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The Policy Trajectory of United States Asteroid Deflection Planning

Joseph Packer, Central Michigan University
Jeffrey A. Kurr, Baylor University
Adam Abelkop, Indiana University

Abstract

Recent scientific studies document how potential dangers posed by asteroid collisions with Earth have been previously underestimated. These findings are alarming given the prevailing trajectory of US asteroid deflection policy, characterized by uncritical reliance on scientifically questionable deflection methods, such as nuclear interception. Numerous intercollegiate policy debate contests provided the authors with opportunities to survey the relevant policy literature and test alternative proposals for asteroid deflection planning. This article translates the results of the interactive research, reflecting on the historical backdrop of the threat posed to the planet by near-Earth Objects (NEOs), considering the relative merits of proposed deflection policies, exploring the issue's connection with ballistic missile defense debates, and finally offering a call to action.

Keywords

asteroid deflection, nuclear weapons, ballistic missile defense, Near-Earth Orbit, outer space, space policy

The Policy Trajectory of United States Asteroid Deflection Planning

Joseph Packer, Central Michigan University
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If anything can be learned from Earth's history, it is that we should not underestimate the staggering power of a Near-Earth Object (NEO) impact. While the dinosaurs may have gone extinct sixty-five million years ago, NEO strikes have not lost their capability of inflicting catastrophic disruption. In fact, humanity's technological advancements, global interconnectedness, and hyper-specialization make society much more vulnerable to a massive NEO strike than the dinosaurs. In spite of this threat, politicians cite the absence of a major collision in a populated area in modern history in order to push the NEO question to the back burner in the face of more "timely issues." Given the time needed to establish mechanisms for international cooperation and to develop technologies for effective deflection, deflection policy should be considered a "timely issue," as the policy choices that get made in the present will likely be the ones we are stuck with in the future.

The United States currently lacks a clear policy on how it would deflect a NEO. Instead, a series of reports and recommendations from various government agencies are the only indicators of what actions the government would take in event of a threat. In 2006, a National Aeronautics and Space Administration (NASA) report suggested sole reliance on nuclear deflection. Nuclear deflection, however, risks fragmenting the NEO, which increases its capacity to inflict harm. In addition, a nuclear deflection may be largely uncontrollable and risks sending the NEO into another orbit that threatens Earth. Nuclear deflection also undermines the possibility for international cooperation in deflection missions because other countries view nuclear weapons as a polarizing issue. The potential for a nuclear deflection system to be used for military purposes proves an equally problematic concern. Perhaps the greatest legacy of the 2006 NASA report is that its call for reliance on nuclear deflection removed impetus from building conventional deflection technologies that can safely and accurately deflect most NEOs.

A 2010 National Resource Council report offered an alternative US deflection policy. The report provided a more even assessment of various deflection options and called for using nuclear weapons only as a means of last resort. A policy of using nuclear deflection only as a means of last resort could encourage the development and use of more accurate conventional technologies, while retaining the nuclear option as a failsafe. The policy of nuclear last resort also opens the door to international cooperation on deflection. Unfortunately, confusion exists over whether the Obama administration has adopted the NRC's recommendations.

Contest round competition on the 2009–2010 intercollegiate policy debate topic on United States nuclear weapons policy afforded the authors with the opportunity to research asteroid deflection policy. At numerous competitions, teams from the University of Iowa and the University of Pittsburgh argued that the United States federal government should amend its asteroid deflection planning by designating its nuclear explosive devices as "means of last resort" for NEO defense. Pre-tournament preparation, contest round argumentation, and follow-up research enabled the authors to glean detailed information from primary and secondary sources, as well as hone research findings in light of the give-and-take generated by exchanges with opponents and judges in contest rounds.

This article presents the authors' research findings in six sections. The first section summarizes background information pertaining to the threat of an asteroid collision with Earth and current United States policy governing asteroid detection and deflection options. With an emphasis on scientific perspectives, the second section presents the effectiveness of nuclear explosives as a less-than-ideal deflection option. In the third section, the authors analyze the opportunity costs of pursuing nuclear deflection relative to potential non-nuclear deflection techniques. The fourth section explores possible deflection decisions that may be made at the domestic and international levels. The fifth section investigates the curious overlap between the United States' nuclear deflection and space weaponization. The sixth section relates the authors' concluding thoughts and call to action.

Background

Historically, scientists have gauged the frequency of NEO collisions by discovering and counting impact craters. Given the minuscule amount of terrestrial impact craters relative to the estimated number of asteroids and comets traveling through the galaxy, researchers previously concluded that these strikes were not only infrequent, but also primarily contained to the Primordial Era following the Big Bang. Dallas Abbott, a geophysicist at Columbia University, notes that, until recently, the search for craters had occurred almost exclusively on land. She reasons that over one hundred large impact craters might lie under water, which after all covers roughly 70% of the planet. In less than a decade of searching, her team has discovered 14 new

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underwater craters (as cited in Easterbrook, 2008). One such crater was formed from the impact of an asteroid 300 meters in diameter, which may have struck as recently as 536 A.D. (Abbott, Biscaye, Cole-Dai, & Breger, 2008). The prevalence of underwater craters is one of the clues that suggest "catastrophic" NEO collisions may occur once every 1,000 years—a drastically shorter time frame than the previous estimate of once every 500,000 years (Blakeslee, 2006).

Some scientists claim that the crater counting method radically underestimates the frequency of dangerous NEO strikes. Mark Boslough, a physicist at the Sandia National Laboratory, posits that most asteroids may in fact not leave a crater at all because the heat from their passage through the atmosphere causes them to explode in mid-air before they ever make contact with the ground (Boslough & Crawford, 2008). In October 2009, an asteroid only 10 meters in diameter exploded in the atmosphere above an island region of Indonesia. Energy released from this explosion was nearly 50 kilotons—over twice the power of the blast of the Hiroshima bomb (Yeomans, Chodas, & Chesley, 2009). In June 2002, a similar-sized asteroid exploded over the Mediterranean Sea with an explosion roughly equivalent to that of the Hiroshima bomb. In a subsequent hearing before the House Committee on Science, Space, and Technology, General Simon "Pete" Worden, Deputy Director for Space Operations of the US Strategic Command, testified that Earth is bombarded with about 30 such asteroids each year (Worden, 2002). An explosion of this magnitude over a major population center would cause massive destruction even if it did not leave a permanent crater.

