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THE NEO THREAT: INTERNATIONAL POLICY ISSUES

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While it is generally recognized that near-Earth object (NEO) impacts are a global threat it is less well understood that the decisions associated with deflection and mitigation of these objects will require international cooperation. Existing and foreseeable future deflection capabilities will require that deflection maneuvers be executed many years ahead of any potential impact in order to provide time for sufficient orbital changes to take effect. As a result any decision to deflect a threatening NEO must generally be made decades in advance of the potential impact. One consequence of this timing constraint is that, in many cases, the residual uncertainty in the position of the NEO at the time of impact will be larger than the diameter of the Earth. The Path of Risk (PoR), the locus of potential impacts across the face of the Earth, will cross many international boundaries thereby placing the people and infrastructure of many nations at risk. Furthermore in the process of deflection the nominal impact point is shifted along the PoR toward the limb of the Earth off which the deflection is targeted. Assuming some risk of an unsuccessful deflection or fragmentation of the NEO in the process of deflection those nations along the PoR in the direction of the deflection will be placed, at least temporarily, in a situation of increased risk until the deflection is successfully completed. Because of these and other considerations international cooperation in the NEO threat decision process will be required. Threshold threat definitions, cost sharing, indemnification, risk sharing and many other issues will confront the international community in arriving at a coordinated agreement on how to respond to NEO impact threats.

BACKGROUND

In 1998 the US Congress established what is popularly known as the Spaceguard Survey[i], assigning the National Aeronautics and Space Administration (NASA) the goal of discovering 90% of all near-Earth objects (NEOs) greater than 1 km in diameter within 10 years. In the intervening 9 years NASA has implemented a search program which, in cooperation with professional and amateur astronomers around the world, has discovered and cataloged 705 of an estimated 1100 such objects[ii].

Recognizing that NEOs much smaller than 1 km can cause devastation at the local and regional level should they impact Earth, and responding to the recommendations of several organizations who had analyzed the situation, the US Congress revised the Spaceguard Survey goal in December 2005 to reflect this concern[iii]. NASA's new goal is now to discover 90% of all NEOs greater than 140 meters in diameter by 2020. While NASA has not yet specified how it intends to meet this goal it is prudent to anticipate the rapid increase in NEO discoveries over the next 13 years and to consider the implications of this acceleration.

In addition to establishing the new Spaceguard goal for NASA, the Congress also amended NASA's legal charter to include the following directive[iv].

> "The Congress declares that the general welfare and security of the United States require that the unique competence of the National Aeronautics and Space Administration be directed to detecting, tracking, cataloguing, and characterizing near-Earth asteroids and comets in order to provide warning and mitigation of the potential hazard of such near-Earth objects to the Earth"

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While the US Congress refrained from explicitly directing NASA to provide warning and mitigation of NEOs it made very clear its intent that the detection, tracking, cataloguing and characterizing of NEOs is to be done in order to support such warning and mitigation.

It is in the context of the emerging NEO environment that this paper explores its implications for the decision process once a NEO threat is discovered. The driving force in the emerging scenario is the 120,000 NEOs in this new 140 meter target population compared with 1100 objects in the former 1 km cohort[v].

It is no exaggeration to state that by 2020, of the approximately 10,000 NEOs anticipated in the new database with a non-zero probability of Earth impact over the next 100 years there will be many that appear to threaten impact with the Earth. The dilemma for decision makers, and the international community specifically, arises in that action to prevent a NEO impact will often have to be made while such an impact is only probable, not certain. It is therefore likely that by 2020 the international community will be confronted with one or more such perceived threats and be expected to make a timely decision re mitigation and/or deflection.

DECISION MAKING

Any concept of protecting the Earth from NEO impacts must include within it three essential components; early warning, deflection capability, and decision making.

With a population of NEOs which can do serious damage on impact in excess of 500,000 the early warning job is substantial[vi]. Given that orbital mechanics and optical limitations combine to provide only episodic tracking of these objects the task is especially daunting. Nevertheless this fundamental element of the challenge is underway in the U.S. and elsewhere, going by the popular name of the Spaceguard Survey.

