GLOBAL INSECURITY AND NUCLEAR NEXT-USE

A Briefing Paper
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1. DEFINITION OF THE GLOBAL PROBLEM

Climax, 61 Kilotons, Nevada, 1953

Everything about the atomic bomb is overshadowed by the twin facts that it exists and its destructive power is fantastically great.

--Bernard Brodie, *The Absolute Weapon*, Harcourt, Brace and Co, New York, 1946, p. 52.

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The focal question of this paper is whether and how nuclear next-use can be avoided, and if not, what should we do to prepare for this eventuality?

The next-use of nuclear weapons is of unknown probability. Such next-use is defined here as detonation against military and civilian targets as distinct from mere threat of use expressed in coercive diplomacy and weapons displays of various kinds. Two types of nuclear next-use may be defined. The first is nuclear next-use by a state against any human target (precluding nuclear tests); the second is nuclear next-use by a sub-national actor against any human target.

Table 1.1 Direct Driving Forces of Nuclear Next-Use

Near or actual nuclear next-use by a state

- ***a. Driven by domestic imperatives that drive post-colonial states***
- ***b. State nuclear next-use may be result of prior sub-national nuclear next-use***
- ***c. Crisis management fails due to increasing number leading to state nuclear next-use***
- d. ***Near or actual nuclear next-use in regional context may drive one or more global nuclear power to enter the fray with escalation risks***
- e. ***Megaterrorism threat or next-use drives state next-use***

Nuclear next-use by a sub-national actor

- ***f. Number and intensity of internal wars increases***
- ***g. Great power interventions accelerate***
- ***h. Nuclear states fail to control leaks of weapons, fissile material***
- ***i. Nuclear next-use by state presents irresistible target***

Note: Driving forces in blue are judged below to be predictable; driving forces in gray are judged to be unpredictable.

At least twenty powerful driving forces converge on this pessimistic conclusion. The nine drivers directly interrelated with nuclear next-use are listed above in Table 1.1. Wherever and whenever next-use occurs, whatever its source and motivation, this event will immediately transform the way that humans inhabit this planet.

The "balance of terror" that dominated the Cold War for five decades began only a few years after nuclear weapons were first used to obliterate two cities. During this period, nuclear weapons had qualitatively transformed the problem of war between great powers. The *qualitative* transformation does not come simply from the greatly increased destructive power these weapons yield. Nor did it arise from the gargantuan nuclear arsenals that were and remain absurd by any calculus.

The central issue was and remains the *apocalyptic* power of nuclear weapons. Nuclear weapons represented, for the first time in history, the prospect that fighting war could extinguish humanity itself rather than merely vanquish or even exterminate an adversary.

In its worst form, global nuclear war might trigger nuclear winter, and even threaten the existence of nature itself. Other forms of rapid mass murder exist—chemical and biological weapons for example; and many ways have been used in the last decades to kill millions relatively slowly with methods ranging from starvation to machetes. But none of these grim methods comes near the absolute power of nuclear weapons.

Since the Cold War ended, global apocalypse remains possible. But the world in which nuclear weapons exist has changed dramatically. Nuclear weapons now exist in a global system constituted of:

a) Great powers with enormous superiority over most states due to combined and separate conventional and nuclear offensive threats; [United States and its allies; Russia, China]
b) States locked in conflicts that are stabilized by defense-dominated deterrence and without recourse to nuclear weapons; [past: North Korea]
c) States engaged in traditional nuclear and conventional high-risk standoffs based on deterrence by retaliatory threat with constant danger of preemption; [Israel; India and Pakistan] and
d) States with no adversaries in sight and not driven to acquire defensive or offensive deterrent capabilities either directly or indirectly extended by others.[1] [New Zealand; Mexico]

Consequently, nuclear weapons are now woven into international affairs in a more complicated and multi-dimensional fashion than during the Cold War. Four trends are observable in this regard, namely:

Trend 1: The triangular nuclear standoff between the United States and its nuclear allies in Europe, the former Soviet Union, and China has shifted to general rather than immediate deterrence against the threat of pre-emptive attack. At the global level, nuclear weapons have receded into the "background" of great power politics, and serve as hedging insurance against regression to confrontational postures by any one of these great powers against the others, whether due to domestic or external causes. This move away from global nuclear war led to significant reductions in American and Russian deployed nuclear forces and the abandonment of Soviet nuclear weapons and material by those who inherited them (See Attachment B for details).

Trend 2: Regional conflicts and local security dilemmas have driven small and regional powers to proliferate nuclear weapons in recent years—most obviously between India and Pakistan, but also in Korea and potentially in the future, Iran offsetting Israel's nuclear force. These arsenals are primarily targeted against neighbors who are geographically proximate rather than inter-continentally, or against great powers that have forward-deployed forces or project power into these conflict zones. These nuclear forces are small in number and arguably serve immediate deterrent roles due to locally "hot" conflicts that could bring these these smaller nuclear powers into head-on collisions. Consequently, nine states now wield the nuclear sword—the United States,

[1] P. Morgan, *Deterrence Now*, Cambridge University Press, London, 2003, p. 237.

Russia, China, Britain, France, Israel, India, Pakistan and soon, possibly Iran and North Korea.

Trend 3: Transnational and networked terrorists and sub-national actors such as religious cults actively seek nuclear weapons capacities ranging from "dirty" radiological weapons to nuclear weapons that may leak out of state stockpiles kept by the great nuclear powers, or acquired from a small nuclear state. If these non-state actors achieve nuclear status, they are likely to use these weapons for coercive threats rather than for deterrence—or may simply detonate them as part of their insurgent strategy against local targets (detested political elites, for example), regional targets (Israel, for example), or global targets (the United States or its allies, Russia, and China).

Trend 4: The revolution in military affairs has rendered it easier for the great nuclear powers to extend deterrence without relying on nuclear weapons-of-mass destruction. Forward-deployed conventional forces are still slow and bulky—but over the next two decades, will become stealthier, smarter, faster and smaller and therefore, much harder to target by local conventional or nuclear weapons. Three effects of this fourth trend are already observable and will accelerate:

a) Great nuclear powers, especially the United States, are likely to intervene against threatening states, especially those that seek nuclear weapons and/or lend support to non-state actors—witness Iraq;
b) Small and regional nuclear powers will accelerate their development and acquisition of long-range delivery systems in order to threaten directly the homelands of the great nuclear powers and thereby deter them from entering into local frays; and
c) Great nuclear powers, especially the United States, will invest heavily in defense-dominant strategies and technologies to counter crude, minimalist nuclear threats from third-rate nuclear powers attempting to counter local conventional dominance; and wholly new weapon systems based on converging IT-computation, nanotechnology, and nano-biotechnology will accelerate this trend and endow the United States and other technologically powerful states with ways to partly or completely neutralize such long-distance threats to both homeland security and extended deterrence based on forward interventions.

These four trends converge to increase the probability that nuclear weapons will be used in war in the coming two decades. Considered separately, none of these trends would necessarily lead to nuclear next-use. Ordinarily, great powers will keep their distance. Local and regional nuclear-armed states will either avoid hot wars or run them as limited wars under the deterring influence of their crude nuclear weapons. All nuclear powers may keep fissile material and weapons stockpiles secure enough to avoid leakage via any route to non-state actors. Great power intervention may terminate nuclear proliferating states and replace them with non-nuclear states. Small nuclear states may be unable to acquire long-range delivery systems or if they do, will be deterred from rattling their own nuclear weapons by the overwhelming offensive nuclear and conventional forces of the great nuclear powers and their local allies and friend.

Considered together, however, complexity and unpredictability associated with the interaction of these different players at different levels is more likely than not to overwhelm controls and rational decision-making somewhere, sometime, somehow. The Cold War was managed as a nuclear balance of terror because the security elites in Washington and Moscow developed and over time, observed some rules to the game. Nuclear weapons became the ties that bound the two adversaries to each other. Even then, they ran close to the brink of nuclear disaster on more than one occasion. "Truels"—or three-way standoffs—are inherently more unstable than duels due to the inability of each party to know if the third is holding fire in the hope of the other two eliminating each other. Part of the problem with the emerging global triangle at the end of the Cold War was precisely that no-one knew if China knew or played by the same rules.

