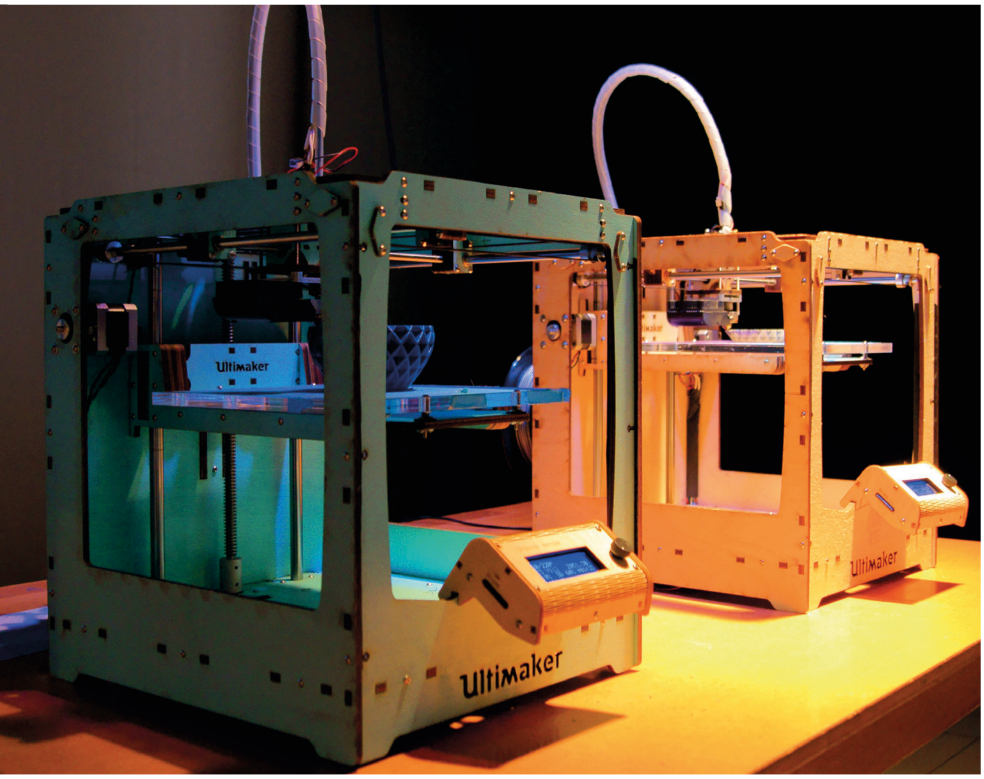
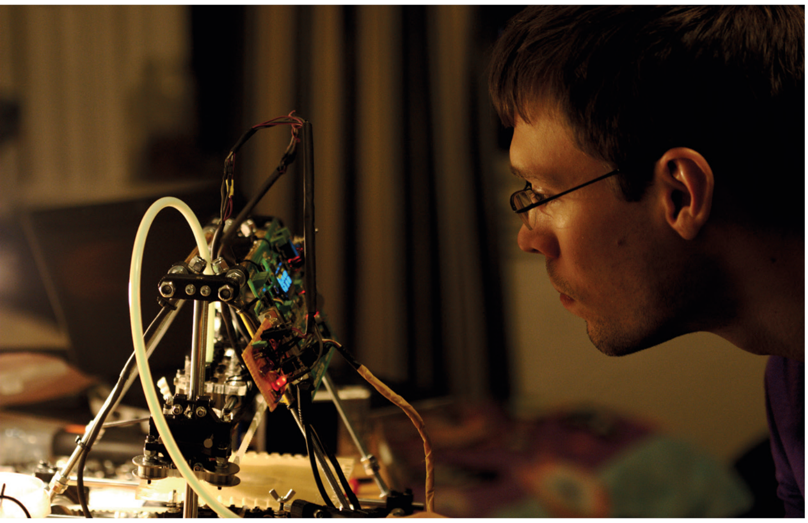
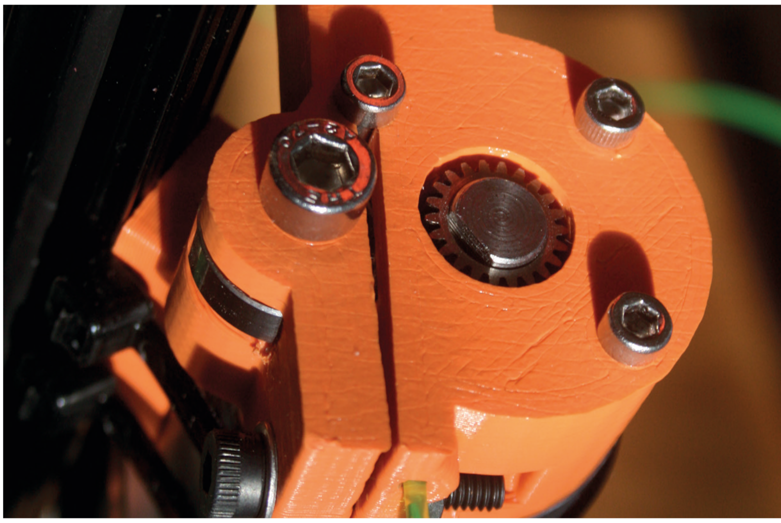
3D Printing

