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THE MAGAZINE FOR SCIENCE & SECURITY

Winter 2011 Volume 64 No 4

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Q&A: HAROLD VARMUS

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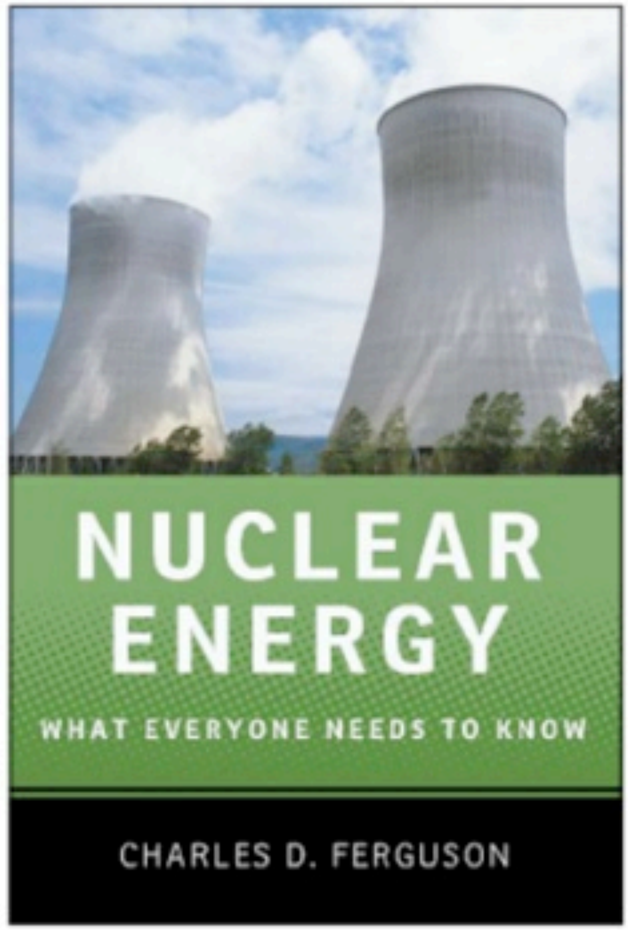
Nuclear Energy

What Everyone Needs to Know

By Charles D. Ferguson

Originally perceived as a cheap and plentiful source of power, the commercial use of nuclear energy has been controversial for decades. Worries about the dangers that nuclear plants and their radioactive waste posed to nearby communities grew over time, and plant construction in the United States virtually died after the early 1980s. The 1986 disaster at Chernobyl only reinforced nuclear power's negative image. Recent years have seen a marked change, however. The alarming acceleration of global warming due to the burning of fossil fuels and concern about dependence on foreign fuel has led policymakers, climate scientists, and energy experts to look once again at nuclear power as a source of energy.

In this accessible overview, Charles Ferguson provides an authoritative account of the key facts about nuclear energy. What is the origin of nuclear energy? What countries use commercial nuclear power, and how much electricity do they obtain from it? How can future nuclear power plants be made safer? What can countries do to protect their nuclear facilities from military attacks? How hazardous is radioactive waste? Is nuclear energy a renewable energy source? Ferguson addresses these questions and more in a book that is essential for anyone looking to learn more about this important issue.



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Key Features

- Easy to navigate, accessible Q&A format is ideal for an introduction to the subject of nuclear energy.
- In a clear, engaging style, the book provides a comprehensive survey of this controversial topic.
- Readily accessible and suitable to readers with various levels of background knowledge on the topic.
- Includes updated information on the nuclear crisis in Japan.

Charles D. Ferguson is President of the Federation of American Scientists and an Adjunct Professor in Georgetown University's Security Studies Program. Trained as a physicist and nuclear engineer, he has worked on nuclear policy issues at the U.S. Department of State and the Council on Foreign Relations.

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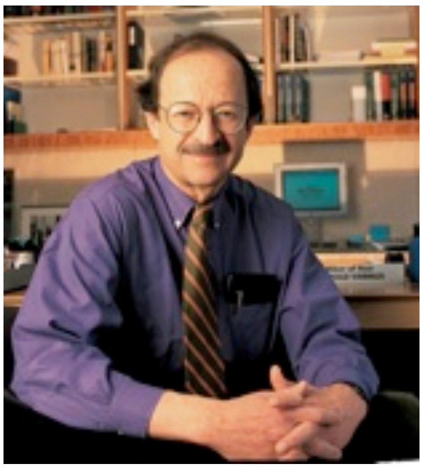

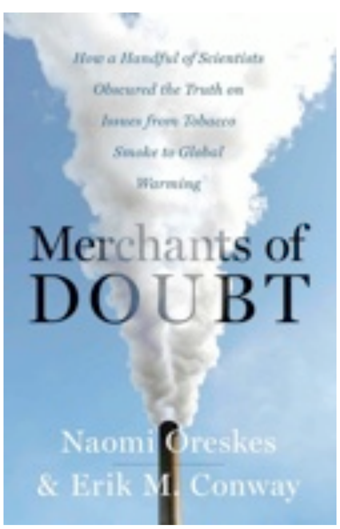

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LETTERS TO THE EDITOR

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The PIR welcomes letters to the editor. Letters should not exceed 300 words and may be edited for length and clarity.

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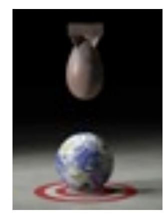


Physicists Have a Responsibility to Society

The debate and controversy over the National Science Foundation (NSF) criterion on the broader societal impacts of NSF-funded research have served the important function of challenging the physics community to re-examine why public money should support pure and applied physics research and what is the role of physicists in society.

On February 27, 2012, FAS President Dr. Charles D. Ferguson joined AAAS President Alan Leshner, APS President Barry C. Barish, and Dr. Don Prosnitz for a discussion on the broader impacts of research and individual responsibility at the March Meeting of the American Physical Society in Boston, MA. Dr. Ferguson argued that while the NSF criterion is well intentioned, it appears ill-informed and runs the risk of creating a checklist of activities to fulfill physicists' responsibility to connect their work to larger societal issues.

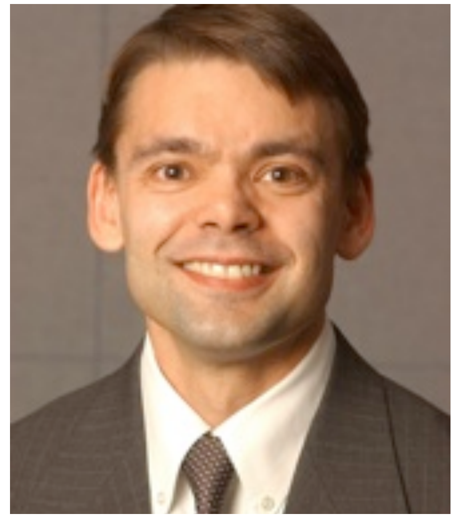
Most government-funded research is already connected to larger societal impacts such as national defense, energy research, and economic issues.

Dr. Ferguson's presentation argues that scientists need to become better educators to policymakers and the public and apply their knowledge and skills to better society.

Read the presentation here: http://www.fas.org/blog/president/2012/02/physicists-and-society/

PRESIDENT'S MESSAGE

Securing Nuclear Materials: Remaining Challenges



In April 2009 in Prague, President Barack Obama recommitted the United States to achieve a nuclear-weapon-free world. Although he cautioned that reaching this goal might not occur in his lifetime, he did pledge his administration to cooperate with other governments and international institutions such as the International Atomic Energy Agency to accomplish securing all vulnerable nuclear materials in four years. The motivation behind that goal was to prevent terrorists from acquiring the essential fissile materials such as highly enriched uranium (HEU) and plutonium needed to make nuclear explosives. No matter how much terrorist groups might covet nuclear weapons, they cannot obtain them without buying, stealing, or being given fissile material or intact nuclear warheads.

The Prague speech led to the first ever Nuclear Security Summit in April 2010 in Washington, D.C. Remarkably, the 2010 summit brought together more than 40 heads of state. Even more importantly, they agreed that preventing nuclear terrorism is a top priority. Many of these leaders pledged to take further steps to lock up nuclear material, phase out the use of HEU (which is the highest risk fissile material because of its relative ease of use in a crude nuclear explosive), and form centers of excellence to promote nuclear security across the globe. While the majority of national leaders were not at the Summit, the ones that were represented most of the countries with large quantities of weapons-usable fissile material.

When the world is facing numerous challenges such as ensuring access to clean water, providing for adequate amounts of nutritional food, and improving public health, it is fair to ask why nuclear security deserves such emphasis. These are not either or choices. Leaders need to work together to solve all these problems. Nonetheless, the motivation behind President Obama's Nuclear Security Summit was to attract high-level political attention to a threat that could have catastrophic consequences worldwide. Nuclear terrorism is not just a threat to the United States or other Western countries. While a nuclear detonation by a terrorist group in any city would immediately kill upwards of a hundred thousand people, this attack could cause panic in numerous cities around the globe and could result in trillions of dollars worth of damage to the global economy.

Encouragingly, 80 percent of the pledged commitments made by the Washington Nuclear Security Summit have been accomplished. But much more work is needed. For example, dozens of research reactors still use HEU. One of the remaining technical hurdles is to develop high-density low enriched uranium fuel and targets for isotope production in order to substitute for HEU. This effort could take several years meanwhile governments should ensure that they are providing the necessary funds for the R&D.

But I would argue that the biggest hurdle is the political will for leaders to link preventing nuclear terrorism with achieving nuclear disarmament. As George Shultz, Sam Nunn, William Perry, and Henry Kissinger assessed in their first *Wall Street Journal* op-ed in January 2007, nuclear weapons have become liabilities rather than assets. Although they believed that during the Cold War nuclear weapons served a purpose to prevent major war between the United States and the Soviet Union by threatening mutual assured destruction, today the most likely route of nuclear weapons use is by a terrorist group. Nuclear-armed terrorists would most likely not be deterred. If the nuclear-armed nations could dismantle their warheads and immediately turn the fissile material into physical states that are not readily usable for weapons, they will have made major strides toward reducing the risk of nuclear terrorism.

But the risk would not be zero as long as HEU or plutonium would continue to be used in research reactors, naval reactors, and commercial reactors. Although the Nuclear Security Summit on March 26 and 27 in Seoul, Republic of Korea, will focus on HEU in research reactors, the agenda fails to call attention to naval reactors. The United States still uses HEU to fuel its submarines and aircraft carriers and is opposed to converting the reactors on these warships to low enriched uranium. Opposition arises from the fact that the HEU-fueled reactors have long-lived cores thus saving on refueling costs. Moreover, the United States has a huge stockpile of HEU dedicated to naval use. No security system, however, is perfect, and it is possible that some HEU from this stockpile may become unsecured. Even if this stockpile remains highly secure, it can make the United States look hypocritical when Washington requests other nations to reduce and eventually eliminate their weapons-usable fissile material.

The other major left-out agenda item is to address the security challenge of the massive plutonium stockpile slated for commercial reactors. About 250 metric tons of civilian plutonium—enough to make more than ten thousand nuclear weapons—has been separated from the protective barrier of highly radioactive fission products in spent nuclear fuel. (This is comparable to the stockpile of military plutonium.) France, Japan, India, and Russia, in particular, have had plutonium-recycling programs. China may soon follow suit. But the Fukushima Daiichi accident and pending changes in Japan's nuclear policy might result in further delays in Japan's reuse of plutonium. This has called into question what Japan will do with the almost 10 metric tons stored in Japan and the 35 metric tons stored in France and the United Kingdom. There are no easy solutions. One option could be to dispose of the plutonium in deep boreholes; another is to surround it with highly radioactive materials; and another is to consume it in burner reactors, but this technology has confronted technical problems and could be used in a breeder mode to make more plutonium.

Making concrete steps toward nuclear disarmament, phasing out use of HEU in naval reactors, and disposing of the huge stockpile of civilian plutonium are serious political and technical challenges that deserve to be on the agenda at the Seoul Summit and at future summits.

Charles D. Ferguson
President, Federation of American Scientists

Q&A: Harold Varmus

Many of the issues of concern to the FAS founders till exist today. Harold E. Varmus is the director of the National Cancer Institute. He received the Nobel Prize for Physiology or Medicine in 1989. Previously he served as President and Chief Executive Officer of Memorial Sloan-Kettering Cancer Center (MSKCC) and as Director of the National Institutes of Health (NIH). He supplied his answers to FAS questions via email.

Learn more about Harold Varmus by visiting: http://www.cancer.gov/aboutnci/director

In the decade since you founded PubMedCentral and cofounded the Public Library of Science, more than 6,000 open access journals have been created. PLoS ONE published a study by a team of researchers from the HANKEN School of Economics that showed very rapid growth of Open Access (OA) publishing during the period of 1993-2009. In 2009, an estimated 191,000 articles were published in 4,769 OA journals. What more needs to be done to improve access to scientific research? How can scientists increase and improve the dissemination of their findings? How do you refute the argument that the OA standard is not as rigorous or objective as subscription journals because scientists are paying to publish their research?

As your numbers indicate, there has been a remarkable increase over the past decade in the access that is now provided to much of the scientific literature, both through "public access" to digital archives like PubMed Central and through full-fledged "open access" to journals like those published by the Public Library of Science.

Still, there are shortcomings that we should not forget while we applaud the progress that has been made. Effective use of PubMed Central required Congress to mandate deposition; the mandate applies only to NIH-supported articles, not those supported by other agencies; deposition can be (and often is) delayed for as long as a year, despite the lack of evidence that shorter delays would significantly diminish journal revenues; and use of the material is often curtailed because the journals continue to hold copyright and do not license use under optimal terms, such as those advocated by Creative Commons. In an ideal world, all journals would use an open access business model (it is sensible, and it works). But I am a realist and know that this complete transformation will take decades. In the near future, I would be pleased if public access occurred more quickly, if an open access "option" was standard for all journals, and if an effort were made to build a public archive of the older scientific literature which is becoming increasingly inaccessible despite its utility.

These changes are occurring slowly, despite their desirability, because some of the most lucrative, subscription-based journals continue to wield an inappropriate influence over the behavior of many scientists. The blame for this should be directed to the scientific community, not the journals. Their influence depends on the inordinate importance that our colleagues place on the journal in which an article appears, rather than on the content of article, in decisions about who wins grants and gets hired and promoted. In this fashion, many scientists have ceded power to the editors of a few highly selective traditional journals, which in turn have little incentive to change their practices, even though an "author-pays" open access model for publishing can be lucrative as well as beneficial. Until scientists acknowledge this inappropriate standard (counting citations in famous journals) and return to the traditional but more difficult task of judging colleagues by actually reading their work, it will be difficult to take open access to the next stage.

The suggestion that the review process used by open access journals lacks rigor because authors pay has not been substantiated and for good reason: all journals want their content to be scientifically sound and highly reputable, otherwise they will not continue to receive submissions. It is important to note that publication online, whether in subscription-based or open access journals, offers an opportunity to make post-publication evaluation by open, online commentary at least as important as secretive pre-publication review. Unfortunately, movement in this direction has been relatively slow.

In retrospect, what – if anything - would you have done differently when launching PubMedCentral and PLoS? What changes would you like to see in the next decade?

I don't think my co-founders (Pat Brown and Mike Eisen) and I made many large errors in the launch of PLoS, although we certainly made some small ones. While I cannot say we've achieved absolutely all our goals, we've had tremendous success, with the help of many great staff members and colleagues. The general strategy of starting our efforts with highly selective journals, like *PLoS Biology*, has helped to calm fears that standards would not be rigorous, and the roaring success of the much more inclusive and generally speedy *PLoS ONE* has proven the soundness of the business model. Now I'd like to see open access journals process and present their articles with new informatics tools, and to feature them more like newspapers do, with all reliable "stories" included but the most important ones highlighted (as "on the front page above the fold") and others positioned less ostentatiously---at least until post-publication commentary indicates that their profiles should be elevated.

The launch of PubMed Central was an earlier, more tortuous, and flawed process. I have tried to present my several missteps as honestly as possible in my book, *The Art and Politics of Science* (2009). But, miraculously, that worked out pretty well too, with a lot of help from others.

In an age dominated by fears of terrorism and the dual use of scientific research, how do you balance the inadvertent spread of knowledge that may aid terrorists with the scientists' need for access to the latest discoveries?

As well known by those who are following the current dispute over publication of papers about aerosol transmission between mammals of avian H5N1 influenza viruses, this is a very difficult question, and I don't pretend to have a simple answer. Of course, such situations are easier to resolve when the potential for dual use can be recognized before the work is undertaken, so that projects can be conducted as classified research. When the situation is highly ambiguous, however, I suspect that the damage that is done to the scientific process by not publishing a full account of the work is likely to outweigh the likelihood of malign use in most circumstances. In these cases in which work is openly conducted before it is deemed potentially dangerous, the results are likely to be known by too many people to be genuinely restricted anyway.

The polarization of U.S. politics continues to grow worse. With a skittish economic recovery and contentious debate to cut the budget and reduce the U.S. deficit, how would you advise the United States in terms of its investment in health, science and technology? Where would you focus more money?

I am a strong believer in the idea that investments in science are critical to the future of our country and the rest of the world, and history has shown that both major political parties have produced champions for such views over the years. Even in economically difficult times, critical investments in science and technology are most likely to be sustained by the federal government, at least in the United States, so the government's financial support will remain crucial.

While I continue to advocate for spending on medical sciences (it is my job and my conviction), I am increasingly concerned about America's failure to devote adequate resources to studies of new sources of energy, earth and ocean sciences, and ecological conditions. In the long run, it is those sciences, not oncology, that might save us from extinction.

As director of the National Cancer Institute, and in light of impending budget cuts, how do you determine research priorities? How do you prioritize what programs get funding?

We've already had some actual cuts to our budget and have been receiving sub-inflationary increases for almost a decade, so the pressure on our resources is long-standing, not "impending." Like all NIH Institutes and other federal science agencies, we depend heavily on peer review of grant applications to help determine who gets funded. We also have numerous meetings and workshops to survey the landscape for missed opportunities that need to be advertised.

In the past year, we've expanded these consultations by engaging people from several disciplines relevant to oncology to help frame "Provocative Questions" that are intended to stimulate clever approaches to unsolved or novel problems in our field (see our essay in the January 26, 2012, issue of *Nature*). Judging from the many enthusiastic participants in our PQ workshops and the over 700 applications for funds to answer PQs, this has been a successful strategy.

Your 2009 memoir The Art and Politics of Science emphasized the civic value of science. What is your advice to scientists who want to get involved in policy?

I say, "Go ahead, get involved!" There are lots of ways to do this, but they need to be titrated against commitments made to other things: bench-work, teaching, family life, and other interests. I am pleased to see the proliferation of stimulating programs to train scientists to work in the policy arena, and many societies and advocacy groups, including FAS, offer opportunities to devote more limited amounts of time to experiences that can be broadening and effective.

You also touched upon the role of science and technology in foreign policy and the growing disparities between the rich and the poor. How can the United States expand the role of science and technology in developing countries? How realistic is the creation of a "Global Science Corps"? How else can the United States use medicine and science to improve relations with developing countries?

There are lots of new ideas for training, scientific exchanges, collaborative research, partnerships between institutions, visits by eminent scientists, health-promoting programs and so on, but a limiting factor is money. At many agencies, efforts to improve conditions in developing countries through scientific initiatives must compete with the good things we are doing domestically. So, ideas like the Global Science Corps (http://sig.ias.edu/gsc) have not gotten the funds they need.

At the NCI, we have established a new Center for Global Health, in an effort to consolidate and improve international projects already underway and plan some new things too. I view such work as beneficial to both poor and rich countries, since it often involves the study of novel problems that will enhance our understanding of cancer everywhere. Furthermore, improving the control of cancer in all countries helps to create a healthier, more productive, and more stable world, while enhancing American prestige and displaying our best values. I have been very pleased to see from the response to our new Center that most scientists and cancer advocates agree strongly with this perspective. ■

Rules of the Road

Responsible Use of Weapons in Space

— BY EVERETT CARL DOLMAN

The world economy is so intrinsically linked to support from space that should a major outage of satellite capacity occur, financial and trade markets could collapse. A recession spanning the globe would ensue, and security tensions would exacerbate. The increasingly chaotic international environment would be further destabilized by the disastrous incapacitation of U.S. military power. Without the assuredness of space-based surveillance, communications, and navigation support, American and allied military forces would be ordered to hunker down in defensive crouch while preparing to withdraw from dozens of then-untenable foreign deployments.

Such a scenario is not only possible—given the growing investment and reliance on space as a national power enabler—it is increasingly plausible. An attack against low-Earth orbit from a medium range ballistic missile adapted for detonation in space could cause inestimable harm to the national interests of developed and developing states alike. Without a space-based defense against such events, the world as we know it exists on borrowed time.

Enabling Rules of the Road

With great power comes great responsibility. The United States Air Force has been charged with ensuring access to space and space support for all states in times of peace and crisis, and when called upon to deny that access to its enemies in times of war. As a martial organization, the Air Force naturally looks to military means in achievement of its assigned ends.

But weapons alone are not the decisive or exclusive means for ensuring peace. Only when used in conjunction with common expectations of behavior, such as in support of domestic laws or international agreements can they be effective for this purpose. In the international realm, this is because the intentions of potentially hostile actors must be constrained by a calculation of self-interest and potential risk for violating norms and rules. The deterrent value of *si vis pacem, para bellum* is moot if understanding is not common.

> **Should a major outage of satellite capacity occur, financial and trade markets could collapse.**

Laws, too, are so constrained. As guides for behavior or shaping common expectations, rules of thumb or traditional practices can be very useful. But when used to prevent a class of activities, especially criminal or hostile ones, rules are too fragile by themselves. Unless the ability to enforce the latter is evident—to find, apprehend, assess, and, if guilty, punish those who violate them, such agreements on correct behavior are no more likely to work than when the mice infamously agreed to bell the cat.

