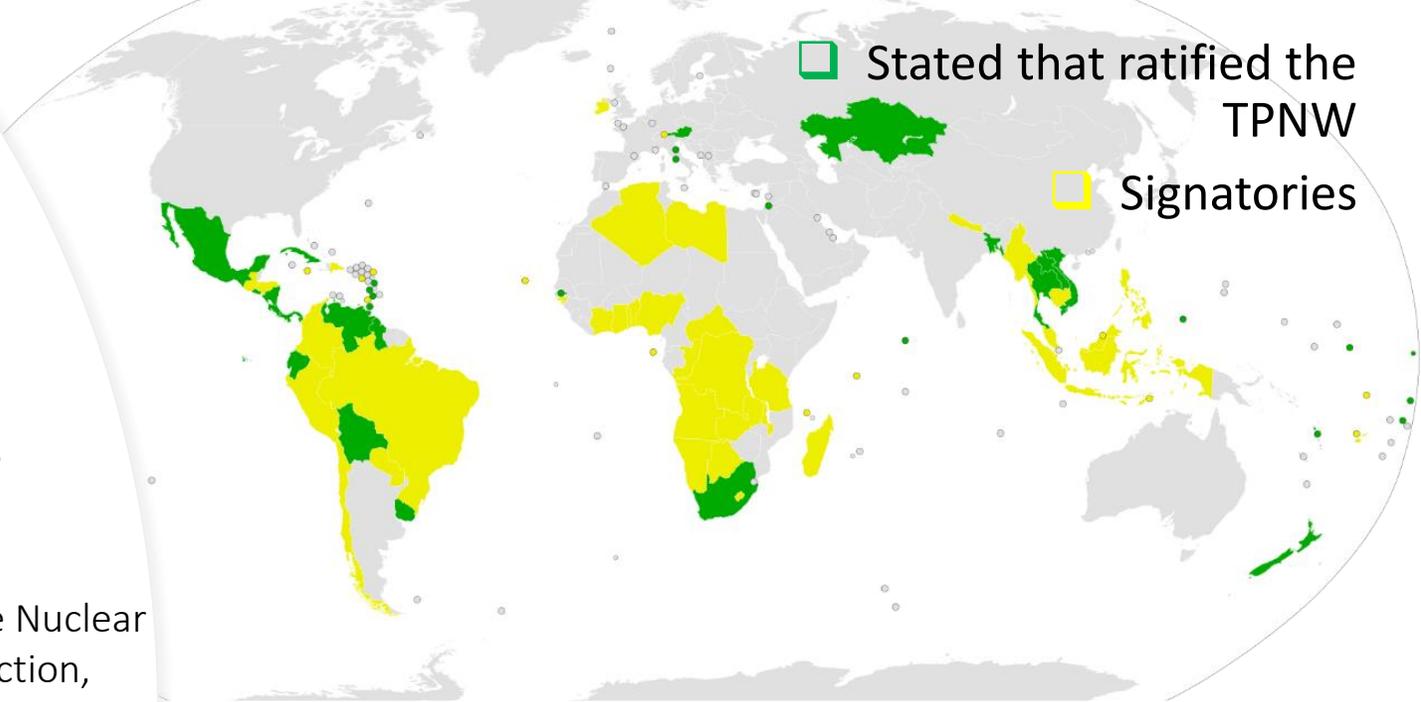
An "unambiguous political commitment" to "fill the legal gap" in the existing international regime concerning nuclear weapons, in 2017.

Does not contain all the legal and technical details to implement elimination.

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A nuclear-weapons-free zone (NWFZ) is an agreement that bans the use, development, or deployment of nuclear weapons in a given area. NWFZs are independently established by a group of states and recognized by the UN.

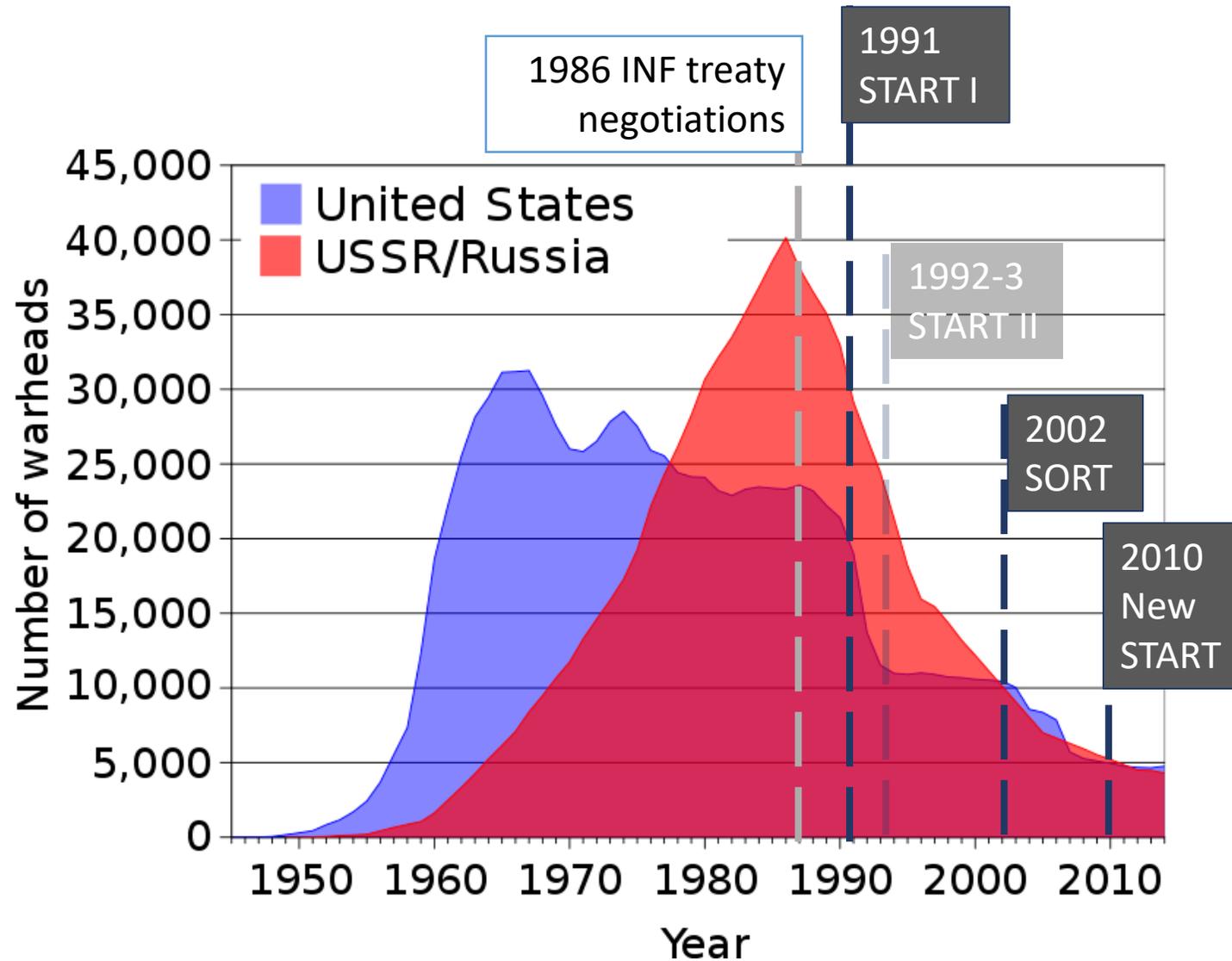
NWFZ were established by different treaties from 1961 to 2009.



