

National Security Implications of the Asteroid Threat^{*}

Randall R. Correll
February 4, 2003

Summary

Every year about thirty asteroids enter Earth's atmosphere and explode, releasing as much energy as the Hiroshima A-bomb. In addition to the damage an asteroid impact could cause, a small asteroid could be mistaken for a missile strike and precipitate a nuclear conflict. The United States has technology to differentiate between missile attacks, nuclear detonations and asteroid explosions, but many less advanced nations do not. Dr. Correll discussed the challenge of distinguishing between asteroid collisions and missile strikes and the feasibility of establishing a global warning center for asteroid explosions.

Dr. Correll's Remarks

Introduction

From the beginning, our planet Earth has inhabited a dangerous neighborhood. The solar system itself was forged in the calamitous period of collapse, condensation and collision in our part of the galaxy over four billion years ago. The Sun formed, a glowing red sphere, and eventually ignited its nuclear furnace, gradually blowing away the mists and revealing the rocky inner planets: Mercury, Venus, Earth, Mars, the unformed asteroid belt, and then the gas giants: Jupiter, Saturn, Neptune, Uranus. Along with the stately Sun and its planetary orbs, there was debris everywhere — dust, pebbles, boulders, and the dirty snowballs we call comets.

Over the next four billion years or so, this solar system debris was gradually swept up by the planets in their revolutions. This was a dangerous process. In the early period, the debris was thick and collisions were frequent. Over time, as the debris was gradually reduced, the impacts became less frequent, allowing some stability in the evolution of things, the

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peacefulness only occasionally punctuated by a random cosmic collision. The moon still bears a record of this ongoing trauma. Lacking atmosphere and tectonic motion to recycle its surface, the moon bears the scar of nearly every impact, except those so small as to be obliterated by subsequent impacts and the settling dust.

The earth's atmosphere itself is sturdy enough to shield the surface from smaller debris. Objects smaller than a few inches in size — dust particles, pebbles, stones, ice crystals — blaze through the atmosphere and are vaporized in meteoritic displays. Larger objects can penetrate the atmosphere and drive into the earth's surface in a violent impact, evidenced by the massive craters they leave behind . . . at least for a while, before the water and the wind erode their features and fill in the crater with silt and mud, and foliage grows over the land to cover the wound, and eventually tectonic motion subvents them beneath the earth's mantle. Smaller asteroids, less than ten meters in size, impact the earth much more frequently. Every year about thirty such asteroids enter Earth's atmosphere and explode, some releasing as much energy as the Hiroshima A-bomb.

In addition to the damage an asteroid impact could cause directly, some researchers have suggested another danger: a small asteroid could be mistaken for a missile strike and precipitate a nuclear conflict. The United States military currently has technology to differentiate between missile attacks, nuclear detonations and asteroid explosions, but many less advanced nations do not. It would seem to be in our nation's best interest to pursue some course of action to prevent the accidental nuclear reprisal by one country against a neighbor based on the mistaken perception that an asteroid impact was a nuclear attack. Could a warning and reporting system be put in place to prevent such a disaster? Before answering this question, it is important to understand the technical, organizational, and diplomatic issues involved.

The Large Asteroid Threat — Species Extinction

Most people by now are familiar with the theory that an asteroid impact 65 million years ago in the Yucatan peninsula precipitated the demise of the dinosaurs. These large impacts have occurred throughout the earth's history, even relatively recently on geological timescales. Just outside this venue, in the surrounding area of the Chesapeake Bay, the geology and ground water are unusually affected by the scarred mantle of the earth hundreds of meters beneath the present day surface — the result of an asteroid impact 35 million years ago (see Figure 1). These large asteroids can cause regional or global damage and

travel in orbits approaching the earth. They are collectively known as near-earth objects (NEOs).

In 1994, the U.S. Congress mandated that the National Aeronautics and Space Administration (NASA) initiate a plan to locate and catalog 90% of all NEOs larger than one kilometer in diameter by the year 2008. This has since become known as the Spaceguard Survey. Asteroids of this size can cause catastrophic damage on a global scale, including massive deaths of plant and animal life and possibly species extinction for the largest of these impacts. The Spaceguard Survey is formally sponsored by NASA with ongoing funding of about \$3.5 million a year; data for the catalog is also provided by the Department of Defense (DoD) and international scientific efforts. The Spaceguard Survey has presently recorded nearly 700 NEOs larger than 1 kilometer in size and is well on its way to meeting its goals for asteroids of this size.

This threat of asteroids impacting the earth is still a concern of the U.S. Congress, as evidenced by their hearing on The Threat of Near-Earth Asteroids, convened on October 3, 2002, in which a panel of experts from NASA, DoD, and academia provided witness to the status of ongoing detection efforts and offered suggestions for possible future efforts:

Scientists are making progress in cataloging and tracking large near-earth objects (NEOs), but a serious threat still remains from smaller objects, an expert panel told the Space and Aeronautics Subcommittee today.

