Second Meeting of States Parties to the Treaty on the Prohibition of Nuclear Weapons

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Consideration of the status and operation of the Treaty and other matters important for achieving the objectives and purpose of the Treaty: other matters important for achieving the objectives and purpose of the Treaty: scientific and technical advice for the effective implementation of the Treaty

Report of the Scientific Advisory Group on the status and developments regarding nuclear weapons, nuclear weapon risks, the humanitarian consequences of nuclear weapons, nuclear disarmament and related issues

I. Introduction

1. The first Meeting of States Parties to the Treaty on the Prohibition of Nuclear Weapons established a Scientific Advisory Group. The President of the second Meeting of States Parties appointed the members of the Group for a term of office beginning on 8 February 2023 and ending on the final day of the first Review Conference of the Treaty. The Group was established on the basis of the mandate contained in document TPNW/MSP/2022/WP.6, which provides further details on the purpose, background and terms of reference of the Group. The members of the Group serve in their individual capacity as independent experts (see sect. II below).

2. The Scientific Advisory Group has met regularly throughout 2023. Further information on Group activities can be found in the report of the Group on its annual activities (TPNW/MSP/2023/6). As part of its mandate, the Group transmits the present report on the status and developments regarding nuclear weapons, nuclear weapon risks, the humanitarian consequences of nuclear weapons, nuclear disarmament and related issues.

3. The present report draws on published open-source materials and the expertise of the Scientific Advisory Group.

4. The Scientific Advisory Group acknowledges with gratitude the assistance of the States Parties to the Treaty on the Prohibition of Nuclear Weapons, the President of the second Meeting of States Parties to the Treaty, the secretariat of the Office for Disarmament Affairs and experts who were invited to give briefings at the meetings.

* TPNW/MSP/2023/1.

II. Members of the Scientific Advisory Group

5. The members of the Scientific Advisory Group are as follows:

- Kouamé Rémi Adjoumani
- Bashillah Bt. Baharuddin
- Erlan Batyrbekov
- André Johann Buys
- Jans Fromow-Guerra
- Bwarenaba Kautu
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- Noël Francis Stott
- Gerardo Suárez Reynoso
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III. Status of nuclear weapons

6. The Treaty on the Prohibition of Nuclear Weapons prohibits comprehensively the development, testing, production, manufacturing, acquisition, possession or stockpiling of nuclear weapons, as well as their use and threat of use under any circumstances. Nuclear-armed States intending to join the Treaty while they still possess weapons must remove all nuclear weapons from operational status and destroy them. States that owned nuclear weapons after 7 July 2017 can also choose to destroy their weapons before joining the Treaty.

7. In the present section, the status of nuclear weapons in the nine nuclear-armed States is discussed, including of weapons stockpiles and capabilities, modernization efforts, and the holdings of plutonium and high enriched uranium, the fissile materials that sustain the nuclear fission chain reaction. The section is based on independent analysis and estimates, as well as the limited official data available.

Weapons stockpiles

8. Nuclear-armed States are adding new weapons or new capabilities to their arsenals. It is estimated that, in early 2023, there were about 12,500 nuclear warheads (most for use on missiles, and some as bombs) in the global stockpile, including some 3,000 retired warheads awaiting dismantlement (see table 1).[1] Worldwide, the largest number of weapons are in storage, rather than deployed and ready for use. About 90 per cent of all warheads are held by the United States of America and the Russian

[1] Hans M. Kristensen and others, "Status of world nuclear forces", Federation of American Scientists, blog, 31 March 2023. Data for alert weapons and yields are from private communication with Matt Korda and Hans Kristensen, Federation of American Scientists. For weapons with variable yield, maximum yield values are used.

Federation. Since the Treaty on the Prohibition of Nuclear Weapons was opened for signature, two countries (the United States and France) have reduced military nuclear weapons stockpiles, according to independent estimates.[2] Estimates of military stockpiles for all other States have increased since that time. Some estimates are highly uncertain.

Table 1
Estimated number of nuclear warheads, by country

	Total number of warheads	*Number of warheads on alert*	*Number of warheads awaiting dismantlement*	*Trend of military warhead stockpiles since Treaty on the Prohibition of Nuclear Weapons opened for signature*	*Explosive yield of deployed and stockpiled warheads (megatons of TNT equivalent)*
Russian Federation	5 900	950	1 400	Increased	980
United States of America	5 240	840	1 540	Decreased	860
China	410	–	–	Increased	130
France	290	80	–	Decreased	29
United Kingdom of Great Britain and Northern Ireland	230	50	–	Increased	23
Pakistan	170	–	–	Increased	3.4
India	160	–	–	Increased	4.1
Israel	90	–	–	Increased	2.5
Democratic People's Republic of Korea	30	–	–	Increased	1.5
Total	**12 520**	**1 920**	**2 940**	**Increasing**	**2 030 megatons**

Source: Federation of American Scientists.
Notes: Rounded to 10 nuclear warheads. Total number includes deployed, stockpiled and retired warheads. Alert warheads are on weapons ready to be launched from land-based silos, mobile missile launchers and submarines on patrol.

9. Total warhead numbers have fallen significantly from the peak, in the 1980s. In the 1990s, up to several thousand warheads were being dismantled each year by the United States and the Russian Federation. Rates of dismantlement of retired nuclear warheads have fallen sharply as the priority has shifted to warhead life extension and modernization, while new weapons continue to be added to the global stockpile. The annual reduction in the global nuclear warhead stockpile is significantly less than it was just five years ago.

10. No nuclear-armed State regularly provides current information on its nuclear warhead stockpile. The United States has been relatively more transparent than others and has provided declarations, including historical data, but this practice has become episodic, and the country has released no data on its stockpile since 2021.[3]

11. From time to time, France has indicated its overall stockpile size. The most recent such time was in 2020.[4]

[2] These statements do not include weapons awaiting dismantlement, and are based on the estimates provided in Stockholm International Research Institute, *SIPRI Yearbook 2018: Armaments, Disarmament and International Security* (Oxford University Press, 2018); and Stockholm International Research Institute, *SIPRI Yearbook 2023: Armaments, Disarmament and International Security* (Oxford University Press, 2023).

[3] United States of America, Department of State, "Transparency in the U.S. nuclear weapons stockpile", 5 October 2021.

[4] Emmanuel Macron, President of France, speech on the strategy of defence and deterrence at the War College, 7 February 2020.

12. The United Kingdom of Great Britain and Northern Ireland has also occasionally released stockpile information, and last published an upper limit on its arsenal in 2021.[5] The United Kingdom recently raised the stockpile ceiling to 260 nuclear warheads and is potentially increasing its stockpile from 225 to that level.

13. China, the Democratic People's Republic of Korea, India, Israel, Pakistan and the Russian Federation have never provided public information on their respective stockpile sizes.

14. Prior to the 2023 suspension of the new Strategic Arms Reduction Treaty (new START Treaty) by the Russian Federation, the United States and the Russian Federation regularly exchanged and published information on aggregate deployed strategic warhead and launcher numbers using treaty-specific warhead counting rules. The future of similar transparency measures is unclear.

15. Yield is an important metric that explains the destructive energy of nuclear weapons and thus their consequences for people and the environment. Yield is measured as the energy released during a nuclear explosion, typically expressed in kilotons (thousands of tons) or megatons (millions of tons) of TNT equivalent. TNT is a chemical explosive. The current arsenals of the Russian Federation and the United States each have a total yield estimated to be more than 800 megatons of TNT equivalent. The smallest nuclear arsenal, that of the Democratic People's Republic of Korea, has an estimated total yield of 1.5 megatons of TNT equivalent, about 100 times the yield of the Hiroshima nuclear bomb. Most warheads in the global stockpile have individual yields of several 100 kilotons of TNT equivalent. Some warheads have yields as low as a fraction of a kiloton of TNT equivalent, while others have yields of several megatons of TNT equivalent. Some warheads have adjustable yields.

Modernization

16. All nuclear weapon States are modernizing nuclear weapons and delivery systems, often with development times of decades and expected weapon system lifetimes ranging up to 50 years or more in some cases.