For example, Declaration I of the 1899 Hague Peace Conference banned the use of balloons for combat purposes, specifically the launching of projectiles or bombs. With proof of powered flight coming just four years later, an extension to the agreement was negotiated and accepted in 1907 that banned the use of *any* means of aerial combat, existing or planned. With war declared in August of 1914, the prohibitions were void, and it was obvious that they had little or no effect on pre-war development of combat aircraft.

There are currently a number of rules-of-the-road agreements proposed, foremost among them sponsored by the European Union, China, and the U.S.-based Stimson Center, that offer compelling logic for establishing a framework for cooperation in space by limiting specific activities or capabilities. Unless these agreements are brokered fairly among and accepted by *all* space-faring states, however, and they don't include unverifiable and unenforceable bans on weapons, an important and extremely beneficial international accord may be missed.

Common to all the suggested approaches is for signatories to avoid adding debris to the increasingly cluttered common orbits in near-earth space. This is an eminently agreeable issue, as debris in space limits all users, regardless of who is responsible for it. No space-faring or space-reliant state should see disadvantage in limiting kinetic destruction of satellites, nuclear detonations in space, or other such mutually undesirable effects. Where these approaches are less workable is in their efforts to concomitantly limit the deployment and use of weapons in space. Due to the risk entailed should any state violate the rule, and the very real problem of defining just what constitutes a space weapon, unless some mechanism for proper enforcement *in* space is encumbered, these much needed treaties are problematic.

Unlike the Hague conventions of 1899 and 1907, which proved utterly unrealistic with the onset of conflict, the parallel Geneva Conventions limiting the use of non-discriminating weapons and requiring humane treatment of prisoners and noncombatants have been relatively robust and effective. This is because there is an advantage to abiding by these agreements *even when an opponent or other signatory does not*. On the battlefield, the side that is known to give food, shelter, and medical aid to surrendering forces is less likely to encounter an opponent willing to fight to the death than the side known for mistreatment of its prisoners. As beneficial as these conventions have been, they have not stopped war or even reduced the number of conflicts. They have simply shaped the conduct of violence.

Ideally, an international agreement creating a multi-national space force capable of protecting the fragile environment beyond Earth's atmosphere from hostile attack will someday be reached. Until then, the United States or some other space power may find it necessary to develop and field a space-based defensive capability against missiles, rockets, and directed energy emanations that would enter into orbit with hostile intent. Such a development is not necessarily welcome, but neither should it be condemned out of hand.

Why Not Space Weapons?

There are two classes of arguments in opposition to the weaponization of space: 1) it *cannot* be done, and 2) it *should not* be done.

Arguments in the first category spill the most ink in opposition, but are relatively easy to dispose of, especially the more radical variants. History is littered with prophesies of technical and scientific inadequacy, such as Lord Kelvin's famous retort, "Heavier-than-air flying machines are impossible." Kelvin, a leading physicist and then president of the Royal Society, made this boast in 1895 and no less a personage than Thomas Edison concurred. The possibility of spaceflight prompted even more gloomy pessimism. A *New York Times* editorial in 1921 (an opinion it has since retracted), excoriated Robert Goddard for his silly notions of rocket-propelled space exploration. "Goddard does not know the relation between action and reaction and the need to have something better than a vacuum against which to react. He seems to lack the basic knowledge ladled out daily in high schools." Compounding its error in judgment, in 1936, the *Times* stated flatly, "A rocket will never be able to leave the Earth's atmosphere."

We have learned much, it would seem, or else bluntly negative scientific opinion on space weapons has been weeded out over time. Less encompassing arguments are now the standard. As the debate moved away from the impossibility of weapons and wars in space to more subtle and scientifically sustainable arguments that a *particular* space weapon is not feasible, mountains of scientific evidence are piled high in an effort, one by one, simply to bury the concept. But these limitations on specific systems are less due to theoretical analysis than to *assumptions* about future funding, political context, and available technology. The real objection, too often hidden from view, is that a *particular* weapons system or capability cannot be developed and deployed *within the planned budget*, or *within narrowly specified means*. When one relaxes those assumptions, opposition on technical grounds falls away.

The devil may very well be in the details, but if one's stance opposing an *entire class* of weapons is premised upon analyses that show *particular* weapons will not work, what happens when a fresh concept or new technology cannot be narrowly disproved? What happens when technology *X*, the unexpected (perhaps unforeseeable) scientific breakthrough that changes all notions of current capabilities, inevitably arrives? Have we thought out the details enough that we can say categorically that no technology will allow for a viable space weapons capability? If so, then the argument is pat; no counter is possible. But, if there are technologies or conditions that *could* allow for the successful weaponization of space, then ought we not argue the policy details first, lest we be swept away by a course of action that merely chases the technology wherever it may go?

Those who argue that space weapons *should* not be deployed generally do so on the grounds that they are too expensive or are potentially destabilizing.

To be sure, a space weapons program would be *very* expensive—tens if not hundreds of billions of dollars. But this money will not come from funds set aside for schools or roads or humanitarian assistance. Federal budgets are not so fungible. Peace dividends fail to materialize. The money for space weapons would come from existing and projected defense expenditures, and this means fewer tanks and soldiers, ships and sailors, aircraft and airmen. Herein is the trade-off in creating what would amount to a space-heavy military force structure. The state would continue to maintain its capacity to intervene in affairs abroad, with violence if deemed necessary, but now with precise and measured doses of very accurate, very deadly violence anywhere on the earth, in a very, very short time. But it would not be bulk violence. This is still the purview of traditional land, sea, and air forces. The state would trade the capacity to intervene quickly and precisely for the ability to do so massively, with lots of collateral damage.

Ramifications for the most critical *current* function of America's armed forces are profound—pacification, occupation, and control of foreign territory. With the downsizing of traditional weapons to accommodate heightened space expenditures, the ability of the U.S. to do all three will wane significantly. At a time when many are calling for *increased* capability to pacify and police foreign lands, space weapons proponents must advocate *reduction* of these capabilities in favor of a system that will have no direct potential to do so. It will be a hard sell.

It will not be any easier for those who consider defensive capabilities reasonable, but offensive capabilities abhorrent. Space weapons are inherently offensive. They defend by attempting to destroy the incoming threat. They deter violence by the omnipresent promise of precise, measured, and unstoppable retaliation. Systemically, they offer no advantage if the target set considered is not global. But as they offer no advantage in the mission of territorial occupation, they are far less threatening than any combination of terrestrial weapons employed in their stead. A state employing offensive deterrence through space-weapons can punish a transgressor, but is in a poor position to *challenge its sovereignty*. Such states are less likely to succumb to the security dilemma if they perceive their national survival is not at risk. What is more threatening, a half dozen lasers deployed in space or, for about the same price, six divisions of ground troops massed on the border? Moreover, the tremendous expense of space weapons inhibits their indiscriminate use. Over time, the world of sovereign states will recognize that space power does not threaten self-determination internally, though it challenges any attempts to intervene militarily in the politics of others, and has severely restricted its own capacity to do so.

Space weapons are inherently offensive. They defend by attempting to destroy the incoming threat.

Perhaps the largest collection of arguments against the weaponization of space is that it would force a crippling space arms race. Especially if the United States were to act first, responsible nations would be compelled to respond in kind, and a space arms race *must* ensue. So long as the Unitd States. refrains, other states will also. The logic escapes me.

The United States has embarked on a revolutionary military transformation designed to extend its dominance in military engagements. Space capabilities are the lynchpin of this transformation, enabling a level of precision, stealth, command and control, intelligence gathering, speed, maneuverability, flexibility, and *lethality* heretofore unknown. Because of its demonstrated utility and reliance, there is no question the United States must *guarantee* space access if it is to be successful in future conflicts. It is simply not possible to go back to the violently spasmodic mode of combat typical of pre-space American intervention. The United States is now highly discriminating in the projection of violence, parsimonious in the intended breadth of its destruction. For the positive process of transformation to continue, however, space weapons must enter the combat inventory of the United States. Indeed, America's reliance on space today is so heavy that any nation desiring an asymmetric military advantage would be hard-pressed not to consider attacking its currently undefended space assets. This is particularly true for states or organizations that are vastly less reliant on space for their economic or military needs.

I have argued elsewhere, primarily in my book *Astropolitik*, that any state with the means and political will to quickly place a small network of weapons in low-Earth orbit capable of engaging missiles or rockets in their boost phase would effectively gain control of the global high ground and all of the tactical advantages that have historically accrued to the controller of the battlespace's most advantageous position. The longer America and the international community dither on their responsibility to protect space from states or organizations that would attack on-orbit assets, the longer the window of opportunity for a potential overthrow of the current international system stays open, and the *more likely* a debilitating arms race will emerge.

If America or some U.S.-included international consortium were to place weapons in space today, it is unlikely that any other state or group of states would find it rational to counter *in kind*. America's space infrastructure, particularly its military space potential, is enormous. The entry cost to generate an equivalent capacity necessary to counter its lead *in* space is too high; hundreds of billions of dollars, at minimum. Without question, states not party to the new weapons regime would object, and try to oppose its actions—but they would do so asymmetrically.

Diplomatic condemnation, economic embargo, and probably conventional arms increases can be expected. If the new regime was shown over time not to be a potent new kind of coercive tool, used non-arbitrarily only to enforce treaties and laws in and for outer space, the capacities to police space would be seen as no more detrimental to international peace than the U.S. military's parallel activities for the world's common areas—the open oceans and non-territorial airspace. Even more so space commerce would be able to thrive. Just as its military limits the activities of brigands and pirates, ensures that disputed regions are not closed to commerce, intervenes to stem the flow of human trafficking, drugs, and illicit arms, business is *more* likely to be safe and reliable. On the other hand, without any enforcement mechanism in space, in ten to fifteen years perhaps, peer competitors could emerge that would be more than willing to challenge the currently dominant space powers. If you desire a space arms race, do nothing, it will come.

This is because America *must* respond to another state's attempt to seize control of outer space. Its position of hegemonic power is based on its potential to control the sea and air, to mobilize quickly and move from place to place faster than an opponent, and these capabilities are predicated on continuing support from space. A threat to that support would correctly be viewed as an attempt to overturn the current international order, to replace American hegemony with a new global leader.

Conclusions

America *will* maintain the capacity to influence decisions and events beyond its borders, with military force if necessary. It will not be bound by treaties that deny such ability. For the most part, America uses its hegemonic power to maintain global stability, ensure free commerce, lessen human suffering, and oppose aggression. The operational deployment of space weapons would increase these capacities by providing for nearly instantaneous force projection worldwide. This force would be precise, unstoppable, and deadly. At the same time, the United States must forego some of its ability to *intervene directly* in other states because its capacity to do so will have been diminished in the budgetary trade-offs required.

Seizing the initiative and securing low-Earth orbit now, while the United States and its allies are unchallenged in space, would do much to stabilize the international system and prevent an arms race *in* space. If peace desiring states could come to an international agreement in which a multinational space force would be capable of maintaining effective order in space, participate in the reduction of debris in orbit, promote commerce, and did so in a way that was perceived as tough, non-arbitrary, and efficient, such an action would serve to discourage competing states from fielding opposing systems. Should they use this advantage to police the heavens (assuming the entire cost), and allow unhindered peaceful use of space by any and all nations for economic and scientific development, over time their control of low-Earth orbit could be viewed as a global asset and a public good.

As leader of the international community, the United States finds itself in the unenviable position that it must make decisions for the good of all. On the issue of space weaponization, there appears no one best option. No matter the choice selected, there are those who will benefit and those who will suffer. The tragedy of American power is that it *must* make a choice, and the worst choice is to do nothing. ■

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THE FAS AWARDS DINNER AND CEREMONY

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The Honorable Steven Chu, the United States Secretary of Energy, received the 2011 Hans Bethe Award.

The inaugural 2011 Richard L. Garwin Award was presented to **Dr. Richard A. Meserve**, President of the Carnegie Institution of Science.

The evening's Master of Ceremonies was **Dr. John Holdren**, the Director of the White House Office of Science and Technology Policy and Science Advisor to the President of the United States.

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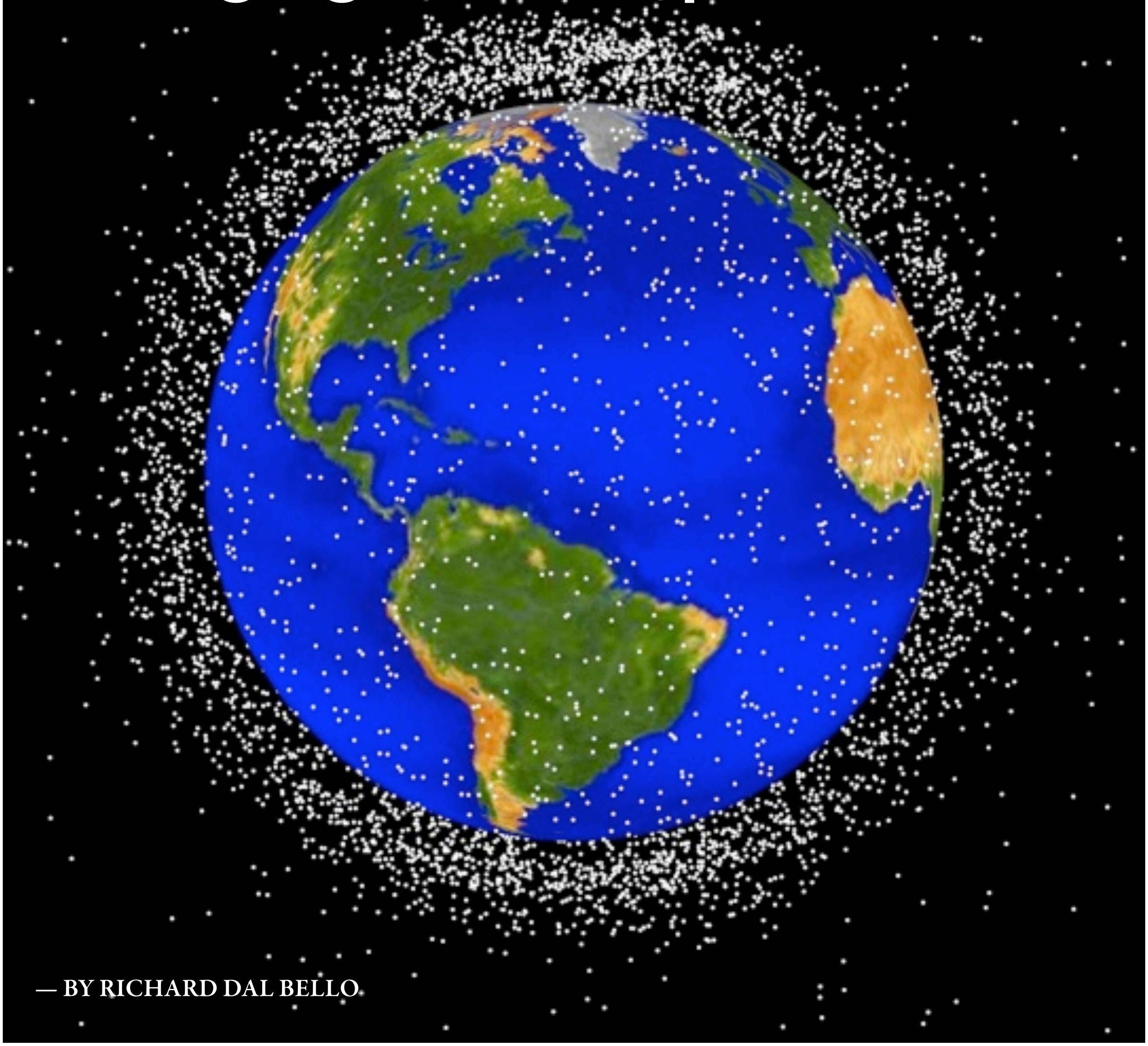
Managing Risk in Space



— BY RICHARD DAL BELLO

Since the launch of Sputnik in 1957, governments and commercial companies have placed thousands of satellites in orbit around the Earth. Most of them have long since burned up reentering the atmosphere or disintegrated into space debris. Today, there are over 16,000 active satellites and debris objects in the public catalog of tracked objects.

The region of space near Earth in which satellites orbit is so large – extending out 22,200 miles for commercial satellites – that one might believe a collision of orbiting spacecraft would be impossible. For example, communications satellites are typically spaced a degree apart - more than 700 km. That would be the same as parking one minibus-sized satellite in Washington, DC and the next in Ottawa. But some satellites are spaced significantly closer, and in fact the International Telecommunications Union (ITU) does not ensure there is any such separation. And as every statistitian knows, there is a big difference between a highly improbable event and an impossible event. Just three years ago, a satellite operated by Iridium Communications for the company's global communication network collided with an uncontrolled Russian spacecraft that had been out of service since 1995. The collision, 490 miles above Siberia, produced over 2,000 pieces of debris larger than 10 centimeters (3.9 inches) in diameter, each one large enough to destroy any orbiting satellite in its path.[1]

To avoid collisions in the increasingly crowded orbital arcs, agencies and companies operating satellites have informally shared position and orbit data for many years. But one problem with informal information sharing is that satellite operators don't use the same standard to represent the position of a satellite in orbit or an object in space. Many different types of software are used to track and maneuver satellites and the data is stored in a variety of formats. So, even operators who wish to share data can't rely on a single, agreed-upon protocol for sharing information. As a result, operators sharing information must maintain redundant file transfer protocols and tools to convert and reformat data so that it is consistent with their own software systems to compute close approaches. While some operators use third-party software for predicting close approaches, others write their own software tools. As the number of satellite operators increases, the problem of maintaining space situational awareness grows more complex. And the smallest operators may not be able to afford, or have the technicians, to participate in the data sharing process.

Recently, the world's leading commercial satellite operators formed the Space Data Association (SDA) to formalize the process of exchanging information and to deal with the overall data compatibility problem. Clearly, the best path to minimize risk in space is for all operators to share what they know about the movement and position of their own satellites in a way that all other companies can use. While this sounds like common sense, governments and commercial companies around the world have each historically acted on their own in launching and monitoring satellites. Agencies and companies coordinate frequency allocation and orbital slots prior to launch, but once a satellite is in orbit, data about the movement of commercial satellites was shared only informally until the establishment of the SDA. Information about the operation and location of many military satellites is still shrouded in secrecy.

The most critical times to share data about satellites are when a new satellite is being placed in orbit or an existing satellite is being shifted from one orbital slot to another. A typical communications satellite is as big and massive as a loaded semi-trailer, and though it appears fixed above the Earth, it is actually traveling thousands of kilometers per hour. Putting a satellite into an orbital slot or moving it to another position above Earth without disturbing any of the other 250+ commercial communications satellites in the GEO[2] plane, as Intelsat routinely does, is a very delicate operation. Yet this process is managed entirely by commercial operators using informal, de facto rules developed through experience and implemented by consensus.

This cooperative process has been used effectively and without incident since the commercial satellite communications era began in the 1960s, primarily because everyone involved realizes that a satellite collision would be catastrophic. Building and launching a satellite costs hundreds of millions of dollars, and this type of investment gives operators a very strong incentive to avoid space collisions at all costs. The increase in the number of satellites and satellite operators has made the need to share data even more acute.

The evolution of how satellite position data is collected has some parallels with the development of air traffic control for commercial aircraft. In the decade following the Wright brothers first controlled, powered flight at Kitty Hawk in 1903, so few airplanes were in the sky at any given time that human flight required little if any monitoring from the ground. However, after the flight experiences during World War I accelerated advances in airplane design, the industry began to flourish, and the first air traffic control systems were put in place.

The formation of the SDA is a major step toward creating a voluntary "air traffic control" system for space. The SDA is an interactive repository for commercial satellite orbit, maneuver, and payload frequency information.[3] The SDA's principal goal is to promote safe space operations by encouraging coordination and communication among its operator members. Through the SDA's Space Data Center, the satellite operators maintain the most accurate information available on their fleets; augment

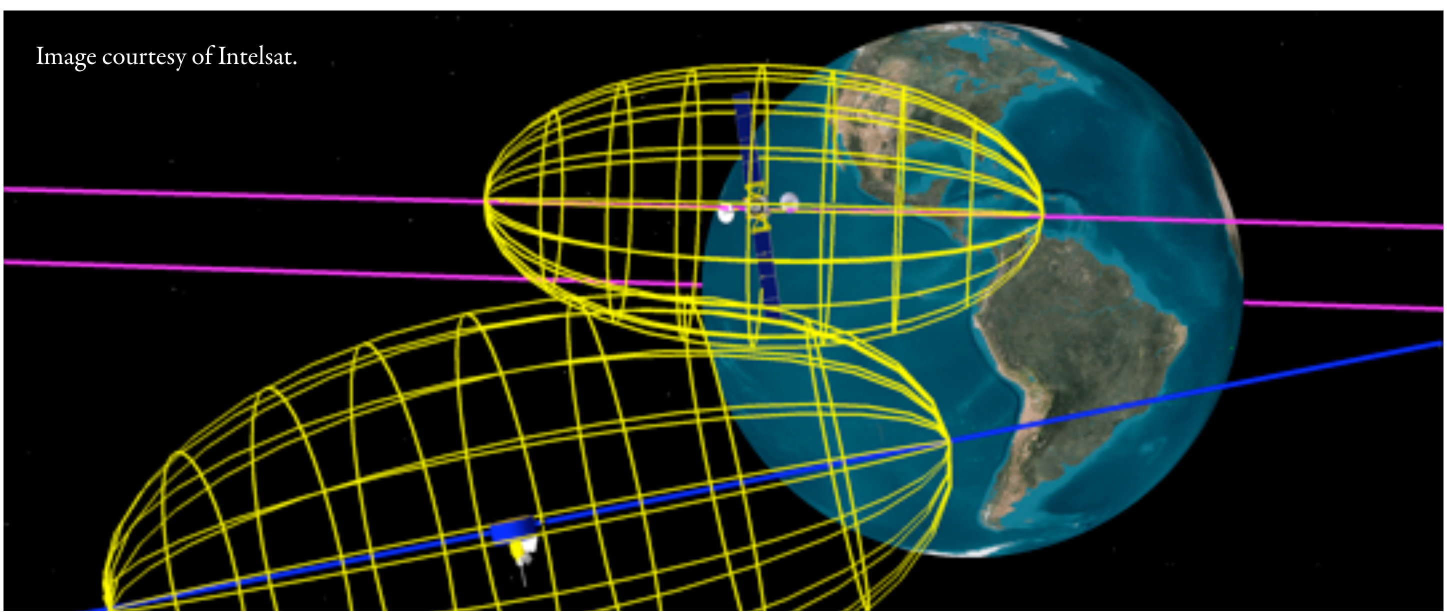


Image courtesy of Intelsat.

augment existing government-supplied data with precise orbit data and maneuver plans; and retrieve information from other member operators when necessary. As a result, the data center:

- Enhances safety of flight.
- Provides efficient, timely, accurate conjunction assessments for members.
- Reduces false alarms, missed events.
- Minimizes member time and resources devoted to conjunction assessment.
- Establishes common format conversions and a common information repository.
- Provides radio frequency interference (RFI) geo-location and resolution support, allowing operators to more rapidly find and address interference sources.
- Encourages the evolution of best practices for members.