These smaller asteroids (200-500 meters wide) could potentially demolish a city with a direct hit or cause a tsunami capable of wiping out entire coastal areas if they land in the ocean. NASA has cataloged nearly 50 percent of asteroids 1 kilometer wide and larger. Astronomers estimate that between 900 and 1300 of the larger asteroids exist while there could be as many as 50,000 in the smaller range.

Press release, Committee on Science, U.S. House of Representatives, October 3, 2002



Figure 1. Asteroid impact crater beneath the Chesapeake Bay—the white lines represent inner and outer crater boundaries resulting from an asteroid impact 35 million years ago. (US Geological Service)

The exact sizes of the asteroids, and the blast effects they create when impacting the earth are uncertain and vary depending on the composition and density of the asteroid and the closing velocity at impact. In rough terms, the effects and frequencies of these larger impacts can be summarized as follows:

General Categories of NEOs and Asteroids			
<i>Type</i>	<i>Size (meters)</i>	<i>Yield (TNT)</i>	<i>Frequency</i>
Bolide (air burst)	< 20	< 1 MT	30 per year
Tunguska-Class	40	5-10 MT	1 per 500 years
Regional Catastrophe	150	1,000 MT	1 per 50,000 years
Global Catastrophe	2000	1,000,000 MT	1 per 1,000,000 years

The Small Asteroid Threat: a Subtler Menace to National Security

The chance of asteroids large enough to cause global or regional destruction impacting the earth is extremely rare, but smaller asteroids pose an indirect threat with much greater likelihood. These smaller asteroids detonate in the atmosphere with an energy equivalent to a small nuclear weapon, on the size of up to several million tons (MT) of TNT. The smaller of these, exploding high in the atmosphere, would cause little damage on the ground but would be quite noticeable if they occurred above populated areas. The larger of these may

penetrate deeper into the atmosphere causing significant damage on the ground, as in the case of the 1908 Tunguska event shown in Figure 2. In both cases, the blast effects from these detonating asteroids would be indistinguishable from a nuclear detonation unless one uses the right remote sensing technology.



Figure 2. Trees of the Tunguska, Siberia forest flattened by the air burst of an asteroid estimated to be 30-50 meters in size. (Smithsonian Institution)

The United States has operational systems capable of distinguishing between nuclear detonations and asteroid impacts, but at the present time there is no procedure for processing the data from these systems in a routine manner.

On June 6, 2002, an asteroid entered the earth's atmosphere and detonated high over the Mediterranean with a yield roughly equivalent to the Hiroshima atomic bomb. There is no record of a human witness to this event, but DoD satellites recorded the explosion. Had the asteroid impacted the earth a few hours earlier, occurring near India or Pakistan, it could have been mistaken for a nuclear explosion and possibly triggered a retaliatory nuclear strike. Researchers

in the scientific and national security communities have recently raised this concern with renewed interest. Some of these concerns have been carried in the media with headlines reading:

Could meteor touch off nuclear fear?

MSNBC News, October 3, 2002

Asteroids a trigger for war?

San Francisco Examiner, October 4, 2002

Asteroids have force of nuclear bomb?

St. Petersburg Times, October 4, 2002

It's the Little Asteroids that Get You

Time Online Edition, September 17, 2002

Satellites spy on meteorite explosions

Nature, November 21, 2002

The threat certainly seems plausible, but how well grounded is this fear? The most recent concerns expressed in testimony to the U.S. Congress, and as somewhat sensationalized in the media, result from the growing amount of data that has been collected over the last decade on asteroids and asteroid fragments impacting the earth.

Observational Capability of National Security Space Systems

The national security space systems which have been collecting data on asteroids are derived from two different operational missions: nuclear detonation detection and space surveillance. The nuclear weapons detonation detection systems were an important part of monitoring the strategic balance of the Cold War, both in the knowledge it provided about the activity and maturity of foreign nuclear weapons programs and in the verification provisions of the Limited Test Ban Treaty and the Non-Proliferation Treaty. Formally known by names such as the Nuclear Detonation Detection System, these systems are described in government budget documents as follows:

The Nuclear Detonation (NUDET) Detection System (NDS) provides a worldwide, highly survivable capability to detect, locate, and report any nuclear detonations in the earth's atmosphere or in near space in near-real time. The NDS supports NUDET detection requirements for

USSPACECOM (Integrated Tactical Warning and Attack Assessment (ITW/AA)), USSTRATCOM (Nuclear Force Management), and AFTAC (Treaty Monitoring). NDS consists of space and ground segments. The space segment consists of NUDET detection sensors (optical, x-ray, dosimeters and EMP) on Global Positioning System (GPS) satellites, and DSP satellites (neutrons and gamma rays). The ground segment includes the Integrated Correlation and Display System (ICADS) and the Ground NDS Terminals (GNT).¹

From the above description, it is clear that these sensors collect data for critical national security needs, and it is unlikely that their data will be made available to unclassified users.