17. The United States is modernizing five different nuclear warhead types, and four additional warhead types are planned for the near future.[6] It is also modernizing its nuclear bomber fleet and developing a new intercontinental ballistic missile model with a planned lifetime of until 2075.[7] The lifetime of existing submarine-launched ballistic missiles will be extended to 2084, and new air-launched cruise missiles will become operational in 2030.[8] The development of a new nuclear-armed sea-launched cruise missile is being debated.[9]

18. Modernization efforts by the Russian Federation to update Soviet-era weapons include silo-based and road-mobile intercontinental ballistic missiles, submarines, strategic bombers and air- and ground-launched cruise missiles. Recently retired

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[5] United Kingdom of Great Britain and Northern Ireland, Cabinet Office, *Global Britain in a Competitive Age: The Integrated Review of Security, Defence, Development and Foreign Policy* (2021).

[6] United States, Department of Energy, National Nuclear Security Administration, *Fiscal Year 2023: Stockpile Stewardship and Management Plan – Biennial Plan Summary*, Report to Congress (Washington, D.C., 2023).

[7] Air Force Nuclear Weapons Centre, Office of Public Affairs, "Fact sheet: LGM-35A Sentinel", April 2022.

[8] Hans M. Kristensen and Matt Korda, "United States nuclear weapons, 2023", *Bulletin of the Atomic Scientists*, vol. 79, No. 1 (January 2023).

[9] Bryant Harris, "GOP moves to instate sea-launched cruise missile nuclear program", Defense News, 21 June 2023.

submarines had an age of nearly 40 years;[10] assuming a similar lifetime for new ones would mean operation until 2063. The Russian Federation recently began to deploy the Avangard hypersonic glide vehicle and is developing new nuclear weapons systems, including the Sarmat intercontinental ballistic missile, the Poseidon nuclear-powered underwater torpedo and the Burevestnik nuclear-powered cruise missile.[11]

19. China has been significantly expanding its number of intercontinental ballistic missile silos, although they have not yet been loaded with missiles. It is developing a new intercontinental ballistic missile and has tested a fractional orbital bombardment system. It also operates six submarine-launched ballistic missile-equipped submarines, has had a near-continuous at-sea-operation since 2021 and is developing a new submarine with an expected lifetime of 40 years. Since 2018, China has re-assigned bombers for a nuclear role and is developing a new aircraft and new air-launched cruise missiles for nuclear weapon missions.[12]

20. The United Kingdom submarine fleet is scheduled for replacement in the early 2030s. Replacement of the submarine-launched ballistic missiles will depend on the United States, which leases them to the United Kingdom[13] A replacement programme for the nuclear warhead of the United Kingdom is under way, but it relies on the United States W93 warhead development programme.[14]

21. France is developing the third generation of its nuclear-armed submarines, which will be operational in 2035.[15] Their operational lifetime is planned to last until 2090.[16] A refurbishment programme and a subsequent replacement programme are under way for the nuclear-armed air-launched cruise missile.[17]

22. Information on the arsenal of Israel is scarce and highly uncertain. The country's main nuclear weapon delivery systems are believed to be ground-launched ballistic missiles and United States-supplied nuclear-capable fighter aircraft. Israel might also have nuclear-armed submarine-launched cruise missiles. Its land-based missiles are currently being upgraded.[18]

23. India has at least three land-based ballistic missiles under development, which are planned to become operational within the coming years, and is working on a possible intercontinental ballistic missile and a new submarine-launched ballistic missile. It also recently purchased a new Rafale fighter aircraft from France, which may be capable of nuclear missions. Its next generation of nuclear submarines might be operational in the late 2020s. The nuclear weapon arsenal of India is growing by an estimated 5 to 10 nuclear weapons per year.[19]

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[10] Pavel Podvig, "Two project 667BDR submarines withdrawn from service", Russian Strategic Nuclear Forces, blog, 14 March 2018.

[11] Hans M. Kristensen, Matt Korda and Eliana Reynolds, "Russian nuclear weapons, 2023", *Bulletin of the Atomic Scientists*, vol. 79, No. 3 (May 2023).

[12] Hans M. Kristensen, Matt Korda and Eliana Reynolds, "Chinese nuclear weapons, 2023", *Bulletin of the Atomic Scientists*, vol. 79, No. 2 (March 2023).

[13] Hans M. Kristensen and Matt Korda, "United Kingdom Nuclear Weapons, 2021", *Bulletin of the Atomic Scientists*, vol. 77, No. 3 (May 2021).

[14] United States, Department of Energy, National Nuclear Security Administration, "W93/MK7 Acquisition Program", January 2022.

[15] H. I. Sutton and Xavier Vavasseur, "France's new submarine will be even quieter than the ocean", Naval News, blog, 26 February 2021.

[16] Interview de Florence Parly, ministre des Armées, à Europe le 19 février 2021, sur la défense spatiale, la dissuasion nucléaire, la résurgence de Daesh et la lutte contre le terrorisme au Sahel.

[17] Hans M. Kristensen, Matt Korda and Eliana Johns, "French nuclear weapons, 2023", *Bulletin of the Atomic Scientists*, vol. 79, No. 4 (July 2023).

[18] Hans M. Kristensen and Matt Korda, "Israeli nuclear weapons, 2021", *Bulletin of the Atomic Scientists*, vol. 78, No. 1 (January 2022).

[19] Hans M. Kristensen and Matt Korda, "Indian nuclear weapons, 2022", *Bulletin of the Atomic Scientists*, vol. 78, No. 4 (July 2022).

24. Pakistan is developing several new delivery systems, including ballistic missiles of various ranges, one possibly able to carry multiple warheads, as well as air-launched, ground-launched and sea-launched cruise missiles. The country is introducing a new aircraft with a nuclear mission and is building new submarines for its sea-launched cruise missiles. The arsenal of Pakistan is increasing by an estimated 5 to 10 nuclear weapons per year.[20]

25. Information on the arsenal of the Democratic People's Republic of Korea is scarce and highly uncertain. In recent years, the country has announced tests of a variety of ballistic missiles, including intercontinental ballistic missiles and submarine-launched ballistic missiles, and is developing a nuclear submarine.[21] In 2023, it announced that it had an operational "tactical nuclear attack submarine".[22]

26. Future research is needed to better understand the dynamics of engagement in the twenty-first century nuclear arms race, as is visible in the modernization efforts described above. Such research should study how country-specific modernization efforts interact with and influence efforts in other countries, how they create challenges for nuclear disarmament in the future and how they add to nuclear risk. Such a study could be conducted by, for example, the United Nations Institute for Disarmament Research.

Nuclear weapon host States and others

27. Beyond the nine nuclear-armed States, six countries host nuclear weapons. Five North Atlantic Treaty Organization (NATO) States – Belgium, Germany, Italy, the Kingdom of the Netherlands and Türkiye – host nuclear weapons belonging to the United States. The United States is currently modernizing the weapons stationed in these NATO countries, and all of them except Türkiye recently upgraded aircraft to be used for nuclear weapon delivery.[23] Greece has a contingency nuclear strike mission.[24] A return of United States nuclear weapons to the United Kingdom is under discussion.[25] Since June 2023, Belarus has been believed to host nuclear weapons belonging to the Russian Federation.[26]

28. The number of non-weapon States that receive some kind of nuclear weapon-related security guarantee from nuclear-armed States has grown in recent years. Commitments by the United States, the United Kingdom and France cover the States members of an enlarged NATO alliance. The United States also provides nuclear assurances to Japan, the Republic of Korea and Australia.[27] Armenia and Belarus have such guarantees from the Russian Federation.[28]

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[20] Hans M. Kristensen, Matt Korda and Eliana Johns, "Pakistan Nuclear Weapons, 2023", *Bulletin of the Atomic Scientists*, vol. 79, No. 5 (September 2023).

[21] Hans M. Kristensen and Matt Korda, "North Korean nuclear weapons, 2022", *Bulletin of the Atomic Scientists*, vol. 78, No. 5 (September 2022).

[22] Josh Smith and Soo-Hyang Choi, "North Korea unveils first tactical, nuclear-armed submarine", Reuters, 8 September 2023.