Because of the proprietary nature of the operational data, the SDA has been designed to protect information and prevent members from using for commercial purposes the data supplied by competing companies. The members of the SDA contribute operational data through a secure web-based interface on a daily basis and can access data related only to the operation of their own satellites. For example, an operator who only has satellites covering Latin America cannot access data from other parts of the globe. The data center processes information to perform real time identification of "conjunctions" (very close approaches that may lead to a collision) and RFI analysis for SDA members' satellites.

So far, the SDA has actual position information on 237 satellites in geostationary Earth orbit (GEO), and another 110 in low Earth orbit (LEO). The greater the membership of the SDA, the more comprehensive the data and the resulting analysis will be. As new satellite operators continue to join the SDA, the data center will continually improve its reliability in all satellite arcs and develop the system into a truly global and comprehensive database for space situational awareness.

Several years ago, the U.S. government began providing commercial operators with satellite position data gathered by the U.S. Strategic Command (USSTRATCOM) using radars and sensors. The position information provided initially for close-approach monitoring, called two-line element (TLE) data, had several drawbacks. First, there was no available and transparent standard for TLE modeling. Second, TLE data did not have the required accuracy for credible collision detection, forcing operators who wanted to avoid collisions to increase the calculated collision margins. This required an increased number of maneuvers, which wasted fuel and could shorten the life of a satellite. TLE data also lacked reliable planned maneuver information, which limited the usefulness of data for longer-term predictions.

The evolution of how satellite position data is collected has some parallels with the development of air traffic control for commercial aircraft.

Recently, USSTRATCOM admitted that the TLE data was imprecise and developed a procedure for providing commercial operators with additional information in the form of conjunction summary messages (CSMs) to operators whose satellites have been identified as closely approaching another space object.[4] These CSMs contain vector and covariance information computed from other data, making it more accurate than TLEs.

However, recent studies funded by Intelsat and SES have concluded that to ensure the highest level of accuracy, it would be beneficial for USSTRATCOM to incorporate data from routine satellite maneuvers. The SDA has offered to augment the global sensor data maintained by USSTRATCOM with more precise operator-generated data to improve the accuracy of conjunction monitoring. The SDA could also provide a standardized method and focal point for operators to share information and facilitate communications between satellite operators and governments interested in making available timely space object catalogues. Hopefully, with the passage of time, the U.S. and other governments will be able to fully capitalize on this industry-sponsored and funded initiative. Solving the problem of government/industry data sharing and the role of the SDA should be a key objective of future international discussions on this topic.

Another major risk to operators is the proliferation of orbital debris from rocket stages, defunct satellites, equipment lost by astronauts and the fragments left from explosions and collisions of satellites. For example, Vanguard 1, launched by the United States in 1958, is expected to remain in orbit at least another 200 years before slowly burning up as it drifts down into the atmosphere.[5] The debris problem is most severe in LEO, where the majority of satellites used for communications and remote sensing operate. Because these satellites are not geostationary and orbit the Earth about every 90 minutes, several satellites are required to provide continuous coverage of any given area. Using observation data produced by radar and optical detectors, operators on Earth maneuver LEO satellites through a debris field of thousands of objects every day.

While GEO is less cluttered with debris than LEO, any objects in GEO pose more of a threat because all of the satellites are in the same orbital plane. In addition, the atmospheric drag that serves to self-cleanse the lower LEO regime of orbital debris is non-existent in the GEO regime, and only the lesser gravity from the sun and moon serve to slowly pull a GEO satellite out of its initial equatorial, circular orbit. In addition, a GEO space object is so distant that any size less than 1 meter (3 feet, 3 inches) in diameter is difficult to see, making the precise nature of the threat unknown.[6]

International efforts are being made to provide better sharing of information about those practices that contribute most to the space debris problem. One is the Inter-Agency Space Debris Coordination Committee (IADC), a coordinating forum for national space agencies that created an important set of voluntary guidelines regarding the mitigation of man-made and natural debris in space.[7] The primary objectives of the IADC are to exchange information on space debris research activities between member national space agencies, to facilitate cooperation in space debris research, to review the progress of ongoing cooperative activities, and to identify debris mitigation options. Although important, the IADC's work is still only a set of guidelines for national regulators to consider.

Because of the major investment required to design, build and launch a satellite, the commercial industry is rightly concerned that the "tragedy of the commons" not be replicated in Earth orbit.[8] The number of operating satellites and the volume of space debris are both increasing steadily, a fact that does not bode well for a cleaner and safer space environment. As land is on Earth, the orbital planes in space are finite resources that can be depleted or polluted in ways that make continued use impossible.

Today, the valuable LEO environment is in some jeopardy of suffering "the tragedy of the commons" as a result of the significant increase in both space debris and RFI interference. As these threats multiply, satellite operators and their customers are at risk of losing access to a satellite service that benefits both commercial and consumer markets.

Space is indeed a limited resource. As vast as it appears when looking toward the heavens on a starry night, the portion of space that can be used effectively for communications, weather monitoring, remote sensing and other satellite-based applications is really just a thin shell that extends outward from Earth less than one tenth of the distance to the Moon. Governments and private companies around the planet are investing billions of dollars in next-generation space technology. Every one of those users and potential users of the orbital environment have a stake in its long-term preservation.

While governments were the first to send satellites to near-Earth space, commercial enterprises and consumer services will be the primary users of the orbital arcs in the 21st century and, hopefully, beyond. Consequently, governments and companies operating spacecraft need to take a new approach to enhancing the safety and efficacy of the space environment, an approach that includes more international cooperation among all parties. The Space Data Association is the major step on this path, and that step should be followed by firm actions of governments and all space users to create an international framework that assures the preservation of this valuable resource. ■

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[1] NASA Orbital Debris Quarterly News, July 2011.

[2] Most commercial and military satellites operate in one of two orbit planes. The first, low-Earth orbit (LEO), is between 160 and 2,000 meters (100-1,240 miles) above Earth's surface. The other, geostationary Earth orbit (GEO), is a circular orbit 35,786 kilometers (22,236 miles) above the equator.

[3] See: www.space-data.org.

[4] Statement of Major Duane Bird, USAF, US Strategic Command to *AMOS Conference*, September 2010.

[5] NASA's National Space Science Data Center.

[6] David Portree and Joseph Loftus. "Orbital Debris: A Chronology," NASA, 1999.

[7] See: http://www.iadc-online.org. The IADC member agencies include the following: ASI (Agenzia Spaziale Italiana), CNES (Centre National d'Etudes Spatiales), CNSA (China National Space Administration), CSA (Canadian Space Agency), DLR (German Aerospace Center), ESA (European Space Agency), ISRO (Indian Space Research Organisation), JAXA (Japan Aerospace Exploration Agency), NASA (National Aeronautics and Space Administration), NSAU (National Space Agency of Ukraine), ROSCOSMOS (Russian Federal Space Agency), UKSpace (UK Space Agency).

[8] Concept first presented in the seminal article by Garrett Hardin, "The Tragedy of the Commons," *Science*, Vol. 162, No. 3859 (December 13, 1968). The tragedy of the commons posits the situation where rational individuals, acting in their own self-interest, may ultimately render a shared and limited resource unusable, even when it is clearly not in their interest to do so.

Space Data Association

The Case for SSA Collaboration and Data Fusion

— BY RICHARD DAL BELLO

The SDA was formed by leading satellite owners and operators with the goal of increasing the safety and efficiency of their operations in space. To achieve this goal, the operator members need to receive *actionable* Space Situational Awareness (SSA), particularly in the areas of Conjunction Assessment (CA) and Radio Frequency Interference (RFI) mitigation.

The SDA's Space Data Center (SDC) comprises the only SSA analysis system incorporating truly-authoritative maneuver plans and RF data for 70percent of all active satellites in geostationary Earth orbit (GEO). Currently, SDA members share actual position information on 237 satellites in GEO, and another 110 in low Earth orbit (LEO). From the data provided thus far, the SDA has identified significant levels of data incompatibility in the orbit determination and analysis packages used in the space operations community, which includes radar/optical networks, satellite operators, and launch providers. The SDC has systematically addressed this issue by conducting extensive research, operator interchange and astrodynamics development to facilitate the technical "rectification" of operator data into compatible, shared reference frames.

The SDC also uses a combination of quarterly, independent orbit determination (OD) verifications and weekly comparisons against external radar and optical data to ensure the ongoing success of this rectification process. When discrepancies are detected, this diverse-comparison approach allows follow-on investigations to clarify whether operator data or radar and optical data are suspect.

Although computing CA is complex, the concept is actually very simple. Assuming one has precise and reliable data, answering the question, "When will these space objects get too close?" is not technically challenging. There are several reliable COTS software solutions for rapidly detecting such threats. The significant challenge is in making sure that inputs and outputs of the CA and RFI analyses are accurate enough to warrant operator confidence in the results so that managers can select and implement viable risk-mitigation strategies.

Assuming one has precise and reliable data, answering the question, "When will these space objects get too close?" is not technically challenging.

Information provided to the SDA by satellite operators is augmented by data from the U.S. Joint Space Operations Center (JSpOC), which operates one of only a handful of global radar and optical sensor networks collecting satellite positioning data. In addition to tracking operational satellites, such networks are the only source for orbital debris information. The JSpOC data is comprised of analytic or "general perturbations" (GP) data (such as the ubiquitous two-line element set or TLE) and higher-fidelity "special perturbations" (SP) data. Using radar and optical sensor networks to track objects in space presents a host of unique technical and programmatic challenges. These include not accounting for routine maneuvers by satellite operators; limited sensor observations; difficulties acquiring satellites; "lost satellites"; conflicting mission priorities; track mis-association problems; lack of sensor scheduling; and sensor lighting constraints. These challenges are chiefly a reflection of the non-cooperative tracking (NCT) technology and not a reflection of NCT staff or tool capabilities.

Satellite operators feel uniquely qualified to generate authoritative satellite data for their space assets because they typically perform hourly transponder ranging sessions with their satellites; have well-calibrated maneuver times, magnitudes and directions; and often have dedicated assets for tracking their spacecraft. Independent analysis of the orbit solutions from satellite operator data has typically revealed very good performance. However, satellite operators face unique challenges as well, including initial difficulties sharing their data with other operators in a mutually-compatible and understandable format and a lack of data for space debris objects.

For an operator to take action based on SSA products, the analyses must be *predictive*, *timely, precise* (i.e., reproducible and convergent) and *accurate*.

It is fairly easy to assess whether a process is *predictive* and *timely*. For CA, space operators typically need a final and definitive assessment of collision risk approximately two days prior to the event. This lead time is sufficient for analyzing the conjunction; planning an avoidance maneuver; briefing the company's decision authority; getting the go-ahead to perform the avoidance maneuver; and executing the maneuver early enough to avoid wasting fuel (because the magnitude of the maneuver required to avoid a conjunction increases as the objects get closer together). Warnings that come with less than two days' notice are problematic because more drastic measures are required to avoid a threat.

To characterize *precision* and *accuracy* in the real world, SSA analysts have a responsibility to apply statistically-relevant, transparent and on-going evaluations of convergence, reproducibility and comparison with complementary data are required. A CA process which predicts satellite conjunction events well in advance and for which predictions of the conjunction vary little from the original prediction or from one another can be said to be *precise* (i.e., reproducible and convergent). Comparisons of SSA predictions with truth models and post-event, best-estimate trajectories can be used to assess SSA whether the prediction is *accurate*.

The SDA members have conducted many systematic studies of CA and RFI analysis convergence. SDA member orbits have been regularly and independently verified for consistency and accuracy. From these studies, the SDA has determined that SSA products are highly sensitive to input errors and process deficiencies.

Consider:

1. For optical sensors, up to 15percent of a satellite's observations are confused or "cross-tagged" with data from another satellite within the sensor's field-of-view, most commonly during the greatest collision threat intervals.[2]
2. By evaluating CA results for a variety of simulated collisions, analysts have determined that SSA based on radar and optical data that neglects satellite maneuvers can drastically underestimate collision risk – to the point of predicting a probability of collision of 1 chance in 10^{300} *(that's 300 zeroes)* for two objects that are in fact on a collision course. [3]
3. Government-led time-difference-of-arrival tests indicate a ten-fold improvement in positional accuracy when operator data is used instead of public data.[4]
4. Because telescopes perform best at night, GEO orbits derived from optical telescopes can experience accuracy degradations of up to 35 km in the daytime.[5]
5. The absence of a radar and optical sensor scheduling algorithm in JSpOC's Space Surveillance Network (SSN)[6] leads to undersampling, cross-tagging, and an inability to improve orbit accuracy.
6. For active satellites being maneuvered, the SDA has found that optical-sensor-derived orbits are usually a week late and can be more than 1,000 km behind operator data in reflecting maneuvers.

The failure of governments and commercial satellite operators to generate a collaborative and accurate SSA picture could result in a geosynchronous satellite collision with potentially dire consequences.[7] Yet there is a clear path for managing this risk, and that path is active collaboration and data fusion. Radar/optical networks and space operators both offer truly unique and complementary capabilities that, when fused together, offer substantially improved SSA. ■

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The Anti-Satellite Capability of the Phased Adaptive Approach Missile Defense System

— BY LAURA GREGO

In early 2008, President Bush tasked U.S. Strategic Command with Operation Burnt Frost: "mitigating" the threat posed by a non-responsive intelligence satellite that was soon to re-enter the Earth's atmosphere. USA-193 had been launched into orbit just over a year earlier, and its fate was sealed after the National Reconnaissance Office was unable to establish control over the satellite after launch. While the imminent re-entry of a satellite was not in itself at all remarkable—70 tons of space debris and scores of large objects drop out of orbit each year without any casualty and without any operations mounted in response—administration officials expressed concern that leftover hydrazine fuel aboard the satellite might survive re-entry and hurt someone on the ground.

On February 14, 2008, General James Cartwright announced the United States would destroy the satellite using the Aegis sea-based missile defense system. After a few days of waiting out rough seas, on February 20, the U.S. Navy Ticonderoga-class cruiser Lake Erie launched an SM-3 missile which intercepted the USA-193 satellite.

While framed as a public safety measure, some observers expressed skepticism that this risk was the real or entire motivation for the exercise. The interception, at an altitude of 240 kilometers (km), vividly demonstrated the ASAT capability of the U.S. Aegis sea-based missile defense system. The intercept reportedly required only modification of the system software,[1] and could have been done from any of the 5 cruisers or 16 destroyers equipped with the Aegis system at the time (two destroyers were slated to be backups to the USS Lake Erie).

The context is important. This was the first time the United States had deliberately destroyed a satellite since 1985; Russia hadn't done so since 1982.[2] This unofficial moratorium had been recently broken by China in 2007, when it destroyed its own aging weather satellite at 800 km altitude. The Bush administration had withdrawn from the Anti-Ballistic Missile Treaty in 2002 and expressed interest in a range of new military uses for space, including space-based weapons and anti-satellite weapons. Just a week before Operation Burnt Frost was carried out, China and Russia had circulated to the Conference on Disarmament a draft treaty that would ban putting weapons in space and using force against satellites.[3] The United States responded with little interest, saying that there was no need for arms control in space.[4]

Operation Burnt Frost, in turn, is important context for the announcement eighteen months later of the Obama administration's new plans for European missile defense, the Phased Adaptive Approach (PAA).

This new PAA plan replaced the George W. Bush administrations' plan that aimed to protect European allies from missile threats in the Middle East using powerful ground-based interceptors in Poland and a radar in the Czech Republic. PAA would rely on and substantially expand and improve the Aegis missile defense system used in Operation Burnt Frost and demonstrated to have anti-satellite capability.

The Phased Adaptive Approach to European Missile Defense

The PAA system's much smaller SM-3 interceptors are to be based primarily at sea on Aegis ships converted to the purpose as well as some land-based "Aegis ashore" sites. It is meant to be flexible and address emerging ballistic missile threats from the Middle East over the coming decade. It will be improved incrementally, in four phases. The current generation of the SM-3 missiles, Block 1, will eventually be augmented with longer-range, more sophisticated missiles. More ships would be outfitted with new missiles and new and improved sensors added. Land-based sites would be added starting in 2015.

Currently, only the Block IA variant of the SM-3 missile is deployed. The Block IB interceptors, currently under testing and development, are based on the same 3-stage booster missile as the Block IA missile, but the Block IB kill vehicle will have sensors that can image the target at two wavelengths and increased capability to maneuver ("divert capability"). Both Block I interceptors have a reported burnout velocity of 3.0-3.5 km/s. The Block IIA will have longer range and a seeker with better discrimination and more divert capability. The Block IIA interceptors are expected to burnout at a velocity 45-50percent faster than the Block I missiles, so in the range of 4.5 to 5.5 km/s.[5] The Block IIB interceptor is still in the conceptual stage, but is meant to engage intercontinental-range ballistic missiles and to have yet higher propulsion. It may be land-based only.

The plan is to make all versions of the SM-3 missile able to be launched from the launch tubes on the Aegis ships.

Also important is the development of more sensors and the capability of the Aegis ships and sites to perform "launch on remote," the ability to launch on the cue from a sensor not on the ship. This will allow the interceptors to launch from a greater range. This capability was first introduced to the Aegis system after Operation Burnt Frost and will now become standard.

Missile Defenses as ASAT Weapons

While Operation Burnt Frost was the first time the United States used a missile defense system to destroy an orbiting satellite, the United States has for years had some intrinsic ASAT capability in its existing missile defense programs. Both the Aegis BMD and Terminal High Altitude Area Defense (THAAD) missile defense systems were considered during the preparation of Operation Burnt Frost,[7] although THAAD, like the SM-3 Block 1 systems, would be useful only against the lowest altitude satellites.

The U.S. Ground Based Midcourse (GMD) missile defense system with a total of 30 deployed interceptors in Alaska and California[8] and the recently shuttered Airborne Laser, also have intrinsic anti-satellite capability.[9] The GMD interceptors could reach nearly any satellite in low earth orbit (LEO).

The SM-3 is designed to intercept warheads in the midcourse phase of flight, when they are above the atmosphere. The kill vehicle carries its own fuel for maneuvering as well as an infrared sensor. The sensor is intended to guide the interceptor toward an object and allow it to home in on and destroy the target by direct impact, or "kinetic kill."

Because midcourse missile defense systems are intended to destroy ballistic missile warheads, which travel at speeds and altitudes comparable to those of satellites, such defense systems also have ASAT capabilities. In fact, while the technologies being developed for long-range missile defenses might not prove very effective against ballistic missiles—for example, because of countermeasure problems inherent in midcourse missile defense—they could be far more effective against satellites.

In many ways, attacking satellites is an easier task than defending against ballistic missiles. Satellites travel in repeated, predictable orbits that ground facilities can accurately determine by tracking them. An attacker would have time to plan an attack against a satellite, could choose the time of the attack in advance, and would be able to take as many shots as necessary to destroy it whereas advance notice of a ballistic missile attack is unlikely. In addition, an interceptor attacking a satellite would not have to contend with the same countermeasure[10] problems that a midcourse missile defense system would face.

Table 1. Summary of important characteristics of the Phased Adaptive Approach system[6]

Phase/year	Number, SM-3 variant	Burnout velocity	Platforms
1/2011	111 Block IA/IB	3 -3.5 km/s	23 Aegis ships
2/2015	263 Block IA/IB	3 – 3.5 km/s 4.5 km/s	38 Aegis ships 1 site in Romania
3/2018	486 Block IA/IB 14 Block IIA TBD Block IIB	3 - 3.5 km/s 4.5- 5.5 km/s ---	43 Aegis ships 1 site in Romania 1 site in Poland
4/2020	486 Block IA/IB 29 Block IIA TBD Block IIB	3 – 3.5 km/s 4.5 – 5.5 km/s ---	43 Aegis ships 1 site in Romania 1 site in Poland

Table 2. Maximum altitude reachable by SM-3 variants.

SM-3 variant	Burnout velocity (km/s)	Maximum reachable altitude (km)
Block IA	3.0	600
Block IIA (lower range)	4.5	1450
Block IIA (upper range)	5.5	2350

Countermeasures can severely limit the ability of a midcourse missile defense to defend against ballistic missiles: warheads and lightweight decoys move on the same trajectories in the vacuum of space, and the interceptor's onboard sensor or ground-based radars would be unable to distinguish these decoys from the warhead. An attacker can release numerous decoys along with the warhead in order to confuse the missile defenses or exhaust them by forcing them to intercept all the decoys along with the warheads.

