Impact of Nanotechnology on Nuclear Weapons

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INTRODUCTION

Nanotechnology is a field that does not stem from one established academic discipline.[1] There are a number of ways in which nanotechnology may be defined. The most common version regards nanoscience as *'the ability to do things – measure, see, predict and make – on the scale of atoms and molecules and exploit the novel properties found at that scale'*.[2] Traditionally, this scale is defined as being between 0.1 and 100 nanometres (nm), 1 nm being one-thousandth of a micron (micrometre), which is, in turn, one thousandth of a millimetre (mm). Another way to characterise nanotechnology is by distinguishing between the fabrication processes of top-down and bottom-up. Top-down technology refers to the *'fabrication of nanoscale structures by machining and etching techniques'*.[3] On the other hand, bottom-up technology – often referred to as molecular nanotechnology (MNT) – applies to the creation of organic and inorganic structures, atom by atom, or molecule by molecule.[4] It is this area of nanotechnology that has created the maximum excitement and publicity. In a mature nanotech world, macrostructures would simply be grown from their smallest constituent components: an 'anything box' would take a molecular seed containing instructions for building a product and use tiny nanobots or molecular machines to build it atom by atom.[5] In short, full-fledged bottom-up nanotechnology promises nothing less than complete control over the physical structure of matter. That this underlying research is now moving into economically viable products can be gauged from the emergence of three alliances i.e. the Europe NanoBusiness Association, the Asia-Pacific Nanotechnology Forum, and the US NanoBusiness Alliance. In addition to this, laboratories around the world are working on new approaches and new ways to scale up nanotechnology to industrial levels. For example, the first factories to manufacture carbon nanotubes and fullerenes are under construction in Japan.[6]

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Research and Development

The main reason for government interest in nanotechnology is strategic; to achieve an advantageous position so that when nanotech applications begin to have a significant effect in the world economy, countries are able to exploit new opportunities to the full. Smith[7] speculates that it is entirely possible that much, or even most, US government research in the field is concentrated in the hands of military planners. Levels of public investment in nanotechnology are reminiscent of a growing strategic interest; this is an area that attracts both large and small countries. Global R&D spending is currently around US$4 billion[8], with public investment increasing rapidly (503 per cent between 1997 and 2002, across the 'lead' countries).

Defence

Nanoscale informatics, pharmaceuticals and medicine remain the most high-profile areas of near-term market application. However, Gsponer[9] contends that the most significant near-term applications of nanotechnology will be in the military domain. This is because micromechanical engineering is historically connected to nuclear weapons laboratories. It was within this domain that the field of nanotechnology was born a few decades ago. New technologies, are playing an increasingly important part in modern warfare–as reflected by recent investments in the US Department of Defence (DOD). Leading strategic commentators, such as David Jeremiah[10], proclaim that military applications of nanotechnology have an even greater potential than nuclear weapons, to radically change the balance of global power in the future. Other applications include[11]:-

(a) Information dominance through advanced nanoelectronics.

(b) More sophisticated virtual reality systems.

(c) Increased use of enhanced automation and robotics.

(d) Required improvements in chemical, biological and nuclear sensing.

(e) Design improvements in systems used for nuclear non-proliferation monitoring and management.

(f) Combined nanomechanical and micromechanical devices for control of nuclear defence systems.

The infantry soldier is anticipated to receive a nanotech-based 'makeover'; a new Institute for Soldier Nanotechnology (ISN) has been created at MIT, with a US Army grant of US$50 million over five years. The goal of this research centre is to greatly enhance the protection and survival of the infantry soldier using nanoscience.[12] Centre for Nanoscience Innovation for Defence (CNID) was created in January 2003 to facilitate the rapid transition of research innovation in Nanosciences into applications for the Defence sector.[13] CNID is sponsored by two federal agencies –the Defence Advanced Research Project Agency (DARPA) and Defence Micro Electronics Activity (DMEA) – to the tune of US$20 million over three years.