[23] Hans M. Kristensen and Matt Korda, "World nuclear forces", in *SIPRI Yearbook 2023: Armaments, Disarmament and International Security* (Oxford University Press, 2023).

[24] Hans M. Kristensen, "NATO steadfast noon exercise and nuclear modernization in Europe", Federation of American Scientists, blog, 17 October 2022.

[25] Matt Korda and Hans Kristensen, "Increasing evidence that the US air force's nuclear mission may be returning to UK soil", Federation of American Scientists, 28 August 2023.

[26] President of Russia, "Plenary session of the St. Petersburg International Economic Forum", 27 June 2023.

[27] The White House, "Japan-U.S. joint leaders' statement: strengthening the free and open international order", 23 May 2022; and The White House, "Washington Declaration", 26 April 2023.

[28] See https://banmonitor.org/the-context-of-the-tpnw.

Fissile material stockpiles

29. The most common fissile materials are plutonium and high enriched uranium. Each can sustain the nuclear fission chain reaction that enables both fission weapons and thermonuclear weapons. Plutonium is chemically separated from irradiated nuclear reactor fuel. High enriched uranium is produced using enrichment technology able to separate uranium-235 from the more abundant uranium-238 isotope. The International Atomic Energy Agency (IAEA) considers nearly all plutonium to be weapon-usable, and treats uranium containing 20 per cent or more uranium-235 as weapon-useable and defines it as high enriched uranium.

30. There are independent estimates as from the beginning of 2022 for both plutonium and high enriched uranium. The following discussion is based on these estimates.[29] Ten countries held a combined stockpile of 550 metric tons of separated plutonium. In nuclear-armed States, this included the plutonium in weapons and available for weapons (140 metric tons). All these States were believed to have plutonium stockpiles that exceeded the amount required for the warheads in their respective arsenals. That means that existing plutonium stockpiles would suffice for significant arsenal build-ups.

31. The Democratic People's Republic of Korea, India, Israel and Pakistan continued to produce plutonium in weapons programmes. France, Japan, the Russian Federation and China produced potentially weapon-usable plutonium for civilian purposes. Japan was the only non-weapon State that held ton quantities of plutonium and had a large-scale plutonium separation programme.

32. At the beginning of 2022, the global stockpile of high enriched uranium was estimated to be about 1,250 metric tons. Non-nuclear weapon States held about 4 metric tons of high enriched uranium. In the stockpiles of nuclear-armed States, about 1,100 metric tons were in weapons or available for use in weapons. In the United States, the Russian Federation, China, France, Pakistan and the United Kingdom, the stockpiles available for weapons significantly exceeded the amount required for the warheads in their respective arsenals. As with plutonium, this excess would allow for future arsenal build-ups without new production. The Russian Federation, Pakistan, India and the Islamic Republic of Iran, as well as, presumably, the Democratic People's Republic of Korea, produced new high enriched uranium. The status of production in Israel was unknown. The stockpiles of high enriched uranium in weapons or available for weapons in the Russian Federation, the United Kingdom and the United States were decreasing owing to the use of high enriched uranium for naval propulsion reactors.

33. Transparency with regard to military fissile materials has been very uneven. The United States last made a declaration of its military plutonium production and total stockpile in 2012.[30] It last reported on total high enriched uranium in 2016.[31] The United Kingdom last made a declaration of its total military plutonium stockpile in

[29] The following estimates are based on Moritz Kütt, Zia Mian and Pavel Podvig, "Global stocks and production of fissile materials, 2019", in *SIPRI Yearbook 2023: Armaments, Disarmament and International Security* (Oxford University Press, 2023). Further information can be found in Moritz Kütt and others, *Global Fissile Material Report 2022: Fifty Years of the Nuclear Non-Proliferation Treaty – Nuclear Weapons, Fissile Materials, and Nuclear Energy* (Princeton, New Jersey, International Panel on Fissile Material, 2022).

[30] United States, Department of Energy, National Nuclear Security Administration, "The United States plutonium balance, 1944–2009", June 2012.

[31] The White House, Office of the Press Secretary, "Fact sheet: transparency in the U.S. highly enriched uranium inventory", 31 March 2016.

2000[32] and last published its total high enriched uranium stockpile in 2006.[33] No other nuclear-armed State has reported on its total or military fissile material stockpile.

34. To enable a more fully informed and up-to-date analysis of the status of nuclear weapons worldwide, greater transparency and regular reporting by nuclear-armed States on their arsenals, modernization plans, weapon-hosting arrangements and fissile material production and stockpiles are urgently needed.

IV. Nuclear weapon risks

35. In the preamble to the Treaty on the Prohibition of Nuclear Weapons, the risks posed by nuclear weapons, including from any nuclear weapon detonation by accident, miscalculation or design, are referred to. States parties to the Treaty have emphasized that these risks concern the security of all humanity and that all States share the responsibility of preventing any use of nuclear weapons.

36. The present section provides a discussion of the special types of risks that nuclear weapons pose, an outline of the risks of nuclear weapons caused by current postures in various countries, a discussion of recently made threats of using nuclear weapons and highlights of ways to think about risks and their limits.

Assessment of risks caused by current postures

37. For as long as nuclear weapons have existed, there have been risks of nuclear explosions. One risk is that the leaders of States intentionally use these weapons according to a plan. Accidental explosions are also possible, for example as a result of technical failure. In addition, nuclear weapons can be used inadvertently, such as if a State feels pressured to launch them because the weapons might otherwise be destroyed. In each category, technological, human and doctrinal factors influence the risk of nuclear weapon use.

38. The risk of intentional as well as inadvertent use is influenced by a State's strategies and force structure. Current strategies and force postures vary across nuclear-armed States, and risk can increase significantly when States are at war or during crises. Table 2 provides a list of important aspects of current nuclear weapons postures for the nine nuclear-armed States, with the caveat that there are often uncertainties and ambiguities in statements on posture, which may be deliberate so as to allow for potentially conflicting interpretations.

Table 2
Nuclear weapons postures

	Forward-deployed weapons	*First-use strategy*	*Weapons on high alert*	*Naval patrol*	*Multiple independently targetable re-entry vehicle capabilities*	*Nuclear response to non-nuclear attack*
United States of America	Yes	Yes	Yes	Yes	Yes	Yes
Russian Federation	Yes	Yes	Yes	Yes	Yes	Yes
United Kingdom of Great Britain and Northern Ireland	No	Yes (NATO)	No	Yes	Yes	Yes

[32] United Kingdom, Ministry of Defence, "Plutonium and Aldermaston: an historical account", 2000.
[33] United Kingdom, Ministry of Defence, "Historical accounting for UK Defence highly enriched Uranium", March 2006.

	Forward-deployed weapons	*First-use strategy*	*Weapons on high alert*	*Naval patrol*	*Multiple independently targetable re-entry vehicle capabilities*	*Nuclear response to non-nuclear attack*
France	No	Yes (NATO)	No	Yes	Yes	No
China	No	No	No	Yes	Yes	Possible in principle (but no first use)
Israel	No	Unclear	No	Possible	Unknown	Possible
India	No	No	No	Yes	In development	Possible in principle (but no first use)
Pakistan	Yes	Yes	No	Planned	In development	Possible
Democratic People's Republic of Korea	No	Unclear	No	Planned	In development	Possible

Abbreviation: NATO, North Atlantic Treaty Organization.

39. Certain strategies arguably increase the risk of nuclear use. Forward-deployed nuclear weapons increase the risk that, in conflict, these weapons might become vulnerable to attack and might thus be used in order to avoid their destruction. First-use doctrines carry the risk that an otherwise conventional conflict will escalate to include the use of nuclear weapons. Having weapons on high alert makes it more likely they will be used quickly, with only incomplete information available, or inadvertently. It is important to note that most weapons on high alert are intercontinental ballistic missiles, which, once launched, cannot be recalled. Furthermore, the risk of intentional use becomes prominent when a State makes threats involving nuclear weapon use. Nuclear-armed States overtly and inadvertently made such threats in the past.