Operation Burnt Frost showed that SM-3 interceptors can successfully intercept satellites if they can be reached. LEO satellites are generally in highly inclined or nearly polar orbits, and their orbits will take them over any given region on earth (with latitude below the inclination angle) twice a day. Since an attacker could choose the timing and geometry, the attack can be mounted when the satellite is overhead and the missile defense interceptor may therefore use its velocity to reach the highest altitude possible rather than to reach out laterally. A rough estimation of the maximum altitude an interceptor can reach may be calculated by setting the kinetic energy of the interceptor at burnout (when the missile ceases powered flight) to the potential energy at the given altitude.

The current Aegis interceptors SM-3 IA/IB can reach only the relatively few satellites in orbits with perigees at or below 600 km altitude. However, even using a conservative estimate of the burnout speed (4.5 km/s), SM-3 Block IIA interceptors would be able to reach the vast majority of LEO satellites (see Figure 2).[11] Interceptors with burnout speeds at the high range of estimates for the SM-3 IIA (5.5 km/s) would be able to reach any satellite in LEO, as would GMD interceptors.

PAA as a Strategic ASAT Weapons System

While the United States has long had ASAT capability in its missile defense systems, the PAA system as conceived is ASAT capability on a much different scale. The enormous potential size of the capability is new. While the projected inventory of Block II SM-3 interceptors is modest—there are 29 Block IIA interceptors and an undefined number

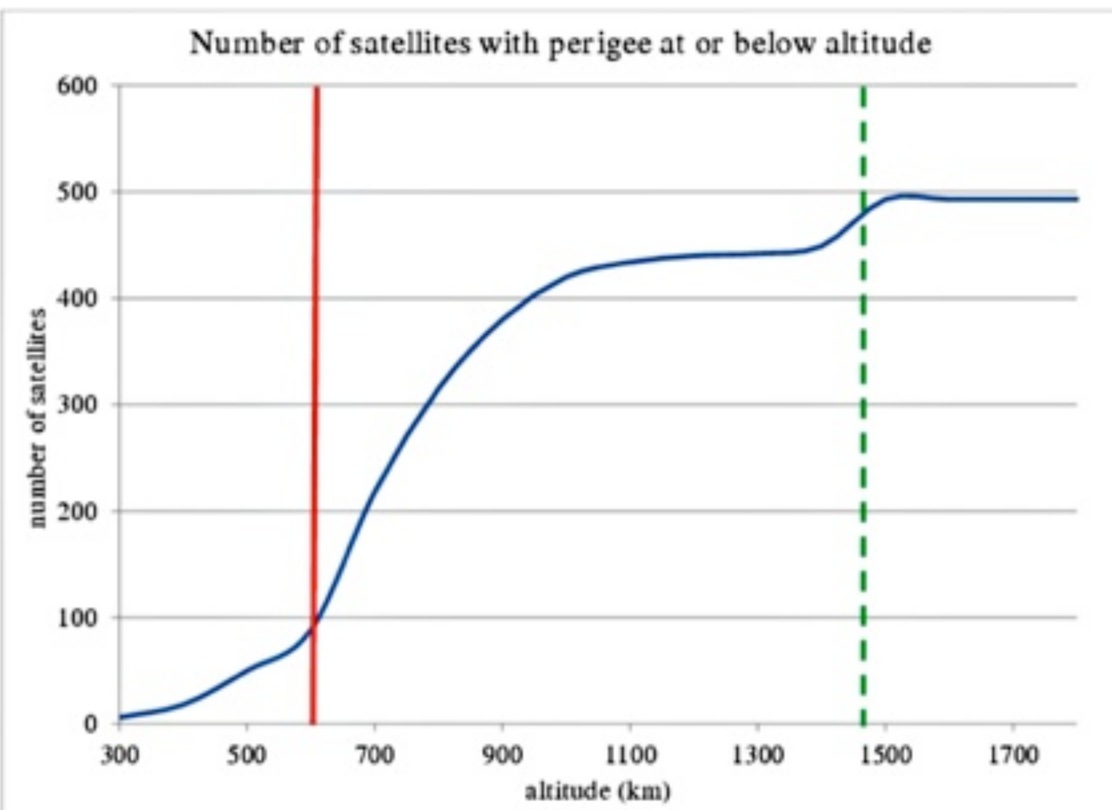

Figure 2. The solid blue curve represents the number of satellites with perigee at or below a given altitude. Low earth orbiting (LEO) satellites tend to stay away from the high-radiation environment above 1500 km. The solid red line at 600 km is the reach of the SM-3 Block IA interceptors. The dashed green line at 1450 km is a lower bound estimate of the reach of the SM-3 Block IIA interceptors; it can reach nearly all LEO satellites.

Table 3. Number of actively operating satellites in low-earth orbits, categorized by primary users.[11]

Country	Civil	Government	Commercial	Military	Total
China	5	36	--	8	49
Russia	2	2	9	30	43

of SM-3 IIB interceptors planned for 2020, Aegis warships are capable of carrying large numbers of interceptors—cruisers have 122 launch tubes and destroyers have 90 or 96 each.[12] This would support a large scaling-up. Block II interceptors are designed to fit in all launch tubes.

The number of ASAT-capable SM-3 missiles can be scaled up and their configuration changed more rapidly and less expensively than the GBI missiles. While GBI interceptors cost about $70 million each, the estimated procurement cost for each SM-3 Block IIA missile is $20-24 million. While locating a new GBI missile site in a different location would take greater than five years for construction, the sea-based SM-3 missiles can be readily moved to the theater in which they are needed.[13]

This potentially large ASAT capability can be compared to the satellite inventory of the two heaviest space users after the United States, which owns just shy of half of actively operating LEO satellites. Satellites stationed in LEO perform important civil and military functions; this is where most earth-observing, reconnaissance and signals intelligence, and weather satellites orbit. Table 3 shows the number of actively operating Chinese and Russian satellites in low-earth orbits. China has a total of 49 and Russia 43. (The United States owns 230 LEO satellites.) The PAA system as it gets to Phase 3 and 4 (see Table 1) could hold at risk a significant portion of either China's or Russia's low earth orbiting satellites, particularly if the numbers of Block II interceptors is increased or it is considered in concert with GMD.

Another important point is that the PAA system is highly mobile. The 43 planned Aegis ships could be positioned optimally to stage a "sweep" attack on a set of satellites nearly at once, rather than a sequential set of attacks as satellites moved into range of fixed interceptor sites. This positioning flexibility also means that the SM-3 missiles would not have to expend much of their thrust going cross-range and could retain the ability to reach the highest LEO satellites. (The more powerful GMD interceptors also could use some of their fuel to reach out laterally over thousands of kilometers, allowing them to hit satellites in orbits that do not pass directly over the GMD missile fields in Alaska and California.)

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The Way Forward

While the primary purpose of the PAA system is not ASAT, as conceived it will be the largest destructive ASAT capability ever fielded and can hold a significant portion of any other space actor's space assets at risk. While some may describe the capability as "latent," it has been clearly demonstrated in Operation Burnt Frost. At the same time, international law treating the interference or destruction of satellites is only very weakly elaborated.

Some restraints on using the PAA system as an ASAT weapon do exist. Operation Burnt Frost required a modification of the missile defense software in order to perform the ASAT intercept and this reportedly will not become a standard option. However, no formal U.S. policy exists that renounces deploying this option, either, and other countries will assume that this change could readily be made to give any Aegis interceptor the ability to intercept satellites.

Additionally, the United States is clearly aware of the debris consequences of using kinetic energy interceptors to destroy satellites. For example, the destruction of a single 10-ton satellite could by itself double the total amount of large debris currently in low earth orbit.[14] This is a major reason why the United States prefers non-destructive ASAT options. It is therefore unlikely to use the PAA as an ASAT weapon simply to signal intent or in any situation outside of a major conflict.

But the existence of this capability also makes significantly less likely the possibility that other countries will also refrain from building such systems. The hit-to-kill intercept technology used by China for its January 2007 satellite destruction was apparently developed as a system that could be used either for ballistic missile defense or ASAT attacks.[15] It is likely that China's first ballistic missile defense test on January 11, 2010, used this same technology.[16] India is also developing a hit-to-kill ballistic missile defense system which could also serve an ASAT role. Long-standing restraint regarding such systems has been weakened.

The Aegis-based missile defense system is also likely to be owned by other countries besides the United States. The Aegis system's interceptor technology is being codeveloped

and operated by Japan, and Japan is modifying all six of its Aegis destroyers with the updated Aegis BMD system. In June 2011, Japan agreed in principle to the export of the codeveloped SM-3 Block IIA missile to other countries,[17] clearing the way for the expected sale of the Aegis BMD system to additional users, including several European countries as well as South Korea and Australia.[18] Given the intrinsic ASAT capability of this system, the United States should review carefully its plans to sell this capability to other countries.

At the same time, the United States is grappling with what to do to address its outstanding space security issues. The National Security Space Strategy outlines a strategy for protecting U.S. interests in space, including supporting the development of norms of responsible behavior for space-faring nations, and increasing the ability of the U.S. military to continue to operate despite interference with its satellites by an adversary.[19] The United States is engaging in diplomatic initiatives such as the effort to create an International Code of Conduct for Outer Space Activities and the United Nations Group of Governmental Experts forum on confidence-building and transparency measures to improve space security and sustainability. However, none of these efforts yet imagine restrictions on "hardware" like missile defense interceptors, and are focused instead on creating norms of behavior. (Even the Russian-Chinese draft treaty on space weapons does not restrict ground-based missile defenses.)

Few limits or guidelines exist on technologies suited to ASAT use and devising effective limits on them becomes increasingly difficult as more weapons are developed and tested and more countries develop policy rationales and military doctrine for using them. Serious efforts to strengthen them should be put forth by all spacefaring nations; such discussions have not taken place for many years.

In addition to strengthening the legal and normative framework, space security requires thoughtful limits on the most dangerous technology. One way to address the inherent ASAT capability of the PAA is to restrict the burnout velocity of the deployed SM-3 missiles and to discontinue the Block II program.

A primary rationale for the high-speed Block II interceptors is to enable "early intercept"—the capability to intercept the attacking missiles after their launcher burns out (post-"boost phase") but before they are able to release countermeasures. However, the Defense Science Board, in an unclassified summary of its report on early intercept states that:

> *Intercept prior to the potential deployment of multiple warheads or penetration aids –the principal reason often cited for EI – requires Herculean effort and is not realistically achievable, even under the most optimistic set of deployment, sensor capability, and missile technology assumptions.*

While the study cites other capability-enhancing or cost-reducing scenarios that the longer-range interceptors could provide, the authors cede that successful operation of midcourse missile defense requires addressing the as-yet-unsolved countermeasures problem.[20] And the Block II missiles do not do so.

While the SM-3 Block II missiles will not solve the countermeasures problem by providing an early intercept capability, they could still have a theoretical capability to intercept Russian and Chinese long-range missiles; this can complicate Russian and Chinese reductions in nuclear weapons.[21] Limiting the allowed burnout speed of the SM-3 missiles would therefore not sacrifice any new capability, and would also avoid the problems that deploying an unlikely-to-be-used but still provocative ASAT system would.

The space environment needs more protection, satellites face growing risks, and space activities continue to be a potential source of mistrust and tension. Making significant progress requires making forward-looking choices. ■

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REFERENCES AND NOTES

[1] It is unlikely these software changes were significant and likely just provided infrared signatures of a satellite for the seeker and eliminated any instructions to ignore satellites. General Cartwright said in a press briefing that the physical modifications were instrumentation; this is presumably to provide information about the test. "Destruction of Spy Satellite." February 21, 2008. C-SPAN, c-spanvideo.org.

[2] In 1982, the Soviet Union conducted its last test of its Co-Orbital antisatellite weapon. In 1985, the United States destroyed an aging weather satellite using a direct-ascent kinetic kill interceptor launched from an F-15 airplane. Grego, L. "A History of Anti-satellite Programs" January 2012. Union of Concerned Scientists.

[3] Russia and China introduced their draft "Treaty on the Prevention of the Placement of Weapons in Outer Space, the Threat or Use of Force Against Outer Space Objects" on February 12, 2008. http://www.reachingcriticalwill.org/legal/paros/wgroup/PAROS-PPWT-factsheet.pdf The treaty forbids "hostile action against outer space objects including, inter alia, those aimed at their destruction, damage, temporarily or permanently injuring normal functioning, deliberate alteration of the parameters of their orbit, or the threat of these actions."

[4] Christina Rocca, U.S. ambassador to the CD, told the delegates in Geneva on February 13, 2007, that "we continue to believe that there is no arms race in space, and therefore no problem for arms control to solve." Statement delivered to the United Nations' Conference of Disarmament on Prevention of an Arms Race in Outer Space. Geneva, February 13. Online at *http://www.reachingcriticalwill.org/political/cd/speeches07/1session/Feb13USA.pdf*.

[5] O'Rourke, Ronald. "Navy Aegis Ballistic Missile Defense (BMD) Program: Background and Issues for Congress." December 22, 2011. Congressional Research Service. Available at http://www.fas.org/sgp/crs/weapons/RL33745.pdf , accessed Feb. 1, 2012.

[6] Ibid.

[7] At an April 23, 2008, hearing of the Defense Subcommittee of the Senate Appropriations Committee, General Henry Obering, director of the Missile Defense Agency, testified as follows: "It took us a couple weeks to analyze, and it turned out that both the ground-based midcourse THAAD and the Aegis all had capability, if they were modified, to go do this mission [to shoot down the failed USA 193]. The Aegis was the easiest to modify and also represented the most flexibility and the minimum impact to our program overall."

[8] Ground-Based Midcourse Defense Fact Sheet. Missile Defense Agency. Accessed February 1, 2012. http://www.mda.mil/global/documents/pdf/gmdfacts.pfd

[9] Wright, D. and Grego, L. "Anti-Satellite Capabilities of Planned U.S. Missile Defense Systems." *Disarmament Diplomacy* Issue No. 68, December 2002-January 2003.

[10] For an extensive discussion of countermeasures to midcourse missile defenses, see A. Sessler et al., *Countermeasures: A Technical Evaluation of the Operational Effectiveness of the Planned U.S. National Missile Defense System*, April 2000, Union of Concerned Scientists.

[11] The satellite information comes from the UCS Satellite Database, January 2012 edition. Available at http://ucsusa.org/satellites.

[12] The number of launch tubes depends on how many cells were used to host loading cranes.

[13] O'Rourke, Ronald. "Navy Aegis Ballistic Missile Defense (BMD) Program: Background and Issues for Congress." December 22, 2011. Congressional Research Service. Available at http://www.fas.org/sgp/crs/weapons/RL33745.pdf , accessed Feb. 1, 2012.

[14] See Wright, D. "Space Debris." *Physics Today*. Vol. 60, No. 10, October 2007, pp. 35-30.

[15] Kulacki, G. and Lewis, J. 2008. "Understanding China's Antisatellite Test." The Nonproliferation Review. Volume 15, No. 2, July 2008.

[16] See Jacobs, A., and J. Ansfield. 2010. "With defense test, China shows displeasure of U.S." *New York Times,* January 12. See also the blog post and the references therein at *China's missile defense interceptor program: An independent Chinese analysis*. Online at *http://thetaiwanlink.blogspot.com/2010/01/chinas-missile-defense-interceptor.html*, accessed on September 19, 2010.

[17] Japan requires three conditions for the export—that third-party recipients of the technology have appropriate domestic systems for export control and information integrity, that they are members of international frameworks on these matters, and that the transfer benefits Japan's security, though it is not clear by what process these conditions are determined to be met.

[18] O'Rourke, Ronald. "Navy Aegis Ballistic Missile Defense (BMD) Program: Background and Issues for Congress." December 22, 2011. Congressional Research Service. Available at http://www.fas.org/sgp/crs/weapons/RL33745.pdf , accessed Feb. 1, 2012.

[19] Text of the National Security Space Strategy and related documents are available at http://www.defense.gov/home/features/2011/0111_nsss/

[20] The Defense Science Board study states that "Although not analyzed in detail during the course of the study, it is clear that the successful operations [of cost-effective ballistic missile defense] is predicated on an ability to discriminate (in the exo atmosphere) the missile warhead(s) from other pieces of the offensive missile complex, such as rocket bodies, miscellaneous hardware, and intentional countermeasures. The importance of achieving reliable midcourse discrimination cannot be overemphasized."

[21] Butt, Y. and Postol T. *Upsetting the Reset: The Technical Basis of Russian Concern Over NATO Missile Defense*. Federation of American Scientists Special Report No. 1, September 2011.

How to Work in the New Space Security Environment

— BY S. PETE WORDEN, JAMES MASON, JAN STUPL, and CREON LEVIT

INTRODUCTION

During the Cold War, space was dominated by the United States and the Soviet Union. Today, more than 40 countries [source: UCS satellite database] operate satellites in orbit. If one includes the members of the European Space Agency (ESA), nearly 30 countries have access to space launch vehicles. Excluding ESA, seven countries have repeatedly demonstrated launches, and there are new players on the verge of joining that exclusive club. These include some truly commercial entities, but also Iran and North Korea. The increasing number of players presents a new and challenging space security environment that demands new approaches.

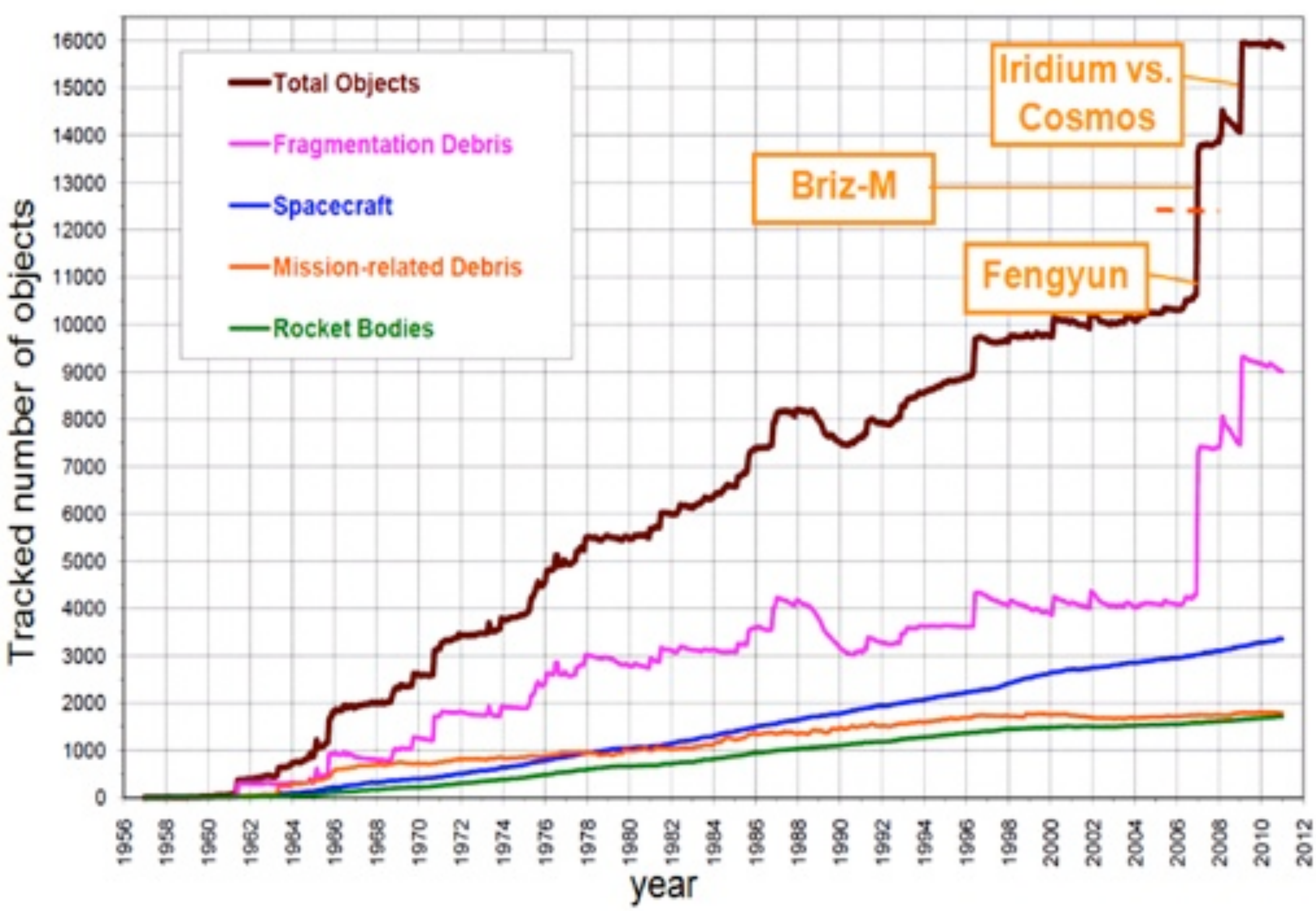
Along with achieving a basic strategic missile capability, most space faring nations have demonstrated a fundamental prerequisite for an impact anti-satellite (ASAT) capability. Only a few have actually performed high precision rendezvous or targeted strikes, but having a space launcher brings one closer towards the possession of an impact ASAT weapon.

Simply testing impact ASAT weapons, besides having obvious political consequences, presents problems for any operators in the space environment: in orbits above about 800 km any generated debris can remain in orbit for decades or even much longer. Every fragmentation event starts a cosmic game of billiards, spreading debris and endangering assets in other, similar orbits.

