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THE POLITICS AND PROCESS OF PLANETARY DEFENSE

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ABSTRACT

The potentially severe consequences of an impact by a Near Earth Object (NEO) require proactive planning for action. Significant events are indeed far between, which has led to a perceived lack of immediate urgency. Although a damaging event tomorrow morning is unlikely, should one occur, it would change life locally, regionally, and beyond. Both likelihood and magnitude determine the risk. As such, deciding how to respond depends on the physical and temporal parameters of the scenario, as well as the state of preparedness maintained locally and globally at the time. Therefore, a decision process that begins well in advance of a hypothetical event will greatly assist and inform real time decisions. The likelihood of impact, the impact corridor, how extensive the damage could be, the mitigation capacity in place, the resources needed for developing such capacity, the size of the mitigation campaign, the global coordination necessary, and what information civil response organizations need to fulfill their respective tasks, are all aspects of the situation a decision maker will need to know at the onset of a threat.

This paper addresses some of these questions and describes a dialog between the decision maker and the technologist for the 2017 International Academy of Astronautics (IAA) Planetary Defense Conference hypothetical asteroid impact scenario. Specifically, the existence of deflection systems at the onset of a crisis versus the lack thereof as two possible states of readiness. Equally important is the debate on whether to launch deflectors early, when the impact uncertainty is high, or to wait for more information at the risk of losing some mitigation options, including the option of sending reconnaissance spacecraft to survey the object before, during and after its deflection. This study produces insights and recommendations concerning the NEO decision process and timing aimed at reducing the NEO threat. Preventing inadvertent shift of risk to other locations, and minimizing risk to life and property, are the goals of the mitigation process. The immediate ability to respond to an evolving threat reduces required resources, and significantly lowers the risk of impact as well as ground damage in the event that complete deflection or destruction of the NEO is impossible. This study recommends that, since proactive decisions regarding mitigation capability development have the capacity to considerably reduce the NEO hazard, such steps are absolutely necessary to assure international safety.

The opinions expressed in this paper are solely those of the authors and do not represent the opinions of their employers.

INTRODUCTION

The basic outline for the handling of an asteroid threat exists, with steps set out for decision makers as far back as the early 2000's[1,2,3]. What the authors of this report wish to bring to the equation is a new perspective from within the decision making process aimed at improving the chances of success of a planetary-defense mission, as well as limiting the cost of a deflection or destruction mission.

As in all asteroid threats, the first step is always recognition and analysis. The first aspect will allow communities at risk to raise awareness within their respective borders and coordinate local preparations and cooperative activities. This is especially important within the parameters of any threat whose potential impact location runs through nations incapable of mounting significant redirection/destruction efforts. This remains a likely condition considering that, as of the time of this paper's writing, of the 193 recognized United Nations member nations, only ten countries have developed the capacity to launch satellites into space[4,5]. Of those same ten, only five nations (the United States of America, Russian Federation, Republic of India, State of Japan and the People's Republic of China) and one supranational organization (the European Space Agency) have the capability to conduct interplanetary scale launches. Thus, at the bare minimum, assuming that the listed nations can singlehandedly complete preventative efforts against an asteroid threat against them alone, nearly 190 recognized countries still remain entirely incapable of self-defense. Thus international cooperation remains a fundamental aspect of Planetary Defense.

Recognizing that the planetary threat does not realistically operate under optimal circumstances, the most effective early-phase measure the international community can undertake at this present time is to ensure the crisis is not handled in a segregated fashion. A vital component in limiting the cost and risk of failure is spreading the effort between a maximum number of willing contributors. Implementing a policy of planetary defense as a global effort allows the application of technological, economic, intellectual, and political resources of as many nations as possible to support terrestrial safety. Creating a unified international front that passively monitors threats over the day-to-day process, and can be activated to handle active threats upon detection by a constituent member, would greatly enhance our flexibility in handling a greater variety of NEO threats.