Recent threats to use nuclear weapons

40. In 2017, the war of words between the then President of the United States, Donald Trump, and the Leader of the Democratic People's Republic of Korea, Kim Jong Un, along with accompanying missile tests and new nuclear weapons development, led to a situation in which rhetorical threats to use nuclear weapons – generally, rather than specifically – reached a point at which many in the United States and the Pacific region were deeply concerned about the possibility of nuclear use.[34] At the height of the crisis, the emergency alert system in Hawaii sent messages in error through television, radio and mobile telephones at 8.07 a.m. on 13 January 2018. In messages, the population was told that missiles were inbound and it should seek immediate shelter. It was emphasized that it was not a drill. It took more than a half hour for people to be informed that it was a mistake.[35]

[34] Peter Baker and Choe Sang-Hun, "Trump threatens 'fire and fury' against North Korea if it endangers U.S.", *New York Times,* 8 August 2017; Nuclear Threat Initiative, The CNS North Korea Missile Test Database, available at www.nti.org/analysis/articles/cns-north-korea-missile-test-database; and United States, Office of the Secretary of Defense, "Nuclear posture review", 2018.

[35] Jill C. Gallagher, "Emergency alerting: false alarm in Hawaii", Congressional Research Service, 17 January 2018.

41. At any time, such an erroneous message could cause panic and consternation among the population. However, because of the increasing political tensions between the United States and the Democratic People's Republic of Korea, many people believed the above-mentioned message to be correct. Apart from the anxiety that the message caused among the Hawaiian population, the incident illustrated the findings from the literature that perceptions of risk increase at times of crisis.[36]

42. In 2022, on the first day of the invasion by the Russian Federation of Ukraine, the President of the Russian Federation, Vladimir Putin, announced an immediate response to those trying to hinder the activities of the Russian Federation, with "consequences that you have never encountered in your history", which was widely perceived as a nuclear threat.[37] A week later, Mr. Putin ordered the Russian Federation to move nuclear forces to a "special mode of combat duty".[38] Further threats were issued by officials of the Russian Federation throughout 2022 and 2023.[39] In 2023, the Doomsday Clock, which is maintained by the *Bulletin of the Atomic Scientists* and set annually by its Science and Security Board as a public practice of risk assessment, was moved forward to 90 seconds to midnight, "largely (though not exclusively) because of the mounting dangers of the war in Ukraine [and] the closest to global catastrophe it has ever been".[40]

Thinking about risk

43. There are many ways in which to think about and estimate risk across known threats and hazards. The most common approach is to gauge risk as a product of the impact or consequence of an event and the probability of that event occurring. This equation works well with regard to many identified risks for which there is adequate information to estimate both factors. In addition, as more information is gathered, or as risk factors change over time, the consequences and the probabilities can be adjusted in the light of new knowledge. The risks of nuclear weapons are in a special category, since all risks of nuclear weapons use are beyond the limits of acceptability. In times of low conflict, it is assumed there is a low probability of nuclear use. However, even then, use would always have a high impact, which means that the impacts dominate the calculation. In times of conflict or high tension, the probability of use increases and thus the risks increase significantly.

44. There are in-built problems with approaching risks as a function of consequence and probability. First, poor understanding of the uncertainties associated with the estimates can lead to either a false sense of security and an underinvestment in mitigation or to an overestimate of risk and a subsequent waste of time and money. Second, in some cases, available data are insufficient to provide a sufficiently accurate estimate of the probability factor in the equation. This is a severe problem when applying the consequence/probability framework to assess the risk of high-consequence events of unknown probability, such as the use of nuclear weapons in conflict. Humans often do a poor job of not only assessing probability but also using it as the basis for decision-making.[41] In addition, with respect to nuclear weapons, assessments

[36] Beyza Unal and others, *Uncertainty and Complexity in Nuclear Decision-Making* (London, Royal Institute of International Affairs, 2022).

[37] Andrew Osborn and Polina Nikolskaya, "Russia's Putin authorizes 'special military operation' against Ukraine", Reuters, 24 February 2022.

[38] Andrew Roth and others, "Putin signals escalation as he puts Russia's nuclear force on high alert", *The Guardian*, 28 February 2022.

[39] Claire Mills, "Russia's use of nuclear threats during the Ukraine conflict", Commons Library Research Briefing, No. 9825 (House of Commons Library, 2023).

[40] John Mecklin, ed., "A time of unprecedented danger: it is 90 seconds to midnight – 2023 doomsday clock statement", *Bulletin of the Atomic Scientists*, 24 January 2023.

[41] Amos Tversky and Daniel Kahneman, "Judgement under uncertainty: heuristics and biases", *Science*, vol. 185, No. 4157 (1974).

of probabilities and consequences are usually focused on first use and thus discount the risk of both intentional and unintentional escalation to additional nuclear use.

45. At the four Conferences on the Humanitarian Impact of Nuclear Weapons (held in Oslo in 2013; Nayarit, Mexico, in 2014; Vienna in 2014; and Vienna 2022), the international community was engaged in a major effort to develop a new, deeper shared understanding of the available evidence and the arguments regarding the risks and humanitarian impacts of nuclear weapons.[42]

46. In 2017, the United Nations Institute for Disarmament Research published a study on understanding nuclear weapon risks, detailing and organizing nuclear weapon risks and related analysis. It was highlighted that the study did not "catalogue all relevant risks", noting that "uncertainty continues to plague existing understanding of nuclear weapon risks" and most fundamentally that "risk is an inherent characteristic of nuclear weapons".[43]

47. In a study on risk analysis methods for nuclear war and nuclear terrorism, mandated by the United States Congress in 2020 and launched by the National Academies of Sciences, Engineering, and Medicine of the United States in 2021, four key questions germane to the risks associated with nuclear weapons were identified:[44]

(a) What can happen? Specifically, what can go wrong?

(b) How likely is it that these events will happen?

(c) If these events happen, what are the potential consequences?

(d) What is the time horizon in which these events might happen?

48. In a report by the National Academies of Sciences, Engineering, and Medicine, it was pointed out that "risk analysis can be a powerful tool for clarifying assumptions; structuring and systematizing thinking about complex, interrelated factors; describing uncertainties; and identifying what further evidence or information might be needed to inform the decisions to be made".[45]

49. Comparative risk tables are helpful to decision makers in deciding on priorities and investments in mitigation and resilience. Risks can be indexed according to acknowledged levels of confidence and proposed mitigation and resilience responses and compared across sectors. It is important to recognize that risks change over time and cannot be seen as static. For example, new military doctrines, changing demographics and new technologies influence risk. Perception of risk changes when new information is revealed that was previously unknown, with different priorities, new situations and new capabilities.

50. Risk analysis involves other pitfalls, including: (a) discounting some high-value scenarios in the mistaken belief that they are highly improbable; (b) false triangulation – believing information to be based on independent sources, when in fact it is not; (c) poor understanding of the uncertainties, complexities and decision pathways; (d) false assumptions leading to inappropriate priorities and overconfidence; and (e) marginalizing the values and objectives of individuals and

[42] For two conferences, the Government of Austria still keeps conference material online, available at www.bmeia.gv.at/en/european-foreign-policy/disarmament/weapons-of-mass-destruction/nuclear-weapons.

[43] John Borrie, Tim Caughley and Wilfred Wan, eds., *Understanding Nuclear Weapon Risks* (United Nations Institute for Disarmament Research (UNIDIR), 2017).

[44] National Academies of Sciences, Engineering, and Medicine, *Risk Analysis Methods for Nuclear War and Nuclear Terrorism* (Washington, D.C., National Academies Press, 2023).

[45] Ibid.

communities that do not participate fully and equally in the risk analysis process, but that are subject to the consequences of risk decisions.

V. Humanitarian consequences of nuclear weapons use and testing

51. In the Treaty on the Prohibition of Nuclear Weapons, the catastrophic humanitarian consequences that would result from any use of nuclear weapons, as well as the unacceptable harm to and suffering of individuals affected by nuclear weapon testing, are recognized. The Treaty provides highlights of the disproportionate impacts of nuclear weapons on Indigenous Peoples and women and girls, as well as the possible impact of such weapons on future generations. Also recognized in the Treaty is the imperative for addressing environmental contamination owing to the testing or use of nuclear weapons.