## Arms control successes

### *Strategic Arms Reduction Talks (START)*

- Presidential orders started the reductions.
- START treaties played an important role in the reduction of strategic nuclear weapons.
- START are arm control negotiations between the United States and the Soviet Union first, and Russia later, aimed at reducing their arsenals of nuclear warheads and delivery devices.
- *The New START Treaty is still in force and expires early in 2021.*
  - The treaty does not limit new Russian nuclear weapons systems
  - The treaty does not include China



Years refer to treaty signature.  
START II never came into force.

# Europe and Middle East

## France – 300 (stockpile)

In February 2015, President Francois Hollande stressed the need for a nuclear deterrent in "a dangerous world". In January 2019, president Macron signed the Aachen treaty with Germany with the promise to extend France nuclear deterrence to Germany.

## United Kingdom – 215

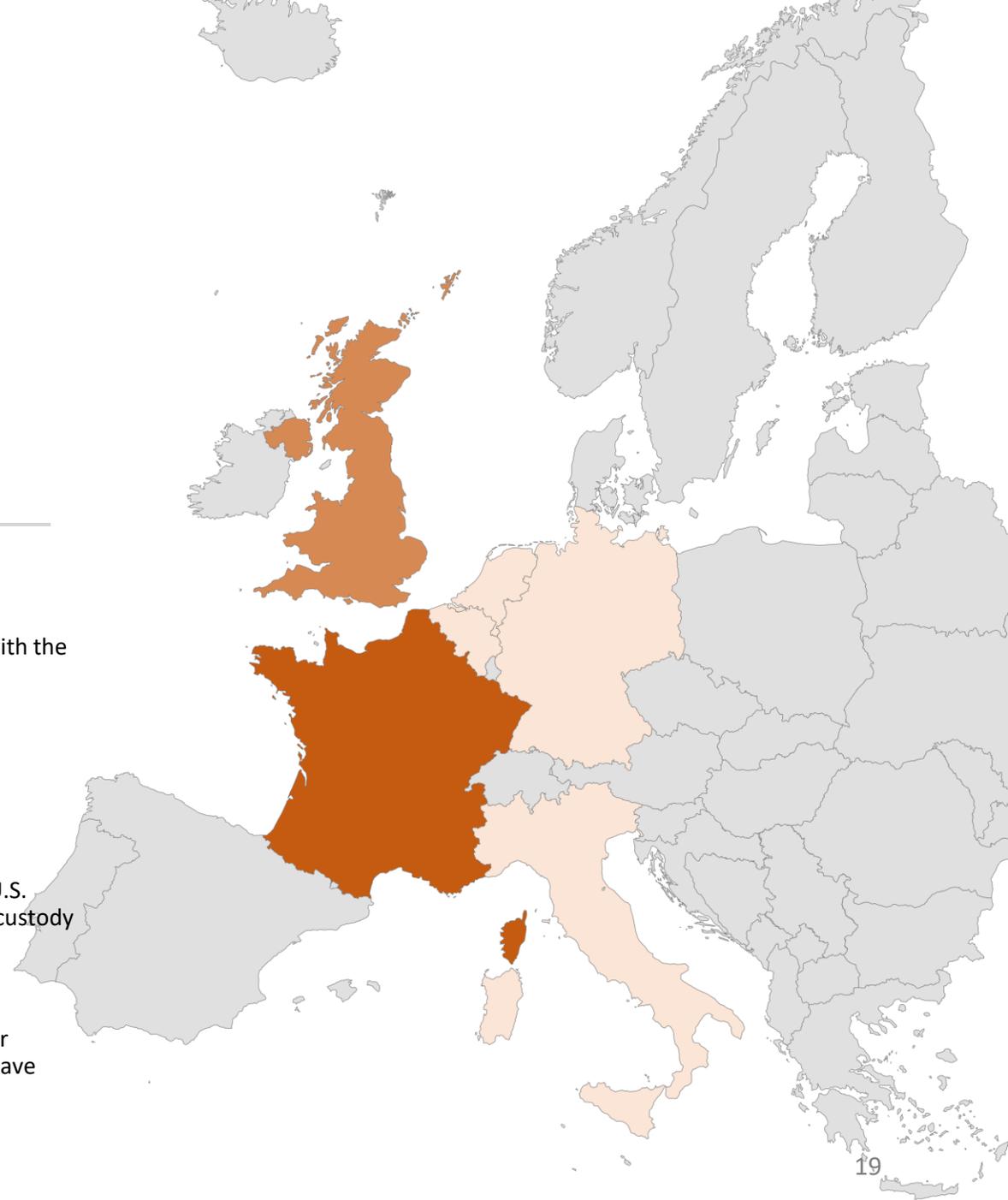
In 2016, the UK House of Commons voted to renew the British nuclear weapons system.