Funding of Military Applications

"Nanotechnology is one of the highest priority science and technology programmes in the Defence Department. Nanotechnology is a 'force multiplier', it will make us faster and stronger on the battlefield." said Clifford Lau, the senior science adviser in the Pentagon's office of basic research. Lau, who also serves as president of the nanotechnology council at the engineering group IEEE, said research is being co-ordinated across the military branches, and plans are in place to transition the technology from basic research to deployment.[14]

Military Research in Nanotechnology in the US. The United States accounts for two thirds of global expenditures for military R&D ($52 billion in 2002, followed by France and the UK with a combined $ seven billion, then Russia and China, combined about $ three billion).[15,16,17] Since the Second World War has been the first to introduce many new military technologies, it comes as no surprise that in the US National Nanotechnology Initiative (NNI – the US government funded nanotechnology programme that began in 2000), the military takes a considerable share of the funds – between 26 and 32 per cent in 2004 running at $ 222 million.[18] Spending figures for other countries are difficult to obtain, but judging from the UK effort in the range of $ two to three million per year,[19] the US may outspend the rest of the world for military nanotechnology by as much as a factor of ten. This could narrow if more countries follow the US example and make military NT a high priority.

The Naval Research Laboratory has founded an Institute for Nanoscience.[20] Here and in the traditional divisions, wide ranging research is being done in the areas of nano-assembly, -optics, -chemistry, -electronics, and -mechanics. The Navy, already, uses nanotech coatings on submarines to eliminate barnacle build-up and protect bearings against corrosion on surface ships. The Army Research Laboratory is working on nanotechnology for chemical and biological defence, structural materials, and particulate materials; in nano energetic materials focus is on insensitive (i.e., safe against unintended ignition) high-energy propellants with improved burning rate and mechanical properties.[21] The Air Force Research Laboratory is active in biology, electronics materials, and physics; one focus is energetic nanoparticles for explosives and propulsion.[22] The Air Force is using lightweight, radar-resistant nano-composite materials in the airframes of unmanned aerial vehicles. Advanced development also is underway to use nanotechnology to improve the detection of and defence against chemical, biological, radiological and nuclear weapons. Stronger, lighter nano-composites will be inserted in advanced body armour.

CHINA AND NANOTECHNOLOGY

China has realised the importance of nanotechnology for future economic development and is responding to global trends. In the middle of 1980s, the Chinese Academy of Sciences (CAS) and National Natural Science Foundation of China (NSFC) initiated support on the development of scanning probe microscopy (SPM) and other scientific issues at the nanometre scale (1987-1995). The Ministry of Science and Technology of China approved the 'Climbing up' project and supported nanomaterial science for ten successive years from 1990 to 1999. Over 3,000 researchers contribute to the field. In 1999, the Ministry of Science and Technology started a national key basic research project 'Nanomaterial and Nanostructure', to continually support the basic research on nanomaterials such as nanotubes. The National High Technology Plan also establishes a series of projects for nanomaterial applications. The Chinese Physics Society and the Chinese Society of Particuology are societies involved in dissemination of nanotechnology research.

To date, more than 50 universities, 20 institutes of CAS and 300 enterprises are engaged in the research and development of nanoscience and nanotechnology. Several centres for research and development of nanoscience and technology have been established in CAS, Tsinghua University, Peking University, Nanjing University, East China University of Science and Technology, and others.

China had planned to spend US $ 250 to 300 million during five-year plan (2001-2005). The National Centre for NanoScience and Technology of China (NCNST) is being built near the Peking University, and is expected to be completed in two years. The government has allocated US$ 33 million for building this Centre[23].

Considering the potential for military force multiplication offered by advanced nanotechnology, the dangerously unstable nature of a nano arms race and the foreseeable temptation to make a premptive first strike, the emergence of China as a major player in the field should be a cause for concern.

