The Hague Centre for Strategic Studies

The Future of CBRN

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Executive Summary

HCSS mapped and analysed the debate on the potential future use of chemical, biological, radiological and nuclear (CBRN) materials in the security and safety domain in the next five to fifteen years. It examined over 120 key documents published in the last decade by authoritative governmental and non-governmental sources, including military institutions, treaty organisations, think-tanks, and universities. The analysis considers the technological and geopolitical aspects of the production, proliferation and actual use of CBRN materials as weapons. In addition, it examines the capacities and potential intentions of state and non-state actors.

Five key observations have emerged with respect to the focus, substance and nature of the CBRN literature:

- The literature tends to focus heavily on the future of biological weapons;
- The literature predominantly discusses the consequences of a CBRN attack as the result of malicious intent;
- Furthermore, there is a strong bias towards describing worst-case scenarios, while CBRN events with a lesser impact tend to be ignored.
- A significant gap exists between the scientific and the policy wonk community. There is little authoritative work that incorporates both geopolitical and scientific/technological dimensions of the debate on the future of CBRN weapons. While scientists tend to focus narrowly on technological details, policy wonks tend to discuss the broader picture without conveying any real understanding of the technological fundamentals underlying it.
- Many authors extrapolate from the present when talking about actor's intentions, the proliferation of materials and the future of dual use technology, despite the fact that there is a significant degree of uncertainty surrounding the impact of revolutions in the field of bio- and nanotechnology, and how these may affect, amongst other things, types of agents, ease of production and magnitude of effects.

Within this context and given some of the aforementioned caveats, a number of conclusions may be drawn with respect to future developments in the field of science and technology, materials, intentions and capabilities.

With respect to science and technology, the literature foresees:
- An increasing convergence of chemistry and biology;
- Tremendous advances in understanding and manipulating genes, cells, and organisms;
- Developments in field of nanotechnology that may revolutionise dispersal methods.

With respect to materials, the literature foresees:
- An increasing availability of CBRN materials;
- The potential to engineer (CB) materials from scratch;
- A growth in the number of dual use materials and technology that may pose major challenges to non proliferation regimes.

With respect to intentions, the literature foresees:
- A persistent intention on the part of state actors to to acquire (new types of) CBN capabilities;
- A persistent intention on the part of non-state actors to acquire (new types of) CBRN capabilities and in some cases an explicit desire to use these capabilities.

With respect to capabilities, the literature foresees:
- Significantly fewer hurdles to state actor CBRN acquisition as a result of knowledge diffusion and economic globalisation;
- Fewer hurdles to non-state actor CBRN acquisition, although these will continue to exist;
- The emergence of a distinction between future and traditional BCW, with the former the prerogative of state-actors while the latter may be within the reach of both state and non-state actors.

Overall, the literature seems to converge that in the 21st century, CBRN materials may be utilised and deployed as weapons in novel ways, both at the battlefield and in the civil domain, in times of war as well as in times of peace.

Introduction

Chemical, biological, radiological and nuclear (CBRN) weapons have been employed throughout the twentieth century: from the mustard gas (chemical weapon) used by both sides in World War I, the experiments with various types of biological agents conducted by Japan in the 1930s and 1940s in China, the nuclear bombs dropped by the US on Japan at the end of World War II, the chemical weapons (CW) used by Iraq against its own population in 1988 and the sarin gas (CW) dispersed in the subway system of Tokyo by the religious sect Aum Shrinikyo in 1995.[1] Yet, despite a handful of other examples, overall CBRN use at a large scale has been limited.[2]

States have dedicated significant attention and resources to countering the proliferation of CBRN weapons and preparing for the potential effects of CBRN attacks. Nonetheless, attaining or retaining CBRN weapon capabilities continues to be a priority for numerous state and non-state actors.

CBRN weapons are often lumped together under the header of weapons of mass destruction (WMD). This is odd, to say the least, given their different nature, both in terms of their make-up, ease by which they may be produced and potential for destruction. The material for chemical and biological weapons, for instance, is oftentimes readily available in the open market, yet the actual weaponisation and the effective dissemination of these agents, is the more tricky part, requiring technological knowhow that until now has largely eluded the capacity of non-state actors. In contrast to this, the key obstacle to attaining a nuclear capacity is attaining or mastering the production of the key materials – enriched uranium or plutonium – which, even in 2009, remains a significant hurdle to aspiring nuclear states. The weaponisation of these materials, although still requiring substantial technological expertise, is a somewhat lesser challenge – especially for state actors – with rough drawings for the construction of fission and fusion devices being available in the open literature.[3]

Similarly, C, B, R, and N weapons are often treated as functional equivalents with regards to their effects, despite the fact that they play very different roles in strategic doctrines of state and non-state actors. For example they may be designed as tactical weapons, geared towards applications on the battlefield or in the civil domain, or as strategic weapons that serve a deterrent value or can be used to wreak massive havoc. Further, their impact might be predominantly psychological (as in the case of some RW) or result in massive physical destruction (as in the case of NW).

The subject of CBRN weapons remains subject to continuing scrutiny and intense debate amongst policymakers, academics and military professionals. This assessment maps and analyses the debate on the potential future use of CBRN materials in the security and safety domain in the next five to fifteen years. It includes an in depth-analysis of over 120 key documents that were published over the last decade by authoritative governmental and non-governmental sources, including military institutions, treaty organisations, think-tanks, and universities. The assessment touches upon technological and geopolitical aspects of the production, proliferation and actual use of CBRN materials as weapons, and examines the capacities and potential intentions of state and non-state actors.