In a four-way standoff where two local nuclear adversaries, each with backing from an external nuclear great power, come to blows over a contested area (Kashmir, for example) with ties to global terrorism and great power interests (the Taliban and Al Queda, for example), wherein transnational terrorists acquire nuclear weapons from persistent attempts to penetrate poorly secured nuclear stockpiles (in Russia, for example) and use them against one of the local nuclear powers or its backers (India? United States or its allies), then each player becomes increasingly concerned about pre-emption and escalation risks to their own existence as they struggle with tying and untying knots and with determining who is pulling on which rope in the overall tangle. The apocalyptic prospect contained in the core ideas of *mutually assured destruction* based on *existential deterrence* will not suffice to avoid nuclear next-use in such complex and chaotic conflicts—especially *ambiguous* next-use that seeks to gain political and military advantage in the midst of fast-moving conflicts. (By ambiguous, we mean no-one claims or easily identified as the source of the attack).

Put another way, great powers may not keep their distance when global stakes embroil them in regional conflicts such as Korea. Local nuclear powers such as North Korea may collapse under pressure and lose control of nuclear weapons in the midst of civil war and external intervention in the Peninsula. Nuclear weapons may be used pre-emptively by one faction or another in such a war to fend off further intervention or South Korean occupation of the North. We may never know who pulled the trigger on a nuclear attack on Seoul, Tokyo, Beijing, or Guam.

2. Implications of Emerging Technologies for Nuclear Next-Use

In this section, we first review briefly the trends in both nuclear and nano-scale technology. (See Attachment B for a more complete description). We then note the implications of rapid development and widespread adoption of nanotechnology on the role played by nuclear weapons.

In the short to medium-term, we find that nanotechnology will reinforce great power propensity to intervene militarily and non-state actor ability to launch precision strikes—two effects that will increase the risk of nuclear next-use, whereas great power reliance on background general deterrence and the propensity of small and medium states to proliferate nuclear weapons and to project long range nuclear threat will be largely unaffected. Only in the long-term could nanotechnology (married with other converging technologies such as IT/computational advances) disrupt deterrence, compellence, and reassurance projected by nuclear threat.

2.1 Impact of Nanotechnology on International Security

The impact of nanotechnology on state-centric security concerns in the short- to medium-term is speculative. A complete analysis of this impact would include the possibility that nanotechnology would change the distribution of physical resources, for example, by facilitating the shift to a solar or hydrogen economy and rendering oil valuable primarily for its materials hydrocarbon value.

Looked at with a narrower military frame of reference, in the long run, according to RAND experts, entire weapon and support systems will be built bottom-up with micro- and nano-scale parts that will be much cheaper than those made with today's top-down macro-engineering production. At first, this trend will become evident in transforming the sensing and processing of information in a variety of civilian and military applications. To this end, the US Defense Department is a major (but not the biggest) supporter of nanotechnology research. In 2003, DOD is spending $201 million of the $710 million US National Nanotechnology Initiative budget on research in nanoelectronics, magnetics, nanomaterials, and detection and protection against chemical, biological, radiological and explosive threats.

2.1.1 Short-Term Applications: Eventually, nanotechnology will enable completely new types of defense systems and offensive weaponry. In the short term, applied nanotechnology in defense systems range from "enhancing the individual soldier" to completely new surveillance and intelligence gathering tools. Much research is underway to reduce the weight of ammunition and food storage and to strengthen equipment. An anti-corrosion, nanocoated paint, for example, is already undergoing navy tests.

2.1.2 Medium-Term Applications: Numerous applications are being sought in the area of bioweapons defense that combine biochemical sensors for early warning with antimicrobial emulsions to defeat biological attack by viruses, bacteria, spores and fungi (NanoBio Corporation has research underway in this area). The US Army-funded Institute for Soldier Nanotechnologies has three areas of focus: protection against bioweapons and ballistic effects; human performance enhancement helping to lift heavy objects; and injury intervention and cure. One project aims to design a new "bodysuit" that incorporates features of smart fabric with lightweight protection (see Figure 2.1).

These types of radical innovations may aggregate to more than incremental improvements in great power, especially American, interventionary capacities. If so, then early military use of nanotechnology would foster the fourth trend noted earlier, namely, that the revolution in military technologies encourages the great nuclear powers, to intervene against threatening states, especially those that seek nuclear weapons and/or lend support to non-state actors. Should such interventions eliminate sources of nuclear attack, such uptake of new technology will dampen the risk of nuclear next-use.

Conversely, to the extent that such technologies are spread by widespread early adoption in civilian production and consumption, then these technologies will become available to those able to adopt and adapt to them quickly. This is probably not the latecomer, post-colonial nuclear states that will be trying to obliterate distance to counter-deter great powers operating against them or in their vicinity although nanotechnology advances might also enable the proliferation of some currently controlled processing capabilities that are not of much interest to sub-national actors (for example, nuclear isotope separation).

Rather, networks of non-state insurgents are likely to be early adopters and users, and if this enables them to deliver their own nuclear next-use during crises, then nanotechnology may play a role in increasing the hazard of escalating nuclear war.

2.1.3 Long-Term Structural Impact on Nuclear Deterrence: If and when nanotechnology moves from expensive materials to the revolutionary concepts of molecular assembly, possibly in conjunction with artificial intelligence derived from great leaps on computational power and software, and further spliced with advances in biotechnology, then some have argued that this synergistic and convergent technological shift will render nuclear deterrence obsolete and even unstable. (See Figure 2.2 for scenarios created by one such vivid imagination).

This argument rests on undefined and unrealizable abstractions such as the ability of advanced nano-bio-informational hybrid technologies to construct physical defenses in very short terms in "nanotech arms races." Without an exhaustive analysis, this vision is fundamentally flawed in that it neglects the absolute power of nuclear weapons to blast, irradiate, and vaporize matter that would be constructed as a defensive barrier by the ostensible countervailing power of combinatorial nano-bio-information technologies. Short of becoming North Korean and living underground in nano-constructed caves most of the time to escape nuclear retaliatory attack, nanotechnology defenses are fantastic ideas that do not undo the irresistible gravitational effects of nuclear weapons on minds and politics.

In reality, realization of offensive nanotechnology weapons of mass destruction (WMD) would simply reinforce the existential deterrent effects of nuclear weapons unless one power managed to develop and deploy such weapons in complete secrecy. Given that only big powers are likely to mobilize the resources to make such an enormous technological breakthrough, let alone have the resources and military ability to deploy nanotechnology-WMD against other nuclear-armed states, this degree of secrecy seems unlikely—and the other great states allowing such an attempt to succeed once it became public is equally implausible.

In reality, more than one state would develop differing types of nanotechnology-WMD at the same time, the net effect of which would be to reinforce the overarching and still over-whelming general nuclear deterrence with a reinforcing threat. In short, far from destabilizing the nuclear balance of terror or neutralizing the power of nuclear weapons, the existence of generally available nanotechnology-WMD to states would be ballast on the keel.

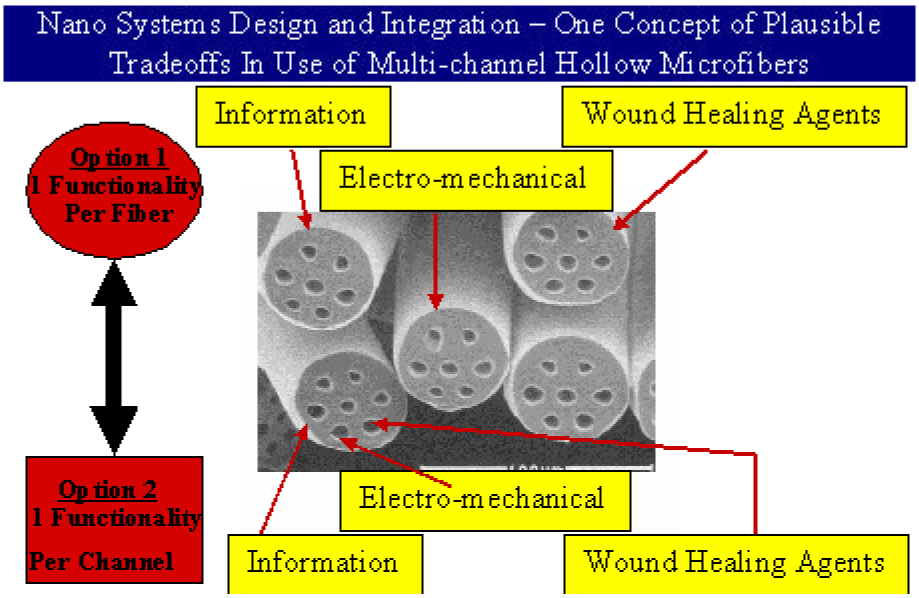
The exception might be large, technologically capable states that develop dual-capable nanotechnology that are not nuclear-armed (Germany and Japan might be cases in point). Such states might “flex their nanotech muscles” to disrupt existing perceptions of power and rank hierarchy in international security affairs. However, these states are already “virtual” nuclear weapons states in many respects, and live with the costs and benefits of extended nuclear deterrence. They would likely elect to live as similar “virtual” nanotech weapon states lent extended nanotech deterrence by nanotech-WMD-armed allied states, just as they already do with nuclear weapons.