WMD Proliferation and Terrorism Risks







CASIMIR PULASKI FOUNDATION

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Zbigniew Pisarski
President of the Board
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Over the last 10 years Francisco Galamas has worked with governamental and international institutions on issues linked to international security and nonproliferation. He is also a member of the Young Atlanticist NATO Working Group of the U.S. Atlantic Council as well as a member of the George C. Marshall European Center for Security Studies. Mr. Galamas regularly publishes articles in magazines such as The Diplomat or the World Politics Review.

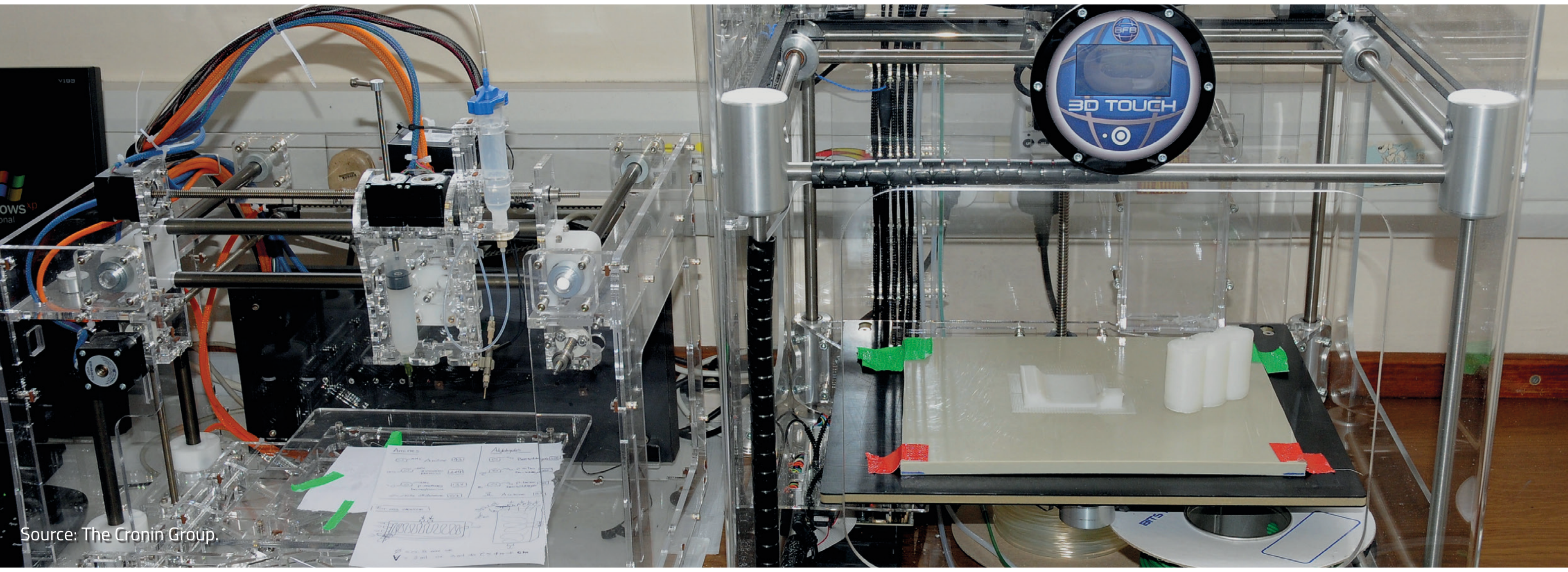
3D Printing
WMD Proliferation and Terrorism Risks

3D printing, or addictive manufacturing, has been expanding its presence in our society at an impressive rate. These printers basically inject layers of plastic, metal or other substances in order to build objects. While at first three-dimensional printing could only produce very simple objects, recent developments allowed this technology to advance for the production of more complex items, such as firearms. For instance, in mid-2013, the world woke up to the reality of 3D printed guns as they fired their first shots on camera, in a video release by the producing company – Defense Distributed.[1] In November of 2013, another company, Solid Concepts, not only printed the first metal 3D printed handgun, but also demonstrated that this gun could fire over 1000 bullets without any mechanical failure.[2] These new technological breakthroughs are the pinnacle of two major tendencies we have been witnessing in the manufacturing sector: 1) the production of items is becoming increasingly simpler and more disperse and 2) information behind it is easily dispersible through cyberspace.[3] 3D printing methods embed both of these trends, as they simplify the production of items, while the know-how can be condensed, in computer files, with the parts design and assembly instructions for the user.

As a number of analysts focus on the problems behind the printing of conventional weapons and the hypothetical effects on domestic security, one must also envision issues brought by these printers to the weapons of mass destruction (WMD) nonproliferation mechanisms and terrorism.