## Belgium, Germany, Italy, Netherlands and Turkey -150

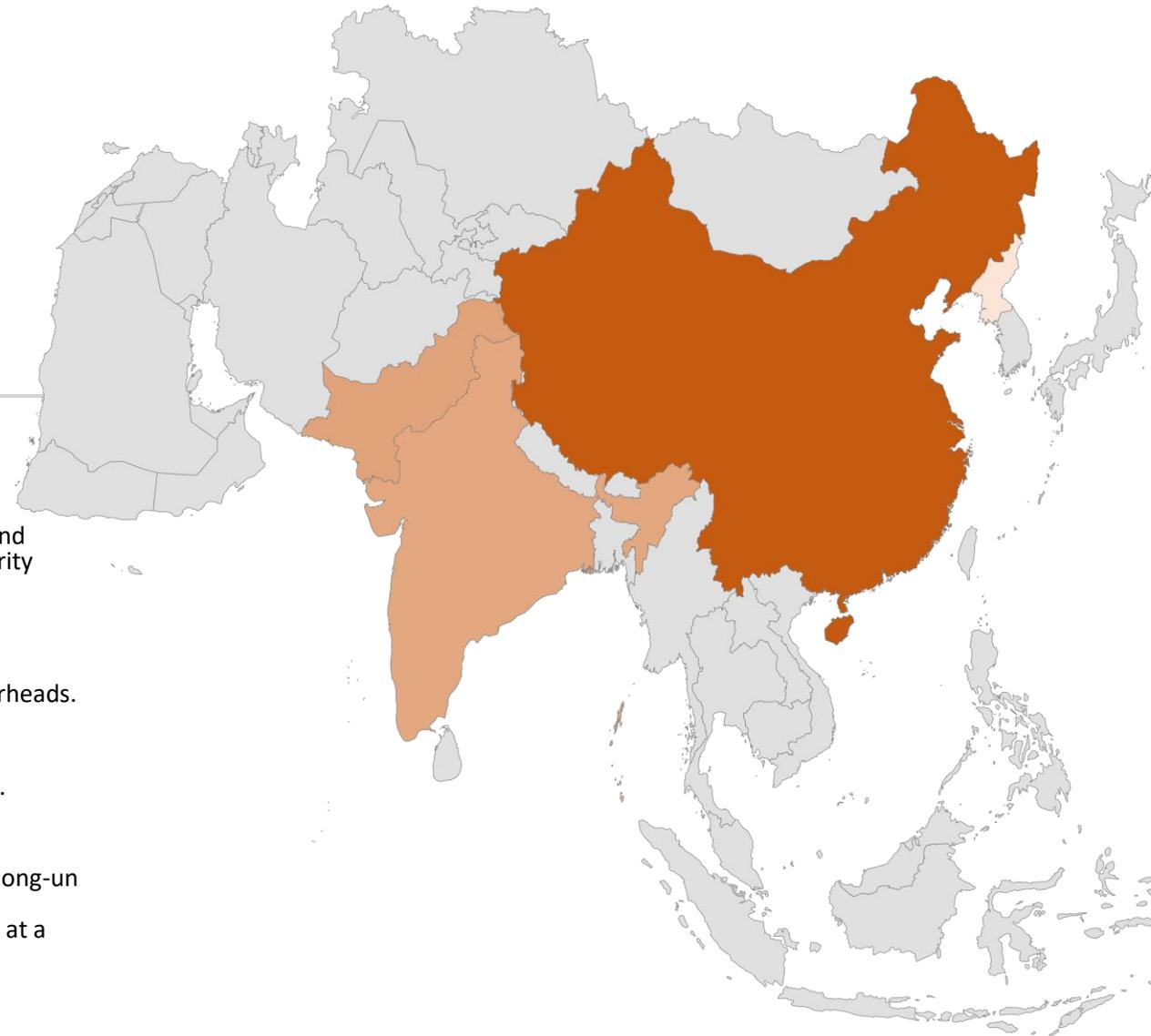
US B61 bombs are deployed in the five countries under the NATO nuclear weapons sharing agreement. According to NATO, the weapons' sharing is compliant with the NPT because "the U.S. nuclear weapons based in Europe are in the sole possession and under constant and complete custody and control of the United States."

## Israel – 75-200

According to the Stockholm International Peace Research Institute, Israel has approx. 80 nuclear warheads (50 deployable by medium-range ballistic missiles and 30 bombers). Israel may also have submarine-launch cruise missiles.



# Asia



## China - 290

The Chinese stockpile currently includes 290 warheads for delivery by ballistic missiles and bombers, it is likely to increase. China is a NPT nuclear-weapon state with negative security assurance and its own "no first use" policy.

## Pakistan – 140

The current stockpile is uncertain and some believe that Pakistan is developing new warheads.

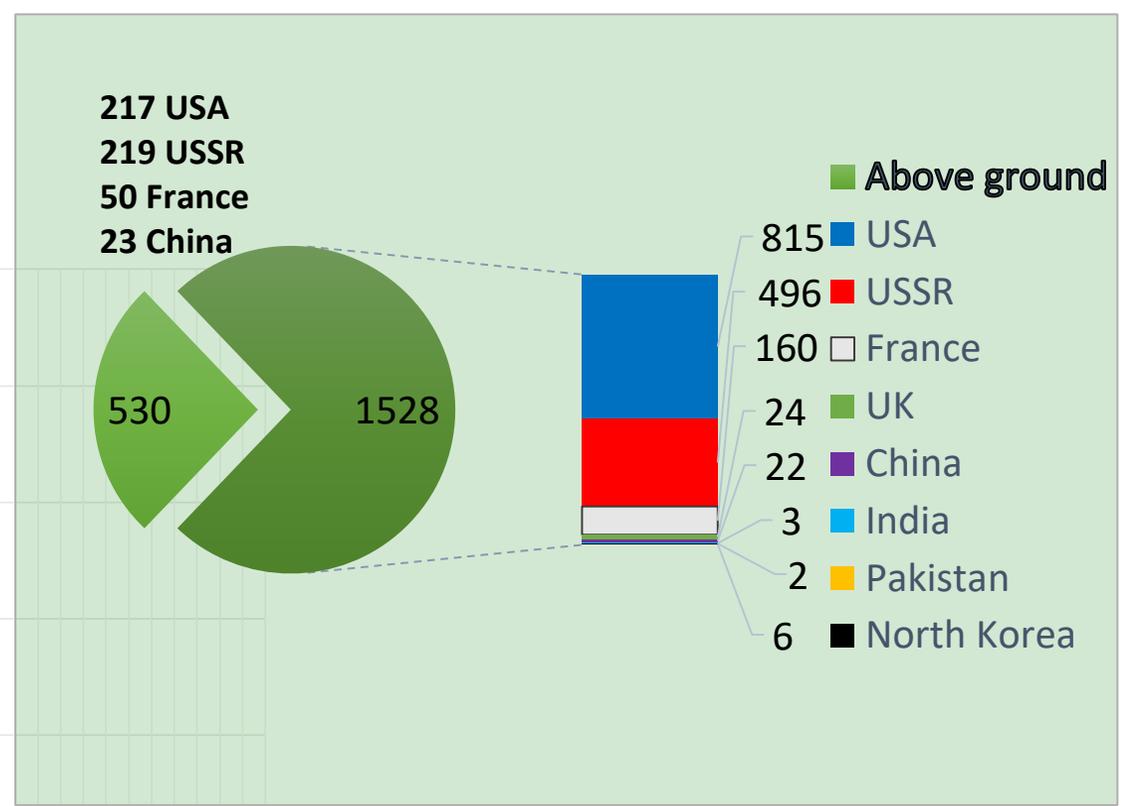
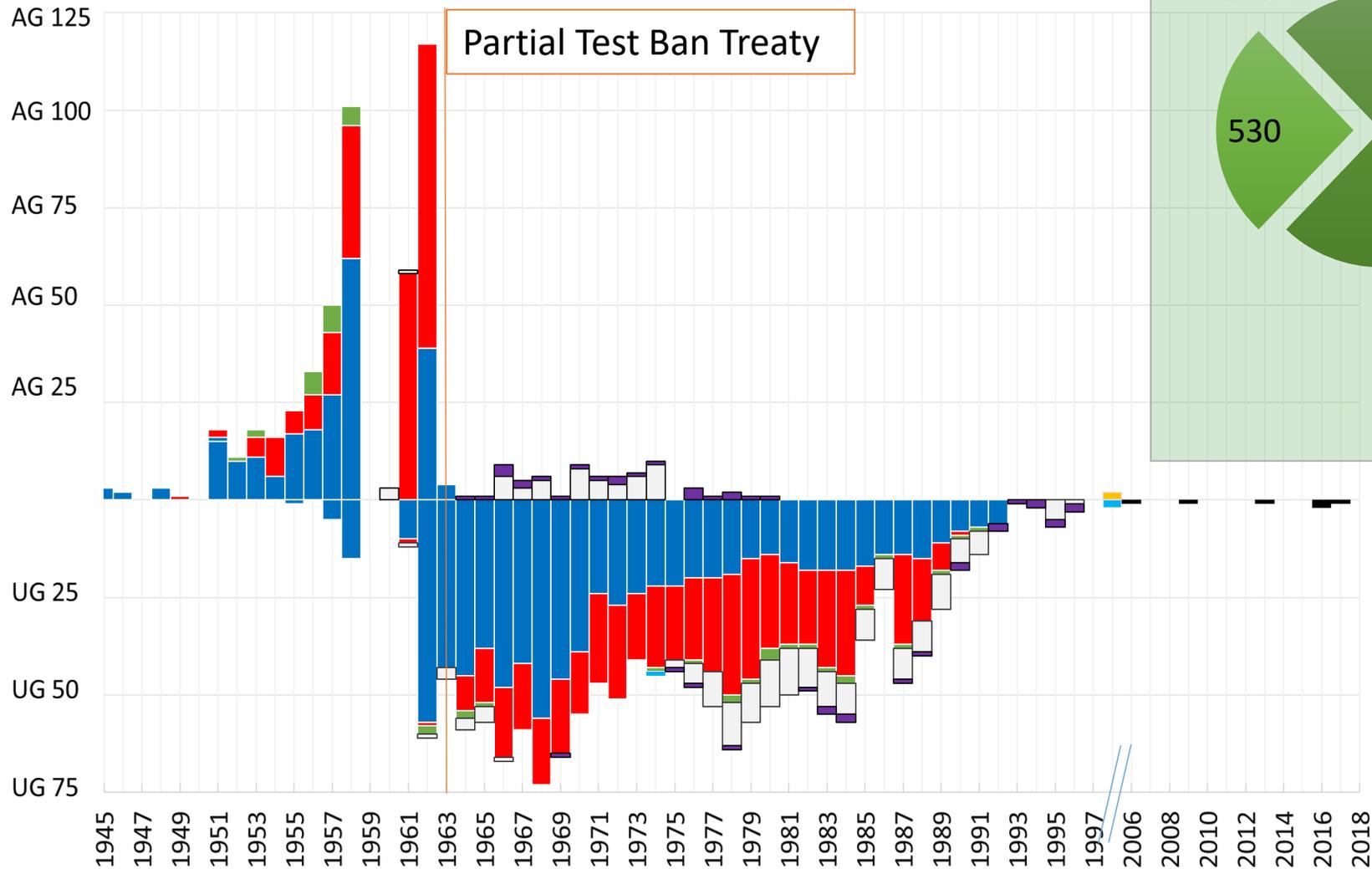
## India - 130

