Nuclear Threat Reduction

Angela Di Fulvio
Nuclear, Plasma, and Radiological Engineering Department
03/24/2020

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.


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.

The map is not to scale.
Fission Timeline

- Neutron Enters the Nucleus
  Time = 0

- Nucleus Deformation

- Neutron Emission
  Time = $10^{-14}$ seconds

- Gamma Ray Emission
  Time = $10^{-12}$ seconds

- Radioactive Decay
  Seconds to Years
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

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

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.
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.

- **Fission primary**
- **Fusion secondary**
- **Fusion capsule implodes because of ablation exerted by surrounding tamper. Tritium *in situ* production in lithium core**
- **Fusion reactions (DT) at the secondary and incipient burn up → fireball**
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.

1955 Soviet Aviation Day “Potemkin village”
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
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.
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".
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.
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
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
A nuclear-weapon-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.

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.
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
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 Achen 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.
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 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.
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 in 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
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 cased the release 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
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—Coup leaders confiscate Mikhail Gorbachev’s nuclear briefcases

18. 1995—US scientific rocket launch interpreted as nuclear missile by the Russians
Policies of concern
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
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
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

• “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

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.

**1962**
800 women strikers for peace in New York near the UN HQ

**1963**
Nuclear test ban treaty

**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.

“As long as weapons of mass destruction exist, primarily nuclear weapons, the danger is colossal”. November, 2019
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

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 [1]

Split support for nuclear energy, trust towards arms control[2],[3]

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. [4]

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

49% of poll participants favor use of nuclear energy; 49% oppose it. [2]

80% percent of the respondents favor extending the New START Treaty beyond its 2021 expiration. [3]

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

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. [3]

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. [4]

[1] Center for International and Security Studies at the University of Maryland, May 2019
In conclusion

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
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)
Indirect effects of multiple bombs

- High socio-economic risk that “will not be affected by national borders”
- Climate disruption and mass starvation
  - 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

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.

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