B612 Foundation

760 Fifth Street East, Sonoma, CA 95476 707-343-1627

Testimony of Russell L. Schweickart, Chairman, B612 Foundation, before the Space and Aeronautics Subcommittee of the House Committee on Science and Technology
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Mr. Chairman and Members of the Committee:

Thank you for the opportunity to testify on this important subject; an issue of increasing interest regarding the protection of life and property around the planet.

I represent B612 Foundation (B612), a private non-profit corporation founded in 2002 by a group of astronauts, astronomers, planetary scientists and engineers to advocate and develop the means of diverting a near-Earth object (NEO) threatening an impact with Earth. B612 has developed several alternative concepts for deflecting NEOs and we have actively urged NASA, the Congress, and others to pursue the NEO challenge beyond search and discovery and into mitigation and prevention.

I will start by commending the Committee for its efforts since the early 1990s in seeing that this public safety issue is responsibly addressed. The impact of near-Earth objects with the Earth is properly described as a cosmic natural hazard of potentially unprecedented dimension, threatening both life and property. Unlike other natural hazards, however, we can in this instance, using current space technology, both predict and prevent the occurrence of such a disaster.

No other natural hazard presents such a wide range of potential destruction, but in no other case are we fortunate enough to have at hand the advanced technology and creative imagination to mitigate such a catastrophic event. The range of explosive impacts we may be called on to prevent extend from the “Tunguska Event” of 1908, approximately a 5 megaton (MT) explosion over Siberia (equivalent to over 300 Hiroshima bombs) up to impacts 100,000 times larger – large enough to destroy civilization and threaten the survival of humanity. We intend to prevent such infrequent but devastating events by slightly and precisely modifying the orbit of a threatening NEO,

causing it to pass harmlessly by the Earth. Stated differently, we intend, using available space technology, to slightly alter the workings of the solar system in order to enhance human survival on planet Earth.

To realize such a bold claim we must put in place three critical components of a response system. They are: advanced notice (i.e. an early warning system), a demonstrated deflection capability, and a standing decision process to enable timely action.

The Congress, NASA, and other key global players are to be congratulated for their excellent work in implementing the first phase of the early warning system, the Spaceguard Survey, which has been in operation since 1998. The Congress is to be further commended for its vision in mandating that NASA take the next critical steps as expressed in the George E. Brown, Jr. Near-Earth Object Survey Act of 2005 (the Act). The Act extends the Spaceguard Survey goal, directing NASA to "detect, track, catalogue, and characterize … near-Earth objects equal to or greater than 140 meters in diameter…" and to "achieve 90 percent completion of [the survey] within 15 years after the date of enactment of this Act."

The Congress also directed that "The Administrator shall transmit to Congress not later than 1 year after the date of enactment of this Act an initial report that provides the following:

(A) An analysis of possible alternatives that NASA may employ to carry out the Survey program, including groundbased and space-based alternatives with technical descriptions.

(B) A recommended option and proposed budget to carry out the Survey program pursuant to the recommended option.

(C) Analysis of possible alternatives that NASA could employ to divert an object on a likely collision course with Earth."

It is NASA's mixed response to these three directives which prompts my testimony here today.

I have been specifically requested to address the following four questions;

1. What are your perspectives on NASA's *Near-Earth Object Survey and Deflection Analysis of Alternatives* Report to Congress? Do you agree or disagree with the report's findings and recommendations?

2. Which, if any, relevant factors, data, or options are not addressed in the report and how should NASA investigate those areas?

3. What does NASA need to do now to understand and mitigate the risks of potential NEO impacts?

4. What governance structures should be established to address potential NEO threats?

1. Perspectives on the NASA Report

My response to the first question is in three parts, corresponding to the three components of the Congressional direction to NASA.

a) Analysis of Survey Program Alternatives:

I believe that NASA did a very good job (with the exception of the NASA life cycle cost estimation for the several survey alternatives) in developing and comparing a set of alternative Survey designs to meet the 140-meter goal. While I am not personally qualified to comment on the NASA costing I note that knowledgeable Pan-STARRS and LSST personnel challenge the NASA figures used. These experts claim that the actual costs for both cooperative and dedicated use of such telescopic facilities are considerably lower than those projected by NASA.