Contemporary scholars who have reviewed primary historical texts have found significant evidence that asteroids and comets have played a considerable role in human affairs. A near miss with a comet around 540 A.D., for example, has been linked with severe environmental degradation. Tree-ring chronologies, ice cores, and primary sources suggest that dust from the tail of that comet darkened the sky and some make the case that the dust from the comet caused plague-like symptoms across the world (Baillie, 2007, p. 108).

Along with findings that large asteroid strikes occur more often than previously believed, new evidence also suggests that relatively small asteroids of roughly 30 meters in diameter—previously believed to be harmless—pose a serious threat (Easterbrook, 2008). In 1908, for example, an asteroid exploded above Tunguska, Siberia. This blast—through both its initial force and secondary firestorm—obliterated hundreds of kilometers of forest. If this explosion had occurred over an inhabited area, the human population and structures would have been completely annihilated. For decades, geophysicists estimated the diameter of this rock to be between 50 and 80 meters. Recent research at the Sandia National Laboratory, however, estimates that the rock was merely 30 meters in diameter—a size that NASA had previously suggested did not pose a significant threat (Boslough & Crawford, 2008). This is a significant finding given that these relatively small asteroids of 30 meters in diameter are much more numerous than the larger asteroids, multiplying the number of potential NEO threats.

Globalization has created more specialization and reduced redundancy such that if a small NEO struck a region producing a vital good (e.g. rice or energy), its negative impacts would be felt globally (MacCracken, 2007, p. 278). Human advances since the 1908 strike also make society more vulnerable to the secondary effects of a NEO collision. The Tunguska event, for example, caused a magnetic storm that stretched 900 km from the epicenter of the impact (Nemchinov, Shuvalov, & Svetsov, 2008, p. 57). The magnetic storm generated by the Tunguska asteroid had little effect on the technologically primitive 1908 society; but in a modern society dependent on telecommunications from satellites and radios, the disruptions caused by a similar magnetic storm could be as harmful as the physical blast itself (Marusek, 2007). The addition of NEOs as small as 30 meters in diameter to the list of potential threats highlights just how much prior probability calculations have seriously underestimated the likelihood of a considerably harmful strike.

The governmental response to NEOs tends to lag behind advances in threat detection research. In 1992, NASA released a report outlining the potential risks posed by NEOs (Chapman & Davis, 1992). In response, Congress directed NASA to track asteroids and comets greater than 1 kilometer in diameter that could potentially threaten Earth, with the goal of being able to detect 90% of such objects within ten years. NASA did not formally accept the goal until 1998 citing a lack of funding (Morrison, 2001). As new research began to suggest that smaller asteroids could pose a danger, Congress adopted the 2005 NASA Authorization Act, which extended the deadline to 2020 and required the cataloging of 90% of NEOs 140 meters in diameter or larger. Note that prior to 2005, these mandates required NASA to detect and map the direction of NEOs, but did not require research into NEO deflection.

The 2005 NASA Authorization Act included the first mandate for NASA to formulate a plan to deflect a NEO rather than to simply catalog the potential threats. Following the mandate's one-year deadline, NASA provided Congress with the 2006 Near-Earth Object Survey and Deflection Study. Critics lambasted the report, and Clark Chapman of the Southwest Research Institute called it "a sketchy 27-page report that lacked any detailed analysis, a budget or an implementation plan" (Hecht, 2007). NASA, meanwhile, kept a much more detailed 271-page analysis secret from the public and only circulated it to study members. The report's secrecy surprised individuals who had a history of working with NASA because of the agency's typical commitment to openness (Hecht, 2007). Under pressure from groups interested in NEO deflection, NASA has since made the full report publicly available. The report emphasized that nuclear weapons may be 10 to 100 times more effective than the alternatives (discussed below) regardless of variables such as the composition, size, location, and speed of the target NEO (*Near-Earth Objects [NEOs]—Status of the Survey Program and Review of NASA's 2007 Report to Congress*, 2007). Dr. Chapman suggested that the logical conclusion of the report was that NASA had selected nuclear deflection as its default deflection mechanism (Chapman, 2007). NASA had even designed a concept delivery vehicle involving an Ares V rocket with six interceptor vehicles equipped with one B83 nuclear warhead each (Coppinger, 2007).

Following release of the full NASA report, Congress authorized the Consolidated Appropriation Act of 2008, which directed the National Research Council (NRC) to conduct a similar report on NEO detection and mitigation strategies (National Research Council, 2010,

p. x). The committee members who worked to compose this report hail from government-sponsored institutes, such as NASA and Sandia National Laboratories, to independent organizations, such as the Southwest Research Institute and various universities (National Research Council, 2010, pp. 118-125). In contrast to the 2006 NASA Report, the NRC report concluded that nuclear deflection should only be used as a last resort and not as the primary deflection option (National Research Council, 2010, p. 4). Drawing upon publicly available research, teams from the University of Iowa and the University of Pittsburgh defended this same position prior to the report's release. The report also found that nuclear deflection would not be necessary for NEOs smaller than 500 m in diameter. Instead, the NRC report promoted non-nuclear technologies as more effective deflectors of NEOs of this size (National Research Council, 2010, p. 84). The stark points of divergence between the 2006 NASA study and the 2010 NRC report carry important implications for policymakers, analysts, and citizens concerned about a potential NEO collision. The following sections explore these implications as they relate to issues of deflection effectiveness, opportunity costs, international cooperation, and space weaponization.