Sensors used for space surveillance — that is, keeping track of satellites and other objects in space — also collect data on the larger asteroids. These sensors are very similar to traditional astronomical telescopes. Many of the recent observations of these NEOs have been collected by technology developed initially for military space surveillance missions:

The Lincoln Near Earth Asteroid Research (LINEAR) project is a MIT Lincoln Laboratory program funded by the United States Air Force and NASA. The goal of the LINEAR program is to demonstrate the application of technology originally developed for the surveillance of earth orbiting satellites, to the problem of detecting and cataloging Near Earth Asteroids (also referred to as Near Earth Objects, or NEOs) that threaten the Earth.²

In addition to these ground-based systems, the DoD has recently tested an experimental space-based sensor to see how well it could detect and locate objects in space. This was the Space-Based Visible sensor on board the Midcourse Space Experiment satellite—a satellite flown to test technologies for missile defense systems. This sensor is not now collecting data for ongoing surveys of NEOs, but it did prove the effectiveness of space-based surveillance systems and is a candidate concept for future space surveillance systems.

Aside from these national security assets, the scientific community, funded by both NASA and the National Science Foundation (NSF), have a number of ground-based telescopes which have been searching and locating the

¹ <http://www.dtic.mil/descriptivesum/Y2003/AirForce/0305913F.pdf>, RDT&E Budget Item, Feb 2002

² <http://www.ll.mit.edu/LINEAR/>

larger, but more distant, NEOs. A summary of the data collected by a variety of scientific and military sensors is graphically summarized in Figure 3 below, which is reproduced from a recent paper in Nature magazine³.

The figure shows the number of asteroids of various sizes that impact the earth on an annual basis. The sizes of the asteroids can be related to an equivalent amount of TNT that would be released, on average, for an asteroid of that size impacting the earth's atmosphere with a nominal average velocity. The chart displays data in a number of different groupings, each group associated with asteroids of a certain size range collected by different sensing systems. The most significant feature in the chart is that smaller asteroids (towards the left) are much more numerous than larger asteroids (towards the right), a fairly obvious and fortunate feature of nature.

³ Brown, P., Spalding, R. E., ReVelle, D. O., Tagliaferri, E., Worden, S. P., The flux of small near-Earth objects colliding with the Earth, *Nature* 420, 314-316 (2002). Questions regarding the paper can be addressed to the authors or to U.S. Northern Command (formerly U.S. Space Command) at norpa@peterson.af.mil, which cleared the paper for release. Questions about the data can be addressed to the authors, the Air Force Technical Applications Center at foia@aftac.patrick.af.mil, or Sandia National Laboratories at ioaboyt@sandia.gov.