In the past, there have been few deliberate fragmentation events, but also a fair number of accidental fragmentations resulting from explosions and collisions. Altogether these lead to an impressive increase in the number of space debris objects (see Figure 1).

In some popular orbits, simulations indicate that the number of fragments has reached a density where the new debris produced by collisions is exceeding the natural re-entry rate due to atmospheric drag, leading to a runaway effect known as the Kessler Syndrome. [1] Keep in mind that these orbits became popular because they are useful for human endeavors. The increased collision risk for satellites in these orbits is already noticeable, reducing expected satellite lifetime by a few percent. [2] For satellites worth billions of dollars this translates into real money.

Figure1: Objects in Earth orbit by object type as cataloged by the U.S. Space Surveillance Network: "Fragmentation debris" include satellite breakup debris and anomalous event debris, "mission-related debris" include all objects dispensed, separated, or released as part of the planned mission. Source: NASA Orbital Debris Program Office, *Orbital Debris Quarterly News*, Vol. 14, Iss.1 (2010). Major debris events annotated.



Space has become more congested and more dangerous. Combine that with times of challenging budgets and it is clear that the old way of flying a few highly capable satellites is no longer feasible.

In short, space has become more congested and more dangerous. Combine that with times of challenging budgets and it is clear that the old way of flying a few highly capable, and very expensive satellites is no longer feasible. The risk that one of these critical assets is disabled in a time of need, through hostile or accidental means, is just too high. The excessive cost and complexity of these systems also means that systems-level redundancy is traded for extreme risk aversion in the engineering cycle, leading to increased cost. Spares are simply infeasible in this self-perpetuating cycle. Large launch vehicles take months to prepare, and keeping them on standby for emergencies is just too costly.

Nation's and multi-nation coalition's security has become more dependent on space infrastructure; the United States most of all, as it leads the revolution towards net-centric warfare. We are facing the dilemma of depending on an infrastructure that is increasingly difficult to protect.

We can mitigate this dilemma if we can manage to do three things: 1) leverage recent advances in consumer electronics to produce large numbers of small cheap satellites which can provide distributed capabilities, 2) provide low-cost, on demand, micro-launchers to launch these satellites, and 3) implement effective space traffic management (space collision avoidance) systems.

A Paradigm Shift Towards Small Satellites and Distributed Capabilities

The Cold War's reconnaissance satellites represent astonishing technical achievements. Spacecraft like the KH9 Hexagon were close to the weight and size of a typical school bus and provided amazing imaging capabilities. Modern systems are even more impressive. However, building up redundant and easily replaceable capabilities based on these assets is just not feasible anymore. As more actors enter space, the heroes of the Cold War have lost their main strength: their invulnerability. ASATs vs. multi-billion dollar orbital assets is operationally, economically, and unsustainably asymmetric.

The key is to shift to distributed systems. Instead of building one satellite with multiple sensors and communication devices, these sensors and devices can be spread over multiple satellites. Where once there was a bus-sized satellite, there will soon be swarms of smaller, modular, and more agile satellites. If one camera fails, replace the camera satellite. If more communication bandwidth is needed, send up another communication module. This approach has been recognized and is boosted by initiatives like the international QB50 project [3] and DARPA's F-6 project.[4]

The resolution of an optical camera is proportional to its diameter - to get high resolution reconnaissance imagery requires large optics. While this does represent a case where distributed sensors cannot (yet) replace the existing capability, it is also true that the improved cadence offered by a swarm of imaging satellites offers value that occasional high resolution does not. To improve resolution, lowering the satellite's orbit will help and if satellites are cheap then the reduced lifetime and increased vulnerability is not a problem. In the future, new interferometric imaging technology may allow swarms of small satellites to mimic the performance of large single systems - synthetic apertures combining multiple small-satellites, and/or single lightweight "photon sieves" might offer a solution.[5]

Shrinking the satellite's size and weight is not sufficient alone, and shrinking cost can be even more difficult. Currently, satellite components are extremely specialized and risk aversion has bred a cult of only flying heritage systems. Components are rarely flown on real missions unless they have been tested and qualified to the n-th degree. The use of commercial off-the-shelf electronic components is nearly unheard of. This approach is understandable if you build a multi-billion dollar satellite and demand the highest quality controls. However, if the goal is to quickly build large numbers of something that can survive in orbit for relatively short time and can easily be replaced, then the consumer electronics industry can show us how to do it.

Reducing these barriers of entry (i.e. cost) will draw commercial and public interest from outside the aerospace and defense industries. Similar to the development of the Internet and the advances in mobile communications, increasing the number of players often leads to new applications that nobody has heard of before. Today, the only people able to contemplate new space capabilities are the incredibly rich. You and I have very little opportunity to come up with something cool in space and have the resources to realize it. Yet in a few days any of us could develop a new "app" for the iPhone and potentially make a fortune. Similarly, an app-based space economy might soon become reality.

At the NASA Ames Research Center we are building a family of cubists[6] based almost entirely on components that can be ordered online.[7] The PhoneSat project is showing the space community that if we emulate what our neighbors in Silicon Valley do, we can build highly capable satellites quickly and at a small fraction of the cost. PhoneSat is using 3D printing to rapidly prototype components, a smartphone as a (comparatively very fast) flight computer, simple brushless motors for 3-axis momentum wheels, steel tape measure as an antenna, magnetorquer coils printed directly onto a PCB, and pick-and-place procedures to rapidly manufacture low cost solar panels. The project is developing the type of spacecraft bus that will enable ultra-low cost distributed sensor networks. This approach fulfills the hardware requirements for a distributed, redundant, and easily replaceable infrastructure in space. However, getting this hardware up there also requires a new approach for launch vehicles and creates a demand for a micro-launch industry.

Making Low Earth Orbit Accessible Cheaply and on Demand

Imagine designing a rocket to lift a heavy payload, such as a several ton satellite. Chemical propulsion has great heritage, but our big satellite requires a lot of fuel to lift it above the atmosphere and propel it to orbital speeds of over 7 km/s. Lifting this much fuel, along with the payload and rocket structure is difficult, and drives the design to multiple, expendable, stages. Our design quickly grows in complexity, size and ultimately cost. In the new world of shrinking national budgets, this is no longer the best model.

Almost all space launch vehicles are expendable chemical rockets, descendants from Germany's WWII missile program. Today's launch sector, with its severe risk aversion, uses the same propellants, much of the same technology and follows many of the same procedures as it has for the past four decades. So, while computers have gotten a million times cheaper and a million times better since the 1960s, the cost to launch a pound to orbit has not changed at all.

NASA is in the business of space exploration and Earth science. Traditionally, we build big rockets or big satellites that need big rockets. When a big satellite is launched, much of the rocket's lifting capacity is often left unused. In the near-term this provides an opportunity for very small satellites, particularly Cubesats. These "secondary payloads" don't get to dictate their final orbit (nor much else, really), but they do get into space. NASA's Cubesat Launch Initiative aims to offer up this capacity to non-commercial organizations.

NASA's, and indeed the industry's, medium-term approach has been to push more onus onto commercial launch providers, who can build rockets faster and cheaper than governments can. Orbital Sciences and SpaceX are actively showing that corporations can build large, capable rockets, and in the process are building confidence in this fledgling economy. Commercial is clearly the way to go for micro-launchers too. A cheap, small, rapidly deployable launch vehicle would be able to respond to small-satellite customers' fast development timeline and would allow them to launch to optimal orbits. A number of new companies have realized this, and push on with their plans to meet this demand.

In the longer-term more exotic launch systems may enter this market. For example, NASA is funding research into directed millimeter wave and laser beam systems, which can heat propellants to much higher temperatures than chemical combustion, to propel small single stage rockets into low Earth orbit.[8] In this case the heavy, complex and expensive power source is left on the ground and the power is beamed to the launcher.

Living in Congested Space using Space Traffic Management

Combining distributed small satellites and cheap launchers provides a redundant and resilient space infrastructure. If an asset is destroyed by a collision it could easily be replaced. While this is superior to the old paradigm of huge multi-purpose satellites, where months or years would be needed for a replacement, it is does not solve the underlying problem of an increasingly congested space. In fact, the small satellite approach might worsen the situation.

With each collision, the number of debris fragments increases and with it the risk of collisions increases again. Replacements will have to be launched more rapidly, bringing more mass into already congested orbits and fueling the runaway debris cascade. Without tackling the underlying problem by preventing collisions, this race will be a race against ourselves, finally to be lost. Congested orbits should be managed similarly to congested airspace, with Space Traffic Management.

Space Traffic Management (STM) is a multi-faceted game. In the past, the term has been used mostly to refer to the allocation of satellite orbits (and trying to manage this process proactively). As the debris environment worsens for the foreseeable future, STM will have to broaden to include improved space situational awareness, space collision avoidance, and the active management of space debris.

Effective STM requires effective space traffic knowledge, most of which is generated through networks of space surveillance sensors, predominantly the U.S. Air Force Space Surveillance System (the VHF "space fence"). There are currently about 17,000 tracked objects, but future plans for improved sensors (including debris laser ranging and a proposed S-band upgrade to the space fence) would raise the number of tracked objects to about 200,000 - many of which are still large enough be lethal to a satellite or manned space mission.

Most concepts to remediate the debris environment suffer from the same drawbacks as classic satellite operations; they require vastly expensive and singular missions. They aim to physically grab and de-orbit the worst potential debris sources: large, heavy objects.[9] Large objects are more likely to collide, and heavy objects cause larger fragmentation clouds. Removing these objects will reduce the overall probability of future collisions. Of course, this assumes no accidental collisions or explosions happen during the rather risky rendezvous, retrieve, and remove ballet.

Simulations show that, on average, five massive objects would have to be removed per year to stabilize predicted debris growth.[10] Such active removal missions would have a considerable project life cycle and so would not be useful for preventing imminent collisions. The active removal of mass may well be necessary, but it is also a game of statistics. The 2007 Fengyun-1C ASAT test and the 2009 Iridium-33, Kosmos-2251 collision have highlighted the sensitivity of the near-Earth environment to single catastrophic events. Even if five massive objects were fastidiously removed every year, there still remains the unlucky possibility of a single large collision rendering all of the good work of the previous years useless. Removing mass from orbit improves the debris environment, but does not enable actual case by case collision avoidance.

ASAT weapons can create a new kind of fall-out: a vast debris cloud that endangers the near-Earth operating environment for everyone.

Not only are ASAT weapons frowned upon by the arms control community and others who are interested in the safety of early warning systems and (nuclear) stability, but kinetic ASAT weapons can create a new kind of fallout: a vast debris cloud that endangers the near-Earth operating environment for everyone, for decades or longer. As such, they appear to only be considered weapons of last resort by the major space-faring nations. Deploying any active removal system, whether ground- or space-based, would effectively introduce a new class of "debris-conscious" ASAT weapons that are more usable because they would not endanger the aggressor's own satellites. Is there a way out of this bind? Perhaps...

Some of the technical and security challenges of space debris management might be resolved using an idea we are exploring at NASA Ames Research Center. The idea employs only photon pressure to slightly nudge space objects to prevent imminent collisions just before they are expected to happen. One has only to slightly (millimeters per second) change the velocity of one of the objects to cause it to arrive at the would-be accident location a fraction of a second earlier/later. At 7.5 km/s velocities, that fraction of a second relates to real displacements. Using a 1.5 meter-class telescope, a 10 kilowatt industrial laser, and adaptive optics to compensate for turbulence, the system would apply an intensity of the order of a few solar constants (bright sunlight) on targets in low Earth orbit.

Our calculations [11] have shown that the resulting photon pressure is sufficient to influence the orbits of a significant amount of debris in LEO. The effect is cumulative, so building up a network of ground stations would expand the efficacy.

Such a network could have multiple applications including debris laser ranging, debris characterization, providing an alternative to expensive collision avoidance

maneuvers, protecting non-propulsive satellites from collisions, preventing debris-debris collisions, performing satellite station keeping and enabling formation flying for small satellites.

The ASAT threat of such a system is negligible. The comparably low power of each single ground station would prohibit applications aiming to do structural damage. Sensors looking directly into the beam might be dazzled or blinded, but the same methods that protect sensors from inadvertent exposure to direct sunlight would be sufficient to prevent permanent damage. Causing collisions using this system is also not feasible: one would need to achieve meter-accuracies in those maneuvers to have a chance of causing a collision, which is orders of magnitude more accurate than the available orbital predictions. Indeed it is much harder to hit a small, and quickly moving, point in space than to hit anywhere outside that point. This system is much less of an arms control concern than any of the active debris removal schemes. It requires only that photons be launched into space and is therefore cheaper and less risky.

The drawbacks are the need for more planning and coordination, possibly involving multiple ground stations around the world, and the fact that it would be an ongoing space traffic management effort, rather than a remediation.

Lessons learned from a long history of air traffic management and satellite operations in geostationary orbit can be applied to low Earth orbit, particularly sun-synchronous orbit. Studies have shown that relatively simple slot allocation rules would allow much more efficient use of these orbits.[12] As more operators vie for space in dense orbital regimes we are going to need to leverage this accumulated knowledge, even without the paradigm shift to smaller satellites. Clearly defining these "rules of the road" is important to secure owner/operator cooperation and also to avoid misunderstandings in the security arena. Among these definitions should be safe passing distances and the assignment of responsibility for taking evasive action. For this to be achievable, paths of communication have to be clear and access to space situational awareness data must be universal and transparent.

Conclusion

We are facing a dilemma where the space environment is growing more congested and dangerous, but where the current approach does not deploy highly redundant and resilient systems. This results from the traditional focus on huge, expensive, multi-purpose satellites and the resulting need for large launch vehicles. We present a vision for the future, based on current trends and ongoing research that combines small satellites with off-the-shelf components, cheap micro-launchers and effective space traffic management. This paradigm shift promotes robust capabilities, preserves stability in the new space security environment, and may indeed set the stage for a smartphone-like app revolution in the space economy. ■

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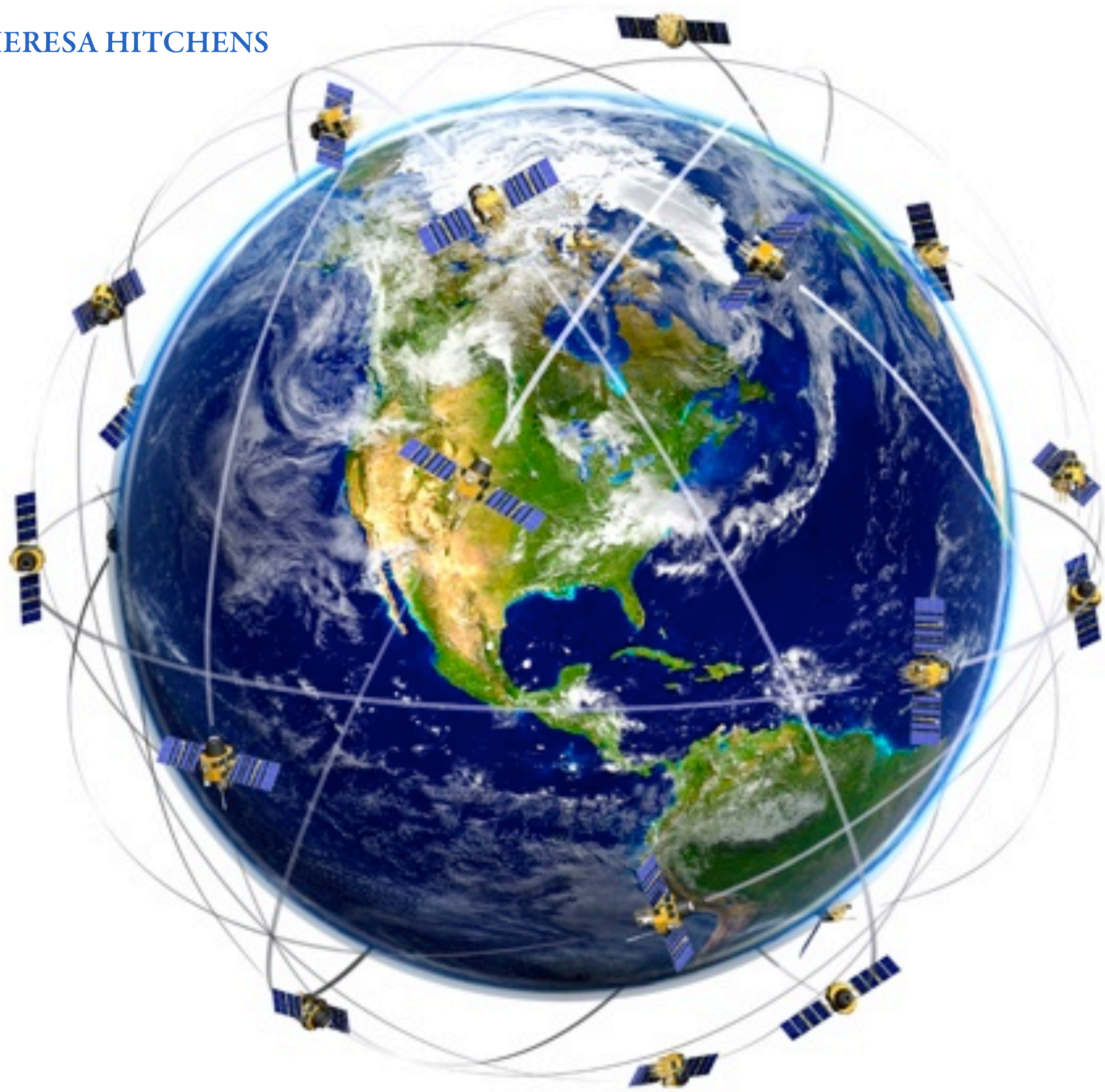
Transparency and Confidence Building in Outer Space

Inching Toward Action

— BY THERESA HITCHENS



Although concerns about the safety and security of humankind's operations in outer space have been with us since the dawn of the space age in 1957, the past decade has seen a steady increase in attention to the issue at the multilateral level.

This reflects the ever increasing importance of space activities to life on Earth. Satellites and spacecraft are critical to the functioning of the global economy: including enabling banking transfers, revolutionizing the movement of goods and services, underpinning the Internet, and predicting weather and natural disasters and enabling rapid response. Space operations are also growing in importance for militaries world wide for operations on the ground, and thus the question of space security – and the potential for satellites to become targets during conflict -- impacts directly on national and international security. Finally, more and more nations are active in the space arena: there are now some 1,100 active spacecraft on orbit and more than 60 states and/or commercial entities owning and/or operating satellites.[2]

It must be said that progress at the multilateral level in addressing the threats to space security – such as competition over access to orbital slots, the proliferation of space debris, and the specter of space warfare – has been glacially slow. No new treaties regarding space security and/or safety

have been signed since 1984, and that treaty, the *Agreement Governing the Activities of States on the Moon and Other Celestial Bodies* (*Moon Agreement*), has little legitimacy with only 13 ratifications and four signatures.

Nonetheless, one can say that 2010-2011 saw the emergence of a consensus around the notion that multilateral cooperation/action is now required to avoid harmful competition, accidents, and the increased potential for conflict in the global commons of outer space. That now unquestioned assessment has led to movement, on several fronts, towards establishing the underpinnings of a more defined international governance structure for space activities. At the foundation of all of these efforts is the widespread recognition that before new governance practices and/or structures can be developed, transparency and confidence in state to state relationships in space must be increased. There are three current multilateral platforms in which the discussion of TCBMs now have a central role: The UN Group of Governmental Experts on TCBMs, established in 2010, that will begin its work in July 2012; the UN Committee for the Peaceful Uses of Outer Space (COPUOS), which started work on a new agenda item, "long-term sustainability of outer space activities," in February 2010; and the European Union's effort to attract international accession to a proposed Code of Conduct for Outer Space.

Transparency and Confidence Building Measures (TCBMs) for Space at the General Assembly

TCBMs have long been an integral part of multilateral statecraft, enshrined in United Nations resolutions as potentially useful for improving mutual understanding, reducing misunderstandings and tensions, and promoting a more favorable climate for arms control and non-proliferation. Nor is the consideration of TCBMs for space new: UN General Assembly resolutions dating back to 1990 recognize their importance. Between July 1991 and July 1993, a Group of Governmental Experts appointed by the UN Secretary-General developed a "Study on the application of confidence-building measures in outer space." The weighty report, which elaborated on potential measures but also revealed strong differences of views about the imperative for action, was transmitted to the General Assembly at its 48th Session in October 1993.

Since 2005, Russia has been the key sponsor of an annual General Assembly Resolution on TCBMs for space activities that has attracted widespread support – with the exception of the United States which voted no from 2005 to 2008. In 2009, the administration of President Barak Obama changed tacks: abstaining from the voting rather than voting no on the text, which invited all UN nations to submit concrete proposals to the Secretary-General and instructed the Secretary-General to compile a report for the October 2010 session of the First Committee. In 2010, another breakthrough was made. Resolution, A/Res/65/68, adopted at the General Assembly's 65th Session, called for the establishment of a new Group of Governmental Experts on "Transparency and confidence-building measures in outer space activities."[2] The resolution passed with 183 nations voting for it, and the United States abstaining. However, during the First Committee debate on space in October 2010, U.S. officials made clear that their lack of a supporting vote should not be seen as a lack of support for TCBMs, rather concern with language in the resolution linking it to the Russian-Chinese draft treaty on the Prevention of the Placement of Weapons in Outer Space and of the Threat or Use of Force against Outer Space Object (PPWT). Indeed, in her Oct. 22 statement to the First Committee, Ambassador to the Conference on Disarmament, Laura Kennedy, stressed U.S. support for TCBMs. She said:

> "*The United States will pursue pragmatic bilateral and multilateral transparency and confidence-building measures (TCBMs) to mitigate the risk of mishaps, misperceptions, and mistrust. … With regard to TCBMs, the United States supports measures that not only enhance U.S. security, but also the security of our allies, friends, and space partners...*

> *Examples of bilateral space-related TCBMs include dialogues on national security space policies and strategies, expert visits to military satellite flight control centers, and discussions on mechanisms for information exchanges on natural and debris hazards. The adoption of international norms or multilateral "codes of conduct" are also examples of TCBMs."*[2]

Russia, which will chair the GGE to commence on July 23 in New York and include representatives of 14 other UN Member States[3] chosen on the basis of regional balance, had previously put forward a more detailed set of potential TCBMs. The Russian proposal explains that TCBMs might be elaborated under three categories: (1) measures aimed at enhancing more transparency of space programs; (2) measures aimed at expansion of information on space objects in orbits; and (3) measures related to the rules of conduct during space activities.[4] More specifically, the Russian proposal, which was submitted to the CD in a 14 August 2009 letter from Ambassador Valery Loshchinin, calls for:

1. Exchange of information on:
-the main directions of the states' outer space policy;
-major outer space research and use programs;
-orbital parameters of outer space objects.

