Nuclear Weapon Risks Briefing

Milan Ilnyckyj

2025-11-27

> The problem of nuclear weapons is nuclear weapons.

—Richard Butler[1]

> So much confusion, so much paranoia, so many good intentions, so much hard work, technical genius, cynicism, manipulation, buckpassing, buckpocketing, argument, grandstanding, risk-taking, calculation, theorizing, goodwill and bad, rhetoric and hypocrisy, so much *desperation*, all point to something intractable behind the problem of how to deploy sufficient and appropriate nuclear arms to protect one's nation from a nuclear-armed opponent. There was such a beast. It was quite simply the fundamental physical fact of nuclear energy: that such power is relatively cheap to generate and essentially illimitable. Nuclear warheads cost the United States about $250,000 each: less than a fighter-bomber, less than a missile, less than a patrol boat, less than a tank. Each one can destroy a city and kill hundreds of thousands of people. "You can't have this kind of war," Eisenhower concluded. "There just aren't enough bulldozers to scrape the bodies off the streets." It followed, and follows, that there is no military solution to safety in the nuclear age: There are only political solutions. As the Danish physicist and philosopher Niels Bohr summarized the dilemma succinctly for a friend in 1948, "We are in an entirely new situation that cannot be resolved by war." The impossibility of resolving militarily the new situation that knowledge of how to release nuclear energy imposes on the world is the reason the efforts on both sides look so desperate and irrational: They are built on what philosophers call a category mistake, an assumption that nuclear explosives are military weapons in any meaningful sense of the term, and that a sufficient quantity of such weapons can make us secure. They are not, and they cannot.

—Richard Rhodes[2,3,4]

[1] Richard Butler. *Fatal Choice: Nuclear Weapons and the Illusion of Missile Defense.* New York: Basic Books, 2001.

[2] Richard Rhodes. *Arsenals of Folly: The Making of the Nuclear Arms Race.* New York: Random House, 2007, p. 101 (italics in original).

[3] J. Robert Oppenheimer told Leo Szilard that "the atomic bomb is shit" because: "Well, this is a weapon that has no military significance. It will make a big bang — a very big bang — but it is not a weapon which is useful in war." Richard Rhodes. *The Making of the Atomic Bomb.* New York: Simon & Schuster, 1986, p. 642.

[4] Rhodes also points out: "Nations, including the United States and the former Soviet Union, have preferred to accept stalemate and even defeat, as in Vietnam and Afghanistan, rather than escalate to nuclear war. Is there better evidence of the military uselessness of nuclear weapons than six decades of futility?" Richard Rhodes. *The Twilight of the Bombs: Recent Challenges, New Dangers, and the Prospects for a World Without Nuclear Weapons.* New York: Random House, 2010, p. 294.

1 Introduction

The purpose of this briefing is to inform planning in the area of the existential risks posed to humanity and the rich global biosphere by nuclear weapons. This logical step is prior to assessing if and where any effort or organization could help produce better outcomes.

Only two known materials are capable of producing the necessary chain reaction and serving as the core of a nuclear weapon. The first is a highly enriched mass of ^{235}U: an isotope present in natural uranium at about 0.7% by mass.[5] This fraction can be increased by enrichment — including historically by methods like gaseous and thermal diffusion, and electromagnetic separation — but most commonly achieved today by high-speed gas centrifuges which take advantage of the mass difference between ^{235}U and ^{238}U.[6,7,8] When enriched to the point of being able to serve as a nuclear weapon core, ^{235}U is referred to as Highly Enriched Uranium (HEU). This fissile material carries the greatest danger of unauthorized use as the result of theft, since little sophistication is required to assemble a supercritical mass for a crude improvised weapon. The critical mass for a bare ^{235}U sphere is 56 kg, or 15 kg if surrounded by a thick uranium tamper.[9,10]

The second usable material for a bomb core is plutonium and specifically ^{239}Pu.[11,12,13] To make quantities sufficient for weapons, plutonium is bred from uranium through neutron irradiation in a nuclear reactor.[14,15,16] Plutonium metal in nuclear weapons is alloyed with gallium (about 3%) to put it in a favourable allotrope for effective pit manufacture and neutron radiation tolerance characteristics.[17] This process of plutonium breeding is inseparable from the normal operation of a reactor, and as such all civilian power reactors breed plutonium in their fuel rods which could be put to weapon use.[18] Separating weapon-usable plutonium from fuel rods is achieved through a chemical process of reprocessing.[19] The careful monitoring and auditing of nuclear material stockpiles is a crucial part of the international safeguards regime against weapons pro-

[5] Rhodes, *The Making of the Atomic Bomb*, p. 285.

[6] During the Manhattan Project, several independent routes to enrichment were attempted simultaneously, with Harold Urey working on gaseous diffusion at Columbia; Ernest Lawrence pursuing electromagnetic separation at Berkeley; and Eger Murphree working on centifuge development. Rhodes, *The Making of the Atomic Bomb*, p. 388–9.

[7] It is also important to note that uranium enrichment is non-linear: enriching uranium to 20% ^{235}U requires 90% of the seperative work to produce weapons-grade uranium. (Enrichment to 5% takes 60% of the seperative work to reach weapons-grade. Vipin Narang. *Seeking the Bomb: Strategies of Nuclear Proliferation*. Princeton: Princeton University Press, 2022, p. 104–5, 214.

[8] Kemp documents how uranium enrichment went from an enormous industrial effort within the scope of superpowers alone to a process that can be done in a space the size of a high school cafeteria using one diesel generator for about $20 million. R. Scott Kemp. "The nonproliferation emperor has no clothes: the gas centrifuge, supply-side controls, and the future of nuclear proliferation". In: *International Security* 38.4 (2014), pp. 39–78, p. 76.

[9] John Kerry King, ed. *International Political Effects of the Spread of Nuclear Weapons*. Washington D.C.: US Government Print Office, 1979.

[10] Richard Rhodes. *Dark Sun: The Making of the Hydrogen Bomb*. New York: Simon & Schuster, 1995, p. 48.

[11] Implosion weapons depend on an explosive lens system first developed by John von Neumann to compress the core to a supercritical density. Rhodes comments that it was the need to produce ultra-precise molds that "paced Fat Man's testing and delivery." (the nickname for the plutonium implosion bomb) Rhodes, *The Making of the Atomic Bomb*, p. 575–7.

[12] ^{240}Pu must be separated out since its spontaneous fission rate makes it unsuitable as a component in a nuclear weapon core. Rhodes, *Dark Sun: The Making of the Hydrogen Bomb*, p. 152.

[13] See also: Rhodes, *The Twilight of the Bombs: Recent Challenges, New Dangers, and the Prospects for a World Without Nuclear Weapons*, p. 288.

[14] Bombardment of uranium samples in a cyclotron by Glenn Seaborg and Emilio Segrè in early 1941 yielded a sample of neptunium of less than a millionth of a gram, which then decayed completely into ^{239}Pu. Rhodes, *The Making of the Atomic Bomb*, p. 354.

[15] By summer 1944, gram quantities of plutonium began to arrive at Los Alamos. Rhodes, *The Making of the Atomic Bomb*, p. 548.

[16] Rhodes, *Dark Sun: The Making of the Hydrogen Bomb*, p. 116.

[17] See: Periodic Videos. *The Plutonium Core of an Atom Bomb - Periodic Table of Videos*. 2020. URL: https://youtu.be/QLZMzsRB86E?si=9nYW7BphRfcra1mJ&t=209 (visited on 01/03/2024).

[18] Garwin and Charpak explain: "A rule of thumb is that a megawatt of fission heat in a natural uranium reactor accompanies the production of about a gram of plutonium-239 per day. About six kilograms were sufficient to make a bomb." Richard L. Garwin and Georges Charpak. *Megawatts and Megatons: The Future of Nuclear Power and Nuclear Weapons*. Chicago: University of Chicago Press, 2002, p. 33.

[19] The PUREX process was developed in the US in WWII and has subsequently been used in the UK, France, and Japan. Fuel rods are dissolved in nitric acid, and then uranium and plutonium are extracted into tri-butyl phosphate in kerosene. Matthew Gill, Francis Livens, and Aiden Peakman. "Chapter 9 — Nuclear Fission". In: *Future Energy (Second Edition)*. Ed. by Trevor M. Letcher. Second Edition. Boston: Elsevier, 2014, pp. 181–198. ISBN: 978-0-08-099424-6. DOI: https://doi.org/10.1016/B978-0-08-099424-6.00009-0. URL: https://www.sciencedirect.com/science/article/pii/B9780080994246000090 (visited on 01/04/2024).

liferation, as administered by the International Atomic Energy Agency (IAEA).[20] A hollow plutonium ball with a diameter of 80–90 mm and a mass of 7.3–10 kg, initiator included, will serve as the critical mass for an implosion-type bomb.[21]

Composite cores made from a mixture of uranium and plutonium are also possible, and were used in US Mark 4 weapons after 1949.[22]

Detonating an implosion weapon depends on a series of specialized components operating with a precise sequence and timing. A nuclear weapon's firing set includes batteries connected to an array of capacitors, which are in turn connected to krytrons (high speed cathode ray switches). These are connected to exploding-wire detonators inserted into a sphere of high explosive blocks around a sphere of HEU or ^{239}Pu.[23] These detonators must fire within a time variation of 10 nanoseconds to avoid asymmetrical compression which would not produce a nuclear yield.[24,25] The design must include an initiator-like device to introduce neutrons at precisely the right moment and not before, though neutron generators have supplanted polonium-beryllium initiators in modern 'shelf-stable' weapons.[26] An implosion weapon could be inadvertently set off by a fire, a bullet striking one of the explosive lenses, or a small error in assembly.[27] Between November 1955 and January 1956, the US performed safety tests for single-point safety on four nuclear weapon designs, to evaluate the risk of something like a single bullet hitting the bomb's explosive lenses.[28,29,30] It was eventually identified that the greatest risk was from a bullet or piece of shrapnel striking the corner where three high explosive lenses intersected.[31] Even if a bomb design did not produce a nuclear yield from such an explosion, it would scatter plutonium dust in the air.[32]

Interestingly, during WWII the scientists working on US nuclear weapons did not expect the emergence of a permanent nuclear establishment to outlast the war.[33] Edward Teller suspected that his colleagues had lost their appetite for weapons work, and Hans Bethe recalled: "We all felt that, like the soldiers, we had done our duty and deserved to return to the type of work that we had chosen as our life's career... Moreover, it was not obvious in 1945 and 1946 that there was any need for a large effort on atomic weapons in peacetime."[34,35] Norris Bradbury, who took over as director from Oppenheimer, said: "In the months immediately following the war, the Laboratory struggled for existence and there is no better way to put it."[36] American bombs of the era relied on 48-hour lead-acid batteries which had to be stored disassembled, and took two days to assemble by a team that was not permanently available. They also relied on short-

[20]For a description of the purposes and procedures of the IAEA, see: Gudrun Harrer. *Dismantling the Iraqi Nuclear Programme: The Inspections of the International Atomic Energy Agency, 1991–1998*. New York: Routledge, 2014.

[21]Rhodes, *Dark Sun: The Making of the Hydrogen Bomb*, p. 194.

[22]Eric Schlosser. *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*. New York: Penguin Random House, 2013, p. 99.

[23]Rhodes, *The Twilight of the Bombs: Recent Challenges, New Dangers, and the Prospects for a World Without Nuclear Weapons*, p. 19, 72–3.

[24]Rhodes, *The Twilight of the Bombs: Recent Challenges, New Dangers, and the Prospects for a World Without Nuclear Weapons*, p. 72.

[25]Luis Alvarez and Lawrence Johnston invented exploding-bridgewire detonators using a high voltage current through a thin silver wire to set off all 32 detonators simultaneously with the required precision. Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 41.

[26]The US Mark 3 bomb "was a handmade, complicated, delicate thing with a brief shelf life." It relied on a battery that had to be charged for days beforehand, and the bomb had to be disassembled to access it. The plutonium cores produced enough heat to melt the explosive lenses if left in place too long. The polonium initiators lasted only a few months. Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 98.

[27]Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 49.

[28]Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 163–4.

[29]Ellsberg describes how nuclear weapons carried by single-person F-100 aircraft in Kadena Air Base in Okinawa were not one-point safe, and thus did not have an estimated 1/1,000,000 assurance against a nuclear yield greater than 4 pounds in the event of an accident. Daniel Ellsberg. *The Doomsday Machine: Confessions of a Nuclear War Planner*. New York: Bloomsbury, 2017, p. 47–8, 56.

[30]Scott D. Sagan. *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*. Princeton: Princeton University Press, 1993, p. 184.

[31]Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 198.

[32]Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 164.

[33]Rhodes, *The Making of the Atomic Bomb*, p. 451.

[34]Rhodes, *The Making of the Atomic Bomb*, p. 754.

[35]For context, shortly after WWII the number of soldiers in the US Army rapidly fell from 8 million to less than 1 million; many planes, ships, and tanks were scrapped; and the defense budget was cut by nearly 90%. Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. . 80.

[36]Rhodes, *The Making of the Atomic Bomb*, p. 755.

lived polonium for initiators, with a 138.3 day half life.[37] Without new polonium, "the atomic bombs in the nation's small stockpile would become unreliable within a year."[38] In 1947, David Lilienthal had to report to President Truman that: "There was no stockpile. There was not a single operable atomic bomb in the 'vault' at... Los Alamos... Nor could there be one for many months to come... We didn't have any weapons, we had piles of pieces."[39,40]

Nonetheless, Los Alamos did become a permanent atomic bomb factory, which necessitated the development of bombs designed to sit on the shelf, in contrast to the Little Boy and Fat Man weapons which "had been meticulously built from selected parts by the people who helped create them."[41] By June 1946, the US had nine 'Fat Man' plutonium implosion weapons, and polonium-beryllium initiators for at most seven.[42] By two years after the war, the US atomic bomb count was 13.[43] By the 1950s and 60s, historian Douglas Lawson of the Sandia National Laboratory argued that "the large growth that we saw [in nuclear weapons production] in the 1950s and 1960s was primarily driven by the capacity of the [production] complex and not truly by [military] requirements."[44]

2 Global and local effects of nuclear detonations

The ^{235}U gun-type bomb dropped on Hiroshima in August 1945 had an estimated yield of 16 kilotons (kt) of TNT, ± 2 kt.[45,46] That is equivalent to about 7×10^{13} joules. Rhodes estimates the resulting deaths at 140,000 in 1945 and 200,000 within five years.[47] The "Little Boy" bomb dropped on Hiroshima was very inefficient; 98.62% of the laboriously enriched HEU was blown apart before it became supercritical, and the weapon's yield came from the 1.38% of HEU that actually fissioned.[48] The Nagasaki bomb had a yield of around 22 kt and killed 70,000 in 1945 and 140,000 over five years.[49] About one fifth of the plutonium in the "Fat Man" bomb dropped on Nagasaki fissioned.[50] Perhaps one-fifth of the deaths from the Hiroshima and Nagasaki bombs resulted from radiation sickness from acute exposure to ionizing radiation, primarily gamma rays.[51] The plutonium weapon used in the Trinity test had a yield determined by radiochemical measurement of 18.6 kt by Herbert Anderson.[52,53] The largest thermonuclear weapon tested by the Soviet Union (RDS-220, called 'Tsar Bomba' in the west) was tested with a yield of about 50 megatons when tested with non-fissionable lead tampers instead of a ^{238}U tamper which would have doubled the yield when caused to fission by neutrons from fusion.[54] 50 megatons is about 2×10^{17} J.

