Nuclear Devices for Planetary Defense

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This paper summarizes the perspectives of panelists participating in the discussion of "Nuclear Devices for Planetary Defense" (PANEL-17) at the AIAA ASCEND conference in November 2020. The panelists' backgrounds, and therefore their individual contributions below, cover the range of relevant disciplines: of course planetary defense threats and missions, but also space systems engineering, nuclear technologies, nuclear deterrence, and last but definitely not least space law. This approach helps illuminate the topic from multiple angles in order to encourage follow-on discussions among the communities of interest.

Nomenclature

DART = *Double Asteroid Redirection Test*
EGT = *Enhanced Gravity Tractor*
GT = *Gravity Tractor*
ICBM = *Intercontinental Ballistic Missile*
KI = *Kinetic Impactor*
NED = *Nuclear Explosive Device*
NEO = *Near-Earth Object*
PHA = *Potentially Hazardous Asteroid*
PHO = *Potentially Hazardous Object*
SLBM = *Submarine-Launched Ballistic Missile*

I. Introduction

The Outer Space Treaty of 1967 currently prohibits any signatory nation from stationing nuclear weapons in outer space, placing them in orbit around the Earth, or installing them on celestial bodies [1]. Furthermore, the Partial Test Ban Treaty of 1963 prohibits detonating nuclear devices in outer space [2]. However, some of the most promising strategies for deflecting or disrupting hazardous asteroids and comets for Planetary Defense purposes require Nuclear

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Explosive Devices (NEDs) ([3], [4], [5]). Such devices can also benefit certain types of space resource utilization and, in the long run, could even enable advanced space transportation and support terraforming efforts ([6], [7]).

Especially for Planetary Defense applications, it would seem critical that end-to-end testing takes place well ahead of a future need, since once an impact threat materializes, nuclear deflection devices must work reliably, even after potentially many years of exposure to the harsh space environment, and must have predictable effects.

Should the current legal regime governing nuclear devices in outer space therefore be modified to allow the major spacefaring nations, who *de facto* carry the responsibility of protecting all of Earth from devastating impacts by asteroids and comets, to conduct this kind of testing, and to use nuclear devices for these kinds of applications? Or are the potential risks to e.g. nuclear stability on Earth too great? Recent publications have illuminated the legal context, for NEDs in particular ([8], [9]) and in the broader context of Planetary Defense [10]. The panel is designed to further the discussion on this important topic.

II. Planetary Defense Missions and Why the "Nuclear Option" May Be Necessary[5]

Nuclear Explosive Devices (NEDs) are one of the three most mature concepts for near-Earth object (NEO) mitigation, the other two being Kinetic Impactors (KIs) and Gravity Tractors (GTs) [17]. Those three concepts, along with some less mature but potentially promising concepts, are currently in various stages of research and development, per the United States National Near-Earth Object Preparedness Strategy and Action Plan [18]. Here we discuss how NEDs may be used for planetary defense missions and describe situations in which the use of NEDs for planetary defense may be necessary or preferred. The analyses and results referenced in the following subsections were based on modeling of existing NEDs and do not assume any new NED development. The lack of need for new NED designs to handle the most probable future NEO threats is an important finding of the work to date on this topic [4]. Another important assumption in this research is that NEDs are provided as needed for launch from Earth and subsequent direct travel to the target NEO. There has been no modeling of pre-positioning NEDs in space or terrestrially, and there are no indications in the current work that in-space pre-positioning of NEDs would offer any improvements in planetary defense mission performance. In fact, for lack of a preferred staging orbit for planetary defense purposes, pre-positioning NEDs in space would likely degrade overall mission performance in terms of trajectory flight times, mass delivered to target, and other performance metrics.

A. NED Deflection or Disruption of NEOs

An NED mitigates the threat posed by an NEO by either deflecting or robustly disrupting[6] the NEO. NED deflection is accomplished by detonating near the NEO's surface, releasing radiation that rapidly vaporizes a thin layer of NEO surface material. The vaporized material blows off due to the surrounding vacuum pressure, imparting a powerful, controlled impulse to the NEO and thus changing its orbit so as to miss the Earth [4]. NEDs also have the unique capability to robustly disrupt NEOs when the situation calls for it, by detonating closer to the NEO and imparting a stronger impulse capable of breaking the NEO apart very forcefully and widely scattering the fragments [13].