Recommendations: As depicted by the "WORLD OF 2020 AND ALTERNATE FUTURES", present-day predictions of future scenarios are invariably inaccurate due to the magnitude of variables involved[6]. Therefore, the best option for the international community is to take proactive measures that benefit our planetary defense capabilities. Thus any minimization of reaction time, research/development of non-preexisting technology, and construction of necessary infrastructure is invaluable in planetary defense efforts. Likewise, retaining a deflection and delivery system at the onset of a threat would similarly lower the response-period, and therefore the overall risk. Because certainty of impact is low at the beginning of threat detection and analysis, the preexistence of necessary infrastructure provides greater maneuverability throughout the preparation. Advance planning increase options, ready physical components, limit supplementary construction time, and allow political ties set in place pre-crisis ensure the greatest efficiency of the program, regardless of scale.

Creating a unified non-political organization specifically aimed at global protection from NEOs could greatly decrease the amount of bureaucracy and differences between existing but separate measures set in place by individual nations. In a crisis where the potential cost is so high and time remains a vital factor in potentially preserving our species and society as a whole, unity and coherence in response is not only desirable but essential to optimizing planetary defense efforts. Coordinated communication and action would help reduce misinterpretation and negate the state of panic that might be triggered by uninformed public at the onset of the crisis when uncertainty is high and misinformation prevails.

There are, however, factors that must be considered in order for an effective membership to form. Many countries currently lacking space-capable infrastructure are unable to afford such institutions due to incomplete socioeconomic development, technological advancement, political will, or even practical requirement. However, since the NEO threat does not distinguish between political boundaries, a significant number of nations remain at risk no matter the magnitude of the hazard. Therefore, membership among such nations is pursuant to their security, but still requires compensation for the additional burden of their protection. As such, these countries are still capable of providing materials, funds, facilities, and specialists to the aforementioned agency. On the other hand, membership could likewise be solicited to low-risk nations based on the future possibility of a threat to their territory.

Belonging to such a collection of nations will benefit non-space-faring member states by advancing their technological capabilities, both allowing greater future contribution to exoatmospheric endeavors and creating practical technologies. Past orbital experiments have produced now-everyday discoveries such as freeze-dried food, solar cells, and temper foam[7]. Future research and development in the field of planetary defense could likewise produce similarly useful advances in aerospace equipment and other comparable technologies. With the rise of private interests in stellar resources, participation in planetary defense could open numerous states to greater economic development and contribute to global stability.

Factored into the incentive to proactively construct mitigation capability by multiple countries is the variability in economic and social conditions between nations having an advanced aerospace industry and those that don’t. All nations risk the threat of widespread impact damage, regardless of socioeconomic-political status. Hence, a country’s early investment in globally coordinated mitigation capability development acquires assurance of its future protection from the NEO threat by reducing the overall global risk of impact, as well as improving its ability to respond to a specific partial or failed deflection.

Also of notable capability for contribution are domestic organizations, both governmental and private. The United States Air Force has traditionally fulfilled the role of aerospace defense for the United States, and therefore logically would fill a niche role in the American component. The Air Force already maintains advanced orbital assets and retains invaluable experience and equipment in this field. And the branch could stand to further improve those resources through the knowledge gained from a successful NEO impact prevention by applying technological and physical discoveries made in the process.

The Obama Administration has expressed interest in experimental space missions involving asteroids, most notably the Asteroid Redirect Mission (ARM), as well as its variant, the Asteroid Redirect Robotic Mission(s) (ARRM)[10]. Also similarly notable is the PDC15-presented proposal of a joint NASA-ESA mission, the "Asteroid Impact and Deflection Assessment" (AIDA)[11], which would exemplify a kinetic deflection and allow analysis of direct physical force projection's merits and weaknesses as a planetary defense method. These various missions demonstrate key elements of planetary defense, including reaching asteroids and manipulating them, and have been stated to have the potential to valuably demonstrate and advance planetary defense capabilities[12]. A review suggested that survey data by the ARM/ARRM mission(s) would provide much needed information on the characteristics and situational qualities of threatening bodies[13]. An ARM/ARRM mission could serve as a precursor to a real NEO threat deflection, and demonstrate the current capabilities of available protective assets and identify desired improvements. The fact remains that no asteroid redirect mission has been undertaken in the past, and as such, missions like ARM/ARRM are strongly advisable as they are the closest comparable endeavor that could simulate the principles of a hypothetical deflection mission and advance the capability to execute one with precision. Likewise, the proposed NASA/ESA AIDA mission to deflect the moon of an asteroid and test the high energy kinetic impact asteroid deflection method could prove invaluable in improving and testing our redirection ability with contemporary designs[11, 12, 13].

