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# ASSESSMENT OF RECENT NEO RESPONSE STRATEGIES FOR THE UNITED NATIONS

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## ABSTRACT

In 2008, the Association of Space Explorers (ASE) and its international Panel on Asteroid Threat Mitigation has prepared a program for action for the United Nations in relation the threat to the Earth from asteroids and comets. The program includes descriptions of three specific functions that the U.N. could develop. This includes specific groups dedicated to information gathering and mission planning that would report to an oversight group that would submit recommendations to the Security Council for appropriate action. These recommendations will be presented to the United Nations Committee on the Peaceful Uses of Outer Space (UN-COPUOS). This paper will examine these most recent recommendations and determine potential issues and improvements to ASE's recommendations. These specific recommendations given by the ASE are a positive first step in discussing specific ways the United Nations can be involved in coordinating a global response to the NEO threat.

## NOMENCLATURE

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| ASE | Association of Space Explorers |
| COPUOS | Committee on the Peaceful Uses of Outer Space |
| IAWN | Information, Analysis, and Warning Network |
| MAOG | Mission Authorization and Oversight Group |
| MPC | Minor Planet Center |
| MPOG | Mission Planning and Operations Group |
| NEO | Near Earth Object |
| PHO | Potentially Hazardous Object |
| UN | United Nations |

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## INTRODUCTION

Both recent observations of planetary bodies and geological records confirm the ever-present threats from asteroids and comets that could be large enough to cause the widespread destruction of modern society. For instance, a massive impact occurred in the Tunguska region of Siberia around 30 June 1908, likely from an approximately several meter wide asteroid or comet, that devastated several hundred square kilometers with a destructive force equivalent to 3 to 5 megatons of TNT (several hundred times the energy unleashed by an atomic bomb over Hiroshima in 1945). Additionally, the Earth's surface still shows scars of previous larger-scale impacts. The more massive K-T (Cretaceous-Tertiary) impact (10 km diameter object), which took place approximately 65 million years ago, is believed to have led to the extinction of the dinosaurs. While K-T class impacts are very infrequent, objects with diameters of approximately 1 km can be expected to intercept the Earth every six to seven hundred thousand years[1]. As seen in Fig. 1 the total number of known Near Earth Asteroids (NEAs) is growing, and with the next generation of surveys coming online within the next few years, this number is expected to increase from thousands to hundreds of thousands[2].

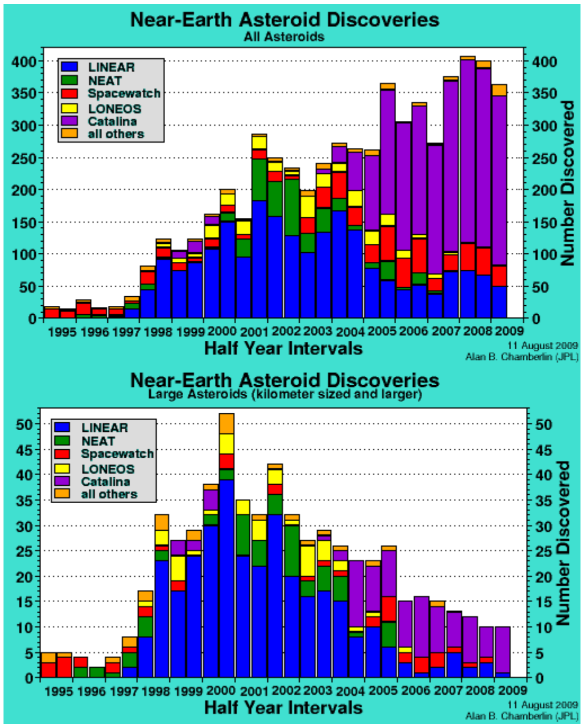


**Figure 1. Near Earth Asteroid Discovery Rate: 11 August 2009 (Source: NEO Discovery Statistics)[2]**

Clearly, some thought and planning must take place in order to provide a reasonable level of protection against such disastrous events. Identification and cataloging of Near-Earth Objects (NEOs) and celestial bodies is an important first step. The question remains: "What should be done if a planetary impactor on a collision course with Earth is actually confirmed?" Effective planetary defense concepts must overcome a variety of challenges including the large variance in size, shape, composition, rotation rate, solid body/rubble pile characteristics, (gravitationally bound), and detection time of NEOs[3,4,5,6]. Economics, reliability, technology constraints, and launch vehicle capacity may limit the size and scope of potential solutions[7].

