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Nanotechnology Applications in National Defence: A review

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ABSTRACT

Nanotechnology is believed to be the next revolutionary force after the computer revolution age, having something in common to the earlier industrial revolution era of textiles, railroad and automobile. All these are enabling technologies. Fundamental advancements in science and technology between 1771 till date have shown that such revolutionary forces come about twice a century and take an average of thirty years to introduce before their widespread adoption. Nanotechnology, described as the control and manipulation of molecular-scale matter of about 1-100 nm in size, has been extensively researched for over twenty years now and many products of its application are currently in the market. Being an enabling technology and due to its multidisciplinary nature, science and technology of nanomaterials have found application in numerous areas. In recent times, the world is witnessing multidimensional security challenges which await solution strategies to secure lives, properties and home land. Typical example is the amazing security threats posed by global climate changes. Experts have also projected that the growing nanotechnology in itself has the potential to generate political, economic and social disorders through creation of novel classes of weapons that could threaten international security. In this article, advancements in nanotechnology applications of military importance have been reviewed. Recent discoveries made in nanoscale science and technologies useful in achieving the goals of national security are explored and possible progress in *nanodefence* through improved manufacturing, water-proof and armour materials, nanomedicine and nanosensors/nano-spies were identified.

Keywords: *Nanotechnology; National defence.*

1. INTRODUCTION

Nanotechnology can be defined as the application and commercialization of nanoscience. It is the study of systems in the sub 100 nm size regime (Hamlett, 2008). A Merill Lynch economist, Norman Poire (2002) have considered nanotechnology as the next phase of the second industrial revolution following the information and communication technology era that may have reached its rapid growth phase by 2025 (Dutta, 2007). Figure 1 shows Norman Poire's prediction of nanotechnology potentials as compared to other major technological evolutions (Hamlett, 2008). The emerging industrial revolutionary force is still a baby technology but has received much attention of researchers especially within the last twenty years. Its application in medicine, electronics, catalysis, sensors, energy, mechanics, and many other fields have also become popular (Bhattacharjee *et al.*, 2011).

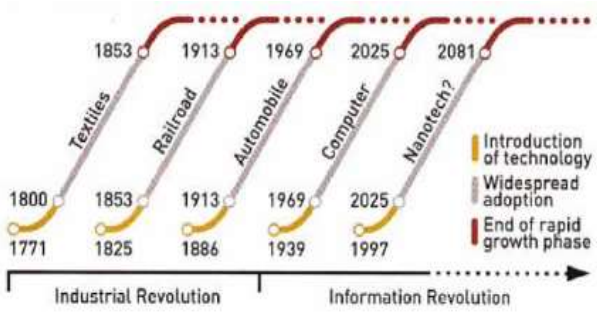

Fig.1: Trend of revolutionary forces from 1771 till date. **Source:** Dutta, 2007; Hamlett, 2008.

Presently, there is gradual acceptance of nanotechnology in addressing a number of the human needs. Majority of developed countries of the world like Europe, Japan and U.S.A. are spending heavily to fund nanotechnology

research for possible applications in various areas (Figure 2) (Almuhanna *et al.*, 2009). For instance, South Africa is expected to contribute about 3% of a projected $9 billion in carbon nanotubes global market by 2020 (Mohammed, 2015), but Nigeria's position is still uncertain. However, with the rising world population of about 6.8 billion people in 2010 to a projected 9.1 billion population by 2050 (FAO, 2009), experts have identified crime, war and terrorism as part of humanity's top ten challenges that may linger for the next fifty years (Wang, 2012). All other global problems identified are somewhat potential security threats.