[37] Rhodes, *Dark Sun: The Making of the Hydrogen Bomb*, p. 261, 277.

[38] Rhodes, *Dark Sun: The Making of the Hydrogen Bomb*, p. 277.

[39] Rhodes, *Dark Sun: The Making of the Hydrogen Bomb*, p. 283–4.

[40] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 96.

[41] Rhodes, *Dark Sun: The Making of the Hydrogen Bomb*, p. 278, 307.

[42] Rhodes explains the function of these devices: "In the few millionths of a second when the shock wave had squeezed the implosion assembly to maximum density, before the assembly began to rebound and disassemble, it needed a squirt of neutrons to start the chain reaction. The initiator was the first device used in atomic bombs to supply those neutrons, by knocking them out of a shell of beryllium foil with alpha particles from another shell of hot, highly alpha-radioactive polonium. It was a small nugget of exotic metals to be set exactly at the center of the bomb, nested in a cavity within the two hemispheres of plutonium... The initiator was nearly as difficult to design as the larger bomb around it, layers within layers, and its ingenuities were compressed within a gadget no bigger than a walnut." Rhodes, *Dark Sun: The Making of the Hydrogen Bomb*, p. 119.

[43] Rhodes, *The Making of the Atomic Bomb*, p. 765.

[44] Rhodes, *Arsenals of Folly: The Making of the Nuclear Arms Race*, p. 83.

[45] George D. Kerr et al. "Bomb Parameters". In: *Reassessment of the Atomic Bomb Radiation Dosimetry for Hiroshima and Nagasaki — Dosimetry System 2002*. Hiroshima: The Radiation Effects Research Foundation, 2005. URL: `https://web.archive.org/web/20150810210007/http://www.rerf.or.jp/shared/ds02/pdf/chapter01/cha01-p42-61.pdf`, p. 52.

[46] Rhodes cites a yield of 12.5 kt. Of 76,000 buildings in Hiroshima, 70,000 were damaged or destroyed, 48,000 completely. Rhodes, *The Making of the Atomic Bomb*, p. 711, 728.

[47] Rhodes, *The Making of the Atomic Bomb*, p. 734.

[48] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 51.

[49] Rhodes, *The Making of the Atomic Bomb*, p. 741–2.

[50] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 53.

[51] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 54.

[52] Rhodes, *The Making of the Atomic Bomb*, p. 677.

[53] William Penney, who later led the British bomb project, held a seminar five days after Trinity where, as Philip Morrison recollected, "he predicted that this weapon would reduce a city of three or four hundred thousand people to nothing but a sink for disaster relief, bandages, and hospitals." Rhodes, *The Making of the Atomic Bomb*, p. 678.

[54] The weapon produced a mushroom cloud that rose 40 miles into the sky, and a fireball which could be seen from 600 km away from ground zero. Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of*

The current US arsenal is comprised of three types of weapons: gravity bombs to drop from aircraft, land-based ICBMs, and SLBMs on nuclear-powered submarines. The two gravity bombs are the B61 and B83. The LGM-30G Minuteman III solid-fueled, land-based ICBM carries the W78 warhead. The UGM-133A Trident II SLBM can be loaded with up to 8 475 kt W88 warheads, 14 90 kt W76-1 warheads, or 14 5-7 kt W75-2 warheads. [TK destructiveness of around 475 kt]

2.1 Small, improvised, or tactical weapon

The least technically sophisticated way to produce a nuclear detonation is to steal two sub-critical masses of highly-enriched ^{235}U. Biographer of the atomic bomb Richard Rhodes described a meeting with a key Manhattan Project scientist:

> In 1986, when I helped the Nobel Laureate physicist Luis W. Alvarez write his memoirs, Alvarez commented one day on the importance of keeping track of highly enriched uranium. Speaking of a quantity sufficient to form a supercritical mass, he told me: "You can make a fairly high-level nuclear explosion just by dropping one piece onto another *by hand*." Alvarez had been intimately involved in the development of the first atomic bombs, and knew whereof he spoke. Some years later I gave a talk at the National Atomic Museum in Albuquerque during which I quoted Alvarez's comments. An audience member from one of the nearby weapons labs, Los Alamos or Sandia, told me afterward with some enthusiasm, probably speaking out of turn, "Yes, and if you can accelerate it even a little you get a *much bigger* explosion."[55,56]

Such an improvised weapon establishes a lower limit for the destructiveness of such a device (which is very distinct from a radiological weapon or 'dirty bomb' which does not rely on fission or criticality). Matthew Bunn and Antony Weir describe how the Senate Foreign Relations Committee asked the three US weapons labs whether terrorists with fissile materials could assemble a bomb. Within months:

> the laboratories had actually built a gun-type device, using only components that, except for the nuclear material itself, were off the shelf and commercially available without breaking any laws. The device was actually brought into a secure Senate hearing room to demonstrate the gravity of the threat.[57]

In mid-1977, South Africa also clandestinely assembled a gun-type device; by 1979 they had produced enough HEU for a bomb, and completed the device by the end of the year.[58] It can therefore be concluded that the main mechanism for preventing rogue groups or governments from developing nuclear weapons is control over fissionable material. In particular, this means blocking the HEU route to a bomb by controlling access to uranium enrichment, and blocking the plutonium route to a bomb by auditing spent fuel and restricting reprocessing. As discussed in the section on nuclear proliferation, this will be particularly challenging as civilian nuclear technology is deployed more broadly. Light water reactors require low-enriched uranium to operate, and the facilities that would be used to make such fuel are the same as could be used to make HEU for a bomb. Likewise, all operating reactors breed plutonium, and technologies to reprocess spent fuel to put it to use and reduce its volume can also be applied to separating plutonium for weapon use.

In 1968, the UN estimated that a full-fledged nuclear weapons program requires 500 scientists and 1,300 engineers, including machine-tool operators with precision engineering experience. A state pursuing nuclear weapons needs expertise in engineering, mining, and explosives and — if it wishes to keep the nuclear weapon program clandestine — it must have sufficient reserves of foreign currency and foreign partners willing to provide technology and expertise in secret.[59]

Safety, p. 286.

[55] Rhodes, *The Twilight of the Bombs: Recent Challenges, New Dangers, and the Prospects for a World Without Nuclear Weapons*, p. 289 (italics in original).

[56] Rhodes notes that without a tamper to help compress the fissile material and reduce predetonation, even a mass of material at twice the critical mass would completely fission less than 1% of the available material before it expanded enough to stop the chain reaction. Rhodes, *The Making of the Atomic Bomb*, p. 461–2.

[57] Rhodes, *The Twilight of the Bombs: Recent Challenges, New Dangers, and the Prospects for a World Without Nuclear Weapons*, p. 290.

[58] Narang, *Seeking the Bomb: Strategies of Nuclear Proliferation*, p. 276, 284.

[59] Feroz Hassan Khan. *Eating Grass: The Making of the Pakistani Bomb*. Stanford: Stanford University Press, 2012, p. 49.

2.2 Teller-Ulam staged thermonuclear weapon

Even before the first fission weapon test, some scientists at Los Alamos had become intrigued by the possibility of a nuclear fusion weapon or hydrogen bomb. As early as September 1941, Edward Teller speculated to Enrico Fermi that a fission bomb could be used to initiate thermonuclear fusion in deuterium, an isotope of hydrogen.[60] During the war, Robert Serber remembered seeing a list of ideas for weapons and delivery vehicles on Teller's blackboard; the delivery method for the largest was listed as "Backyard": "Since that particular design would probably kill everyone on earth, there was no use carting it elsewhere."[61]

In an intermediate position between a simple fission bomb and a true staged fusion weapon, the US developed tritium 'boosted' weapons and successfully tested one in May 1951.[62,63,64] When a boosted core implodes, tritium and deuterium inside the core fuse and produce neutrons which induce further fission; through this method, the explosion can be made 10–100 times larger, and smaller and more efficient bombs could be built using less fissile material.[65]

By February 1951, the concept for a Teller-Ulam staged thermonuclear weapon had been developed.[66,67] Stanislaw Ulam's insight was that a fission-based primary could be physically separated from thermonuclear materials and that the enormous flux of x-rays from the primary could be used to ignite the fusion secondary.[68,69,70] By spring 1954, the US had tested the first deployable thermonuclear weapon, which relied on solid lithium deuteride as fission fuel, in place of the cryogenic tritium and deuterium used in the 'Ivy Mike' shot of November 1, 1952.[71,72] This 'Castle Bravo' test used a weapon small enough to be deployed by aircraft, and produced a yield of 15 megatons.[73,74] The ironically-named "Shrimp" device detonated in the test revealed that ^{7}Li was not inert as the designers assumed, but bred tritium which increased the explosive yield and quantity of fallout.[75] The test inadvertently exposed the crew of the Japanese fishing boat Lucky Dragon to radioactive fallout, killing one crew member and leaving the rest hospitalized for 8 months.[76,77] The Soviet Union followed with their own true thermonuclear test on November 23, 1955.[78]

2.3 Nuclear winter

The crucial dimension of difference between, for instance, a thermonuclear exchange involving several tens of weapons used against cities or built-up areas, and the thousands of weapon tests carried out by the

[60] Rhodes, *The Making of the Atomic Bomb*, p. 374–5.

[61] Rhodes, *Dark Sun: The Making of the Hydrogen Bomb*, p. 253.

[62] Rhodes, *The Making of the Atomic Bomb*, p. 768–9.

[63] Like plutonium, the hydrogen isotope tritium does not exist in nature. It decays with a half-life of 12.5 years and must be made in a nuclear reactor through lithium bombardment. Rhodes, *Dark Sun: The Making of the Hydrogen Bomb*, p. 256.

[64] British efforts to breed tritium in their air-cooled Windscale reactors via magnesium-lithium cartridges placed in the graphite reactor core contributed to the October 10, 1957 Windscale fire. Richard Wakeford. "The Windscale reactor accident—50 years on". In: *Journal of Radiological Protectiont* 27 (2007), pp. 211–215. URL: https://web.archive.org/web/20190414092225id_/https://iopscience.iop.org/article/10.1088/0952-4746/27/3/E02/pdf (visited on 01/04/2024).

[65] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 129.

[66] Rhodes, *The Making of the Atomic Bomb*, p. 773.

[67] As early as September 1941, Fermi shared the concept of using a fission bomb to initiate deuterium fusion with Teller. Rhodes, *Dark Sun: The Making of the Hydrogen Bomb*, p. 248.

[68] Rhodes, *The Making of the Atomic Bomb*, p. 774.

[69] On the mechanisms of x-ray use in a thermonuclear weapon, see: Rhodes, *Dark Sun: The Making of the Hydrogen Bomb*, p. 457–8, 466.

[70] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 127–8.

[71] Rhodes, *The Making of the Atomic Bomb*, p. 778.

[72] Rhodes, *The Making of the Atomic Bomb*, p. 482–512.

[73] Rhodes, *The Making of the Atomic Bomb*, p. 778.

[74] The Castle Bravo device used lithium enriched to 40% ^{6}Li and was small enough to carry in a B-47 weapon bay. Rhodes, *Dark Sun: The Making of the Hydrogen Bomb*, p. 541.

[75] National Security Archive. *Castle BRAVO at 70: The Worst Nuclear Test in U.S. History.* 2024. URL: https://nsarchive.gwu.edu/briefing-book/nuclear-vault/2024-02-29/castle-bravo-70-worst-nuclear-test-us-history (visited on 08/28/2024).

[76] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 140.

[77] If a weapon of the same time were detonated in Washington D.C. it would give a lethal dose of radiation to everyone in Washington, Baltimore, and Philadelphia — and kill half the population of New York City. Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 140–1.

[78] Rhodes, *The Making of the Atomic Bomb*, p. 778.

great powers, and chiefly US and USSR, during the Cold War is soot.[79] In 1990, Carl Sagan et al. warned in Science:

> For the most likely soot injections from a full-scale nuclear exchange, three-dimensional climate simulations yield midsummer land temperature decreases that average 10° to 20°C in northern mid-latitudes, with local cooling as large as 35°C, and subfreezing summer temperatures in some regions.[80,81,82]

A thermonuclear weapon used against a city would ignite everything combustible across large scales of distance, instantaneously from the flash and thermal energy of the bomb, and successively as well from shock wave blast and other weapon effects. The scale of destruction would be such as to destroy all emergency and medical services for a large distance from the detonation point of the weapon, leaving countless secondary fires to burn as the gas distribution infrastructure is shattered, along with fuel pipelines, refineries, nuclear power stations, and industrial facilities of all sorts left in a damaged, unpowered, uncrewed, and ultimately explosively destructive state.[83] After WWII, Winston Churchill asked William Strath, an official at the Central War Plans Secretariat, to research the effects of a thermonuclear attack on the UK. Strath concluded that one hydrogen bomb in a built-up area would start 100,000 fires within a circle with a circumference of 60–100 miles.[84] The soot from these fires would likely cause the worst impacts of a general nuclear war for humanity and the rest of nature:

> It is the smoke, after all (not the fallout, which would mostly remain limited to the northern hemisphere), that would do it worldwide: smoke and soot *lofted* by fierce firestorms in hundreds of burning cities into the stratosphere, where it would not rain out and would remain for a decade or more, enveloping the globe and blocking most sunlight, lowering annual global temperatures to the level of the last Ice Age, and killing all harvests worldwide, causing near-universal starvation within a year or two.[85]

Nuclear attacks against cities thus threaten existential consequences for all of humanity, whether those threatened are directly attacked or not.

