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# Decision program on asteroid threat mitigation

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**Abstract**

The Association of Space Explorers Committee on Near-Earth Objects (NEOs) and its Panel on Asteroid Threat Mitigation have prepared a decision program to aid the international community in organizing a coordinated response to asteroid impact threats. The program is described in the ASE's report, *Asteroid Threats: A Call for Global Response*, which will be considered by the United Nations Committee on the Peaceful Uses of Outer Space in its 2009 sessions. The findings and recommendations of this report are presented here as well as some of the major implications of the complex decision-making involved in developing a coordinated international response to the challenge of protecting the Earth from NEO impacts.


*Keywords:* Asteroid; NEO; Impact; Deflection; UN; United nations; Near-Earth object

## 1. Background

In its 2009 sessions the United Nations Committee on the Peaceful Uses of Outer Space (UN-COPUOS) will be presented with [1] a decision program on asteroid threat mitigation developed over a two year period by the Association of Space Explorers [2] (ASE), the international organization of astronauts and cosmonauts from 34 nations. The program was developed by the ASE Committee on Near-Earth Objects (ASE-NEO) and its Panel on Asteroid Threat Mitigation [3] (Panel), a distinguished international group of experts in science, law, diplomacy, and disaster management.

The ASE effort was initiated during its 2005 Congress when the members took note of the series of international disasters which had occurred that year (especially the Indian Ocean tsunami, hurricanes Katrina and Rita, and the Pakistani earthquake) and the recognition of the critical role of preparation and warning in saving lives. Being also aware of the devastation caused by NEO impacts with Earth, the accelerating discovery rate of NEOs and the emerging technical capability (with adequate early warning) to divert such NEOs from impacting Earth, the Association realized the need for systematic preparation for this eventuality by the international community.

Recognizing the significance of this need the ASE issued an open letter [4] to world institutions and leaders calling on them to "acknowledge this challenge and accept the responsibility for prevention of these most devastating of all natural disasters". To support such efforts ASE created an ASE-NEO committee and charged it with supporting "national and international responses by providing relevant information, organizing meetings or workshops, and providing expert witnesses".

In agreeing on a way to implement the recommendations of the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNIPACE

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III), COPUOS agreed to establish Action Teams, under the leadership of governments, to analyze all issues involved in implementing specific recommendations and to make proposals to the committee on the way forward. Action Team 14 was established to deal with all NEO issues.

In 2006 the ASE-NEO Committee, utilizing the ASE's Observer status in UN/COPUOS, assumed membership on Action Team-14 (NEO) of COPUOS and initiated an effort to develop a decision program on asteroid deflection for consideration by the international community. To support this effort ASE-NEO formed its international Panel on Asteroid Threat Mitigation and initiated a series of four workshops to develop this program. The result of this effort is the report, *Asteroid Threats: A Call for Global Response*.

## 2. Summary findings

Our highly interconnected society is vulnerable to the destructive power of impact events ranging from the 1908 Tunguska event in which the impact of an estimated 45 m diameter object destroyed 2000 $km^2$ of Siberian forest to the 12 km diameter object responsible for the Chicxulub impact 65 million years ago which is thought to have caused the extinction of the dinosaurs and 70% of all species alive at the time. Such cosmic collisions occur infrequently juxtaposed with a human lifetime, and yet when they do happen they dwarf other natural disasters more common in human experience.

Yet surprisingly in the instance of this most devastating of natural disasters we are far from helpless. With our telescopic and spaceflight capabilities we can detect and predict potential impacts, and with adequate early warning we can deploy space systems capable of altering the orbit of threatening NEOs sufficient to cause them to pass harmlessly by the Earth thereby avoiding an impact. In the event of a discovery where insufficient time is available to successfully divert a threatening NEO we will nevertheless, if prepared, be able to mitigate the effects of an impact by evacuation and other disaster preparedness measures.

What is needed to match the technical capability for responding to the NEO impact challenge is an in-place international system of preparation, planning and timely decision-making. The need for attention to this issue now by the international community is driven by the rapid expansion of the number of NEOs which will be discovered and tracked in the next 10–15 years, and the inherent geographic variability associated with impact prediction and deflection operations.