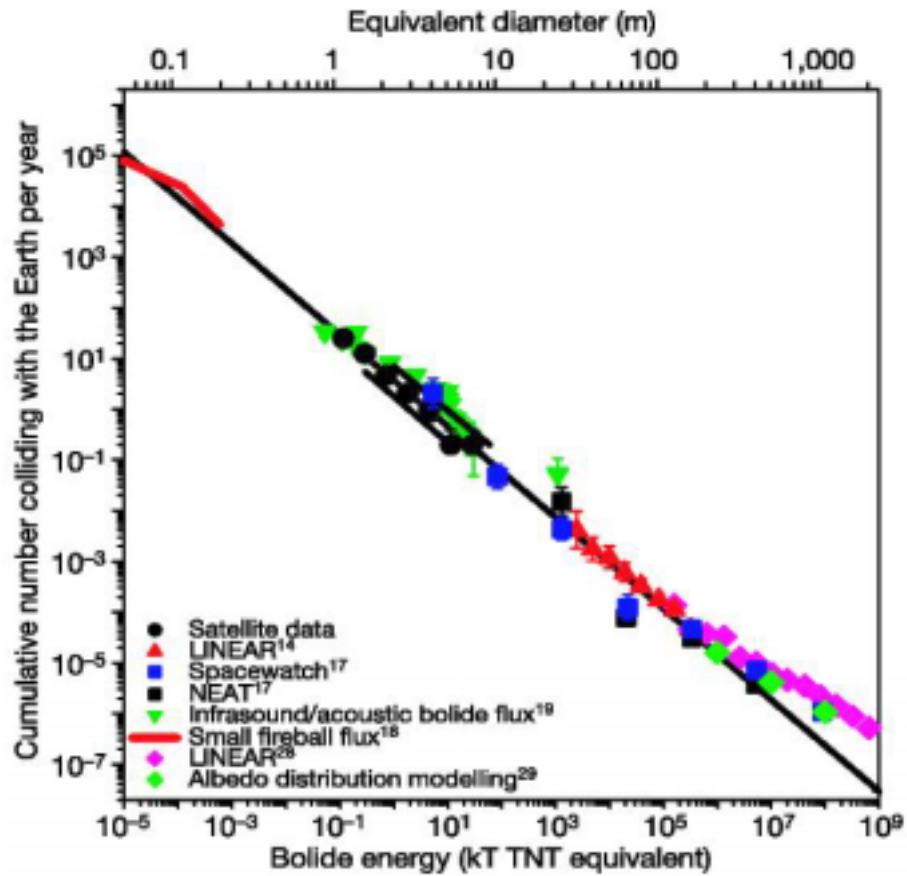


Figure 3. Estimated Flux versus Energy of asteroids impacting the earth compiled from a number of scientific and military sensors. Data collected with estimated sizes greater than 20 meters were collected by telescopes surveilling the sky. Data collected with estimated sizes from 1 to 20 meters were collected by satellite and by ground-based infrasound. Data for objects less than half a meter in size were from ground-based observations of meteors. (Brown, et al., reproduced with author's permission)

Just left of center on the chart, corresponding to smaller asteroids with lower energy detonations, we see data that was collected by DoD satellites using optical sensors and ground based infrasound sensors. Both systems were developed to support nuclear treaty monitoring requirements. These data are of actual impacts of small asteroids with the earth's atmosphere. On the right side of the chart, corresponding to larger asteroids with greater detonation energy, we see data collected by DoD and scientific community ground-based telescopes on

distant asteroids that may someday come close to crossing the earth's orbit. These asteroids have the potential to impact the earth at some date in the future if their orbits have close approaches to the earth's orbit.

Thus we see that much of the data on large asteroids that may impact the earth, and on smaller asteroids that have impacted in the earth's atmosphere, is being collected by sensor systems developed and operated by the DoD.

Overcoming Current Limitations

Despite the significant technical capability of national security systems to observe asteroids, they are currently hamstrung in their ability to be marshaled in support of an emergency warning or crisis reaction response due to the classified nature of the data these systems collect — it is not made available to the scientific community or the general public, except under unusual circumstances. The observant reader will notice that the data discussed above is in fact data from classified defense satellites. How was that data released, and why can't it be released routinely?

The data reported from ground-based telescopic observations come mainly from the LINEAR telescopes, a research project developing new sensor technologies and not currently part of the operational space surveillance system; its data is releasable to the Spaceguard Survey project. For the more numerous asteroid impacts detected by operational satellite sensors and recently reported with much acclaim, the story is different. One of the authors of the Nature magazine article also testified to the House Science Committee during the October 2002 hearing, saying that:

Some data about asteroid strikes have also been released to the scientific community. Unfortunately, it takes several weeks for this data to be released. I believe we should work to assess and release this data as soon as possible to all interested parties, while ensuring sensitive performance data is safeguarded.⁴

When I contacted the above witness and other co-authors of the Nature paper regarding the data, they explained that the data has not been cleared for release, but that I may be given access to the classified data if I have a clearance and a government sponsor. It seems that the data has only been shared amongst

⁴Statement of Brigadier General Simon P. Worden, U. S. Strategic Command, to the House Science Committee, 3 October 2002, <http://www.house.gov/science/hearings/space02/oct03/worden.htm>.

national security insiders for the purposes of publishing a paper in an scientific journal, but it is not available to be reviewed by their scientific peers — not the best situation for the advancement of scientific knowledge on the subject, especially considering the sensational claims of the authors in reducing the long standing estimate of the frequency of Tunguska-class events from once in every 300 years down to once in every thousand years. Only time will tell as to whether the data will truly be made available for the scientific community to assess its significance.

Another major obstacle to using this data as part of a crisis response system is the lengthy time required to process the data for asteroid impact events. This data processing is currently not part of the mission requirements for nuclear detection detonation or space surveillance. In the case of nuclear detonation detection systems, the asteroid impact events are actually gleaned from ancillary system data — the so-called state-of-health data. It is stored for later use when analysts can make the time to review it for impact events. This effort in itself is not funded and is usually accomplished when analysts have “spare” time. Additionally, the data does not seem to be very well calibrated or understood due to the fact that it is being used for purposes not intended, hence the need to calibrate it with other data sources such as infrasound data for events detected by both systems.