52. In the present section, current scientific knowledge of the humanitarian consequences of nuclear weapons use and testing is discussed. Some open questions are identified for future scientific research that would support the goals of the Treaty on the Prohibition of Nuclear Weapons and its implementation.

Consequences of nuclear weapons use

53. In Japan, the bombings of the cities of Hiroshima and Nagasaki on 6 and 9 August 1945, respectively, released explosive energies estimated at 16 and 21 kiloton equivalent of TNT, respectively.[46] There remain uncertainties as to the number of deaths from the intense heat generated by the nuclear fireball, blast injuries and exposure to ionizing radiation – the estimates vary by a factor of about two. Early United States military estimates suggested that about 110,000 people died in the two cities, while in later independent research, 210,000 deaths were estimated.[47] The immediate physical impact was the near total destruction of urban infrastructure and widespread fires extending to kilometre distances. A modern thermonuclear weapon, typically with a yield of hundreds of kilotons equivalent of TNT, exploded on an urban target would produce blast damage and prompt radiation effects and ignite a firestorm extending to much larger distances. For such weapons, the firestorm would extend significantly farther than the blast and would prompt lethal radiation effects.

54. Many of the studies of the longer-term effects of ionizing radiation on the human body have relied on studying survivors of the above-mentioned bombings in Japan, the hibakusha.[48] In the studies, the radiation dose received by individuals has been considered on the basis of their location at the time of the explosion, and it has been suggested that radiation exposure increased the risk of cancers and other non-cancer diseases (cataracts, heart disease and stroke, among others). Furthermore, the percentage of cancer deaths attributable to radiation increases with dose, and there

[46] John Malik, "The yields of the Hiroshima and Nagasaki nuclear explosions", No. LA-8819 (Los Alamos, New Mexico, Los Alamos National Laboratory, 1985).

[47] Alex Wellerstein, "Counting the dead at Hiroshima and Nagasaki", *Bulletin of the Atomic Scientists*, 4 August 2020.

[48] Dennis Normile, "Aftermath", *Science*, vol. 369, No. 6502 (2020).

are higher risks for younger individuals and women.[49] There remain open questions about the social and psychological impacts of radiation exposure on individuals with the passage of time after the initial exposure.

55. Decades of scientific studies based on an improved understanding of nuclear weapon effects, prevailing nuclear weapon doctrines and known military, industrial, political and demographic targets suggest that a nuclear war could lead to tens of millions of immediate casualties.[50] It would be impossible to meet the medical needs of the tens of millions of injured people.[51] Casualties would not be limited to areas near the intended targets, as explosions aimed at destroying hardened military structures could lead to lethal doses from radioactive fallout received by population centres hundreds of kilometres away.[52]

56. Beginning in the 1980s, scientists proposed that nuclear war could cause hemispheric or global-scale cooling of the atmosphere, a phenomenon known as "nuclear winter". Weapons exploding in or near cities, industrial complexes or forests cause extensive fires, producing enough heat and smoke to inject large amounts of soot into even the stratosphere, where it absorbs a significant amount of incoming solar radiation and has a residence time on the order of several years.[53] This causes a significant decrease in near-surface temperatures over at least one hemisphere, leading to widespread failure of crops and dramatic reductions in the availability of food.

57. A recent study using a state-of-the art climate model showed that stratospheric injection of between 5 million and 150 million metric tons of soot could result from conflicts ranging from limited to full-scale nuclear war between the United States and the Russian Federation. The resulting change in surface temperatures would lead to mass food shortages in almost all countries in the full-scale nuclear war scenario. In the study, it is estimated that between 250 million and 5 billion people could starve to death.[54] Injection of 150 million metric tons of soot would also cause massive changes in global ocean circulation and chemical composition, as well as in marine ecosystems, probably lasting decades near the surface and hundreds of years in the

[49] Kotaro Ozasa and others, "Studies of the mortality of atomic bomb survivors, report 14, 1950-2003: an overview of cancer and noncancer diseases", *Radiation Research*, vol. 177, No. 3 (2012); Eric J. Grant and others, "Solid cancer incidence among the life span study of atomic bomb survivors: 1958–2009", *Radiation Research*, vol. 187, No. 5 (2017); Yukiko Shimizu and others, "Radiation exposure and circulatory disease risk: Hiroshima and Nagasaki atomic bomb survivor data, 1950–2003", *BMJ*, vol. 340 (2010); Evan B. Douple and others, "Long-term radiation-related health effects in a unique human population: lessons learned from the atomic bomb survivors of Hiroshima and Nagasaki", *Disaster Medicine and Public Health Preparedness*, vol. 5, No. S1 (2011); and Mary Olson, "Disproportionate impact of radiation and radiation regulation", *Interdisciplinary Science Reviews,* vol. 44, No. 2 (2019).

[50] Sidney D. Drell and Frank von Hippel, "Limited nuclear war", *Scientific American*, vol. 235, No. 5 (November 1976); Frank N. von Hippel and others, "Civilian casualties from counterforce attacks", *Scientific American*, vol. 259, No. 3 (September 1988); and Matthew G. McKinzie and others, *The U.S. Nuclear War Plan: A Time for Change* (Washington, D.C., Natural Resources Defense Council, 2001).

[51] Fred Solomon, Robert Q. Marston and Lewis Thomas, eds., *The Medical Implications of Nuclear War* (Washington, D.C., National Academies Press, 1986).

[52] Sébastien Philippe and Ivan Stepanov, "Radioactive fallout and potential fatalities from nuclear attacks on China's new missile silo fields", *Science and Global Security*, vol. 31, Nos. 1–2 (2023).

[53] Richard P. Turco and others, "Nuclear winter: global consequences of multiple nuclear explosions", *Science*, vol. 222, No. 4630 (1983); National Research Council, *The Effects on the Atmosphere of a Major Nuclear Exchange* (Washington, D.C., National Academies Press, 1985); and A. Barrie Pittock and others, *Environmental Consequences of Nuclear War, SCOPE 28*, vol. 1: Physical and Atmospheric Effects (New York, John Wiley and Sons, New York, 1986).

[54] Lili Xia and others, "Global food insecurity and famine from reduced crop, marine fishery and livestock production due to climate disruption from nuclear war soot injection", *Nature Food*, vol. 3, No. 8 (2022).

deep ocean. It is projected that sea ice could spread into some populated coastal areas for perhaps thousands of years.[55]

58. These recent assessments recognize that a more complete understanding of the broader implications of nuclear war for the planet's human population, environment, ecosystems and species is needed. This includes assessing how societies, crops, natural ecosystems and insect communities, including pollinators, would react to a sudden sustained decrease in temperature, as well as changes in surface ozone, ultraviolet radiation, precipitation and fresh water, and to radioactive contamination. There also is a need to better assess disruption of food distribution and trade after nuclear war and how individual and collective human behaviour might change.

59. In 2021, the United States Congress asked the National Academy of Sciences of the United States to "review the potential environmental effects and socio-economic consequences that could unfold in the weeks-to-decades following nuclear wars, exploring scenarios ranging from small-scale regional nuclear exchanges to large-scale exchanges between major powers".[56] Recently, a few research groups in Europe and North America began to carry out a similar interdisciplinary study.[57] Comprehensive new assessments are needed to complement these studies and to investigate specifically the complex interaction between environmental and societal effects of nuclear weapon use.

60. A global scientific study on the climatic, environmental, physical and social effects in the weeks to decades following nuclear war, mandated in a General Assembly resolution, would be timely and useful. There has been no such United Nations-mandated study in more than 30 years. The three precedents for Assembly resolutions and studies on the effects of nuclear weapons and nuclear war date from the 1960s, 1970s and 1980s. The most recent of these, carried out in accordance with Assembly resolution 40/152 G, was published in 1989 as a study.[58] A new, twenty-first-century study could be focused on the impacts on current local, national, regional and global socioeconomic and political systems, supply chains, health care, food and energy systems and natural ecosystems. It could also analyse whether and how the interactions of these different physical, environmental and social effects over various timescales might lead to cascading humanitarian consequences. The study could potentially be completed in time for the first Review Conference of the Treaty on the Prohibition of Nuclear Weapons.