NEDs are best deployed after rendezvous[7] with an NEO. That makes it much easier to position the NED at the correct distance from the NEO's surface and along the correct vector through the NEO's center of mass, so as to impart the necessary amount of momentum to the NEO and in the direction that is most effective for deflecting the NEO away from future Earth impact. However, NEO rendezvous is not always practical, particularly for short warning scenarios. In such cases, an NED can be detonated near the NEO during a high-speed intercept. While doable in principle, it is more challenging than NED detonation after rendezvous and requires additional technology development.

B. Combining NEO Reconnaissance and Deflection/Disruption Into a Single Mission

One of the key advantages of an NED is its high energy density, meaning that a relatively low mass NED is capable of imparting a powerful impulse to even relatively large NEOs. As an example, a 1 Mt NED with a mass of

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[5] This section was authored by Brent Barbee.

[6] In this context, "robust" disruption means that none of the remaining fragments poses a significant threat to Earth.

[7] Rendezvous means matching the NEO's position and velocity, such that the spacecraft can remain in close proximity to the NEO thereafter.

approximately 550 kg is capable of imparting a change in velocity of approximately 6.5 to 16.5 cm/s to a ~560 m diameter NEO, depending on the NEO's composition [4]. This is significant because NEO deflection usually requires only one to several cm/s of velocity change, depending on circumstances including warning time, and 550 kg is not a difficult payload mass to deliver to an NEO. By comparison, imparting a velocity change of ~6.7 cm/s to a similar model asteroid using KIs requires a total KI spacecraft mass of 605,900 kg [11], which would certainly be impractical. Finally, it should be noted that the 1 Mt NED results described here are merely for example purposes and 1 Mt is more than would be needed for the most probable future NEO threats.

The low mass of NEDs raises the possibility of equipping an NEO reconnaissance spacecraft with NEDs, so that a single spacecraft can be deployed to reconnoiter a potentially hazardous NEO, characterize the NEO's orbital and physical properties, deploy the NED to deflect or disrupt the NEO if the NEO is indeed found to be a threat to Earth, remain on station with the NEO afterwards to provide information about the outcome of the NED detonation, and provide ongoing monitoring and situational awareness. The ability to perform reconnaissance, mitigation, and in situ monitoring with a single spacecraft would improve operational responsiveness while reducing mission cost and improving the probability of mission success.

A single GT spacecraft could also perform reconnaissance, mitigation, and monitoring functions. However, the force applied to the NEO by a GT comes from gravity due to the small mass of the GT spacecraft [14] and is, therefore, exceedingly small. Thus, many years or decades of GT operation are required to alter the NEO's trajectory enough to avoid Earth impact. That, in turn, requires at least a couple of decades of warning time. The Enhanced Gravity Tractor (EGT) concept addresses some of the GT concept's shortcomings by using mass collected from the NEO in situ to augment the mass of the spacecraft, thereby greatly increasing the gravitational force of the spacecraft on the NEO [16]. This results in the NEO being accelerated more quickly, reducing the total time required for the EGT to deflect the NEO's orbit enough to avert an Earth impact. That, in turn, reduces the warning time required for deployment of the EGT, making it more responsive than the GT. However, the EGT requires the development of complex technologies for efficiently and reliably collecting tens to hundreds of metric tons of material from the NEO's surface and stowing it securely on the EGT spacecraft, which is not currently practical.

C. Handling Uncertainties in NEO Properties

The physical properties of an NEO, particularly its mass, may not be well known prior to the required launch date for the deflection/disruption mission, which would complicate the design and sizing of the spacecraft, particularly in the case of KIs or GTs. However, NEDs offer flexibility to help deal with this situation, because the momentum imparted to an NEO by an NED is a function of the distance from the NEO surface at which the NED is detonated. Thus, an NED with sufficient yield to handle the expected worst-case NEO physical properties can be sent to the NEO, and then the detonation distance can be selected later during the mission, after the NEO's physical properties have been measured by the spacecraft instruments. In this way, the momentum imparted to an NEO by an NED can be tuned by adjusting detonation distance.