India signed a nuclear cooperation agreement with Australia in 2014 for uranium supply.

## North Korea - ?

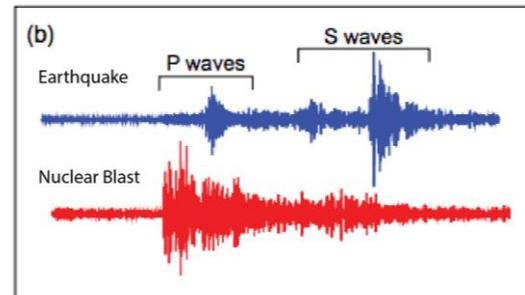
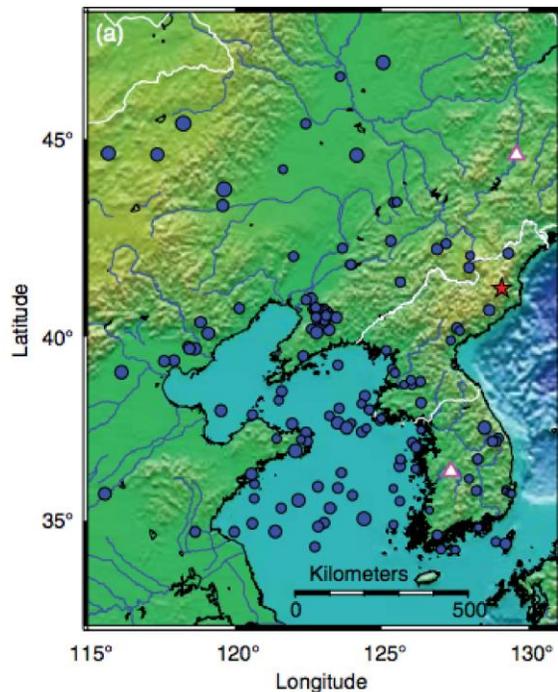
North Korea withdrew from the Nuclear Non-Proliferation Treaty in 2003. In 2018, Kim Jong-un announced a halt in nuclear weapons tests and made a conditional commitment to denuclearization of the Peninsula. In December 2019, state media report a "crucial test" at a satellite launch site.

# Weapon tests

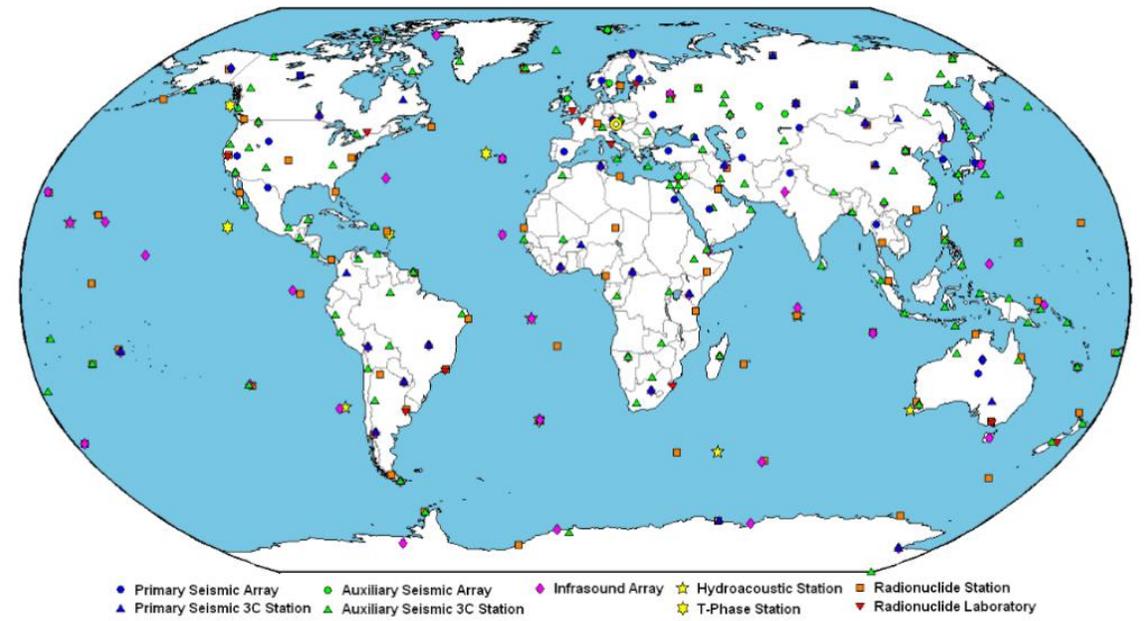


# Weapon test monitoring

- The Comprehensive Nuclear-Test-Ban Treaty (CTBT) bans all nuclear explosions, for both civilian and military purposes, in all environments.
- Adopted by the United Nations General Assembly in 1996 but has not entered into force.
- China, US, Egypt, Iran, and Israel have signed but not ratified the Treaty.
- Geophysical and other technologies are used to monitor states' compliance with the Treaty: forensic seismology, hydro-acoustics, infrasound, and radionuclide monitoring.