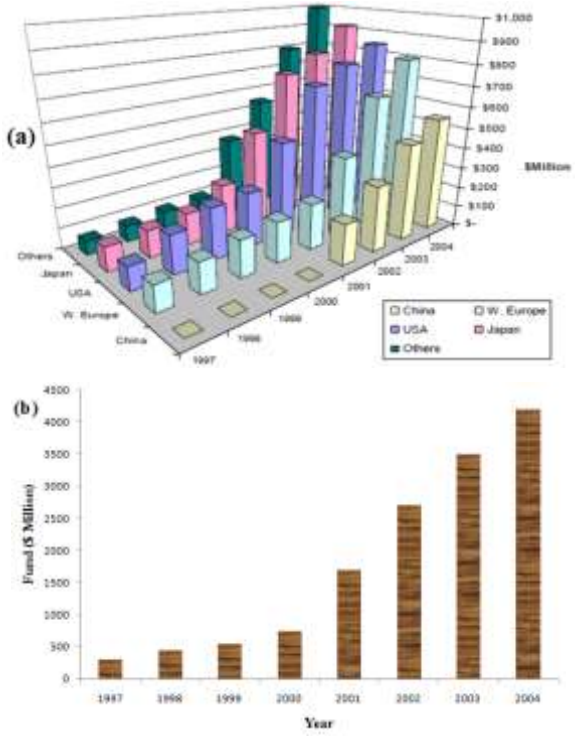

Fig. 2: Global government-funded nanotechnology (1997 – 2004) (a) by countries, and (b) total. **Source:** Almuhanna *et al.* (2009).

What are the root causes? It is certain that man cannot survive without food and water. Amidst malnutrition and hunger, the global environment is witnessing critical climate changes that affect agricultural activities, resulting in poverty and diseases (Shetty *et al.*, 2015). These and the lack of adequate education accessible to the growing world populace have resulted in increased crime, war and terrorism (Shetty *et al.*, 2015; Abeygunawardena *et al.*, 2003). It also has the potential to increase conflicts among countries over the scarce resources because the world population is on the continuous increase. Though, it is believed that the solution to these problems is many-fold, Nanoscience and technology can be supportive in securing the future of current international security problems. While the advanced stage of molecular nanotechnology is perceived as the platform for the next technological revolution which will be possibly more beneficial than earlier ones, it could also be the most dangerous (Vandermolen, 2006). There are possibilities to cheaply mass-produce the nanomaterials in large quantity with high precision at atomic level, and hence the matured form of nanotechnology can be a threat to international security (Vandermolen, 2006). This potential hazard can be addressed by active participation of all countries at ensuring that international regulations are enforced to direct the growing nanotechnology research towards economic development rather than destructions. Notably, there are milestones that have been made which are promising discoveries and significant developments in national defence and the military, and that is presented in this review. It gives insight into various ways by which recent advancements in nanotechnology could be seen to have potential applications to achieving the goals of national security.

2. SECURITY-EXACERBATING ENTITIES

In 2003, Richard Smalley projected that humanity is bedevilled with at least ten problems which would continue till the next fifty years (Figure 3) (Wang, 2012).

Fig. 3: Humanity's top problems for the next half century.

Central to these problems is security which has strong link to all other items in the list. In the listed factors, two major security-exacerbating issues have posed significant long-term threats to national security. These are global climate change (environment) and world population growth. The duo has the tendency to worsen the risk of security threats.

2.1. Global climate change and security

Climate change is possibly the most significant long-term security threat (Morisetti, 2014). While factors such as terrorism are known to pose immediate threat, climate change has been associated with long-term security threats. The problems of demands on resources, climate change (such as drought) and increased population on the scarce mineral resources, food and water supplies are likely to lead to tension, which could result in conflict (Morisetti, 2014). In view of the growing awareness to reverse the catastrophic consequences of greenhouse gas emissions for the planet, the role of the growing nanotechnology in addressing climate changes need to be evaluated. Again, the solution to combating climate change and reducing emissions of the greenhouse gases is multidimensional. The achievement of this goal would involve the development of energy forms that are less-carbon dependent, improvement in efficiencies of the systems and reduction in the demand for fossils (Vandermolen, 2006). Within the context of nanotechnology, reducing demand may be out of its sphere of influence but as an enabling technology, if integrated with many other technologies, improved efficiencies and novel sources of energy could be made available to the market. Nanoscientists and technologists have identified specific roles that nanotechnology could play to make impact. Primarily, in the energy sector which has a link to the lingering climate change, nanotechnology applications can produce improved fuel additives that will help increase the efficiency of fuel cells and hydrogen economy; diesel engines. Other areas include manufacture of more efficient solar cells from improved photovoltaic technology; improved energy storage from efficient batteries and super capacitors and improved insulation for houses and offices (Changseok *et al.*, 2013). Currently, nanotechnology application in fuel additives such as the use of nanoparticles to increase the fuel efficiencies of vehicles has been actualized (Nature, 2007). It was reported in the UK that about 2 to 3 million tonnes of CO_2 per annum could be saved by this technology. Nanocrystals of molybdenum disulphide (MoS_2) have also been used as catalysts in the oil industry to remove potentially harmful sulphur compounds from crude oil (Lauritsen & Besenbacher, 2006).