Given mankind's technological progress the time has arrived where a serious examination of a response to the threat from asteroids and comets can be made. This examination has both technical and political dimensions. Beyond any possible technical approaches to observation, characterization, or mitigation there are multiple issues related to the policy and plans for any asteroid/comet threat. Is there a need for and how is international coordination done? Who are the globally responsible parties? Is this an area where only those states with power in terms of space capabilities (earth-to-orbit launch, in-space transport, in-space infrastructure, etc,) can participate in discussions and can dictate terms for any potential response? Is the United Nations the correct international body for both technical and policy discussions related to a global NEO threat? Should only member states of the U.N. Security Council be involved in discussions?

These and other such questions introduce the debate of whether humanity needs to organize some type of global information, response, and strategy mechanism in the area of planetary defense. Some would argue that once a threat from an asteroid or comet arises (i.e., a high probability of Earth impact is confirmed), major spacefaring states will either individually or in combination, develop a response. Others would argue that there should be international mechanisms/protocols in place to coordinate such responses. These mechanisms would be used to coordinate limited global resources, though the impact point (for a non-global devastation impact threat) may not affect a country that lacks space power projection capabilities.

The opinions expressed here represent the personal opinions of the authors and do not reflect any official position or policy of their respective organizations. Any errors are solely the responsibility of the authors.

## BACKGROUND OF ASE GLOBAL RESPONSE STUDY

This discussion focuses on a recent initiative to develop a globally-oriented response process for planetary defense against asteroids and comets. The specific proposals have been set forward by the Association of Space Explorers (ASE), which have advocated for such a response and done a credible job on mobilizing others to discuss the issue. In September 2008, the ASE most recently laid out a specific series of recommendations from their report called "Asteroid Threats: A Call for Global Response"[8,9,10].

ASE's Panel on Asteroid Threat Mitigation has submitted their plan to the United Nations Committee on the Peaceful Uses of Outer Space (UN/COPUOS) via Action Team-14 (NEO) for introduction in the COPUOS 09 meeting. This paper provides an analysis of their findings and is based upon an executive summary that has been publicly released. All the details of the report will not be reiterated here. The report advocates for a global, coordinated response by the United Nations to the NEO impact hazard composed of what are deemed three logical necessary functions (as seen in Fig. 2). The major functions indentified include the following[8,9]:

- Information Gathering, Analysis, and Warning: An Information, Analysis, and Warning Network [IAWN] should be established. This network would operate a global system of ground- and/or space-based telescopes to detect and track potentially hazardous NEOs. The network, using existing or new research institutions, should analyze NEO orbits to identify potential impacts. The network should also establish criteria for issuing NEO impact warnings.
- Mission Planning and Operations: A Mission Planning and Operations "Group," [MPOG] drawing on the expertise of the spacefaring nations, should be established and mandated to outline the most likely options for NEO deflection missions. This group should assess the current, global capacity to deflect a hazardous NEO by gathering necessary NEO information, identifying required technologies, and surveying the NEO-related capabilities of interested space agencies. In response to a specific warning, the group should use these mission plans to prepare for a deflection campaign to prevent the threatened impact.
- Mission Authorization and Oversight Group [MAOG]: The United Nations should exercise oversight of the above functions through an intergovernmental Mission Authorization and Oversight Group [MAOG]. This group would develop the policies and guidelines that represent the international will to respond to the global impact hazard. The Mission Authorization and Oversight Group should establish impact risk thresholds and criteria to determine when to execute a NEO deflection campaign. The Mission Authorization and Oversight Group would submit recommendations to the United Nations Security Council for appropriate action.