1 CBRN Weapons – Key Trends

1.1 Chemical Weapons

Chemical weapons (CW) come in many shapes and forms, with most conventional weaponry also relying on chemical explosives. CW, however, are distinct to the extent that they are understood to be 'non-living, manufactured chemical agents combined with a dispersal mechanism that, when activated, produce incapacitating, damaging or lethal effects on human beings, animals or plants.'[5] Chemical agents are dispersed in three different forms: gas, (solid) aerosol, or as a liquid, and are delivered through inhalation, ingestion, or absorption by the skin. Effects of such agents as blister, blood (cyanides), chocking (pulmonary), and nerve agents may surface immediately or only over the course of days.

State Proliferation, the Chemical Weapon Convention (CWC) and Challenges

Modern chemical weapons where first used on a large scale during World War I. Active research and development continued through the interwar years and World War II, although actual use was rather sporadic. The Cold War saw the development of extensive stockpiles of CW on both sides, and several developing countries successfully acquired CW capabilities. They were extensively used by the Iraqi forces under Saddam Hussein against Iran, as well as parts of their own population. The introduction of the Chemical Weapon Convention (CWC) in 1997 has significantly reduced existing stockpiles and there are a number of states that have declared CW stockpiles and have started their destruction under the rules of the convention, including the US, Russia, India, South Korea, Libya.[6]

Despite the fact that all state parties have committed to destroy their chemical weapon-stockpiles by 2012, some countries are behind schedule, most notably the US and Russia, and it is unlikely that they will be able to meet the deadline. There are a number of reasons for this delay, including insufficient funding, technical difficulties, CW-destruction related accidents resulting in increasing attention for public health issues, and lack of political will. It is also impossible for the Organisation for the Prohibition of Chemical Weapons (OPCW) to inspect every facility in the country to verify actual compliance and huge discrepancies exist in the depth and scope of implementation between the different state parties. Over half of the CWC member states have so far failed to provide the legal framework to regulate the import and export of chemicals and related technology, and in many countries no licensing regime is yet in place.

Furthermore, progress in the field of chemical materials and weapons disposal is behind schedule and (illegal) chemical weapon dumpsites, for instance at sea, pose an environmental hazard.[7] Finally, it should be remembered that while a very large number of states have signed the CWC, its membership is not universal. Some of the non-signatories as well as some of the signatory states are suspected of retaining a clandestine CW capability, including China, Iran, Egypt, Syria, and Israel.[8]

A further challenge arises from the huge amounts of chemical compounds that are continuously processed and transported around the globe in industries with a wide variety of purposes. Some of these chemicals are toxic and generally referred to in the literature as Toxic Industrial Chemicals (TICs).[9] The median lethal toxicity of TICs is between 10-100 times lower than that of CW agents, but as compared to ca. 70 existing CW agents there are approximately 70,000 different TICs, many of which are produced in great quantities and stored and transported around the world.[10]

The fact that large amounts of, in some cases, extremely dangerous chemical agents are produced and stored in relatively poorly secured civilian industrial facilities and routinely transported over long distances, creates a considerable, threefold risk:

- TICs might be released accidentally during transport, handling or storage.
- TICs transports or production sites might become targets of a attacks (particularly by non-state actors) aimed at releasing TICs into the environment
- TICs constitute a proliferation risk as particularly non-state actors might divert large amounts of dangerous chemical agents relatively easily and use the material as basis for a CW attack.

How devastating the impact of TICs can be, whether released intentionally or accidentally, was demonstrated by the Bhopal accident in 1984. The release of ca.

40 tons of methyl isocyanate (MIC) caused ca. 4.000 death in the immediate aftermath of the accidents and an estimated 20.000 more victims from the long-term consequences.[11] The magnitude of the threats from TICs can also be inferred from the fact that NATO classifies MIC only as a 'medium hazard' agent in its toxic industrial materials hazard index list.

The dual use nature of chemical materials and technology to weaponise these agents poses a challenge to the CWC regime. Whether the efforts to supplement the CWC with additional regimes, such as for instance the European project REACH (Registration, Evaluation, Authorisation, Restriction of Chemicals) will strengthen governmental oversight, remains for now to be seen.[12]

Chemical Terrorism

Universal adherence to and strict national implementation of the CWC are also deemed to be vital in meeting the threat of the use of toxic chemicals by terrorist organisations. In their absence, terrorist organisations will find it easier to acquire a chemical weapon capability. Nevertheless, it should be borne in mind that the CWC was not designed as a counter-terrorist convention. As such, the CWC focuses on the production of militarily significant quantities of chemical agents and not on smaller quantities which might be useful to terrorist organisations. Within the current verification regime, it is impossible to guarantee that a diversion of a kilogramme of quantities of key toxic chemicals will be detected.

Although the fabrication of advanced and effective CW will likely remain a technological challenge to non-state actors, the intent of non-state actors to use CW is certainly present. The Monterey WMD terrorism database reports both attacks and 'plot incidents', in which the perpetrators were able to acquire CW agents, but failed to use it. In a sample drawn from the Monterey WMD terrorism database from the period 1988-2004, 207 of the 316 CBRN incidents recorded involved CW.[13] Yet, these incidents mostly involve conventional explosives mixed with openly available chemicals to make them more deadly, or are failed attempts to weaponise chemical agents. The only attack that involved a standard CW agent – the Tokyo Sarin gas attacks by Aum Shrinikyo in 1995 – showed how difficult it is to mount an effective CW attack, even for an organisation with high levels of expertise and sufficient funding.