Deflection Effectiveness

Although the 2006 NASA report recommended nuclear explosives as the optimal deflection mechanism, independent scientists have met this prescription with substantial skepticism. The first problem with a nuclear explosion is that the powerful blast and massive release of radiation makes it difficult to predict where the NEO will be deflected. The uncontrollable nature of the blast could send the NEO into another orbit that intersects with Earth (T. Graham & Schweickart, 2008). On the other hand, there is a chance that the nuclear blast will have little or no impact on an incoming NEO's trajectory. On Earth, a nuclear explosion's destructive power comes from exerting force on surrounding atmosphere sending shock waves that can level cities. In space, there is only a vacuum, which means there is nothing to be forced into the NEO by the explosion. A nuclear explosion would deflect the NEO by releasing radiation to push against it and alter its trajectory. Certain asteroids and comets are surrounded by a thin layer of dust particles that could absorb this radiation without diverting the course of the NEO. The explosion's release of radiation also complicates the ability of scientists to verify whether the NEO has been deflected, because any ship close enough to measure the change in direction could be destroyed by the ensuing blast (Schweickart, 2004).

The second and deadlier issue with nuclear deflection is that it risks fragmenting the NEO without changing the fragments' trajectory toward Earth. Dr. Ed Lu, president of the B612 Foundation suggests that this would "[turn] a speeding bullet into a shotgun blast" (*Near Earth objects [NEOs]: Hearings before the Subcommittee on Science, Technology and Space of the Senate Commerce Committee*, 2004). Many scientists believe that being hit by numerous smaller fragments would be worse than one large asteroid or comet, and new scientific evidence suggests that even if the NEO was turned into dust, the high concentration of particles could still impact Earth with significant force (Nemchinov, et al., 2008, p. 59). The NASA study downplayed this risk in part because it focused on large solid NEOs, despite the fact that the vast majority of NEOs are either comprised of porous rock or small rocks held together by weak gravitational pull (rubble piles). Rubble piles and porous NEOs face a much higher risk of fragmentation from a nuclear blast. Perhaps the most pernicious effect of fragmentation is that it renders non-nuclear means of deflection useless, as Chapman argues, "Once you disrupt a comet or asteroid into many different chunks, you've lost all ability to affect what happens next" (Chapman, 2003). Given the possibility that fragmentation could greatly diminish the success rate of other means of deflection, NASA's choice of nuclear deflection as the first and only line of defense was short-sighted.

Opportunity Costs

Despite the NASA report's indication to the contrary, there has been serious scientific research on the viability of conventional asteroid deflection technologies. These range from simple techniques like ramming the NEO with a heavy object—referred to as a "kinetic impact"—to unexpected strategies such as lasers, gravitational "tug boats," or even superheating the asteroid's surface by painting it black to absorb solar energy (Britt, 2002). Some of these non-nuclear deflection technologies already exist or could be created using technology that is currently available. Koenig and Chyba write that kinetic impactors require "no new technologies, would not require development or testing of nuclear warheads, and would likely be the least costly, least risky, and fastest to effect" and defend the technology for nearly all scenarios for NEO deflection (2007, p. 58). Many other studies published around the same time of the 2006 NASA report supported the use of kinetic impactors over nuclear deflection (Bekey, 2007; Chobotov & Melamed, 2007; Dachwald, Kahle & Wie, 2007; Rathke & Izzo, 2007). In fact, the Deep Impact mission demonstrated that NASA had all of the technical capabilities necessary for a kinetic deflection mission (A'Hearn et al., 2005).

Many conventional deflection methods rely on technologies that already exist. One idea, a gravity tractor, is simply a spaceship that orbits a NEO and uses its gravitational pull to slowly change the NEO's direction (Greczyn & Chicka 2007; Lu & Love, 2006; Schweickart, Chapman, Durda, & Hurt, 2006). Mass drivers are machines that would attach to an NEO and launch pieces of the object into space to create force to change the NEO's direction (Friedman et al., 2004; O'Leary, 1977). A deflection mission that took advantage of the Yarkovsky effect would paint a portion of a spinning NEO. The increased solar radiation would alter the orbit of the NEO, causing it to miss Earth (Agle, 2003; Spitale, 2002). No shortage of other possible conventional technologies exist, including lasers, tethers, or focused sunlight (Chobotov & Melamed, 2007; Preston, Johnson, Edwards, Miller, & Shipbaugh, 2002; Vasile, 2009).

Some of these technologies may lack the maturity of kinetic impactors or nuclear blasts, but the NASA report may have been too quick to disqualify them from serious consideration. The move to ignore slow push technologies represents a potentially grave decision, because porous asteroids have a high resistance to direct energy impacts, like those from a kinetic impactor or nuclear blast (Holsapple, 2002). Techniques that slowly apply force can bypass the natural energy dispersing characteristics of porous asteroids.

In contrast to nuclear weapons and kinetic impactors, these non-nuclear technologies rely on creating a small change in an asteroid's trajectory decades in advance. Given the vast distances involved, this small nudge would send an NEO sailing safely past Earth. The miniscule forces at work allow better calculations to be made about the NEO's altered trajectory, which means these techniques are less likely to send an asteroid into another threatening orbit. The minute force also means there is significantly less—and in some cases zero—risk of fragmentation. Perhaps the greatest benefit of non-nuclear deflection methods is that they are not mutually exclusive. The B612 organization advocates using kinetic impactors and a gravity tractor to deflect most NEOs. The reduced risk of fragmentation from non-nuclear technologies and their reliance on small forces over time, rather than massive explosions, opens up the possibility of dozens of potential deflection combinations.

At the same the NASA report outlined a default to a nuclear deflection strategy, other nations began to design and build non-nuclear deflection technologies. In 2009, British scientists at EADS Astrium, a subsidiary of the European Aeronautic Defence and Space Company, completed the design for a gravity tractor. The EADS Astrium design would be 30 meters in length and have to be launched twenty years prior to collision. They believe this gravity tractor would be capable of deflecting a NEO up to 393 meters in diameter (Gray, 2009). In addition to the work of EADS Astrium, the European Space Agency (ESA) was actively developing kinetic energy deflection in the Don Quijote mission (European Space Agency, 2009). This mission consisted of two spacecraft: Sancho, the orbiter or observer spacecraft, and Hidalgo, the impactor. The European Space Agency also began funding the development of prototype deflection vehicles that use lasers to change an NEO's course (Shiga 2009). Despite its initial support for nuclear deflection a few years ago, the Russian Federal Space Agency (RFSA) recently announced a conventional deflection mission to intercept Apophis, a large NEO that has a very small probability of colliding with Earth in 2036 (Barry, 2009). The head of the RFSA, Anatoly Perminov, even invited NASA and other countries to work with the RFSA on this mission. To date, NASA is not working with the RFSA on this campaign ("Armageddon 2036: Russian scientists say no," 2009).