2.1.4 Nanotechnology and Nuclear Next-Use: Should deterrence fail or simply not pertain and nuclear next-use occur in a major conflict, with resulting transformative impacts on the ways that humanity lives on the planet in terms of urban form, mobility, and trade, then societies that adopt nanotechnology early would be more resilient against the enormous social stresses from such a rapid transition from the current world system. Such states would be in the best position to shift from a world economy based on international trade in both raw materials and finished goods to primary reliance on decentralized production for local consumption, using locally available materials.

Until then, everyone remains extraordinarily vulnerable to the immediate and long-term aftermath of nuclear next-use and nanotechnology does little to make us immune to the on-going effects of nuclear weapons, both positive and negative.

Figure 2.1: MIT INSTITUTE FOR SOLDIER NANOTECHNOLOGIES (ISN)

MIT hosts the US Army funded ISN, along with corporate partners such as Dow Corning, Triton Systems, Dendritic Nanotechnologies, Inc., Nomadics, Inc. and Carbon Nanotechnologies, Inc. and W.L. Gore and Associates. One project in its seven fields of research is on Battlesuits made of microfibers.



Project 7.3: Battlesuit systems architectures for optimal use of nanotechnologies

Approach
To meet Project 7.3's objectives, researchers use the following approaches:

- Harvest existing battlesuit and space suit architectures from Army and NASA
- Devise new architectures using human nervous system and human skin and blood system as models
- Develop exfoliation diagrams for vital survivability systems, e.g. ballistic protection, performance enhancement, wound healing, thermal management, and communications

From: http://web.mit.edu/isn/research/team07/project07_03.html

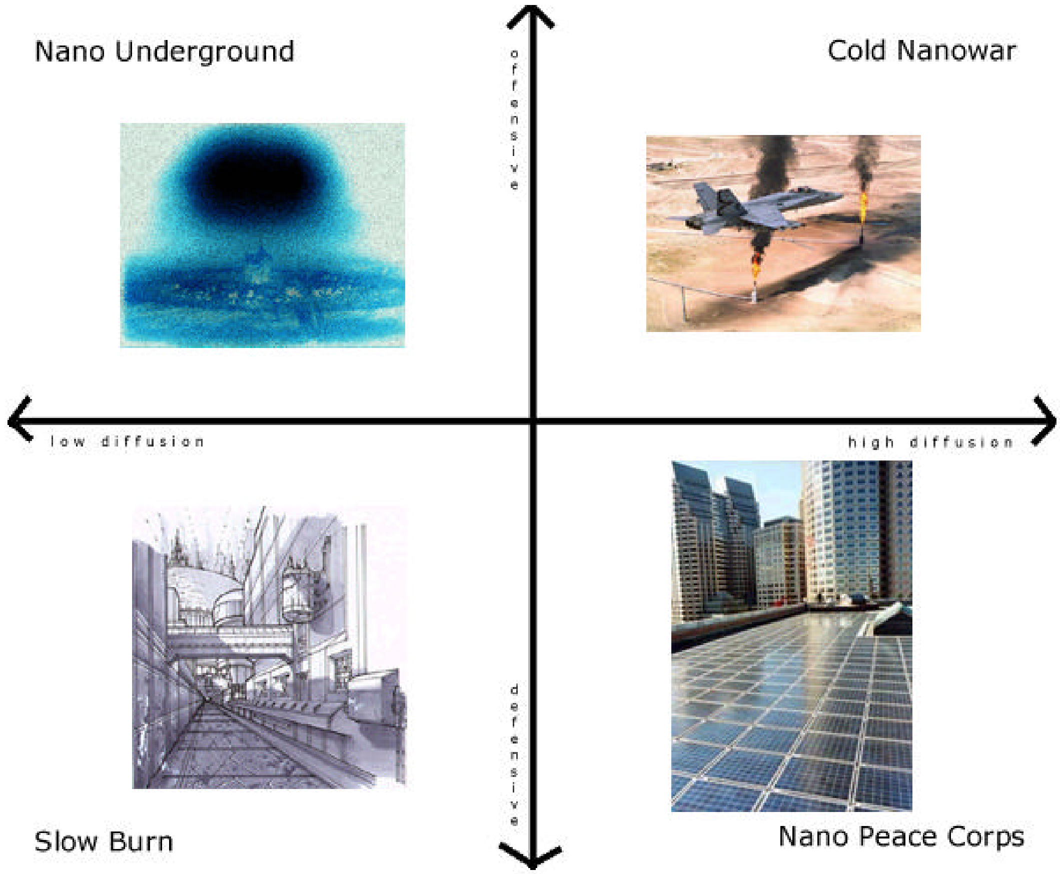


Figure 2.2: Imaginary Nano-Wars and Nano-Peace

Source: **www.plausiblefutures.com, "Nanowar Scenarios and the Future of Warfare," *Plausible Futures Newsletter*, August 2003**

3. Anticipating Nuclear Next-Use

3.1 **Avoiding Nuclear Next-Use**

Everything that can be should be done to avoid nuclear next-use. Every organization and every citizen should have an explicit responsibility and role in avoiding nuclear next-use, including:

- Exploiting the transparency, social networks, and surveillance capabilities of civil society to penetrate, identify and even disable state and non-state WMD proliferating actors and activities;
- Networking agile and transnational corporate plant and workplaces, and networking city-level surveillance, police, and first responders on a global basis;
- Reducing vulnerability to WMD, especially nuclear attack, by minimizing the presentation of lucrative targets and using ubiquitous sensors to track and identify the signatures of such attack at key points of departure and entry such as port cities.
- Supporting global institutions and national governments that minimize the reliance on general and extended nuclear deterrence, nuclear nationalism, and unilateral military interventions.
- Applying new defensive technologies to support peacemaking, peacekeeping, and humanitarian missions that resolve internal and cross-border conflicts.
- Applying new defensive technologies to avoid and to block breakout from local and regional arms control and disarmament agreements.
- Finding ways to strengthen collective enforcement capacities to deter or compel small states to not proliferate WMD, and to avoid great power unilateral interventions to this end.

We need to also realize the ten solutions listed in Table 3.1. More systematic analysis is called for to identify the technological requirements and opportunities arising from implementing the whole array of necessary solutions.

TABLE 3.1: AVOIDING NUCLEAR NEXT-USE

Predictable Solution-Drivers

1. ***Momentum of residual, traditional arms control-disarmament institutions***
2. ***Extended nuclear deterrence remains general and sufficient***
3. ***IAEA grows teeth***
4. ***Transparency increases so that proliferators are discovered immediately***
5. ***New technical barriers impede un-authorized access and attack***

Unpredictable Drivers, Solutions

1. ***Cooperative engagement is more effective than unilateral military intervention***

2. ***Some nuclear or proliferating states simply collapse or are defeated by the United States or great powers***
3. ***Regional nuclear states prove to be rational, cautious, crisis-stable***
4. ***Regional conflicts are stabilized and resolved***
5. ***Anticipatory steps in response to nuclear next-use are taken now***

3.2 Responding to Nuclear Next-Use

Although it is conceivable that the four trends that lead irrevocably to nuclear next-use can be reversed, it is not prudent to assume that we will be able to do so effectively or forever. Instead, we should anticipate failure now in order to reduce the immediate and catastrophic effects of failure.