The kinetic deflector remains one of the simplest, most affordable, and technologically available proposed methods of asteroid deflection[14], and therefore would be tested in depth by an AIDA mission, when compared to other proposals. Alternatively, survey and post-mission data from a successfully executed NEO deflection would assist in any future ARM/ARRM or AIDA mission or comparable project. Therefore, the goals of these programs, while distinct, benefit from their counterparts. Without predecessor missions, ARM/ARRM and NEO deflection are codependent for practical physical data in this field. Thus a certain synergy should be a goal of planetary defense planners, in which the benefits of planetary defense efforts are maximized, in order to justify the inevitable costs and complications within the program. To make up for the distinct difference in funding between national space programs and other budgetary priorities, a condition that exists among all spacefaring nations, tying the objectives of planetary defense to those of comparable and linked projects is key to building widespread support and producing a dedicated and effective international coalition-backed global protection protocol-infrastructure.

With the increase in domestic interest in privatized involvement in space, involving private enterprises in planetary defense efforts could serve as a boost to commercial expansion. Private sector corporate investment in interplanetary endeavors is needed to further advance technologies and operations applicable to NEO mitigation, and, in turn, greatly improve global security. Likewise, private enterprises have reason to invest in these endeavors, both as a measure toward the material security of their own corporate infrastructure within threatened nations, as well as a commercial opportunity to pursue government funding and contracts for their input. The growth of companies like SpaceX demonstrates the possibility of creating an atmosphere for financial success within the aerospace community. The advances in reusable rocketry (the primary example being the Falcon9 lifter) have shown that such companies can make influential steps needed to make the future of space investments far more feasible financially and materially. Securing the assistance of such private investors, in combination with government resources, would both further the efforts of the planetary defense program itself, and at the same time support the growth of public interest and investment in space.

In the event that the aforementioned suggested international framework is set in place, the following steps can be taken. Passive measures include funding research and development of observatory infrastructure to enhance threat-detection capacity, which are, in fact, ongoing as of the writing of this paper, as well as always improving deflection-delivery vehicles and payloads to optimize probability of deflection. Member nations will contribute proportionally to their current economy and technological advantages.

There are two primary schools of thought on how to undertake a deflection mission[15]. When a threat is detected, dedicated installations will track and analyze the object, determining Earth approach likelihood and trajectory, object size and composition, and other factors. Information sharing is maximized as networks will automatically link decision makers, technical experts and department heads. Launch facilities already set in place can be prepared, depending on how imminent launches are required. Pre-constructed components can be transported for assembly and use. By the first option, the United States retains such a technological, logistical, and subject matter expertise advantage that it could realistically deal with a threat on its own, and thereby avoid risk of spreading that advantage to potential political rivals and sacrificing prestige. A notable concern is that the U.S. sharing its technological advantage with other nations could allow exploitation and misuse in a fashion counterproductive to American or international interests. The challenge of course, is to set up an international global planetary defense entity without compromising the advantages of any one nation. On the other hand, the second option is to pursue international cooperation in primary aspects of planetary defense in the interest of minimizing cost and burden on individual nations. The advantages to this system have been stated, and are believed to counterbalance the possible risks, especially when those potential hazards can be avoided through strict compartmentalization of state-specific private components. Contributions in non-threatening formats, such as logistic and financial, can adequately serve as the necessary support where unwanted dissemination of information is a risk.

PDC17 Simulated NEO Impact Scenario Decisions

The 2017 IAA Planetary Defense Conference (PDC17), held on May 15-19, 2017 in Tokyo, Japan, brings together experts on what is known about asteroids and comets that might threaten impact to our planet, the consequences of such an impact, how such a threat might be mitigated, and the political, policy, and other factors that could affect a decision to take action. Conference attendees participate in a realistic exercise designed to illustrate how an asteroid threat might evolve, and explore the decision-making and disaster mitigation and response challenges characteristic of such an event. The exercise is based on the evolution of a threat posed by a fictional asteroid scenario[16]. The orbit for the central point of the risk corridor for the 2017 PDC object has been loaded into a NASA/JPL NEO Deflection App[17]. This on-line tool allows users to study the velocity change required to deflect 2017 PDC off the Earth, as a function of deflection time.