Consequences of nuclear testing

61. The development of nuclear arsenals has relied extensively on nuclear weapon testing, resulting in widespread dispersion of radioactive fallout and leading to environmental contamination and population exposures.[59] A total of 2,056 nuclear tests, with a combined yield of about 510 megatons of TNT equivalent, were

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[55] Cheryl S. Harrison and others, "A new ocean state after nuclear war", *AGU Advances*, vol. 3, No. 4 (August 2022).

[56] See the independent study on potential environmental impacts of nuclear war of the National Academies of Sciences, Engineering, and Medicine, available at www.nationalacademies.org/our-work/independent-study-on-potential-environmental-effects-of-nuclear-war.

[57] See the grant programmes on nuclear war research of the Future of Life Institute, available at https://futureoflife.org/grant-program/nuclear-war-research.

[58] *Study on the Climatic and Other Global Effects of Nuclear War* (United Nations publication, 1989).

[59] United Nations Scientific Committee on the Effects of Atomic Radiation, "Exposures to the public from man-made sources of radiation", in *Sources and Effects of Ionizing Radiation* (United Nations publication, 2000).

conducted between 1945 and 2017, including 528 atmospheric tests with a combined yield of about 440 megatons between 1945 and 1980.[60]

62. Nuclear weapons have been tested in Africa (nuclear testing by France in Algeria), Asia (nuclear testing by the Soviet Union in Kazakhstan, Novaya Zemlya, Turkmenistan and Uzbekistan; nuclear testing by China in western China; and nuclear testing by India, Pakistan and the Democratic People's Republic of Korea on national territory), Europe (nuclear testing by the Soviet Union in Ukraine and Russia), North America (nuclear testing by the United States and the United Kingdom in the continental United States) and Oceania (nuclear testing by the United Kingdom in Australia; and nuclear testing by France, the United Kingdom and the United States throughout the Pacific, including Kiribati, Marshall Islands and French Polynesia).

63. Estimates of the global collective radiation dose received by people as a result of atmospheric nuclear tests began with the pioneering work of Linus Pauling and Andrei Sakharov in the 1950s. A recent estimate suggests that several million people may eventually suffer serious harm from just the radioactive carbon-14 in the nuclear fallout from those tests.[61]

64. From the 1960s onward, the United Nations Scientific Committee on the Effects of Atomic Radiation estimated and re-estimated the cumulative effective radiation dose equivalent to the past, current and future population from nuclear testing.[62] The most recent such Scientific Committee assessment, made in 2000, pointed to a lack of systematic and comprehensive reconstruction of the impact of nuclear weapon testing on communities and individuals at the local and regional levels.[63]

65. Studies of communities living downwind of test sites have revealed evidence of increased risks for certain cancers and mental health disorders that are associated with the condition of living in or near contaminated areas. Some communities also experience loss of land and relocation, or the occupation of contaminated areas at or near the former test sites.[64] New research in the rapidly evolving field of epigenetics may significantly advance understanding of the health and environmental consequences of exposure to nuclear radiation beyond the level of genetic mutations, to include possible transgenerational effects.[65] A new assessment by the United Nations Scientific Committee on the Effects of Atomic Radiation leveraging two decades of additional scientific literature would be useful.

66. There are overlapping areas of scientific research between the Treaty on the Prohibition of Nuclear Weapons and the Comprehensive Nuclear-Test-Ban Treaty. They include source terms for nuclear explosions (the amount of radionuclides, along with their spatial and particle size distribution, following a particular explosion); atmospheric transport modelling and deposition of radionuclides; the reconstruction of sources from monitoring data; and technical knowledge and experience regarding

[60] Ibid. See also, Arms Control Association, "The nuclear testing tally", fact sheet, August 2023.

[61] Frank N. von Hippel, "The long-term global health burden from nuclear weapon test explosions in the atmosphere: revisiting Andrei Sakharov's 1958 estimates", *Science and Global Security*, vol. 30, No. 2 (2022).

[62] See A/5216, annex F: environmental contamination.

[63] United Nations Scientific Committee on the Effects of Atomic Radiation, "Exposures to the public from man-made sources of radiation", in *Sources and Effects of Ionizing Radiation* (United Nations publication, 2000).

[64] Yuliya Semenova and others, "Mental distress in the rural Kazakhstani population exposed and non-exposed to radiation from the Semipalatinsk nuclear test site", *Journal of Environmental Radioactivity*, vol. 203 (July 2019).

[65] Nele Horemans and others, "Current evidence for the role of epigenetic mechanisms in response to ionizing radiation in an ecotoxicological context", *Environmental Pollution*, vol. 251 (August 2019); and Matt Merrifield and Olga Kovalchuk, "Epigenetics in radiation biology: a new research frontier", *Frontiers in Genetics*, vol. 4, No. 40 (April 2013).

contamination measurements. The approaches being used in on-site inspection activities related to the Comprehensive Nuclear-Test-Ban Treaty at test sites may also be useful in the context of the Treaty on the Prohibition of Nuclear Weapons. Working with the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization could strengthen the general technical capacity of States Parties to the Treaty on the Prohibition of Nuclear Weapons in the field of environmental radioactivity and with respect to the consequences of nuclear weapon explosions.

67. Research on the radiological and environmental legacy of nuclear testing at the local and regional levels would support the positive obligations of the Treaty on the Prohibition of Nuclear Weapons. Such research would benefit from improved capabilities for modelling the atmospheric transport of radionuclides.[66] The availability of high-quality atmospheric re-analyses covering the entire period of atmospheric use and testing now allows for detailed, regional-scale consequence modelling of past events.[67] Furthermore, historical ambient measurement data from nuclear-armed States are being declassified, and techniques for the investigation of environmental radioactive contamination have become more easily available and more sensitive.[68]

68. States parties to the Treaty on the Prohibition of Nuclear Weapons, other States and international organizations, such as the World Meteorological Organization and its members, possess legacy data from nuclear fallout-monitoring programmes during and after the period of atmospheric testing. Taking stock of and making these data easily accessible would be valuable. The data could be shared in a common public archive that could be managed by a United Nations body. This is another topic of common interest to States members of the Comprehensive Nuclear-Test-Ban Treaty.

69. New research on the capability of and best practices for providing assistance to victims of nuclear testing, including medical care, rehabilitation and psychological support, can complement studies on the humanitarian effects of testing. Further research to improve understanding of the different and disproportionate impacts of nuclear testing on age and gender, both at the individual level and with regard to social processes, would help to support victim assistance without discrimination.

[66] Roland Draxler and others, "World Meteorological Organization's model simulations of the radionuclide dispersion and deposition from the Fukushima Daiichi nuclear power plant accident", *Journal of Environmental Radioactivity*, vol. 139 (January 2015); C. Maurer and others, "Third international challenge to model the medium- to long-range transport of radioxenon to four Comprehensive Nuclear-Test-Ban Treaty monitoring stations", *Journal of Environmental Radioactivity*, vol. 255, No. 106968 (December 2022).

[67] H. Hersbach and others, "ERA5 hourly data on single levels from 1940 to present", Copernicus Climate Change Service, 2023; Sébastien Philippe, Sonya Schoenberger and Nabil Ahmed, "Radiation exposures and compensation of victims of French atmospheric nuclear tests in Polynesia", *Science and Global Security*, vol. 30, No. 2 (2022); and Sébastien Philippe and others, "Fallout from US atmospheric nuclear tests in New Mexico and Nevada (1945–1962)", ArXiv Preprint, 20 July 2023.

[68] Maverick K.I.L. Abella and others, "Background gamma radiation and soil activity measurements in the northern Marshall Islands", *Proceedings of the National Academy of Sciences*, vol. 116, No. 31 (2019); Carlisle E.W. Topping and others, "In situ measurements of cesium-137 contamination in fruits from the northern Marshall Islands", *Proceedings of the National Academy of Sciences*, vol. 116, No. 31 (2019); Cyler Conrad and others, "Anthropogenic uranium signatures in turtles, tortoises, and sea turtles from nuclear sites", *PNAS Nexus*, vol. 2, No. 8 (August 2023); K. Hain and others, "$^{233}U/^{236}U$ signature allows to distinguish environmental emissions of civil nuclear industry from weapons fallout", *Nature Communications*, vol. 11, No. 1275 (2020); Sarah Kamleitner and others, "^{129}I concentration in a high-mountain environment", *Nuclear Instruments and Methods in Physics, Research Section B: Beam Interactions with Materials and Atoms*, vol. 456 (October 2019); and G. Wallner and others, "Retrospective determination of fallout radionuclides and $^{236}U/^{238}U$, $^{233}U/^{236}U$ and $^{240}Pu/^{239}Pu$ atom ratios on air filters from Vienna and Salzburg, Austria", *Journal of Environmental Radioactivity*, vol. 255 (December 2022).