Technological Developments and Future Use of Chemical Materials

Rapid developments in science and technology have also complicated the nature of the work of the OPCW. The globalisation of chemical industry, with thousands of facilities spread all over the world, and many 'multipurpose batch facilities that can be readily switched from one product to another,'[14] is a challenge to any inspection regime and provides an increased logistical burden to the OPWC. The introduction of micro-reactors allowing for safe, small-scale production of chemical agents, which are easy to hide and thus more difficult to detect, create additional difficulties.[15]

A key trend in science and technology that is likely to affect the future of CW is the increasing convergence of chemistry and biology. This might result, among other things, in different synthesis routes to existent toxics and the possibility of new, laboratory-designed toxics. [16] Discoveries in nanotechnology offer additional possibilities to assist in dispersal methods.[17] States with a relatively weak knowledge base will be able to produce and effectively deploy advanced CW. However, the production and effective deployment of advanced CW will likely remain a considerable technological challenge to non-state actors, although according to some analysts not an insurmountable one.[18] Cruder ways of chemical agents' dispersal – such as currently practiced by Iraqi insurgents, who combine chlorine with conventional explosives, to name only one known example – may certainly belong to the realm of possibilities, especially within an asymmetric context.[19]

While usually discussed in the context of the future of BW, the biotech revolution has potentially similarly fundamental implications for the future of CW. To understand this, one only has to think of the fact that most drugs that will result from advanced biotechnology are likely to be chemical agents. Similar to future BW, future CW will profit from an advanced understanding of the biochemical processes in human bodies.[20]

This opens the possibility to develop advanced CW (ACW). Particularly, this has led to renewed interest by state actors to develop a specific class of ACW, which are usually variously described as non-lethal / less-lethal / advanced riot-control / immobilizing / incapacitating agents / capacities / technologies / techniques / devices, but never actually as ACW.[21] The reason for this diffuse and euphemistic labelling is to avoid the impression that these research programmes constitute a violation of the CWC, which bans CW R&D but explicitly allows for the development and deployment of riot control agents for law enforcement purposes.[22] The most extensive known state-led research programmes into ACWs are run by the US, Russia, and the Czech Republic. These programmes are often funded by the military and include research into advanced means of dispersal (e.g. grenades, mortar shells, smoke, paintball-like bullets, sponge-like bullets etc.).[23]

What this type of ACWs have in common is that (a) they aim to incapacitate, immobilise or render the target unconscious within seconds after exposure to minor doses, (b) their effects last for at least a few minutes or longer, (c) they intend to minimise the danger of lethal effects or permanent damage to the target and (d) they typically rely on advanced neuroscience which allows for an understanding and manipulation of complex chemical processes in the human brain.[24] In essence, law enforcement agencies and the military are looking for a powerful, non-lethal knock-out agent dispersed in different forms for wide-ranging application in 'peacekeeping missions; crowd control; embassy protection; rescue missions; and counter-terrorism', as well as 'hostage and barricade situations; crowd control; close proximity encounters, such as, domestic disturbances, bar fights and stopped motorists; to halt fleeing felons; and prison riots'.[25]

A good example of such agents is the powerful opiod fentanyl and its analogues. An aerosolised derivative of fentanyl, which has been extensively studied in the US as incapacitating agent, was used by Russian special forces to end the 2002 Moscow theatre siege. Fentanyl however also points to the risks of ACWs. Many of these supposedly 'non-lethal' agents are actually quite deadly: the lethality of the gas used in Moscow was higher than that of the CW agents used during WWI.[26] As a remedy, US researchers have suggested to combine fentanyl-based AWC with a delayed release of the antidote naloxone to lower mortality rates.[27] Nonetheless, it should be clear that these weapons are anything else than harmless 'sleeping gas'. A further indication of the dangers of fentanyl is its widespread use in the US as an illicit drug. It is produced by traffickers in illegal labs and goes under the street name 'Drop Dead', having literally resulted in the deaths of hundreds of drug users in the country.[28]

The fact that drug traffickers are able to produce and widely distribute an ACW agent in the US might also point to significant proliferation risks, as it suggests that terrorist networks might find it easy to get their hands on larger quantities of fentanyl or a comparable agent. The literature contains however little discussion on proliferation risks associated with ACWs or the difficulty of weaponising an ACW agent such as fentanyl. This may be due to the fact that descriptions such as 'non-lethal riot control agent' distract from the fact that terrorist groups might have considerable interests in such powerful agents.

1.2 Biological Weapons

Lindstrom defines a biological weapon (BW) as combining 'a biological warfare agent with a means of dispersing it. Biological warfare agents are micro-organisms such as viruses or bacteria that infect humans, livestock or crops and cause an incapacitating or fatal disease.'[29] They are delivered through ingestion, inhalation or through absorption by the skin. Symptoms of illness have a time lagged effect and appear after a period ranging from days to weeks. Biological agents, according to Lindstrom, are categorised in three different forms of micro-organisms: bacteria; viruses; and rickettsiae, fungi and toxins. The last category, toxins are sometimes also considered to be chemical agents as they are non-living poisons, although produced by living plants, insects and animals.

State Proliferation, the Biological Weapon Convention (BWC) and Challenges

Primitive biological warfare has been waged by humans since ancient times.[30] However, only in the 20th century the advent of modern medicine and biology allowed for the systematic development of a range of biological warfare agents and their weaponisation. Several countries manufactured and used experimental BW during WWI and WWII, even though with rather limited success.[31] Research and development of BW continued throughout the Cold War with US and the Soviet Union at the forefront, leading to the successful weaponisation of such deadly agents as anthrax or the smallpox virus.