Within the parameters of the PDC17 exercise, and through application of the NEO Deflection App[17], there are shown to be three launch opportunities over the decade from discovery to projected impact. The three points are, in chronological order, immediately upon discovery, and afterward every approximately 1200-1300 days. At the point immediately following discovery, the asteroid (using the average size given) could be deflected with a single Atlas V lifter-though this estimate may not be precise when min/max size or density is considered, but the benefit of the mission remains in question as the projected impact probability at this time is only one-in-a-hundred at best. Concurrently, the United States government does not retain planetary defense rockets available on short notice, nor kinetic delivery devices needed to deflect the incoming hazard. More likely, the second or third launch windows will be considered if impact odds increase notably. The second launch period, standing at approximately 7.5 years from projected impact, would require greater effort to deflect the approaching object to a statistically adequate miss. The task could be accomplished with either two Atlas V deliveries, or a single Delta IV launch (again, using the single average selected set of parameters). Here, the cost of deflection rises dramatically, possibly even doubling the cost. And finally, at approximately 4 years before impact, there is a launch window in which the asteroid is particularly close to the impact epoch, and therefore requires heavy deflection to reach adequate orbital shift for a miss. Specifically, the options here would be three Atlas V vehicles, two Delta IV launches, or a NASA SLS lifter. Note that at the time of writing the NASA SLS remains in the research and development stage, and as such, relegates the SLS to experimental options until development finishes.

While the first launch period remains unavailable during this scenario, it poses a pair of important issues. In a scenario when launch periods are more limited, possibly to a single time close to discovery, the first launch period may be the only deflection option. Recognizing that if this was the case, the lack of a constantly available interceptor ready at a launch facility is a notable weakness. It should then be noted that working toward a launch earliest to notice should be a goal of future planetary defense strategists. Simplified, an asteroid threat of this type gives a spectrum of options with detractions and positives, with earlier launches as least expensive, but most likely to be wasted on non-threats, and later launches being more expensive, but being executed with more preparation and with a greater certainty of necessity. In preparation for future threats of a similar nature, infrastructure, including lifter rockets and standard kinetic deflection vehicles (once an accepted design is manufactured), should be put into limited production, so that assembly in a time-relevant crisis and early launch can remain a viable launch option, unlike in the PDC17's case.

In most actual NEO threats, impact probability will be negligible after additional measurements are made. In such cases, the need for deflection can possibly vanish after the lifter already launched. The ability to launch early could protect against rare impactors, but would better serve as a demonstration of capability rather than a true hazard deflection if the original redirection mission is aborted. In order to retain the ability to protect while averting at least some of this waste, deflection devices could be designed with secondary objectives in mind that could be activated in the event of an aborted deflection. Secondary objectives could include the finding and characterizing of unknown NEOs, as well as opportunities for space mining, scientific study and commercial goals. Also, instead of multipurpose deflectors, dedicated reconnaissance probes could be launched during this early launch period in order to provide relevant data needed to improve subsequent launches against its subject, or even disproving the need for further launches at all.

The minimum/maximum possible values for the asteroid threat, as well as the required minimum deflection payload lifter requirements are shown below. Foreign lifters, Falcon-9, and other experimental models are not shown. Values for the Falcon-9 and Delta IV Heavy, as modeled in the

NEO Deflection App[17], serve as comparable heavy lifters and can be considered practically interchangeable for the purposes of this physical model.

Table 1. Minimum launch effort needed for min/max PDC17 threat parameters

Porous Rock (100m):

Launch Period (Days from earth impact/ Days from earth launch to NEO interception)	Early: 3750/100	Middle: 2450/375	Late:1250/200
Deflection Requirement	1 Atlas V	1 Atlas V	1 Atlas V

Porous Rock (250m):

Launch Period (Days from earth impact/ Days from earth launch to NEO interception)	Early: 3750/100	Middle: 2450/375	Late:1250/200
Deflection Requirement	1 Atlas V	2 Atlas V, or 1 Delta IV	3 Atlas V, or 2 Delta IV

Dense Rock (100m):