One factor not addressed in NASA's analysis of options to meet the revised Survey goal was the capability of various search system options for NEO tracking vice NEO discovery. While all of us in the NEO community strongly support moving aggressively to meet Congress's 140-meter discovery goal the fundamental intent of this enterprise is to protect the Earth from NEO impacts. This ultimate purpose is achieved by both the discovery of NEOs

which might pose a threat AND also by tracking them accurately to determine whether or not a deflection campaign is necessary.

It is an unfortunate reality that ground-based telescopic tracking produces, for many challenging NEOs, discontinuous information; data dropouts may last for several years at a time. Should such a critical data dropout occur just as a NEO is found to threaten an impact, the decision on mounting a deflection campaign may well have to be made on the basis of uncomfortably "stale" tracking data. The well-known NEO Apophis, which currently has a 1 in 45,000 probability of collision with the Earth in 2036, is in such a data dropout period at this time. We were last able to see Apophis in August 2006 and we will not see it again until 2011-2012. For Apophis this data interruption is uncomfortable, but not critical since we will see it again before we need to decide on a deflection campaign. This is, however, simply a matter of chance and in many instances in the future we will not be so fortunate.

The orbital phasing responsible for this interrupted tracking can be eliminated by selecting any of several space-based search options in NASA's analysis to augment the ground-based systems. While NASA reports that overall costs for space and ground tracking are comparable (a controversial claim), the tracking quality provided by a telescope in a Venus-like orbit, in particular, is vastly superior. The dual-band IR telescope is especially preferable since it also improves greatly our estimates of NEO mass (and thus impact energy).

In summary, NEO search and discovery is extremely important. NEO tracking, however, is equally important for deciding whether and when to mount a deflection campaign. The dual-band IR telescope in a Venus-like orbit offers both discovery and tracking advantages at a cost comparable to the best ground-based telescopic options.

b) Recommended Program and Supporting Budget:

With respect to the second Congressional charge to recommend a program to meet the 140-meter search goal and a budget to support it, NASA failed to respond. NASA opted instead to state the obvious, that "… due to current budget constraints, NASA cannot initiate a new program at this time." Of

course NASA's tight fiscal situation is precisely why the Congress requested not only a recommended program but also a proposed budget necessary to carry it out.

One can sympathize with NASA's fear of the dreaded "unfunded mandate" from Congress while decrying the Agency's decision to defy the Congressional directive and to delay the initiation of this critical search program. Congress, however, must also recognize and confront the dilemma it imposes on NASA (and other agencies) when it directs action without the specific identification of funds to support the work. Yet given that Congress explicitly directed in its mandate that NASA provide it with a proposed budget to support the program NASA cannot be excused.

I can only urge that **the Congress should again direct NASA in the clearest language possible to comply with the law and recommend a search program and supporting budget. (Recommendation 1)** It is time for the nation to aggressively pursue this urgent NEO program.

c) Analysis of Deflection Alternatives:

B612 Foundation believes that NASA's analysis of deflection alternatives, as reported to the Congress, has serious technical flaws. NASA's findings and recommendations misunderstand, mischaracterize, and misrepresent many of the critical issues and options involved in the diversion of a threatening NEO. Furthermore the NASA Report fails to address a number of crucial issues which lie at the very heart of the deflection challenge.

An analysis of the errors of both commission and omission are too numerous and detailed to include in this testimony. I have therefore attached to this written testimony, and urge the Members and their staff to read, several documents which address these errors in depth. These documents include;

1. An exchange of correspondence with Congressman Dana Rohrabacher regarding clarification of the intent of the Congress in the nature of the NEOs to be considered for diversion (attachments 1 & 2),
2. An "*Independent Analysis of Alternatives that could be employed to divert a NEO on a likely collision course with Earth.*" (attachment 3; also available at http://www.b612foundation.org/press/press.html, #15), and

3. Two detailed critiques of the NASA Report addressing on a point-by-point basis specific errors in the NASA analysis. (attachments 4 & 5; also available at http://www.b612foundation.org/press/press.html, #16)

To appreciate the depth of the technical errors in the Report, I strongly urge that these appended documents be reviewed in detail. I will summarize here a few of the key points.