The threat of BW was significantly reduced with the introduction of the Biological Weapons Convention (BWC) in 1972, which outlawed the development, use, and stockpiling of all BW and mandated their destruction.[32] Nonetheless, several countries, such as the Soviet Union or Iraq, are known to have continued extensive clandestine BW programmes, sometimes until well into the 1990s.[33] Despite recent successes in dismantling BW programmes (e.g. in Iraq or Libya), at least half a dozen countries around the world are suspected to retain at least some form of offensive BW capacity today.[34]There are several countries that have not ratified or signed the treaty, including Israel, Egypt, and Syria. The dangers from state-led BWs programmes have been reduced in recent years, but concerns remain over residual capacities and possible clandestine BW programmes. Worries about future proliferation focus mainly on non-state actors and the fact that advanced biotechnology is growing in an increasingly important part of the global economy, also in developing countries. The fundamentally dual-use character and accelerating diffusion of biotechnology leads to a mushrooming of actors with potential access to material, infrastructure and expertise needed to develop BW and even advanced BW (ABW).[35] This may include many developing countries and potentially even subnational actors. Non-proliferation efforts will also be challenged by the fact that potential BW programmes are likely to be very difficult to distinguish from legitimate biotechnology enterprises. These developments pose a fundamental challenge to the existing non-proliferation regimes for BWs.[36]

Biological Terrorism

In recent years, the debate around BWs and non-proliferation has increasingly focused on non-state actors, and terrorist groups in particular. At least 25 'distinct subnational actors' are known to have 'shown concerted interest' in acquiring BW, with at least eight of them known to have been successful.[37] The experiments of Aum Shrinikyo with Anthrax and Ebola, as well as the 2001 Anthrax attacks in the US are well-documented examples. If successfully deployed, a terrorist attack with BW could have devastating consequences, with 10 grams of anthrax spores being theoretically able to kill as many people as a ton of the nerve gas sarin, and 30 kg as many people as a nuclear bomb of the size used in Hiroshima.[38] Handling BW agents is obviously hazardous but obtaining them is considered relatively easy and very cheap in comparison to chemical or let alone nuclear weapons. However the key challenge for a non-state actor would be to effectively weaponise and deploy an agent, which demands extensive scientific and technological know-how. In most cases, this will make the use of BW by terrorist groups 'more difficult or less effective than most people realise'.[39]

Technological Developments and Future Use of Biological Materials

Many experts stress that dominant influence on the future of BW is likely to be the ongoing precipitous development of biotechnology. Advances in understanding and manipulating genes, cells, and organisms are reinforced through parallel revolutions in information and nanotechnology, as well as neurosciences. While many of these advances promise benign applications, the literature also suggests that future biotechnology may lead to dangerous new BWs.[40] At present, some biological agents are readily available in the natural environment, whereas others may be ordered through facilities that supply the market for civilian research. It is foreseen that the capacity to manufacture old and new biological agents from scratch will become more prevalent over the next decade. In the last decade, American scientists managed to recreate the 'Spanish Flu' influenza virus in this manner, but new –and more advanced– agents are expected to appear in due course.[41]

It has been suggested that the impact of biotechnological advances on future BWs can be summarised in three principal phases:[42]

- Enhanced counter measures will become available against the limited number of existing 'traditional' BW agents.
- It will become possible to enhance 'traditional' BW agents into more stable, more easily delivered, more contagious, and/or more lethal variants. Nonetheless, possibilities for manipulating 'traditional' BW agents are limited and countermeasures against these enhanced BWs will also eventually become available.
- Continuing advancements in biotechnology will make it eventually possible to design a large variety of 'advanced' BW (ABW) agents. These highly effective ABWs may target a wide range of different biological processes and be designed to create a very wide range of different effects.

It is the eventual possibility of creating ABWs that is particularly worrisome. Such ABWs might consist, e.g., of binary BW (where a second agent must be deployed to trigger the effects of the BW), malign gen therapy (where harmful genes are inserted into a target organism), or designer diseases (where a disease and its pathogen are engineered from scratch).[43] It has been suggested that the effects of such weapons could be very precisely tailored to the wishes of a user and, e.g., target specific ethnicities or mask the source of the attack, etc.[44] ABWs may also target plants or animals.[45] This threatens to create a 'diffuse and fundamentally unknowable'[46] range of potential BW agents and hence a 'diverse and elusive threat spectrum'.[47]

It is and will be within the reach of the majority of state actors, even those with less developed economies, to produce BWs. However, it is less clear whether all states will partake in the revolution in the biotechnology and nanosciences and create and produce ABWs. Similar to CWs, the effective weaponisation of biological agents may continue to pose a problem for non-state actors, depending on how widespread the fruits of the nanotechnology revolution will be reaped. Cruder and more traditional forms of the dispersion of biological agents –such as the poisoning of a well or through an infected individual, or other unforeseen ways– should obviously not be ruled out.

NAME	DESCRIPTION	POTENTIAL USE
BINARY BW	Two BW agents with the effects being triggered only when they are combined.	Binary BW could make handling of the weapon more easy and safe, because the agent becomes active only in the final stages of the attack, e.g. during the flight of a missile.
GENETICALLY MODIFIED BWS/ DESIGNER GENES	BWs that are enhanced with the help of genetic engineering, or even BWs that are genetically engineered from scratch.	Would principally allow for much more deadly and sturdy BWs (e.g., more resistant to heat or cold), make countermeasures ineffective (e.g., render pathogens resistant to antibiotics), circumvent nonproliferation regimes (e.g., by synthesizing outlawed pathogens) etc.
MALIGN GEN THERAPY	BWs that attack and modify the target organisms genome, possibly creating a wide range of harmful effects. Genetically engineered retroviruses could be an example.	Could cause damage from a BW hereditary, switch of the immune system, cause cancer etc.
STEALTH VIRUSES	BW that enter a target organism without discernible symptoms and then lie dormant, until activated by an external signal.	Would allow to deploy the BW without the target noticing that it has been attacked. An external signal could then 'switch on' deadly effects. Could be used as a tool for blackmail.
DESIGNER DISEASES	Basically a disease 'a la carte'. Desired symptoms, transmission channels, target populations, incubation times etc. are determined, and the respective pathogen is designed.	It has been suggested that designer diseases may affect specific ethnic groups, have long incubation times, or have a wide variety of other effects dependent on the specific needs of the attacker.