2.2. World population growth and security

Developed countries of the world have put in place strategies to control its population as shown in Figure 4, but it has been observed that the escalating population in developing countries is posing security challenges in a number of ways (Sherbinin, 2011).

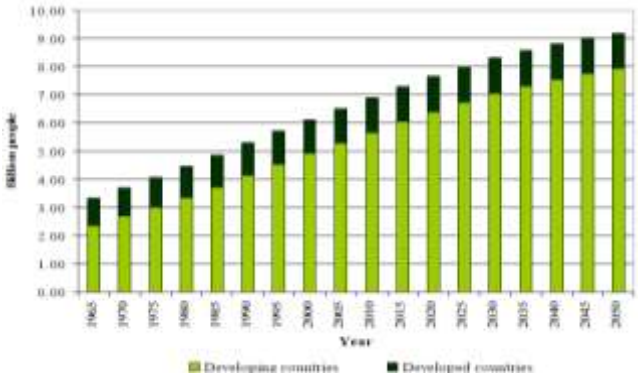

Fig.4: World Population, 1965 – 2050**. Source:** Peter (2013); FAO (2009).

Though, the rise in world population could be described as a natural phenomenon, there are concerns by the developed nations about the impact of population growth on their national security (Sherbinin, 2011). Around 1950s, the U.S response to world population growth was nonexistent despite early urgings by some prominent activists and demographers to combine fertility reduction efforts with the broader public health measures already taking place in the developing world. Later, following recommendations by

Draper Committee (set up by President Eisenhower in 1958) that the U.S. government should engage itself in population programs in any country that might request its assistance, discussion of family planning had become somewhat more politically acceptable, as a growing number of public health and religious groups endorsed birth control by the early 1960s. In the continued effort towards population control by the US, the Clinton Administration created the office of Undersecretary of State for Global Affairs to oversee population-related issues, among others. The United States did much to promote new thinking on international population issues that recognizes the crucial role of women' empowerment and education in helping to reduce fertility. According to Sherbinin (2011), population growth can affect national security of the developed world in many ways. The growing population can induce resource scarcity that could result in regional conflicts and population displacements. It is also believed that a rapid growth in the younger age groups together with growth discrepancy among various ethnic or religious groups in a country can cause political and economic instability (Sherbinin, 2011). On the part of the developing countries, feeding the overwhelming human population is a major challenge that could cause hunger, conflicts and general threats to national security (FAO, 2009). Again, the whole fear of population growth can be reduced through advancements in nanotechnology applications in creating efficient and advance technologies towards feeding the world, securing the global environment and participating in stabilizing climate conditions. The overall result would be ability to abate security threats that are related to shortage in food supply, domestic earnings and national conflicts over resources.

3. NANOTECHNOLOGY ADVANCEMENTS TOWARDS NATIONAL DEFENCE

Materials at nanoscale, single atoms or molecules exhibit important properties different from the properties of bulk materials (Musso, 2011; Das *et al.*, 2015). Nanoscience and technology make use of these nanomaterials that have unique physical, chemical, and biological properties towards innovative developments. As an enabling technology that cut across all fields, the applications offered by nanomaterials and *nanosystems* is actualized by combining nanotechnology with other appropriate technologies. In this context, advancements in nanotechnology have potentials to help solve threats to homeland security through developments of improved manufacturing, fabrics and materials, robotics, security, weaponry, vehicles, and nanomedicine for improving the health of military personnel.