Going further on 3D printing

As people heard of the first 3D printing breakthroughs involving plastic filament made items, the metal 3D printers were already swiftly increasing their capabilities. Not only are these devices becoming more efficient, but the metal 3D printers are also becoming available for domestic users. Recently, a prototype for a home metal 3D printer was presented with the future goal of "printing custom jewelry (...), specialized machine parts, ornamental hardware, metal chains, or even special hardware such as miniature turbines or pistons".[4]
Using more evolved models, missiles are a good example of what the 3D printers can do. Even though creating a whole missile with a 3D printer is currently unheard of, the same cannot be said about the missile parts. In August 2013, NASA was able to 3D print an engine injector, a rocket component which delivers propellants and allows rockets to lift off. By using a laser melting method and a nickel-chromium alloy powder, this 3D printed injector was able to generate twenty thousand pounds of thrust, which is almost ten times more thrust than any previous 3D printed rocket engine injector had endured. Such tremendous progress also allowed the production of this rocket component with only two parts, instead of the 115 parts used in previous models. This means that lesser parts will also allow for lesser costs involved in production. Moreover, this particular injector also endured temperatures of over three thousand degrees Celsius.[5] Almost a year later, the company Aerojet Rocketdyne went a step further. This missile propulsion systems manufacturer built an entire liquid oxygen fuelled rocket engine, which was later successfully tested, by solely resorting to 3D printing.[6]



Source: The Cronin Group.

As a demonstration of another technological breakthrough, Lockheed Martin received a patent on using 3D printing to make specialized warheads from previously unavailable materials or shapes.[7] The U.S. Army has already understood the potential 3D printing uses in missile technology. For example, the U.S Army Aviation and Missile Research Development and Engineering Center has partnered with NASA in order to research and develop 3D printing linked to "materials and processes for specific missile applications", among other missile related purposes.[8] Furthermore, 3D printing technology is being used by the U.S. military to produce warhead components. This particular method intends not to only make munitions more affordable, but also to make different warhead designs to meet the mission requirements.[9] It will come as no surprise if, in the near future and as this technology expands, important parts of warheads, rockets or missiles can be built through the use of available designs and this new printing method by other state or non-state actors.

On the nuclear weapons front, the 3D printers cannot produce fissile materials, but they may manufacture "precise, high speed centrifuges" that ultimately can enrich uranium for energy purposes as well as for posterior use in nuclear weapons production.[10] The major problem was accessing the design of the centrifuges, but such is no longer a trade secret and some countries have already gained indigenous capability to produce them. For instance, in 2013, two American experts stated that North Korea's nuclear scientists mastered the domestic production of key components for enriching uranium.[11] As 3D metal printing technology advances, countries that are developing (or intend to develop) nuclear programs will find it easier to produce some of their own equipments without importing them. Because acquiring the equipments and parts to enrich uranium is not an easy task as some designs become available in different platforms, 3D technology could also allow proliferating states or trafficking networks to access this sort of previously inaccessible sensitive materials. The same might be said about other specific dual-use nuclear related equipments that might be involved in nuclear program activities. For instance, the United States' International Thermonuclear Experimental Reactor (ITER) team is using metal 3D printing to support some of the nuclear reactor's elements design process. This group of researchers could also use this very same technology to manufacture some of the nuclear reactor components "such as the fast gas valve for the reactor's disruption mitigation system" at one-to-one scale.[12]

The 3D printing has also entered the realms of biology. Commonly known as "bioprinters", the use of the 3D printers and biological materials has already created a number of significant scientific breakthroughs.
For example, researchers working at the Wake Forest University have already used "bioprinters" to produce human skin and a two-chamber heart in an experimental proceeding. Other experiments allowed the creation of bladders, intestinal segments and bones by using 3D printing methods.[13] Another good example of "bioprinter" use was developed by Invetech and Organovo, which led to the production of the first commercially available "bioprinter" to create human tissue.[14] While resorting to "bioprinting" methods, Organovo was able to produce strips of liver tissue, 20 cells thick, so as to help the research of experimental drugs.[15] Months later, in October 2013, Organovo announced that these printed liver cells can

preserve essential liver functions for 40 days and that they were already being subject to drug experimentation.[16] Moreover, a German laboratory has "bioprinted" sheets of heart cells that could be used to repair damages originated from heart attacks.[17]