Depending on the type of target, nuclear next-use will affect drastically every aspect of our lives. A single successful nuclear attack on any one of the world's major cities will disrupt, even shut-down, international commerce, travel, and communications, at least for months and even years.

Multiple or serial next-uses against cities will lead to rapid de-population and redesign of vulnerable urban infrastructure to less concentrated and less targetable forms such as linear cities, local and regional production and away from a globalized economy, massive increases in surveillance, reduction in privacy, and increased social and political control on individuals and minorities. Millions of people may decide to de-target themselves by moving out of mega-cities. Next-use would likely contract permanently the reach of global markets.

Some of the result specific responses that would be implemented, many of which will be dependent on technological innovations of the kinds discussed above to be affordable in sufficient quantity to be effective, include:

- Stronger border controls and individual identification and control systems of all kinds on people and objects;
- Ubiquitous sensor systems in critical areas on a currently inconceivable density and with devolved intelligence based on networked information processing;
- Self-reliant energy and food production systems;
- Virtual mobility to substitute for cross-border travel;
- Long-term relocation and redesign of high-impact, centralized and vulnerable infrastructure such as big cities, dams, LNG terminals, airports, container ports, bridges, financial city centers and buildings;
- EMP-hardened civilian computing and communication systems on a devolved basis, not just for command authorities;
- Rapidly-deployable, globally networked corporate and city-level first responders in anticipation of next-use;

- Interoperable, multinational forces to capture fissile material and nuclear weapons operating under permanent UN Security Council authority to act immediately;
- Defensive weapon systems to preempt or disable bio-nanotechnological weapons and to counter asymmetrical threats such as ecosystem, species or environmental terrorism, or bio-warfare.

Many of these measures will have effects that will undermine or worsen existing insecurities. However, nuclear next-use will drive us to consider and to adopt at least some subset and some version of these measures, and others not considered here.

4. Conclusion

From my experience, if nuclear war happens again, it would be better that all should be killed. Those remaining alive would all be crippled. I know because I have suffered it all. It is worse than dying. You become crippled, no eyes, no nose, you have blood oozing out of your ears. Your legs just crumble off. What's the meaning in living like this?

--Mrs. Kim Jeong-soon, Korean survivor of Nagasaki bombing, interviewed May 1988, Seoul

ATTACHMENT A: DRIVERS OF NUCLEAR NEXT-USE

This attachment provides notes, analysis, and sources drawn upon in producing the text of this report on the risk of nuclear next-use. In the first section, we provide a summary analysis of the key driving forces of nuclear next-use, and a review of the interrelationships between these forces. We reflect briefly on the significance that the unpredictable forces may be more interrelated with other unpredictable forces than are the predictable drivers. Next, we list in summary the complete list of driving forces for nuclear next-use (only the top five or so predictable and unpredictable forces were used to simplify the textual analysis). We also list other global problems that are linked to nuclear next-use as distinct from drivers of nuclear next-use (these may not be completely disparate sets). Finally, we provide explanation and notes with respect to each driver.

[Editorial Note: for reasons of time, the drivers' are not ordered the same way in this attachment as in the textual analysis.]

SUMMARY ANALYSIS OF DRIVING FORCES OF NUCLEAR NEXT-USE

More than twenty driving forces behind nuclear next-use were identified for this study. Of these, the five most significant were selected as drivers of both the problem and solutions. These in turn were divided into predictable and unpredictable but significant driving forces, both for the problem and the solution. The drivers mentioned in the analytical text are selected from a larger set of drivers in each category that are listed in Table A1.

The five most significant and predictable problem-drivers are:

1. *Global governance undermined by unilateral great power interventions;*
2. *Regional proliferation driven by local security dilemmas;*
3. *Domestic political imperatives driving proliferation in post-colonial states;*
4. *Failure to control nuclear stockpile leakage in nuclear states; and*
5. *Technological Modernization of Nuclear Weapons.*

Below each driver are listed interrelated drivers that constitute either possible sequences or possible multiple determinants at a particular time and place. Most of the (light blue) *predictable* drivers are interrelated with other predictable, rather than the unpredictable drivers (which are highlighted in gray).

It is almost entirely predictable, for example, that regional interstate security dilemmas will be worsened by great power interventions, and that increasing numbers of nuclear decision-makers will make it much harder to control escalation at a nuclear brink (as might arise between India and Pakistan on the one hand, and China and the United States on the other). Combinations of regional conflicts are particularly fraught with escalation potential because in such cases, great nuclear powers such as the United States may be drawn into two major regional wars concurrently, and feel obliged to use nuclear threat or actual use to avoid over-extension or defeat.

However, one catastrophic outcome is the result of mutually reinforcing drivers in which the unpredictable drivers may result in chain reaction next-uses. This is the fifth driver in which crisis management fails due to the large number of states who fail to stop nuclear escalation because they are driven by their fears of what other states may do when faced with more than one nuclear adversary.

The five unpredictable drivers that are significant for nuclear next-use are:

1. *The number and intensity of internal wars increases;*
2. *Great power interventions increase;*
3. *Megaterrorist threat increases; and*
4. C*risis management fails due to increasing numbers of nuclear-armed states*

In contrast to the predictable drivers, the *unpredictable* drivers are more interrelated with other unpredictable than with predictable drivers (the other unpredictable drivers not selected here are shown in TableA.1). Only the increasing number and intensity of internal wars is primarily interrelated with predictable factors. The other unpredictable drivers are either interrelated with composites of predictable and unpredictable drivers, or are interrelated with only unpredictable drivers.

The importance of sub-national nuclear next-use, especially an ambiguous attack, in complicating and even precipitating state nuclear next-use suggests that we should pay particular attention to predictable and unpredictable driving forces that are interrelated with this driver, namely:

- *Number and intensity of internal wars increases*
- *Great power interventions accelerate*
- *Nuclear states fail to control leaks of weapons, fissile material*
- *Nuclear next-use by state presents irresistible target*

TABLE A1: COMPLETE LISTING OF NUCLEAR NEXT-USE DRIVERS

Predictable Problem-Drivers

1. ***Great power unilateralism and conflict undermine global security governance.***
2. ***Interstate security dilemmas drive regional proliferation***
3. ***Domestic imperatives drive post-colonial states***
4. ***Nuclear states fail to control leaks from stockpiles***
5. ***Crisis management fails due to increasing numbers of nuclear-armed states***
6. ***Nuclear weapons establishments drive nuclear modernization***
7. ***Great powers hedge against uncertainty***
8. ***WMD threat grows against vulnerable infrastructure***
9. ***Global markets rapidly diffuse modern industrial capacities via commerce***
10. ***Increased cross-border flows of people***

Unpredictable Problem-Drivers

5. ***Near or actual nuclear next-use by a state***
6. ***Nuclear next-use by a sub-national actor***
7. ***The number and intensity of internal wars in1`creases***
8. ***Great power interventions increase***
9. ***Mega-terrorism***
10. ***New global cold war***
11. ***Technological breakthroughs***
12. ***Space-based nuclear weapons or infrastructure***
13. ***Major nuclear weapons accident***

GLOBAL SOLUTION

Predictable Solution-Drivers

6. ***Momentum of residual, traditional arms control-disarmament institutions***
7. ***Extended nuclear deterrence remains general and sufficient***
8. ***IAEA grows teeth***
9. ***Transparency increases so that proliferators are discovered immediately***
10. ***New technical barriers impede un-authorized access and attack***
11. ***Conventional weapons are more lethal, smaller, faster, cheaper***

Unpredictable Drivers, Solutions

6. ***Cooperative engagement is more effective than unilateral military intervention***
7. ***Some nuclear or proliferating states simply collapse***
8. ***The United States and/or great powers defeat-in-detail proliferators***
9. ***Civil society networks take charge***
10. ***New national pro-abolition political leadership emerges***
11. ***Defensive technologies and "revolution in military affairs" devalue offensive nuclear threats while controls succeed on alternative offensive threats***
12. ***Borders dissolve or crossed so often***
13. ***UN Security Council creates a meaningful multilateral framework***
14. ***Extra-planetary threat to human survival***