Launch Period (Days from earth impact/ Days from earth launch to NEO interception)	Early: 3750/100	Middle: 2450/375	Late:1250/200
Deflection Requirement	1 Atlas V	1 Atlas V	1 Atlas V

Dense Rock (250m):

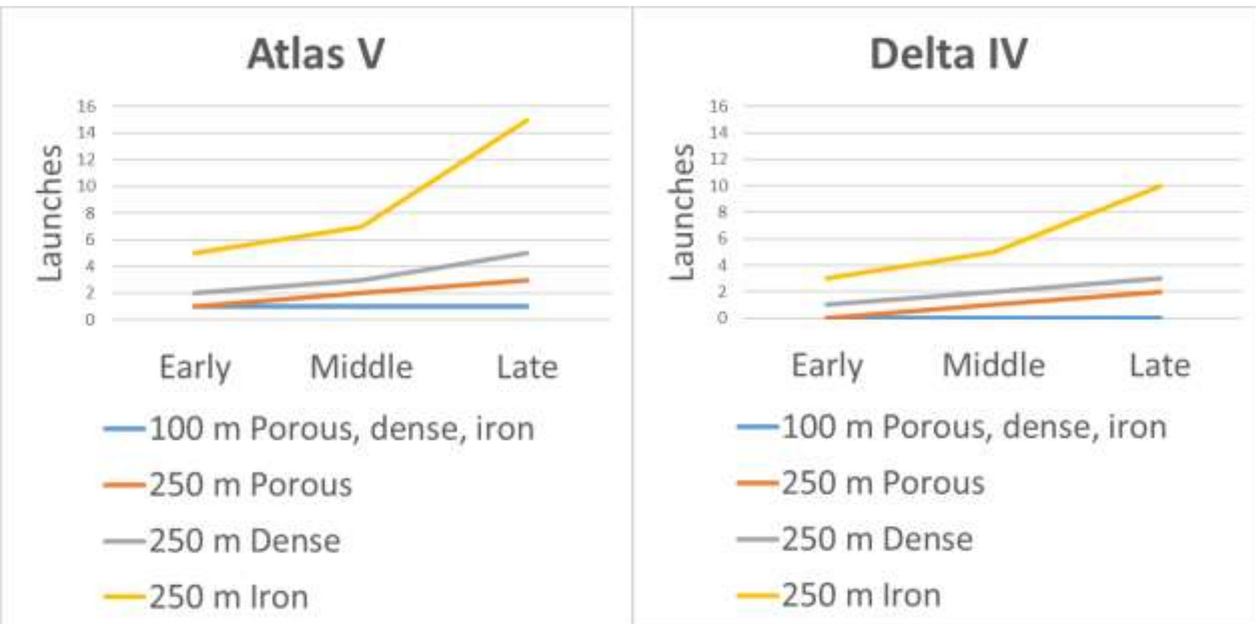
Launch Period (Days from earth impact/ Days from earth launch to NEO interception)	Early: 3750/100	Middle: 2450/375	Late:1250/200
Deflection Requirement	2 Atlas V, or 1 Delta IV	3 Atlas V, or 2 Delta IV	5 Atlas V, or 3 Delta IV, or 1 SLS

Iron (100m):

Launch Period (Days from earth impact/ Days from earth launch to NEO interception)	Early: 3750/100	Middle: 2450/375	Late:1250/200
Deflection Requirement	1 Atlas V	1 Atlas V	1 Atlas V

Iron (250m):

Launch Period (Days from earth impact/ Days from earth launch to NEO interception)	Early: 3750/100	Middle: 2450/375	Late:1250/200
Deflection Requirement	5 Atlas V, or 3 Delta IV	7 Atlas V, or 5 Delta IV, or 1 SLS	15 Atlas V, or 10 Delta IV, or 2 SLS