The NRC report validated these efforts of other nations when it called for a policy of using nuclear weapons only as a means of last resort for NEOs that conventional technologies could not deflect. The report acknowledged problems with nuclear deflection like fragmentation and explained in what circumstances these risks would be minimal or necessary. In contrast, the 2006 NASA report only mentioned fragmentation as possible means of deflection, not a potential downside of nuclear deflection even though the scientists at the time had written on the issue (Claybaugh, et al., 2006). The 2006 NASA report also misjudged the costs of conventional deflection by including unnecessary propulsion technology, which led them to be labeled expensive (Hecht, 2007). The NRC report and the actual experience of Russian and European scientists point to a much larger role for conventional deflection.

A US policy of defaulting to nuclear deflection trades off with conventional deflection techniques for three reasons. First, it removes the impetus for the United States to develop its own conventional deflection methods. While Russia and Europe have moved forward to develop lasers, gravity tractors, and kinetic impactors, there is no evidence that the US has made any effort to develop any conventional deflection technologies, at the time of this paper's final submission. Given the history of NASA, one of the oldest and most established space programs, and its development of detection technologies, it is reasonable to assume the agency may confer insights or capabilities for developing conventional deflection that other nations would not have. Second, a US nuclear deflection mission risks fragmenting the threatening NEO, which would render conventional deflection techniques useless (Chapman, 2003). Finally, the radiation from a nuclear blast risks rendering any nearby gravity tractors, kinetic impactors, mass drivers, and other deflection technologies, inoperable and thus inhibit the ability of other nations to take action.

The 2006 NASA report focused primarily on the science of NEO deflection. The reliance on nuclear weapons as the primary method of deflection, however, raises concerns that fall outside the narrow question of their effectiveness. The following sections examine potential problems of a nuclear deflection strategy that emerge from the way it could effect the geopolitical environment.

International Dimensions

Any US plan for unilateral nuclear asteroid deflection would have important international dynamics, given how an Earth-bound asteroid potentially places the entire planet—not just one nation—at risk. Further, unilateral deployment of nuclear devices for any space mission raises treaty concerns that deserve careful consideration in this policy context. The 2006 NASA report largely ignored the potential political implications of various asteroid deflection despite them being repeatedly emphasized in the literature on NEO deflection (Ahrens & Harris, 1992; Ailor, et al., 2004; Harris, Canavan, Sagan, & Ostra, 1994; Schweickart, et al., 2006).

For instance, the Outer Space Treaty prohibits the stationing of weapons of mass destruction either in orbit around the Earth or on celestial bodies. While not a problem for large objects that are detected decades in advance, celestial objects that provide little warning time, such as long-period comets, could only be deflected if a system is already developed and stationed in outer space, as the current design of nuclear weapons precludes the possibility of space deflection (Bucknam & Gold, 2008). Although intercontinental ballistic missiles (ICBM) and submarine-launched ballistic missiles (SLBM) temporarily travel through outer space when they near their apex, they lack the functionality to travel far enough into space to be effective delivery vehicles for nuclear deflection (Bekey, 2009). While imminent threat of a NEO collision may establish the conditions where countries would allow for an amendment to the treaty, it would likely be too late to use nuclear deflection to its maximum effectiveness. Because many small NEOs are not detected until weeks if not days before they impact, this timeframe would preclude the possibility of amending the treaty and designing and building the deflection system (Bucknam & Gold, 2008). Some have suggested that if the United States or another nation were to potentially violate international law by using nuclear weapons to deflect an asteroid, the international community would not likely resort to sanctions or other penalties (Gerrard & Barber, 1997).

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This may hold true for an extremely large NEO that obviously threatened massive devastation. For smaller NEOs that posed a less obvious threat, other nations may not acquiesce to the US behavior so easily, and it is difficult to imagine any scenario where other nations accept the US stationing nuclear interceptors permanently in space. Furthermore, violation of the Outer Space Treaty under circumstances of dubious peril may result in international bickering and/or weakening of norms underlying the treaty, which could lead to the potential for a destabilizing arms race in space (Rusek, 2008; Union of Concerned Scientists, 2004). Even absent an arms race, any delay and debate over the use of nuclear deflection in violation of international law could reduce the mission's probability of success (Nemchinov, et al., 2008, p. 56).

While the prospect of nuclear deflection poses complex international challenges, conventional deflection technologies present their own set of global concerns. The small controllable forces involved in conventional deflection technologies raise the possibility that a NEO would not be completely deflected. This leaves the country that had attempted to move the asteroid potentially ethically, legally, and politically responsible for the shift in impact location (Bucknam & Gold, 2008). Some have even suggested that countries could use slow push deflection techniques to turn NEOs into weapons (Preston, et al., 2002; Sagan & Ostro, 1994).

While the United States may be the most capable of deflecting a NEO, cooperation between multiple nations would optimize this effort (Binzel, et al., 2010; National Research Council, 2010, p. 99). International cooperation would allow resources to be shared including survey and characterization technologies. During a 2008 NEO impact over Sudan, an informal network of scientists and astronomers was able to estimate the time of impact to within a minute and the location to within a kilometer of the explosion (National Research Council, 2010, p. 100). Formalizing these lines of communication between nations would allow more time to prepare for a potential impact if mitigation was not possible. In addition to detection technologies, pooling resources for deflection technology lessens the budgetary constraint on any one space agency on providing the most adequate mitigation methods. This holds especially true for non-nuclear deflection methods, because the various techniques can operate in tandem even if governments create the programs independently. For example, if the US builds mass drivers and the European Space Agency builds kinetic impactors, they can deploy these technologies together (Schweickart, 2004).

Space Weaponization

Given the concerns surrounding nuclear weapons and the long list of viable non-nuclear deflection alternatives, it is difficult to believe that NASA defaulted to a one-size-fits-all deflection policy on the merits of the science alone in its original 2006 report. Independent scientists have suggested both in print and in private emails that NASA was pressured to give such a strong endorsement to nuclear deflection at the behest of higher authorities (Rowe, 2008). The commonly cited reason is that nuclear deflection could provide political cover for the development of space weapons.