New telescopic resources coming into service within the next decade will dramatically increase the number of NEOs discovered and tracked. The US Congress has charged NASA with discovering and tracking 90% of all NEOs larger than 140 m in diameter by 2020. While meeting this goal poses a considerable challenge, it is clear that with new telescopes coming online (e.g. Pan-STARRS [5] and LSST [6]) this goal will be approached in the 2020–2025 timeframe. In the process of achieving the 140 m goal many smaller but still dangerous NEOs (∼45 m and larger) will be discovered with the number of such objects likely to exceed 300,000. Based on current empirical experience the number of potentially damaging NEOs with a non-zero probability of impact within the next 100 years is likely to exceed 10,000 by this time. Of these NEOs with at least a small probability of impact over the next 100 years many are likely to appear threatening enough to necessitate a decision of whether action should be taken to prevent an impact.

The need for international coordination in making such a decision is determined by the natural uncertainty regarding which specific populations are at risk in predicting an impact and the inherent shifting of risk in the process of deflection. All measurements have an associated uncertainty and in the instance of NEO observations these measurement uncertainties, projected forward in time, manifest as a risk corridor across the face of the Earth within which, if it impacts, the NEO will hit. While in the end an impact would occur at a specific point, at the time a decision must be made to deflect a threatening object the impact zone will extend for some distance along the risk corridor and, in fact, in many instances may well extend beyond the Earth's limbs for many Earth diameters in both directions. Hence, at the time a deflection decision must be made (to provide adequate time to conduct the operation and for the deflection to take effect) it is likely that the people of many nations will be at risk. Furthermore in the process of deflection per se, there will be a temporary shifting of risk between populations as the NEO impact point is itself shifted from a point on the Earth's surface to a safe distance along the risk corridor either ahead of or behind the Earth.

Because NEO impacts can occur anywhere on our planet and affect the entire international community, a collaborative, global response is required. Furthermore it is highly desirable that a decision process, with agreed criteria, policies and procedures be established prior to the development of a specific threat in order to assure that minimization of risk to life and property prevail over competing national self interests.

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## 3. Primary recommendations

A global, coordinated response by the United Nations to the NEO impact hazard should ensure that three logical, necessary functions are performed.

### *3.1. Information gathering, analysis, and warning*

An information, analysis, and warning network 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 establish criteria for issuing NEO impact warnings.

### *3.2. Mission planning and operations*

A Mission Planning and Operations "Group", drawing on the expertise of the space-faring nations (SFNs), 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.

### *3.3. NEO threat oversight and recommendation for action*

The United Nations should exercise oversight of the above functions through an intergovernmental Mission Authorization and Oversight "Group". 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 Security Council for appropriate action.

## 4. The nature of the challenge

The NEO environment has remained virtually constant for the past three billion years. The question therefore logically arises regarding the basis for needing a decision process to address NEO impact threats now. The simple answer to this fundamental question is that our telescopic observations of the NEO population are rapidly converting what has been a statistical threat into direct knowledge of specific impact threats which necessitate response.

What is the nature of these threats? And what responses are possible? How often might actual threats materialize? These and a host of additional questions arise when it is realized that effective action can be taken in response to an impact threat thereby either materially reducing the loss to life or preventing an impact occurrence entirely.

### *4.1. A coming wave of discovery*

The current NEO search program (Spaceguard Survey), initiated in 1998, has resulted in the discovery and tracking of over 5600 NEOs in the past 10 years. These NEOs, of all sizes, have been discovered in the process of achieving the goal of discovering 90% of all NEOs greater than 1 km in diameter by the end of 2008. Approximately 80% of the statistical population of these large NEOs has been discovered, and the search continues.

In 2005 the US Congress established a new goal for the Spaceguard Survey; to discover 90% of all NEOs greater than 140 m in diameter over the next 15 years. This revised goal reflected the understanding that these smaller NEOs will also cause terrible destruction on impact and should therefore be discovered and tracked in order to enable responsive action.

While a specific revised search program has not yet been developed there are large new telescopes currently in development and testing that will enter operation within the next 5–10 years. (i.e. Pan-STARRS and LSST [7]) As these powerful telescopes begin their observations the rate of NEO discoveries will take a dramatic turn upward. Based on expected performance and current Spaceguard Survey experience it is estimated that within the next 15 years over 500,000 NEOs of all sizes will be discovered and enter the tracking database, and that over 300,000 of these will be of a size capable of doing substantial damage at the Earth's surface on impact.