TABLE A1.2: NUCLEAR NEXT-USE DRIVERS

Predictable Problem-Drivers

11. **Great power unilateralism and conflict undermine global governance**
    - ***Domestic imperatives drive post-colonial states to proliferate poses great power coordination problem***
    - ***Interstate security dilemmas driving regional proliferation pose great power coordination problem***
    - ***Global conflict between great powers reduces collaborative controls on nuclear leaks***
    - ***Great power conflicts compound regional nuclear escalation due to n-player problem***

12. **Interstate security dilemmas drive regional proliferation**
    - ***Great powers worsen regional interstate conflicts by providing external support for proliferation***
    - ***Crisis instability due to increasing numbers makes insecurity worse at brink of war***

13. **Domestic imperatives drive post-colonial state proliferation**
    - ***Near or actual nuclear next-use by a state may result in next, next-use driven by revenge by a state or non-state actor***
    - ***Regional interstate security dilemmas fuel nationalist nuclear motivations***

14. **Nuclear states fail to control leaks from stockpiles**
    - ***Great power unilateralism and conflict make controls weaker***
    - ***Nuclear establishments achieve huge hedging nuclear warhead stockpiles, resist shutdown of fissile material production***

15. **Technological Modernization of Nuclear Weapons**
    - ***Megaterrorism threat using bio or chemical weapons drives small nuclear weapons aimed at reaching deeply emplaced command posts, stockpiles, or bio-chem squads***
    - ***Nuclear establishments continue to develop such weapons under own momentum in search of missions and budgets***

TABLE A1.2: NUCLEAR NEXT-USE DRIVERS (continued)

Unpredictable Problem-Drivers

1. **The number and intensity of internal wars increases**
    - ***Great power intervention increases may accelerate number/intensity of internal wars***
    - ***Worsens inter-state security dilemmas and drives regional proliferation***
    - ***Worsens domestic imperatives of post-colonial states to proliferate***

2. **Great power interventions increase**
    - ***To halt excesses, avoid escalation, or exploit internal conflicts***
    - ***Massive multilateral great power intervention follows sub-national nuclear next-use***
    - ***To search-and-destroy anti-megaterrorists singly or in coalitions***

3. **Mega-terrorism**
    - ***Number and intensity of internal wars increases***
    - ***Nuclear next-use by state drives megaterrorism***
    - ***Great power interventions increase***
    - ***Nuclear states fail to control leaks of weapons, fissile material***

4. **Crisis management fails due to increasing numbers of nuclear-armed states**
    - ***Domestic imperatives drive post colonial state proliferation***
    - ***Interstate security dilemmas worsen***
    - ***Number and intensity of internal wars increase in a region laden with insecurities***
    - ***Nuclear great powers intervene in a regional conflict or in response to near or actual nuclear next-use by a state or by a non-state actor***
    - ***Near or actual nuclear next-use by a state, or megaterrorism or nuclear next-use in the region by sub-national actor from the region creates crisis***

5. **A major nuclear weapons accident contaminates a major global city**
    - ***Great power intervention increases may accelerate number/intensity of internal wars***
    - ***Domestic imperatives drive post-colonial state proliferation with weak safety procedures and control technologies***

LINKED GLOBAL PROBLEMS

1. Conventional warfare—as driver of conflicts with nuclear dimension; nuclear as substitute for conventional means of destruction; as combined threat with RMA making conventional wars more not less likely
2. Diversion of science and resources into nuclear weapons, lack of binding ethical frameworks for scientists and engineers
3. Arms trade and weapon diffusion (NWs the great equalizer)
4. Misperception, ethnocentrism
5. Global nuclear war leads to climate change (ozone damage, nuclear winter)
6. Militarization of space
7. Governmental secrecy and unaccountability
8. Nuclear testing and damage, nuclear fuel cycle
9. Global energy insecurity
10. Unaccountable and unrepresentative UN Security Council/UN system
11. Nuclear winter/climate change
12. Nation states and territorial sovereignty, especially border geopolitics and population management

EXPLANATION AND SOURCES OF NUCLEAR NEXT-USE DRIVERS

Predictable Problem-Drivers

16. ***Great power unilateralism and conflict undermine global governance.*** Driven by bad analysis and ethnocentric misinterpretations of intentions and capabilities of adversaries combined with over-confidence due to high-technology conventional weapons superiority, great powers continue to embark upon disastrous military and political interventions that divide domestic polities, stress and rupture key alliances, set up great power conflicts, and undermine core non-proliferation commitments and institutions based on multilateral commitments such as the Nuclear Non-Proliferation Treaty collapses, the International Atomic Energy Agency falls apart, the Comprehensive Test Ban, Landmine, and Chemical and Biological Weapons treaties.[2]
17. ***Interstate security dilemmas drive regional proliferation*** unlinked to great power nuclear deterrence or coercive diplomacy. This localized nuclear veto-power breeds caution but also creates lessening propensity to negotiate settlement of newly emerging conflicts between over territory, economics, environmental issues. As nuclear weapons make conventional force less-usable, these new conflicts find other, non-military expression such as state-sponsored terrorism, displacement into combative economic or diplomatic postures; and, if facing a nuclear great power adversary linked via alliance to a local adversary, such states may need to seek medium- or long-range nuclear threat to great power homelands so as to deter a local adversary's great power ally the forward deployments are non-targetable due to their small size, speed, and stealth.[3]
18. ***Domestic imperatives drive post-colonial state proliferation*** driven by emotional nationalism in search of cohesive identity and immune to regional or global trends (DPRK, India).
19. ***Nuclear states fail to control leaks from stockpiles*** and some weapons, fissile material, technology, knowledge, and nuclear-capable people.[4]
20. ***Crisis management fails due to increasing numbers of nuclear-armed states*** (from the current 8 to 12-20 WMD states by 2020) complicates deterrence and creates a new insecurity spiral feeding on itself with new nuclear opponents creates sequential crises each of which requires unique responses by the United States.
21. ***Nuclear weapons establishments drive nuclear modernization*** in nuclear-armed states—basically, about ~10,000 individuals in 24 countries are responsible for continued vertical and horizontal proliferation.
22. ***Great powers hedge against uncertainty*** and maintain a deterrence-dominated great power system that almost precludes war between them; this is manifested in grossly overblown general deterrence capabilities in the United States and Russia,

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[2] The centrality of these institutions to the security of most states is noted in J. Cirincione et al, Deadly Arsenals, Tracking Weapons of Mass Destruction, Carnegie Endowment for International Peace, Washington DC, 2002, p. 19.

[3] P. Morgan, *Deterrence Now*, Cambridge University Press, London, 2003, p. 223.

[4] See M. Bunn, A. Wier, and J. Holdren, *Controlling Nuclear Warheads and Materials: A Report Card and Action Plan*, Washington, D.C.: Nuclear Threat Initiative and the Project on Managing the Atom, Harvard University, March 2003, at: http://www.nti.org/e_research/cnwm/overview/report.asp

each of which keeps thousands of stored warheads. The nuclear great powers over-emphasize nuclear weapons and reduces confidence between them to disarm; and the sledgehammer nuclear threats may remain more useful than precisely calibrated conventional threats given the difficulty of fathoming adversarial motivations.

23. ***WMD threat grows against vulnerable infrastructure*** and more nuclear powers assign nuclear deterrence to "counter" such threats.
24. ***Global markets rapidly diffuse modern industrial capacities via commerce*** thereby reducing the cost and increasing the speed by which medium and long-range missiles are acquired, enabling small and medium-sized adversaries to project nuclear threat at great power homelands and to offset modernized conventional forces, while these same small and medium-sized states acquire advanced technologies via global commerce including fiber optics, better IT, satellite imagery, diverse communications systems, stealth and precision technologies, and other dual capabilities emanating from the private sector and distributed via global markets.
25. ***Increased cross-border flows of people*** present new targets via new porosity to enraged nuclear-armed adversaries.

Unpredictable Problem-Drivers

1. ***Near or actual nuclear next-use by a state*** due to increase from 8 to 12-20 WMD states complicates deterrence, results in confusion, chaos, crisis instability, and many near-misses.[5] Moreover, the type of next-use may be unanticipated—a small, recently proliferated nuclear state, for example, may use a high-altitude, electromagnetic pulse rather than a counter-value (city) attack against local or global adversaries.