The military community has a long history of investment in NEO deflection technology with an eye towards military applications, with nuclear asteroid deflection as a particular favorite research area (Mellor, 2007). In 1994, Los Alamos scientist Edward Teller argued that nuclear blasts were a mandatory part of NEO deflection (Morrison & Teller, 1994, pp. 1135-1143). Even today, much of the literature supporting nuclear interceptors comes from either military journals or military personnel writing in scholarly journals. In *Survival,* Mark Bucknam, a deputy director for the Secretary of Defense and a colonel in the United States Air Force, argues, "Only nuclear explosions could deliver enough of a push to achieve the necessary change in velocity" (Bucknam & Gold, 2008). Additionally, in *Air and Space Power*, two officers of the USAF propose that the lead agency in charge of asteroid deflection should be the US Strategic Command (STRATCOM) operating in conjunction with Air Force Space Command (AFSPC). Both of these articles explicitly connect asteroid deflection to military space power. Bucknam and Gold go so far as to suggest that NEO deflection may merit new underground nuclear testing to perfect the devices, a practice that would have obvious military applications. Nor would the United States be the first nation to use the threat of asteroids to develop new weapons systems.

China cited the potential need to test nuclear weapons to deflect an NEO as a justification for its refusal to sign the Comprehensive Nuclear-Test-Ban Treaty (CTBT). The CTBT bans nations from testing nuclear weapons without exception. Members of the Chinese arms control community offered a variety of potential peaceful uses of nuclear weapons that they argued would merit further nuclear testing, like irrigation and creating oil reservoirs. One of the potential peaceful uses of nuclear weapons that received lots of attention was the issue of asteroid deflection, an idea that Chinese scientists at the Institute for Applied Physics and Computational Mathematics had raised recently (Jianshi, 1995; Min, 1995; Tyler, 1996). Many individuals both now and at the time viewed China's concern with asteroids as a delaying technique designed to give them time to conduct additional nuclear tests, which they did prior to signing the CTBT in 1996 (Johnston, 2008; Roy, 1998).

The possibility of military meddling in NEO deflection decisions should cause serious concern. Backdoor efforts to weaponize space or expand nuclear capability through the Trojan Horse of NEO deflection bypass the kind of open public debate that is critical to a well functioning democracy (Mitchell, 2000, 2001). The US military has a history of misrepresenting scientific data and technological capacity to expand weapon systems, such that the population ends up unwittingly supporting government policy that they may not have if the public had access to all the relevant data. Military influence in the selection of the United States' NEO deflection policy raises the possibility that the technologies chosen will be optimized for security interests rather than deflection capability. Compromising deflection science in favor of short-term military or geopolitical gains potentially increases the risk of a failed deflection attempt and a subsequent NEO strike.

Even absent direct military influence on NEO policy, too heavy reliance on the nuclear option can raise the *appearance* of weaponization. This alone has the potential to create diplomatic problems for the United States. For example, the National Research

Council Report (2010) indicates the government could reduce the time necessary to launch a nuclear deflection mission by 100-fold if it developed an extraterrestrial fuse mechanism, a new container cylinder, and made plans to integrate the nuclear device with the booster rocket (p. 81). Other nations could easily interpret the development of space-capable nuclear-armed rockets as threatening. Russian mistrust and anger over plans to build a ballistic missile defense system, despite repeated efforts by the US to calm their fears, demonstrates the perils of building up technology with military applications (Glaser & Fetter, 2001; Handler, 2003; Mankoff, 2012). The clandestine manner with which the US government treats its nuclear capabilities could shroud nuclear deflection in a veil of secrecy that would make it even more difficult to allay the fears of other nations.

Conclusion

The United States has taken some recent steps to better prepare itself for the possibility of a threatening NEO. The NASA Advisory Council's Ad-Hoc Task Force on Planetary Defense, which met July 8-9, 2010, recommended that NASA organize for effective action on planetary defense, acquire essential search, track, and warning capabilities, investigate the nature of the impact threat, prepare to respond to impact threats, and lead US planetary defense efforts in national and international forums (David, 2010). In response to these recommendations and other information, John Holdren, the director of the White House Office of Science and Technology Policy (OSTP), sent letters to Congressional committee leaders on October 15, 2010 indicating that NASA would play a leading role in preventing a dangerous asteroid impact (Reich, 2010, October 21). In addition to this role, the letters requested a tripling of NASA's budget to detect near-Earth objects and required NASA to inform other agencies if a NEO posing a threat was discovered. The US, however, has failed to clearly articulate a policy for how it would deflect a threatening NEO.

On April 20, 2010, the Union of Concerned Scientists helped facilitate a conference call entitled "The Next Generation Speaks: Briefing and Discussion on Key US Nuclear Weapons Policy Initiatives," which involved a question and answer period with Ben Rhodes, President Obama's Deputy National Security Advisor for Strategic Communication and the principal author of the Obama administration's first formal national security strategy (Sanger & Baker, 2010). This article's lead author participated in the conference call and asked Mr. Rhodes:

> Is it currently the policy of the Obama administration to use nuclear weapons to deflect asteroids, and if so, under what circumstances? And the second part is if there are circumstances, how does a long term commitment to nuclear asteroid deflection square with the Obama administration's "global zero" aspirations? (Union of Concerned Scientists, 2010)

Mr. Rhodes replied that he was not "entirely familiar with [the] stated policies" concerning NEO deflection (Union of Concerned Scientists, 2010). While he mentioned that the Nuclear Posture Review is focused "on nations," he hypothesized that the administration might favor conventional technologies to perform the same role as nuclear technologies, as that is in line with the development of conventional weapons to replace the nuclear deterrent (Union of Concerned Scientists, 2010). Sean Meyer, on behalf of the Union of Concerned Scientists, offered to act as an intermediary to provide a follow-up answer pending Mr. Rhodes looking into the matter. Unfortunately, the follow-up is still pending at the time of this paper's final submission. The opacity of deflection procedure means that the United States may very well maintain a plan to use nuclear weapons against any NEO threat, with all the inherent dangers of that policy. This possibility gains credence from the fact that the government has made no visible efforts to expand development of conventional deflection technologies.