Table 1. POTENTIAL FUTURE BIOLOGICAL WEAPONS

1.3 Radiological Weapons

Radiological weapons (RW) combine radioactive material with a means of dispersing it among a target population, resulting in the inhalation or ingestion of, or immersion with, radioactive material. The resulting exposure to alpha and beta particles, gamma rays and neutrons produces incapacitating or lethal effects through external and internal radiation. Dispersal could take place through combining radioactive material with conventional explosives in a 'dirty bomb', by dispersing it in form of aerosols or liquids, or even by contaminating water or food supplies. The effects of RWs and the speed with which they manifest will vary considerably, depending on the type of radioactive material used, the length and form of exposure, and the countermeasures taken.[48]

A RW thus essentially relies on spreading hazardous radioactive material among a target population. While some R&D towards RWs was conducted during the Cold War, state actors have rarely developed RWs[49]–presumably preferring to concentrate their efforts on acquiring much more powerful and deadly nuclear weapons (NW). However, interest in RWs has increased in recent years as it has been claimed that they may constitute an attractive weapon for non-state actors with limited capacities and resources.[50] Far less destructive than a NW, an effective RW could nonetheless cause considerable casualties, widespread panic and disruption, as well as sizeable economic damage.[51]

Availability of Radioactive Material

Much of the argument for RWs as terrorists 'weapon of choice' has concentrated on the fact that acquiring radioactive material in sizeable quantities is thought to be relatively easy: different suitable isotopes are used in large quantities in various civilian applications around the globe, some of which lack strict monitoring or security arrangements as will be discussed more in depth in the section on NWs.[52] Radioactive material may also be obtained from the civilian nuclear fuel cycle, e.g. by harvesting it from widely used mixed oxide fuel (MOX), which is a relatively simple technical procedure.[53] The more potent the material and the greater the quantities acquired, the more hazardous it would become to transport and handle the material. However, it has been suggested that terrorist groups with a fanatical following with little regard for their own life might be willing to accept their own exposure to harmful radiation while preparing and executing an attack.[54]

Weaponising Radioactive Material

The typical example discussed in the literature for dispersing radioactive material in order to harm a target population is the so-called 'dirty bomb': a dirty bomb simply packs the radioactive material together with powerful conventional explosives. The explosion of the dirty bomb would then disperse particles of radioactive material over a large area. There are divergent opinions on effectiveness of a dirty bomb and much of it will depend on the force of the explosion, the type of radioactive material used, the particle-size of the dispersed material, weather conditions, counter measures etc. However, there seems to be a consensus that the amount of casualties would be relatively low and probably not reach the three figures.[55] Nonetheless, the repercussions of a RW are likely to be severe due to the large scale disruption of public life, an enormous stress on the health care system, extremely expensive clean-up operations, and the likelihood of a sizeable psychological impact.[56] While it isn't trivial to produce a dirty bomb with optimal particle size and dispersion pattern to maximise casualties, it is considerably simpler than constructing a nuclear device, as no fission or fusion reactions have to be triggered.

Experts have drawn attention to alternatives to dirty bombs in dispersing radioactive material. It has been suggested that a variety of approaches could be used to disperse fine particles amongst an, in most cases unwitting, target population, provoking it to inhale, ingest or to become immersed with radioactive matter. This could be achieved e.g. by radioactively contaminating water or food supplies, aerosolizing radioactive material or dissolving it in water which could be used to soak victims with it.[57] Such an approach could be considerably more dangerous than a dirty bomb if it is successful in getting victims to absorb radioactive material into their bodies, as miniscule amounts of radioactive material are likely to be lethal if ingested or inhaled.

In the aftermath of 9/11, a fervent discussion has ensued on the prospects of terrorist groups attacking civilian nuclear reactors in order to either seize dangerous radioactive material for the purpose of assembling a 'dirty bomb' or to sabotage the nuclear plant in order to cause the hazardous leakage of radioactive material. Experts seem to agree that the threat from using spent fuel rods in a RDD is relatively minor, paradoxically because of the fact that they are so dangerous: unshielded exposure to fuel rods is likely to cause a lethal radioactive dose in a very short time span and the extremely hot and heavy rods are difficult to manipulate, let alone to transport to a suitable target for detonation.[58]

A particular focus of the research has been the likely consequence of a commercial airplane deliberately being crashed into a nuclear power plant in an attack modelled after the 9/11 attacks.[59] It is relatively difficult to establish clear conclusions from these debates, as they involve intricate technical detail and have been highly politicised. Stakes are high as many experts are intimately connected to the nuclear industry and additional security measures can be immensely costly. Similarly, opponents of nuclear energy have used the debate to underline their argument that nuclear power plants constitute an incalculable security risk. It shouldn't be surprising then that the key findings have been very controversial. Positions range from those who contend that even the targeted impact of a fully fuelled commercial airliner on basic reactor security would be negligible,[60] to those who claim that it might result in a reactor meltdown and the release of radioactive material on a scale that very well could exceed that of Chernobyl.[61]

1.4 Nuclear Weapons

According to the Lexicon for Arms Control, nuclear weapons are explosive devices that are based on nuclear reactions. [62] Nuclear explosives are based on self-sustained nuclear reactions which transform the nuclear structure of atoms and in the process release great bursts of energy. These processes are characterised by either fission reactions or (more powerful) fission and fusion reactions. Devastating damage accrues through a combination of effects comprising a powerful blast wave, thermal radiation, and initial and residual radiation. Whether based on fission only (atomic bomb), or fission and fusion (hydrogen bomb), the assembly of nuclear weapons requires fissile material (typically highly-enriched uranium or plutonium) and substantial engineering expertise. It has been suggested that cruder 'improvised nuclear devices' (INDs) might also be constructed. If successful, the latter might compare to a smaller 'conventional' nuclear bomb. If failing to reach a critical mass for a self-sustained nuclear reaction, the impact might nonetheless compare to a gigantic conventional explosion and would include dangerous radiological fall-out.[63]