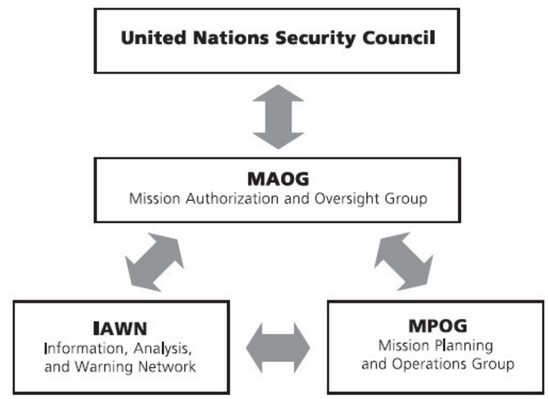


**Figure 2. ASE's Suggested Structure of New Supporting Organizations to U.N. on NEOs[8,9,10]**

## OBSERVATIONS

This paper presents several identified issues with this report. The comments made here are not meant to indicate that the actions proposed by the ASE are inappropriate. Rather, this is a critique of selected items from the report. This author believes in general that the proposals by the ASE report are worthy of consideration in bodies such as the United Nations Committee on the Peaceful Uses of Outer Space (UN-COPUOS). The following section provides various comments (in no particular order) that are these author's initial perceptions of the ASE document. These observations and recommendations are not conclusive and result from an initial examination of the ASE NEO committee's outputs.

### Issue of Funding and Overlap

Many of the recommendations require staff and facilities to adequately perform the functions described. The Mission Authorization and Oversight Group (MAOG) is inherently a new organization that will require funding. This group could be the most closely tied to the U.N. and thus require organization and coordinated funding from the member states. For the other two groups supporting the MAOG, namely the IAWN (Information, Analysis, and Warning Network) and the MPOG (Mission Planning and Operations Group), there is the potential for outsourcing of these functions if they are not to be performed by a U.N. agency. This too will also require new funding. These funding issues will be notrivial and will require some prioritization of effort. As we currently can see, international coordination on multiple issues is difficult to achieve given manpower and financial constraints. This will also be the case for any of these new groups.

There may also be overlap with other existing groups and/or government agencies that could perform or are performing similar functions. For instance, given the proposal for the IAWN, there is an issue of the status of the Minor Planet Center (MPC) which currently acts as a clearinghouse for data on many of these NEO observations. Does the new entity of IAWN take over the responsibilities of the MPC, or is the MPC enhanced by the IAWN?

Given the political and economic expense of setting up new groups (as well as overlap with existing institutions) it may be useful to prioritize the development of three groups (IAWN, MPOG, and MAOG). Of the two groups supporting the MAOG, the IAWN should be established prior to the MPOG.

## Consensus on Earth Regarding Miss Distance

A fundamental issue involves how good the error ellipse will be for Earth impact. Many make the point that international coordination will be required because, in the case of a hypothetical non-Earth devastating impactor, questionable incentives exist for a country with the capability for some type of mitigation. What incentive is there for a nation not threatened to respond to the need of a country without such a capability but within the impact error ellipse (3-sigma position probability)? Another scenario would involve what incentive the same space-power capable state has when it moves the impactor's error ellipse off of that state and onto another state (and presumably not away from the earth). However, to create such circumstances, one must possess very good position estimate into the future where the 3-sigma position ellipse is, one in fact smaller than the earth's diameter. This may be difficult if there are not enough observations from which to propagate the trajectory (ground, space, or in-site based). This circumstance may be achieved if there are many observations of the body. For instance, the asteroid Apophis is a recent asteroid of interest that currently has a 1 in 45,000 chance of hitting the Earth in 2036 during a close approach in 2029. It will be about 6 Earth diameters away from the surface of the planet. At this point, the uncertainty of its position (length of the 3-sigma error ellipse) is approximately 4500 km.

The point being made here is that with several observations of an asteroid, the exact impact point may not be known to within the geographic boundaries of any one country on the planet. For instance there were 2 radar delay, 5 Doppler, and 731 optical observations of Apophis from 2004 until 2006. In this case a transponder mission may be required. Thus, a question arises about whether we should be concerned about actually moving the error ellipse just off one country. The reason is that the number of perturbations on an object's trajectory that are important when talking about such small miss distances are large (beyond the sun, planet, minor objects, thermal effects, Earth at close approaches, and so on). Thus, one may not really want to move an asteroid away from only one country, but rather be certain that it does not hit the Earth given these uncertainties.

One specific area for one of the proposed groups, most likely the MPOG, would be a minimum consensus miss distance for any object that has a high probability of impact. Many mitigation studies in the past have used widely different miss distances; some using just one Earth diameter which, to this author, may be technically appropriate buy may be too close for even policy makers. That is, if one is going to move an asteroid away from an Earth impact, it is this author's contention that consensus opinion from multiple stakeholders would be that the miss distance should be several Earth radii.