Insight into the potential effects of nuclear weapon use on built-up areas can be gleaned from the experiences of mass conventional bombing in WWII. Rhodes quotes novelist Kurt Vonnegut, Jr. on the fire storms kicked off in Dresden by conventional incendiary bombing in WWII:

> A fire storm is an amazing thing. It doesn't occur in nature. It's fed by the tornadoes that occur in the midst of it and there isn't a damned thing to breathe.[86]

When US forces bombed Tokyo with incendiary bombs on March 10, 1945 it produced what the US Strategic Bombing Survey called a "conflagration."[87,88] This featured:

> a fire front, an extended wall of fire moving to leeward, preceded by a mass of pre-heated, turbid, burning vapors. The pillar was in a much more turbulent state than that of a fire storm, and being usually closer to the ground, it produced more flame and heat, and less smoke. The progress and destructive features of the conflagration were consequently much greater than those of a fire

[79] The U.S. conducted 1,054 nuclear tests between 1945 and 1992, 70% of them underground. Rhodes, *The Twilight of the Bombs: Recent Challenges, New Dangers, and the Prospects for a World Without Nuclear Weapons*, p. 123.

[80] Richard P Turco et al. "Climate and smoke: An appraisal of nuclear winter". In: *Science* 247.4939 (1990), pp. 166–176. URL: https://www.science.org/doi/abs/10.1126/science.11538069.

[81] See also: Matthew R. Francis. *When Carl Sagan Warned the World About Nuclear Winter: Before the official report came out, the popular scientist took to the presses to paint a dire picture of what nuclear war might look like.* 2017. URL: https://www.smithsonianmag.com/science-nature/when-carl-sagan-warned-world-about-nuclear-winter-180967198/ (visited on 12/29/2023).

[82] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 445–6.

[83] For projections of what would happen to oil refineries and nuclear power stations if left without a functional crew, see: Alan Weisman. *The World Without Us*. New York: Harper Perennial, 2008.

[84] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 141.

[85] Ellsberg, *The Doomsday Machine: Confessions of a Nuclear War Planner*, p. 17 (italics in original).

[86] Rhodes, *The Making of the Atomic Bomb*, p. 593.

[87] Rhodes, *The Making of the Atomic Bomb*, p. 599.

[88] Rhodes called this bombing "indiscriminate to the point of atrocity" and noted that by the end of the war it extended to totally or partially burning out the cores of 63 Japanese cities. Rhodes, *Dark Sun: The Making of the Hydrogen Bomb*, p.21.

storm, for the fire continued to spread until it could reach no more material... An extended fire swept over 15 square miles in 6 hours. Pilots reported that the air was so violent that B-29s at 6,000 feet were turned completely over, and that the heat was so intense, even at that altitude, that the entire crew had to don oxygen masks. The area of the fire was nearly 100 percent burned; no structure or its contents escaped damage.[89]

That night, more than 100,000 people died in Tokyo, a million were injured, and a million lost their homes.[90] All this was brought about by 2,000 kg of incendiary bombs.[91] In 10 days and 1,600 sorties, Curtis LeMay's Twentieth Air Force burned out 32 square miles of the centres of Japan's largest cities and killed at least 150,000 people.[92] These real tragedies underscore the risks posed every day by the existence and forward deployment of nuclear weapons of all types.

In an October 1949 report for the Atomic Energy Commission, I. I. Rabi and Enrico Fermi urged against the development of megaton-scale thermonuclear weapons. The Nobel Laureates expressed their judgment that:

> Such a weapon goes far beyond any military objective and enters the range of very great natural catastrophes. By its very nature it cannot be confined to a military objective but becomes a weapon which in practical effect is almost one of genocide... It is necessarily an evil thing considered in any light.[93]

In President Truman's farewell address he warned:

> The war of the future would be one in which man could extinguish millions of lives in one blow, demolish the great cities of the world, wipe out the cultural achievements of the past — and destroy the very structure of a civilization that has been slowly and painfully built up through hundreds of generations. Such a war is not a possible policy for rational men.[94]

While the rationale for megaton-scale weapons may be questionable, the fact of their possession by an enemy has been a motivating force for some national leaders. When President Truman met David Lilienthal, Dean Acheson, and Louis Johnson in January 1950 to discuss thermonuclear weapons, he decided that since it was possible for the Soviets to develop thermonuclear weapons the US had to do so as well.[95] Rhodes comments on how a post-war General Advisory Committee report fed such arms race analysis:

> When the GAC argued that building the Super might unleash unlimited destruction, then, it unwittingly enlarged the scope of its opponents' fears and encouraged them to pursue the project with even greater urgency, because they immediately translated the weapon's destructive potential into a threat and imagined the consequences if the enemy should acquire it first. An arms race is a hall of mirrors.[96]

This illustrates the central dynamic of the security dilemma: a state feels threatened and so deploys weapons which it considers defensive, then other states observe that builup and assess it as aggressive action which requires further armament of their own as a defensive response, and so on.

In Rhodes' assessment of the Cuban Missile Crisis:

> In 1962, [General Thomas S.] Power was prepared to deliver almost three thousand strategic nuclear weapons, many of them thermonuclear bombs, with yields totaling seven thousand megatons. Under such a rain of destruction, the United States would have killed at least 100 million human beings in pursuit of the small group of Soviet leaders, as [General Curtis] LeMay said, "[who] have as their primary goal... retention of power inside the USSR in the few hands in which it now resides." If the Soviet field commanders in Cuba had launched their missiles as

[89] Rhodes, *The Making of the Atomic Bomb*, p. 599.
[90] Rhodes, *The Making of the Atomic Bomb*, p. 599.
[91] Rhodes, *The Making of the Atomic Bomb*, p. 599.
[92] Rhodes, *The Making of the Atomic Bomb*, p. 600.
[93] Rhodes, *Arsenals of Folly: The Making of the Nuclear Arms Race*, p. 76.
[94] Rhodes, *Arsenals of Folly: The Making of the Nuclear Arms Race*, p. 79.
[95] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 124.
[96] Rhodes, *Dark Sun: The Making of the Hydrogen Bomb*, p. 402.

well, more millions of Americans would have been killed. Seven thousands weapons was also more than enough fire and brimstone to initiate a lethal nuclear winter over at least the Northern Hemisphere, freezing and starving yet more millions in Europe, Asia and North America — a phenomenon that scientists had not yet identified and that neither SAC [the Strategic Air Command] nor Washington had yet assessed. How extraordinary that Curtis LeMay believed for the rest of his life that the United States "lost" the Cuban Missile Crisis and the Cold War. If John Kennedy had followed LeMay's advice, history would have forgotten the Nazis and their terrible Holocaust. Ours would have been the historic omnicide.[97]

There was thus a plausible chain of escalation from US commanders' misunderstanding of the force deployment of nuclear weapons into Cuba to a large-scale thermonuclear exchange that would have put humanity in peril.

By the mid-1980s, the global nuclear arsenal had grown to about 50,000 bombs. McNamara wrote in 1986 that a few hundred of those bombs "could destroy not only the United States, the Soviet Union and their allies, but, through atmospheric effects, a major part of the rest of the world as well."[98] In 2000, former Soviet leader Mikhail Gorbachev expressed the same fear: "Models made by Russian and American scientists showed that a nuclear war would result in a nuclear winter that would be extremely destructive to all life on earth."[99,100,101]

A mass nuclear 'exchange' between the US and Russia is not the only possible cause of nuclear winter. One assessment considered the effects of 50 Hiroshima-sized bombs against Indian cities and 50 against Pakistani cities. The authors estimated that such an exchange would produce three teragrams of smoke from Pakistan and four from India.[102,103] The projected effects are global:

> Sunlight was immediately reduced, cooling the planet to temperatures lower than any experienced for the past 1,000 years. The global average cooling, of about 1.25 degrees Celsius (2.3 degrees Fahrenheit), lasted for several years, and even after 10 years the temperature was still 0.5 degree C colder than normal. The models also showed a 10 percent reduction in precipitation worldwide.[104,105]

This compares with a 0.5 degree C cooling from the 1815 Tambora eruption, which resulted in the 'Year without a Summer.'

3 Risks from accidental or unauthorized use

> Any military commander who is honest with himself, or with those he's speaking to, will admit that he has made mistakes in the application of military power. He has killed people unnecessarily: his own troops or other troops, through mistakes, through errors of judgment. 100, or thousands,

[97] Rhodes, *Dark Sun: The Making of the Hydrogen Bomb*, p. 575–6.

[98] Rhodes, *Arsenals of Folly: The Making of the Nuclear Arms Race*, p. 69.

[99] Alan Robock and Owen Brian Toon. *South Asian Threat? Local Nuclear War = Global Suffering*. 2010. URL: https://www.scientificamerican.com/article/local-nuclear-war/ (visited on 12/30/2023).

[100] In the summer of 1986, Gorbachev told Richard Nixon that nobody gained from the arms race: "The weaker party could just explode its nuclear stockpile, even on its own territory, which would mean suicide for it and a slow death for the opponent." Rhodes, *The Twilight of the Bombs: Recent Challenges, New Dangers, and the Prospects for a World Without Nuclear Weapons*, p. 5.

[101] By 1968, the Soviet defense ministry had concluded that the USSR could not win a nuclear war, even if they struck first. In 1981, the Soviet General Staff concluded that "nuclear use would be catastrophic." Perry and Collina argue: "Today, climate science tells us that a full-scale nuclear attack by either side would be suicidal even if there were no retaliation. The impact on the global climate from a unilateral attack would be so extreme as to eventually doom the attacker." William J. Perry and Tom Z. Collina. *The Button: The New Nuclear Arms Race and Presidential Power from Truman to Trump*. Dallas, Texas: BenBella Books, 2020, p. 26.

[102] Robock and Toon, *South Asian Threat? Local Nuclear War = Global Suffering*.

[103] See also: Alan Robock, Luke Oman, and Georgiy L. Stenchikov. "Nuclear winter revisited with a modern climate model and current nuclear arsenals: Still catastrophic consequences". In: *Journal of Geophysical Research: Atmospheres* 112.D13 (2007). URL: https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2006jd008235 (visited on 04/24/2025).

[104] Robock and Toon, *South Asian Threat? Local Nuclear War = Global Suffering*.

[105] Rhodes likewise argues that a hundred-weapon exchange between India and Pakistan would "darken and chill the earth for a decade" making "even a 'small' regional nuclear war... an unmitigated disaster for the entire world." Rhodes, *The Twilight of the Bombs: Recent Challenges, New Dangers, and the Prospects for a World Without Nuclear Weapons*, p. 8.

or tens of thousands, maybe even a hundred thousand, but he hasn't destroyed nations. And the conventional wisdom is: "Don't make the same mistake twice. Learn from your mistakes." And we all do. Maybe we make the same mistake three times but hopefully not four or five. There will be no learning period with nuclear weapons. You make one mistake and you're going to destroy nations.

—Robert McNamara, US Secretary of Defense 1961–8[106]

Scott Sagan cited Peter Feaver on the "always/never" dilemma with respect to nuclear weapons: commanders and national leaders want weapons which will always work when ordered and which will never work except when ordered:

> Political authorities have demanded, for the sake of deterrence, that the organization always be able and willing to destroy an enormous variety of targets inside the Soviet Union, at a moments notice, under every conceivable circumstance. They have demanded that military commanders always be able to execute such attacks at any time of day, 365 days a year. They have demanded that our nuclear forces always be effective, regardless of whether the U.S. struck first or was retaliating after having suffered a catastrophic nuclear attack. And, finally, they demanded that the military, while doing all this, never have a serious nuclear weapon accident, never have an accidental detonation, and never permit the unauthorized use of a weapon to occur.[107]

This situation is properly called a dilemma because it grants only the opportunity to choose between undesirable options. Any protocol or physical control mechanism which helps to prevent unauthorized use might prevent the use of a weapon in the disrupted circumstances of a conflict or crisis.

Sagan identifies three ways an accidental nuclear war could begin: through unauthorized weapon use, through the accidental launch or detonation of a weapon, or because a false warning led decision-makers to think an enemy attack was underway.[108] He also identifies ways in which all three were involved in the Cuban Missile Crisis. ICBM officers jerry-rigged an independent launch capability with inadequate safeguards; interceptor aircraft were dispersed in which the pilots had the ability to use their weapons; and a bear caused a sabateur alert.[109] A lost B-52 flew into the Soviet air defence warning net, and a test ICBM was launched without top-level approval during the crisis. US nuclear forces in the periphery of the Soviet Union made independent preparations for war without full awareness from national leaders.[110]

In the aftermath of WWII, American bombs lacked locking mechanisms, allowing them to be used by anyone with physical possession.[111] Early versions of electromechanical locking systems for US bombs were being considered by the time of the Kennedy administration. These relied on a four digit code which was only half-known by each technician.[112] All of the branches of the US armed forces opposed such locks, fearful that any such controls would stop weapons from being used in a crisis.[113] No coded locking devices were in place on US ICBMs during the Cuban Missile Crisis.[114] By 1970, the Nuclear Safety Department had derived three safety principles to avoid unauthorized detonations: weapons designed to operate only with a unique arming signal that could not arise from a short circuit or stray wire, isolation of the firing set and detonators behind a physical barrier which excludes fire and electromagnetic energy; and a 'weak-link' part in the firing system that would predictably and irreversibly fail in an abnormal environment.[115,116,117] As an anti-theft

[106] Errol (Director) Morris. *The Fog of War: Eleven Lessons from the Life of Robert S. McNamara.* 2003. URL: https://www.imdb.com/title/tt0317910/.

[107] Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, p. 278–9.

[108] Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, p. 117.

[109] While US interceptor pilots lacked the legal and constitutional authority to use their weapons, they had the capability to launch their missiles independently. Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, p. 139.

[110] Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, p. 117.

[111] Rhodes, *Dark Sun: The Making of the Hydrogen Bomb*, p. 326.

[112] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 263.

[113] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 264.

[114] Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, p. 83.

[115] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 330–1.

[116] The B-61 bomb, in 1977, became the first US weapon to feature weak link/strong link technology. Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 372.