Currently, the biological 3D printers cannot print living bacteria or viruses just by using DNA available in digital format, but when addressing the topic of "bioprinters", one must also consider the advancements made in other fields, such as synthetic biology. Generally speaking, synthetic biology allows trained professionals to replicate microorganisms by solely using chemicals and DNA sequences without requiring a physical sample of the virus or bacteria. Besides, not only the costs of synthetic biology have significantly decreased, but its synergy with 3D printing could bring significant changes to this particular field.[18] As Laurie Garrett states in her Foreign Affairs article "The most difficult part of the process now is putting the DNA components in a sensible sequence, but that is unlikely to be true for long. The world of biosynthesis is hooking up with 3D printing, so scientists can now load nucleotides into a 3D "bioprinter" that generates genomes. And they can collaborate across the globe, with scientists in one city designing a genetic sequence on a computer and sending the code to a printer somewhere else – anywhere else connected to the Internet. The code might be for the creation of a life-saving medicine or vaccine. Or it might be information that turns the tiny phi X174 virus that Venter worked on a decade ago into something that kills human cells, or makes nasty bacteria resistant to antibiotics, or creates some entirely new viral strain."[19] When attainable, a "bioprinter" could not only have an impressive array of valuable uses but it may also allow a terrorist to produce some biological agents as information on pathogens DNA are already available in open sources. Based on the same principle Craig Venter, the biologist known for creating the first synthetic genome cell presented an idea for future vaccination. His proposal relied on DNA 3D printing so as to produce vaccines in a more expeditious and affordable manner but, in theory, the same process could also be used to produce and distribute deadly pathogens.[20]

All of the above-mentioned are fine examples of what researchers are doing with "bioprinters", but then there is the issue of the financial burden behind such devices as the cost of these "bioprinters" is still far from the decreasing costs of regular 3D printers. But this reality may change. For instance, a group of "biohackers" used a regular HP printer and, after modifications and experimentation, successfully created a "bioprinter" for US$150. Obviously, this model is nowhere near the quality of the "bioprinters" used in public and private laboratories with considerable budgets, but still it was able to print a sheet of fluorescent E.Colli cells.[21]

Other uses of 3D printing in the biology field can have additional detrimental effects in the nonproliferation mechanisms of biological weapons, especially regarding the transfer of dual-use equipments. For instance, Cathal Garvey, a former PhD student, decided to use 3D printing technology in order to manufacture laboratory equipment in his own bedroom. To do so, he used freeware and public databases to create equipment for his legitimate research, otherwise expensive to acquire. While operating a 3D printer and publicly available designs, C. Garvey produced vital parts of a centrifuge

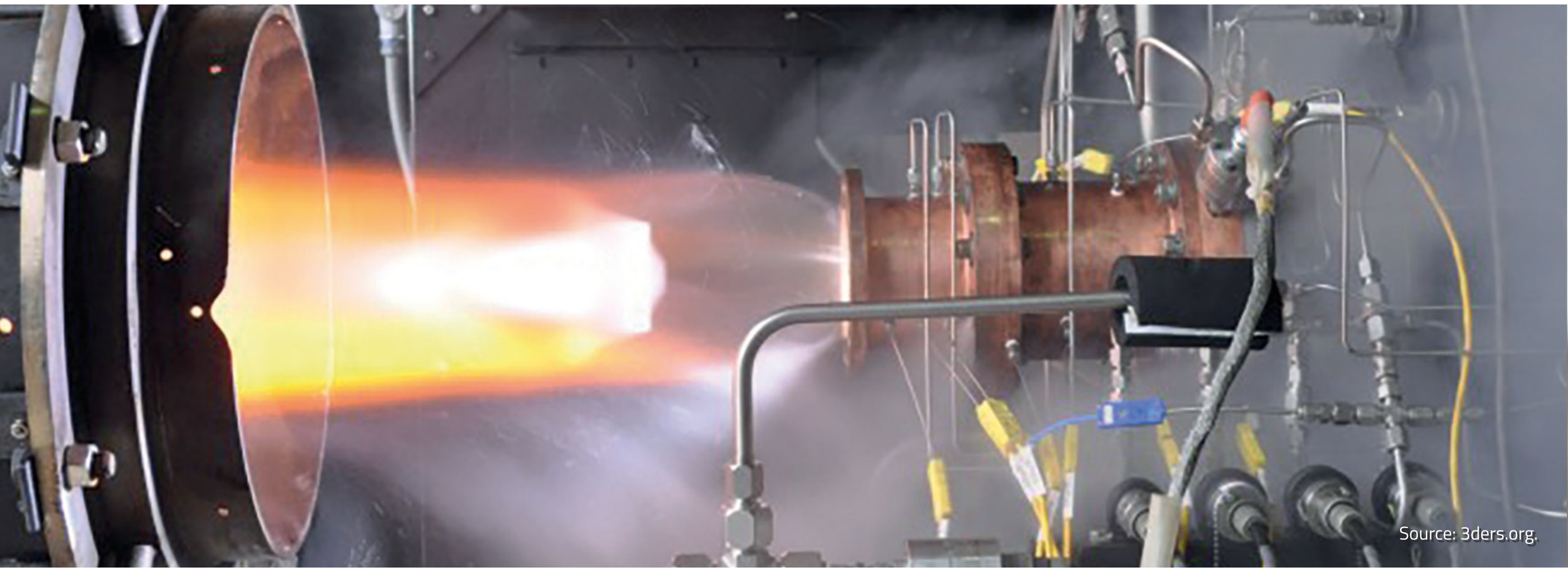
Source: Gizmag.com.

that otherwise would have cost thousands of dollars.[22] So why is this important for nonproliferation mechanisms? Equipment procurement is one of the major alert signs for intelligence and security services when trying to prevent non-conventional terror attacks or detecting countries' WMD programs. Any technology that empowers individuals or countries with the capability to produce their own laboratory equipment will inevitably decrease the security and intelligence agency capabilities to detect earlier signs of such activities.