It is possible that an NEO can only tolerate up to a certain amount of imparted momentum before it begins to weakly break apart, potentially leaving significant NEO fragments on Earth impact trajectories. One hypothetical concept for avoiding NEO fragmentation involves performing multiple smaller applications of momentum change to the NEO, each of which is below the threshold for fragmentation. Neither the nature of the fragmentation threshold nor the matter of whether multiple smaller momentum applications would indeed avert fragmentation are yet understood, but both are being actively researched. The ability to tune the momentum imparted to the NEO by adjusting NED detonation distance is useful for purposes of avoiding unwanted accidental NEO fragmentation. Additionally, if multiple smaller momentum applications are indeed found to avert fragmentation, that could be readily accomplished by loading multiple smaller NEDs onto the deflection spacecraft.

D. Short Warning Responses and Late Response Efforts

The low mass of a NED means that launch vehicles are capable of delivering NED-equipped spacecraft to NEOs on high energy, short flight time trajectories during late response situations. A late response situation could arise due to either extremely short warning, or a late response may be considered if earlier response attempts failed. In those cases, the spacecraft might be launched only several months before the NEO's Earth impact date and intercept the NEO at high speed only a month or two before Earth impact. With such a short time remaining before Earth impact, the change in NEO velocity required for deflection would likely be unattainable, even with a NED, and would almost certainly disrupt the NEO anyhow. Therefore, the purpose of such a late NEO intercept would be to use the NED to robustly disrupt the NEO.

It is important to note that our current launch infrastructure isn't able to launch on extremely short notice such as a few weeks to a few months. In fact, current launch vehicle procedures tend to require at least a couple of years of preparation, and that is not including the separate preparation of the spacecraft itself (although at least some of that could be done in parallel with launch vehicle preparation). Additionally, issues remain to be studied regarding the evolution of the NEO debris field resulting from disruption and its possible interactions with the Earth-Moon system and the spacecraft assets therein. However, if highly responsive launch becomes possible, and if disrupted NEO debris relatively near Earth-Moon system encounter is found to pose acceptable levels of risk in comparison to not disrupting the NEO for a given scenario, then NEDs provide enough energy density to make such late NEO disruption missions practical.

E. Handling Binary NEOs

It is possible that Earth will be faced with an incoming NEO that is a binary asteroid, consisting of a larger primary body and smaller secondary body that are gravitationally bound together and both orbiting their common center of mass, usually several hundred meters to several kilometers apart. The probability of facing a binary Earth-impacting NEO is not insignificant. Roughly 16% of NEOs larger than 200 m in size are expected to be binary asteroids [15]. Indeed, the target NEO of NASA's Double Asteroid Redirection Test (DART) mission, known as Didymos, is a binary asteroid that is also categorized as a Potentially Hazardous Asteroid (PHA) and will be making a relatively close approach to Earth in early October 2022 [12]. Mitigating the threat posed by an incoming binary NEO requires dealing with both the primary and secondary bodies, which would be difficult to do using KIs or GTs. At a minimum, it would likely require more KI spacecraft, more launch vehicles, more mission complexity and risk, and introduce more potential failure modes for the mission. Even with decades of warning time, GTs would still likely encounter guidance, navigation, and control difficulties when attempting to station-keep in close proximity to a binary asteroid system in a manner that serves to deflect the binary asteroid's center of mass from Earth impact.

NEDs can deal with binary NEOs in a simpler fashion, by detonating a single NED in between the binary NEO's primary and secondary bodies such that the larger primary body is deflected from Earth impact while the smaller secondary body is robustly disrupted, or, when appropriate, such that both bodies are robustly disrupted. Suitable configurations for this approach are likely to be available, but if necessary the binary NEO can still be dealt with straightforwardly by delivering two NEDs instead of one. That may still be accomplished by a single spacecraft, due to the relatively low mass of NEDs. The issues surrounding mitigation of binary NEOs are described in further detail in the proceedings of the 2017 Planetary Defense Conference Hypothetical Asteroid Impact Scenario [19].

F. NEO Deflection Direction: Eastward or Westward

When an Earth-impacting NEO is deflected, the Earth impact location is moved along a line that traces a chord across the Earth's disk at the time of Earth impact, in an eastward/westward direction. Deflecting the NEO eastward requires slowing the NEO down, which requires a KI to be traveling slower than its target NEO at the time of intercept. For a westward deflection, the KI must speed the NEO up and therefore be traveling faster than the NEO at the time of intercept. The NEO's undeflected Earth impact point may be anywhere along the chord. If the Earth impact point is closer to one edge or the other, then deflecting it towards the closer edge will require less momentum to be imparted to the NEO, whereas deflecting the NEO towards the farther edge would require imparting more momentum to the NEO. Imparting more momentum to an NEO requires more spacecraft mass and increases the risk of accidental unwanted fragmentation of the NEO. Additionally, deflecting the NEO in one direction or the other might involve moving the Earth impact location across greater or fewer populous areas in various nations. Therefore, the consequences of a partially successful deflection that only shifts the Earth impact location to a new place may be higher or lower for either the eastward or westward deflection directions.