3.1. Smart Fabrics and materials

Nanoscientists and technologists have been able to produce nano Teflon by Chemical Vapour Deposition (CVD) process for making water-proof and bullet-proof army tactical vests. This development is credited to Prof. Karen Gleason of the Institute for Soldier Nanotechnologies. The CVD was used to manufacture waterproof surfaces that are ultra hydrophobic shown in Figure 5 (Downing, 2003).

Fig.5: An image of the water-proof and bullet-proof Army outer tactical vest. **Source:** Downing, (2003).

Using CVD, nanolayers of Teflon was deposited on Kevlar panels which is the material used to make bullet-proof vests (Downing, 2003). Teflon is the same material that is used on kitchen frying pans.

3.2. Nano Air Vehicle (Sensor/Nano spy) - Nano Hummingbird

One of the popular successful applications of nanotechnology in different fields is in robotics (Cerofolini *et al.*, 2010; Yarin, 2010). An example is the ongoing reservoir robots (resbots) project used in crude oil wells to collect reservoir data. In a related development to

intelligence and surveillance, a nano spy which is a robot that mimics a flying hummingbird has been successfully created. Hummingbird is the smallest natural bird known that swings its wings more than fifty times per second. Figure 6 shows the nano Hummingbird while hovering (AeroVironment, 2013).

Fig. 6: Nano air vehicle (A nano spy)

The nano air vehicle was the research breakthrough of AeroVironment, based out of Monrovia, Central America. The researchers developed their Nano Hummingbird under a DARPA research contract (AeroVironment, 2013). The nano spy can fly indoors and outdoors. By this development, the next generation of fighter jets is nano-sized jets, the size of a seed that can go anywhere. The scientists are still working on this revolutionary achievement that will facilitate the collection of military intelligence. The development will enhance the operational effectiveness of soldiers and first responders.

3.3. Chemical and biological sensors

Nuclear substances such as phosgene, sarin, mustard gas, chlorine; and biological warfare such as anthrax, Ebola virus, *Brucella*, and anthrax spores have been used on battlefields and in some acts of terrorism. Some others that are both biological and chemical; toxins like botulinum neurotoxin and ricin which are produced by living organisms have also been threats to global security. It becomes important to device ways of detecting and sensing the presence of these substances. According to a study commissioned by Defense Advanced Research Projects Agency (DARPA), key sensor metrics are (Carrano, 2005):

- Sensitivity
- Probability of correct detection
- False positive rate
- Response time

Recently, it has been discovered that the development of improved detection techniques is possible through nanotechnology. Electronic nose and bio-inspired nanosensors are some of the existing nanotechnology-improved sensors. According to Shelley (2008), the application of nanotechnology can help in advancing detection of biological and chemical substances in a number of ways. Because of their small size, light weight and large reactive surface area, engineered nanostructures can improve, by orders of magnitude, the sensitivity, selectivity and response time of sensor technology. Nanosensors have certain advantages over conventional detection techniques. Some nanosensors can detect a target chemical from multiple chemical species (Shelley, 2008). Projects towards the development of more nanosensors are ongoing. For instance, iPhone chemical sensor is being developed by NASA which can help notify security agents in case of any suspected threat. With the involvement of citizens in the use of such sensors, first responders would find it easier to distinguish between false positives and true threats (Jones *et al.*, 2013). A nanosensor called electronic nose has also been created that can be used to differentiate 19 different toxic industrial chemicals (Lim *et al.*, 2009).

3.4. Electrochromic camouflage

'Going invisible' by manipulating light so that soldiers seem to disappear or invisible from their enemy is another way by which nanoscientists have attempted to advance security (Fountain, 2010). Military uniforms would have to be made from fabric which changes colours instantly to blend in with the surroundings. Objects can be made invisible through the use of optical negative-index metamaterials (NIM). The refraction of light through a conventional material is different from its refraction

through a negative-index metamaterial. Optical NIMs have also being applied in antennae, microscopes and circuits (Cai, 2007; Shalaev, 2007; and Xiao, 2010).