State Proliferation, Non-Proliferation Treaty (NPT) and Challenges

Developed and deployed first by American forces during World War II, NWs have become the epitome of WMD and symbol of ultimate destructive power. Around the mid-20th century, only a handful countries had managed to develop their own NWs, but today it is estimated that between 35-40 countries possess the knowledge and capacity to attain a nuclear capability in a relatively short time span.[64] In 2009 there exist nine states with a nuclear capability of some sort: US, Russia, UK, France, China, India, Israel, Pakistan and North Korea. Iran is suspected to seek a nuclear capability.

Only four states are not party to the principal nuclear Non-Proliferation Treaty (NPT) – India, Israel, North Korea, Pakistan. Nonetheless it has been argued that the NPT is plagued by a number of fundamental weaknesses. Foremost, a number of nuclear 'don't-haves', seem to be increasingly interested in acquiring NWs, especially since the nuclear 'haves' seem to do little to fullfil one of the key tenets of the treaty: giving up NWs.[65]

Furthermore, the prerogatives of the International Atomic Energy Agency (IAEA), the institution charged with the enforcement of the NPT, are limited. The IAEA is charged particularly with 'preventing diversion of nuclear energy from peaceful uses to NWs or other nuclear explosive devices.'[66] However the IAEA has only limited verification responsibilities and lacks clear authority to secure nuclear material, to install near-real-time surveillance devices at the sites it inspects, or to conduct the wide-area surveillance needed to monitor activities covered under the so-called Additional Protocol to the NPT. Neither can the IAEA prevent the indigenous weaponisation of states that are not signatory to the treaty.[67]

Furthermore, it is beyond the capacities of the IAEA to monitor the tremendous amounts of fissile material worldwide. Finally, the NPT features a three month withdrawal clause, allowing states to acquire technology and nuclear material under the auspices of the IAEA, and, having obtained this technology, withdraw from the treaty. Additional non-proliferation agreements and organisations cover the trade in dual use technologies, such as the Nuclear Suppliers Group.[68] Recent years have provided ample evidence about the existence of a thriving black market in nuclear materials and technology.[69] Materials traded are dual use goods and subcomponents for example for gas centrifuges, reactors, computer-numerically controlled machine tools, laser alignment systems and hot cell technology, among other things.[70] It is projected that concealing such technologies will be easier in the future.[71] The existence of poorly guarded nuclear facilities in the former Soviet Union continues to form a source of proliferation concern.[72]

Moreover, highly enriched uranium is not only found in military facilities, but is stored in civilian facilities in over 40 countries worldwide, where it is used for research purposes. Estimates of civilian HEU reactor material are in the range of 50 tons, which would be sufficient to produce 2,000 NWs.[73] Recent history is rife with examples of nuclear material that went missing and is unaccounted for until today.[74]

NWs continue to be seen by many states as playing a key role in the international balance of power and as a valuable instrument in the promotion of national security. The advent of one new nuclear state may thus create a momentum towards further proliferation, as neighbouring states are confronted with a worsened security situation that will drive them to attain a nuclear capability of their own.[75] Amongst potential proliferators are mentioned Egypt, Jordan, Saudi Arabia and Turkey, in the event that Iran goes nuclear, Japan and South Korea if North Korea goes nuclear, Syria to counter Israel, and Burma.[76]

The U.S. nuclear umbrella has dissuaded many allies from attaining a nuclear capability of their own. This is seen as a major factor in stemming proliferation.[77] If, for whatever reason – e.g. US isolationism or ruptures in US bilateral relations – states would lose their faith in the US protective umbrella, it may motivate them to go nuclear.[78] In the face of proliferation, existing nuclear powers may also resume nuclear testing to ensure the reliability of new weapon systems, further undermining the spirit of the NPT and the Comprehensive Test Ban Treaty (CTBT), with ample opportunities for international crises to erupt.[79]

Nuclear Terrorism

There are a number of reports of non-state actors' intending and attempting to acquire NWs, although whether these attempts need to be taken seriously are doubted by some analysts.[80] So-called 'catastrophic terrorists' do have the intention however, to wreak massive havoc on societies and it is expected that catastrophic terrorism will be around for at least the next decade. While non-state actors would face significant obstacles in building a nuclear bomb, some experts stress that they in principle would be able to build an improvised nuclear device, if not a fully fledged NW, if they are able to obtain enough weapons-grade uranium or plutonium.[81]

Alternatively, it has been hypothesised that state actors may hand over a NW to a non-state actor.[82] States that would be afraid to use the NWs themselves would share the weapons with a non-state group that wouldn't have to fear for annihilation. This scenario is not very realistic since it would be possible to trace the source of the weapon with a fair degree of accuracy.[83] Still, radical elements within a state apparatus may be inclined to share a nuclear device.[84] This is considered by some analysts to be a risk in the former Soviet Union and in Pakistan, as they express doubts about the level of security of their NWs facilities (although others are less outspoken on the topic).[85] In a worst-case scenario, these weapons may fall in the hands of non-state actors in case of state failure, which is at present a concern with respect to Pakistan, but which may apply to numerous nuclear state actors of the future.[86]