If an administration that has claimed the goal of a nuclear weapons free world refuses to commit to a last resort nuclear deflection strategy, it portends poorly for the policy. As the NRC report articulates, nuclear deflection has many advantages over conventional deflection in certain circumstances, but relying solely on nuclear deflection raises a host of technical and diplomatic problems. The Obama administration may feel it can safely put the NEO deflection question on the back burner to deal with more important issues, but an NEO threat can emerge at any time. The long timeframe to refine deflection techniques and build an institutional framework for cooperation means that decisions made now will play a major role in delimiting the possible policy responses to a threatening NEO, if and when one emerges.

References

Abbott, D.H., Biscaye, P., Cole-Dai, J., & Breger, D. (2008). *Magnetite and silicate spherules from the GISP2 core at the 536 A.D. horizon*. EOS Transactions. Paper presented at the American Geophysical Union. Fall Meeting Supplement. Abstract PP41B-1454.

Agle, D. (2003). NASA scientist use radar to detect asteroid force. NASA Jet Propulsion Laboratory Press Release #2003-163. December 5. Retrieved from http://www.jpl.nasa.gov/releases/2003/163.cfm

A'Hearn, M.F., Belton, M.J.S., Delamere, W.A., Kissel, J., Klaasen, K.P., McFadden, L.A., et al. (2005). Deep impact: Excavating comet Tempel 1. *Science, 310*(5746): 258-264.

Aherns, T.J., & Harris, A.W. (1992). Deflection and fragmentation of near-Earth asteroids. *Nature, 360*(6403): 429-433.

Ailor, W., Barrera, M., Bekey, I., Belton, M., Byrnes, D., Burrows, W.E., et al. (2004). Summarizing findings and recommendations from the 2004 Planetary Defense Conference: Protecting Earth from asteroids [White Paper]. *Planetary Defense Conference*. Washington, DC March 5-8. Retrieved from http://www.planetarydefense.info/

Armageddon 2036: Russian scientists say no. (2009). *RT.* December 31. Retrieved from http://rt.com/Top_News/2009-12-31/armageddon-2036-russian-scientists.html?fullstory

Barry, E. (2009). Russia to plan deflection of asteroid from Earth*. The New York Times*, December 31, p. A6.

Baillie, M. (2007). Tree-rings Indicate global environmental downturns that could have been caused by comet debris. In P.T. Bobrowsky & H. Rickman (Eds.), *Comet/Asteroid Impacts and Human Society* (pp. 105-122). New York: Springer.

Bekey, I. (2007). Very short reaction time, low Delta V, non-nuclear mitigation of some NEOs: A case study. Paper presented at the Planetary Defense Conference. March 5-8. Washington, DC

Bekey, I., ed. (2009). *Dealing with the threat to Earth from asteroids and comets*. International Academy of Astronautics position paper. Retrieved from http://iaaweb.org/iaa/Scientific Activity/Study Groups/SG Commission 3/sg35/sg35finalreport.pdf

Binzel, R.P., Chapman, C.R., Johnson, L.N., Jones, T.D., Schweickart, R.L., et al. (2010). Report of the NASA advisory council ad hoc task force on planetary defense. Retrieved from http://www.nasa.gov/pdf/490945main_10-10_TFPD.pdf

Blakeslee, S., (2006, November 14). Ancient crash, epic wave. *The New York Times*. Retrieved from http://www.nytimes.com/2006/11/14/science/14WAVE.html?_r=1&pagewanted=all

Boslough, M., & Crawford, D. (2008). Low-altitude airbursts and the impact threat. *International Journal of Impact Engineering, 35*(12): 1441–1448.

Britt, R.R. (2002). Asteroid might hit Earth in 2880, unless it is painted. Space.com.

Bucknam, M., & Gold, R. (2008). Asteroid threat? The problem of planetary defence. *Survival, 50*(5), 141-156.

Chapman, C, & Davis, D.R. (1992). Near-Earth asteroids: Observer alert network and physical observations. US Department of Commerce National Technical Information Service. Retrieved from http://www.ntis.gov/search/product.aspx?ABBR=N9326699

Chapman, C. (2003, March 3). Great impact debates: Collision course for Earth. *AstroBiology Magazine*. Retrieved from http://www.astrobio.net/debate/389/collision-course-for-earth

Chapman, C. (2007). Critique of "2006 near-Earth object survey and deflection study: Final report." Retrieved from http://www.boulder.swri.edu/clark/frep7crt.doc

Chobotov, V., & Melamed, N. (2007). Deflection of near Earth objects by means of tethers. Paper presented at the Planetary Defense Conference. March 5-8. Washington, DC. Retrieved from https://aeroweb.aero.org/p_dir/propaprscat.nsf/50ad1a0d8e59c75a882570d50066361a/f3b090eaeab69dc48825730500661ba4?OpenDocument

Claybaugh, B., Mulville, D., Shaw, M., Johnson, L., Barker, E., Yeomans, D., et al. (2006). 2006 Near-Earth Object Survey and Deflection Study. Washington, DC: National Aeronautics and Space Administration. Retrieved from http://www.hq.nasa.gov/pao/FOIA/NEO_Analysis_Doc.pdf

Coppinger, R. (2007, August 3). NASA plans 'Armageddon' spacecraft to blast asteroid. *Flight International*. Retrieved from http://www.flightglobal.com/articles/2007/08/03/215924/nasa-plans-armageddon-spacecraft-to-blast-asteroid.html

Coyle, P.E. (2006). The limits and liabilities of missile defense. *Current History, 105,* 391.