Size matters

In examining the technical alternatives for diverting threatening NEOs, NASA selected "… a set of five [note: there were actually 7] scenarios representing the likely range of threats." In fact, the set of impact scenarios NASA chose as "typical" were extraordinarily challenging, resulting in a preference for a deflection concept delivering extraordinary capability, i.e. nuclear explosives.

The least challenging of the NEOs NASA considered in its analysis is part of a group that comprises just 2% of the potential impact cases. The impact frequency of such an object is once every 35,000 years. The remaining objects considered by NASA range upward to a one kilometer asteroid (one impact per million years) and a one-kilometer, long-period comet (even more rare).

In fact, objects which hit much more frequently and yet deliver considerable impact energy make up 98% of the likely impact threat. The most likely of these objects to impact is comparable to the Tunguska event of 1908 in Siberian Russia. That event is estimated to have exploded with the force of about 5 megatons of TNT equivalent, or over 300 Hiroshima bombs. Had the Tunguska event been instead the "London event", or "Moscow event", it would have destroyed not just 800 square miles of forest and a few reindeer but an entire city and its population.

As Congressman Dana Rohrabacher stated in his clarification letter to B612 on this subject, "While it is important to understand what technology exists or needs to be developed to divert the larger and more devastating NEOs

the first order of business is to insure that we have a clear understanding of that the options are for the situations we are most likely to encounter."

A random impact occurring directly over a major city is, of course, highly unlikely. Yet when the possibility of such an event and the means of preventing it from occurring are known to exist by the general population it is reasonable to conclude that public pressure on the international community will successfully demand that we initiate a deflection.

Given then a cohort of "most likely NEOs to be deflected" ranging from a Tunguska-like object at the smallest and most frequent end of the scale up to events 100 times less frequent, we find that over 99% of them can be deflected using non-nuclear means.

The need for the availability of nuclear explosions for deflection in extreme cases cannot currently be ruled out, but the likelihood of such a demand materializing over the next several decades is extremely small. Furthermore our search efforts will make the need for such a solution increasingly unlikely over time.

Precision matters

NASA uses the word "effectiveness" in its Report purely as a measure of how much momentum change can be imparted to the asteroid. E.g., in its "Key Findings for Diverting a Potentially Hazardous Object", the first sentence of the first finding states "Nuclear standoff explosions are assessed to be 10-100 times more effective than the non-nuclear alternatives analyzed in this study." The technical term for NASA's undefined word "effectiveness" in this instance is "total impulse", i.e. the amount of momentum imparted to the asteroid in the process of the deflection.

Without doubt the total impulse available is a key measure of any deflection concept. However all of the impulsive (i.e. relatively instantaneous as juxtaposed with slow) deflection techniques evaluated are, while quite powerful, highly uncertain with regard to predicting the precise total impulse delivered. Experts in the field estimate uncertainties ranging from factors of two to five or even higher in the resulting total impulse delivered by either the nuclear or kinetic impact deflection concepts.

Certainly “strength” may well be needed in the deflection of an object on an impact trajectory. The first order of business is, without question, to ensure that the NEO is deflected sufficiently that it miss the planet.

What NASA totally missed however is that whenever an asteroid passes near the Earth (or any planet) it passes through a region in which are scattered hundreds of small impact “keyholes”, small areas in Earth’s proximity through which if the asteroid passes it will return within a few years and impact the Earth. Any deflected asteroid which misses the Earth must transit this minefield of impact keyholes.

Because the percentage of space taken up by such keyholes is small compared with the space between them the probability of the NEO passing through one is fairly low. However the consequences of passing through such a keyhole are severe. Thus, whether or not a deflected NEO misses the keyholes cannot be left to chance. A successful deflection must therefore be defined as one which causes the potentially impacting asteroid to not only to miss the Earth but also to miss all impact keyholes. Without this constraint any deflecting agency would be limited to declaring, “we successfully deflected the asteroid away from an impact with Earth… and it is unlikely that it will return for an impact any time soon.”