Another interesting breakthrough in 3D printing is linked to chemistry. Researchers, led by Lee Cronin of the University of Glasgow, have developed a prototype that could enable "strategies to produce integrated 3D printer/design-software/chemistry packages whereby individuals could one day have access to chemistry and chemical discovery without the need for expensive laboratory infrastructures".[23] By using a US$2000 3D printer, this team was thus able to develop a prototype that can inject and control the combination of chemical reactants as well as the ratio and speed of the mixture. The use of specific software could allow this prototype to combine different sets of reactants so as to create specific chemical components such as the ones used for medical drugs.With this idea in mind, the short-term goal of these researchers is to produce simple drugs such as ibuprofen, something already possible when using this current early stage prototype.[24] Although the possibility of using a 3D printer, reactants and dedicated software to produce medical drugs is highly commendable, as it could allow medication to have a wider geographical reach at much lower costs, it may also bring additional security risks. The chemical weapon "recipes" are known among people with chemistry training and also available in some public sources.[25] Phosgene, a known chemical pulmonary agent used during the First World War, could be one of the potential candidates for this new production method.[26] Therefore, as this technology gathers followers and worldwide implementation while carrying tremendous potential benefits, it can also potentially help countries or terrorist movements to develop chemical weapons, even if rudimentary, without depending on specific expertise or specific chemical precursors suppliers.

Impact on the nonproliferation regimes

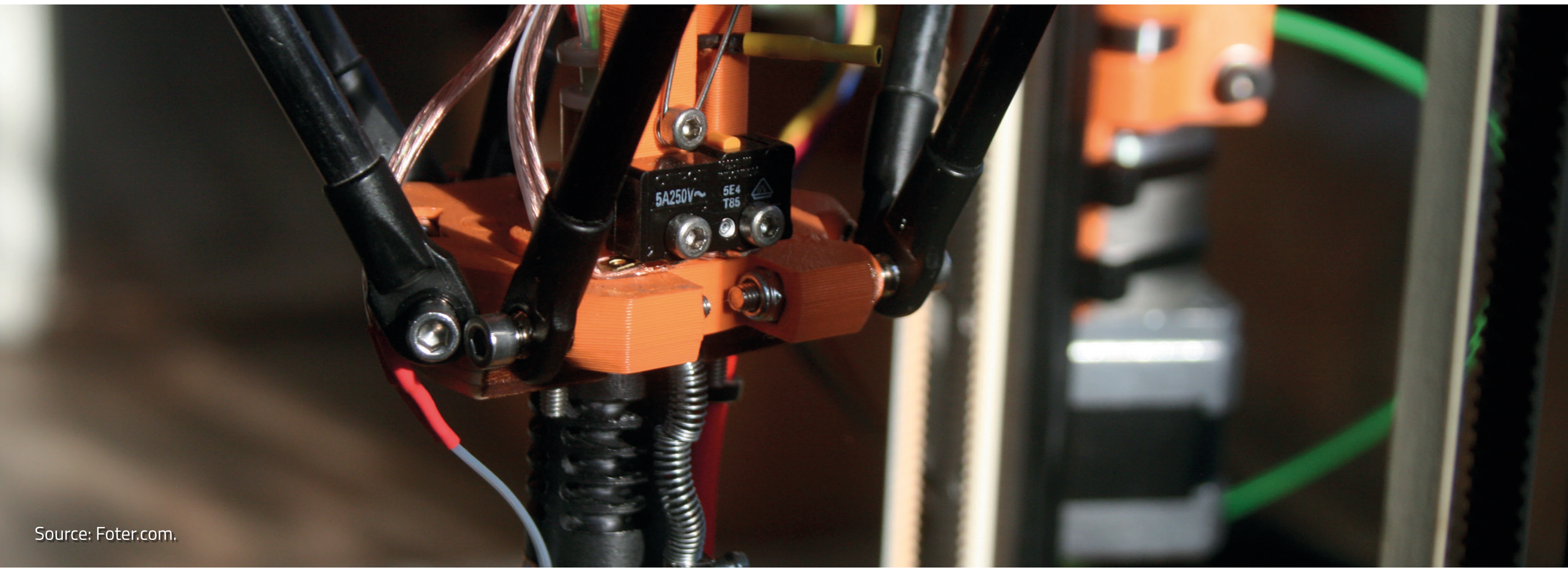
When looking at the above mentioned innovations and one confronts these with the mechanisms that prevent the proliferation of WMD, it is possible to anticipate some preliminary repercussions. One of the most immediate "victims" of the 3D printing revolution would be the multilateral export control regimes. These inter-governmental agreements, such as the Missile Technology Control Regime (MTCR), the Nuclear Suppliers Group (NSG) or the Australia Group, rely on several custom lists that include references to materials and equipments with potential use in WMD programs or related delivery means. When a suspicious order arrives for a listed item, export control officials start to scrutinize the importing company's background, the end-user certificate and other documents that can attest that this particular item is not destined for other use than the one declared. This process is also an early-warning tool for intelligence communities to understand a proliferation network dynamics and its procurement channels. Moreover, the analysis of these procurement behaviors is what allows intelligence and defense analysts to understand what type of activities the