How does one overcome these limitations? Should the investment be made to have other agencies duplicate these observational capabilities for asteroid warning and emergency response? NASA and the NSF, being science agencies, employ a patient and deliberate methodology ingrained in their professional ethos to achieve their scientific aims, and, I would argue, should not be pressed into service in operational missions. They do collect significant data which can be useful in providing long-term warnings and improving our scientific knowledge of the phenomena. Crisis events and the sensors that typically detect them are mainly the purview of the DoD or agencies such as the Federal Emergency Management Agency (FEMA). With regard to the DoD, there are significant, low-cost actions that can be taken to provide warning or confirmation to other U.S. agencies or foreign governments in case of a threatening close approach of a large asteroid or the damage or crisis caused by a smaller asteroid impacting the earth.

Preserving the Equities of the National Security Community

The most significant improvement in DoD's contribution to asteroid impact detection and warning would come from a change in perspective: that of

enlightened self-interest. Consider how the recent DoD contributions came about. Sensors collecting data for space surveillance and nuclear detonations detection missions were serendipitously recording asteroids in earth-crossing orbits and small asteroid impacts in the earth's atmosphere. As the international scientific community becomes more interested in asteroid threat issues and are in need of observational data, they will continue to advocate funding to set up sophisticated technical sensors for the task. Once these new systems are put in place, they may begin to serendipitously record classified U.S. satellites in space or other events in the earth's atmosphere that the U.S. National security community would rather they not find. Thus, by providing science data on asteroids extracted from national security sensors, the DoD would make it *cost-ineffective* for the international scientific community to transcend DoD's ability to keep certain national security space operations hidden.

This is probably the most significant point to be considered by the DoD. Asteroid detection and threat warning is not a mission assigned to the DoD, nor to any other government agency. But there is clearly much at stake if the DoD loses the blanket of secrecy it desires for its own space operations. Providing high quality scientific data as a dual-use by-product from its existing and planned sensors is one way to prevent or delay an international network of asteroid sensors revealing DoD space operations.

What Could Be Done?

There has always been a high degree of cooperation between the military and civil space communities, especially regarding dual use technologies. From the first use of military boosters for the manned-space program to the examples of sharing sensor data on asteroid detections given today. This cooperation between security and exploration has existed throughout history, from the great migrations of human populations in the past to the more recent exploration of western North America by the Lewis and Clark expedition. With this in mind, I would recommend an approach that leverages the strengths of the various existing government agencies but that pushes hard to make sure the asteroid threat does not fall between the organizational cracks, as is so likely to happen when something new is not recognized as being part of the traditional mission.

It must be recognized that no agency has yet been assigned any formal role in planning and operating a comprehensive government approach to the problem. So the first order of business is assigning roles and missions. I would recommend that the DoD be the organization responsible for operating the mission; that DoD, NASA, and NSF develop technologies and continue

advancing the science; and that the Department of State (DoS) take the lead in building international support for an asteroid threat clearinghouse. More specific activities for each agency would include:

NASA

- Continue space missions to asteroids and comets as planned.⁵
- Continue the current, ground-based survey programs in partnership with DoD and the scientific community.
- Consider a series of numerous, inexpensive microsatellite missions to a large number of asteroids or comet fragments to survey composition.
- Continue funding improvements to the capability of the Minor Planet Center (Smithsonian Astrophysical Observatory, Cambridge, Massachusetts) for processing and cataloging orbits of NEOs.
- Consider ways to exploit asteroids and comet fragments not as potential hazards but as potential mineral and chemical resources to further space exploration.

DoD

- Continue upgrades to ground-based space surveillance networks.
- Continue development of space-based space surveillance satellites.
- Develop data processing and operational procedures for the rapid analysis, declassification, and dis-semination to emergency management organizations to discriminate between nuclear detonations and asteroid impacts (such as the agreement between the U.S. and Russia to share missile warning data⁶).

NSF

- Continue to pursue construction of the Large-aperture Synoptic Survey Telescope which could aid in the large scale search of distant or smaller NEOs. It could locate

⁵ Statement of Ed Weiler, National Aeronautics and Space Administration, to the House Science Committee, 3 October 2002, <http://www.house.gov/science/hearings/space02/oct03/weiler.htm>.

⁶ "U.S., Russia will share Early Warning Missile Launch Data" by Linda Kozaryn, http://www.defenselink.mil/news/Sep1999/n09171999_9909174.html

90 percent of NEOs down to 300 meters in size, enabling computations of orbits and likelihood of impacting the Earth.⁷

DHS (Department of Homeland Security)

- Explore FEMA's role in U.S. emergency response and participation in international emergency response efforts.

DoS

- Facilitate formal discussions with the international community of scientists, national security experts, and diplomats to explore structures for asteroid impact threat and emergency response notification.

The technologies employed by the United States for space surveillance, nuclear weapons monitoring, and science missions have already proven their applicability. The question remains as to how all of this capability can be marshaled into an impact warning or an emergency response notification system? The question also remains as to whether the U.S. should pursue a unilateral approach to the problem, which would protect sensitive capabilities, or whether they should advocate a cooperative international venture. It would seem that since one of the goals is to prevent the accidental initiation of a nuclear war amongst other countries, an international approach would be advisable.