Based on tracking experience to date the vast majority of these NEOs will have zero probability of impacting Earth within the next 100 years. Nevertheless on the order of 3% of these new NEO discoveries will likely have some, generally small, probability of impact in that timeframe. Within these thousands of potential Earth impactors there will likely be dozens which will appear threatening enough that they will require proactive decisions regarding mitigation or deflection.

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### 4.2. Mitigating an impact

When a threatening NEO is discovered too late to permit a deflection the only response option, if an impact is confirmed, is to mitigate the potential damage through conventional disaster response mechanisms, primarily an evacuation.

A similar case arises when, at the time a deflection campaign could have been mounted, it was not, due either to an insufficient probability of impact to justify such action or the inability of the international community to reach a decision. Should the probability of impact subsequently increase to 100% the remaining option is again mitigation.

In either of the above instances, as the time of the potential impact is approached, we will know in which direction to point our telescopic resources to determine whether or not an impact is imminent.

If a potential impact is destined for the nighttime hemisphere of Earth optical telescopes will be able to confirm its approach by looking up the "final approach" path and provide a month or more of warning.

If, on the other hand, the potential impactor is approaching toward the daylight hemisphere optical telescopes cannot be used due to the solar glare and early warning will be possible only by using radar telescopes. Since the range of active radar telescopes is considerably less than their optical counterparts the warning time may be as low as a couple of days.

It should be emphasized, however, that in both of the above situations the probability of impact will likely be extremely low and that the almost certain outcome of looking up the "final approach" path will be the issuance of an "all-clear". Nevertheless it is the possibility of that one chance of an impact materializing, and the saving of many lives that justifies the required telescopic observations.

### 4.3. Preventing an impact

Whenever a sufficiently threatening NEO is discovered early enough to mount a deflection campaign an impact can be averted. For such a scenario to be realized three essential elements have to be in place; a capable early warning system, a deflection capability, and an institutional process capable of making timely decisions.

In order to provide the time required for preparation and deployment of a deflection campaign, and adequate time following the deflection action per se for it to take effect, the early warning system will have to provide the information required to make a deflection decision at least 10–15 years ahead of impact.

Confidence in the time required to prepare and accomplish a deflection should be provided by designing and flight testing deflection systems well in advance of their use. Such preparation will not only provide technical confidence in the planning of an actual deflection operation, but also develop confidence in the general public regarding their personal safety.

### 4.4. Time criticality

Most critical, however, is the requirement that the international community be prepared to authorize a deflection campaign in a timely manner. Failing to provide a decision-making framework before a threatening NEO situation is discovered will risk lengthy argument, political delays, and collective paralysis. Such avoidable inaction will preclude a deflection and force the world to absorb a damaging—and preventable—impact. With the lead time for an authorization decision typically needed 10–15 years ahead of a potential impact, we should begin now to forge that vital decision process.

## 5. Deflection and its implications

### 5.1. Deflection means

NEO impact deflection concepts have been discussed now for several years and while there is not yet a consensus on the most appropriate techniques there is a growing understanding of the nature of the task. Furthermore there is considerable agreement that there currently exist deflection concepts adequate to divert the vast majority of the potential NEO impact threats.

The diversion of a NEO on a path toward an Earth impact requires, depending on the specific circumstances, either a precise, but modest orbit change or the combination of a robust orbit change followed by a precise orbit trim. A successful deflection campaign is one in which both an immediate impact and all near-term return impacts are prevented. These conditions correlate with the robust and precision deflection requirements respectively.

Robust orbit change, i.e. orbit changes requiring substantial total impulse [8] applied to the NEO, can be provided by either a kinetic impact (KI) or a nuclear stand-off explosion. Both are available technologies and KI was demonstrated conceptually during the 2005 Deep Impact mission, albeit that impact was designed for a different purpose. A nuclear stand-off explosion has not been demonstrated but the technology is arguably available for use. Both of these techniques,

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while capable of transferring substantial momentum change to a NEO cannot do so with adequate precision to assure a fully successful deflection.

A precise NEO orbit adjustment is conceptually available via a number of techniques. However the most simple and readily available concept is that of the gravitational tractor (GT) [9] which provides precise adjustment to the NEO orbit by "hovering" in close proximity to the NEO thereby using mutual gravity to change the NEO's velocity.