## Public Overreaction to the New, Higher Numbers of Potential Hazardous Objects (PHOs)

Within the confines of the report it is stated that there will be a coming wave of discovery with new observatories coming on-line (Pan-STARRS and LSST)[8]. Within the next 15 years over 500,000 NEOs may be discovered (versus 5600 in the last 10 years). The ASE paper estimates that 3% may be potentially hazardous. There is concern that there will be many warnings with an associated over-reaction by the media and subsequently the public at large (i.e., multiple Apophis scenarios). Some people have speculated that this may not be a desirable situation and we may require a coordinated "clearing house" to prevent such media excitement.

Paradoxically, it may be advantageous to actually have such a situation. As more and more potentially hazardous objects (PHOs) are found and are announced by the media, eventually the public, after a period of potential overexcitement, will become more accustomed to the occasional announcement of a NEO threat. There may be a period of excitement but it may actually lead to a period of relative pragmatic interpretation of the data. One analogy could be the public's eventual acceptance of causalities within a long war, at the beginning there is a lot of attention, but as a conflict continues, the public eventually may become not as intensely focused on the same number of casualties per month in month forty-eight of a war versus month four (for good and/or bad). Another analogy would be the public's recent reaction to news accounts that the Large Hadron Collider (LHC), an international particle accelerator project, could create a mini-black hole that would devour the planet. Scientists had to confront this incorrect assumption on the part of the media and public by engaging with the media to explain the LHC's real purpose and effect. Without the public's initial incorrect assumptions driving the story, scientists may have never received the public platform to discuss the project. It may be interesting to consider the possibility of dealing with a period of media overreaction to the constant announcement of high probability impact events, and to use it as a chance to engage with the media. Such a situation would not negate the need of these proposed ASE groups within the U.N. but perhaps refocus their plans.

## Responsibilities of the IAWN and MPOG

There are major policy responsibilities assigned to the IAWN. Specifically, the following two deserve attention[8]:

A. To serve as the official source of information on the NEO environment.
B. To maintain (or where appropriate designate) the official clearinghouse for all NEO observations and impact analysis results.

These two activities may require a large amount of international coordination, offline and online. These are very broad mandates entrusted to the IAWN. These activities may require a larger than anticipated infrastructure to accomplish (in terms of resources).

There may be a need to rearrange some of the specific functions that have been divided up to the IAWN, MPOG, and MAOG. Within the ASE document, some of the responsibilities of the IAWN include the following two[8]:

A. To develop in cooperation with member states a comprehensive set of designated national disaster response entities [labeled as f. in the ASE report]
B. To coordinate mitigation response planning with the designated national disaster response entities [labeled as g. in the ASE report]

It is recommended that these two areas be move to the MPOG. The fundamental purpose of the MPOG to this author appears to be mitigation and that encompassed ground mitigation. The inclusion of disaster response in the IAWN seems to dilute the very important mission of information and planning.

For the IAWN, there are two specific responsibilities dealing with the public and media that may need to be combined. The following two responsibilities are listed separately for the IAWN[8]:

A. To consider and recommend to the NEO Threat Oversight Group a public information policy on evolving NEO impact threats, and to explore threshold levels at which such information as the risk corridor, potential tsunami simulations, and other impact information for a potential NEO impact should be released to the public [labeled as e. in the ASE report].
B. To develop and recommend to the NEO Threat Oversight Group a public information plan to include all parameters to be made available, update rate (or criteria), dissemination means, and enquiry handling policy [labeled as i. in the ASE report]

There may be a need to be more specific with regards to these two areas of responsibility. Is the second responsibility listed above more general than the first? Perhaps a combined narrative into one area would bring together both broad and specific information dissemination responsibilities.

For the MPOG, one of the areas described deals with analysis of mitigation options and specifically cost[8]:

A. To develop costing models for each approved deflection campaign concept and for each planning and mission operations event [labeled e. in the ASE report].

The specific phrase used which is "to develop costing models" may not be the most appropriate term for what may be desired[8]. A more appropriate approach would be to use the phrase: "generate cost, operational, and schedule estimates."