The monitoring provisions of the Comprehensive Test Ban Treaty (CTBT), in which signatory countries all field and share a global network of nuclear testing sensors, makes a good model for multilateral cooperation and data sharing that would be suitable for an global network of asteroid impact monitoring stations. However, the prospects of using the formal structures and the classified technologies of the LTBT, or the internationally shared technologies of the CTBT, are not promising. A press announcement from the Department of State's website, dated 24 January 2002, reads as follows:

...[Under Secretary of State John] Bolton, who spoke earlier at the Conference on Disarmament (CD), said the Bush administration is opposed to the Comprehensive Nuclear Test Ban Treaty (CTBT) "and we have no plans to seek [U.S.] Senate action on it as part of the

⁷ Statement of Joseph Burns, National Research Council, to the House Science Committee, 3 October 2002, <http://www.house.gov/science/hearings/space02/oct03/burns.htm>.

Nuclear Posture Review the Department of Defense recently concluded."⁸

The national security community will most likely remain opposed to contributing classified data to the civil community for use in monitoring natural hazards, but a compromise solution could be achievable. As argued above, it is technically feasible to extract data on natural phenomena from the classified mission data, process both streams in parallel, and report the asteroid-related data to an international warning center.

A significant amount of work would need to be done to ensure that the leadership of all nations were cognizant of such a facility. A center for the collection and dissemination of only asteroid data most likely would not be remembered by government officials in time of crisis. But an international center for emergency management — for natural cataclysms such as floods, earthquakes, fires, and man-made disasters such as weapons of mass destruction, terrorism, etc. — would be well-known and frequently exercised by most all international government officials. The point is that a one-of-a-kind asteroid warning center would probably not suffice. Thus, the challenge to the asteroid community is that they must engage other diplomatic and national security groups to assure that a high-profile, international emergency management center would be established. Probably not a bad idea in any event.

Conclusion

As we enter the new century, the nation's space program has enormous new opportunities. Traditionally, military systems were designed to very specific mission requirements and operated with a myopic focus. But, if we allow a bit more latitude and try to be a little more creative, we often find system designs and operation concepts that provide much improved capability at very little extra cost. This "capabilities-based" approach is currently *de rigueur* within the Pentagon, and the staff there is busy trying to figure out exactly what it means and how to implement it. I suggest that such an approach should be able to achieve dual-use capability in our nation's space surveillance and treaty monitoring technologies enabling them to support asteroid warning and detection in a cost-effective manner.

⁸ "Bolton Says U.S. Will Not Resume Nuclear Testing" 24 January 2002, <http://usinfo.state.gov/topical/pol/arms/02012400.htm>

The civil space program is literally at a crossroads where they must consider pursuing the old modes of human space flight and exploration or make drastic shifts to a new paradigm, pursuing affordable and safe access to space with new technologies and new space vehicles, while examining exactly the goals of where to travel, what to explore, and how to do so. It seems that at this time, there is a natural synergy between the national security community and the space exploration community to cooperate for the security of nations and for the security of human life in our solar system by an invigorated partnership to catalog, monitor, warn, and explore the asteroids in near-earth orbit.

* * *

Questions and Answers

Q: Supposing there is the destruction of a city, and you want to find out if it's due to some kind of an asteroid or it is due to a bomb. How much time is required to report and what would be the key observation?

Correll: Well, if it were a nuclear detonation, it would have been reported in the time that you took to say that; it would have been reported and the ops messages generated automatically. The satellite sensors have been monitoring detonations for years and they work in real time; when something comes up that matches the signature of a nuclear detonation, it is reported automatically. So in the time we've had this discussion, it would have been reported. Now because, as I said, a nuclear explosion and an asteroid impact look very much the same -- but not exactly the same -- the monitors' sensitivity is set to discriminate nuclear events from false alarms. An asteroid impact has slightly different signature; since it's not nuclear, it is discarded by the ground software. But somebody has to say, there's an explosion, is it nuclear or not? There's a subtle difference: if it's nuclear, I know right away; if it's not, I have to scratch my head and say well, I didn't see anything, so I'm not sure, what are we talking about?

Q: What would you look for in a nuclear explosion? What are the key observations?

Correll: I can't tell you the key observation because it's classified. Actually, I spent four years doing that, and what I know of the answer is classified. I don't know if there is a non-classified source that talks about that. If you look, you can probably find some technical books on nuclear weapon phenomena that might talk about it. Like most things, the details are in how it happens, and consider

how a nuclear bomb works: there are nuclear time scales different than the natural that tell it.

Q: Is it a matter of seconds, or a matter of minutes, or a matter of days?