Technological Developments and Future Nuclear Weapons

Nuclear materials, technology and knowledge will very likely continue to proliferate as a result of increasing mobility of information and people, and a diminished capacity on the part of states to monitor and control these flows. The globalisation of education opens up myriad possibilities to gain the necessary scientific expertise, both in the field of nuclear enrichment and in weapons design.[87] Mastering the production of the key materials – enriched uranium or plutonium – is the main challenge. The weaponisation of these materials, although still requiring substantial technological expertise, is a slightly lesser challenge – especially for state actors – with rough drawings for the construction of fission and fusion devices available in the open literature.[88]

Experts have also discussed the development of new types of NWs and alternative uses. Specifically, they describe the development of low yield tactical weapons such as nuclear bunker busters and Robust Nuclear Earth Penetrators (RNEP),[89] as well as electromagnetic pulse-effect bombs and high-altitude nuclear blasts designed to disrupt an enemy's information networks and systems via a powerful electromagnetic impulse.

Table 2 describes a number of present and possible future NWs and summarises how they could be used by state and non-state actors.

NAME	DESCRIPTION	POTENTIAL USE
TACTICAL NUCLEAR WEAPONS		
TACTICAL NW	Relatively short range NW (up to ca. 500 km), with varying yields usually in the range of tens kt.	Various 'non-strategic' battlefield applications, including artillery, mines, rockets etc.
STRATEGIC NUCLEAR WEAPONS		
STRATEGIC NW	Large, long-range NW. Usually with intercontinental range and with yields in the hundreds or even thousands of kt.	Massive death and destruction on global scale.
IMPROVISED NUCLEAR WEAPONS		
IMPROVISED NUCLEAR DEVICE (IND)[90]	Nuclear 'suitcase bomb'. Crude nuclear device produced from ca. 25 kg of HEU or 8 kg of plutonium. A successful IND would produce a yield of 10-25 kt, a 'fizzled' IND only a fraction of this yield.	Used to threaten and blackmail governments, whether detonated or not. Leaders would be troubled not to give into the demands given the potential consequences of detonation.
POSSIBLE FUTURE NUCLEAR WEAPONS		
SPACE DETONATED NW[91]	Relatively small (existing) NW would be detonated in the low earth orbit (LEO) causing a High-Altitude Nuclear Explosion (HENA). A 10 kt device would be sufficient.	Detonated at 100km over a states' own territory, the HENA will cripple 90% of the world's LEO satellites within a month due to the initial EMP pulse and the following artificial radiation belt that would deliver a 'lethal' dose of radiation to satellites. Essentially would knock out ca. 250 satellites at an estimated replacement cost of 100 billion USD and destroy most of global communications infrastructure.
MICRO/MINI/ TINY NUKES[92]	Yield: ca. 0.01 kt/0.1 kt/1 kt respectively.	It has been suggested that such smaller NWs present a more credible deterrent against rogue states; offer possibility for 'surgical strikes', e.g,. against underground WMD production facilities; offer lower collateral damage compared to larger NW.
ROBUST NUCLEAR EARTH PENETRATOR (RNEP)[93]	A 'nuclear bunker buster'. E.g., a modification of the currently stockpiled B61 nuclear bomb by placing a hardened bomb casing around it. Would penetrate ca. 20 feet when dropped from 40,000 feet.	Similar damage to deeply buried structures with considerably less yield. Meant to lower the collateral damage from a NW strike on underground facilities.
ULTRA-ROBUST WARHEADS[94]	Theoretical nuclear weapons with a suppressed electromagnetic pulse and/or reduced residual radiation.	For more effective missile defence, to intercept WMD warheads, for low collateral damage.
COBALT BOMBS (SALTED BOMBS)[95]	Theoretical nuclear weapon that would use cobalt, which on explosion would then transmute to the radioactive isotope Cobalt-60 and produced deadly fallout.	'Doomsday Device' in principle could kill everybody on earth. Designed in such a way that a radioactive isotope could be dispersed world wide before it decayed.

Table 2. PRESENT AND POTENTIAL FUTURE NUCLEAR WEAPONS

Conclusion

The potential future use of CBRN materials as weapons in the next five to fifteen years depends as much on technological – as it does on geopolitical developments. Production and proliferation of CBRN materials is expected to evolve continuously resulting in potentially lower entry barriers to aspiring CBRN actors. While this will undoubtedly affect the composition of the CBRN actor landscape, it is unclear whether this will automatically produce an increase in the frequency of CBRN weapons' use. Overall, however, the literature seems to converge that this does open up the possibility that CBRN materials may be utilised and deployed as weapons in novel ways, both at the battlefield and in the civil domain, in times of war as well as in times of peace.

STATE	NUCLEAR WEAPONS CAPABILITY	BIOLOGICAL WEAPONS CAPABILITY	CHEMICAL WEAPONS CAPABILITY
ALGERIA	Suspected R&D	Suspected R&D	Suspected Capability
CHINA	Declared Stockpile	Suspected Capability	Suspected Capability
EGYPT	Ended	Suspected Capability	Suspected Capability
ETHIOPIA	-	-	Suspected Capability
FRANCE	Declared Stockpile	Ended	Ended
INDIA	Stockpile	-	Suspected Capability
INDONESIA	-	-	Suspected R&D
IRAN	Suspected R&D	Suspected Capability	Suspected Capability
ISRAEL	Stockpile	Suspected R&D	Suspected Capability
KAZAKHSTAN	Ended	-	Suspected Capability
LAOS	-	-	Suspected Capability
MYANMAR	-	-	Suspected Capability
NORTH KOREA	Suspected Stockpile	Suspected Capability	Stockpile
PAKISTAN	Stockpile	-	Suspected Capability
RUSSIA	Declared Stockpile	Suspected Capability	Stockpile
SAUDI ARABIA	-	-	Suspected Capability
SOUTH AFRICA	Ended	Ended	Ended/Susp. Capability*
SUDAN	-	-	Suspected R&D
SYRIA	Suspected R&D	Suspected R&D	Stockpile
TAIWAN	Ended	-	Suspected Capability
UK	Declared Stockpile	Ended	Ended
US	Declared Stockpile	Ended	Stockpile
VIETNAM	-	-	Suspected Capability

Table 3. STATES WITH (SUSPECTED) CBN PROGRAMMES[96]

* South Africa has declared past CW programmes, but officially abandoned them and destroyed all of its CW after the end of the Apartheid regime. However, multiple sources contain specific and plausible allegations suggesting that it might have retained a residual CW capability.