Source: 3ders.org.

proliferating state and non-state actors are planning. Any technology that enables states, individuals or terrorist group capabilities to produce WMD related equipments or substances will automatically decrease the threshold for detection of these very same capabilities by the national intelligence and security agencies. Another likely consequence may be linked to the national implementation mechanisms of the major nonproliferation Conventions. As 3D printing achieves global presence, Member States of the legally binding instruments, such as the Nuclear Nonproliferation Treaty, the Biological and Toxin Weapons Convention or the Chemical Weapons Convention, may be required to put additional emphasis – and financial resources – on their national implementation strategies and mechanisms. Another important question is where the focus of the nonproliferation efforts should be directed to. Although some of the equipments, substances and materials may be produced by resorting to these new methods, most of them possess some degree of complexity that 3D printers cannot completely fulfill yet. Therefore, export controls should remain one of the main driving forces behind nonproliferation efforts, and will thus need to be strengthened bearing in mind the progresses allowed by 3D printers. The transmission of information is another essential aspect brought up by the tridimensional printed equipments. While there are laws and barriers regarding the export of almost every component that might be involved in WMD production, such as national legislation, export controls, multilateral nonproliferation conventions or international security standards, the same cannot be said about the flow of relevant information. For example, as genetic sequences of pathogens are being stored in computers and internet websites all around the world, it is difficult to imagine successful ways of preventing such sequences to reach terrorist groups or rogue states.[27] Worse, if combination of 3D printing technology and synthetic biology procedures materializes, those who might aspire to become bioterrorists would only need basic biology and chemistry knowledge, a "bioprinter" and some dual-use support equipment to develop a biological agent. The same can be said about other components of nonconventional weapon programs, such as missile parts, dangerous chemicals and dual-use laboratory equipment. Furthermore, with 3D technology, the WMD proliferation dynamics becomes increasingly harder to control because the problem no longer exclusively lies in the physical access to the materials and equipments but rather in the information to produce them. Basically, 3D printing substantially diminishes the barriers for producing some key elements linked to the production of nonconventional weapon materials and equipments.

Concomitantly, the proliferating state or terrorist groups seeking these materials are highly benefited as the information flow is much less detectable than the physical transportation. Therefore, it may be necessary for government officials to start thinking about the need for nonproliferation and for cybersecurity experts to jointly devise strategies to prevent that 3D printing based information could be used to facilitate WMD proliferation.[28] Of particular relevance are the issues linked to sanctions. If countries are able to domestically produce certain equipments (even if not related to nonproliferation programs) that are under sanctions, how effective are the latter going to be? For several years, we have been witnessing countries under sanctions but still able to progress on their nonconventional weapon programs. Even if



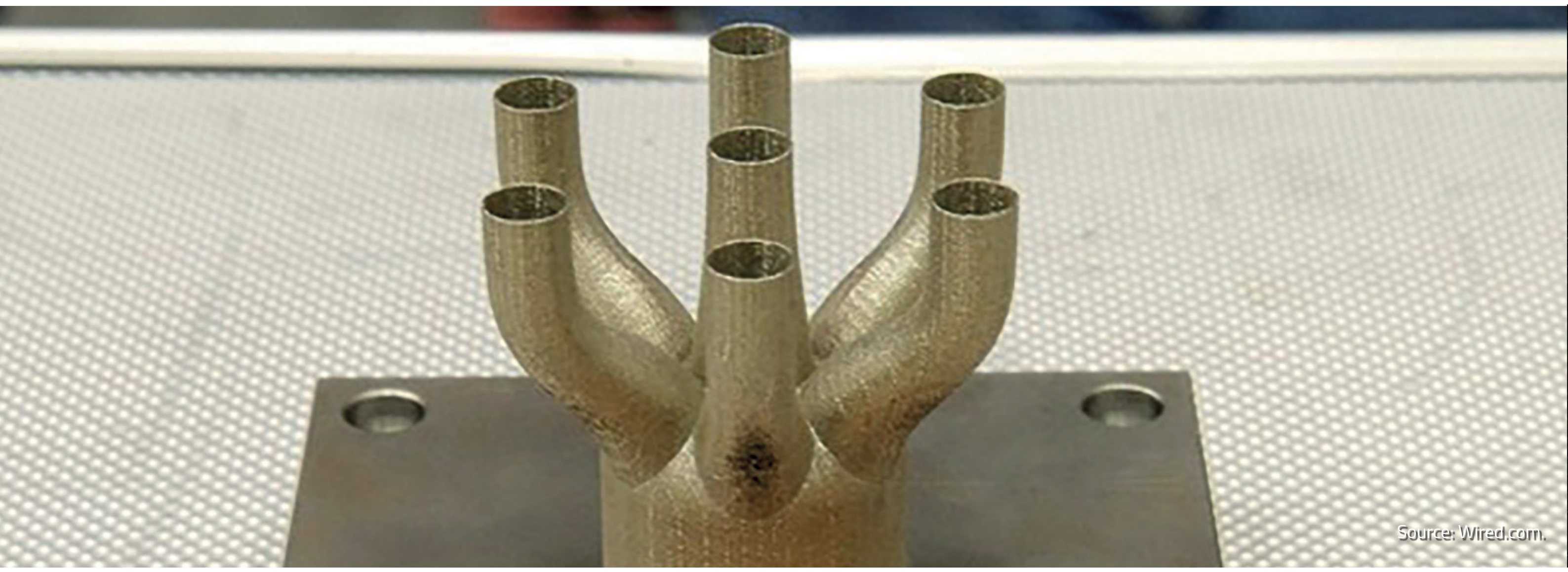
Source: Foter.com.