Analysis of IMS data  
(a, red star) North Korea claims the detonation of a nuclear device in 2006. Earthquakes were detected nearby (blue dots) by the IMS stations (white triangles) in South Korea. (b) Seismograms recorded during the explosion (red wave) and a recent earthquake (blue wave) near that experiment shows structural difference between the two signals



International Monitoring System (IMS)

# Close calls and accidents involving nuclear materials I

1. 1950—A B-50 bomber accidentally drops nuclear weapon over Quebec
2. 1958—A B-47 bomber accidentally drops a Mark 6 atomic bomb into a family's backyard South Carolina. No nuclear material is released
3. 1959—A B-52 bomber carrying two atomic bombs collides with an aircraft in Kentucky
4. **1961—Plane crash causes the drop of two nuclear bombs into Goldsboro, NC**
5. 1962 – Cuban Missile Crisis
6. 1962—Alarm of sabotage activated by a bear almost leads to attack

~~FORMERLY RESTRICTED DATA~~

Lapp's report lacks objectivity and accuracy. His sources of information are patently erroneous, or he chooses to misuse them for his own benefit. But the central point is correctly stated. One simple, dynamo-technology, low voltage switch stood between the United States and a major catastrophe!

There is no need to do a safety analysis of the Goldsboro caper. That was amply covered by deMontmollin and Hoagland in 1961\*. But, in today's atmosphere, one more conclusion would have been drawn. The Mk 39 Mod 2 bomb did not possess adequate safety for the airborne alert role in the B-52\*\*. Alt 197 was performed on these bombs to provide additional safety, but it only interrupted (additionally) the lines between the bisch generator and the low voltage thermal battery. When the B-52 disintegrates in the air, it is likely to release the bombs in a near normal fashion\*\*\*. The unalterable conclusion is that the only effective safing device during airborne alert was the ready-safe switch, be it the MC772 (Goldsboro) or the MC1288 (Alt 197).

If a short to an "arm" line occurred in a mid-air breakup, a postulate that seems credible, the Mk 39 Mod 2 bomb could have given a nuclear burst.

\*SC-DR-81-61, Analysis of the Safety Aspects of the Mk 39 Mod 2 Bombs Involved in B-52G Crash Near Greensboro (sic), North Carolina.

\*\*The same conclusion should be drawn about present day SAC bombs, i.e., the B28FI, the B53, and the B41.

\*\*\*This characteristic was graphically demonstrated at Palomares, as well.



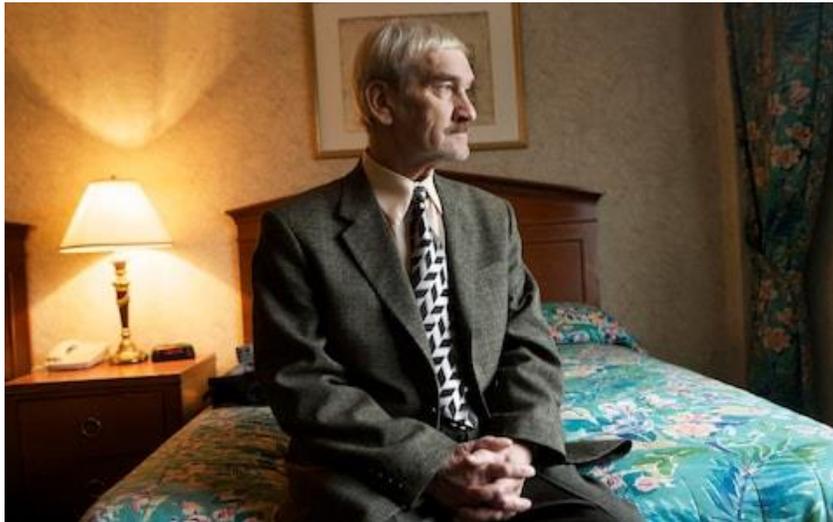
President John F. Kennedy meets with U.S. Army officials during the Cuban missile crisis in 1962

## Close calls and accidents involving nuclear materials II

7. **1962 - "Black Saturday" during the Cuban Missile Crisis, the United States and the Soviet Union came close to a nuclear attack five times**
8. 1962—New Jersey radar operators interpret a misplaced simulation tape as an attack from Cuba
9. 1962—CIA secret agent is arrested in Moscow and gives a false alarm of nuclear attack
10. 1966—Plane collision causes detonation of two bombs and release of radioactive material in Palomares (Spain)
11. 1968—Plane crash caused the release of radioactive material (no full detonation) in Greenland
12. 1969—Collision between American and Soviet submarines
13. 1979—Military exercise tapes placed in the operational missile detection computer system and interpreted as an attack from 2200 Soviet missiles
14. 1980—Fuel explosion at a nuclear missile silo in Arkansas



Stanislav Petrov during a trip to the US, in 2014, during which he was honored at the United Nations for his service in 1983.



## Close calls and accidents involving nuclear materials III

15. **1983—Malfunctioning Soviet Oko nuclear early warning system warns of missile attack**
16. 1983 - NATO military exercise interpreted as attack in Moscow
17. 1991—Coups leaders confiscate Mikhail Gorbachev's nuclear briefcases
18. 1995—US scientific rocket launch interpreted as nuclear missile by the Russians

# Policies of concern

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## Launch-on-warning

A warning of an attack from satellites, radars, etc. is transmitted to the President if it is considered reliable.

Once the warning is received, the leader has 10-15 minutes to decide whether to attack or not.

Approximately 1900 missiles are currently on alert in silos and submarines (95% in US and Russia; also UK, France).