Annex A – States with (suspected) CBN programmes

The table on the left page shows only states with at least suspected R&D in either C, B, or N weapons. Countries that have ended all CBN weapons programmes (e.g. Lybia or Iraq) are not listed. CBN weapons programmes are generally highly secretive in nature. Therefore, considerable uncertainty prevails with regards to their actual existence, extent, and status in many countries.

Suspected R&D: Multiple credible sources contain specific and plausible allegations suggesting a country is seeking to attain C, B, or N capabilities.

Suspected Capability: Multiple credible sources contain specific and plausible allegations suggesting a state has attained the principal ability to produce, or has already produced, C, B, or N weapons.

Stockpile: There is specific and plausible evidence suggesting a state has produced, or continues to produce C, B, or N weapons.

Declared Stockpile: A state has made a credible declaration that it possesses C, B, or N weapons.

Ended: States that have admitted to past C, B, or N weapons programmes, with strong, corroborated evidence showing that they have permanently terminated these programmes and destroyed all C, B, or N weapons capabilities.

Annex B – Signatory States to CWC, BTWC, NPT, CTBT and Additional Protocol Treaties

	CWC	BTWC	NPT	CTBT	ADDITIONAL PROTOCOL
FULL TITLE	Convention on the Prohibition of the Development, Production, Stockpiling, and Use of Chemical Weapons and their Destruction	Convention on the Development, Production, and Stockpiling of Bacteriological (Biological) and Toxin Weapons and their Destruction	Treaty on the Non-Proliferation of Nuclear Weapons	Comprehensive Nuclear Test Ban Treaty	Additional Protocol to the NPT Safeguards Agreement
IN FORCE SINCE	1997	1975	1970	Not yet in force*	1997
NUMBER OF STATES THAT HAVE SIGNED THE TREATY	188	175	189	180	123
NUMBER OF STATES THAT HAVE RATIFIED THE TREATY	186	163	18917	148	91
MAJOR STATES THAT HAVE EITHER NOT RATIFIED OR ARE NOT PARTY TO THE TREATY	Israel, Myanmar, Angola, DPRK, Egypt, Somalia, Syria	Israel, Angola, Chad,Cameroon, Eritrea, Mauretania	Pakistan, India, Israel	China, Egypt, Indonesia, Iran, Israel, US; DPRK, India, Pakistan * To go into force, CBTC will have to be ratified by China, Egypt, Indonesia, Iran, Israel, and the US; as well as signed and ratified by DPRK, India and Pakistan.	Algeria, Angola, Argentina, Bahrain, Brazil, Cambodia, Congo, DPRK, Eritrea, Ethiopia, Egypt, India, Israel, Kenya, Laos, Lebanon, Myanmar, Oman, Pakistan, Qatar, Saudi Arabia, Somalia, Sri Lanka, Sudan, Syria, Venezuela, Yemen

Table 4. SIGNATORY STATES TO CWC, BTWC, NPT, CTBT AND ADDITIONAL PROTOCOL TREATIES[97]

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95 Glasstone.S., & Dolan, P.J., 'The Effects of Nuclear Weapons', *United States department of defense*, 1977. See: http://www.princeton.edu/sgs/publications/articles/effects/effects-9.pdf, Sublette, C.,'Section 1.0 Types of Nuclear Weapons', *The Nuclear Weapon Archive*, 1 May 1998. Site last visited: 21/09/2009; http://nuclearweaponarchive.org/Nwfaq/Nfaq1.html#nfaq1.6

96 The table is based on a combination of the following sources: Congressional Research Service, 2008, Nuclear, Biological, and Chemical Weapons and Missiles: Status and Trends, Table 1 p. 20; James Martin Center for Nonproliferation Studies, 2002, Chemical and Biological Weapons: Possession and Programmes Past and Present, available online at http://cns.miis.edu/cbw/possess.htm#16; GlobalSecurity.org, 2009, World Special Weapons Guide, available online at: http://www.globalsecurity.org/wmd/world/index.html

97 The table is based on a combination of the following sources: James Martin Center for Nonproliferation Studies (2009), *Inventory of Nonproliferation Organisations and Regimes* (2009 Ed.); IAEA (2009), *Safeguards Current Status (as of July 9 2009);* OPWC (2009), *Status of Participation in the Chemical Weapons Convention as at May 21 2009; The Biological and Toxin Weapons Convention Website.*

The potential use of CBRN materials as weapons remains subject to continuing scrutiny and intense debate amongst policymakers, academics and military professionals. Against the background of rapid advances in scientific methods and relentless proliferation of the means to produce CBRN materials, this assessment maps and analyses the debate on the potential future use of these materials in the security and safety domain in the next five to fifteen years.

In doing so, it touches upon technological and geopolitical aspects of the production, proliferation and actual use of such materials as weapons, and it examines the capacities and potential intentions of state and non-state actors. Within the community of experts considerable divergence exists on these different aspects. Yet, there seems to be convergence on one issue: the global CBRN landscape of the 21st century will be changing drastically in the years to come.

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