contemplating the possibility of financial sanctions, the domestic capability to produce sanctioned materials and equipments will surely diminish some of the international community's ability to exercise pressure upon the targeted country.

On a more strategic level approach to WMD proliferation, we may witness the inauguration of a fourth trend in WMD proliferation dynamics, as 3D printing technology is assimilated by the economies all around the world. It should be mentioned that the beginning of another trend does not mean the end of a previous one. The first trend of proliferation was characterized by the states' progress in programs of WMD by solely basing their efforts on domestic research and development capabilities, even if resorting to some degree of scientific espionage. The second trend of proliferation emerged when, for strategic and foreign policy imperatives, countries that had already developed and possessed nonconventional weapon technology transferred the necessary know-how and technology to allies or friendly countries. When private entities, with or without state support, started to be involved in the proliferation dynamics, such as the notorious A.Q. Khan network, the third trend of proliferation dynamics materialized. This proliferation tendency has been developing for the past 20 years as globalization expanded, fuelled by the end of the Cold War, and empowered several non-state actors and/or states to either develop nuclear weapons, traffic nuclear related materials, access dual-use equipments and produce rudimentary chemical and biological weapons. Now, the 3D printing technology may allow a fourth proliferation trend to surface. This trend will be based on the diffusion of technology and information that potentially allows individuals to effectively produce some rudimentary forms of WMD or related equipments without requiring a substantial infrastructure, financial or technical support. One could call this trend a digital WMD proliferation era. Especially regarding chemical and biological agents, if the current technological breakthroughs are further enhanced and enter the mass production market, the detection capabilities of governments could prove insufficient to prevent individuals, as well as small groups, from producing such weapons or related production equipments. So the emphasis is clearly placed upon the intelligence and surveillance capabilities of states in order to anticipate and prevent any attack. This brings us to the issue of terrorism.

WMD Terrorism

It is not difficult to imagine what terrorist groups could do if the potential of such technology allows WMD production. Not only could they produce usable elements for WMD, but they might also manufacture related materials for financial gain and plan additional operations. One particular type of terrorism seems quite threatening as this 3D technology evolves – the lone wolf type. Attacks perpetrated by lone wolf terrorists still represent a small percentage of the attacks, but they are rising in Western countries, as recent examples in Europe and Australia demonstrate. Between 1970 and 2000, lone wolf attacks increased 45% in the United States and 412% in other Western countries. If one only considers Islamic extremism linked attacks, there were 73 attacks between 1990 and 2013 from which 40 were committed in the years 2000-2009 and 29 in 2010-2013.[29] Reasons



Source: Wired.com.