Studies are also needed to understand best practices and new options for providing equitable and sustainable social and economic inclusion for affected individuals in these communities.

70. Lastly, new research on the status of former nuclear test sites and on remediating radiologically contaminated environments, as well as assessments of relevant best practices, would provide significant support for efforts to meet relevant obligations and goals of the Treaty on the Prohibition of Nuclear Weapons. Such research could benefit from IAEA studies that are specific to the Treaty, using the best currently available technical methods. IAEA previously undertook radiological assessments at the nuclear test sites in Moruroa and Fangataufa (1998), Bikini (1998), Kazakhstan (1999) and Algeria (2005).[69] They were preliminary studies, following a 1995 resolution of the General Conference of IAEA, that were intended to provide expert assistance in assessing the radiation risks at these former test sites and to inform decisions on remediation. They offer an important precedent for an updated and more comprehensive IAEA analysis of relevant former test sites.

VI. Nuclear disarmament and related issues

71. The Treaty on the Prohibition of Nuclear Weapons advances and complements the complex set of international and regional treaties, agreements, practices, policies and institutions focused on the goal of achieving and maintaining a world free of nuclear weapons. It provides an enabling and transformative framework for additional steps and instruments for the cooperative, irreversible, verifiable and transparent elimination of nuclear weapons and weapons programmes.

72. In the present section of the report, scientific assessments relevant to the disarmament provisions of the Treaty on the Prohibition of Nuclear Weapons (article 4) and the recognition in article 8 of possible "further measures for nuclear disarmament" are discussed.

Disarmament verification

73. Article 4 (Towards the elimination of nuclear weapons) of the Treaty on the Prohibition of Nuclear Weapons provides an outline of various pathways for the verifiable elimination of nuclear weapons programmes. States Parties to the Treaty will need to grapple with a range of conceptual and practical issues relating to the irreversible and verifiable elimination of nuclear weapons programmes, including the elimination or irreversible conversion of all nuclear weapons-related facilities.[70]

74. Significant research on disarmament verification is being undertaken by nuclear weapons laboratories in nuclear-armed States and in partnership with allies. New initiatives are needed to expand the capacity of academic groups and research institutions to do this work, especially in States Parties to the Treaty on the Prohibition of Nuclear Weapons. Such centres can offer independent and fresh perspectives, unconstrained by nuclear weapons institutions and perspectives shaped

[69] The *Radiological Assessment Reports Series* of the International Atomic Energy Agency (IAEA) are available at www.iaea.org/publications/search/type/radiological-assessment-reports-series.

[70] Tamara Patton, "An international monitoring system for verification to support both the Treaty on the Prohibition of Nuclear Weapons and the Non-proliferation Treaty", *Global Change, Peace and Security*, vol. 30, No. 2 (2018); Moritz Kütt, "Weapons production and research", in *Toward Nuclear Disarmament: Building up Transparency and Verification*, Malte Göttsche and Alexander Glaser, eds. (Berlin, German Federal Foreign Office, 2021); and Tamara Patton, Sébastien Philippe and Zia Mian, "Fit for purpose: an evolutionary strategy for the implementation and verification of the Treaty on the Prohibition of Nuclear Weapons", *Journal for Peace and Nuclear Disarmament*, vol. 2, No. 2 (2019).

by United States-Soviet Union and United States-Russian Federation arms race and arms control treaty verification measures, which have assumed an adversarial nature, including concerns that cheating has occurred, that nuclear weapons would continue to be deployed by each side and that nuclear secrets are to be preserved. In addition, much of this research has been focused on technologies, procedures and capacities needed to verify agreed limits on the size of nuclear arsenals, warhead authentication and possible approaches to monitoring nuclear warhead dismantlement, rather than on the verification of the comprehensive, transparent and irreversible elimination of nuclear weapons programmes required in the Treaty.

75. Some academic research has been focused on new verification paradigms. One approach has been aimed at avoiding secrecy by using a zero-knowledge approach of not measuring any information that may currently be seen as sensitive, while another approach has been focused on verifying the absence of nuclear weapons.[71] Other ideas have included the concept of societal verification, suggested by Joseph Rotblat, in which non-governmental groups, citizens and scientists share the responsibility to support verification of their own State's actions, including through the sharing of open-source information and whistle-blowing.[72] A "Rotblat clause", making it the right and duty of every citizen to report possible activities prohibited in the Treaty on the Prohibition of Nuclear Weapons and protecting those who do so, could be an important part of the verification plan and national implementation legislation of States Parties to the Treaty covered in article 4.[73] It would provide a set of measures to complement any international authority, democratize verification and aid in irreversibility.

76. Limited efforts exist to build capacity in countries in the global South and to foster regional approaches to nuclear disarmament verification research and innovation in Africa, Central Asia and Latin America.[74] More such efforts are needed. Brazil has proposed that a United Nations-led multilateral group of scientific and technical experts be established to advance nuclear disarmament verification.[75] If such a group were to be established, it would be important to develop a relationship

[71] Alexander Glaser, Boaz Barak and Robert J. Goldston, "A zero-knowledge protocol for nuclear warhead verification", *Nature*, vol. 510 (2014); Sébastien Philippe and others, "A physical zero-knowledge object-comparison system for nuclear warhead verification", *Nature Communications*, vol. 7, No. 12890 (2016); UNIDIR, "Evidence of absence: verifying the removal of nuclear weapons", 2018; Pavel Podvig and others, *Menzingen Verification Experiment: Verifying the Absence of Nuclear Weapons in the Field* (Geneva, United Nations Institute for Disarmament Research, 2023); Eric Lepowsky, Jihye Jeon and Alexander Glaser, "Confirming the absence of nuclear warheads via passive gamma-ray measurements", *Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 990 (February 2021); Eric Lepowsky and others, "Ceci n'est pas une bombe: lessons from a field experiment using neutron and gamma measurements to confirm the absence of nuclear weapons", *Science and Global Security* (2023); and Johannes Tobisch and others, "Remote inspection of adversary-controlled environments", *Nature Communications*, vol. 14, No. 6566 (2023).

[72] Joseph Rotblat, "Societal verification", in *A Nuclear-Weapon-Free World: Desirable? Feasible?*, Joseph Rotblat and others, eds. (Boulder, Colorado, Westview Press, 1993); Marvin Miller and others, "Societal verification", in *Global Fissile Material Report 2009: A Path to Nuclear Disarmament* (Princeton, New Jersey, International Panel on Fissile Materials, 2009); Harold A. Feiveson and others, *Unmaking the Bomb: A Fissile Material Approach to Nuclear Disarmament and Non-proliferation* (MIT Press, 2014); and Sara Al-Sayed, "Revisiting societal verification for nuclear non-proliferation and arms control: the search for transparency", *Journal for Peace and Nuclear Disarmament*, vol. 5, No. 2 (2022).

[73] Zia Mian, Tamara Patton and Alexander Glaser, "Addressing verification in the Nuclear Ban Treaty", *Arms Control Today*, vol. 47 (June 2017).

[74] Noel Stott, "Regional hubs for research and capacity-building on nuclear disarmament verification", VERTIC, 10 September 2022.

[75] A/74/90, para. 39.

with the planned network of scientific and technical institutions and experts in support of the goals of the Treaty on the Prohibition of Nuclear Weapons.