NANOTECHNOLOGY AND NUCLEAR WEAPONS

The Strategic Context

Two important strategic lessons were learnt from wars in Iraq, Yugoslavia, and Afghanistan, in which full extent of Western military superiority was displayed. Firstly, the amount of conventional explosive that could be delivered by precision-guided munitions like cruise missiles was ridiculous in comparison to their cost; some targets could only be destroyed by expenditure of numerous delivery systems while a single loaded with a more powerful warhead would have been sufficient[24]. Secondly, the use of weapons producing a low level of radioactivity appear to be acceptable, both from a military point of view because such a level does not impair further military action, and from a political standpoint because most political leaders did not object to the battlefield use of depleted uranium.[25]

During and after these wars, it was often suggested that some new earth-penetrating weapon was needed to destroy deeply buried command posts, or facilities related to weapons of mass destruction.[26] It is not, therefore, surprising to witness the emergence of a well-funded scientific effort to create the technological basis for making powerful new weapons – an effort that is not for maintaining a high level of military superiority, but for extending human enterprise to the next frontier; the inner space of matter to be conquered by the science of nanotechnology.

Nanotechnology, was born a few decades ago – in nuclear weapons laboratories under the names of 'micromechanical engineering' and 'microelectromechanical systems' (MEMS). A primary impetus for creating these systems was the need for extremely rugged and safe arming and triggering mechanisms for nuclear weapons such as atomic artillery shells. In such warheads, the nuclear explosive and its trigger undergo extreme acceleration (10,000 times greater than gravity when the munition is delivered by a heavy gun). A general design technique is then to make the trigger's crucial components as small as possible. For similar reasons the detonators and the various locking mechanisms of nuclear weapons were increasingly designed as more and more sophisticated microelectromechanical systems. Consequently, nuclear weapons laboratories such as the Sandia National Laboratory in the US are leading the world in translating the most advanced concepts of MEMS engineering into practice.[27]

A second impetus for MEMS and nanotechnology, is the ongoing drive towards miniaturisation of nuclear weapons and related quest for very-low yield nuclear explosives for use as a source of nuclear energy in the form of controlled micro explosions. Such explosions (with yields in the range of a few kilograms to a few tons of high-explosive equivalent) would in principle be contained, but they could just as well be used in weapons if suitable compact triggers are developed. It is easier to design a micro-fusion than a micro-fission explosive (which has advantage of producing much less radioactive fallout than a micro-fission device of the same yield). Enormous progress has been made, and the research on micro-fusion bombs has now become the main advanced weapons research activity of the nuclear weapons laboratories, using gigantic tools such as the US National Ignition Facility (NIF) and France's Laser Megajoule. The tiny pellets used in experiments, containing the thermonuclear fuel to be exploded, are certainly the most delicate and sophisticated nano-engineered devices in existence.

A third major impetus for nanotechnology is the growing demand for better materials with extremely well characterised specifications. These can be new materials for improved insulators which will increase the storage capacity of capacitors used in detonators, nano-engineered high-explosives for advanced weaponry, etc. They can also be conventional materials of extreme purity, or nano-engineered components of extreme precision. For instance, to meet NIF specifications, the 2-mm-diameter fuel pallets must not be more than 1 micrometre out of round; that is, the radius to the outer surface can vary by no more than 1 micrometre (out of 1,000) as one moves across the surface. Moreover, the walls of these pellets consist of layers whose thickness is measured in fractions of micrometres, and surface-smoothness in tens of nanometres. Thus, these specifications can be given in units of 1,000 or 100 atoms, so that even minute defects are absent for the pellets to implode symmetrically when illuminated by laser.

The final major impetus for MEMS and nanotechnology, which has the greatest overlap with non-military needs, is their promise of new high-performance sensors, transducers, actuators, and electronic components. The development of this field of applications is expected to replicate the micro-electronic industry, which was originally driven by military needs, and which provides the reference for forecasting a nano-industrial boom and a financial bonanza.

Nanotechnological Improvement of Existing Nuclear Weapons

Nuclear weapon technology is characterised by two sharply contrasting demands. On one hand, the nuclear package containing the fission and fusion materials is relatively simple, i.e. more sophisticated than complicated. On the other hand, many ancillary components required for arming the weapon, triggering the high-explosives, and initiating the neutron chain-reaction, are more complicated. Moreover, the problems related to maintaining political control over the use of nuclear weapons, i.e. the operation of permissive action links (PALs), necessitated the development of protection systems that are meant to remain active all the way to the target, meaning that all these ancillary components and systems are required to meet very stringent requirements for security, safety, and reliable performance under severe conditions. The general solution to these problems is to favour the use of hybrid combinations of mechanical and electronic systems, which have the advantage of dramatically reducing the probability of common mode failures and decreasing sensitivity to external factors. It is this search for maximisation of reliability and ruggedness, which is driving the development, and application of nanotechnology and MEMS engineering in nuclear weapons science.