[117] An "abnormal environment" in this sense includes "fire, explosion, bullets, or lightning." Sagan, *The Limits of Safety:*

feature, NATO nuclear weapon storage igloos were equipped with nozzles to spray an immobilizing foam on intruders.[118] Later Category D PALs had six million possible codes, a feature to lock the weapon after a set number of incorrect tries, and the existence of multiple sets of codes to allow the president to arm only some weapons selectively.[119] By the late 1970s, a coded switch was added to the Minuteman ICBM silos; however, due to distrust of civilian decision-makers, the SAC set the codes on all the weapons to 00000000.[120,121] The US also developed "insensitive" high explosives meant to not explode in accidents.[122] By the time of the 1980 Damascus Titan II incident, the missile in question had a butterfly valve which would only feed oxidizer to the combustion chamber if the correct butterfly lock valve code had been entered during the launch checklist. This code was not kept on site, but would be included as part of a launch order. The valve lock also included an explosive anti-tampering device which would seal the oxidizer line shut if interfered with.[123] After the Damascus and Grand Forks incidents of 1980, the SAC agreed to put PAL locks in their bombers.[124] The 1990 Drell Panel on Nuclear Weapons Safety recommended that every nuclear weapon have weak link/strong link devices; all weapons used on planes should have insensitive explosives and a flame-resistant core; and that the Pentagon "should affirm enhanced safety as a top priority."[125]

Sagan argues that new nuclear powers will have arsenals at greater risk of accidental or unauthorized detonations. They may be unable to afford mechanical safety devices and modern warning sensors, leaving them more vulnerable to accidents and false warning.[126] Unsophisticated weapons may also have larger quantities of fissile material.[127] Military leaders in new nuclear weapon states may be less constrained by civilians than in the US. Some public information exists about protective measures on non-US weapons.[128] The states most motivated to develop nuclear weapons will be those with pressing security concerns, which may also induce them to deploy weapons in dangerous ways.[129] Feroz Hassan Khan describes how protective systems for Pakistan's arsenal include the use of multi-person civilian-military 'dual key' systems; as well as a rule that a nuclear core can only be inserted in the presence of three people. Khan reports that as of 2012 weapons were stored disassembled and not ready for immediate use. This was in part to reduce the danger of capture or unauthorized use. Weapons and fissile materials were kept in multiple secret locations. Khan reports that Pakistan operated less sophisticated yet functionally similar devices to the PALs (Permissive Action Links) used to prevent physical possession of a US weapon from enabling use.[130]

3.1 Accidents and close calls

The reality of the danger of unauthorized or accidental use is underscored by the large number of close calls which are known to have taken place across the history of nuclear weapons. Scott Sagan, among others, has identified a large number of "close calls" with US nuclear weapons: "serious incidents within the U.S. nuclear arsenal that could have produced an accidental or unauthorized detonation of a nuclear weapon, and potentially even an accidental war, had they occurred under different, though plausible, circumstances."[131] This is by no means a comprehensive or representative list — it is simply a set of incidents which are described in credible sources.[132] The US-focused nature of the list indicates greater US openness about nuclear weapon issues, not how the US nuclear weapon safety culture varies from that in other states.[133]

Organizations, Accidents, and Nuclear Weapons, p. 184.

[118] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 372.

[119] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 371.

[120] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 371.

[121] Ellsberg, *The Doomsday Machine: Confessions of a Nuclear War Planner*, p. 62.

[122] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 332.

[123] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 28.

[124] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 440–1.

[125] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 455-6.

[126] Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, p. 266.

[127] Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, p. 266.

[128] Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, p. 266–7.

[129] Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, p. 267.

[130] Khan, *Eating Grass: The Making of the Pakistani Bomb*, 331–2.

[131] Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, p. 4.

[132] Ord provides a more concise list, including only Vasili Arkhipov preventing the use of a nuclear torpedo during the 1962 Cuban Missile Crisis, the 1979 NORAD training tape incident, Stanislav Petrov's decision not to report a faulty launch warning in 1983, and the Norwegian rocket incident of 1995. Toby Ord. *The Precipice: Existential Risk and the Future of Humanity.* New York: Hachette Books, 2020, p. 4–6, 96–7.

[133] Sagan provides a similar caveat. Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, p. 8.

In 1956, Fred Iklé completed a report on the risk of accidental or unauthorized use of nuclear weapons. Iklé noted that during training exercises in 1957 a fission of fusion bomb had been inadvertently jettisoned in one out of 320 flights, and that B-52 bombers crashed on average once every 20,000 flying hours.[134] In 1957, Air Force secretary Donald Quarles asked the Atomic Energy Commission to compile a list of accidents that had already taken place with nuclear weapons. The Air Force submitted a list of 87 accidents and incidents between 1950 and 1957. The Sandia national lab provided 7 more, while the army and navy revealed that they had not kept track of such incidents.[135]

Prior to the Trinity test in 1945, the first plutonium bomb was left atop a metal tower during a thunderstorm overnight. Isidor Isaac Rabi recalled his fear that the device might be set off accidentally.[136] Donald Hornig was sent up the tower — under which mattresses had been stacked to catch the bomb if the cable holding it broke — to "babysit the bomb."[137]

On May 21, 1946 at Los Alamos, Louis Slotin was performing a dangerous experiment with the core of a Mark 3 plutonium implosion bomb. Slotin used a screwdriver to slowly lower the second half of the beryllium shell around the plutonium core — a hazardous procedure described as "tickling the dragon's tail." When the screwdriver slipped and the shell shut, the core went supercritical. Slotin threw the top half of the weapon's tamper onto the floor, but still died in excruciating agony a week later. Three of the other seven men nearby also eventually died from radiation-induced illnesses.[138] Subsequently, the Naval Explosive Ordnance Disposal School showed each class being taught how to dismantle nuclear weapons the video of Slotin dying.[139]

On February 13, 1950 a US B-36 bomber was flying a training mission out of Fairbanks, Alaska — on a mission to simulate dropping a Mark 4 atomic bomb on San Francisco before flying to Fort Worth, Texas. Ice caused three of the plane's six engines to catch fire. Despite stuck bomb bay doors, the co-pilot was able to jettison the weapon and its high explosives detonated 3,000 feet above the water. The crew ejected from the plane by parachute, and it later crashed on Mount Kologet in British Columbia.[140]

On August 5, 1950 a US B-29 took off from Fairfield-Suisun Air Force Base in California. After two engines failed during takeoff, the plane crashed, caught on fire, and broke into pieces. Flares and .50 caliber ammunition began to burn in the wreckage. Eventually, the high explosives in a Mark 4 bomb detonated, killing a sergeant and five firefighters, and injuring almost 200 people. Burning fuel and fuselage was spread over an area of about two miles.[141]

On July 27, 1956 in Sufolk, England a US B-47 bomber veered off the runway during a touch-and-go landing and collided into a storage igloo holding Mark 6 atomic bombs.[142] An SAC officer wrote to LeMay in a classified telegram: "Preliminary exam by bomb disposal officer says a miracle that one Mark Six with exposed detonators sheared didn't go."[143]

On January 31, 1958 a US B-47 carrying a Mark 36 bomb, including its nuclear core, had a tire blow out and fire spread into the fuselage. The fire burned for two and a half hours and burned some of the high explosives in the bomb without detonating it. The accident report described how the hydrogen bomb and plane melted together into an eight thousand pound slab which had to be jackhammered apart to remove radioactive pieces.[144]

Less than a month after the Morocco incident, a Mark 6 bomb with a variable yield of 8–160 kt fell into a family's yard in Mars Bluff, South Carolina. The bomb was dropped by a B-47 en route from Georgia to the UK, and produced a crater about 50 feet wide by 35 feet deep. The bomb was accidentally released when the plane's navigator accidentally grabbed the manual release lever for support while trying to insert a locking pin to keep the bomb in place.[145,146]

[134] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 191.
[135] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 167.
[136] Rhodes, *The Making of the Atomic Bomb*, p. 666.
[137] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 42–3.
[138] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 95.
[139] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 416.
[140] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 167–8.
[141] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 169.
[142] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 170.
[143] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 170.
[144] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 184–5.
[145] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 186–7.
[146] A year earlier, another weapon without a nuclear core had been accidentally dropped by a B-36 when the navigator steadied

In February, 1958 an F-86 fighter plane collided during a night exercise with a B-47 and the crew was given permission to jettison the bomb prior to an emergency landing. [TK]

On October 5, 1960 the early warning RADAR in Thule, Greenland provided data to NORAD indicating dozens of Soviet missile launches.[147] The cause was later identified as a misinterpretation of the moon rising over Norway.[148,149]

On January 16, 1961 the pilot of a US F-100D fighter plane in Suffolk, England accidentally jettisoned his underwing fuel tanks when starting the engines. A Mark 28 hydrogen bomb was engulfed in flames, but they were extinguished before setting off the primary's high explosive shell.[150]

In 1961, a B-52 crashed in Goldsboro, North Carolina after jettisoning two Mark 39 thermonuclear bombs.[151] After an air-to-air refuelling mishap, the bomber entered an uncontrolled spin which caused a lanyard attached to the bomb release mechanism in the cockpit to be pulled. One weapon fell under a parachute into a field near Faro, North Carolina and only did not detonate because a ready/safe switch in the cockpit had been set to 'safe.'[152,153] The other fell without a parachute, and had its dense thermonuclear secondary penetrate 70 feet into the ground, where it was never recovered.[154] If a device had detonated, it would have deposited fallout across Washington, Baltimore, Philadelphia, and New York.[155,156,157]

The Cuban Missile Crisis of 1962 provides one of the most acute demonstrations of the risks associated with nuclear weapons in a crisis situation.[158,159,160,161] Overflights of Cuba by U-2 surveillance aircraft revealed the surprise decision of Soviet premier Nikita Khrushchev to place nuclear-capable missiles in the Caribbean nation, a short flight time from the US. The crisis involved substantial miscalculations from both sides, with the Soviets apparently reasoning that they could achieve a missile deployment similar to the placement of US missiles in Turkey without provoking a violent response, and the Americans not knowing for most of the crisis that Soviet nuclear weapons in Cuba were usable in the event of American airstrikes or invasion.[162,163] Unknown to Kennedy and his advisors, almost 100 tactical nuclear weapons on the island

himself by grabbing the manual release lever. In that case, the weapon landed in an unpopulated area about 1/3 of a mile from Sandia. Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 187.

[147] For technical details on US early warning capabilities, see: Perry and Collina, *The Button: The New Nuclear Arms Race and Presidential Power from Truman to Trump*, p. 59–60.

[148] Union of Concerned Scientists. *Close Calls with Nuclear Weapons*. 2015. URL: https://www.ucsusa.org/sites/default/files/attach/2015/04/Close%20Calls%20with%20Nuclear%20Weapons.pdf (visited on 12/30/2023), p. 4.

[149] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 253–4.

[150] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 262.

[151] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 245–6.

[152] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 246.

[153] Parker F. Jones, a safert engineer at Sandia, wrote in a memo about the accident: "One simple, dynamo-technology, low-voltage switch stood between the United States and a major catastrophe!" Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 247.

[154] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 246.

[155] Ed Pilkington. *US nearly detonated atomic bomb over North Carolina — secret document*. 2013. URL: https://www.theguardian.com/world/2013/sep/20/usaf-atomic-bomb-north-carolina-1961 (visited on 12/30/2023).

[156] See also: Alex Wellerstein. *The final switch: Goldsboro, 1961*. 2013. URL: https://blog.nuclearsecrecy.com/2013/09/27/final-switch-goldsboro-1961/ (visited on 12/30/2023).

[157] Sandia National Laboratories. *Broken Arrow, North Carolina, 1961*. 2010. (Visited on 12/30/2023).

[158] For a detailed account of the crisis, see: Max Hastings. *Abyss: The Cuban Missile Crisis 1962*. New York: Harper, 2022.

[159] Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, p. 53–116.

[160] Sagan describes additional close calls within the Cuban Missile Crisis, including a bear mistaken for a sabateur leading to nuclear-armed interceptors nearly being launched (until an officer drove his car on to the runway to flash his lights and stop them), as well as an error with a test software tape at an early warning RADAR site. Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, p. 3, 6, 99–100, 130–1.

[161] Sagan also describes how, on October 26, a test launch of an Atlas ICBM was conducted from Vandenberg Air Force Base, even though other missiles at the base had been hastily armed with nuclear warheads and senior officials in Washington were unaware of the planned test. Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, p. 79–80.

[162] Khrushchev hoped to announce the Soviet nuclear weapon deployment to Cuba in a UN speech and to offer to remove them only if NATO agreed to leave West Berlin. Otherwise, he planned to keep the weapons in Cuba and build a base on the island for ballistic missile submarines. Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 289.

[163] Perry and Collina reference President Kennedy's estimate that the crisis carried a one-in-three risk of nuclear war, adding: "When Kennedy made that estimate he did not know that Soviet forces in Cuba already had completed the operational readiness of about a hundred tactical nuclear weapons and had the authority to use them in self-defense." Former US Strategic Command (STRATCOM) commander General George Lee Butler said: "The fog of fear, confusion and misinformation that enveloped the principals caught up in the Cuban Missile Crisis could have at any moment led to nuclear annihalation." Perry and Collina, *The Button: The New Nuclear Arms Race and Presidential Power from Truman to Trump*, p. 52, 53.

would have been used by local commanders to repel an American attack — had they attacked the US fleet offshore or a US naval base, escalation to all-out nuclear war could have taken place.[164] The Kennedy administration imposed a 'quarantine' on ships carrying offensive weapons to the island, and the crisis was eventually resolved via back-channel diplomatic means. Nonetheless, the Cuban Missile Crisis reveals elements of how national leaders and top military commanders can lose control over nuclear weapons in a crisis situation. Rhodes cites an officer in control of American Minuteman I solid-fuelled missiles saying that he would have been able to launch the weapon by himself, and that PAL locks were not incorporated into US weapons in 1962.[165] US Secretary of Defense McNamara was concerned during the crisis that US Jupiter missiles in Turkey — which had no PAL locks — might be seized by Turkish officers and used to retaliate independently against the USSR if American assets in Turkey were struck; US commanders in Turkey were ordered to somehow render the missiles inoperable if this happened.[166] The US Navy also pursued submerged Soviet submarines and attacked them with "practice depth charges." [CITE] During the period of the Cuban Missile Crisis, none of the SAC's weapons or the navy's weapons were locked with PALs.[167]

On November 13, 1963 workers at an AEC base in Medina, Texas were moving partly disassembled Mark 7 bombs into a storage igloo. Two explosive spheres ignited while being unloaded, probably from friction, and caused the sphere to burn for 45 seconds before detonating. That explosion set off 123,000 pounds of high explosives in the building.[168]

On December 8, 1964 a B-58 carrying five hydrogen bombs was blown off the runway by a sudden gust of wind, collapsing the landing gear and starting a fuel fire. One bomb melted completely into the tarmac; another was dragged while burning for 50 yards by firefighters, who dumped it in a trench and covered it with sand to extinguish the flames.[169]

During the same week, a fault in an electrical connector and a technician's screwdriver caused a retro-rocket atop a Minuteman ICBM to fire. This lifted the reentry vehicle containing a W-56 thermonuclear weapon, bounced it off the wall and then off the missile, and caused it to land in the bottom of the silo.[170]