# Hair-trigger alert

*Silo-based ICBMs on high alert to be launched quickly on warning of an attack*

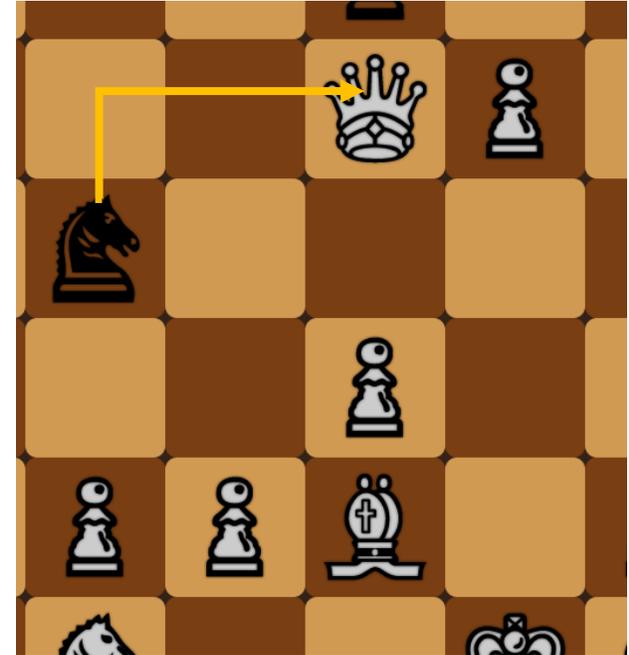
- The United States and Russia each maintain ~900 nuclear weapons that can be launched in minutes, i.e., on prompt-launch status or high alert or hair-trigger alert.
- Rationale during Cold War:
  - Protect missiles in silos, which are vulnerable targets
  - An attacking missile is detected by radars
  - The missile in the silo is launched before being destroyed
  - A surprise attack would fail so the policy acts as a deterrent



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# Hair-trigger alert

- A post-attack launch is considered viable by military strategists
- Having launch on warning capability during a crisis would increase the risk of a mistaken launch based on a misinterpreted warning signal
- If land missiles are not “on warning”, their value is somewhat reduced



“The United States should remove as many weapons as possible from high-alert, hair-trigger status—another unnecessary vestige of Cold War confrontation.”  
G. W. Bush, 2000



During the presidential campaign, Barack Obama promised to "take our nuclear weapons off hair-trigger alert [...] Maintaining this Cold War stance today is unnecessary and increases the risk of an accidental or unauthorized nuclear launch." 2008

# Absence of no-first-use policy

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- “It is the policy of the United States to not use nuclear weapons first” (S. 272/H.R. 921) by Senator Elizabeth Warren and Representative Adam Smith. January 30, 2019.
- US policy of “calculated ambiguity” regarding no-first-use.
- “The United States would only consider the employment of nuclear weapons in extreme circumstances to defend the vital interests of the United States, its allies, and partners” 2018 Nuclear Posture Review (NPR). The NPR also stated that the purpose of nuclear weapons should not only be deterrence.
- China and India do have no-first-use policy.

# Refurbishment and rebuilding of the US nuclear arsenal

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Acquisition of new types of “low-yield” warheads (15-20 kT max), intended for use against conventional forces

- Developed to compensate a “technological gap”
- 100-kiloton W76 with no secondary stage
- No need to test them
- No limitations on the refurbishment of existing warheads to add new military capabilities or diversify the existing ones

# Public perception of the nuclear threat

## *From the late 50s to the 70s*

According to pollsters, in August 1945, 85% of the U.S. public approved of President Truman's decision to drop two atomic bombs on Hiroshima and Nagasaki.



**1957**

Minot (ND) Air Force base opened, in 1960 became a Strategic base with ICBMs.

**1958**

First protestor at the F.E. Warren Air Force Base in Cheyenne, Wyoming, an Atlas site.

**1963**

Nuclear test ban treaty

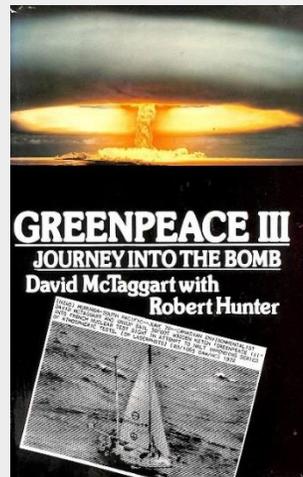


**1962**

800 women strikers for peace in New York near the UN HQ

**1968**

NPT



**1972**

David McTaggart from Greenpeace defied the French government by sailing small vessels into the Pacific French nuclear test zone and managed to interrupt the testing program



**1977**

The Abalone Alliance holds its first blockade at Diablo Canyon Power Plant (CA). Several anti-nuclear groups campaigned to stop construction of proposed plants in the seventies.

**1979**

Three Mile Island accident

# Public perception of the nuclear threat

## *The anti-nuclear movement gains momentum in the 80s*

Non coordinated demonstrations continued during the following decades, with the most recent probably being in July 2012, when Megan Rice, an 82-year-old nun and two fellow pacifists entered the Y-12 complex at Oak Ridge (TN) and painted antiwar slogans on a building that houses nuclear fuel.



### 1980

"Call to Halt the Nuclear Arms Race" by Randall Forsberg.  
The Nuclear Weapons Freeze Campaign (NWFC) started.

### 1982

"Nuclear War: What's in it For You?" by Roger Molander  
"Freeze! How You Can Help Prevent Nuclear War" by senators Ted Kennedy (D-MA) and Mark Hatfield (R-OR).  
NWFC delegation delivered at the UN Second Special Session on Disarmament a petition signed by 2.3 million citizens supporting the freeze to the Soviet and American UN missions.

### 1983

U.S. Senate to blocked the passage of a first **nuclear Freeze** resolution.  
"It really chaps me when one of our elected public officials begs to get one of these projects in my backyard" Allen Kirkbride, rancher in Cheyenne

### After 1983

President Reagan adopts NWFC language "a nuclear war cannot be won and must never be fought." .. "To those who protest against nuclear war, I can only say: 'I'm with you.'  
"The new thinking" of Russian President Mikhail Gorbachev absorbed the demands of the public and the scientific community.



AT A PRESS CONFERENCE convened by the Union of Concerned Scientists in March 1984, Kurt Gottfried, Hans Bethe, Richard Garwin and Henry Kendall (shown left to right) ad-



# Examples of initiatives by the physics community

- 1944, Bohr warns Churchill of the future challenges in international relations which could be caused by nuclear weapons
  - Churchill ignored Bohr's warning
- 1945, Franck Report by Franck, Seaborg, Szilard and Rabinowitch "the way in which nuclear weapons are first revealed to the world appears to be of great, perhaps fateful importance. ... If no efficient international agreement is achieved, the race for nuclear arms will be on in earnest not later than the morning after our first demonstration."
  - Truman later proposed establishing a commission that would have potentially full control over research involving nuclear physicists
- 1987, "American Physical Society (APS) Directed Energy Weapons Study," by a group chaired by Bloembergen and Patel to show scientific evidence of inefficacy of the Reagan Strategic Defense Initiative.

# Public perspective on nuclear weapons today



Low awareness on the military capabilities of the United States and other countries

40% of the respondents expected the US to have an arsenal including fewer than 4,000 warheads <sup>[1]</sup>



Split support for nuclear energy, trust towards arms control<sup>[2],[3]</sup>



In the event of North Korea testing long-range missiles that could reach the US, 30% of interviewed people would be in favor of a preemptive nuclear strike on North Korea, even if it killed a million civilians. <sup>[4]</sup>

<sup>[1]</sup> Center for International and Security Studies at the University of Maryland, May 2019

<sup>[2]</sup> Gallup poll, 2019

<sup>[3]</sup> YouGov, September 2019

<sup>[4]</sup> YouGov and the Bulletin of the Atomic Scientists, June 2019

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49% of poll participants favor use of **nuclear energy**; 49% oppose it.<sup>[2]</sup>

80% percent of the respondents favor extending the New START Treaty beyond its 2021 expiration.<sup>[1]</sup>

Two-thirds of the respondents believe that the United States should not withdraw from the INF Treaty <sup>[1]</sup>.