Dachwald, Kahle, R. & Wie. B. (2007). Head-on imapct deflection of NEAs: A case study of 99942 Apophis. Paper presented at the Planetary Defense Conference. March 5-8. Washington, DC Retrieved from http://www.dachwald.de/paper/200703_Washington_DachwaldKahleWie.pdf

David, L. (2010, July 26). NASA panel calls for asteroid defense office. Space.com. Retrieved from http://www.space.com/news/nasa-asteroid-impact-near-earth-objects-planetary-defense-100726.html

David, L. (2010, October 19). Planetary defense office proposed to fight asteroids. Space.com. Retrieved from http://www.space.com/news/nasa-planetary-defense-fights-asteroids-101019.html

Easterbrook, G. (2008). The sky is falling. *The Atlantic*. Retrieved from http://www.theatlantic.com/magazine/archive/2008/06/the-sky-is-falling/6807/

European Space Agency. (2009). Don Quijote concept. *NEO Space Mission Preparation*. Retrieved from http://www.esa.int/SPECIALS/NEO/SEMZRZNVGJE_0.html

France, M. (2000). Planetary defense: Eliminating the giggle factor. *Air & Space Power Journal, Chronicles Online Journal*. Retrieved from http://www.airpower.maxwell.af.mil/airchronicles/cc/france2.html

Friedman, G., Gertsch, R.E., Lewis, J.S., Snively, L., Valentine, L., & Wingo, D. (2004). Mass drivers for planetary defense. Presentation at the Planeary Defense Conference. February 23-26. Orange County, CA. Retrieved from http://arc.aiaa.org/doi/abs/10.2514/6.2004-1450

Garver, J.W. (2001). *Protracted contest: Sino-Indian rivalry in the twentieth century*. Seattle: University of Washington Press.

Gerrard, M., & Barber, A. (1997). Asteroids and comets: US and international law and the lowest-probability, highest consequence risk. *New York University Environmental Law Journal, 6*(1): 1-49.

Glaser, C.L., & Fetter, S. (2001). National missile defense and the future of US nuclear weapons policy. *International Security, 26*(1), 40-92.

Graham, B. (2002, April 11). Nuclear-tipped interceptors studied. *Washington Post*.

Graham, T., & Schweickart, R.L. (2008, February 18). NASA's flimsy argument for nuclear weapons. *Scientific American*. Retrieved from http://www.scientificamerican.com/article.cfm?id=nasas-flimsy-argument-for-nuclear-weapons

Gray, R. (2009). Scientists design spacecraft to save Earth. *Telegraph.co.uk*. Retrieved from http://www.telegraph.co.uk/science/space/6110022/Scientists-design-spacecraft-to-save-Earth.html

Greczyn, W.G. & Chichka, D.F. (2007). Opportunities for deflection of asteroid threats. Proceedings of the 2007 Planetary Defense Conference, Washington, DC, March 5-8. Retrieved from http://www.aero.org/conferences/planetarydefense/2007papers/P3-7--Greczyn-Paper.pdf

Handler, J. (2003). National missile defense, proliferation, arms control, Russia, and the United States. Liechtenstein Institute on Self Determination paper.

Retrieved from http://www.princeton.edu/~lisd/publications/wp_russiaseries.html

Harris, A.W., Canavan, G.H., Sagan, C., & Ostro, S.J. (1994). The deflection dilemma: Use vs. misuse of technologies for avoiding interplanetary hazards. In T. Gehrels (Eds.), *Hazards Due to Asteroids and Comets* (pp. 1154–56). Tucson: University of Arizona Press.

Hecht, J. (2007, May 21). NASA analysis of asteroid risk deeply flawed, critics say. *New Scientist*. Retrieved from http://www.newscientist.com/article/dn11901-nasa-analysis-of-asteroid-risk-deeply-flawed-critics-say.htm

Holsapple, K.A. (2002). The deflection of menacing rubble pile asteroids. *Workshop, Scientific Requirements for Mitigation of Hazardous Comets and Asteroids*. Retrieved from http://keith.aa.washington.edu/papers/mitigation.pdf

Jianshi, Z. (1995). Nuclear explosion for preventing collision between Earth and celestial bodies. In Program on Science and National Security Studies (Ed.), *Arms Control: Collected Works*. Beijing: Institute of Applied Physics and Computational Mathematics.

Johnston, A.I. (2008). *Social States: China in International Institutions, 1980-2000*. Princeton, NJ: Princeton University Press.

Koenig, J.D., & Chyba, C.F. (2007). Impact deflection of potentially hazardous Asteroids Using Current Launch Vehicles. *Science and Global Security, 15*, 57-83.

Kraig, M., & Roston, M. (2002, May 1). Nuclear-tipped foolishness. *Foreign Policy in Focus*. Retrieved from http://www.fpif.org/articles/nuclear-tipped_foolishness

Kunich, J. (1997). Planetary defense: The legality of global survival. *The Air Force Law Review, 41*, 119-160.

Lu, E.T., & Love, S.G. (2005). Gravitational tractor for towing asteroids. *Nature, 438*, 177-178.

MacCracken, M.C. (2007). The climatic effects of asteroid and comet impacts: Consequences for an increasingly interconnected society. In H.R. Peter & T. Bobrowsky (Eds.), *Comet/asteroid impacts and human society: an interdisciplinary approach* (pp. 277-289). New York: Springer.

Mankoff, J. (2012). The politics of US missile defence cooperation with Europe and Russia. *International Affairs, 88*(2), 329-347.

Marusek, J. (2007). Comet and asteroid threat impact analysis. *American Institute of Aeronautics and Astronautics*. Retrieved from http://www.aero.org/conferences/planetarydefense/2007papers/P4-3--Marusek-Paper.pdf

Mellor, F. (2007). Colliding worlds: Asteroid research and the legitimization of war in space. *Social Studies of Science, 37*(4), 499-531.

Min, L. (1995). Utilizing the nuclear warheads in a peaceful method. In Program on Science and National Security Studies (Ed.), *Arms Control: Collected Works*. Beijing: Institute of Applied Physics and Computational Mathematics.

Mitchell, G.R. (2000). *Strategic deception: rhetoric, science, and politics in missile defense advocacy*. East Lansing: Michigan State University Press.

Mitchell, G.R. (2001). Japan-US missile defense collaboration: Rhetorically delicious, deceptively dangerous. *Fletcher Forum of World Affairs 25*(1), 85-108.