The above statistical data shows that, within the parameters of the PDC17 scenario, the technology and equipment required to successfully launch a delivery device used to deflect the approaching object exists and includes models that have been both tested and used on numerous missions (with the exception of the NASA SLS), and therefore could be undertaken by the U.S. alone. However, the cost of deflecting larger/denser objects highlights the need to consider alternatives should these attributes be confirmed or considered likely. While technically feasible, the cost of up to fifteen Atlas V or ten Delta IV lifters significantly disadvantages the sustainability of the program, especially when setting an example for future NEO-countering missions. Within the scenario, there are present multiple significant opportunities to lay the foundation for international cooperation here and in future missions. The projected impact corridor of the PDC17 asteroid runs primarily along the Northern Hemisphere and the Eurasian Continents. Recognizing that this puts multiple ESA members, the Russian Federation, the People's Republic of China, the Republic of Korea, and the State of Japan at risk of impact[16], the involvement of these nations could strongly unburden the U.S. of significant technical-financial strain. By calculation of possible impacts, the exact likelihood of atmospheric entry is unknown, while the impact of the asteroid could cause a thermal-kinetic explosion in the multi-megaton range. The possible impact corridor runs across multiple national capitals, including Copenhagen, Beijing, and Tokyo, as well as populated regions in the United Kingdom, Western Russia, and East Asia. Due to this threat, securing the support of these nations would be greatly simplified, and would provide greater flexibility in deflection options. It, however, is to be observed that if such ties or the proposed international network had been in place before PDC17's detection, the analysis/deflection procedure could begin immediately, instead of having to establish these ties only at the onset of a crisis.

In terms of support from nations under threat here, the European Space Agency, Roscosmos State Corporation of Russia, Japanese Aerospace Exploration Agency, and the Chinese National Space Agency all maintain launch capability[5], allowing them to provide lifters for delivery devices, or similarly required resources in service of deflection as probability of impact rises. Governments and militaries around the world dedicate significant funds to the maintenance of detective and countermeasure programs to defend against human-produced threats. Similarly, since the inbound asteroid retains considerable damaging capacity comparable to nuclear weapons, a similar amount of support should be dedicated to handling the threat of PDC17. The argument that the early low-probability of confirmed interception makes such investment unviable can be disproved by the fact that the United States government already takes steps to protect against low-probability crisis, human-based or otherwise, through agencies such as Federal Emergency Management Agency (FEMA) and the Centers for Disease Control (CDC), though imminent natural disasters and pandemics are not commonly probable. Since agencies already exist to handle low-probability/high-consequence threats, comparable protective measures should be developed to include NEOs as a hazard comparable to those already within the jurisdiction of existing agencies.

Now, recognizing that the first launch period is not a feasible option and that the third launch period requires either great expense or international cooperation, if the U.S. hopes to handle this crisis singlehandedly, the clear approach is to conduct necessary research on the NEO and prepare a lifter and a kinetic delivery vehicle for the second launch period. Delta IV launches are commonplace at the time of writing, and the technology used in kinetic deflection is achievable with today's standards. Therefore, a purely American undertaking in deflecting PDC17 in the second launch period is completely possible. However, since the United States is not under direct threat and no clear jurisdiction exists in this field for such a situation, the legality of American involvement is unclear. Instead, to avoid political complications, the United States can cement its involvement by declaring the protection of threatened nations to be within American interests, and offer the state's significant resources in conducting a joint operation. This would be done in coordination with the UN-endorsed Space Mission Planning Advisory Group (SMPAG) and the International Asteroid Warning Network (IWAN) which are independent bodies of the world's national space agencies and offices[18]. Since the projectile does not pose a direct threat to the United States, American involvement here already transcends purely local interest. National investment in a threat to primarily Eurasian nations implicitly suggests an American investment in all asteroid threats, and sets the perception of the situation as either an American global planetary defense role, or alternatively, American support for international cooperation on NEO threats toward fellow nations worldwide. By doing so, an altruistic image can be set in place for future involvement in planetary defense, and promote similar attitudes internationally.

International association does not, however, change the situational physical/technological disadvantages. It does, instead, make a launch during the second period more affordable, and perhaps even more importantly, raises the third period as a realistic option. With the advent of international support, needed equipment like the NASA SLS and comparable lifters can be spread among existing and developing models of multiple participants. Delta IV and comparable heavy lifters remain in use, or are in development by the space programs of the threatened nations, and, along with U.S. development of kinetic deflectors, can be accomplished more quickly and with greater effectiveness.