A successful deflection requires <u>both</u> adequate strength <u>and</u> high precision. Immediately following an impulsive deflection the new orbit of the asteroid must be precisely determined and examined for a future keyhole transit. if headed for a keyhole then a small “trim” maneuver can be executed using a weak but precise “slow push” (as NASA refers to it) deflection to avoid that critical passage.

This combination of imprecise strength and precise adjustment is both necessary and sufficient to declare to the world that a fully successful deflection has been achieved. NASA completely missed this essential point in its analysis.

These two key flaws are illustrative of the quality of the analysis on deflection alternatives in the NASA Report. I again refer you to the attachments for greater detail.

2. How should NASA now proceed on these issues?

I believe that **NASA should produce a supplement to its Report to Congress based on new knowledge which has come to light since it began its analysis. (Recommendation 2)** The state of knowledge of the NEO deflection challenge is increasing very rapidly and NASA has not stayed abreast of recent developments. This is not entirely NASA's fault since it has no assigned responsibility in this critical area. Nevertheless given the Congressional request for an analysis of alternatives, and the urgent need for a legitimate understanding of these options, I urge that NASA revisit this matter. I list below, inter alia, a few suggestions in this regard.

a) NASA should re-examine the NEO deflection challenge utilizing the most likely set of threatening NEOs that we will likely confront. The lower bound of this cohort should lie in the range of the 1908 Tunguska event. (Note: This does not imply a change in the 140 meter search goal. In meeting the 140-meter goal NASA will discover a large fraction of the Tunguska sized NEO cohort as well.)

b) NASA should examine the need for precision and control in the deflection process taking particular account of the role impact keyholes play during a deflection.

c) NASA should further review and analyze its current (and future) database of NEOs to determine the frequency with which close gravitational encounters occur between the time of NEO discovery and the time of potential impact. In the case where such encounters occur (e.g. Apophis, the most threatening NEO in the current database) analysis shows that a single mission can often be employed to both determine if an impact is indeed threatened and take "slow push" preventive action if necessary. We must understand this class of prospective impacts and capitalize on the potential for a simple and less costly deflection mission.

d) NASA should fully assess the value of a dual-band IR telescope in a Venus-like orbit for search <u>and</u> tracking purposes. NASA has already

analyzed this instrument's search capability, but it should extend its thinking to evaluate how to use such an instrument to support our impact prevention capability.

e) NASA should correct its faulty analysis of the cost and technological readiness of the Gravity Tractor.

3. What needs to be done to mitigate the risks of potential NEO impacts?

There are two key actions to be taken that would make significant progress toward protecting the Earth from the potential devastation of NEO impacts. Neither of them is expensive yet both of them are extremely important, even urgent, in light of the anticipated rapid rise in the NEO discovery rate in the near future.

a) **NASA should assign someone in its NEO Program to the specific task of thinking through, analyzing and understanding the NEO deflection challenge. (Recommendation 3)** So long as the NASA effort, and therefore thinking, is restricted to the NEO discovery process only, the government will lack the critical information and understanding needed to protect the Earth from NEO impacts. There is critical linkage between the upstream process of NEO search and orbit analysis and the downstream information needed to deflect NEOs. Absent someone explicitly thinking this through we stand justly accused of focusing on numeric goals for the sake of meeting an abstract quota. I hasten to point out that NASA cannot make such an assignment without being given the explicit responsibility for this critical function.

b) **NASA should validate a basic NEO deflection capability through the execution of a demonstration mission. (Recommendation 4)** While deflection concepts can and indeed must first be worked out conceptually, in an endeavor as critical to public safety as deflecting an asteroid bound for an impact, our ultimate success in such a vital undertaking cannot depend solely on a paper analysis. A demonstration program can be performed on a non-threatening

asteroid at a cost no more than that of a typical small scientific mission. This effort need not, and perhaps should not, be undertaken as a US mission per se. The European Space Agency (ESA) has already performed the initial feasibility and design phase of such a mission (though it should be modified to validate the "slow push" component). Were an international partnership agreement negotiated a reasonable cost estimate for a complete NEO deflection demonstration campaign could be performed for about the cost of a single scientific mission.