While the non-nuclear combination of a kinetic impact and gravity tractor will suffice for approximately 98% of the statistical impact threat, the use of nuclear means cannot be ruled out absent further technology development. The frequency of NEO impacts which would require the use of nuclear means is approximately 1 in 100,000 years based on the current best estimate of NEO size–frequency distribution [10].

### 5.2. Impacts and impact precursors

A NEO impact will occur when the orbits of the NEO and the Earth intersect in space and both bodies reach that intersection at the same time.

Such intersections are not static over significant periods of time due to the occasional gravitational perturbation of NEO orbits due to close passes by planets or other large NEOs. Most frequently a NEO threatening an impact with Earth has experienced prior close passes by the Earth which have, in fact, set up the subsequent impact. Such close gravitational encounters with the Earth can substantially change the orbit of a NEO, and on occasion, cause a precise change which brings the NEO back several years later for a direct impact.

The small region near the Earth through which a NEO must pass for such a resonant impact to occur is referred to as a gravitational keyhole. Whenever a NEO passes nearby, whether passing in front or behind the Earth, it passes through a field of dozens of such keyholes. Since the size of keyholes is very small compared with the distance between them near-misses seldom result in a resonant return and subsequent impact. Conversely virtually all impacts, projected back in time, are the result of a precursor close gravitational encounter, most often with the Earth.

Consequently a NEO deflection is most easily accomplished when knowledge of its orbit is gained sufficiently in advance of a possible impact that it can be diverted from a precursor keyhole passage rather than diverting it subsequently from a direct impact. A deflection operation to avoid a target of a kilometer or so in size (i.e. a keyhole) is far less daunting than a deflection to avoid a target of several tens of thousands of kilometers (i.e. the Earth).

Missing a collision with the Earth (or a keyhole) is a matter of slightly increasing or decreasing the size of the NEO orbit, far enough in advance of impact, such that the NEO arrives either slightly late or early at the intersection. While such a deflection will have avoided a direct impact with Earth the NEO will now be passing through the nearby field of resonant keyholes and risks a return impact unless its passage between them is assured. Should a deflected NEO in fact be headed for a return keyhole following a primary deflection it is the precise capability of the gravity tractor (or other precision adjustment means) that will assure a successful deflection.

### 5.3. Deflection implications

The deflection process, regardless of the technology used, can be understood as an operation which, by slightly adjusting the velocity of a NEO, will cause it to arrive at the impact point slightly earlier or later than it otherwise would have. With a sufficient change in the NEO velocity the change in the arrival time is sufficient that the impact point has moved completely off the Earth.

A deflection can thus be seen as a process whereby an impact point is shifted from its original ("act of God") location to a point ultimately off the Earth's leading or trailing limb. Should, for any reason, the deflection be terminated or only partially completed, the impact point will now be displaced along the risk corridor in the direction of the intended goal. Whether the deflection is a continuous gravity tractor process or an impulsive kinetic impact or nuclear explosion, a partial completion will result in a new impact point displaced along the risk corridor from the original undisturbed impact point.

Hence people not originally near the impact point will experience a temporary increase in risk in the process of reducing the risk of an impact to zero for everyone. Risk shifting is an inseparable element of risk elimination in NEO deflection.

Agreeing to deflect a NEO and deciding on which direction the impact point should be shifted are therefore clearly decisions which must be coordinated among the international community.

## 6. Functional needs

In fact the above example is just one of many challenges which will necessitate coordination between nations in order to protect life on Earth from future NEO

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impacts. In preparing its recommended decision program, *Asteroid Threats: A Call for Global Response,* for the United Nations the ASE and its Panel on Asteroid Threat Mitigation recognized the vital role the UN must play in providing the forum for affecting such international coordination.

While the final shape of an international regime for responding to the NEO challenge will appropriately be determined only following substantive discussion among and between nations, the ASE and its Panel have identified three functional areas which would need to be addressed within any such agreement.

### *6.1. Information gathering, analysis, and warning*

An Information, Analysis, and Warning Network 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 establish criteria for issuing NEO impact warnings.