behind this increase vary, but they include disturbing trends such as increasing availability of weapons, the prevention difficulties behind this sort of attacks, and terrorists' use of the internet for recruitment and radicalization purposes. This latter aspect is especially relevant when we think about the al-Qaeda network, whose leadership has appealed its members to conduct lone wolf type attacks. Moreover, lone wolf attacks have a higher operational flexibility as their plans are not subject to a group decision-making process and to political supporters.[30]When addressing lone wolf terrorists, al-Qaeda network should be closely monitored, including its affiliates and ideologically inspired individuals. As Osama Bin Laden was killed in Pakistan, intelligence experts believe that a new strategic mastermind, Abu Musab al-Suri, climbed the hierarchy of this terrorist network. Whilst Bin Laden ran al-Qaeda with a hierarchical top-down approach, al-Suri – in his 1,600-page manifesto – advocates the creation of self-generating cells of lone wolf terrorists and small groups. In practical terms, this means that these terrorist attacks would have lesser impact but a lower detection pattern and a higher incidence rate.[31] But how does lone wolf terrorism relate to any hypothetical use of 3D printing technology to produce unconventional weapons? According to lone wolf expert, Jeffrey D. Simon, lone wolves – regardless of ideology and motive – have demonstrated to be highly innovative concerning terrorist tactics. In the US, they were responsible for the "first vehicle bombing (1920), major mid-air plane bombing (1955), domestic hijacking (1961), product tampering (1982) and anthrax letters (2001)".[32] Furthermore, in an e-mail interview to Time magazine, the very same author envisaged bioterrorism as a likely scenario for a lone wolf terrorist, based upon the anthrax letters incident.[33] Considering the innovation historical background of these terrorists, it is not hard to imagine one of them resorting to 3D printer technology or "bioprinter" to produce chemical or biological substances with hostile purposes as soon as it is technologically feasible to do so. Such scenario would need to envisage the enormous difficulties behind the detection of lone wolves as well as of the production of some dual-use chemical and biological substances. The domestic production of some laboratory equipments without resorting to commercial suppliers may also undermine the efforts of intelligence agencies in preventing nonconventional terrorist attacks.

Conclusion

One may wonder if such conclusions may be overstated, but the fact is that this technology is just emerging and the timing is perfect to devise solutions that can prevent any misuse of 3D printer technology. The production of some types of conventional weapons with 3D printers is already a reality that still has not been properly dealt with. Additionally, even if WMD are currently too complex to be produced solely by the 3D printers, the previously mentioned examples, at the very least, demonstrate that these can provided very important supporting tools in the production of some elements of any WMD program.

Furthermore, when debating chemical and biological terrorism, it is also possible to argue that there are more accessible and less technological demanding platforms to produce these agents. Even though this point is currently valid, one must take into consideration two important aspects. The first one is linked to the increase of

Source: Solidconcepts.com.

amateur scientist communities in the recent years. Amateur biologists and their online platforms – such as DIYbio – have been expanding, thus allowing a growing number of people to access relevant biological and genetic information. Most of these informal scientific communities have been trying to prevent the misuse of scientific knowledge by implementing some safety protocols either by themselves or by promoting outreach events with the support of governmental entities.[34] Such efforts are truly commendable, but we are all aware that as scientific communities expand, so do the difficulties of supervising the work of all its members. The second important aspect concerns the "de-skilling" dynamics enabled by these technologies. Albeit 3D printers will bring important technical breakthroughs, they also make scientific procedures less complex and more accessible to non-professional scientists. In the long run, one must consider if we are approaching a time when someone with very basic scientific knowledge can produce chemical or biological agents with just the support of specific 3D printers and software, without the need for the currently more accessible equipments that require conventional training. To prevent the materialization of such reality, it is imperative that lawmakers, export-control authorities and intelligence officials begin to think about effective solutions.

Whereas some may ask for prohibition of these new technologies, such is unlikely to be a permanent solution for two reasons. First, the 3D printer technology already began its implementation in the world economy, and banning it is nearly impossible. Additionally, when high quality printers and scanners first appeared, authorities did not forbid this technology as criminals used it to counterfeit currency. Instead, they formulated new solutions and safety features to prevent fake currency circulation. Second, the same technology that may assist terrorists in the above-mentioned threats may also bring solutions that mitigate the risks emanated by WMD use. For example, tridimensional printing technology is allowing scientists at the Wake Forest Baptist Medical Center's Institute for Regenerative Medicine to launch a program called "Body on a Chip" that aims to create "Miniature lab-engineered, organ-like hearts, lungs, livers and blood vessels – linked together with a circulating blood substitute – (...) to predict the effects of chemical and biologic agents and to test the effectiveness of potential treatments".[35]

Obviously, the above-mentioned breakthroughs are all early-stage research projects, but the main point is that this technology is steadily emerging as tomorrow's reality. As we see the progressive improvement of technology as a substitute for previously human performed tasks, one should wonder if information, its access and its use, could become one of the core security issues of the 21st century. In this particular point, recent disclosures on governmental eavesdropping may create additional barriers for governmental agencies, both in the United States and in other countries, to intercept communications. But Western governments and populations must make a choice on the need and methods used to prevent terrorist attacks and other security threats. Technology already enables non-state actors to anonymously operate and coordinate actions at greater distances. As future technologies make it possible for terrorists and criminals to produce weapons solely by using information available on digital platforms,


Source: Forbes.com.

societies must start addressing solutions for these security problems. Making populations believe that it is possible to prevent terrorist attacks in the 21st century without resorting to some degree of electronic messaging interception is absolutely utopian. Thus, it is important to start the public debate on the necessary security strategies to prevent these threats, how compatible they are with Western democracies and what limits they should have. In particular when considering the latent possibilities of 3D printing, this is the time to do so as the progress of technology will not wait for the lawmakers and security agencies to devise proper solutions.

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