Morrison, D. (2001). Goal of the spaceguard survey. *Asteroid and Comet Impact Hazards*. April 30. Retrieved from http://impact.arc.nasa.gov/news_detail.cfm?ID=24

Morrison, D., & Teller, E. (1994). The impact hazard: Issues for the future. In T. Gehrels (Ed.), *Hazards due to Comets and Asteroids* (pp. 1135-1144). Tucson, AZ: University of Arizona Press.

National Research Council. (2010). *Defending planet Earth: Near-earth object surveys and hazard mitigation strategies: Final report*. Washington, DC: National Academies Press.

Near-Earth objects (NEOs): Status of the survey program and review of NASA's 2007 report to Congress. (2007). Hearing before the Subcommittee on Space and Aeronautics, Committee on Science and Technology, House of Representatives, 110th Cong. November 8.

Near Earth objects (NEOs): Hearings before the Subcommittee on Science, Technology and Space of the Senate Commerce Committee, 108th Cong. (2004) (testimony of Dr. Ed Lu).

Nemchinov, W., Shuvalov, V., & Svetsov, V. (2008). Main factors of hazards due to comets and asteroids. In V. Adushkin & I. Nemchinov (Eds.), *Catastrophic Events Caused by Cosmic Objects* (pp. 1-89). New York: Springer.

O'Leary, B. (1977). Mass driver retrieval of Earth-approaching asteroids. In J. Grey (Ed.), *Proceedings of the Third Princeton/AIAA Conference Conference on Space Manufacturing Faciltiies.* New York: American Institute of Aeronautics and Astronautics.

Peiser, B. (2003, March 3). Great impact debates: Collision course for Earth. *AstroBiology Magazine*. Retrieved from http://www.astrobio.net/debate/389/collision-course-for-earth

Preston, B., Johnson, D.J., Edwards, S.J.A., Miller, M., & Shipbaugh, C. (2002). *Space weapons: Earth wars*: Santa Monica, CA: RAND Corporation.

Rathke, A. & Izzo, D. (2007). Keplerian consquesences of an impact on an asteroid and their relevance for a deflection demonstration mission. In G.B. Valsecchi, D. Vokrouhlicky, & A. Milani (Eds.), *Near Earth Objects, Our Celestial Neighbors: Opportunity and Risk Proceedings of IAU Symposium 236* (pp. 417-426). Cambridge: Cambridge University Press.

Reich, E.S. (2010, October 21). NASA to lead global asteroid response. *Scientific American.* Retrieved from http://www.scientificamerican.com/article.cfm?id=nasa-to-lead-global-asteroid-r

Rowe, A. (2008, July 27). Nukes are not the best way to stop an asteroid. *Wired*. Retrieved from http://www.wired.com/wiredscience/2008/07/nukes-are-not-t/

Roy, D. (1998). *China's foreign relations*. Lanham, MD: Rowman & Littlefield.

Sagan, C., & Ostro, S. J. (1994). Dangers of asteroid deflection. *Nature, 368*, 501.

Sanger, D., & Baker, P. (2010, May 27). New US strategy focuses on managing threats. *The New York Times*. Retrieved from http://www.nytimes.com/2010/05/28/world/28strategy.html

Rusek, B. (2008). The Outer Space Treaty at a glance. *Arms Control Association*. Retrieved from http://www.armscontrol.org/factsheets/outerspace

Schweickart, R. (2004). *Asteroid deflection: Hopes and fears*. Paper presented at the World Federation of Scientists Workshop on Planetary Emergencies. Erice, Sicily. August 4. Retrieved from http://www.taralynkelly.com/b612/wp-content/uploads/2011/08/Asteroid_Deflection.pdf

Schweickart, R., Chapman, C., Durda, D., & Hut, P. (2006). Threat mitigation: The gravity tractor [White Paper]. NASA NEO Workshop. Vail, Colorado, June 26-28. Retrieved from http://arxiv.org/abs/physics/0608157

Shiga, D. (2009, March 25). How to save the world from an asteroid impact. *New Scientist*. Retrieved from http://www.newscientist.com/article/mg20127015.600-how-to-save-the-world-from-an-asteroid-impact.html

Spitale, J.N. (2002). Asteroid hazard mitigation using the Yarkovsky effect. *Science, 296,* 77. Retrieved from http://www.sciencemag.org/content/296/5565/77.citation

Stein, J. (2008, May 16). The end might be nearer than you think. *CQ Politics*.

Tyler, P.E. (1996, April 27). Chinese seek atom option to fend off asteroids. *The New York Times*. Retrieved from http://www.nytimes.com/1996/04/27/world/chinese-seek-atom-option-to-fend-off-asteroids.html?pagewanted=all&src=pm

Union of Concerned Scientists. (2010). The next generation speaks: Briefing and discussion on key US nuclear weapons policy Initiatives. Conference call with US Deputy National Security Advisor Ben Rhodes. April 20.

Union of Concerned Scientists. (2004). International legal agreements relevant to space weapons. Retrieved from http://www.ucsusa.org/nuclear_weapons_and_global_security/space_weapons/policy_issues/international-legal.html

Vasile, M. (2009). A multi-mirror solution for the deflection of dangerous NEOs. *Communications in Nonlinear Science and Numerical Simulation, 14*(12), 4139-4152.

Villard, R. (2009). Ignoring a clear and present danger. Discovery.com weblog. Retrieved from http://blogs.discovery.com/cosmic_ray/2009/08/ignoring-a-clear-and-present-danger.html

Weisman, J. (2010, April 9). After arms pact, a push to ratify. *Wall Street Journal*. Retrieved from http://online.wsj.com/article/SB1000142405270230419800457517120322383 0386.html

Worden, S.P. (2002). Statement of Brigadier General Simon P. Worden, USAF, before the Committee on Science, United States House of Representatives, Oct. 3. Retrieved from http://impact.arc.nasa.gov/gov_threat_2002.cfm

Yeomans, D., Chodas, P., & Chesley, S. (2009). Asteroid Impactor reported over Indonesia. *NASA Near Earth Object Program*. October 23. Retrieved from http://neo.jpl.nasa.gov/news/news165.html

Contact

Address correspondence to Joseph Packer: joepacker at gmail dot com.