## ADDITIONAL MEASURES AND METRICS TO HELP POLICY MAKERS

For those policy makers who at some point may be involved in decisions about mitigation (such as in the MAOG), multiple factors should be examined in order to determine the optimum mitigation option. Determining an optimum mitigation concept is dependent upon multiple factors. Some factors are technical, some are cost, and some may be legal/policy related. All factors should be weighed relative to each other. Processes do exist to help evaluate such concepts and to combine technical metrics (like deflection distance) and policy/legal implications. As seen in Fig. 3, such prioritization methods can help develop an overall score, referred to here as an Overall Evaluation Criteria (OEC), for various mitigation concepts[6].

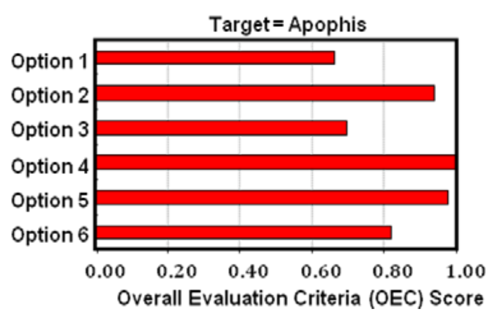


**Figure 3. Quantifying an Optimum Mitigation Approach**

This score can be developed by qualitative and quantitative analysis by decision-makers (weighing each metric relative to every other). One such envisioned process is seen in Fig. 4 that combines analysis with expert judgment to help develop an OEC that includes metrics to account for technical feasibility, life cycle cost, and legal/policy impacts. This is referred to as the NOMAD (NEO Objective Mitigation Analysis Decider) process that utilizes trajectory modeling, mitigation performance analysis, cost assessment, and expert judgment into an overall prioritization process[6].

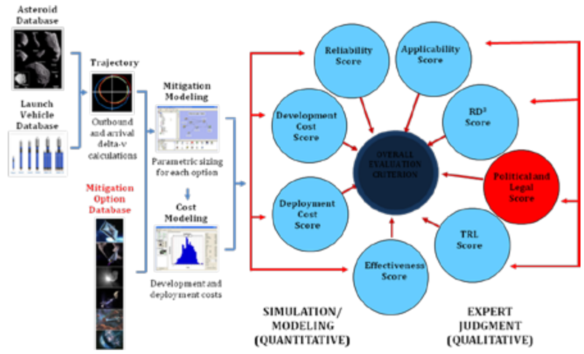


**Figure 4. Example Comparison Process: NOMAD (NEO Objective Mitigation Analysis Decider)[6]**

Decision makers weigh the types of metrics seen in Fig. 4 in various ways, depending upon what metrics are important to them. Fig. 5 shows a sample prioritization chart for various metric weightings. This output can be used to help prioritize focus and investment on the most optimum solution. It helps compare potential options for different sets of user values.

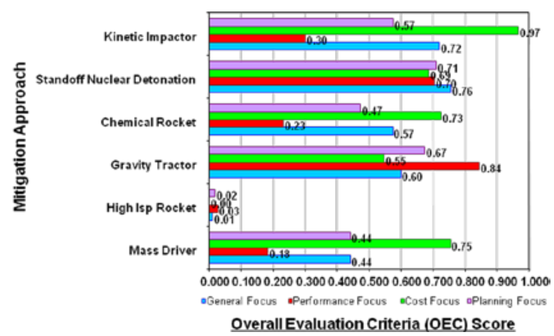


**Figure 5. Outputs of Comparison Process[6]**

One of the issues with such a prioritization process is how to include some level of rigor for more "soft" metrics like politically viability, measures that would be important for a future mitigation strategy body like the MAOG. In essence the challenge is to help decisions makers take into account all measures of value, some that need to be computationally modeled and others that are more subjective.

### Legal Degree of Difficulty ($LD^2$)

A quantitative scale for legal/political viability has been developed by the authors and is placed in the public domain for discussion. Using as guides previous scales such as the Technology Readiness Level (TRL) scale and the Research and

Development Degree of Difficulty ($RD^3$) scale, this proposed scale helps to describe the policy and legal characteristic of a mitigation option[11,12]. An assumption made here is that legal and policy aspects may be related. This proposed scale is a new construct by the authors and future revisions to it are envisioned after feedback.