2. ***Nuclear next- use by a sub-national actor*** against Israel, United States, Australia, or against other sub-national actors leads to instant and dramatic changes in behavior at many levels including: greatly reduced international mobility, heightened surveillance, reduced international trade, redesign of cities and infrastructural targets of all kinds. Such attacks will be easier to deliver using off-shelf hardware shelf combined with miniaturized, stealth and monitoring communication technologies that make it easier to mount long-range attacks and harder to stop with surveillance; such pinpoint attacks on high-value, disrupting targets—witness September 11--will amplify the political effects.[6]

3. ***The number and intensity of internal wars increases*** due to social dislocation and the search for viable collective identities; ethnic and religious

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[5] Paul Bracken notes that in a three-way ""truel," in which each of three competitors is in direct opposition against the other two…The players have to decide (l) whether to shoot at all, and (2) if so, which countries to shoot at, with how many missiles, at what targets, and in what order." Moreover, "solutions to the problem require more stringent assumptions about communication, trust, and commitment than with two players, where only weak assumptions are needed to achieve crisis stability. The number of possible scenarios is enormous compared to the two-person duel." Paul Bracken, *The Structure Of The Second Nuclear Age*, September 25, 2003, distributed electronically by Foreign Policy Research Institute, available on-line at: http://www.ceip.org/files/projects/npp/pdf/conference/presentation/The%20Second%20Nuclear%20Age.pdf

[6] P. Morgan, *Deterrence Now*, Cambridge University Press, London, 2003, p. 219.

conflicts and contending worldviews; and revolutionary or reactionary insurgencies that are transnational in scope and organization; such conflicts "spillover" into international affairs periodically but are very fluid, context-dependent, and not amenable to application of gross tools such as nuclear threat; these conflicts are linked via local and regional players to the interventionary actions of multiple nuclear great powers.

4. ***A major nuclear weapons accident*** contaminates a major global city, for example, in a recent proliferator with weak safety procedures and control technology, and drives states to negotiate faster dismantlement of nuclear warheads and weapons movements.
5. ***Great power interventions increase*** due to periodic failure of deterrence drives many formerly non-nuclear states to reconsider their non-nuclear commitments because under nuclear cover, nuclear great powers reserve nuclear deterrence for their own relationships, and engage in much higher levels of conventional conflict and unconstrained short, medium, and long-range attacks delivered either singularly or repeatedly over time than was the case during the Cold War.
6. ***Mega-terrorism*** (short of nuclear detonation) or its threat becomes more realistic (due, for example, to an intercepted sale of actual nuclear weapons or sufficient weapons-grade fissile material for a nuclear or dirty bomb) and generates dramatic technological innovation and design changes, incremental leaps in defensive and offensive technology.[7]
7. ***New global cold war*** arises between Russia-United States, Russia-Europe, Russia-China, or other nuclear-armed states with long-range delivery systems; this factor is especially risky if linked in some way to the possibility of Next Use in a regional conflict by a small nuclear state.
8. ***Technological breakthroughs*** such as "personal centrifuges" that make it harder to control acquisition of nuclear weapons; and increasing trade driven by global investment and finance make it easier to deliver nuclear weapons across borders (cargo containers in port cities, for example)
9. ***Space-based nuclear weapons or infrastructure*** drives local proliferation and threats to C3I systems of great powers, possible crisis instability.

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GLOBAL SOLUTION
Predictable Solution-Drivers

12. ***Momentum of residual, traditional arms control-disarmament institutions*** will constrain small and medium-states from considering/exercising nuclear options; Most states will remain non-nuclear and sustain and reinforce the NPT-IAEA regime; they align and coalesce groups of non-nuclear, near-nuclear, and nuclear states to reconstitute the NPT and reassert Article 6 obligations on the nuclear great powers.

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[7] See R. Garwin, Remarks to Nuclear Terror panel of CEIP November 15, 2002, at: http://www.ceip.org/files/projects/npp/pdf/conference/lottmantranscripts/Garwinterror.pdf; also available in an earlier form at *Technology Review*'s web site, http://www.technologyreview.com/articles/garwin0902.asp?p=1

13. ***Extended nuclear deterrence remains general and sufficient*** to reassure and/or deter proliferation by most non-nuclear states. Indeed, the lower cost and greater reach and lethality of conventional weapons for the great nuclear powers makes long-distance alliances and interventions easier, thereby increasing their sphere-of-influence and the possibility of overlapping spheres-of-influence/power projection zones.[8] The related use of small, fast and hard-to-target forces for such interventions renders targetless short- or medium-range nuclear forces unable to reach "homelands" of nuclear great powers.
14. ***IAEA grows teeth*** and controls fuel cycle leakage and increases NPT member state confidence in the IAEA due to near-universal adoption of 94+ safeguards
15. ***Transparency increases so that proliferators are discovered immediately*** due to improved surveillance and detection technology; information processing, distribution, and analytic capabilities that are integral to the Revolution in Military Affairs;[9] secrecy and deception will be hard, even impossible, to maintain in most states. DPRK example—even there, found out by technical means.
16. ***New technical barriers impede un-authorized access and attack*** involving nuclear and other WMD, for example: trusted person databases, biometrics, shift from radiation-powered or driven devices such as fire detectors or food irradiation machines to x-ray or electron beam acceleration devices; radiological survey devices (post attack surveys of people and property); collective pressurized and filtered air in public buildings against bioterror attacks.[10]
17. ***Conventional weapons are more lethal, smaller, faster, cheaper*** and render nuclear weapons obsolete for deterrence or compellence. Stealth weapons such as UAVs, plastic tanks, "non lethal" chemical weapons that incapacitate humans and machines, draw primarily on the internationalized civilian high technology economy, not on weapons bureaucratically or to military specifications.

Unpredictable Drivers, Solutions

15. ***Cooperative engagement is more effective than unilateral military intervention*** in achieving long-term dismantlement of nuclear weapons capacities by proliferating states such as Iran and the DPRK; this generates a demand for new monitoring and verification technology and systems, and the use of such tools in the cooperative monitoring to ensure non-diversion of "incentives" to military-industrial activities (for example, flow meters on heavy fuel oil to DPRK, cooperative, real-time monitoring, etc).
16. ***Some nuclear or proliferating states simply collapse***, for example, Pakistan or the DPRK, without loss-of-control of weapons or fissile material, and these weapons are either dismantled or transferred to nuclear states.

[8] P. Morgan, *Deterrence Now*, Cambridge University Press, London, 2003, p. 221.
[9] P. Morgan, *Deterrence Now*, Cambridge University Press, London, 2003, p. 208.
[10] R.L. Garwin, *Nuclear and Biological Megaterrorism*, presented at the 27th Session of the International Seminars on Planetary Emergencies, Erice, Sicily, August 19-24, 2002. (A shorter version was published in MIT's Sept. 2002 *Technology Review*, titled "The Technology of Megaterror" at http://www.technologyreview.com/articles/garwin0902.asp).

17. ***The United States and/or great powers defeat-in-detail would-be proliferators*** such as sub-national WMD-proliferating countries, networks, organizations, and individuals ("war on terrorism," "preventive wars."), especially the use of precision-guided aerial attack.
18. ***Regional nuclear states prove to be rational, cautious, crisis-stable***, even more so than nuclear great powers during and after the Cold War.
19. ***Regional conflicts are stabilized and resolved*** by regional leaders and UN-led negotiations
20. ***New national pro-abolition political leadership emerges*** for unilateral disarmament and/or support for general nuclear abolition (Reagan-Gorbachev surprise; South Africa; Ukraine, Khazakstan, Belarus; Argentina and Brazil); and expansion of regional nuclear-free zones.
21. ***Defensive technologies and "revolution in military affairs" devalue offensive nuclear threats while controls succeed on alternative offensive threats*** based on new technologies (such as a successful nano-technology weapon system that slips under an array of defensive systems).[11] In short, forestalling the threat of attack by the threat of defense rather than by retaliation would potentially transform international affairs because, in crises, stability would be much less of a problem as neither side (or no sides in an n-power standoff) could hope to overcome any single nation let alone all nations in a defense-dominated security system. This shift would make nuclear weapons and related delivery systems such as missiles and bombers obsolete. It would also make collective deterrence and collective institutions less salient and unilateral defenses more attractive because a defensively very powerful state on the attack--presumably exploiting a technological shift or a circumvention of strategic defenses--would be inherently difficult to tackle.
22. ***Civil society networks take charge*** by conducting effective surveillance and enforcement, blocking sub-national nuclear next-use, and negotiating cooperative solutions that avoid nuclear proliferation in key countries, while mobilizing to overcome nuclear establishments in the 24 key countries.
23. ***Borders dissolve or crossed so often*** between great and medium-power nuclear adversaries that mass hostage-taking is no longer meaningful threat;
24. ***UN Security Council creates a meaningful multilateral framework*** to ensure proper control and legal, multinational or authorized national capture of weapons of mass destruction anywhere on Earth.
25. ***Extra-planetary threat to human survival***, for example, a meteorite, generates cooperative and multilateral control of existing nuclear arsenals in the course of organizing a collaborative solution.