Thus, because one deflection direction generally requires more NEO momentum change than the other and/or involves more significant consequences for partially successful deflections, it is likely that one of the two deflection directions—eastward or westward—will be strongly preferred. However, it is generally much more difficult, in fact often impractical, for a KI to apply a westward deflection to an NEO. This is because many NEOs occupy appreciably eccentric orbits with semi-major axes larger than that of Earth's orbit. Meanwhile, KIs launch from Earth's nearly circular heliocentric orbit, with limited launch energy that curtails their ability to attain eccentric heliocentric orbits with semi-major axes appreciably larger than their target NEOs. As a consequence, KIs will tend to be travelling at lower heliocentric velocities than NEOs at the time of intercept at NEO perihelion, meaning that KIs are often only able to slow an NEO down rather than speed it up. This means that it will usually only be practical for a KI to deflect its target NEO in the eastward direction.

NEDs, on the other hand, are readily delivered via high-speed intercept or rendezvous to detonation points either ahead of or behind the target NEO. Thus, NEDs are able to deflect an NEO eastward or westward with equal ease. These issues are well described in detail in the proceedings of the 2019 Planetary Defense Conference Hypothetical Asteroid Impact Scenario [20].

III. Technological Uncertainties Regarding Nuclear Devices for Planetary Defense Applications[8]

As outlined in the previous section, the use of nuclear explosive devices for deflecting or disrupting a Potentially Hazardous Object (PHO) has been studied in depth for many years. Practical issues such as handling of NEDs and launch safety considerations for NED-based planetary defense missions have also been discussed [21]. However, these analyses assume that a NED will work as expected, generating the design yield even after spending many months, if not years, in the harsh environment of deep space on its way to the targeted PHO. Environmental conditions in space differ significantly from those on Earth, for which nuclear weapons are primarily designed.

In particular, the space environment exposes payloads to both extreme temperatures (ranging from approximately -100°C to almost 300°C [22]) and extreme temperature swings, unless measures are taken to create a thermally-controlled environment on board the spacecraft. Such temperature cycles can affect payload materials.

Furthermore, beyond Earth orbit, payloads are exposed to cosmic rays and potentially high-energy solar particle events, with observed particle energies above 1 GeV and flux durations of up to several days [23]. The energy spectrum of this deep-space radiation environment is likely different from that for which nuclear weapons are designed, and thus creates the risk of unexpected effects. Another risk is posed by micrometeoroids impacting parts of a NED, necessitating designs with a high degree of redundancy and potentially physical shielding.

Finally, while most nuclear weapons are designed to withstand the high acceleration of an ICBM or SLBM launch, and subsequent near-weightlessness of the coast phase, the exposure to microgravity during a Planetary Defense mission will be significantly longer, which has the potential to affect NED materials and subsystems.

IV. Implications for Terrestrial Deterrence[9]

While theoretically feasible and perhaps the best technical approach, placing multiple nuclear weapons in space should be considered with extreme caution; the "cure" may well be worse than the disease[10]. The potential political repercussions could be highly destabilizing, given the security implications entailed with testing and placing nuclear weapons in space. There is a reason that the Limited Test Ban Treaty specifically excludes "any nuclear explosions in space", irrespective of the purpose [26]. Even in 1963, states were worried about the Cold War expanding into space and that states might attempt to claim the "ultimate high ground" for military purposes ([27], [28]).

Particularly in the absence of a known threat, placing a nuclear device in space—whether for testing or as a fully capable system—has the potential to create an intense security dilemma. A security dilemma arises when State A increases its military capabilities to increase its own security. Even if purely defensive, these actions can have a negative effect on State B's perception of its security, as State B is prone to interpret State A's action as an indication that it has aggressive intentions. State B thus also increases its arms, and the two engage in an action-reaction cycle of arming that leaves both states worse off [29].