On December 5, 1965 an A-4E Skyhawk with a Mark 43 hydrogen bomb was lost overboard after it rolled off an elevator. Pilot, plane, and bomb were never found.[171]

On January 17, 1966, near Palomares, Spain, an American B-52 bomber collided with a KC-135 refueling tanker. The plane crashed with four Mark 28 hydrogen bombs aboard.[172,173] High explosives on one bomb had detonated, spreading plutonium in the area.[174] The fourth bomb was not found until March 15, after a search by four submersibles.[175]

On January 21, 1968 an American B-52 was flying a figure-of-eight 'bowtie' pattern around Thule, Greenland.[176] The purpose of these missions was to identify if the Ballistic Missile Early Warning System (BMEWS) RADAR was ever destroyed in the opening minutes of a surprise attack.[177] Even so, the plane was armed with four 1.1 megaton Mark 28 bombs.[178,179] Cold flight crew members stuffed foam rubber cushions under seats to try to keep warm, and these were ignited by a system that pulled high temperature air in from the engine manifold. After the crew ejected from the smoke-filled plane, it crashed into the

[164] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 295.
[165] Rhodes, *Dark Sun: The Making of the Hydrogen Bomb*, p. 573.
[166] Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, p. 109–10.
[167] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 298.
[168] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 309–10.
[169] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 310–1.
[170] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 311–2.
[171] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 312.
[172] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 316.
[173] Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, p. 178.
[174] Former Los Alamos director Siegfried Hecker claimed in 2025 that it was probably only because of modifications arising from hydronuclear tests on one-point weapon safety that the Palomares bombs did not result in a significant nuclear explosion. Siegfried Hecker. *Lessons From Los Alamos: America Has the Most to Lose From Restarting Nuclear Testing*. 2025. URL: https://www.foreignaffairs.com/united-states/lessons-alamos.
[175] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 317–9.
[176] For a detailed account of the 1968 Thule incident, see: Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, p. 156–203.
[177] Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, p. 157, 170–3.
[178] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 321.
[179] Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, p. 156.

ice of Bylot Sound, seven miles from the base.[180,181] The crew was unable to notify Thule or the SAC command centre before they parachuted from the plane.[182] The high explosives of all four bombs detonated and, along with 225,000 pounds of jet fuel, burned for 5–6 hours. Plutonium was scattered across the ice and in smoke for miles.[183] Most worrisomely, if the bombs had detonated during a crisis situation, it could have been misinterpreted as the beginning of a pre-emptive Soviet attack against American early-warning RADARs.[184,185]

On November 9, 1979 computers at NORAD (as well as two other US command posts) showed launches from Soviet submarines off the coast and from inside the Soviet mainland.[186] Warheads were projected to begin hitting targets within 5–6 minutes.[187] Following procedure, SAC bomber crews were ordered to their planes, missile crews were put on alert, and fighters were scrambled. This happened because "software simulating a Soviet missile attack in Pentagon computers was inexplicably transferred into the regular warning display at NORAD's headquarters" via a precise mode of failure that could not be subsequently replicated.[188] An off-site computer testing facility was established to reduce the danger of such a mistake with a training tape in the future.[189]

On June 3, 1980 at 2:29am national security advisor Zbigniew Brzezinski was notified that the USSR had launched 220 missiles — and later 2,200 missiles — at the US.[190] Just before he was going to call the president, Brzezinki was told it had been a false alarm. On June 6, another false alarm took place. Ultimately, it was determined that a test message meant to indicate that there were zero missiles in flight had been altered by a defective computer chip with 200 or 2,200 missiles.[191,192] The faulty chip had cost $0.39.[193,194]

On September 15, 1980 a B-52 out of Grand Forks Air Force Base in North Dakota loaded with four Mark 28 bombs caught fire.[195] The plane burned for over an hour and a half. When Dr. Roger Batzel, the director of the Lawrence Livermore National Laboratory, testified in a closed senate hearing, he said the B-52 could have scattered plutonium over 60 square miles of North Dakota and Minnesota. If one of the bombs had detonated, it would have destroyed Grand Forks and blanketed nearby places with deadly fallout.[196]

On September 19, 1980 a crew member servicing a US Titan II ICBM near Damascus, Arkansas with a 9 megaton warhead inadvertently caused a fuel leak. The Titan II missile was propelled by a hypergolic mixture of Aerozine-50 (a 50/50 mix of hydrazine and unsymmetrical dimethylhydrazine (UDMH)) as fuel and nitrogen tetroxide as oxidizer.[197] The fuel was toxic, highly carcinogenic, capable of being easily absorbed through the skin, and explosive in a proportion as small as 2%. The oxidizer was a deadly poison that turned to corrosive acid in the presence of water.[198,199] Any combination of the two would produce an immediate fire or explosion. While attempting to service the missile, senior airman David Powell dropped a socket down the silo which hit the thrust mount, pierced the fuel tank, and caused fuel to begin spraying out like

---

180 Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 321.

181 Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, p. 156.

182 Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, p. 180.

183 Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 322.

184 As Schlosser puts it: "Nobody expected the Thule monitor to destroy Thule." Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 323.

185 Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, p. 183.

186 Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, p. 228–31.

187 Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 365.

188 Perry and Collina, *The Button: The New Nuclear Arms Race and Presidential Power from Truman to Trump*, p. 60–1.

189 Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, p. 230.

190 Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, p. 231.

191 Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 368.

192 Shockingly, the system was designed to send routine peactime messages that "there were 000 ICBMs and 000 SLBMs detected on the way to the United States." Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, p. 232.

193 Perry and Collina, *The Button: The New Nuclear Arms Race and Presidential Power from Truman to Trump*, p. 62–3.

194 Sagan says $0.64. Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, p. 232.

195 Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 377–81.

196 Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 384.

197 Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 4.

198 Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 4.

199 Like the phosgene gas used as a chemical weapon in WWI, nitrogen tetroxide kills painfully via a process of "dry land drowning." Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 421.

water from a hose.[200] The Titan II's aluminium skin depended on the pressure from fuel inside the tank to maintain structural stability. Eventually, the leak caused the fuel tank to collapse, ruptured the oxidizer tank, and blew up the missile in its silo.[201] Three explosions had taken place in succession: a relatively small fuel vapour explosion, the rupturing of the oxidizer tank, and then the fuel and oxidizer mixing.[202] The reentry vehicle containing the warhead was thrown from the silo.[203] The enormous 15,000 pound steel and cement silo door was thrown over 200 yards.[204] If the warhead had detonated, it would have destroyed much of Arkansas.[205]

On September 26, 1983 a Soviet early warning satellite indicated 5 US nuclear missile launches. Lieutenant Colonel Stanislav Petrov reasoned that the warning was false because a US attack would not begin with five missiles. The warning was later revealed to be the result of unexpected sunlight reflection off the top of clouds, because of an unexpected alignment between the satellites, sun, and US missile fields.[206]

In 1983, NATO risked prompting a Soviet pre-emptive strike with their Able Archer exercise.[207] The command post exercise was meant to simulate escalation into nuclear conflict. This risk was elevated because, in 1981, Soviet premier Yuri Andropov initiated Operation Raketno-Yadernoe Napadenie (RYAN) to collect intelligence on possible plans by the Reagan administration to launch a nuclear pre-emptive strike. Rhodes summarizes that:

> In 1983, shaken by the Reagan administration's belligerent military buildup, and misjudging the intent of a major NATO field exercise in West Germany called Able Archer, which included a practice run-up to nuclear war, the Soviet leadership under Yuri Andropov had very nearly launched a preemptive nuclear strike against the United States. Though it all but escaped public notice, the Able Archer incident was the Cuban Missile Crisis of its day.[208]

In the Able Archer / RYAN case, the fortunate defection of Oleg Gordievsky led to improved US understanding of Soviet paranoia about a potential first strike.

On January 25, 1995 a Russian early warning RADAR detected what looked like a US submarine-launched ballistic missile attack from off the coast of Norway. The missile was actually a US-Norwegian scientific rocket meant to study the aurora borealis. Norway had notified the Soviets of the launch, but the information was not properly passed along.[209]

In February 1999, India and Pakistan fought a war over the area around Kargil, in Kashmir and near the line of control between the two states.[210] Pakistani troops seized territory near Kargil before being ejected by Indian forces.[211,212,213,214] At least 1,000 soldiers died.[215] Rhodes describes it as a "near-nuclear war."[216]

On January 13, 2018 the Hawaii Emergency Management Agency broadcast an official message to over one million people: "Ballistic missile threat inbound to Hawaii. Seek immediate shelter. This is not a drill"

[200] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 60, 109–10.

[201] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 65, 392.

[202] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 435.

[203] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 425–6.

[204] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 428.

[205] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 395.

[206] Perry and Collina, *The Button: The New Nuclear Arms Race and Presidential Power from Truman to Trump*, p. 64.

[207] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 448–9.

[208] Rhodes, *The Twilight of the Bombs: Recent Challenges, New Dangers, and the Prospects for a World Without Nuclear Weapons*, p.5.

[209] Perry and Collina, *The Button: The New Nuclear Arms Race and Presidential Power from Truman to Trump*, p. 64–5.

[210] The Economist. *Talking about Kashmir.* 2001. URL: https://www.economist.com/unknown/2001/05/24/talking-about-kashmir (visited on 01/04/2024).

[211] The Economist. *Talking about Kashmir.* 2001. URL: https://www.economist.com/unknown/2001/10/17/the-fears-in-kashmir (visited on 01/04/2024).

[212] See also: The Economist. *Clinton warms to India.* 2000. URL: https://www.economist.com/asia/2000/03/23/clinton-warms-to-india (visited on 01/04/2024).

[213] The Economist. *A rivalry that threatens the world.* 2011. URL: https://www.economist.com/briefing/2011/05/19/a-rivalry-that-threatens-the-world (visited on 01/04/2024).

[214] The Economist. *Why India and Pakistan hate each other.* 2017. URL: https://www.economist.com/special-report/2017/07/24/why-india-and-pakistan-hate-each-other (visited on 01/04/2024).

[215] The Economist. *Your place or mine?* 2004. URL: https://www.economist.com/special-report/2004/02/12/your-place-or-mine (visited on 01/04/2024).

[216] Rhodes, *The Twilight of the Bombs: Recent Challenges, New Dangers, and the Prospects for a World Without Nuclear Weapons*, p. 298.

— days after North Korean leader Kim Jong-un had declared that a nuclear launch button was "always on my table" and President Trump tweeted that his button was "much bigger & more powerful." The alert arose because an employee pushed the wrong button.[217]

4 Risks from weapon deployment policies

Because nuclear weapons with long-range delivery systems can cause such immense destruction so rapidly, they create intense fears that an enemy may carry out a pre-emptive 'decapitation' attack, meant to kill their enemy's leaders and destroy their military control systems.[218] Because of this danger, nuclear weapon states must make plans and design policies with the danger of such an attack in mind. Decision-makers may also be compelled to act on the warning of an incoming attack, which could be an error or a deliberate deception. Furthermore, the temptation to decapitate could escalate crises: if both sides know they need an intact command and control system to execute an effective nuclear attack against their enemies, there may be a strong impulse to decapitate your opponent before they do the same to you. The risk of decapitation also creates an incentive to pre-delegate authority for retaliatory strikes, either to human beings in other locations or to an automated system.

Between closely-space opponents like India and Pakistan — or in the context of a conflict where submarine-launched missiles may have only minutes of flight time — nuclear weapons have been deployed in circumstances where only minutes are available to differentiate between a 'bolt from the blue' surprise attack against nuclear weapon sites, early warning sites, and command nodes and some kind of misunderstanding or deliberate deception.[219,220] Fear of such an attack produced the concept of 'launch on warning' — in which weapons which could be destroyed in an enemy first strike would be launched on the warning of an attack, rather than when it actually happened.[221,222,223,224] One manifestation of the fear of pre-emptive attack was the decision in the late 1950s to keep a portion of the B-52 fleet on constant airborne alert.[225] These alerts continued until July 1968.[226] The Economist notes: "About a third of American and Russian nuclear forces are designed to be launched within a few minutes, without the possibility of recall, merely on warning of enemy attack."[227] In 2021, The Economist cited James Acton of the Carnegie Endowment saying that China was shifting to a 'launch on warning' doctrine akin to those of the US and Russia. Acton noted that this: "increases the risk of inadvertent launch, such as a response to a false warning."[228]

The risk of communication failures is especially acute in the context of multi-party conflicts between actors with limited experience and infrastructure for crisis communication. In 2016, General George Lee

[217] Perry and Collina, *The Button: The New Nuclear Arms Race and Presidential Power from Truman to Trump*, p. 47–8.

[218] See: Ellsberg, *The Doomsday Machine: Confessions of a Nuclear War Planner*, p. 69.

[219] On some of the risks from a surprise attack against command, control, communications, and intelligence facilities, see: Bruce G. Blair. *Strategic Command And Control: Redefining the Nuclear Threat.* Washington D.C.: Brookings Institution Press, 1985.

[220] Perry and Collina identify that, by the 1960s, the US had to worry about pre-emption in the form of a decapitating strike from Soviet long-range missiles. Perry and Collina, *The Button: The New Nuclear Arms Race and Presidential Power from Truman to Trump*, p. 15, 25–46.

[221] William Perry sequentially highlights the various dangers of this policy: US weapons are poised to be launched under warning of attack; weapons are kept on high alert status for launch within minutes; once launched, nuclear-armed ballistic missiles cannot be recalled; the US and Russians are investing trillions in new weapons; a false alarm could result in an order to use nuclear weapons; and cyberattacks could create such a false warning. Perry and Collina, *The Button: The New Nuclear Arms Race and Presidential Power from Truman to Trump*, p. xix.

[222] Perry and Collina argue: "We strongly believe that the risks of having nuclear weapons ready to launch within minutes, on the president's sole authority, outweigh any perceived benefits. This system is unconstitutional, dangerous, outdated, and unnecessary." Perry and Collina, *The Button: The New Nuclear Arms Race and Presidential Power from Truman to Trump*, p. 5.

[223] The reason the US Air Force has not implemented in-flight kill-switches is because of concern they could be exploited by an enemy to neutralize an attack. This illustrates Sagan's always/never dilemma. Perry and Collina, *The Button: The New Nuclear Arms Race and Presidential Power from Truman to Trump*, p. 60.

[224] On the risk of cyberattack on nuclear weapons, see: Perry and Collina, *The Button: The New Nuclear Arms Race and Presidential Power from Truman to Trump*, p. 70–3.

[225] Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, p. 167, 198.

[226] Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, p. 195.