Correll: For the confirmation, again, if it's an asteroid or you don't see the nuke – typically when somebody reports seeing something, you double check your data and if you don't see anything, you can check the data that sees the asteroid and check the specific features essential to a nuclear explosion event and signatures essential to a natural event. Right now there's no procedure. That could be done on the order of five to ten minutes, checked and confirmed. Right now it's not done on that time scale, and that's what we need to work out. Given that the data's already there, what additional computer processing or operating procedures do we need to let us do that? I think that's just a small incremental addition; it's not a huge amount of resources, but it is *some* resources, and if you ask the people to divert money from their primary mission, they're not going to offer up their money. So that's an issue, even if it's a small amount.

Q: Is there any use for the large radars, the Harris Goldstone radar operated by JPL for these asteroids? Arecibo has seen asteroids for a number of years.

Correll: Let me tell you what I know about it; you may know more than I do. The Department of Defense uses radar fences to look for a satellite or space debris in very near-earth orbit.

Q: These are much bigger than those, I guess.

Correll: When they study the distant asteroids to get those basic images, they have to stare at them. So these radars are useful for getting a detailed image, to get an estimate of the size, and then from a radar picture of the size and an optical image of the light reflected, you can calculate albedo and start pulling size and mass and so on. But I don't think you can use these radars to search.

Q: They are looking at asteroids they already know are there.

Correll: They already know they're there. I can collect a lot of data to see that asteroid's out there and I can take a picture of it, but I have to stare at it for hours. So the problem is scanning the whole sky to find these: you can't do it to that distance. They use those radars for things orbiting the earth close by, because you're close enough to see them.

Q: They're using some of these big radars, Goldstone and Arecibo and others, for imaging asteroids and also some of the big radar telescopes are getting their own funding which will greatly increase the search and create capability for this kind of thing.

Correll: I would suggest that's an avenue that needs to be pursued on the science side. Science will develop future sensors. Clearly, there's a lot of science radars to focus on for taking a look at asteroids. I don't think currently they're capable of doing surveys, but they are really getting close in that type of development.

Q: I have a couple questions. You mentioned that one of the concerns with, for instance, other countries developing the capability to sort out for themselves whether it is a nuclear strike or not, was that the kind of radar or optical observation it was making would compromise one of our satellites. What kind of resolution are we talking about, before we start a discussion of the types of observations, how large of an object in near-earth orbit? I know we are more and more in touch with satellite tracking radar as opposed to broader missile defense, and I am also curious as to what kind of resolution is needed for near-earth orbit objects

Correll: First, on resolution: how much capability do we need? There are two facets of that problem. One was already mentioned: I can take a detailed image of something if I already know where it is. But to take a detailed image, typically you have to find it, specifically you would have a system of sensors designed to do a survey and they look for distinct points of light. Once you've found the point of light in your catalog, then you have larger telescopes cued to track the object's location. So I don't know what the answer to required resolution is but wherever it is, it is a dual track, first you find it, then you have it on the sensor, and then you image it.

The second one on missile defense technologies and improved radar. They are going to be concentrating more and more on things coming into the earth in a matter of minutes, so they are going to be here on short-range radar, scanning the skies. Some of that would be done in space, with the space-based sensors. People in government are advocating capabilities-based planning to try to build in from the beginning and make sure new systems have flexible capability, so there are advocates inside the system working for that. I don't know that SIBRS program has put a lot of focus on that problem.

Q: The thing that intrigued me is this possibility of a mistake, the fact that there's

a possibility of a mistake. Why didn't we think of that before?

Correll: That's a good question. I mentioned in my talk that recently people have brought up in the media and testified to Congress that there is a risk of an asteroid impacting over India or Pakistan, for example. Even if it didn't kill anyone, it would look like a small nuclear weapon. Would one of those countries, if it impacted over their area, would they think "it looks like a nuclear weapon, are we under attack and should we launch our missiles in retaliation?" Now you've got a nuclear conflagration. The first I really heard of it was just in the last year or two. Maybe if you did a literature search, you'd find an earlier mention of this. But the emphasis that this is not just the asteroid "dino-killer," that there's this new wrinkle, has just really gotten attention in this past year.

Q: It seems to me that that's more of a threat than getting hit by one of these things.

Correll: Well, it's the more likely thing to happen. It would cause less damage than if, for example, one came in and destroyed half the life on the planet, but that said, it is the more likely occurrence. An asteroid mistaken for a nuclear detonation and causing war is more likely on the time scale of our lives.

Q: When I write this story, how do I present this to people and say, "This is a possibility, but don't go build a bomb shelter"? Whenever we do a story on asteroids and the earth, people laugh at us.