Disarmament and safeguards

77. In article 4 of the Treaty on the Prohibition of Nuclear Weapons, the conclusion of safeguards agreements with IAEA is required to provide credible assurance of the non-diversion of declared nuclear material from peaceful nuclear activities and of the absence of undeclared nuclear material or activities in the State as a whole. It should be noted that, while 134 non-weapon States have both comprehensive safeguards agreements and additional protocols in force, agreements on limited IAEA measures are in place in some nuclear-armed States.[76]

78. India, Israel and Pakistan have in force safeguards agreements based on INFCIRC/66/Rev.2. India has an additional protocol to its INFCIRC/754 safeguards agreement in force. China, France, the Russian Federation, the United Kingdom and the United States have voluntary offer safeguards agreements and additional protocols in force.[77] European Atomic Energy Community safeguards are also in place in France, as well as previously in the United Kingdom. All these measures provide a basis for IAEA to begin to develop approaches and measures to expand existing safeguards systems specifically to be applicable to States that have eliminated their nuclear weapons and weapons programmes in the context of the Treaty on the Prohibition of Nuclear Weapons.

Verification beyond nuclear materials

79. As noted by the Group of Governmental Experts, nuclear disarmament is “a complex undertaking, the verification of which will require addressing a range of political, legal, scientific, technical and institutional issues”.[78]

80. With regard to the Treaty on the Prohibition of Nuclear Weapons, verification can take advantage of a nuclear-armed State’s systematic and cooperatively agreed transformation into a country that is transparently and irreversibly in compliance with its obligations under Treaty.[79] It is in a context of national debates and decisions remaking national security priorities, institutions, practices and ideas that a former nuclear-armed State would cooperate with States Parties to the Treaty and a Treaty-designated competent authority or authorities for the purpose of verifying the irreversible elimination of its nuclear weapons programme.

81. A disarming State would demonstrate domestically and internationally, through the design and implementation of its verifiable, time-bound disarmament plan, the profound and very practical political, legal, military, institutional, social and technological material reforms that it is undertaking to adhere to the principles and prohibitions of the Treaty on the Prohibition of Nuclear Weapons. These reforms would necessarily have concrete implications for irreversibility that could be assessed by third parties.

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[76] IAEA, “Safeguards statement for 2022”, 2023; IAEA, “Status list: conclusion of safeguards agreements, additional protocols and small quantities protocols”, 3 May 2023; and IAEA, *Annual Report 2021* (Vienna, 2022).

[77] See William Walker and others, “International safeguards in the nuclear weapon States”, in *Global Fissile Material Report 2007: Developing the Technical Basis for Policy Initiatives to Secure and Irreversibly Reduce Stocks of Nuclear Weapons and Fissile Materials* (Princeton, New Jersey, International Panel on Fissile Materials, 2007).

[78] See A/78/120.

[79] Sébastien Philippe and Zia Mian, “The TPNW and nuclear disarmament verification: shifting the paradigm”, in *Verifying Disarmament in the Treaty on the Prohibition of Nuclear Weapons*, Pavel Podvig, ed. (Geneva, UNIDIR, 2022).

82. Basic concepts such as irreversibility, conversion and the definition of nuclear weapons programmes require further technical research and analysis. Scientific activities should be undertaken to develop a repertoire of active and public disarmament measures that go beyond approaches that are focused on nuclear warheads and nuclear weapon materials to show national populations and the international community the scope of the public renunciation and enduring transformation of the institutions, technologies, investments and capabilities that had allowed a State to be nuclear-armed.

Lessons from past verification initiatives

83. Many lessons can be learned from past and current monitoring and verification initiatives, including the measures under the Strategic Arms Reduction Treaty (START Treaty), the new START Treaty and the Intermediate-Range Nuclear Forces Treaty (INF Treaty), as well as from States that have renounced nuclear weapons, and from limited experience with safeguards in nuclear-armed States.

84. South Africa is the only country that had a nuclear weapons programme and disarmed. Detailed case studies of the disarmament plan of South Africa to identify key success factors for verifiable and irreversible disarmament would be useful. The process through which both Kazakhstan and Ukraine returned Soviet nuclear warheads to the Russian Federation for elimination is also instructive for States Parties to the Treaty on the Prohibition of Nuclear Weapons. An important aspect of verifying nuclear disarmament is the elimination of the infrastructure to test nuclear weapons. A deeper understanding of the experience of Kazakhstan in closing the Semipalatinsk nuclear test site, eliminating the infrastructure and dealing with the consequences of nuclear weapon tests would be valuable.

Disarmament and delivery systems

85. The Treaty on the Prohibition of Nuclear Weapons does not demarcate the scope of nuclear weapons programmes for the purpose of their elimination, and delivery systems are not explicitly addressed in the Treaty. It is notable that, in the preamble to the Treaty, the elimination of nuclear weapons and the means of their delivery are called for. The Missile Technology Control Regime and the Hague Code of Conduct against Ballistic Missile Proliferation reflect enduring concerns about delivery systems.

86. Most bilateral nuclear arms control treaties (the START Treaty and the new START Treaty, for example) have been focused on regulating delivery systems. The 1987 Intermediate-Range Nuclear Forces Treaty between the United States and the Soviet Union prohibited land-based ballistic and cruise missiles with ranges of between 500 and 5,500 km that could carry either nuclear or conventional warheads and required destruction of the missiles, their launchers and support structures, and related equipment. The Intermediate-Range Nuclear Forces Treaty eventually collapsed in 2019. As part of the elimination of its nuclear weapons programme, South Africa ended its ballistic missile development programme and destroyed under supervision the associated key hardware, installations, blueprints and technical files.

87. Nuclear-armed States develop, certify and deploy dedicated nuclear weapon delivery systems, but there are also delivery systems with dual-purpose capabilities enabling them to have nuclear or conventional missions. Restrictions on nuclear weapon certified and dual-capable delivery systems may be considered under “further measures for nuclear disarmament” detailed in article 8 of the Treaty on the Prohibition of Nuclear Weapons. It is foreseeable that nuclear-armed States may need to dismantle such delivery systems as part of their irreversible disarmament obligations under the

Treaty. There are few examples of recent scholarly work on the verification of delivery systems in the context of disarmament.[80] Such work could be expanded in the future.

Comprehensive Nuclear-Test-Ban Treaty

88. In the Treaty on the Prohibition of Nuclear Weapons, the importance of the Comprehensive Nuclear-Test-Ban Treaty and its verification regime is recognized. Almost all current States parties to the Treaty on the Prohibition of Nuclear Weapons are parties to the Comprehensive Nuclear-Test-Ban Treaty and therefore part of the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization. Data from the International Monitoring System of the Preparatory Commission and analyses from the International Data Centre of the Preparatory Commission are available to them and may be used and interpreted by them, as deemed appropriate. Even though the Comprehensive Nuclear-Test-Ban Treaty is not yet in force, its verification system, with the exception of on-site inspections, is in provisional operation mode, with 90 per cent of the monitoring stations operational.

89. States Parties to the Treaty on the Prohibition of Nuclear Weapons should make best use of the opportunities offered by the Comprehensive Nuclear-Test-Ban Treaty, such as through training and scientific workshops and by sending experts to Working Group B of the Preparatory Commission, dealing with verification issues. Scientific forums that may serve as an exchange platform include the Science and Technology conferences of the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization and the future network of scientific and technical research institutions and experts in support of the goals of the Treaty on the Prohibition of Nuclear Weapons.

VII. Conclusion

90. The present report constitutes the first report of the Scientific Advisory Group on the status and developments regarding nuclear weapons, nuclear weapon risks, the humanitarian consequences of nuclear weapons, nuclear disarmament and related issues in accordance with the Group's mandate. It is anticipated that the Group will produce further reports that will update, augment and build on the topics addressed in more detail, in addition to others, as required.

[80] Alexander Glaser and Moritz Kütt, "Verifying deep reductions in the nuclear arsenals: development and demonstration of a motion-detection subsystem for a 'Buddy Tag' using non-export controlled accelerometers", *IEEE Sensors Journal*, vol. 20, No. 13 (2020); Moritz Kütt, Ulrich Kühn and Dmitry Stefanovich, "Remote monitoring: verifying geographical arms limits", *Bulletin of the Atomic Scientists*, vol. 79, No. 1 (2023); and Pavel Podvig, ed., *Exploring Options for Missile Verification* (Geneva, UNIDIR, 2022).