[227] The Economist. *America should not rule out using nuclear weapons first.* 2019. URL: https://www.economist.com/leaders/2019/08/15/america-should-not-rule-out-using-nuclear-weapons-first (visited on 12/30/2023).

[228] The Economist. *China seeks to join the nuclear big league.* 2021. URL: https://www.economist.com/china/china-seeks-to-join-the-nuclear-big-league/21806104 (visited on 12/30/2023).

Butler wrote that "it is increasingly evident that senior leaders on both sides [of the Cold War] consistently misread each other's intentions, motivations, and activities, and their successors still do so today."[229]

A risk also exists that nuclear weapon use could be initiated by a subordinate commander, possibly while misinterpreting a crisis situation. From early on, President Truman explained that he didn't want "to have some dashing lieutenant colonel decide when would be the proper time to drop one."[230] President Kennedy's national security advisor McGeorge Bundy informed him that based on the pre-delegation of weapon use authority under attack that Eisenhower had granted to the armed forces:

> A subordinate commander faced with a substantial Russian military action could start the thermonuclear holocaust on his own initiative if he could not reach you (by failure of the communication at either end of the line).[231]

In May 1969, 23-year-old US Air Force mechanic Sergeant Paul Meyer stole a B-45 bomber from Alconbury Air Force Base in the UK and took it for a joyride before crashing it and dying.[232,233] In Iklé's 1956 Rand corporation report, he argued that technical safeguards meant to prevent a deliberate, unauthorized attempt to detonate a nuclear weapon could be circumvented by "someone who knew the workings of the fuzing and firing mechanism" and that on at least one occasion a drunk enlisted man overpowered the guard at a weapon storage site and tried to gain access to the bombs.[234] The report also estimated that ten or twenty US Air Force personnel who worked with nuclear weapons would be expected to have a severe mental breakdown in any given year.[235] In an appendix to the report, Gerald Aronson argued that setting off an unauthorized nuclear detonation could appeal to those with paranoid delusions, and that mentally ill officers and men with poor impulse control might be drawn to nuclear weapons.[236] By the time of the Kennedy administration, the US had an arsenal of atomic bombs, thermonuclear bombs, nuclear artillery shells, nuclear depth charges, nuclear land mines, and a bazooka-like recoilless rifle carried by an infantryman; of these, only the land mines known as Atomic Demolition Munitions had any sort of lock to prevent someone with physical possession from detonating them, and the land mines had easily-pickable three-digit locks.[237,238] In December 1960, Los Alamos physicist Harold Agnew inspected US weapons in Germany and was alarmed to see F-84F fighter planes armed with Mark 7 atomic bombs and guarded by a single rifle-carrying soldier who had not been told what to do if someone tried to steal a plane.[239]

Daniel Ellsberg states that an SAC manual from the 1950s described procedures for bomber crews to implement an Execute order to make use of nuclear weapons. Pilots were issued paper envelopes with one group of numbers on the outside and a card with four more numbers sealed inside. If a pilot received a radio signal with the numbers on the outside of the envelope, they were meant to open it and see if the next numbers matched those inside. If so, they were to execute their attack.[240] This procedure was used for single-pilot planes, and the codes were the same for all aircraft and changed infrequently. Because not all pilots might receive an order to attack by radio, any pilot that did complete the authentication sequence was instructed to pass it along to squadron-mates by line-of-sight high frequency radio. As a result, a single rogue pilot could have started a squadron-wide thermonuclear attack against the USSR.

There is also a danger of bad decision-making at the top. Major Harold Hering — undergoing missile training at Vandenberg Air Force Base — insisted in 1973 on asking his higher-level commanders about how to make sure any orders to use nuclear weapons come not just from the president (a question which elaborate

[229] Perry and Collina, *The Button: The New Nuclear Arms Race and Presidential Power from Truman to Trump*, p. 27.
[230] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 88.
[231] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 256.
[232] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 189.
[233] Emma Jane Kirby. *The mystery of the homesick mechanic who stole a plane.* 2018. URL: https://www.bbc.com/news/stories-43800089 (visited on 01/23/2024).
[234] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 191–2.
[235] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 192.
[236] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 192–3.
[237] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 256–7.
[238] The "Davy Crockett" recoilless rifle used atomic projectiles that weighed only 50 pounds and would be easy to steal. The weapon also only had a 1.5 mile range, making it likely to kill whoever fired it. Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 265, 268.
[239] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 258.
[240] Ellsberg, *The Doomsday Machine: Confessions of a Nuclear War Planner*, p. 57–9.

safeguards were in place to answer) but from a *sane* president.[241] Hering was eventually forced out from the Air Force. Former US Director of National Intelligence James Clapper said in 2017:

> Having some understanding of the levers that a president can exercise, I worry about, frankly, the access to the nuclear codes... If in a fit of pique [Trump] decides to do something about Kim Jong-un, there's actually very little to stop him. The whole system is built to ensure rapid response if necessary. So there's very little in the way of controls over exercising a nuclear option, which is pretty damn scary.[242]

While the American system is based on sole presidential authority, the Soviet system required joint authorization from the president, minister of defense, and chief of the general staff.[243] The three leaders could act together to generate a combined code for nuclear weapon use, which would then need to be combined with a key from one of three commanders in chief.[244] The system was designed to be able to order retaliation within 15–30 minutes of a ballistic missile attack being launched from the US.[245]

Nuclear weapons could be seized as part of a military coup. In April 1961, dissident French officers in Algeria sought to gain control of a weapon intended for a test. The Gerboise verte nuclear test was held promptly to prevent officers who were trying to overthrow the de Gaulle government from getting it.[246] A classified history of the US Minuteman ICBM program described the possibility of SAC commanders attacking 50 cities in the Soviet Union without authorization, and described such an incident as "an accident for which a later apology might be inadequate."[247] On August 18, 1991 Mikhail Gorbachev was held hostage and incommunicado in an attempted coup. Both other Soviet officials with nuclear codes supported the coup.[248] After the coup failed on August 21, Gorbachev was put back in communication.[249]

There is also risk arising from the inflexibility of nuclear planning. In December 1960, President Eisenhower approved the Single Integrated Operational Plan (SIOP), meant in part to coordinate nuclear strikes by America's various armed services.[250] The plan included 3,729 targets in the Soviet Union, China, North Korea, and Eastern Europe. It called for 3,423 nuclear weapons targeted at more than 1,000 ground zeroes. Implementing the SIOP was projected to kill about 220 million people within three days, including 54% of the population of the USSR and 16% of China's population.[251] Like the WWI plans for troops to be deployed on trains, the SIOP was designed to be implemented all at once and not piecemeal as directed.[252] The plan was designed to be inflexible, with Joint Chiefs of Staff Chairman General Nathan Twining instructing that: "atomic operations must be pre-planned for automatic execution to the maximum extent possible."[253] By 1968, the US still did not have the technical or administrative means to fight a limited nuclear war.[254] Later, by the time of the Reagan administration, US nuclear war plans were revised to include limited and regional options involving fewer weapons.[255] When General George Lee Butler became head of STRATCOM in 1991, he spent weeks going through the SIOP and declared it "the single most absurd and irresponsible document I have ever reviewed in my life" and added: "I came to fully appreciate the truth... we escaped the Cold War without a nuclear holocaust by some combination of skill, luck, and divine intervention, and

[241] Ron Rosenbaum. *An Unsung Hero of the Nuclear Age.* 2011. URL: https://slate.com/human-interest/2011/02/nuclear-weapons-how-cold-war-major-harold-hering-asked-a-forbidden-question-that-cost-him-his-career.html (visited on 12/30/2023).

[242] Perry also notes than only 25% of the US public is aware of sole presidential authority for nuclear weapon use. Perry and Collina, *The Button: The New Nuclear Arms Race and Presidential Power from Truman to Trump*, p. 4.

[243] Rhodes, *The Twilight of the Bombs: Recent Challenges, New Dangers, and the Prospects for a World Without Nuclear Weapons*, p. 85, 92–3.

[244] Rhodes, *The Twilight of the Bombs: Recent Challenges, New Dangers, and the Prospects for a World Without Nuclear Weapons*, p. 93.

[245] Rhodes, *The Twilight of the Bombs: Recent Challenges, New Dangers, and the Prospects for a World Without Nuclear Weapons*, p. 95.

[246] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 260.

[247] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 300.

[248] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 457.

[249] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 458.

[250] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 203–7.

[251] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 206.

[252] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 252.

[253] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p.203.

[254] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 355.

[255] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 361, 442.

I suspect the latter in greatest proportion."[256] The danger of weapon use as a result of misunderstanding or manipulation is heightened because orders to use nuclear weapons sometimes cannot be rescinded; out of concern that an enemy might be able to issue fake stop or recall orders, or manipulate their enemies to do so, nuclear-armed forces including US bombers have had go code processes with no mechanism to cancel an attack once ordered.[257]

Credible sources also describe weapons and fissile material being held under inadequate guard, or weapons being usable unilaterally by soldiers such as fighter-bomber pilots. During the 1960s, US nuclear-armed interceptors were single-seat aircraft that carried weapons without PAL locking devices, making a violation of the "two-man rule" for handling such weapons inevitable in routine operations.[258] When US senator Sam Nunn inspected NATO weapon storage sites in 1972, he was assured by top commanders that security was "perfect" and then warned in a handwritten note from a sergeant which led to a discussion of "drug abuse, alcohol abuse, a story of U.S. soldiers actually guarding tactical nuclear weapons while they were stoned on drugs." When he met with three or four sergeants in their bunker, Nunn was told that "a group of six to eight well-trained terrorists [could] gain control over one of our tactical nuclear compounds in the middle of Western Europe."[259] In 1994, US diplomat Andy Weber was informed of 600 kg of HEU at the Ulba Metallurgical Plant outside Ust-Kamenogorsk, Kazakhstan — a quantity sufficient for 20 nuclear weapons.[260] The material was removed to the US Oak Ridge Y-12 facility.[261]

5 Psychology of nuclear weapon possession

Though questions about nuclear weapons are frequently assessed with reference to concepts like rationality and tools like game theory, important psychological dimensions of nuclear weapon possession contribute to the risk posed to humanity by these weapons. In particular, this includes viewing nuclear weapon possession as proof of national greatness or of great power status. It also includes what I will argue are dangerous false lessons about the effect of nuclear weapons on international security. While rationalists argue that nuclear weapons raise the risks of conflict so high as to rationally deter it from happening, this sanguine assessment understates the risks which have been revealed across the last 78 years of nuclear weapon possession.

5.1 Nuclear status and national prestige

Nuclear weapons are seen to confer prestige on their possessors, independent from their usefulness in protecting national security. Shortly after the US Castle Bravo test, Winston Churchill committed the UK to develop its own hydrogen bombs, on the reasoning that "influence depended on possession of force" and that H-bomb possession was "the price we pay to sit at the top table."[262]

5.2 Dangerous false lessons about rationality and stability

In his 2001 dissertation, Nathan Busch summarized the debate between nuclear weapon "optimists" and "pessimists," where optimists see nuclear proliferation as potentially beneficial and with surmountable associated hazards, while pessimists disagree. He roots each form of analysis in a theory of human decision-making: with rational deterrence models holding that nuclear proliferation will increase stability between states while organizational models hold that " organizational, bureaucratic, and other factors prevent states

[256] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 457.
[257] Ellsberg, *The Doomsday Machine: Confessions of a Nuclear War Planner*, p. 64.
[258] Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, p. 93–4.
[259] Rhodes, *The Twilight of the Bombs: Recent Challenges, New Dangers, and the Prospects for a World Without Nuclear Weapons*, p. 99.
[260] David E. Hoffman, Svetlana Savranskaya, and Thomas Blanton. *Project Sapphire 20th Anniversary.* 2014. URL: https://nsarchive2.gwu.edu/NSAEBB/NSAEBB491/ (visited on 12/31/2023).
[261] The entire incident is described in: At The Brink Podcast. *Project Sapphire: A Secret Mission to Thwart Nuclear Terrorism.* 2020. URL: https://open.spotify.com/episode/4WcS8lmxx0AUjYiJfRvXid?si=ad8b0b739f26466d (visited on 12/31/2023).
[262] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 142.

from acting rationally."[263,264,265] Former US defense secretary William Perry wrote in 2020: "Today's military leaders have learned the wrong lessons from the Cold War and are keeping the most dangerous aspects of US nuclear policy when they no longer need to."[266] Former US missileer Bruce Blair explains the instability of nuclear deterrence: an power that fears a pre-emptive strike which could destroy a large fraction of their retaliatory capability is impelled to strike pre-emptively themselves. The stronger power may believe that the weaker power fears an imminent pre-emptive strike and is thus considering its own pre-emptive attack, which could push the stronger side to attack while they can.[267]

Blair also identifies a fundamental but erroneous simplifying assumption that people frequently make about states: that they can and will act as unitary actors.[268] This ignores the thousands of people involved, and the "diffuse and decentralized nature of actual operations.[269]

At a conference shortly after the atomic bombings of Japan, University of Chicago economist Jacob Viner argued that this new and cheapest way ever to kill human beings had profound military and political implications. He expected the bombs to be peacemaking in effect, describing what Rhodes called "the essential principle of deterrence, of the balance of terror in a nuclear-armed world."[270] Others later argued that nuclear weapons would provide a "crystal ball effect" — making the consequences of war so obviously terrible that no rational leader would launch it.[271] Historian John Lewis Gaddis and political scientist Kenneth Waltz are among those who argue for this protective discouragement effect from nuclear weapons.[272] Waltz was also sanguine about the possibility of nuclear weapon proliferation, reasoning that the spread of the weapons would spread the stability.[273]

6 Nuclear weapon proliferation

Similarities between the US and Soviet nuclear weapons programs arose from both espionage and efforts on both sides to solve common problems. Describing similarities between the US and Soviet nuclear weapon programs during WWII, Rhodes argues:

> Such parallels seem enigmatic, but in fact the two bomb programs ran in parallel because the raw materials, the processing and the technology depended upon universal physical fundamentals that both sides could determine independently. As that basic level, there never was any "secret" of how to make an atomic bomb. Knowledge derived from espionage could only speed up the process, not determine it, and in fact every nation that has attempted to build an atomic weapon in the half-century since the discovery of nuclear fission has succeeded on the first try.[274]

On July 16, 1945 the United States detonated the first plutonium implosion weapon in their Trinity test

[263] Nathan Edward Busch. "Assessing the optimism-pessimism debate: nuclear proliferation, nuclear risks, and theories of state action". In: *Dissertation Abstracts International, A: The Humanities and Social Sciences* 62.11 (2002). URL: https://tspace.library.utoronto.ca/handle/1807/15974 (visited on 12/30/2023), p. 2.