Among the responsibilities that might be assigned to this Information, Analysis, and Warning Network are the following:

(a) To serve as the official source of information on the NEO environment.
(b) To designate and maintain the official clearinghouse for all NEO observations and impact analysis results.
(c) To review the existing NEO information set provided by JPL/Sentry and NEODyS and possibly recommend modifications to them.
(d) To recommend policies to the Mission Authorization and Oversight Group regarding criteria for warning and, with MOAG approval, issue NEO warnings and “all-clear” notices.
(e) To consider and recommend to the Mission Authorization and Oversight Group a NEO threat public information policy, and explore what threshold should trigger release of information like the risk corridor, potential tsunami simulations, and other potential impact information.
(f) To identify in cooperation with United Nations Member States a focal point to engage designated national/international disaster response entities.
(g) To assist in mitigation response planning.
(h) In cooperation with the Mission Planning and Operations Group, to recommend to the Mission Authorization and Oversight Group the criteria for initiating the planning of a deflection campaign.
(i) To develop and recommend to the Mission Authorization and Oversight Group the threshold NEO characteristics that warrant international community attention.
(j) To develop and recommend to the Mission Authorization and Oversight Group a NEO impact public information plan.

### *6.2. Mission planning and operations*

A Mission Planning and Operations “Group”, drawing on the expertise of the space-faring 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.

Examples of responsibilities which might be assigned to a Mission Planning and Operations Group are:

(a) To determine specific decision and event timelines for all NEOs selected for preliminary deflection campaign analysis
(b) To develop and recommend to the Mission Authorization and Oversight Group a process for assigning operational responsibility for a deflection campaign.
(c) To evaluate and recommend to the Mission Authorization and Oversight Group alternative deflection concepts proposed by space-faring nations.
(d) To develop the necessary information requirements for mission planning, and transmit them to the Information, Analysis, and Warning Network.
(e) To develop cost models for each approved deflection campaign concept, including each planning and mission operations event.

### *6.3. Mission authorization and executive oversight*

The United Nations should exercise oversight of the above functions through an intergovernmental Mission Authorization and Oversight “Group”. 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

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Group would submit recommendations to the Security Council for appropriate action.

This institutional element, which must represent the international community as a whole, should have responsibility, inter alia;

(a) To develop a policy to fund those United Nations Member States who conduct authorized NEO activities on behalf of the international community. Submit final recommendations on such a funding policy to the United Nations Security Council for adoption and implementation.
(b) To consider and propose for adoption, by the appropriate United Nations organs, threshold criteria submitted by the Information, Analysis, and Warning Network concerning NEO alerts, warnings and actions.
(c) To consider and decide those general policy questions presented and/or recommended by the Mission Planning and Operations Group.
(d) To sit ex-officio on all Information, Analysis, and Warning Network and Mission Planning and Operations Group sessions.

These, and other necessary actions that will emerge in the substantial discussion on this challenge to follow, must be systematically integrated into a coordinated decision system by the international community.

## 7. In conclusion

An adequate global action program must include deflection criteria and campaign plans which, when conditions warrant, can be implemented rapidly and with little debate by the international community. In the absence of an agreed-upon decision-making process, we may lose the opportunity to act against a NEO in time, leaving evacuation and disaster management as our only response to a pending impact. A single such missed opportunity will add painful fault-finding to the devastating physical effects of an impact. The international community should begin work now on forging its warning, technology, and decision-making capacities into an effective shield against a future collision.

Now that humankind has the scientific, technical and operational capabilities both to predict whether an asteroid will come too close for comfort, and to launch operational missions to divert a potential impact, it is time for the international community to identify the decision-making institutions and begin the development of a coordinated decision-making process. This decision-making program proposed by the International Panel is only the first step in that direction.

The Association of Space Explorers and its Panel on Asteroid Threat Mitigation are confident that with a program for concerted action in place, the international community can prevent most future impacts. The Association of Space Explorers and its Panel are firmly convinced that if the international community fails to adopt an effective, internationally mandated program, society will likely suffer the effects of some future cosmic disaster—intensified by the knowledge that loss of life, economic devastation, and long-lasting societal disruption could have been prevented. Scientific knowledge and existing international institutions, if harnessed today, offer society the means to avoid such a catastrophe. We cannot afford to shirk that responsibility.

## References

[1] Since the presentation of this paper at the Glasgow IAC in October 2008, the ASE report was formally introduced in the February 2009 UN COPUOS Scientific and Technical Subcommittee, and the Report and its recommendations are under active consideration by COPUOS.
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[4] Open Letter of the Association of Space Explorers, in: 19th Annual Congress, Salt Lake City, 14 October 2005 ⟨http://www.space-explorers.org/committees/NEO/docs/Open_Letter.pdf⟩.
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