4. What governance structures should be established to address potential NEO threats?

I believe this to be the single most important question of this hearing. Until and unless an explicit assignment of responsibility within government is made to protect the Earth from NEO impacts, no significant advances in our capability will be made, and the US public, and indeed the world public, will remain unnecessarily at risk

Ironically and somewhat counter intuitively, the full cost of assigning such responsibility and paying for its operations is almost vanishingly small. It is, nevertheless, a sobering responsibility, and an historic one. The very concept of being able to slightly alter the workings of the cosmos to enhance the survival of life on Earth is staggeringly bold. Yet this very capability lies within our technical means today. The missing element, the fatal missing element, is a governmental assignment of responsibility.

I would break this charge into two logical pieces.

a) First it seems to me that there exists today a single logical entity that should be responsible for the analysis, design, manufacturing and testing of a NEO deflection capability. That entity is NASA. NASA is our national space agency and is clearly charged with the development of our national space capability. This is, I believe, a clear and obvious choice.

   NEO work in NASA is, however, administratively in an orphaned status. Protecting the Earth from NEO impacts is neither space science nor

exploration, although there are elements of both involved. Protecting the Earth from NEO impacts is a public safety activity. Yet today within NASA and its supporting space science and exploration communities the strong perception is that a dollar spent on NEO work is a dollar taken from space science or exploration. This "zero-sum game" presumption cannot be allowed to persist. Yet until explicit responsibility and funding for NEO research, as a public safety responsibility, is assigned to NASA by the Congress, this terrible conflict will persist. I therefore recommend **that the Congress expressly assign to NASA the technical development elements of protecting the Earth from NEO impacts as a public safety responsibility. (Recommendation 5)**

b) The second element is considerably more challenging and controversial. That is, to which agency of government should fall the overall responsibility for protecting the Earth from this infrequent, but devastating natural hazard? This responsibility is greater than and somewhat separate from the technical issues discussed above.

While we have not addressed this matter above I will simply state unequivocally that the NEO mitigation decision process and the policies embedded within it are inherently international. Any NEO deflection will necessarily shift risk, however temporarily, between people and property across the planet. As we move a NEO away from an Earth impact, we necessarily shift its impact point from one region to another until we complete the deflection.

Given this characteristic, and I ask that you grant this arguendo, the response to a threatening NEO will involve complex and very sensitive international coordination and probably negotiation. This is a planetary challenge, not a national one. The policies, procedures, criteria, thresholds, and agreements which must be addressed are international political challenges and the US involvement will place in the hands of the agency responsible the lives and property of the world's entire population.

It would frankly be presumptuous of me to make a specific recommendation here. Obvious candidates for such a responsibility

include the Department of Homeland Security (DHS), the Department of Defense (DoD), and of course NASA. Many other agencies will clearly need to be involved in the decision processes given the potential of evacuation, migration (including cross border), and potentially unprecedented property destruction.

I therefore recommend **that the Congress study the issue of overall governmental responsibility for protection of the Earth from NEO impacts, perhaps with the assistance of specialized policy entities, and ultimately hold public hearings to engage a wide perspective on the issue. (Recommendation 6)**

In closing I would suggest a personal perspective based on having spent the last 6 years of my life studying this issue. NEOs are part of nature. A NEO impact is a natural hazard in much the same way as are hurricanes, tsunamis, floods, etc. NEO impacts are deceptively infrequent, yet devastating at potentially unimaginable levels. NEOs are however not our enemies. We do not need to "defend" against NEOs, we need to protect ourselves from their occasional impact, as we do with other natural hazards.

Unlike other natural hazards, however, NEO impacts can be predicted well ahead of time and actually prevented from occurring. If we live up to our responsibility, if we wisely use our amazing technology, and if we are mature enough, as a nation and as a community of nations, there may never again be a substantially damaging asteroid impact on the Earth. We have the ability to make ourselves safe from cosmic extinction. If we cannot manage to meet this challenge, we will, in my opinion, have failed to meet our evolutionary responsibility.

Thank you.