2. Demonstrations:
-experts visits, including visits to space launch sites, flight command and control centers and other objects of outer space infrastructure on a voluntary basis;
-invitation of observers to launches of spacecraft on a voluntary basis;
-demonstration of rocket and space technologies.

3. Notifications of:
-the planned spacecraft launch;
-the scheduled spacecraft maneuvers which may result in dangerous proximity to spacecraft of other states;
-the beginning of descent from orbit of unguided outer space objects and the predicted impact areas on Earth;
-the return from orbit into atmosphere of a guided spacecraft;
-the return of a spacecraft with a nuclear source of power on board, in case of malfunction and danger of radioactive materials descent to Earth.

4. Consultations:
-to clarify the provided information on outer space research and use programs;
-on ambiguous situations, as well as other issues of concern;
-to discuss the implementation of the agreed TCBMs in outer space activities.

> **Though no new space treaties have emerged since the mid-1980s, COPUOS has made progress in addressing space safety and security. In 2007, COPUOS adopted a set of voluntary guidelines for space debris mitigation.**

5. Thematic workshops:
-on various outer space research and use issues, organized on bilateral and multilateral basis, with the participation of scientists, diplomats, military and technical experts.[5]

All of these proposed measures reflect the application to the space domain of classical TCBM structures, and thus could perhaps form a basis for the launch of discussions at the GGE.

The GGE meets in three sessions: July 23-27, 2012 in New York; April 1-5, 2013, in Geneva; and July 8-12, 2013 in New York. GGEs work by consensus, so if an agreement can be found the final report would be transmitted by the Secretary-General to the First Committee in October 2013. If the group fails to reach consensus one of two things could result: no report would be issued; or a report that reaches no recommendations but instead outlines competing views (similar to the 1993 report) will be forwarded.

COPUOS "Long-Term Sustainability"

There are 69 member states in the Vienna-based COPUOS and a large number of non-governmental and intergovernmental organizations are observers. Technically, COPUOS is the only formal UN body empowered to negotiate new international space treaties; however, COPUOS's mandate does not include military space activities which has meant that discussions of space weapons have been ceded to the Conference on Disarmament in Geneva. COPUOS activities are divided between two subcommittees, the Legal Subcommittee and the Scientific and Technical Subcommittee. Though as stated above, no new space treaties have emerged from the Legal Subcommittee since the mid-1980s, COPUOS has made progress in addressing space safety and security within the Scientific and Technical Subcommittee. And while COPUOS has not addressed directly the issue of TCBMs, its work includes activities that would qualify as de facto TCBMs.

In 2007, for example, COPUOS adopted a set of voluntary guidelines for space debris mitigation based on technical recommendations developed by the Inter-Agency Debris Coordinating Committee (IADC)[6] and subsequently endorsed by the General Assembly in January 2008.[7] The accord is a significant achievement for space security, especially regarding Article 4, which pledges nations not to deliberately create long-lived debris.[8] In its most recent report, the Scientific and Technical Subcommittee agreed that "implementation of the voluntary guidelines for the mitigation of space debris at the national level would increase mutual understanding on acceptable activities in space, thus enhancing stability in space and decreasing the likelihood of friction and conflict."[2]

Building on the success of the debris mitigation effort, COPUOS in February 2010 initiated a new working group under the Scientific and Technical Subcommittee on the "long-term sustainability of outer space."

The group was empowered to:

> *…examine the long-term sustainability of outer space activities in all its aspects, consistent with the peaceful uses of outer space, and avail itself of the progress made within existing entities, including but not limited to the other working groups of the Subcommittee, the Conference on Disarmament, the International Telecommunication Union, the Inter-Agency Space Debris Coordination Committee, the International Organization for Standardization, the World Meteorological Organization and the International Space Environment Service. The Subcommittee agreed that the Working Group should avoid duplicating the work being done within those bodies and instead identify areas of concern for the long-term sustainability of outer space activities that are not covered by them. [The Subcommittee also agreed that the Working Group should consider organizing an exchange of information with the commercial space industry to understand the views of that community.]*[3]

The working group has been charged to consider new measures to enhance the sustainability of space activities and a possible set of "best practice guidelines."[4] These eventual guidelines in effect fall under the rubric of "space traffic management" – i.e., processes, procedures, and new regulations for how spacecraft are launched, operated and disposed of at the end of their working lifetimes. While the need for a space traffic management regime has for many years been a topic for the professional space community, the issue has not been widely addressed in the political sphere. It is clear that given the increased usage of space and the growing problems of orbital crowding and debris, space operations will soon require more robust and accepted rule sets to avoid accidents and collisions, as well as dampen drivers for conflict in the case of such incidents.

According to the group's terms of reference established by General Assembly Resolution A/AC.105/C.1/L.307/Rev.1, published Feb. 21, 2011[2], the objective of the working group is the production of "a set of guidelines that could be applied on a voluntary basis by international organizations, non-governmental entities, individual States and States acting jointly to reduce collectively the risk to space activities for all space actors and to ensure that all countries are able to have equitable access to the limited natural resources of outer space."

The scope section notes that topics to be studied include several items that could be seen as de facto TCBMs, despite the COPUOS's mandate to cover only the peaceful uses of outerspace:

1. Collection, sharing and dissemination of data on functional and non-functional space objects;
2. Re-entry notifications regarding substantial space objects, and also on the re-entry of space objects with hazardous substances on board;
3. Capabilities to provide a comprehensive and sustainable network of key data in order to observe and measure space weather phenomena adequately in real or near-real time;
4. Pre-launch and maneuver notifications; and,
5. Adherence to existing treaties and principles on the peaceful uses of outer space.

The working group's workplan is multi-year, stretching from 2011 through 2014. A draft report including the agreed guidelines are to be presented to the Scientific and Technical Subcommittee at it's 51st Session in February 2014, where the report is to be finalized and presented to the full COPUOS in June 2014.

EU Proposal for an International Code of Conduct

The First Committee at the 2009 meeting also endorsed the by the 27-nation European

Union to draft a "Code of Conduct on Outer Space Activities" – which was adopted by the EU Council of Ministers in 2008.[2] The proposed code, which was presented to the Conference on Disarmament in 2009, in effect would be another approach to TCBMs by establishing best practice guidelines for space activities and pledging signatories to certain norms of behavior. Rather than a legally binding treaty, the EU has shaped the proposed code as a politically binding set of commitments. Thus, this can be looked at as an effort to develop a set of norms that define acceptable and unacceptable actions in space.

In particular, the draft code would pledge signatories to: "refrain from any intentional action which will or might bring about, directly or indirectly, the damage or destruction of outer space objects unless such action is conducted to reduce the creation of outer space debris and/or justified by imperative safety considerations."[3] It would also commit States to a number of notification measures, including when scheduled maneuvers might result in "dangerous proximity to space objects", as well as to adhere to the existing legal framework governing space.[4]

During 2009 and early 2010, the EU consulted with a number of non-EU states about the content of the draft code. A revised version was adopted in October 2010[5], the EU is now launching a second round of consultations that EU officials hope will result in a signing ceremony in 2013. Although plans for these consultations and a signing have yet to be formalized, the EU is hoping to have a first experts meeting in early June 2012 just prior to the COPUOS meeting. The code is envisioned as a free-standing accord along the model of the Hague Code of Conduct on Ballistic Missiles rather than a COPUOS or CD initiative.

In January 2012, after a long and protracted inter-agency debate, the United States announced that while it could not accept all of the code language as now drafted, Washington would work with the EU to refine the text and to promote participation by other nations. U.S. Secretary of State Hillary Clinton announced the decision on Jan. 17, 2012, saying:

"The long-term sustainability of our space environment is at serious risk from space debris and irresponsible actors. Ensuring the stability, safety, and security of our space systems is of vital interest to the United States and the global community. These systems allow the free flow of information across platforms that open up our global markets, enhance weather forecasting and environmental monitoring, and enable global navigation and transportation.

Unless the international community addresses these challenges, the environment around our planet will become increasingly hazardous to human spaceflight and satellite systems, which would create damaging consequences for all of us.

In response to these challenges, the United States has decided to join with the European Union and other nations to develop an International Code of Conduct for Outer Space Activities. A Code of Conduct will help maintain the long-term sustainability, safety, stability, and security of space by establishing guidelines for the responsible use of space."[6]

Mindful of the routine backlash from right-wing politicians and Members of Congress against any multilateral approaches to space, Clinton stressed: "As we begin this work, the United States has made clear to our partners that we will not enter into a code of conduct that in any way constrains our national security-related activities in space or our ability to protect the United States and our allies."

Therefore, while it is unclear just what textual changes the U.S. government might demand in order to "sign on" the proposed code, but it is a good guess that it will involve language creating "wiggle room" for national security concerns and activities. As of March 1, 2012, no other non-EU nations have expressed formal interest in adopting the code. Indeed, a number of non-European nations – most visibly Brazil, India and South Africa – have questioned the code on the grounds that it might somehow limit their aspirations and development in space. China, meanwhile, is loath to share information on its national space policies and military space doctrines and continues to stress the need for a legally binding treaty to prevent the weaponization of space, and thus remains cold to the code proposal.[2]

Conclusions

While it is apparent that a flurry of interest in and activity towards the development of TCBMs is underway within the international community, there are also a number of potential roadblocks.

First and foremost, there is a serious question yet to be answered about how to coordinate among the three major efforts previously discussed. While treading some of the same ground, at the moment these efforts are being kept stovepiped – indeed, there seems to be some political competition emerging among them. If such political competition becomes full-blown, progress towards a TCBM regime is likely to be halted in its tracks. Only if these efforts are seen as complementary pieces linking together to form a framework for future international space governance can near term positive action become possible.

A second set of tensions has already arisen between the pursuit of TCBMs and the long-standing pursuit of a treaty on the Prevention of an Arms Race in Outer Space within the Conference on Disarmament. As noted above, the Russians and the Chinese in 2008 put forward the PPWT as a starting text for PAROS negotiations.[2] Both Moscow and Beijing have repeatedly expressed the view that while TCBMs are worthy in and of themselves, they should not be seen as a substitute for a legally binding treaty on space weapons. In addition, a number of civil society groups – particularly in the United States – have expressed similar reservations about the focus on TCBMs and codes of conduct. Despite the fact that the Conference on Disarmament on March 15, 2012, failed once again to agree to a program of work, after 15 years of stalemate, there continues to be a constituency who would prefer discussions of "hard" space security to be focused on an arms control treaty and remain within the CD. Once again, it will be important for making progress toward space security that rather than being seen as competitive, that the two paths be seen as mutually re-enforcing parts of a larger framework.

A third set of potential hurdles is perhaps more obvious: i.e., differing perceptions between established space powers with heavy military dimensions and emerging and or developing space powers about potential constraints on space activities, especially constraints that increase the cost of entry such as a requirement for specific technical measures to mitigate debris creation. The space arena is not immune from long-standing North-South political issues, nor from the economic issues that divide developed and developing nations. It is worth noting, for example, that the COPUOS working group mandate includes measures to help developing states obtain and create space capacity. Resolving these tensions and developing mutual understanding about the threats and solutions to space security will require much good will and concerted diplomatic engagement from all parties to avoid the creation of political "blocks" that can only impede progress.

All that said, there is reason for optimism. The simple fact that there is a globally shared understanding about the need for multilateral solutions in order to keep activities in space safe, sustainable and secure is in and of itself progress. If all goes well, the next five years will prove to be a watershed in establishing space as a global commons requiring global action to protect. ■

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RESEARCH REPORT

How to Make Twitter Available in North Korea

BY DEVABHAKTUNI SRIKRISHNA and RAJEEV KRISHNAMOORTHY

INTRODUCTION

Since Hiroshima's destruction in 1945, the march of nuclear proliferation throughout the world has shown no signs of halting. Nuclear proliferation is fueled, in part, by a fundamental disagreement between governments about whether their citizens have freedom of speech, expression, and thought – North Korea being one example. There are some nation-states that differ on the role of fundamental human rights versus NATO countries and their allies. As former Secretary of State William Perry explained recently,

> *"A world without nuclear weapons will not simply be today's world minus nuclear weapons.... The world we are looking to has to have some international way of dealing with conflict, that focuses on preventing the conflict in the first place, dealing with the causes of conflict. We are very far from that world today."*[1]

Freedom of expression would bring additional economic and social benefits with the free flow of ideas and commerce across the globe. North Korea imposes almost total Internet censorship on its citizens. Similarly, Iran controls internal access to external websites and media through packet-filtering technology. Egypt shut down all Internet access in a crisis. Technically the only way to overcome these filters is to physically bypass the infrastructure points that contribute to censorship.

Citizens with securely designed wireless mesh-enabled smartphones (SocialMesh) can overcome the Internet censorship imposed by national governments. These devices enable basic uncensored social applications such as Twitter, Facebook, and Google. Wireless data networks, which are formed virally from handheld radio-routers and adapted to changing RF propagation and interference — without relying on managed cellular infrastructure — can be designed to bypass packet filters and other countermeasures often relied on by nation-states that impose censorship.

Using low-cost hardware, self-organizing routing software, and code division multiple access (CDMA), wireless data networks can retain enough system capacity even under heavy load from users or interference from jammers to overcome Internet censorship anywhere in the world. A peer-to-peer viral distribution strategy could include bootstrapping incentives for end-users to help build the network, such as the more new users that sign up, the more bandwidth you receive.

The investment for developing, manufacturing, and deploying SocialMesh through viral distribution is estimated to be in the range of $10 million, which is less than one percent of the annual expenditure for maintaining U.S. troops along the Korean Demilitarized Zone (DMZ). If successful in reducing the tensions between North and South Korea, a SocialMesh can diminish the need for deployment of troops and of nuclear weapons in the Korean peninsula.

Eliminating state censorship through freedom of speech for Internet users anywhere in the world can neutralize and dissolve the differences that create conflict. Needless to say, a world free of nuclear proliferation would lead to a much more secure and peaceful world.

National governments cannot escape the mathematics of game theory and the prisoners' dilemma – often locking them in a balance of power with their adversaries. The Korean border is a case in point. North Korea has tested nuclear weapons and is believed to have several, while South Korea is protected by U.S. nuclear security assurances – placing populations of both Koreas and the United States at a constant state of risk for nuclear war. In addition to nuclear weapons, the security balance on the Korean border is maintained by a massive conventional military presence by both sides.

The widespread availability of mobile and social media has catalyzed social revolutions[3] including texting in the Philippines[4] and most recently the uprisings[5] known collectively as the Arab Spring.[6] Where Internet censorship is in place, the Obama administration has recently expressed interest in virally expanding wireless networks to enable citizens to bypass censors,[7] and is actively considering them for use all over the world. Such networks of devices in the hands of citizens promise to create universal access to mainstream applications of the web such as search (Google, Bing, etc), social networks (Facebook/Twitter), and personal communications (Skype, Google Chat, and Apple's Facetime) that enable people to communicate. How do they work in practice?

CIVILIAN AND MILITARY WIRELESS ARCHITECTURE

Mesh networks were first described by Paul Baran in the 1960s as a way to eliminate central points of failure and reduce the vulnerability of communication networks to a first nuclear strike by the Russians during the Cold War — when the telephone network architecture was based entirely on centralized switching.[8]

The idea of a survivable, mesh network consisting of wireless links inspired what became known as the Internet. Vint Cerf and Bob Kahn first envisioned this solution for "ad-hoc" battlefield communications for soldiers. DARPA funded an experimental "packet radio" network based on spread-spectrum techniques first built across the San Francisco Bay Area in the 1970s. Subsequently, wireless mesh networks have found application in several different domains.

The first city-scale wireless mesh network was operated by Metricom Corporation in the 1990s using unlicensed spectrum (900MHz and 2.4GHz) radio-routers hung on lamp posts across multiple major metropolitan areas in the United States. These were based on proprietary, expensive frequency-hopping spread-spectrum radio technology and while technically successful, it ended up being a commercial failure.

Table 1: Comparison of North Korean and South Korean military capabilities

Military capability[2]	North Korea	South Korea
Annual budget	$1.5 billion	$13 billion
Troops (active)	1.1 million	0.69 million
Special Forces	88000	
Tunnels near (DMZ)	20	
Underground bunkers (DMZ)	4000	
Tanks	3500	2300
Artillery	10000	4500
Combat aircraft	605	538
Combat boats	305	111
Submarines	91	20
Mortars	7500	6000
Air-defense guns	11000	600
Surface-to-air missiles	10000	1000

At the same time in the 1990s, one of the authors took part in a standardization effort for low-power spread-spectrum radios used in local area networks called IEEE 802.11 (later known popularly as Wi-Fi or wireless Ethernet). After a decade, Wi-Fi was ubiquitously available and affordable throughout the world. At the time it was believed that public-access wireless networks had to be operated by regional telephone companies and cellular operators. Next-generation wireless routing technology built by Tropos Networks applied to Wi-Fi radios enabled city-scale wireless mesh networks that were similar in concept to the Metricom architecture, but more cost-effective and easy to operate.

Individual municipalities and small service providers were able to offer Wi-Fi based broadband service. Hundreds of municipal Wi-Fi mesh networks that used Tropos routers[10] (as well as those from vendors such as Belair Networks) are in operation today spanning thousands of square miles of contiguous broadband coverage including Oklahoma City, OK and Mountain View, CA.[11]

The freedom to experiment, learn, and innovate in unlicensed spectrum resulted in architectural and performance innovations for Wi-Fi mesh networks that are not seen in traditional cellular networks —enabling their rapid and resilient construction. These innovations demonstrate that it is possible to overcome multiple interference, propagation, and transmit power handicaps imposed by unlicensed spectrum regulations compared with licensed spectrum.

Aside from their use in local area networks indoors, the limitations of the spectrum allocation have thus far kept unlicensed radios from being used outdoors by a majority of the end-user population in favor of 3G and 4G networks operated by cellular carriers in licensed spectrum. In licensed cellular systems, high amounts of power can be transmitted to end-users by base stations leading to considerably strong performance on the downlink. However the amount of power transmitted by the handset is still limited by battery life and portability considerations to approximately 100 milliwatts (mW), resulting in performance limits on the uplink very similar to unlicensed spectrum.

In principle the idea of a network owned and operated entirely by citizens is promising, as adoption can grow virally until everyone can participate in the network. The software and hardware required can piggyback on advances in the large-scale production, development, and cost-reduction made possible by the open-source Android ecosystem based on Linux using Wi-Fi. The form factor for such a device can be similar to any modern Android-based smartphone commonly available today from manufacturers such as HTC, Motorola, or Samsung. Each device can participate in a self-organizing Wi-Fi or cellular (GSM) mesh network that can span multiple hops to external backhaul links and create connectivity in virtually any terrestrial environment.[12]

The applicability of citizen mesh networks based on unlicensed or licensed commercial radios is also severely limited both by the Wi-Fi or cellular radio interface as well as by how effectively they can bypass efforts by a censorship state to deploy a filter or block.

NORTH KOREA: A CASE STUDY

Consider North Korea as an illustrative example. Pyongyang, North Korea's capital, is located only 20 miles from international waters and 150-200 miles from the South Korean border and Seoul. In theory, a wireless mesh (SocialMesh) spanning such distances and feeding off of external network links (backhaul) in South Korea, from a ship in international waters or by satellite, is sufficient to end Internet censorship there through viral adoption by the resident population. The 40km span from international waters to Pyongyang is shown in Illustration 1, where several hypothetical wireless mesh links carry data back and forth. The Internet gateways (backhaul) are shown in red and relay mesh nodes in light blue, with white lines illustrating the network connections established automatically by SocialMesh.