With such quantitative values, legal/policy aspects can then be incorporated into a numerical prioritization process such as the NOMAD process described earlier. As seen in Fig. 6 this scale, referred to as a Legal Degree of Difficulty ($LD^2$), is defined as a scale from 1 to 5 that indicates the legal difficulty of implementing a mitigation option. The value could be based upon the amount of precedents for such actions as well as the types and number of jurisdictions involved.


**Figure 6. Legal Degree of Difficulty ($LD^2$)**

The scale goes from 1 to 5 with 1 indicating an option is east to achieve legally/politically and then 5 indicating it is easy to do. The scale is initially conceived to be linear from 1 to 5 with each step a similar range of difficulty.

**<u>Lincoln Scale</u>**

Just because a mitigation option may be legally easy to do does not mean that society in general can easily accept the mitigation approach. Space examples of this include public protests after the launching of nuclear radioisotope thermal generator (RTGs) for missions such as Cassini. It was determined that perhaps an additional scale to reflect this public acceptance may also be important to an overall prioritization process such as NOMAD.

As shown in Fig. 7 this scale would relate how willing the public would be to accept a particular mitigation concept. This would be in place of a valid, statistical poll (desired but potentially difficult data to obtain). This scale asks the person putting in the value for a prioritization process, their estimate of what the public perceives. Other polls can be used to help calibrate responses for this scale.

This scale, referred to as the Lincoln Scale (from the 2009 University of Nebraska-Lincoln Conference on NEOs and Space Policy), is a scale from 1 to 100 that indicates the public's willingness to accept a mitigation option. These values can be viewed to be relatively independent of impact probability since they are being used in a prioritization process for specific threats. Fig. 7 shows example poll values for this scale that could help guide decisions on values for various mitigation options.

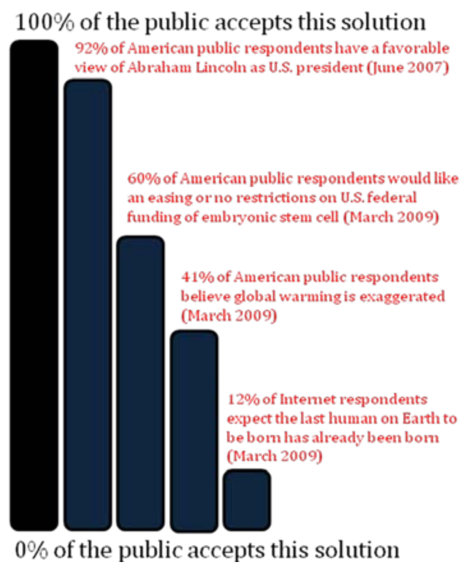


**Figure 7. Outputs of Comparison Process**

Sources for various poll value shown:
- Majority of Americans Likely Support Stem Cell Decision, 09 March 2009
URL: http://www.gallup.com/poll/116485/Majority-Americans-Likely-Support-Stem-Cell-Decision.aspx6
- Historical rankings of United States Presidents (Wikipedia)
URL: http://en.wikipedia.org/wiki/Historical_rankings_of_United_States_Presidents
- Increased Number Think Global Warming Is "Exaggerated", 11 March 2009
URL: http://www.gallup.com/poll/116590/Increased-Number-Think-Global-Warming-Exaggerated.aspx
- Slashdot poll: I expect the last human on Earth to be born ...
URL: http://slashdot.org/pollBooth.pl?qid=1749&aid=-1

Using these two new scales, sample values were generated for various mitigation options (see Table 1). For example, a propulsive tug may be very acceptable to the public and be a well known mitigation approach (legally) where the technology is known and has been used before. Yet a gravity tractor, requiring more time for eventual effect on a Potentially Hazardous Object (PHO), may be a more uncertain legal/political approach given its long action time and potential for slowly moving an impact point over and away from the earth (and potentially only viable on "keyhole" close approaches). The table it given as an example of how such scales could be utilized. Eventually such information would be incorporated with technical and costs analysis, such as that in the NOMAD prioritization process, to develop guidance for decision makers on the actual cost-benefits of various mitigation approaches. Such scales and processes could be of benefit to the proposed ASE structure within the U.N. to deal with the NEO threat.