3.5. Nano-Armor

Lessons from nature as observed in sea snails and abalone have helped nanotechnologists in developing armour that are exceptionally strong to satisfactorily protect the contemporary combatant (Halber, 2008). With the use of a scanning electron microscope (SEM), Prof. Ortiz and her students investigated the nanostructure of the scales of the dinosaur eel, a species that is believed to have been able to survive enemy attacks for more than 96 million years (Bruet, 2008). Their studies revealed that the four layers of the scales dissipate the energy of a strike, protect the soft tissue beneath the scales, and also prevent the spread of fractures within the scale. The research findings are now being applied towards human body armour (Bruet, 2008)

3.6. Nano-medicine in military

One of the main branches of nanotechnology research is nanomedicine, which is continually breaking grounds in advancing the medical field worldwide. Sometimes, wounded soldiers could lose their lives on battlefield because of delayed medical attention. Professor Joseph Wang at the University of California at San Diego has developed method for screen printing sensors on the waistband of underwear (Yang *et al.,* 2010). On the waistband, the sensor is in close contact to the skin where it can monitor biomarkers in the sweat of the person wearing the underwear (Yang *et al.*, 2010). The anti-toxin uses nanotechnology on packaging films to detect micro-organisms like pathogens that may cause illness or disease. An adhesive chest patch worn by the soldiers is fitted with sensors and a tiny radio. They would be provided vital signs and location to medics via radio, thanks to the sensors. Also, artificial muscles are being developed to enable soldiers to leap tall walls or buildings.

3.7. All-electric warship

One of the challenges with the conventional war ships is that it requires the involvement of thousands troops to run the battleships. An all-electric warship that could be run by a crew of about 100 people is being manufactured by the US Navy researchers. But, the greatest hurdle encountered in this course lies in distributing power to the entire ship. The team of electronic experts has resorted to nanotechnology as a way out of the challenge (Fallon, 2011).

Fig.7: Artistic rendering of the All-electric warship

The overall advantages of the electric warship are in survivability, cost savings and improved effectiveness. In addition, spaces required for energy production on warships are significantly reduced, thereby freeing onboard space that can be used for other functions.

3.8. Advanced manufacturing materials

Another consequence of nanomaterials is the development of advanced manufacturing materials such as improved aircraft bodies and armour parts. Carbon nanotubes (CNTs) are examples of nanomaterials which exhibit very light weight but possess excellent mechanical, thermal and electrical properties. The CNTs are lighter but stronger than steel (Musso, 2011). Nanotubes also exhibit exceptional electrical conductivity and thermal conductivity better than the conventional copper (Musso, 2011). Hence, the nanomaterials have the potential towards development of better manufacturing materials. Many other security-related nanotechnology developments have been found. For instance, in the area of combating crime the research on nano-'fingerprints' that can aid identity

verification is ongoing. The nano-'fingerprints' can be used to verify ID cards, passports and related documents with just a scan. This nanotechnology concept can also be applied in the packaging of products and its measured accuracy has been reported to be greater than DNA tests with a reliability of about a million trillion. In addition, nanotechnologists especially researchers in the US military have recorded several breakthroughs in the direction of nondefense.

4. CONCLUSION

Nanotechnology is perceived as the next phase of industrial revolution and possibly more beneficial than earlier revolutions. Humanity is faced with a number of lingering challenges among which security is most fundamental. Thus, national security issues which are multidimensional have become extremely important aspect of global society. It involves the greater task of protecting citizens and state from organized crime, responding to natural and man-made disasters and preventing terrorist acts. Different applications areas of nanotechnology in national defence have been identified with reference to the recent advancements in nanoscience and technology. In order to promote vibrant researches in nanotechnology towards security objectives, security R&D activities are essential. This way, potential benefits exist in protecting against terrorism and crime; improving security of infrastructures and utilities; attaining efficient intelligence surveillance and border security; restoring security and safety in case of crisis.

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