To give an example: modern nuclear weapons use insensitive high-explosives (IHE) which can only be detonated by means of a small charge of sensitive high-explosive that is held out of alignment from the main charge of IHE. Only once the warhead is armed does a MEMS bring the detonator into position with the main charge. Since the insensitive high-explosive in a nuclear weapon is usually broken down into many separate parts that are triggered by individual detonators, the use of MEMS-based detonators incorporating individual locking mechanisms are an important ingredient ensuring the use-control, and one-point safety of such weapons.[28]

Further improvements on existing nuclear weapons are stemming from application of nanotechnology to materials engineering. New capacitors, new radiation-resistant integrated circuits, new composite materials capable of withstanding high temperatures and accelerations, will enable a further level of miniaturisation and a corresponding enhancement of safety and usability of nuclear weapons. Consequently, the military utility and the possibility of forward deployment, as well as the potentiality for new missions, will be increased.

Fourth-Generation Nuclear Weapons

First and second generation nuclear weapons are atomic and hydrogen bombs developed during the 1940s and 1950s, while third-generation weapons comprise a number of concepts developed between the 1960s and 1980s, eg the neutron bomb, which never found a permanent place in the military arsenal. Fourth-generation nuclear weapons are new types of nuclear explosives that can be developed in full compliance with the Comprehensive Test Ban Treaty (CTBT) using inertial confinement fusion (ICF) facilities such as the NIF in the US, and other advanced technologies, which are under active development in all the major nuclear-weapon states and in major industrial powers such as Germany and Japan.[29]

In a nutshell, the defining technical characteristic of fourth-generation nuclear weapons is the triggering, by advanced technology such as a superlaser, magnetic compression, antimatter etc of a relatively small thermonuclear explosion in which a deuterium-tritium mixture is burnt in a device whose weight and size are not much larger than a few kilograms and litres. Since the yield of these warheads could go from a fraction of a ton to many tens of tons of high-explosive equivalent, their delivery by precision-guided munitions or other means will dramatically increase the fire-power of those who possess them - without crossing the threshold of using kiloton-to-megaton nuclear weapons and, therefore, without breaking the taboo against the first-use of weapons of mass destruction. Moreover, since new weapons will use no (or very little) fissionable materials, they will produce virtually no radioactive fallout. Their proponents will define them as "clean" nuclear weapons and possibly draw a parallel between their battlefield use and the consequences of the expenditure of depleted uranium ammunition.[30]

In practice, since the controlled release of thermonuclear energy in the form of laboratory scale explosions (ie equivalent to a few kilograms of high-explosives) at ICF facilities like NIF is likely to succeed in the next 10 to 15 years, the main arms control question is how to prevent this know-how being used to manufacture fourth-generation nuclear weapons. As we have already seen, nanotechnology and micromechanical engineering are integral parts of ICF pellet construction. But this is also the case with ICF drivers and diagnostic devices, and even more so with all the hardware that will have to be miniaturised and 'ruggedised' to the extreme in order to produce a compact, robust, and cost-effective weapon.

CONCLUSION

A thorough discussion of the potential of nanotechnology and microelectromechanical engineering in relation to the emergence of fourth-generation nuclear weapons, is, therefore, of utmost importance. It is likely that this discussion will be difficult, not just because of secrecy and other restrictions, but mainly because the military usefulness and usability of these weapons is likely to remain very high as long as precision-guided delivery systems dominate the battlefield. It is, therefore, important to realise that the technological hurdles that have to be overcome for laboratory scale thermonuclear explosions to be turned into weapons may be the only remaining significant barrier against the introduction and proliferation of fourth-generation nuclear weapons.

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