49% of the respondents think that the US should cooperate with the other nuclear armed countries to eliminate all nuclear weapons from all countries, according to the 2017 “Nuclear Ban Treaty”. Only 32% think that the US should continue to ignore the new treaty and keep its nuclear weapons regardless of other countries’ decisions.<sup>3]</sup>



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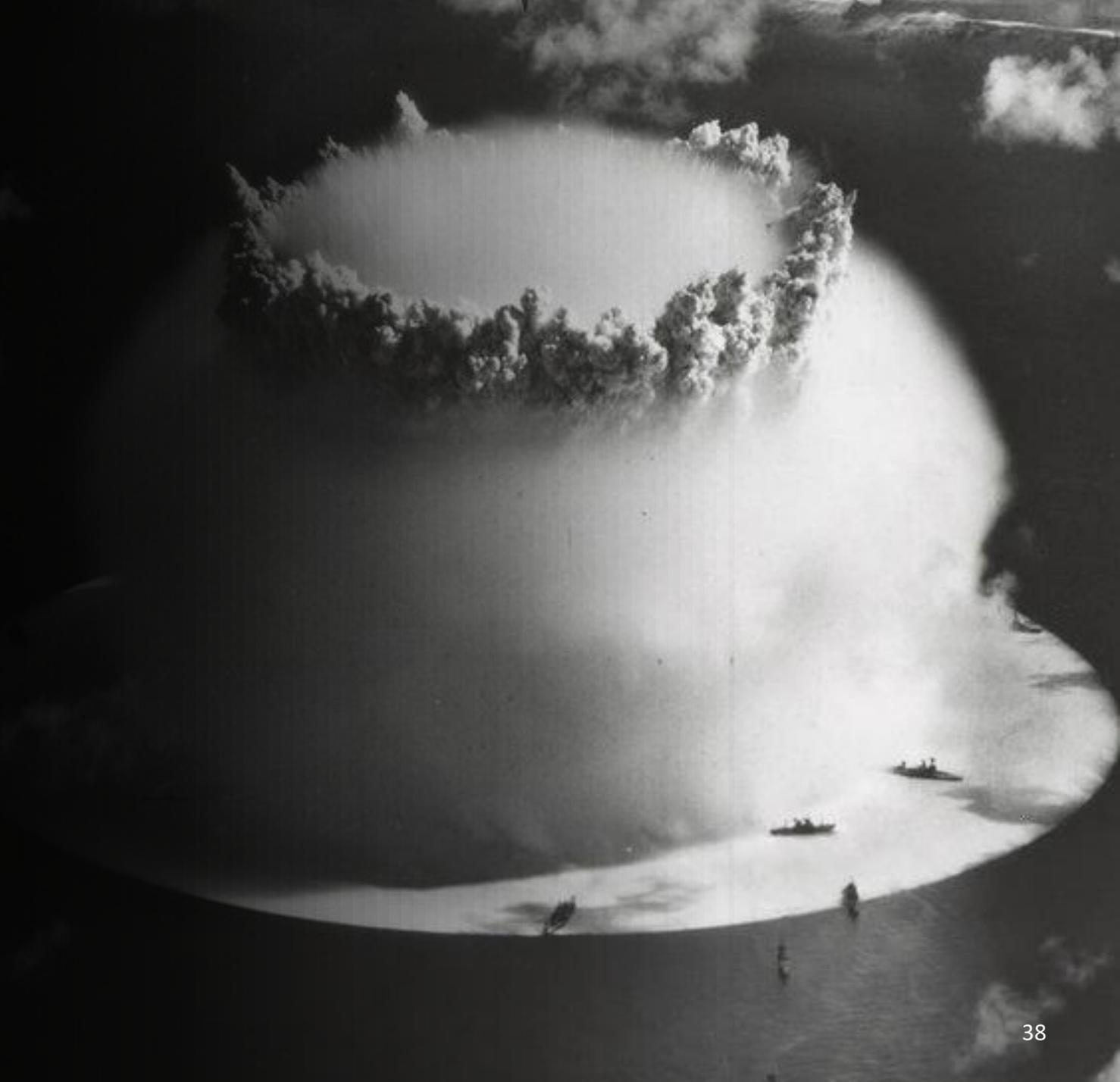
## In conclusion

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Political efforts towards threat reduction are still needed.

Threat reduction requires pressure from the public.

The physics community can play an influential role in advocacy for threat reduction.