Conclusion

Inside the situational confines of the PDC17 scenario, the choice falls on what steps can be taken to deflect this example NEO effectively should its threatening nature become apparent. Analytic probes or kinetic deflectors can be launched at the intervals highlighted, and experimental designs can be further developed for possible late-scenario use. But the real decision involves the procedural execution of these steps. As stated previously, the United States can individually deflect the scenario's NEO with modern technology, but the PDC17 scenario must, in the eyes of the writers of this paper, be used to set a precedent for specifically international and unified responses to both this example danger, as well as hypothetical confirmed ones in the future. In PDC17, by developing measures to strengthen international cooperation on handling the fictional asteroid, groundwork can be developed for a real version in the near future for use in real situations.

References

1. Blair R. B., "Decision Model for Potential Asteroid Impacts," Research Paper, EB560 – Decision Analysis, Division of Economics and Business, Colorado School of Mines, http://www.digitalspace.com/projects/neo-mission/docs/Blair_ADM03.pdf
2. Schweickart L. R. et al, "Asteroid Threats: A Call For Global Response," Association of Space Exploders, 25, September 2008, http://www.nss.org/resources/library/planetarydefense/2008-AsteroidThreatsACallForGlobalResponse.pdf
3. Schweickart L. R., "Decision Program On Asteroid Threat Mitigation," Acta Astronautica, Volume 65, Issues 9–10, November–December 2009, Pages 1402–1408, http://www.sciencedirect.com/science/article/pii/S0094576509002161?np=y
4. United Nations, Overview, 16 October, 2016, http://www.un.org/en/sections/about-un/overview/index.html
5. Christensen A. I, Fuller J., "National Space Technology Capability Base Index," AIAA 2010-8884, AIAA SPACE 2010 Conference & Exposition, 30 August - 2 September 2010, Anaheim, California, http://enu.kz/repository/2010/AIAA-2010-8884.pdf
6. "The world of 2020 and Alternative Futures," Defensc Technical Information Center, DTIC-BLS Cameron Station, Alexandria VA 22304-6145, June 1992
7. "NASA spin-off technologies," https://en.wikipedia.org/wiki/NASA_spin-off_technologies

8. U.S. DOD News Transcript, "FY 2017 Air Force Budget Request," 9 Feb 2016, http://www.defense.gov/News/Transcripts/Transcript-View/Article/654828/department-of-defense-press-briefing-by-maj-gen-martin-brig-gen-fienga-and-depu/source/GovDelivery
9. "House bill offers $19.5 billion for NASA in 2017," 17 May 2016, http://spacenews.com/house-bill-offers-19-5-billion-for-nasa-in-2017/
10. "NASA's Asteroid Redirect Mission Completes Robotic Design Milestone," http://www.nasa.gov/feature/nasas-asteroid-redirect-mission-completes-robotic-design-milestone
11. "Asteroid Impact and Deflection Assessment (AIDA) Mission," https://www.nasa.gov/planetarydefense/aida
12. Mazanek D. D., et al., "Asteroid Redirect Mission (ARM) Formulation Assessment and Support Team (FAST) Final Report," NASA/TM–2016-219011, February 2016, https://www.nasa.gov/sites/default/files/atoms/files/nasa-tm-2016-219011-arm-fast-final-report_0.pdf
13. Gates M., "Asteroid Redirect Mission Update," NAC Human Exploration and Operations Committee, July 28, 2015, https://www.nasa.gov/sites/default/files/files/Gates-NAC-HEO-Committee-rev5-TAGGED.pdf
14. Bishop B., "New research explores asteroid deflection using spacecraft to crash into body at high speeds," Lawrence Livermore National Laboratory, 16 February 2016, https://www.llnl.gov/news/new-research-explores-asteroid-deflection-using-spacecraft-crash-body-high-speeds
15. Worden S., "The Threat of Near-Earth Asteroids," Hearing Statement, United States Strategic Command, 3 October 2002, http://www.spaceref.com/news/viewsr.html?pid=6723
16. "The 2017 PDC Hypothetical Asteroid Impact Scenario," http://neo.jpl.nasa.gov/pdc17/
17. "NASA/JPL NEO Deflection App," http://neo.jpl.nasa.gov/nda/
18. "Small Bodies Assessment Group (SBAG) Goals Document – Planetary Defense," Draft version 0.5, 26 June 2015, http://www.lpi.usra.edu/sbag/goals/Goal_II_sbag_pdg_draft0.5.pdf