Employing a nuclear device for planetary defense has the potential to create such a dilemma for two key reasons. First, the test data could be used for military purposes to better understand blast and shock effects in space. Such information could be used, for example, to improve national missile defense capabilities or antisatellite capabilities, both of which could be leveraged to facilitate a more effective first-strike attack [30]. Analyses to date—in collaboration with the National Nuclear Security Administration's (NNSA's) national laboratories—have assumed and validated the use of only existing nuclear devices through modeling and simulation. Yet, in the event that an NED program is approved for development, it seems possible that policymakers and the laboratories will have to consider whether a literally existential mission should be undertaken by a purpose-designed device. It should be noted that the

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[8] This section was authored by Jan Osburg.

[9] This section was authored by Alexis Blanc.

[10] For the technical feasibility of such an approach, see e.g., [4]. For the counterargument that nuclear weapons may not provide the best technical approach, given the porosity of some Near-Earth Objects (NEOs) and the potential for nuclear weapons to increase the destructive risks from debris, see e.g. [24] and [25].

most probable future NEO threats are far more numerous, smaller NEOs, which are not capable of causing extinction-level events. Yet, while much less likely to occur, a scenario involving an NEO large enough to imperil our species would raise the stakes to an unprecedented level and could necessitate extreme measures. Nuclear devices must work reliably, even after potentially many years of exposure to the harsh space environment and must have predictable effects. Additionally, their overall performance requirements would be higher when facing an NEO large enough to pose an existential threat. Thus, it is possible that a decision could be made to design and build a device specifically tailored to an existential mission. Such a device would be designed to precisely direct the energy from the explosion [31]. This information could be used by militaries to improve capabilities to destroy hard and deeply buried targets. These kinds of targets are often the locations for leadership in a time of crisis, to allow for assured command and control, or the location of survivable retaliatory forces. The ability to destroy both thus presents the risk of a decapitation strike. In both of these scenarios, the stability of deterrence is undermined because a state's confidence its ability to detect an attack and its ability to retaliate, are called into question[11].

Pursuing this kind of solution may also increase the risk of horizontal and vertical proliferation. Normative arguments aside about whether a return to testing and whether pursuing a peaceful role for nuclear weapons undermines the global taboo against their use, a nuclear device for planetary defense could thus have additional, negative security consequences. If a purpose-designed NED is pursued, such a device could allow existing nuclear weapon states to develop new capabilities like directed energy, that could be deployed in their terrestrial nuclear weapon stockpile, thus leading to so-called vertical proliferation. It could also provide other states with a peaceful pretext for developing their own nuclear weapons program (i.e., horizontal proliferation). After all, a nuclear device for planetary defense is indistinguishable from a nuclear weapons program for terrestrial military purposes. If in fact a world with more nuclear weapon states increases the risk of purposeful, accidental, or inadvertent nuclear war, then this is a scenario that should be concerning [35].

Numerous, thorny, political issues also exist that will further complicate any decision to employ a nuclear device for planetary defense. It is likely that NEDs would be launched only when needed to deal with a specific incoming NEO scenario, and that would necessitate political agreements regarding, at a minimum, how many NEDs will be launched, which state(s) will provide the NED(s), who will launch the devices, whether test runs and test detonation(s) will be conducted, and who will monitor the results of such tests. While pre-positioning NEDs in space for planetary defense purposes is unlikely to be recommended for lack of a preferred staging orbit (due to the prevailing orbital physics), any such pre-positioning initiative would require similar decisions, including how many devices must be pre-positioned in space, where they should be positioned, who will put them there, for how long they should loiter, who will monitor them, who will maintain their orbits, and how and when will such a device be disposed of given that eventually each device will reach the end of its usable life [36]. In either scenario, each decision has the obvious potential to be divisive.

Even the process of making each decision is poised to be politically fraught: do nuclear weapon states and non-nuclear weapon states have an equal "vote"? Do space-faring nations and non-space faring nations get an equal vote? After all, the ultimate high ground has only gotten more valuable, providing the capabilities that underpin the economies of most modern societies. These latter, process issues will of course exist irrespective of whether the planetary defense solution is nuclear or non-nuclear. Yet, the nuclear characteristic further complicates each issue in meaningful ways. For example, a launch vehicle armed with a nuclear device imbues a much different hazard throughout the launch process (let alone the test and recovery processes) compared to a launch vehicle without such a payload.