North Korea is well known to have very active RF jamming and countermeasures for radios, cell phones, and other wireless communication.[13] According to South Korea's defense minister, North Korea has an active RF jamming program for GPS, while South Korea is preparing to offer broadcast radios to North Korean citizens for deployment in case of a war.[14] Limited internal cellular communications exist inside North Korea,[15] and Internet access to external sites is blocked by state censorship. Chinese cellular signals penetrate the border to a small extent,[16] although North Korea is actively confiscating cell phones that operate on these frequencies.[17]

SOCIAL MESH

Is it possible to enable a virally expanding network with a ~100 mW mass-market smartphone (e.g., Android-based) if we assume the RF and radio layer is not constrained by legacy assumptions

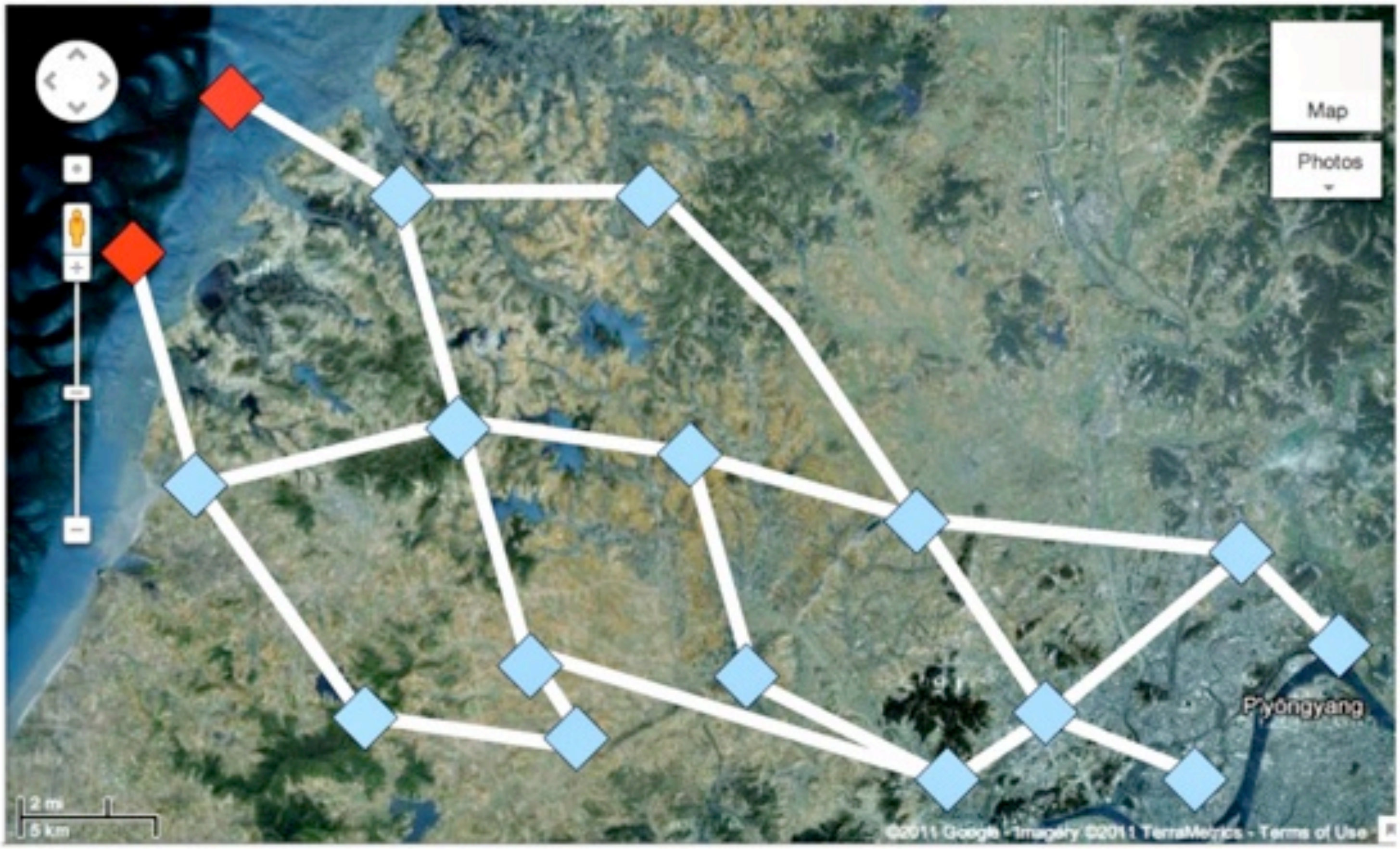

Illustration 1: A peaceful road to Pyongyang.

on spectrum allocation?

Android-based smart-phones are available in large quantities at low cost with an open-source operating system. Resembling its unlicensed spectrum counterparts, the SocialMesh would be a peer-to-peer, self-organizing mesh network of user-friendly smartphones with access to the uncensored Internet. A SocialMesh would also have to be resistant to countermeasures that could be employed by the censorship nation, including physical disruption, jamming, and protocol-based attacks.

In a companion paper,[18] network discovery and operation can be made resilient to physical disruption using wireless mesh routing to RF jamming through uncoordinated direct sequence spread spectrum (UDSSS) or alternatives, and protocol-based attacks through use of public-key cryptography during link-establishment. The following countermeasures may be overcome through design of the SocialMesh:

1. physical disruption of SocialMesh nodes
2. impersonation of SocialMesh nodes
3. RF jamming of SocialMesh nodes
4. Before the mesh reaches ubiquitous penetration with end-users, the censoring nation can hunt down a small number of users deterring further end-user adoption.

A smartphone radio operating in prime spectrum (250-750MHz) at 100 mW transmit power will be sufficient to create a SocialMesh network spanning the land from international waters to Pyongyang, providing secured broadband access to the Internet for end-users. For an estimated cost in the tens of millions of dollars, the U.S. can adopt policies to standardize, manufacture, and distribute SocialMesh nodes that permanently end government censorship across the world through viral expansion and adoption by the residents of these nations.

DATA RATE AND RELIABILITY OF LINKS IN THE NETWORK

In Figure 1, the link budget is used to calculate the expected single-link performance and reliability of this system as a function of transmitter and (equivalent) interferer/jammer distance under a variety of conditions, which is intended to approximate the equivalent of many neighboring interferers and jammers. The Mathematica notebook used to generate them is linked from Appendix A. Actual mileage will vary depending on the circumstances, but these can serve as a rough guide. In the plot below, the x-y axes are the distance of the transmitter and interferer to the receiver. The z-axis is the data rate achievable at transmit power of 200 milliwatts.

In Figure 1, unobstructed propagation is modeled by using a path loss exponent of 2.5 where the interferer and transmitter distance range from 0-10 km. The far end of the graph where distance to the interferer is 10km shows a near-ideal situation where interference is minimized and communication rate is noise-limited. Multi-megabit communication is possible for several kilometers and the communication rate rises into the tens and hundreds of megabits as the distance to the transmitter gets below one km. The plot shown is cutoff at 100 Mbps, which is why the plot appears flat as the distance to the transmitter approaches zero. The effect of increasing interference is modeled as the distance to the interferer is reduced from 10km to below 4km where we start to see significant effects.

MODEL SPECS FOR SOCIALMESH NODE

We propose a SocialMesh network consisting of access nodes, routers, and communication links that would shift power of choice into the hands of end-users who want access to information, and away from repressive state censors.

New developments need to be made to the communication radio for operation in 250-750MHz (or other wideband) and software for medium-access control, network routing (meshing), and secure design. The functional requirements for a SocialMesh include:

1. Broadband: The network will supply broadband to support essential apps such as email, video, voice to anyone who wants it, as much as allowed by physical constraints even with arbitrary countermeasures by state censors.

2. Environmental Propagation: The nodes would need to work well in a variety of environments, including wooded areas, plains, and a variety of temperature ranges.

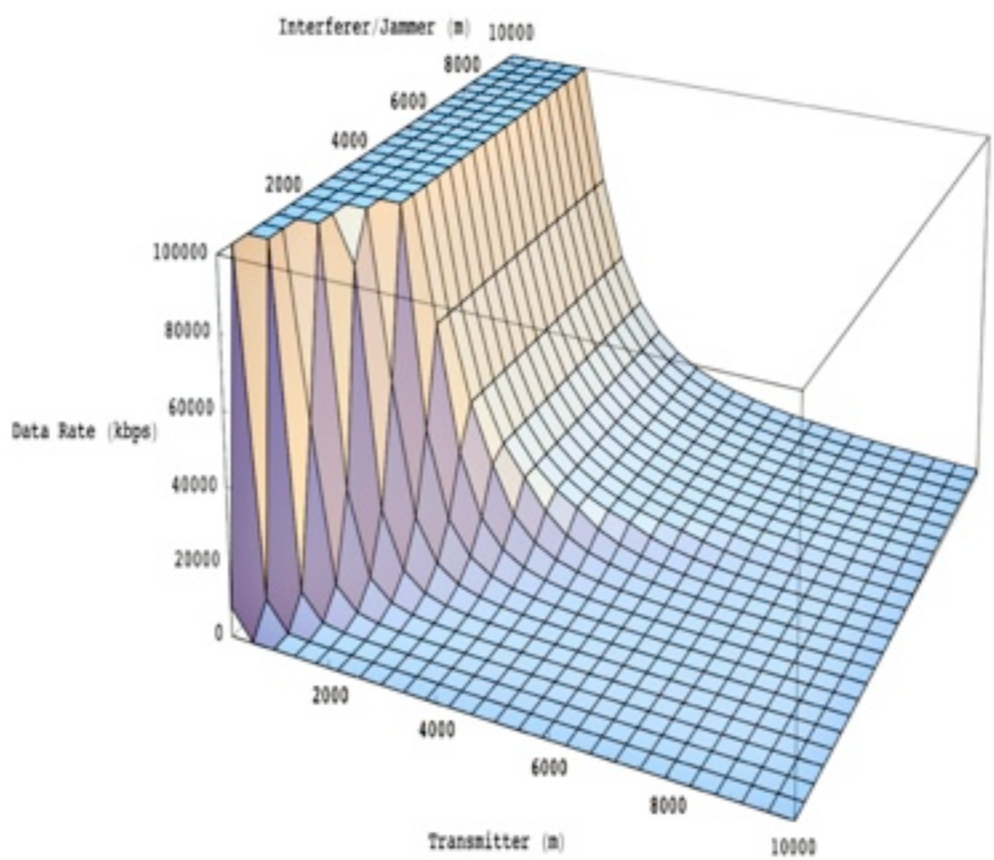

Figure 1: Path Loss Exponent = 2.5 (0-100 Mbps, 0-10 km)

3. Power Consumption: Battery, solar, recharging stations.

4. Plug-and-Play: The need to involve end-users in network configuration or setup ought to be minimal or zero.

5. Geographically Restricted Operation: Since the SocialMesh's radio will not be compliant with local regulations in "censorship-free" countries like South Korea, the nodes will have to include a GPS receiver to be non-operational except in areas of interest such as North Korea. Using location, the node can be programmed by software to operate only within the borders of the area of interest and not transmit if located outside this area.

Viral Deployment Strategy and Bootstrapping Incentives

The bootstrapping of a SocialMesh may begin with a small number of network nodes bridging across key areas, driven by individuals who are brave enough to take a risk. Islands of connectivity may form and eventually coalesce into a single unified network. These are the three stages of network deployment based on the framework of Malcom Gladwell's *The Tipping Point*:[20]

1. Connectors: The SocialMesh nodes are first offered to curious, early adopters who are connecters at heart and wish to circumvent the communications censors. This is known as the "seed" of the network that establishes its footprint early on.

2. Mavens: Next, the nodes are supplied to a broader population who want to grow the network and use it in a limited fashion, experiment with its capabilities, and learn how to use it effectively. They will start to make information available via Twitter and other sources. This will comprise about 15 percent of the population.

3. Salesmen: These individuals will convince others to adopt the SocialMesh in a viral manner, creating large-scale growth in the network. Since SocialMesh network capacity is limited, network access may be scarce at times. This fact can be used to motivate the salesmen through referral incentives. Through controls built into SocialMesh software, salesmen can be granted preferential access to the network over other users based on the number of additional SocialMesh users (nodes) they enable. Essentially the more users you sign up, the more bandwidth you have access to.

Finally, a larger group of people (lurkers) will be compelled to join the communications network to "tune in" and watch the content being created by the previous two groups. They may operate their radios in "listen-only" mode to pay close attention to what is transpiring in order to make better decisions. They will comprise more than 50 percent of the population.

Handset cost estimates

For a representative bill of materials of a typical high-end smartphone see "iPhone 3Gs Carries $178.96 BOM and Manufacturing Cost, iSuppli Teardown Reveals"[21] which lists the cost of an iPhone less than $200. The additional cost for adding the new LTE standard to an existing phone is in the range of $50 according to "Teardown of HTC ThunderBolt Provides Insights on Rumored LTE iPhone."[22]

Multiple antennas to enable the obfuscation of transmitter location would be embedded in the smart phone case. An extra antenna adds only pennies to the overall increase in cost. The marginal cost increment is small — power amplifiers for handsets cost less than $1 currently.

The eventual cost of the handsets is going to be dominated by the supply chain, the volumes, and the maturity of the products (how long they are in production.) As an example, looking at the iPhone BOM, the multimode baseband IC is $13 and the RF transceiver for all the 3G standards is $2.80. The WAN communications electronics therefore account for less than 10 percent of the total BOM of the handset.

TOTAL COST

Outdoor mesh networks have been built for areas of several hundred square miles covering entire metropolitan areas (Oklahoma City and Philadelphia are examples). To setup a SocialMesh the size of 100 x 100 square kilometers at a density of 10 per square km would require on order of 100,000 SocialMesh nodes. In mass production, the hardware cost of each node may be on the order of $100 each, bringing the total cost to $10 million. Considerably reduced functionality phones can be designed in the range of $20.

The initial investment needed to develop SocialMesh technology is likely to be on the order of tens of millions or less, as comparable technology has been developed and marketed by companies in the United States (e.g. Tropos Networks, Qualcomm, TZero).

CONCLUSIONS

The U.S. Departments of State and Defense should take action to end state censorship worldwide. An official policy needs to be approved for eliminating censorship worldwide based on deployment of SocialMesh. Almost anyone can use and deploy SocialMesh nodes once the design is developed, tested, and standardized. The deployment of a SocialMesh in censorship states would permanently end censorship by enabling viral adoption among the resident population.

SocialMesh nodes can be designed to be resilient to jamming and disruption by censors based on user-friendly smartphone technology and operating in a wireless mesh architecture. By shedding legacy assumptions about spectrum allocation in censor-free nations, a smartphone radio operating in prime spectrum (250-750MHz) at 100 mW transmit power will be sufficient to create a SocialMesh over multiple mesh hops from international waters to provide secure broadband communications to citizens of these countries.

To maintain the balance of security with North Korea, South Korea maintains 12 brigades and the U.S. stations 18,000[23] troops between Seoul and the DMZ – costing taxpayers in both countries several billion dollars annually. The total investment in SocialMesh technology development, mass manufacturing, and network deployment is estimated in the tens of millions of dollars, or a fraction of one percent of the annual cost of maintaining the troop presence. The U.S. government should adopt policies and standardize the technology for SocialMesh to be deployed in censorship states through viral distribution by citizens – to eliminate the differences that fuel nuclear proliferation. ■

Appendix A: RF Calculations and 3-D plots

See both the linked spreadsheet[23] for the RF link budget and the Mathematica Notebook used to generate the 3-D plot. Reference materials are available online at www.FAS.org.

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Dr. Rajeev Krishnamoorthy was most-recently the founder of TZero Technologies, a pioneer in Ultrawide-band RF radios. While at Bell Labs, he was instrumental in the design and development of the early 802.11 and 802.11b systems and in the formation of the 802.11 (Wi-Fi standard). He holds a Bachelor of Science from the California Institute of Technology and a Master of Science and PhD from Cornell University.

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DULY NOTED

Missile Defense System

NATO and Missile Defense

AMBASSADOR STEVEN PIFER *

At their Lisbon summit meeting in November 2010, NATO leaders decided to develop a capability to defend "NATO European populations, territory and forces" against limited ballistic missile attack. They then met with Russian President Dmitry Medvedev and agreed to explore a cooperative NATO-Russia missile defense arrangement. While the Alliance is making progress on its missile defense system, the prospects for cooperation with Russia appear murky. NATO nevertheless should leave the door open for a cooperative arrangement.

NATO leaders decided to make missile defense an Alliance mission for differing reasons. Washington has long sought a capability to defend the United States against limited ballistic missile attack from countries such as Iran and North Korea, and has deployed 30 ground-based interceptor missiles (GBIs) in Alaska and California. The Bush administration proposed to put a third GBI site in Poland. The Obama administration in 2009 changed to the phased adaptive approach (PAA) based on the SM-3 interceptor, which it believes offers earlier protection against Iranian missiles, which can now reach Turkey and parts of Greece, Bulgaria and Romania. The PAA is "adaptive" in that the capabilities of the SM-3 are planned to be upgraded to tackle longer-range missiles in anticipation that Iranian missiles will over time acquire greater range.

Most NATO members do not worry much about the prospect of an Iranian missile attack but had other reasons to support a NATO missile defense system. For Central European members, the plan offers a welcome and reassuring U.S. presence, particularly in Romania and Poland, which will host SM-3 interceptors and small detachments of U.S. military personnel to operate them. Other NATO allies see missile defense as assuming part of the deterrence and defense burden and perhaps enabling less reliance on—and a reduction in the number of—U.S. nuclear weapons in Europe. Still other allies judged this issue to be of significant importance to Washington and simply went along, particularly as the U.S. military will bear most of the costs.

Despite the 2010 agreement to explore cooperation on missile defense, the NATO-Russia dialogue has been stalemated over the past year by Moscow's demand for a "legal guarantee" that U.S. missile defenses would not be directed against Russian strategic missiles. The Russians worry particularly about Phase 4 of the PAA, when the SM-3 is to acquire some capability against intercontinental ballistic missiles (ICBMs). Even if it wished to, the Obama administration cannot offer a legal guarantee, as it would have zero chance of ratification in the Senate, where the missile defense issue unfortunately has become highly politicized.

The Russian concern that missile defenses could affect the strategic balance has validity. If missile defense capabilities continue to develop, and the United States and Russia continue to reduce their strategic offensive forces, at some point there will need to be a serious discussion—and perhaps a negotiation—about the offense-defense relationship. But that is down the road. It is difficult to see the SM-3, even in Phase 4, posing much if any threat to Russian ICBMs.

If NATO and Russia can get past Moscow's call for a legal guarantee, the sides' ideas on practical cooperation seem to coincide on many areas, including transparency, joint exercises and a jointly manned data sharing center. So the challenge for NATO is getting Russia to yes on missile defense cooperation.

That may not be easy. Vladimir Putin, who will return to the Russian presidency on May 7, has taken a hard-nosed stance on missile defense and the need for a legal guarantee from the United States—something he did not seek when exploring missile defense cooperation with the Bush administration.

NATO leaders will meet in Chicago in May and undoubtedly reaffirm their commitment to missile defense. In the meantime, NATO should take several steps. First, Washington and the Alliance should offer Moscow maximum transparency regarding NATO plans and the capabilities of the SM-3. That includes reiterating the offer by the U.S. Missile Defense Agency to allow Russian experts (con'd)

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Russia's Negative View of the European Phased Adaptive Approach

ARIEL COHEN and MICHAELA BENDIKOVA *

Russia's perspective on the European Phased Adaptive Approach (EPAA) has been remarkably consistent. Moscow opposes the missile defense program, alleging that it is somehow detrimental to Russia's deterrence and demanding that the United States provides a legally binding security guarantee that its missile defenses are not aimed against Russia.

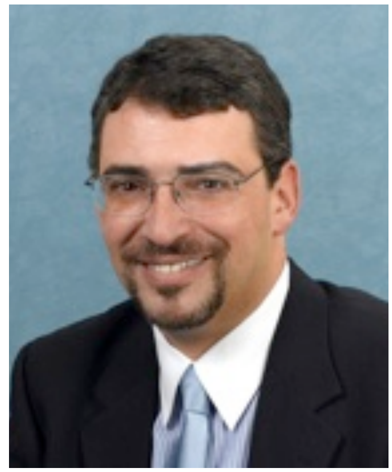
The EPAA includes four phases: phase 1 (2011 timeframe) consisting of deploying a land-based AN/TPY-2 radar and existing Aegis BMD-capable ships equipped with proven SM-3 Block IA interceptors. This phase's deployment is already underway.

Phase 2 (2015 timeframe) will comprise of the deployment of a more capable SM-3 Block IB interceptor and a land-based SM-3 ballistic missile defense interceptor site in Romania. "The situation completely changes with the realization of the third and fourth stages of the missile defense... This is a real threat to our strategic nuclear forces," said Lt. Gen. Andrei Tretyak, head of the General Staff Main Operations Directorate.[2] A more advanced SM-3 Block IIA interceptor, a second land-based interceptor site in Poland and a deployment of a SM-3 Block IIB interceptor capable of countering medium-, intermediate, and intercontinental-range ballistic missiles will be developed and deployed during phases 3 and 4.

The Russians offered additional insight into the current thoughts of their leadership about the EPAA in the context of the New Strategic Arms Reductions Treaty (New START). The Russians insisted on inserting language in the Preamble of the treaty that recognizes the interrelationship between strategic offensive and defensive arms. Moscow has interpreted this language as binding and has been using it as a vehicle to limit U.S. missile defense options.

Moscow also repeatedly threatened to withdraw from the Treaty if the United States does not change its missile defense plan. "All our military specialists are convinced that the proposed European missile shield configuration will impair the world's strategic parity and the relations that we recently had, including the [New] START Treaty," stated Russian President Dmitry Medvedev recently.[3]

Kremlin has also accused NATO of a lack of transparency regarding its missile defense system. This is just factually incorrect. The United States has been very transparent regarding capabilities of its missile defenses and conducted many high-level briefings on the capabilities of the U.S. missile defense system. Washington even invited Russia to observe one of the U.S. SM-3 tests. There is no such reciprocity regarding Russia offering insights into its strategic and missile defense build up.



Some statements of U.S. officials suggest that obstacles in U.S.-Russian missile defense cooperation are of political nature and that the situation will change after elections pass.[2] This is unlikely. Vladimir Putin will be the next Russian president and he recently stated, "Yes, we do have a dispute over the AMD system and how it should be developed, but this didn't start yesterday. It started before this modern-day détente you mentioned. There is nothing new here."[3] This will make negotiations more difficult.[4]

Twenty years after the end of the Cold War, Russia has not overcome the Mutually Assured Destruction (MAD) mindset. There are no demands for nuclear parity between Washington and Paris, or Beijing and London. Moscow is still viewing Washington as the "glavny protivnik" – the principal adversary.