The deflection challenge is considerably less well developed. While several viable concepts exist using available technology, they have not been tested nor are there any existing plans within the world's space-faring nations to do so. Furthermore the existing concepts, even if demonstrated, would be effective for only a portion of the overall threat. A comprehensive deflection capability will require advanced space propulsion and there are no plans currently under consideration to develop this technology.

Notwithstanding the challenges of early warning and deflection the issue of making timely decisions when a threatening NEO is discovered is likely to prove even more intractable. The fundamental reason for this is that unlike early warning and deflection which can be reasonably addressed by national entities, the decision making for NEO deflection is inherently an international issue and nation states will have to work together toward a common position. Since the NEO challenge is planet-wide and all nations are at risk the United Nations would seem to be the logical institution to deal with this challenge.

WHY THE UN?

Before exploring the decision process itself the rationale for recommending the United Nations as the responsible agency needs to be examined further.

The determining factor which leads to this conclusion is that telescopic measurements of the location of a NEO are not exact but always contain small uncertainties. Successive measurements over time lead to a decrease in the uncertainty of the current position of the NEO but never shrink the uncertainty to zero. Furthermore as the orbit of the NEO is calculated and its position along the orbital path is projected into the future, the small initial uncertainties stretch into an extremely long and narrow ellipsoid aligned with the orbital path.

This extended ellipsoid of uncertainty defining the future possible positions of the NEO is so long and narrow that it is generally referred to as a line of variations (LOV)[vii]. Even after a year or more of tracking the LOV may remain several thousand Earth diameters in length at the time of potential impact while at the same time being only several tens of kilometers in width.

The prediction of a potential impact then reduces to the question of whether in the future this line of virtual asteroids cuts through the Earth as the paths of the NEO and the Earth cross. If the LOV cuts through the Earth at some future time then there is a possibility that the actual NEO is represented by the virtual asteroids in that portion of the LOV and an impact probability is calculated.

Over time and with continuing telescopic and occasional radar sightings, the uncertainty of the position of the NEO is reduced and the LOV shrinks.

If the revised LOV no longer cuts through the Earth the impact probability drops to zero and no impact threat exists. However, if as the LOV shrinks it still cuts through the Earth then the impact probability generally rises.

Until the LOV shrinks to less than the diameter of the Earth the potential impact point can lie anywhere along a line extending across the entire planet. This line, the locus of the potential impact points across the Earth, is referred to as the Path of Risk (PoR) (Figure 1).

While the length of the LOV generally shrinks as more observations are integrated into the database, the PoR itself does not vary until the LOV either moves off the Earth or shrinks to a length less than the Earth's diameter. In many, if not most cases, at the latest time a decision to deflect can be made the PoR still extends across the planet. The uncomfortable fact is that at the decision time all nations through which the PoR passes are approximately equally at risk. Which of them then makes the deflection decision? Or how, between them, do they collectively make this decision?

Since each NEO with a non-zero probability of impact has a unique PoR this potential dilemma exists for all nations (Figure 2). It is therefore our position that general principals of action should govern the decision making, that these principals and policies should be developed prior to a specific threat arising, and that the development of these general decision principals should be the responsibility of the UN.

An even more challenging aspect of NEO deflection is that once a deflection is initiated the original impact point located at some specific place along the PoR is now shifted either toward the leading or trailing edge of the Earth. A successful deflection will shift the NEO trajectory so that the impact point moves entirely clear of the Earth. Should the deflection be interrupted (e.g. during a slow deflection such as the case of a Gravity Tractor) or only partially successful (e.g. in the case of a Kinetic Impactor) then there will be a new impact point located in the direction of the Earth limb toward which the deflection was aimed. Of note is that this new impact point will nevertheless lie on the original PoR.

Since there is always the possibility, however small, that a deflection once initiated will be interrupted or only partially successful, the implication is that there will be a set of nations which will be exposed to slightly increased risk to their populations in the process of totally eliminating the risk to all.

Again, the choice of which direction a deflection takes and perhaps which technology is utilized for the deflection will require the cooperation of many nations. These choices will be difficult to make, and especially so under the pressure of an unrelenting deadline. For this reason we call for the establishment of general decision principals and criteria prior to the realization of a specific threat.

DECISION TIMING

Given any set of deflection means there comes a time when, if passed, a deflection is no longer possible. Beyond this time the only recourse for society is to evacuate the specific area prior to the impact event, i.e. mitigation. Since there will be substantial advanced warning there should be minimal loss of life albeit the infrastructure losses may be severe.