For all of these reasons, at least from a political perspective, using a nuclear device for planetary defense should be approached with extreme caution. The world is already experiencing the destabilizing effects of a space race as the U.S. worries about Chinese and Russians efforts to target U.S. assets in space in a crisis or conflict. After all, the U.S. stands to lose much more, in terms of the decrease in military effectiveness, if its space assets are destroyed [37]. Nuclear testing in space, let alone multiple devices loitering in space, could thus conceivably supercharge existing concerns about the militarization of space.

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[11] Most prominently, see [32], [33], and [34].

V. Legal Considerations[12]

Not only in the political, but also in the legal realm, the use of nuclear devices for planetary defense is the most difficult and sensitive topic to tackle. This goes back to post-Hiroshima history of course; and when the relevant international law addressing the use of nuclear devices in outer space was developed, largely back in the 1960s, the main concern was the potential, and potentially devastating, use of such devices as weapons in the context of the Cold War turning into a hot one.

Thus, the 1963 Partial Test Ban Treaty prohibited the detonation of *any* nuclear device, whether for testing purposes or otherwise, in outer space in order to avoid the risks of states mistakenly or correctly understanding a nuclear explosion in outer space to constitute an armed attack, and to retaliate correspondingly. The 1967 Outer Space Treaty backed this provision up with a clause prohibiting the stationing or orbiting of weapons of mass-destruction (of which nuclear weapons formed the most important subset by far, certainly in the context of outer space) anywhere in outer space, to prevent the mere threat exuded by a nuclear weapon somehow waiting overhead to spur states into preemptive military strikes with the risk of escalating into full-fledged war. As for the celestial bodies, an even stricter regime was imposed – *any* military installations or maneuvers were prohibited.

Once it became clear that nuclear devices could also play a beneficial role in the peaceful exploration and use of outer space, mainly by using nuclear energy for non-propulsive purposes, the international community was able to adopt a United Nations General Assembly Declaration in 1992 (the 'Principles Relevant to the Use of Nuclear Power Sources in Outer Space'), but this merely contained a set of legally non-binding recommendations for the safe operation of such devices. By doing so, it confirmed the legality of using nuclear energy in outer space as long as it did not involve nuclear explosions or explosive devices, since the Resolution did not in any way change the limitations thereon pursuant to the Partial Test Ban Treaty and the Outer Space Treaty.

From the vantage point of planetary defense, it should be further noted that the legal regime summarily sketched above was premised on the assumption that the use of nuclear explosive devices almost by definition would be an act of war, directly targeting (an) enemy state(s). For that reason, when faced with the difficult question of the legality of the use of nuclear weapons in a context of self-defense and an international community of sovereign states for the most part not signing up to treaties prohibiting the use of such weapons altogether, such as in the 1974 Nuclear Tests Case and the 1997 Advisory Opinion, the International Court of Justice walked a very thin line between admitting the absence of an international prohibition on such use and admitting the legality thereof.

Once, therefore, the theme of planetary defense including the possible use of nuclear explosive devices (even if mainly as a last resort) became a feature of international discussions on outer space activities and the applicable legal regime, this raised the overarching question of whether the existing prohibitions, formulated in quite absolute terms yet certainly meant for the specific context of intra-state conflicts, should also be continued to be applied to the different context of defending all of humankind against a threat from deep space – given also the fear that states might be tempted to undertake actions in outer space involving nuclear devices ultimately threatening other states under the ruse of planetary defense-related operations.

While there might be several legal concepts or doctrines allowing for possibilities to accept the use of explosive nuclear devices in the context of planetary defense (such as the options to renounce either of the key treaties, or to use a fundamental change of circumstances or the potentially absurd result of strict adherence to the prohibitions if the survival of humankind would be at stake as an argument to temporarily set aside relevant prohibitions in a very specific context and for very narrowly circumscribed situations) the overarching question remains how to make sure the main thrust of those prohibitions – to eliminate the specter of a nuclear war – is not thereby put at risk.

VI. Conclusions

As discussed in the preceding sections, using NEDs for deflecting or disrupting potentially-hazardous objects offers significant benefits, but also creates significant risks that reach far beyond the Planetary Defense domain. The decision on whether to test NEDs for Planetary Defense applications in order to reduce the related technological uncertainties will therefore require significant thought and negotiation, and, consequently, significant time. The related processes should therefore be initiated soon, before a specific PHO forces the timeline and, once an impact area is known, may create additional political complications.

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