[264] On organization theory, see: Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, p. 13–7.

[265] Sagan also contrasts "high reliability theory" which presumes that well-designed systems can avoid accidents with "normal accidents theory" which holds that accidents are inevitable in complex and tightly coupled systems. Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, p. 46.

[266] Perry and Collina, *The Button: The New Nuclear Arms Race and Presidential Power from Truman to Trump*, p. xxi.

[267] Blair, *Strategic Command And Control: Redefining the Nuclear Threat*, p. 17.

[268] Blair, *Strategic Command And Control: Redefining the Nuclear Threat*, p. 7.

[269] Blair, *Strategic Command And Control: Redefining the Nuclear Threat*, p. 7.

[270] Rhodes, *The Making of the Atomic Bomb*, p. 753.

[271] Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, p. 260.

[272] Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, p. 260–1.

[273] Sagan, *The Limits of Safety: Organizations, Accidents, and Nuclear Weapons*, p. 264–5.

[274] Rhodes, *Dark Sun: The Making of the Hydrogen Bomb*, p. 162.

in the Jornada del Muerto desert on the Alamogordo Bombing and Gunnery Range.[275,276,277,278,279,280] On August 6th and 9th, the US dropped uranium gun-type and plutonium implosion bombs on the cities of Hiroshima and Nagasaki, Japan. Over the course of the Manhattan Project, espionage by Klaus Fuchs and others meant crucial information about the development of the bomb was shared with the USSR and Stalin, who in fact knew about the bomb's existence before Harry Truman did.[281,282,283,284,285] On August 29, 1949 the Soviet Union tested their first plutonium implosion weapon — a copy of the American device produced through espionage and slave labour.[286,287,288,289,290]

The history of nuclear weapon proliferation since then has been driven by fear and prestige competitions between nation-state adversaries.[291,292,293,294] In part because nuclear weapon possession was seen as part-

[275]On the scale of effort that went into the Manhattan Project, Rhodes quotes Bertrand Goldschmidt's estimate that in three years $2 billion was spent on factories and laboratories, a cost equivalent to the entire US auto industry. Rhodes, *The Making of the Atomic Bomb*, p. 605.

[276]During the 1950s US weapon production capability expanded substantially, as did cost and energy use. Two new vast gaseous diffusion plants together used more electricity than the Tennessee Valley Authority, Hoover, Grand Coulee, and Bonneville dams could produce together. By 1957, the Atomic Enery Commission was using 6.7% of US electrical production. New production complexes required 11% of US nickel production, 34% of stainless steel, and 33% of hydrofluoric acid. By 1955, the AECs capital investment was over $9 billion and exceeded the capital investment of General Motors, Bethlehem and US Steel, Alcoa, DuPont, and Goodyear combined. Rhodes, *Dark Sun: The Making of the Hydrogen Bomb*, p. 561.

[277]Rhodes estimates the cost of the arms races for nuclear weapons and delivery systems in the US at $4 trillion, equivalent to the national debt in 1994. Rhodes, *Dark Sun: The Making of the Hydrogen Bomb*, p. 582.

[278]Stephanie Cooke estimates that between 1940 and 1996, the US spent $5.5 trillion on nuclear weapons, or 11% of total federal spending. Stephanie Cooke. *In Mortal Hands: A Cautionary History of the Nuclear Age*. New York: Bloomsbury, 2009.

[279]Rhodes estimates that the US arsenal costs $50 billion per year to maintain. Rhodes, *The Twilight of the Bombs: Recent Challenges, New Dangers, and the Prospects for a World Without Nuclear Weapons*, p. 284.

[280]Perry and Collina also cite an annual cost of $50 billion per year. Perry and Collina, *The Button: The New Nuclear Arms Race and Presidential Power from Truman to Trump*, p. 8.

[281]Rhodes, *The Making of the Atomic Bomb*, p. 690, 770.

[282]Rhodes, *Dark Sun: The Making of the Hydrogen Bomb*, p. 57–8, 71, 103–20, 211.

[283]When Fuchs was interrogated in 1950, he revealed that he had provided the Soviets with key bomb design information, including the design of the initiator and explosive lens system, and the required thicknesses of the different layers in the bomb so as to avoid hydrodynamic instability. Rhodes, *Dark Sun: The Making of the Hydrogen Bomb*, p. 168.

[284]David Greenglass also provided important details on the high explosive lenses and exact design of the initiator. Rhodes, *Dark Sun: The Making of the Hydrogen Bomb*, p. 187.

[285]On Fuchs' trial in the UK in 1950, see: Rhodes, *Dark Sun: The Making of the Hydrogen Bomb*, p. 421–2.

[286]Rhodes notes: "Soviet agents wanted only conservative, reliable, tested technology from America. Their bosses were managers, not engineers or scientists, and had no way to evaluate untried ideas. The agents knew the penalty for taking risks when mistakes counted as heinous crimes." Rhodes, *Dark Sun: The Making of the Hydrogen Bomb*, p. 87.

[287]On the decision to copy the US Fat Man design, see: Rhodes, *Dark Sun: The Making of the Hydrogen Bomb*, p. 332.

[288]Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 85.

[289]Rhodes notes likewise that the first Soviet plutonium production reactor was practically a carbon copy of the American 305 reactor at the Hanford site. Rhodes, *Dark Sun: The Making of the Hydrogen Bomb*, p. 268.

[290]On the use of slave and convict labour in the Soviet program, see: Rhodes, *Dark Sun: The Making of the Hydrogen Bomb*, p. 287, 314.

[291]Rhodes comments on the motives and patterns for proliferation: "Now an ultimate power had appeared. If Churchill failed to recognize it he did so because it was not a battle cry or a treaty or a committee or men. It was more like a god descending to the stage in a guilded car. It was a mechanism that nations could build and multiply that harnessed unlimited energy, a mechanism that many nations *would* build in self-defense as soon as they learned of its existence and acquired the technical means. It would seem to confer security upon its builders, but because there would be no sure protection against so powerful and portable a mechanism, in the course of time each additional unit added to the stockpiles would *decrease* security by adding to the general threat until insecurity finally revealed itself to be total at every hand." Rhodes, *The Making of the Atomic Bomb*, p. 533 (italics in original).

[292]Australia's Canberra Commission on the Elimination of Nuclear Weapons concluded: "Nuclear weapons are held by a handful of states which insist that these weapons provide unique security benefits, and yet reserve uniquely to themselves the right to own them. This situation is highly discriminatory and thus unstable; it cannot be sustained. The possession of nuclear weapons by any state is a constant stimulus to other states to acquire them. Canberra Commission on the Elimination of Nuclear Weapons. *Report of the Canberra Commission on the Elimination of Nuclear Weapons*. 1996. URL: https://www.dfat.gov.au/sites/default/files/the-canberra-commission-on-the-elimination-of-nuclear-weapons.pdf (visited on 12/30/2023), p. 7.

[293]Rhodes also explains how the security dilemma drove the US and USSR to expand their arsenals: "Actions that were justified domestically as defensive were perceived by the other side to be hostile." Rhodes, *The Twilight of the Bombs: Recent Challenges, New Dangers, and the Prospects for a World Without Nuclear Weapons*, p. 5.

[294]As Perry and Collina argue, the security dillemma is even more acute when neither side has an accurate assessment of their opponent's strength, leading to them relying on a worst-case assessment to choose their own armament level. The other side then imperfectly perceives that buildup and responds in kind. Perry and Collina, *The Button: The New Nuclear Arms Race*

in-parcel with great power status, and in part because they did not trust the US to put its own cities at risk to defend the United Kingdom, the UK developed their own bomb (again aided by Fuchs) and tested it near an island off the Australian coast on October 3, 1952.[295,296,297,298] Given their historical rivalry and distrust of the UK, the French government first tested a bomb on January 13, 1960. Driven in part by concerns about prestige and fear of both the US and USSR, China tested a nuclear weapon on October 16, 1964.[299] Fear of China contributed to India's decision to develop and test a bomb on May 18, 1974.[300] That in turn helped prompt the first test from Pakistan on January 20, 1972.[301,302] As a means of legitimating the regime, and driven by perceived threats abroad, North Korea first tested a bomb on October 9, 2006.

Israel is an unusual case. A national security doctrine of "amimut" or ambiguity prohibits disclosure of Israel's nuclear weapon status. Avner Cohen describes the policy as functioning through three institutional layers: the Israeli Atomic Energy Commission; the Office of Security at the Ministry of Defense (MALMAB); and the Office of the Military Censor (Censora)[303] Whether Israel has ever conducted a nuclear test is not known, though a mysterious incident on September 22, 1979 warrants discussion. An aging U.S. Vela satellite with a bhangmeter on board to detect nuclear detonations recorded the characteristic double flash of a nuclear bomb in the South Indian Ocean.[304] While numerous analyses have reached conflicting accounts about what occurred, Rhodes concludes that it was a clandestine joint Israeli–South African weapon test, probably of an Israeli nuclear artillery shell.[305]

South Africa is another unusual case.[306] In 1991, South Africa became the first nation which had developed nuclear weapons and then to scrap that capacity (as distinct from former Soviet republics returning their weapons to Russia after the collapse of the USSR).[307] South Africa had developed and built gun-type weapons based on HEU by the mid-1970s.[308] When US ambassador and arms control negotiator Tom Graham visited the building where the South African bombs had been assembled and then stored in bank vaults.[309,310] Graham recalled that "there was nothing there that you would not find in a high school machine shop" and learned that 150 people (janitor included) and $25 million had been sufficient for South Africa to develop nuclear arms.[311] Rhodes describes them as "the only nation in the world with an indigenously produced nuclear arsenal that has voluntarily disarmed."[312]

and Presidential Power from Truman to Trump, p. 32.

[295] Rhodes notes that after WWII: "James Chadwick and most of the British Mission returned to Great Britain with pockets full of secrets." Rhodes, *The Making of the Atomic Bomb*, p. 759.

[296] Rhodes notes that Fuchs "became a vector for nuclear proliferation to England as well as the Soviet Union. Rhodes, *Dark Sun: The Making of the Hydrogen Bomb*, p. 259.

[297] On the first British test, see: Rhodes, *Dark Sun: The Making of the Hydrogen Bomb*, p. 502.

[298] For a detailed breakdown of the functioning of the Mike device, see: Rhodes, *Dark Sun: The Making of the Hydrogen Bomb*, p. 505–8.

[299] On China's decision to nuclearize, see: Narang, *Seeking the Bomb: Strategies of Nuclear Proliferation*, p. 163–4.

[300] See: Narang, *Seeking the Bomb: Strategies of Nuclear Proliferation*, p. 58.

[301] See: Narang, *Seeking the Bomb: Strategies of Nuclear Proliferation*, p. 61.

[302] Complicating the story, Narang argues that India only sprinted to finishing a nuclear weapon program because they believed Pakistan was about to do so. Narang, *Seeking the Bomb: Strategies of Nuclear Proliferation*, p. 66-8, 72.

[303] Avner Cohen. *The Worst-Kept Secret: Israel's Bargain with the Bomb*. New York: Columbia University Press, 2012, p. 88.

[304] Rhodes, *The Twilight of the Bombs: Recent Challenges, New Dangers, and the Prospects for a World Without Nuclear Weapons*, p. 164 (also includes an explanation of the physics of the double flash).

[305] Rhodes, *The Twilight of the Bombs: Recent Challenges, New Dangers, and the Prospects for a World Without Nuclear Weapons*, p. 169.

[306] See: Narang, *Seeking the Bomb: Strategies of Nuclear Proliferation*, p. 271–83.

[307] On the logistical and political implausibility of the post-Soviet states keeping these weapons, see: At The Brink Podcast. *Did Ukraine Make a Mistake Giving Up Nuclear Weapons?* 2022. URL: `https://open.spotify.com/episode/0mE5PVAsFhhfjNEUDqmSbM?si=1753f8b50265401a` (visited on 12/31/2023).

[308] Rhodes, *The Twilight of the Bombs: Recent Challenges, New Dangers, and the Prospects for a World Without Nuclear Weapons*, p. 160–1.

[309] Rhodes, *The Twilight of the Bombs: Recent Challenges, New Dangers, and the Prospects for a World Without Nuclear Weapons*, p. 210.

[310] On US and Soviet awareness of the South African weapons program in the 1970s see: William Burr. *The Discovery of South Africa's Secret Nuclear Test Site, August 1977*. 2023. URL: `https://nsarchive.gwu.edu/briefing-book/nuclear-vault/2023-10-26/discovery-south-africas-secret-nuclear-test-site-august-1977` (visited on 08/19/2024).

[311] Rhodes, *The Twilight of the Bombs: Recent Challenges, New Dangers, and the Prospects for a World Without Nuclear Weapons*, p. 210.

[312] Rhodes, *The Twilight of the Bombs: Recent Challenges, New Dangers, and the Prospects for a World Without Nuclear Weapons*, p. 156.

The Bulletin of the Atomic Scientists releases annual updates on the nuclear weapons capabilities of:

- The United States[313]
- Russia[314]
- The United Kingdom[315]
- France[316]
- China[317]
- India[318,319]
- Pakistan[320]
- North Korea[321]
- Israel[322]

Two regions are particularly at risk of having multiple states develop nuclear weapons capability: the Middle East and Southeast Asia.

In the Middle East, the desire for prestige and security could drive several states to nuclearize. In particular, there has been extensive speculation that if Iran tests a weapon or declares itself as a nuclear power, Saudi Arabia will follow suit.[323,324] Saudi Arabia has announced its intention to build 16 nuclear generating stations, all of which would breed plutonium, and would probably rely on uranium enriched to the level required for most light-water reactor designs.[325] Within the region, the United Arab Emirates (UAE) is also deploying power reactors with potential weapon uses.[326] Iraq also plans eight nuclear power reactors.[327] The Economist speculated in 2021 that if Saudi Arabia becomes a nuclear power, Turkey could follow.[328]

---

313 Hans M. Kristensen and Matt Korda. *Nuclear Notebook: United States nuclear weapons, 2023*. 2023. URL: https://thebulletin.org/premium/2023-01/nuclear-notebook-united-states-nuclear-weapons-2023/ (visited on 12/31/2023).

314 Hans M. Kristensen, Matt Korda, and Eliana Johns. *Nuclear Notebook: Russian nuclear weapons, 2023*. 2023. URL: https://thebulletin.org/premium/2023-05/nuclear-notebook-russian-nuclear-weapons-2023/ (visited on 12/31/2023).