The decision time is defined by the sum of two independent phases leading to a successful NEO deflection; the deflection interval and the execution interval. If one backs up from the nominal time of impact to the latest time at which a deflection maneuver can be successfully completed, this defines the deflection time and the deflection interval. Backing up further from the deflection time to the latest time at which a decision to deflect can be made defines the decision time and the execution interval. The execution interval must include all elements of design, manufacturing, testing, launch, rendezvous and deflection execution. Additional time must be allotted to account for the availability of launch windows and for the execution of a backup mission should that be desired.

Considering orbital mechanics and the global experience with space operations the decision time will seldom be less than 20 years prior to an anticipated impact and may extend to beyond 30 years depending on the specific deflection challenge.

One issue introduced by the timing sequence above is that of liability, moral if not legal. If, for example, the United Nations, proactively decides not to act to deflect the NEO, after due consideration of the specific threat, and the threat materializes, are the UN member states liable for offsetting the cost of evacuation for the nation or nations affected? Similarly, and perhaps even more contentious, if the UN simply continues to debate the options until the deflection time has passed, is there implied liability?

QUALITY OF INFORMATION

A critical question for the decision maker regards the quality of the information available in each particular case at the time a decision has to be made. Clearly if circumstances are such that a substantial amount of tracking over several years have been completed and the uncertainty in the position of the NEO at the time of impact is smaller than the dimensions of the Earth, the decision is obvious. There will be very little uncertainty that the Earth will be impacted if nothing is done.

However if, as will often be the case, the uncertainty in the position of the NEO at the time of impact is significantly larger than the dimensions of the planet, there will remain a large uncertainty as to whether or not an impact will actually occur in the absence of action. If, for example, at the decision time for a specific NEO the probability of impact is 1 in 10 should a deflection be initiated? If the probability is 1 in 100? 1 in 1000?

Compounding this challenge are the cases in which the NEO at issue will experience a close gravitational encounter prior to the nominal impact[viii]. In these instances the good news is that the deflection itself is likely to be far less demanding than if such an encounter did not intervene. The consequent bad news is that the uncertainty of whether or not the NEO will indeed pass through the critical keyhole is much higher than the uncertainty if the NEO were headed for a direct impact.

When one looks at the existing database and works through the numbers it becomes clear that there will be, for a considerable time to come, many instances in which decisions of whether or not to initiate a deflection will have to be made while the impact probability is uncomfortably low.

CONCLUSION

The decision of what to do about a NEO that appears to threaten an impact with Earth is inherently an international issue. Not only will it frequently be the case that the potential impact may ultimately occur in any of several countries, but in the event a deflection is initiated several of these countries will experience a slight increase in risk in the process of reducing the risk to everyone to zero.

While international coordination can be organized outside the United Nations the fact that all nations are, in general, threatened by NEO impacts argues for the deflection principles and policies to be determined within the only international institution that represents all nations.

A decision to act (or not act) to avoid a NEO impact must be made well in advance of a specific threat. While the promise of advanced technology may ultimately allow some relaxation in the deflection interval a late deflection decision will always be considerably more expensive than an early one. Assuming the availability of current technology it is only a portion of the potential threat (unknown in size) that can be deflected. The development of higher performance advanced propulsion is critical to the eventual availability of a comprehensive planetary protection capability.

Understanding the decision timing as well as the implications of the various deflection options will require access to a considerable amount of analytic data about the NEO itself, its orbital characteristics, the launch constraints and the performance characteristics of the deflection methodology.

At the current time this data is only available to the United Nations via a few nations who are monitoring the NEO impact challenge. Unfortunately even in these nations the full set of information necessary to making a rational deflection decision is not being developed. Without improvement in this situation no rational, coordinated NEO deflection decision can be made.

The circumstances described in this paper led the Association of Space Explorers (ASE) to form its Committee on NEOs[ix]. The ASE, which obtained official observer status at the UN Committee on Peaceful Uses of Outer Space (COPUOS)[x] over 20 years ago, was granted membership in Action Team 14 (NEO) of COPUOS and is working with member states to address the issues identified above. The ASE is conducting a series of four international workshops in which a group of preeminent international specialists in diplomacy, international law, space technology, risk analysis and casualty insurance will draft a Protocol on NEO Deflection which will be submitted to the UN/COPUOS via AT-14 in the spring of 2009. This draft protocol will hopefully form the basis for a formal international agreement specifying how, when confronted with a NEO threat, the UN will arrive at a timely, coordinated decision on appropriate action.