**Table 1. Sample $LD^2$ and Lincoln Scale Values**

| Mitigation Option | Description | Sample Legal, Political Issues | $LD^2$ [1-5] | Lincoln Value [1-100] |
|---|---|---|---|---|
| Propulsive tug | Attach a propulsion system to a NEO | Nuclear power option | 3 | 80 |
| Gravity tractor | Use gravitational attraction of spacecraft to change NEO trajectory | Long action time | 1 | 40 |
| Electromagnetic force fields | Generate a field such that the NEO interacts with | Long action time, nuclear power option | 2 | 30 |
| Kinetic impactor | Hit a NEO with a mass to impart momentum change | Need for multiple impacts, imprecise control?, potential nuclear warhead option (weapons in space) | 4 | 80 |
| Space Billiards | Impact a NEO with another NEO | Certainty of NEO-NEO collision, change of multiple objects in solar system | 4 | 20 |
| NEO Spin | Spin a NEO until it reaches a fragmentation point | Potential to break up target into multiple pieces | 2 | 30 |
| Mass driver | Automated sling attached to throw material away | Break into multiple pieces (expand impact points) | 2 | 50 |
| Electromechanical resonators | Develop a mechanical pulse to shed layers [2nd place | Break into multiple pieces (expand impact points) | 2 | 40 |
| Body Solar Sail | Coating over the surface of an asteroid to increase its reflectivity, enabling deflection by solar radiation pressure | Long action time | 1 | 60 |

## CONCLUSION

The development of the recommendations by the ASE of how the U.N. could coordinate action on the NEO threat, developed through the leadership of Rusty Schweickart, is to be commended. They are a very good first draft of the protocols and process that the international community may want to examine if they are serious in their response to this natural threat from asteroids and comets. The comments here are made to help develop the ASE recommendations further and to offer some preliminary thoughts on the output of the ASE process. Suggestions are given for two new scales, the $LD^2$ and Lincoln scale, which could help quantify legal difficulty and public acceptability of mitigation options. These scales, along with a prioritization process, could be helpful to decision makers within such a U.N. structure.

## REFERENCES


1. Chapman, C. R., "The hazard of near-Earth asteroid impacts on earth," Earth and Planetary Science Letters 222 Frontiers, (2004) 1 –15.
2. JPL NEO Discovery Statistics, URL: http://neo.jpl.nasa.gov/stats/. Last accessed: August 11, 2009.
3. Adams, R. B., Alexander, R. Bonometti, J., Chapman, J., Fincher, S., Hopkins, R. Kalkstein, M., Polsgrove, T., Statham, G. and White, S., Survey of Technologies Relevant to Defense from Near-Earth Objects, NASA-TP-2004-213089, NASA-MSFC, July (2004).
4. Rogers, G. and Izenberg, N., "Comparison of the Efficiency of Various Asteroid Hazard Mitigation Techniques," White Paper, NASA NEO Workshop, Vail, Colorado, 26-28 June, (2006).
5. Colombo, C., Sanchez Cuartielles, J. P., Vasile, M. and Radice, G., "A Comparative Assessment of Different Deviation Strategies for Dangerous NEO," 57th International Astronautical Congress, IAC-06-A3.5.8, Valencia, Spain, 2-6 Oct., (2006).
6. Schaffer, M. G., Charania, A., Olds, J. R., "Evaluating the Effectiveness of Different NEO Mitigation Options," Planetary Defense Conference, AIAA-2007-P2-1, Washington, D.C., March 5-8, (2007).
7. NASA Report to Congress, "Near-Earth Object Survey and Definition: Analysis of Alternatives," March, (2007).
8. Schweickart, R. L., "Decision Program On Asteroid Threat Mitigation," International Astronautical Congress, IAC.E.8.4.1, Glasgow, Scotland, September 29 – October 03, (2008).
9. Schweickart, R. L. (Chair), "Press Release: Asteroid Threats: The Geopolitical Challenge," http://images.derstandard.at/ 2008/09/26/Asteroid Threats-A Call for Global Response.pdf, September 25, (2008a).
10. Schweickart, R. L. (Chair), "Asteroid Threats: A Call for Global Response," http://www.space-

explorers.org/ASE_NEO_Final_
Report_excerpt.pdf, September 25, (2008b).

11. Mankins, John C. "Technology Readiness Levels: A White Paper," April 6, 1995.
12. Mankins, John C., "Research & Development Degree of Difficulty (RD3): A White Paper," March 10, 1998.