315 Hans M. Kristensen and Matt Korda. *Nuclear Notebook: How many nuclear weapons does the United Kingdom have in 2021?* 2021. URL: https://thebulletin.org/premium/2021-05/nuclear-notebook-how-many-nuclear-weapons-does-the-united-kingdom-have-in-2021/ (visited on 12/31/2023).

316 Hans M. Kristensen, Matt Korda, and Eliana Johns. *Nuclear Notebook: French nuclear weapons, 2023*. 2023. URL: https://thebulletin.org/premium/2023-07/nuclear-notebook-french-nuclear-weapons-2023/ (visited on 12/31/2023).

317 Hans M. Kristensen et al. *Nuclear Notebook: Chinese nuclear weapons, 2024*. 2024. URL: https://thebulletin.org/premium/2024-01/chinese-nuclear-weapons-2024/ (visited on 12/31/2023).

318 Hans M. Kristensen and Matt Korda. *Nuclear Notebook: How many nuclear weapons does India have in 2022?* 2022. URL: https://thebulletin.org/premium/2022-07/nuclear-notebook-how-many-nuclear-weapons-does-india-have-in-2022/ (visited on 12/31/2023).

319 For an extensive set of sources on the Indian nuclear weapons program, see footnote 1: Narang, *Seeking the Bomb: Strategies of Nuclear Proliferation*, p. 56.

320 Hans M. Kristensen, Matt Korda, and Eliana Johns. *Pakistan nuclear weapons, 2023*. 2023. URL: https://thebulletin.org/premium/2023-09/pakistan-nuclear-weapons-2023/ (visited on 12/31/2023).

321 Hans M. Kristensen and Matt Korda. *Nuclear Notebook: How many nuclear weapons does North Korea have in 2022?* 2022. URL: https://thebulletin.org/premium/2022-09/nuclear-notebook-how-many-nuclear-weapons-does-north-korea-have-in-2022/ (visited on 12/31/2023).

322 Hans M. Kristensen and Matt Korda. *Nuclear Notebook: Israeli nuclear weapons, 2022*. 2022. URL: https://thebulletin.org/premium/2022-01/nuclear-notebook-israeli-nuclear-weapons-2022/ (visited on 12/31/2023).

323 Jonathan Tirone. *Arms control experts concerned by Saudi nuclear reactor push*. URL: https://www.aljazeera.com/economy/2020/5/21/arms-control-experts-concerned-by-saudi-nuclear-reactor-push (visited on 12/30/2023).

324 Al Jazeera. 2020. URL: https://www.aljazeera.com/news/2020/11/17/saudi-minister-wont-rule-out-nuclear-armament-over-iran (visited on 12/30/2023).

325 Reuters. *Saudi plans to build 16 nuclear reactors by 2030*. 2011. URL: https://www.reuters.com/article/idUSLDE75004Q/ (visited on 12/30/2023).

326 Patricia Sabga. *Nuclear Gulf: Experts sound the alarm over UAE nuclear reactors*. 2020. URL: https://www.aljazeera.com/economy/2020/7/15/nuclear-gulf-experts-sound-the-alarm-over-uae-nuclear-reactors (visited on 12/30/2023).

327 Khalid Al-Ansary and Anthony Di. *Iraq plans nuclear power plants to tackle electricity shortage*. 2021. URL: https://www.aljazeera.com/economy/2021/6/8/iraq-plans-nuclear-power-plants-to-tackle-electricity-shortage (visited on 12/30/2023).

328 The Economist. *The world is facing an upsurge of nuclear proliferation*. 2021. URL: https://www.economist.com/leaders/2021/01/30/the-world-is-facing-an-upsurge-of-nuclear-proliferation (visited on 12/30/2023).

In Southeast Asia, North Korea's illicit nuclear weapons program coupled with perceptions about improving their security in the region and prestige could drive other states to nuclearize, including South Korea, Taiwan, and Japan. The Economist described Japan as "the only non-nuclear-armed state which operates major facilities for enriching uranium and reprocessing plutonium from spent reactor fuel, both potential routes to fissile material for a bomb."[329,330,331,332,333] Mark Fitzpatrick, who formerly oversaw non-proliferation policy at the US State Department, has stated that Japan, South Korea, and Taiwan could make a nuclear weapon in less than two years — far less in Japan's case.[334]

Nuclear proliferation carries the risk of creating situations similarly dangerous to the Cuban Missile Crisis, but where the actors involved are more numerous and less experienced with managing crises with one another. After the crisis, a hot line was created between the US and USSR, with terminals in the White House and Communist Party headquarters.[335] Such communication channels, including the backchannel links used to resolve the Cuban crisis, may not be in place or functional during a crisis between newer nuclear powers with less history of interaction with one another. As The Economist reported:

> New actors with more versatile weapons have turned nuclear doctrine into guesswork. Even during the cold war, despite all that game theory and brainpower, the Soviet Union and America frequently misread what the other was up to. India and Pakistan, with little experience and less contact, have virtually nothing to guide them in a crisis but mistrust and paranoia. If weapons proliferate in the Middle East, as Iran and then Saudi Arabia and possibly Egypt join Israel in the ranks of nuclear powers, each will have to manage a bewildering four-dimensional stand-off.[336]

6.1 Delivery system proliferation

While covering it in detail would impracticably expand this briefing, it is essential to note that nuclear weapons only confer any utility to their possessors if they can be delivered to the enemy. The major means of doing so are each included in America's 'nuclear triad' of bombers, land-based ICBMs, and submarine-launched SLBMs.

6.2 Complicity of the nuclear weapon states in weapon proliferation

Article I of the Treaty on the Non-Proliferation of Nuclear Weapons (NPT):

> Each nuclear-weapon State Party to the Treaty undertakes not to transfer to any recipient whatsoever nuclear weapons or other nuclear explosive devices or control over such weapons or explosive devices directly, or indirectly; and not in any way to assist, encourage, or induce any non-nuclear-weapon State to manufacture or otherwise acquire nuclear weapons or other nuclear explosive devices, or control over such weapons or explosive devices.[337,338,339]

[329] The Economist. *Nuclear proliferation is not fast, but it is frightening.* 2021. URL: https://www.economist.com/briefing/2021/01/30/nuclear-proliferation-is-not-fast-but-it-is-frightening (visited on 12/30/2023).

[330] On South Korea, see also: Jennifer Lind and Daryl G. Press. *Should South Korea build its own nuclear bomb?* 2021. URL: https://www.washingtonpost.com/outlook/should-south-korea-go-nuclear/2021/10/07/a40bb400-2628-11ec-8d53-67cfb452aa60_story.html (visited on 12/30/2023).

[331] Jesse Johnson. *South Korean support for a domestic nuclear arsenal is growing — for surprising reasons.* 2022. URL: https://www.japantimes.co.jp/news/2022/02/23/asia-pacific/south-korea-nuclear-weapons-survey/ (visited on 12/30/2023).

[332] Zaheena Rasheed and Heejin Kang. *Why some South Koreans want their own nuclear bomb.* 2022. URL: https://www.aljazeera.com/news/2022/6/3/why-south-koreans-want-their-own-nuclear-bomb (visited on 12/30/2023).

[333] Foster Klug. *South Koreans want their own nukes. That could roil one of the world's most dangerous regions.* URL: https://outrider.org/nuclear-weapons/articles/south-koreans-want-their-own-nukes-could-roil-one-worlds-most-dangerous (visited on 08/19/2024).

[334] The Economist, *Nuclear proliferation is not fast, but it is frightening*.

[335] Schlosser, *Command and Control: Nuclear Weapons, the Damascas Accident, and the Illusion of Safety*, p. 296.

[336] The Economist. *The new nuclear age.* 2015. URL: https://www.economist.com/leaders/2015/03/05/the-new-nuclear-age (visited on 12/30/2023).

[337] United Nations Office for Disarmament Affairs. *Treaty on the Non-Proliferation of Nuclear Weapons (NPT).* 1970. URL: https://disarmament.unoda.org/wmd/nuclear/npt/text/ (visited on 12/29/2023).

[338] On the history and negotiation of the NPT, see: Rhodes, *Arsenals of Folly: The Making of the Nuclear Arms Race*, p. 73.

[339] Rhodes argues: "More than any other factor, the NPT had limited the proliferation of nuclear weapons across the world."

The Treaty on the Non-Proliferation of Nuclear Weapons opened for signature in 1968, entered into force in 1970 and was extended indefinitely with the consent of the state parties in 1995. The treaty defines nuclear weapon states as those that had built and tested a device before January 1m 1967: the US (1945), USSR (1949), UK (1952), France (1960), and China (1964). The basic deal made in the NPT is that non-nuclear weapon states would have access to civilian nuclear technology, and that weapon states would seek to negotiate disarmament. Non-parties to the NPT which went on to develop nuclear weapons are India, Israel, North Korea (which was a member but withdrew), and Pakistan.

Despite their legal obligation not to do so, nuclear weapon states as defined in the NPT have massively aided the weapon development projects of states which were meant to be bound by non-proliferation.

France provided extensive assistance to Israel's clandestine nuclear weapons program. Cohen argues:

> The scope of the Israeli request for French technological assistance, the details of which Shimon Peres spelled out in Paris in 1956/1957, was tantamount to a national proliferation commitment. Enough is now known about the extent of the Dimona deal to appreciate how determined Ben-Gurion was to pursue it. The Dimona nuclear complex was designed to include all the technological components required for a plutonium-based nuclear-weapons infrastructure. The project's scope and purpose were evident in the facility's sanctum sanctorum, the deeply dug underground reprocessing facility designed to extract plutonium from spent uranium rods. Nothing is more indicative of Israel's initial commitment to build a nuclear-weapons capability than this supersecret and costly facility. From the beginning, Israel hoped that [sic] within a decade or so to have enough fissile material to build its own nuclear device.[340]

France also built Iraq's 40 megawatt light-water reactor at Al Tuwaitha, which was pre-emptively destroyed by the Israeli Air Force in 1981.[341,342]

In an extreme example, the Bulletin of Atomic Scientists alleged in 2015 that:

> It is generally believed that Beijing provided Pakistani nuclear scientist A. Q. Khan with blueprints for the uranium implosion device that China detonated on October 27, 1966 (the so-called CHIC-4 test/design). It is also suspected that on May 26, 1990 China tested a Pakistani derivative of the CHIC-4 at its Lop Nor test site, with a yield in the 10 to 12 kiloton (kt) range.[343,344,345]

Furthermore, Vipin Narang alleges that — via the AQ Khan illicit proliferation network — Pakistan provided the Chinese CHIC-4 missile mateable warhead design to Libya in 1995.[346]

6.3 Countermeasures in the context of a climate-driven global nuclear energy deployment

Nuclear energy is an established and acknowledged low-carbon source of energy, which also has other desirable characteristics from the perspective of the power grid. In 2013, scientists at the NASA Goddard Institute for Space Studies and Columbia University's Earth Institute estimated that nuclear energy had avoided 64 gigatonnes of CO_2 emissions, and could prevent 80–240 gigatonnes of further emissions by 2050 depending on which fuel is replaced.[347] Large reactors can each add about a megawatt of baseload power to the grid, with availability constrained chiefly by maintenance and refuelling requirements, in contrast with

Rhodes, *The Twilight of the Bombs: Recent Challenges, New Dangers, and the Prospects for a World Without Nuclear Weapons*, p. 5.

340 Cohen, *The Worst-Kept Secret: Israel's Bargain with the Bomb*, p. 57–8.

341 Rhodes, *The Twilight of the Bombs: Recent Challenges, New Dangers, and the Prospects for a World Without Nuclear Weapons*, p. 15.

342 For a detailed but not necessarily balanced account of the attack, see: Roger Claire. *Raid on the Sun: Inside Israel's Secret Campaign that Denied Saddam the Bomb*. New York: Crown, 2005.

343 Hans M. Kristensen and Robert S. Norris. *Pakistani nuclear forces, 2015*. 2015. URL: `https://web.archive.org/web/20160319004043/http://fas.org/wp-content/uploads/2015/10/Nov-Dec-Pakistan-FINAL.pdf`, p. 2–3.

344 See also: Khan, *Eating Grass: The Making of the Pakistani Bomb*, p. 188.

345 Rhodes, *The Twilight of the Bombs: Recent Challenges, New Dangers, and the Prospects for a World Without Nuclear Weapons*, p. 6.

346 Narang, *Seeking the Bomb: Strategies of Nuclear Proliferation*, p. 308–10.

347 Richard Rhodes. *Energy: A Human History*. New York: Simon & Schuster, 2018, p. 325.

the intermittency of renewable energy.[348] While some countries — most notably, Germany and Japan — have been pulling away from nuclear energy in the aftermath of the March 2011 Fukushima Daiichi accident, many other states are planning to deploy their first power reactors or enlarge their fleets.

Methods of verification developed for dismantling Cold War weapons give an indication of the kinds of methods which can be used to prevent diversion of fissile materials. These include 'fingerprinting' weapon casings using adhesive tape, super-adhesive bar codes and sealing tape, and fibre optic seals for weapon casings.[349] One basic safeguard is the use of uranium oxide ceramic in reactor fuel instead of uranium metal for naval and power reactors, a practice which was identified as a counter-proliferation safeguard back when Hyman Rickover was first developing nuclear reactors for submarines.[350] Rhodes identifies the emergence of mechanisms which could support nuclear weapon abolition:

> Where the largest-scale instruments of man-made death are concerned, the elements of that discipline of public safety have already begun to assemble themselves: materials control and accounting, cooperative threat reduction, security guarantees, agreements and treaties, surveillance and inspection, sanctions, forceful disarming if all else fails.[351]

This briefing was prepared in order to provide a well-documented starting point for assessing the risks posed by nuclear weapons. It does not jump ahead to assess what we as an institution might be able to do to reduce those risks.

[348] In 2016, US nuclear generating stations produced almost 20% of US electricity and operated at full power 92.1% of the time. In comparison, hydropower systems delivered power 38% of the time; wind turbines 34.7% of the time; and solar photovoltaic farms 27.2% of the time. Thermal plants running on coal and gas operate about half the time. Rhodes calls nuclear "easily the most promising single energy source available to cope with twenty-first-century energy challenges." Rhodes, *Energy: A Human History*, p. 331, 336.

[349] Rhodes, *The Twilight of the Bombs: Recent Challenges, New Dangers, and the Prospects for a World Without Nuclear Weapons*, p. 110.

[350] Rhodes, *Energy: A Human History*, p. 286.

[351] Rhodes, *The Twilight of the Bombs: Recent Challenges, New Dangers, and the Prospects for a World Without Nuclear Weapons*, p. 302.