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[11] As Morgan notes, "While deterrence can certainly be achieved via an impressive defense, normally such a defense seems particularly valuable because it obviates the *necessity* to rely on deterrence. With a good defense hopefully you are safe even if deterrence fails and the enemy does his worst; with deterrence by retaliation you are safe only if he *chooses* not to do his worst. Hence shifting to a defense-dominant world could have major implications." P. Morgan, *Deterrence Now,* Cambridge University Press, London, 2003, p. 225.

LINKED GLOBAL PROBLEMS

1. Conventional warfare—as driver of conflicts with nuclear dimension; nuclear as substitute for conventional means of destruction; as combined threat with RMA making conventional wars more not less likely
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ATTACHMENT B: TECHNOLOGY TRENDS

This attachment summarizes technology trends in nuclear weapons; and nanotechnology.

A. Nuclear Weapons Technology Trends

Overall: Technological innovation in weapon systems is incremental and of limited military utility as nuclear lethality is already unlimited for deterrence purposes. Micro-mechanical devices may enable nuclear weapons to be made into precision weapons for tactical and battlefield uses. Application of advancing computational power continues to increase nuclear target identification and surveillance capabilities, targeting analysis and systems, and increased connectivity has been achieved in most levels and types of nuclear command, control, communications and intelligence systems, at least among the great nuclear powers. The latter systems remain crude in the new nuclear powers, however. Stringent safety procedures and systems, especially one-point locks and other controls, are not used by all nuclear powers.

Specific Trends:

- The bulk of the weapons are in the strategic range in terms of destructive power and delivery system range.
- Theater and tactical nuclear weapons for the most part have been removed from the active US and Russian arsenals; many of the delivery systems no longer exist while warheads are in storage.
- Russian stockpile security is improved by still porous.
- The United States is upgrading "Earth penetrating bunker buster" tactical nuclear weapons (megaton blockbusters would annihilate deep targets but would also create gigantic collateral and downwind damage).[12]
- Micro-mechanical technologies may be applied to the development of micro-fusion bombs that could be used as bunker busters
- China continues to modernize its strategic and theater nuclear forces, especially submarine launched weapons.
- Israel has submarine missile delivered as well as land-based nuclear weapons.
- India and Pakistan are developing medium-range missile delivery systems.
- Al Queda attempted to obtain nuclear and radiological bomb materials and design information; and conducted research and development on chemical and biological weapons.
- The Japanese cult Aum Shinrikyo, which attacked Japanese civilians with deadly gas on March 20, 1995 also tried to mine its own uranium in Australia and to buy Russian nuclear warheads.[13]

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[12] C. Paine et al, The Bush Administration's Quest for Earth-Penetrating and Low Yield Nuclear Weapons," Natural Resources Defense Council, Washington DC, May 2003, at: http://www.nrdc.org/nuclear/bush/abb.pdf

B. NanoTechnology Trends

Near-Term Nanoparticle Production

- Production already underway of nano-scale particles of pure elements, simple compounds and composites for use in bulk sprays, powders, and coatings, by condensing vaporized molecules.
- Nanoparticles are used already in the manufacture of scratchproof eyeglasses, crack-resistant paints, anti-graffiti coatings for walls, transparent sunscreens, stain-repellant fabrics, self-cleaning windows and ceramic coatings for stronger solar cells.
- Catalyst nanometer-sized particles are much more reactive than micron-sized particles due to the increased surface area available for reaction which is transforming the plastics industry to make lighter and tougher products.
- Nanoparticles will contribute to stronger, lighter, cleaner and "smarter" surfaces and systems such as smart fabrics that will deflect or absorb heat, maintenance-free building exteriors, breathing building surfaces

Near-Term Nano-Materials

- Molecules of pure carbon called nanotubes and buckyballs have unique properties with enormous commercial applications.
- Nanotubes are 100 times stronger than steel and six times lighter; they conduct electricity better than copper and can also act as semi-conductors.
- Nanotubes can be as small as one nanometer, and strung out in self-assembling tubes or spheres
- Nano-scale carbon transistors may replace silicon transistors for tiny, ultra-fast computers within a decade depending on the feasibility of mass production of cheap, uniform nanotubes. In May 2002, IBM reported that they have created high performance carbon nanotube transistors.
- Nanotubes are incorporated into objects already such as tennis racquets and soon be used in artificial bones and "body suits" for military application
- Macro-objects made from nano-particles will display increased surface area and be harder, less likely to crack, more resilient under temperature, pressure, and light stresses, such as breakproof glass and plastics and super-strong hulls for all kinds of vehicles.
- Nanotubes will be applied first in structural reinforcements of materials such as the Nissan X-Trail which uses a carbon nanotube enhanced plastic composite material for fenders. The material allows the fenders to return to their initial shape in case of crashes.

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[13] Testimony before the Permanent Subcommittee on Investigations of the Senate Committee on Government Affairs by the DCI, John M. Deutch, March 20, 1996 at: http://www.kimsoft.com/korea/ciachem1.htm

Near-Term Production Prospects

- About 140 companies worldwide are producing nanoparticles today
- The world market for nanoparticles is projected to rise 13% per annum, exceeding $900 million in 2005.
- The emerging nanosector includes the tools needed to produce and manipulate nanomaterials. The market for atomic force microscopes is projected to grow from $181 million to $800 million by 2007.
- Although nanotechnology continues to attract interest from public and private sectors commercial mass production of carbon nanotubes for research and industrial use is still in its early stages. Due to massive venture capital cutbacks, little venture capital investment is flowing into nanotechnology. Most industrial meetings concentrate on science rather than business applications.
- Nanotechnology activity lacks standards on quality, production techniques and other key aspects of industrial production which are essential to cost-effective research and development with early payoffs.
- Nanotubes cost today about $100-500/g versus 0.04 USD/gram for carbon fiber—a huge price differential to overcome.
- Carbon nanotubes will be used as probe tips and for nanolithography and will be applied early in cathode ray lighting elements, flat panel display and new transistors and memory devices.
- Nano-scale electronics will be slower to commercialize due to the problems of mass production
- The world nanotechnology market size was estimated to $1.4 million in 2000 and potential market in 2004 is estimated at more than $430 million. By 2010, US National Science Foundation predicts annual sales of $340 billion for nano-structured materials and processes alone.
- Fifty five companies are making carbon nanotubes and twenty are moving into commercial production of buckyballs.
- An "Easy Tube NanoFurnace" costing less than $100,000 was on the California market in 2002

Possible Medium-Term Applications and High Impact Uses

A number of technologies converge with nanotechnology to create an emerging set of "smart materials." According to RAND experts, for example, "Several different materials with sensing and actuation capabilities will increasingly be used to combine these capabilities in response to environmental conditions." Applications include:

- Clothes that respond to weather, interface with information systems, monitor vital signs, deliver medicines, and protect wounds using cloth interwoven with threads of super-tough carbon nanotube fibres that store electricity and can power embedded devices.

- By 2015, nanomaterials such as semiconductor "quantum dots" could revolutionize chemical labeling and enable rapid processing for drug discovery, blood assays, genotyping, and other biological applications;
- Personal identification and security systems; and
- Buildings and vehicles that automatically adjust to the weather.