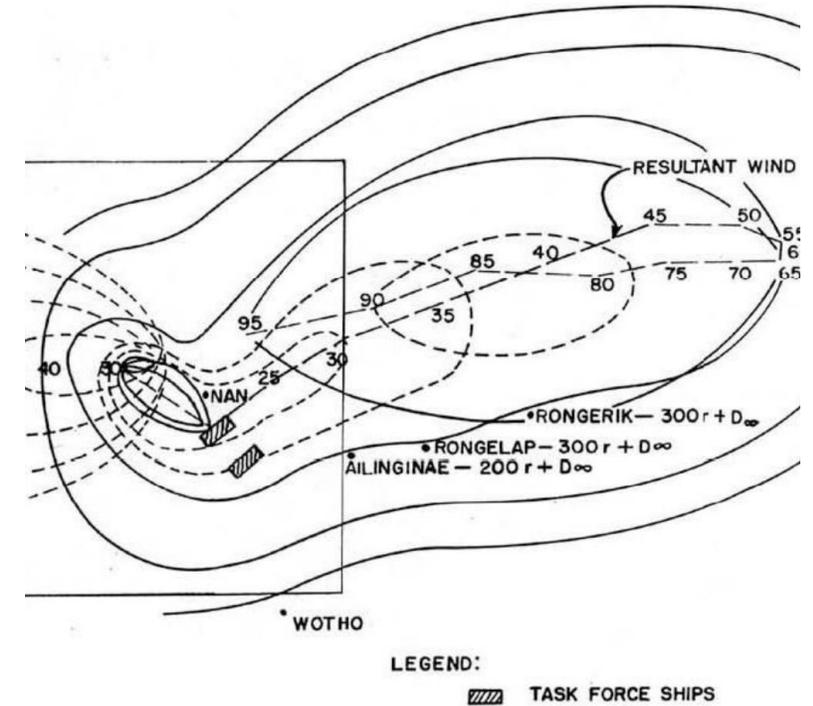
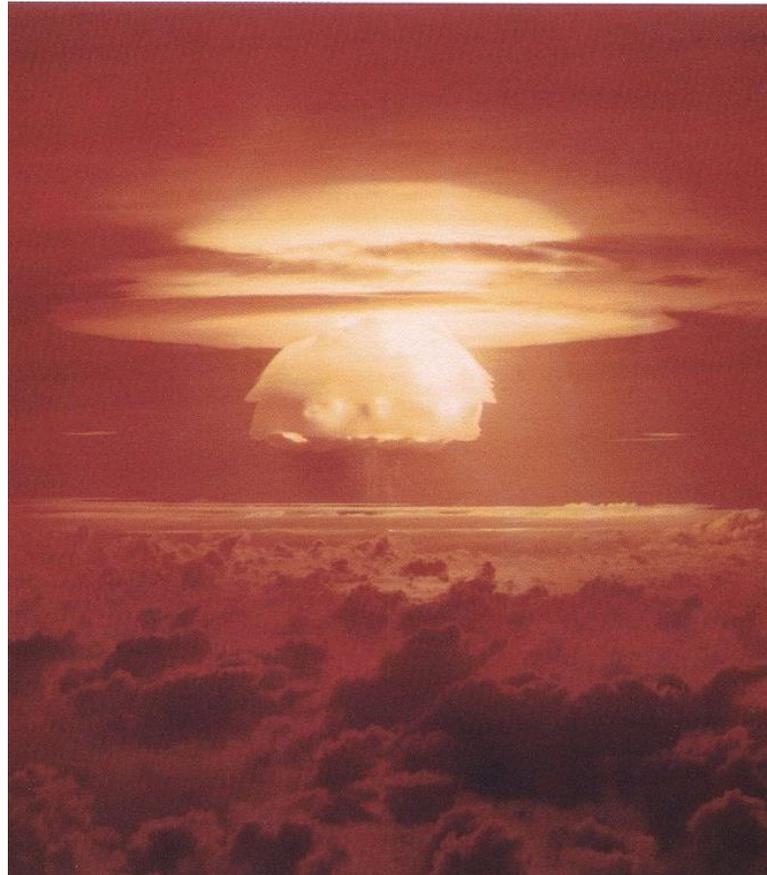
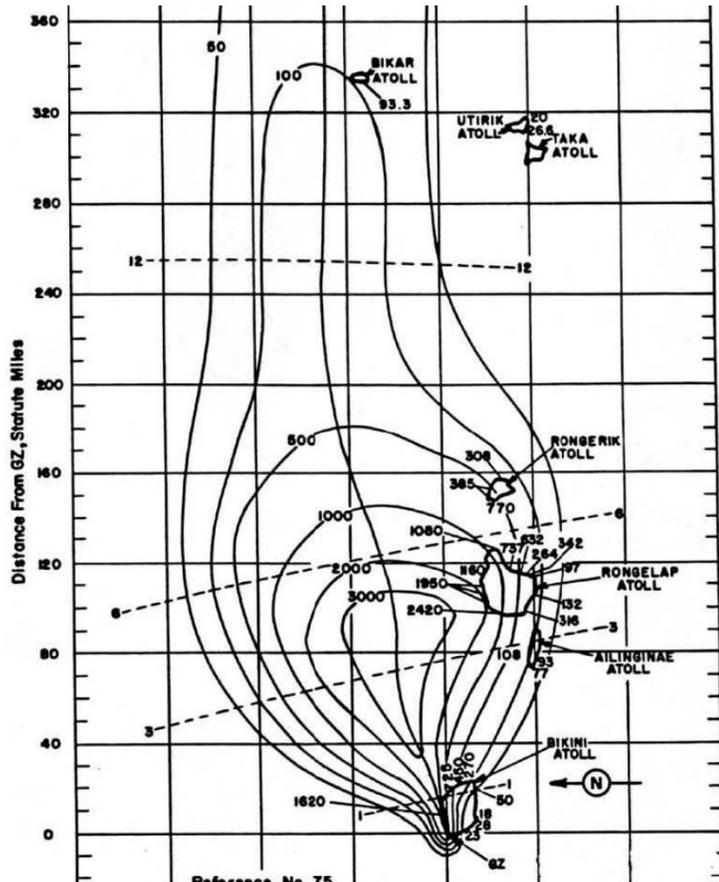
## A final remark: effects of a single bomb

*"Little Boy" dropped on the Japanese city of Hiroshima 1945, energy equivalent of 15,000 tons of TNT.*



- Blast: The severe blast contour was at 1.8 kilometres (>5 psi) from the point under the explosion
- Fire: fireball of 370 m diameter, with a surface temperature of 6,000 °C
- Radiation: burst of intense neutron and gamma radiation

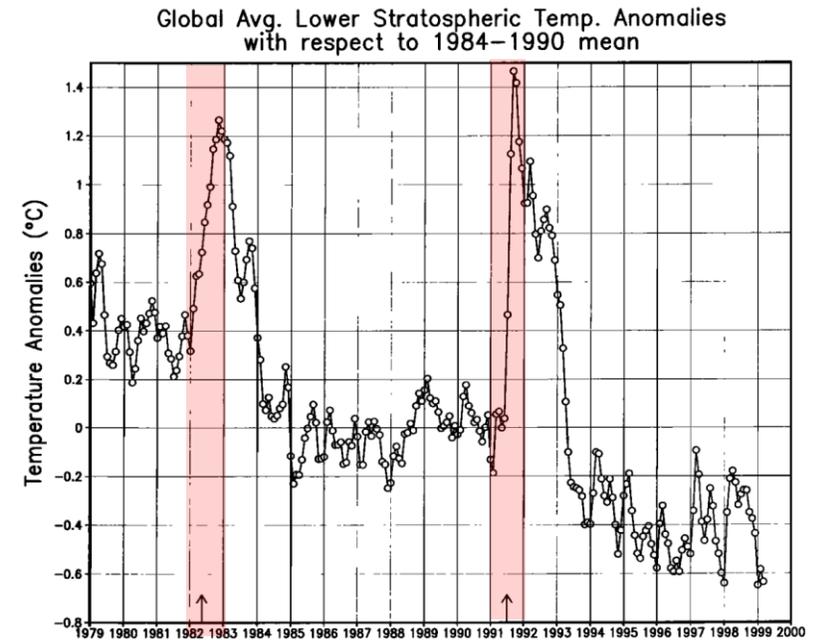
Human Shadow Etched in Stone



## A final remark: effects of a single bomb

*Castle Bravo: the first deployed dry thermonuclear bomb with an estimated yield of 15 megatons*

- Reconstruction of the BRAVO fallout pattern
  - US Naval Radiological Defense Laboratory (left)
  - Maynard 1954 (right)



Volcano eruption effect on the global average monthly stratospheric temperatures. Anomalies (°C) are with respect to the 1984-1990 nonvolcanic period. Times of 1982 El Chichon and 1991 Pinatubo eruptions are denoted in red.

## Indirect effects of multiple bombs

- High socio-economic risk that “will not be affected by national borders”
- Climate disruption and mass starvation<sup>[1]</sup>
  - Severe effects even in the case of a regional nuclear war (3% use of global stockpile)
  - Release of massive amounts of smoke into the atmosphere
  - Blocks out solar radiation
  - Result: sunlight, temperature, and precipitation decrease for over ten years.
- Ozone depletion
- Effects similar to those caused by volcano eruptions <sup>[2]</sup>

[1] Robock and Toon Bulletin of the Atomic Scientists 68(5) 66–74

[2] Robock, Volcanic Eruptions and Climate, Reviews of Geophysics, 38, 2

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*This basic force 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 recognise our inescapable responsibility to carry to our fellow citizens an understanding of atomic energy and its implication 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.*

A. Einstein, Jan 22, 1947