Correll: That's a good point. The asteroid community, the people who track NEOs, have already had their share of false alarms. A couple of years ago, some researchers took data on an asteroid, computed an orbit and said it's likely to impact the earth in twenty or thirty years – I forget the exact details – but you know, they were doing this from a typical scientific detachment, and when it got into the press, there was a lot of alarm. Their follow-up calculations showed that when they corrected and refined the orbit, the numbers were wrong and the impact figures went down. So the scientific community is somewhat gun-shy because they've already been accused of saying that the sky is falling. But that's only part of the issue; you can't ignore it, either. To approach it, you have to have scientists, policy people, people who view the situations, to kind of look at how they can together assess the level of threat and response.

Q: I wonder whether it would be practical to rely on the military concerning the coordination between the scientists and the military. Would you say that the

military needs to provide some of this data to the civilian scientists, so that they can do a correct analysis and really determine if there is a threat and what to do about it? In my experience, the military doesn't like to give up information on anything, so how do you overcome that?

Correll: Well, that's true, and it's understandable; the military does want to protect their data. But I think the question raises the issue that there are larger concerns, which I think in this case are not just national, but international concerns, that somebody at a higher level needs to be made aware of. So that's what I'm advocating: that the policy people in Washington find a way to protect the critical parts of the military system, but certain things may not be so critical anymore, or maybe they still are, but there is a higher gain here by looking at them from a proper perspective of international security. And that decision needs to be made by political leadership, not just the military offices.

Q: How often do we see asteroids of substantial size fall over populated areas?

Correll: The ones that look like nuclear weapons? We're saying that over the last ten years, when we compiled this data from satellites and infrasound, they had about 300 over the last ten years that were on the kiloton to tens of kilotons range. So this happens, as we say, twenty to thirty times a year right now. Typically they fall over not very well-populated areas or the oceans, so typically they are not noticed, especially if they are small and they are high in the atmosphere. You will often see reports in the newspapers of where there was a bolide seen in the sky and you'll see a few of these reported each year, but there are more that are unreported, so it is a question of time. I haven't done the calculations, but I guess you could calculate; if you make a list of every major city and draw a 100-mile circle around each, you could calculate the probability of one hitting over a large city. Again, it probably wouldn't damage the city; it would make a flash of light, and you would feel a rumble, and these incidents have been reported. I think a year or two ago in Arkansas there was a report; people saw a flash and felt a rumble and everything. So this is what you get from the smaller ones. The larger ones that could actually do damage would maybe be down to five a year or so, that is, a Hiroshima-sized explosion.

Q: Do you think we could agree to focus on this when we have the war on terrorism, and possibly war with Iraq? How can we get the DOD pay a little more attention to outer space?

Correll: Well, persistence pays off. As I said, these people have been plugging

this data for at least ten years and it's the type of thing that has to do – there will always be other priority issues.

Q: This concept of mistaking a natural event for a nuclear explosion is not really a new one. The Vela satellite, thirty or forty years ago, detected gamma ray bursts which were of concern because they looked like nuclear weapons signatures. It turned out they were from cosmological objects, gamma ray bursts. That was found more recently, but for a time, that was a real puzzle and that was classified for quite a while. So natural events masquerading as nuclear blasts, that's even closer.

Q: You mentioned at the very end that we need more international systems to track the threat and share this data. Certainly the U. S. detection systems are probably the most advanced in the world, but I would imagine that the Russians have nuclear detection systems as well. Did you look at the prospects for U.S.-Russian cooperation as a first step leading the way to sharing this data with other countries?

Correll: Regarding the Russians, I know they have space surveillance systems but I don't know they have a separate nuclear detonation detection. I don't know if the community of people I was associated with, working as a government consultant, have talked about this issue. I know some of our people have talked with allies about the microsatellite program, the future of space surveillance. Also I have been remiss in not mentioning that aside from our DoD sensors, I did show one telescope of the NSF which does detect asteroids. There are other international groups within the scientific community which use similar telescopes which collect this data and provide it to their science centers, as part of their research.

So, NSF, the University of Arizona, other international science groups provide data. But as far as working for international collaborations, military facilities, establishments, I know we have talked with some of our allies about that, but I don't think that they have made any plans to share that data. This is a question that was brought up – it's not a new thing, under the SDI program, they were going to work with the Russians and apparently the Defense Agency, so it's not unheard of to share data, but I am just not aware of any cooperation, other than the U.K., Canada and Australia.

Q: Does the establishment of the Department of Homeland Security offer the opportunity for more support in correlating all this asteroid data?

Correll: I believe it does. Any time you have a change like that, it does. I haven't been following that real closely. My first instinct would be, what comes to mind is FEMA, because that's where it is now. I think it's natural that they should take the lead. The Department of State is important in working other countries, but clearly they would integrate our U. S. effort, which would be the Department of Homeland Security, so that should be adequate.

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