Other longer-term nanotech applications that are anticipated include:

- Seeding the atmosphere with self-replicating “skybots” that would consume dust particles;
- Seeding the oceans with self-replicating “seabots” to absorb carbon faster out of the atmosphere to reduce climate change radiative forcing;
- Placing protein-stuffed nanotubes into plastic used in parts such as airplane wings that release proteins when tubes are broken during impact to act as self-repairing adhesive.
- Incorporating integrated microsystems or nano-sized mechanical-electrical devices into almost any macro-object to endow it with smart capabilities to sense, communicate, and locate information. For example, a nano-sensor is under development to detect hazardous gas leaks in petrochemical plants.
- Nanotube hydrogen storage for fuel cells has not been confirmed and practical applications may prove unrealistic in spite of substantial corporate research effort and a rapidly increasing investment in hydrogen energy infrastructure, especially in Europe. Researchers are also working on less visible nanotechnologies such as catalysts and membranes for separating different types of gases. These can be used in fuel cells or other energy transforming technologies

More futuristic visions of **molecular manufacturing** by self-replicating nano-robots and the development of hybrid nano-bio machines are envisaged in various combinations such as bio-sensors. These applications are unlikely to be commercially realistic in the next two decades. A RAND study synthesized these trends in the figure below.

Nanotechnology Companies

Applied Nanotechnologies Inc. - http://www.applied-nanotech.com/
Applied NanoMaterials Inc. - http://www.apnano.com/
Applied Sciences Inc. - http://www.apsci.com/
BuckyUSA - http://www.flash.net/~buckyusa/
C Sixty Inc. - http://www.csixty.com/
CarboLex - http://carbolex.com/
Carbon Nanotechnologies Inc. - http://www.cnanotech.com/
Carbon Solutions Inc. - http://carbonsolution.com/
Catalytic Materials LLC - http://www.catalyticmaterials.com/
Eikos Inc. - http://www.eikos.com/
Frontier Carbon Corporation (Japan) - http://www.f-carbon.com/
Fullerene International Corporation - http://www.fullereneinternational.com/

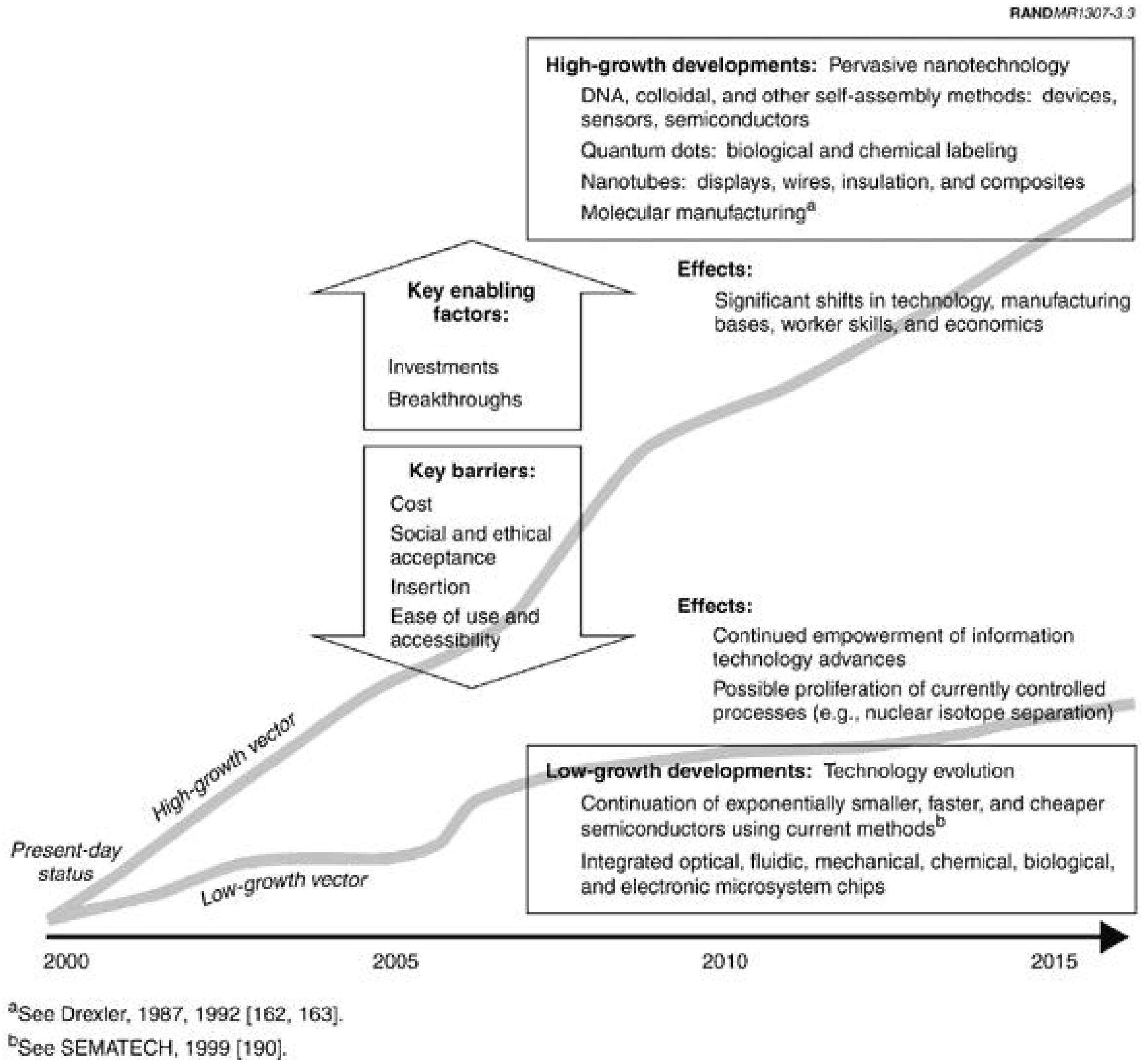

Figure 3.3--Range of Possible Future Developments and Effects of Nanotechnology from: P. Anton et al, *The Global Technology Revolution, Bio/Nano/Materials Trends and Their Synergies with Information Technology by 2015*, RAND MR-1307, Santa Monica, California, 2001, at www.rand.org

GZ Energy (China) - http://www.gzenergy.com/
Hyperion Catalysis International, Inc. - http://www.fibrils.com/
ILJIN Nanotech (Korea) - http://www.iljinnanotech.co.kr/
Institut National Polytechnique de Toulouse (France) - http://www.inp-toulouse.fr/
Materials and Electrochemical Research Corporation - http://www.mercorp.com/
MicroTechNano - http://www.microtechnano.com/
Mitsui & Co. Ltd. Nanotechnology Department XNRI - http://www.xnri.com/
Molecular Nanosystems - http://www.monano.com/
Nano-C - http://www.nano-c.com/
NanoCarbLab (Russia) - http://www.nanocarblab.com/
Nanomix Inc. - http://www.covalentmaterials.com/
Nanocs International - http://www.nanocs.com/
Nanocyl (Belgium) - http://www.nanocyl.com/
NanoDevices - http://www.nanodevices.com/
NanoLab - http://www.nano-lab.com/
NanoLab Inc. - http://www.nano-lab.com/
Nanoledge (France) - http://www.nanoledge.com/
Nanostructured & Amorphous Materials Inc. - http://www.nanoamor.com/
Rosseter Holdings Ltd (Cyprus) - http://www.e-nanoscience.com/
SouthwestNanotechnologies Inc. - http://www.swnano.com/
SES Research - http://www.sesres.com/
SI Diamond Technology Inc. - http://www.sidiamond.com/
Reade Advanced Materials - http://www.reade.com/
C-Nano (China) - http://www.c-nano.com/
Versilant Nanotechnologies - http://www.versilant.com/
Sun Nanotech Co Ltd (China) - http://www.sunnano.com/
Shenzhen Nanotech Port Co., Ltd. (China) - http://www.seasunnano.com/

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www.plausiblefutures.com, "Mass Production Of Carbon Nanotubes; Science And Applications," *Plausible Futures Newsletter* July 2003

www.plausiblefutures.com, "Nanowar Scenarios and the Future of Warfare," *Plausible Futures Newsletter*, August 2003

F. Tiboni, "War Game Stuns U.S. Strategists," *Defense News* | May 12, 2003, at: http://209.157.64.200/focus/f-news/910628/posts