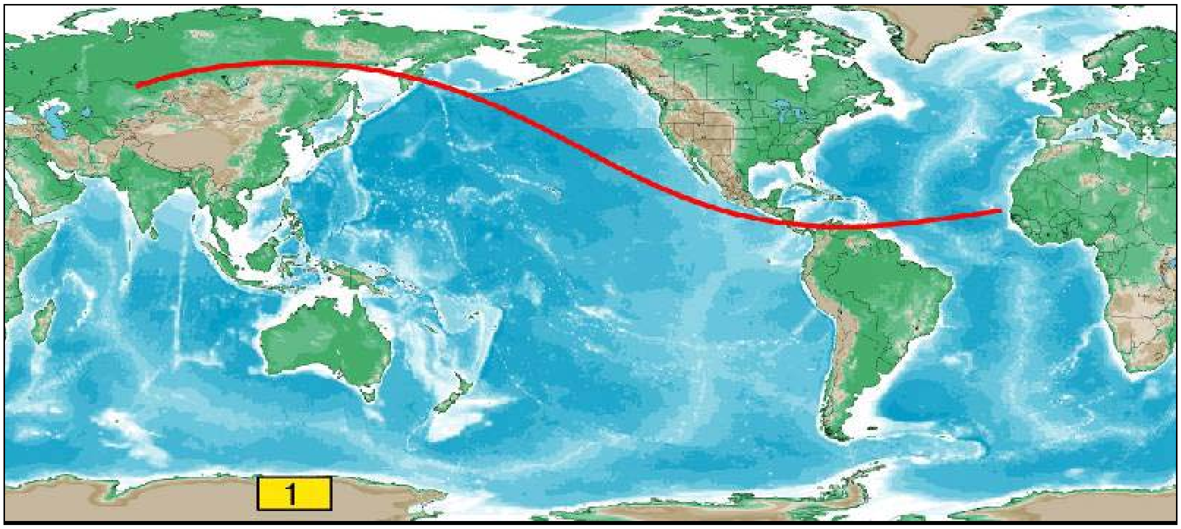

Figure 1. Apophis Path of Risk. This red line stretching over 180 degrees around the planet defines the narrow corridor within which, if it impacts the Earth on April 13, 2036, Apophis will hit. The probability of this occurrence, as of Feb07 is 1 in 45,000.

Figure 2. Apophis plus 100 randomized Paths of Risk. The red lines show a representative set of Paths of Risk for the 100 NEOs of comparable concern to Apophis anticipated by the completion of the current Spaceguard Survey in 2020. Virtually every country in the world will be at some risk thus illustrating the need for international cooperation in any deflection decision.

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[i] *Spaceguard Survey*, NASA Ames Space Science Division, 115 pages, http://impact.arc.nasa.gov/downloads/spacesurvey.pdf
[ii] NEO Discovery Statistics, NASA/JPL, http://neo.jpl.nasa.gov/stats/
[iii] George E. Brown, Jr. Near-Earth Object Survey, S. 1280, Sec. 321, http://frwebgate.access.gpo.gov/cgibin/getdoc.cgi?dbname=109_cong_public_laws&docid=f:publ155.109.pdf
[iv] Ibid; Sec. 321 (d)(2)(B)
[v] The population of near Earth asteroids, Figure 2-3, pg. 17, http://neo.jpl.nasa.gov/neo/neoreport030825.pdf
[vi] Ibid
[vii] See definition, http://neo.jpl.nasa.gov/risk/doc/sentry.html
[viii] Threat Characterization: Trajectory Dynamics, White Paper 39, NASA Workshop on NEOs, June 06, http://www.b612foundation.org/papers/wpdynamics.pdf

[ix] Association of Space Explorers Committee on NEOs, see http://www.space-explorers.org/committees/NEO/neo.html
[x] United Nations Committee on Peaceful Uses of Outer Space, see http://www.unoosa.org/oosa/COPUOS/copuos.html