Russian opposition to U.S. missile defense is fundamentally based on its desire to maintain the balance of terror, and to keep Americans and U.S. allies, including civilians, vulnerable to a ballistic missile attack. If Washington limits U.S. missile defense system according to Russia's desires, which would be self –defeating, the United States would make itself vulnerable to North Korean and the future Iranian long-range missiles, as well as to accidental launches. This is not the policy Washington wishes to pursue considering an increasing pace of ballistic missile proliferation.

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DULY NOTED

NATO and Missile Defense

to observe SM-3 tests in order to see for themselves that the interceptor lacks the capabilities to pose a serious threat to Russian strategic missiles.

Second, NATO officials should stop saying that cooperation with Russia would not in any way affect Alliance missile defense plans. If the Russians have ideas for a cooperative arrangement that might alter NATO's plans but would not degrade the Alliance's ability to defend NATO members, why not consider them?

Third, NATO should underscore the "adaptive" part of the PAA. It is not just about upgrading SM-3 capabilities to cope with Iranian missiles of increasing range. Alliance officials should point out that Phase 4—the one that concerns Moscow most—could be slowed if Iran is not progressing toward an ICBM.

Fourth, the Alliance could propose cooperation on a *provisional, time-limited* basis. If, after three or four years, Moscow continued to be concerned about U.S. missile defense capabilities, it could freely walk away, and the Alliance would acknowledge that in advance.

Finally, NATO should make clear that the door remains open for cooperation and encourage Mr. Putin to come to Chicago. If the sides can get past the legal guarantee stumbling block, a rich menu of cooperation appears possible. ■

Russia's Negative View of the European Phased Adaptive Approach

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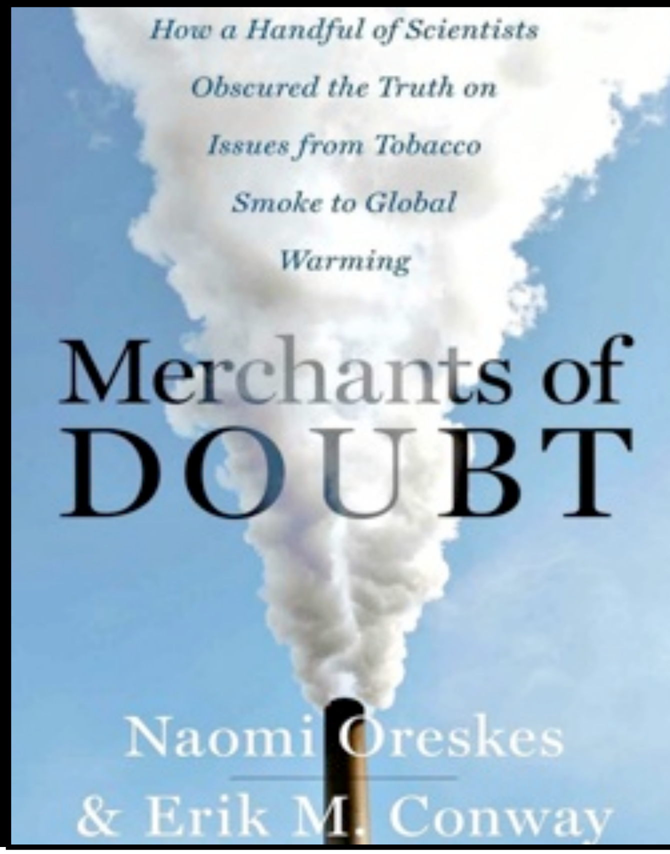
BOOK REVIEW



In *Merchants of Doubt,* historians Naomi Oreskes and Erik Conway explain how a group of high-level scientists, with extensive political connections, ran effective campaigns to mislead the public and deny well-established scientific knowledge over four decades. Oreskes and Conway roll back the rug on this dark corner of the American scientific community, showing how the ideology of free market fundamentalis skewed public understanding of some of the most pressing issues of our time.

By ANDREW KARAM

Anyone who is not a scientist might be surprised to hear that science is a fairly conservative way to make a living. Not conservative in the political sense so much as conservative in that most scientists spend their careers filling in the blanks of existing theories – doing what they can to support and extend the scientific status quo – rather than boldly striking off into novel territory. Genuinely revolutionary ideas come about perhaps once in a generation – for every Newton, Darwin, or Einstein there are hundreds or even thousands of scientists setting the stage or tidying up the loose ends of the existing theories. And when something comes up that seems poised to upset the scientific applecart (as it were), the first reaction of most scientists is to be skeptical and to question the new way of looking at things. Some new ideas crumple and fall under serious scientific scrutiny – cold fusion is one example – while others grow stronger the harder they are tested (evolution and relativity theory come to mind here). The point is that most scientists tend to be hesitant to embrace something truly new and revolutionary until it's been tested and shown to be solid.

The question is where to draw the line between healthy skepticism and denial (or even obstruction) of a new way of looking at the world. In many cases even unhealthy scientific skepticism is literally of only academic importance – refusal to accept some aspects of plate tectonics for example don't make a huge difference to society. But there are some cases in which scientific skepticism taken too far can have a significant impact on society. And when that skepticism is deliberate – when scientists use their tools to purposely befuddle and obstruct – the impact can be profound. It is this deliberate obfuscation that Naomi Oreskes and Erik Conway write about in their thoughtful book *Merchants of Doubt*.

I can understand being skeptical on these topics. Consider ozone depletion – CFCs were an accepted technology widely used around the world and replacing them was neither cheap nor easy. It makes sense that, before embarking on a decades-long multi-billion dollar international project to eliminate CFCs, there be a high degree of confidence about the entire chain of logic – that the ozone layer was really being depleted, that the reason for this was the wide use of CFCs, and that the loss of the ozone layer would really be harmful to humans and to the environment. Only after having a high degree of certainty on all of these points could outlawing CFCs been seen as a reasonable action – after all, it doesn't make sense to take a controversial action based on a guess. Similarly, scrubbing sulfur from the exhaust gas of coal-fired power plants to reduce acid rain should only be done when we are fairly certain that there is a link between burning coal and the acidification of mountain lakes and soils. But once the scientific evidence is in and consensus coalesces then taking action to avoid dreadful consequences seems reasonable. And as a corollary, deliberately prolonging the public debate by making specious arguments might not serve us well.

The authors make a compelling case that a relatively small group of politically motivated scientists set out to deliberately obscure the fact that the scientific community had reached a general consensus on a number of topics – acid rain, secondhand smoke (and first-hand smoke as well), ozone depletion, DDT, and global warming – primarily because this consensus might lead to extra expense, regulation, and inconvenience across society.

As a scientist I can understand scientific skepticism. I remember in particular that I spent some time working on calculations

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about ultraviolet radiation and its absorption by ozone. I have to confess I was deeply skeptical about the impact of ozone depletion on the Earth's organisms - my skepticism really didn't abate until I realized that the loss of Earth's ozone layer would cause UV irradiance to increase by a factor of 400 or more. When I realized that, absent an ozone layer, I would need to go outdoors wearing SPF-400 sunblock I convinced myself that ozone depletion was something to be avoided. In some areas where I lack the expertise to make an assessment myself, my options are more limited – I can try to learn the science in each of these areas well enough to make my own determination or I can learn enough to satisfy myself that the consensus among those who are competent to make these determinations seems to be well-founded. But through this I must also maintain my own scientific integrity – I can't hang onto an idea that is contrary to the consensus of qualified scientists simply because I don't want to accept their conclusions. Rejecting the conclusions of the scientific community simply because they are inconvenient or because I don't like them is intellectually dishonest. And I cannot imagine using my scientific training to obscure rather than to illuminate an issue. Yet, according to Oreskes and Conway, a number of scientists did just this in order to help avert actions that might be expensive, that might involve added governmental regulations, or that might have an impact on industry.

In their book Oreskes and Conway make a good case that a relatively small number of scientists deliberately raised objections to the scientific consensus in fields in which they had no scientific expertise because of their personal philosophical and political objections. In so doing, these scientists helped to delay necessary corrective actions, letting problems continue to build.

My only real quibble with this book is that it is obvious where the authors' sympathies lie. While I cannot say that I disagree with them, I have read other of Oreskes' books and had expected more objectivity in this one. Having said that, this does not appear to detract from the quality of the information or the analysis presented. That aside, there was nothing in the book that was troubling.

This again brings us to the question about skepticism. Personally, I dislike using the term "skeptic" as a pejorative – I firmly believe that a scientist's job is to be skeptical, and the more revolutionary or the more far-reaching the claim the more skeptical a scientist should be (thus the common comment that "extraordinary claims require extraordinary evidence"). Thus, to me a "global-warming skeptic" is simply a scientist being a scientist. But at some point we have to ask ourselves if skepticism remains a reasonable response to a scientific claim or if skepticism has turned into a refusal to accept (or a denial of) a new scientific understanding. To some extent, even this can be accommodated by the scientific process – this is captured by the comment (sorry, I can't remember who came up with this one) that a new scientific theory finally triumphs when the last adherents of the old theory have died. What upsets me is not resistance to a new idea – even when the new theory has been widely accepted – so much as using one's scientific training and reputation to actively convince others that an accepted theory is wrong or is too poorly understood to take action. I suspect that this upsets Oreskes and Conway as well, as it should upset us all.

There is one final point to make – how do we know that scientific consensus is correct? Six centuries ago a vote among scientists would have told us that the sun and planets orbit the Earth. Three centuries ago polling scientists might have concluded that swallows spent the winter hibernating at the bottom of rivers, and just a century ago a vote among scientists would have showed that the continents are fixed in place on the face of the Earth. And these votes would all have been wrong. This makes things easy for the merchants of doubt that Oreskes and Conway castigate, but it is a very real question – and a question with very real (and expensive) implications. How do we know when it's time to accept the scientific consensus – when it's time to stop studying a question and to take action? This question – at the boundary of science and policy – may not be amenable to a formulaic solution. Oreskes and Conway don't answer this question either, but they provide a wealth of information and insights that can help the reader to better understand now this process can work – and how it has been undermined so effectively. ■

Merchants of Doubt - How a Handful of Scientists Obscured the Truth on Issues from Tobacco Smoke to Global Warming (Bloomsbury Press, 2010. Trade paperback, 355 pages, $18.00).

Naomi Oreskes is professor of History and Science Studies at the University of California, San Diego, and adjunct professor of Geosciences at the Scripps Institution of Oceanography. She is an internationally renowned historian of science and author.

Erik M. Conway is a historian at the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California. He has published two previous books: *High Speed Dreams* (2005) and *Blind Landings* (2007). He is a co-author of a new secondary-level education text, *Science and Exploration* (2007), and he is currently working on a history of robotic Mars exploration

Andrew Karam has worked in radiation and radioactivity since 1981. He is a science writer with more than 200 bylined articles in the encyclopedia series "Science and its Times," books on science for middle-school students, and an account of life on a submarine, *Rig Ship for Ultra Quiet.*

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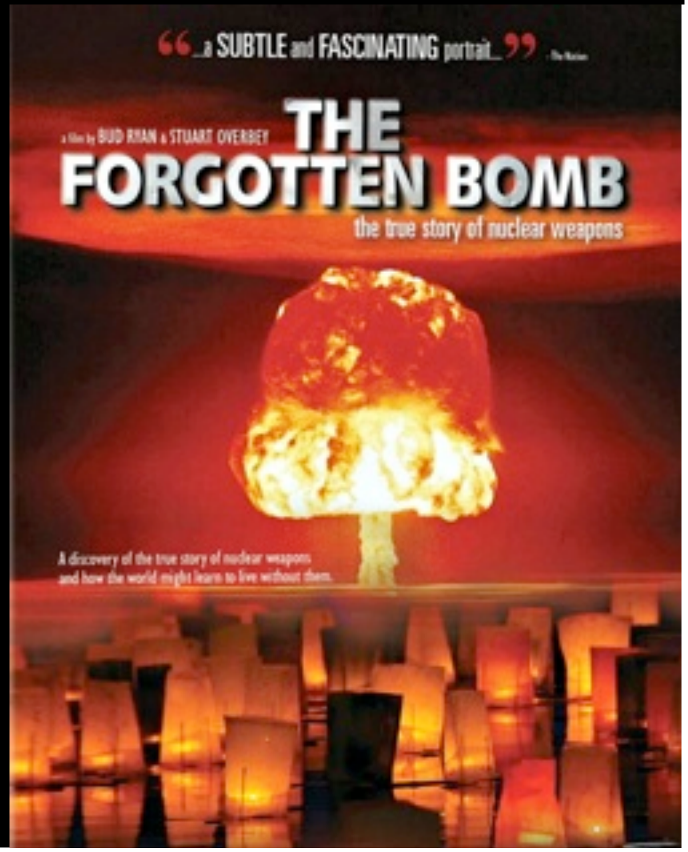

The Forgotten Bomb examines the political and legal implications of nuclear weapons, but also the cultural and psychological reasons behind the arsenal's existence. Through interviews with atomic scientists, politicians, authors, statesmen, and atomic bomb survivors, *The Forgotten Bomb* examines what The Bomb means to us all, and why we need to think about it again, even though the Cold War is long over.

By CHARLES P. BLAIR

Born and raised in Los Alamos, New Mexico, I gravitated early toward documentaries dealing with nuclear weapons. The early 1980s were a sort of “golden era” in that regard. Jon Else’s 1980 masterpiece, *The Day After Trinity,* was a vivid, cerebral exploration of the thinking of J. Robert Oppenheimer and other Manhattan Project scientists in the decades after the first atomic tests. It garnered an Academy Award nomination for best documentary. In 1982, *The Atomic Café* vividly demonstrated the effects of the Hiroshima and Nagasaki bombings, revealing the clear irrationality of nuclear weapons, often in the grimly humorous context of early American propaganda efforts that aimed to educate the public in the virtues of both civilian and military applications of “the atom.” The release of these documentaries coincided with the first, saber-rattling years of the Reagan administration and growing global concern about nuclear war. In 1983, in the wake of President’s “evil empire” speech about the Soviet Union and seeking to tap into a growing anti-nuclear market, ABC television released *The Day After*, a film that—in part because of its graphic depiction of nuclear attacks, which included the instantaneous vaporization of many wholesome residents of the American heartland—had an immediate and profound effect on American political discourse.

Bolstered by these films and others, the nuclear disarmament movement grew into and continued to be a strong force throughout the 1980s. With the dissolution of the Soviet Union in 1991, however, the American public generally—and erroneously—seemed to conclude that the threat nuclear weapons posed to humanity had largely passed. By 2004, polls showed the American public to be woefully uninformed on nuclear dangers, one survey finding that Americans believed their government had only 200 nuclear weapons available for immediate use, when the actual number was far more than 2,000.

Recent and important documentaries offer new hope for reversing this disturbing, dangerous trend toward nuclear ignorance. An excellent example is Bud Ryan’s *The Forgotten Bomb*.[1] A passionate nuclear abolitionist, Ryan started on his road to nuclear Damascus during a 1991 visit to the Hiroshima Peace Memorial Museum. In fact, Ryan’s film begins and ends in Hiroshima—an explicit attempt to make tangible “a type of apocalypse we have become numb to.” Between its Hiroshima bookends, *The Forgotten Bomb* displays an impressive array of interviews with disarmament luminaries, local activists and *Hibakusha* (survivors of the atomic bombings of Hiroshima and Nagasaki) as it travels to key U.S. nuclear facilities around the country. The most striking interviews are with former Secretary of State George P. Shultz and renowned historian and nuclear abolitionist Jonathan Schell, both of whom lament the “awesomely irresponsible” nuclear postures that keep thousands of U.S. and Russian nuclear weapons on hair-trigger alert more than 20 years after the end of the Cold War.[2] Indeed, *The Forgotten Bomb’s* greatest accomplishment may be a factual reminder: At any moment, within 30 minutes, a total of almost 2,000 nuclear weapons could be launched from U.S. and Russian silos and submarines. Nuclear Armageddon is still a very real danger, a situation that Schultz accurately deplores as “outrageous and senseless.”

The interview with Shultz is particularly compelling because, as President Reagan’s Secretary of State, he is generally perceived as a no-nonsense hawk. Now a nuclear abolitionist, Shultz takes the idea of nuclear disarmament out of the realm of “utopian nonsense.” Schell notes that the national security establishment “traditionally just laughed at the idea.” Shultz’s endorsement, however, “removes what

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had traditionally been one of the obstacles" to nuclear disarmament.

American denial in regard to the potential for nuclear annihilation is also vividly demonstrated by portrayals of "the bomb" in many U.S. museums. In contrast to the vivid, grim exhibits Ryan encountered at the Hiroshima Peace Memorial Museum, U.S. exhibitions are often devoid of graphic imagery. In one of *The Forgotten Bomb*'s more effective moments, a curator from the Smithsonian affiliated National Museum of Nuclear Science and History explains to Ryan that "this is a family museum" — disturbing images are only available in the museum's back offices.

Ryan is onto something important here. Bob Anderson, leader of the Albuquerque-based organization "Stop the War Machine" explains what it is: Many U.S. nuclear museums are "designed to entice children into [the display] without any critical thinking." The ultimate aim of those museums, Ryan and others contend, is to portray nuclear weapons as central components of American peace and prosperity. The consequences of nuclear weapons, *The Forgotten Bomb* demonstrates, are purposely ignored, both on the "front-end" of the nuclear cycle—for example, higher cancer rates among uranium ore miners—and on the "back-end," which has produced victims ranging from the residents of Nagasaki and Hiroshima to the "downwinders" who lived near nuclear test sites in the South Pacific and in Nevada.

The Forgotten Bomb is at its weakest when it overreaches and tries to cast the U.S. nuclear weapons infrastructure as universally and inherently evil. In his interview of former Los Alamos National Laboratory Director Harold Agnew, Ryan attempts to present the unreconstructed cold warrior: an aging nuclear weaponeer who typifies the U.S. national security establishment's supposedly blasé attitudes about the use of nuclear weapons. Agnew's view—that there "is no difference between burning them up with fire or burning them up with a nuclear explosion"—is presented in a way that clearly is designed to leave viewers shaking their heads with disbelief. Agnew, however, accompanied the Hiroshima air-attack mission, and his statement is nothing more than a recital of fact. The U.S. and Allied fire bombings of Japan and Germany in World War II took far more lives than nuclear weapons, and, like the atomic bombings, those campaigns targeted and killed civilians in a horrid, indiscriminate manner.[3] Even more regrettable is Ryan's decision to include footage from his interview with James W. Douglass, an author and activist who contends that John F. Kennedy was assassinated because of his desire to halt and reverse the arms race.[4] This bit of dialog connects the film to the dubious realm of conspiracy theory, an unnecessary distraction from its otherwise powerful and articulate message.

In addition to its compelling narrative, *The Forgotten Bomb* is cinematically engaging. For the most part Ryan allows others to drive the film, but his passion is nonetheless present throughout. Although there is no new footage of nuclear testing or U.S. propaganda films, Ryan makes good use of archival film in making his points. Moving from interviews to visits to nuclear facilities to Cold War testing footage, *The Forgotten Bomb* maintains a sense of urgency that will be engaging to long-time nuclear scholars and more casual viewers.

In the early 1980s, liberals led a Nuclear Freeze movement that influenced the highly conservative Reagan administration to moderate and even reverse some of its most hawkish positions on disarmament. Today's situation is different, and paradoxical: There are now strong political voices—many of them conservative—calling for nuclear weapons to be taken off hair-trigger alert and for global arsenals to be greatly reduced or eliminated.[5] But in the current environment, Jonathan Schell observes, "we don't have the public movement" to effectively push the world's major nuclear powers toward sane nuclear policies. It is this void that *The Forgotten Bomb* seeks to fill. ■ (www.forgottenbomb.com)

The Forgotten Bomb was independently produced by A Tale of Two Museums, LLC in association with halflife* digital inc. (Documentary, $19.95, 94 minutes, January 17, 2012).

New Mexico filmmakers Bud Ryan and Stuart Overbey spent nearly four years working on their directorial debut, *The Forgotten Bomb.* Bud Ryan was born and raised in New York City. A 1991 trip to Hiroshima prompted him to tell this story. Stuart Overbey began as a freelance writer and reporter for a public radio station in Albuquerque, NM. She earned her Bachelor's degree from the University of New Mexico.

Charles P. Blair is FAS's Senior Fellow on State and Non-State Threats.

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FAS MATTERS

FAS NEWS FROM DC HEADQUARTERS

The Future of Nuclear Power in the United States

FAS released a new report produced by FAS and Washington and Lee University at a briefing on Capitol Hill on February 8, 2012. The report, on the future of nuclear power in the United States, was written by a distinguished group of experts who provided insights about the safety, security, building, financing, licensing, regulating, and fueling of nuclear power plants. Speakers at the event included authors Dr. Albert Carr Jr., Mr. Stephen Maloney, Dr. Ivan Oelrich and Ms. Sharon Squassoni. Dr. Charles Ferguson and Dr. Frank Settle, editors of the report, served as moderators of the panel. Please visit: http://www.fas.org/pubs/reports/20120208_nuclear_energy.html

PODCASTS

FAS produced a new podcast to commemorate the one year anniversary of the 9.0 magnitude earthquake and tsunami that struck the northeast coast of Japan and resulted in the crisis at the Fukushima-Daiichi nuclear power plant. There are massive amounts of nuclear waste and high levels of radiation, and those citizens who live near the plant have not been able to return to their homes. As a result of this crisis, many questions still remain. FAS President Dr. Charles D. Ferguson also examines the safety of U.S. nuclear power plants post-Fukusima. Please visit: http://is.gd/McIQ9b. To listen to all FAS podcasts, go to: http://www.fas.org/podcasts/index.html.

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The PIR welcomes letters to the editor. Letters should not exceed 300 words and may be edited for length and clarity. The deadline for the Spring issue is **April 27, 2012**. To submit a letter, please email pir@fas.org or fax 202-675-1010.

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