RAPID RESPONSE TO AN IMPACT THREAT. Joseph A. Nuth[1], [1]NASA's Goddard Space Flight Center, Code 690, Solar System Exploration Division, Greenbelt MD 20771 USA joseph.a.nuth@nasa.gov.

Introduction: With the upcoming launch of the NEO Surveyor Mission and the continuing operation of ground-based observational surveillance facilities, the timely detection of significant impact threats is assured. I suggest that the next priority for Planetary Defense should be ensuring a rapid response to the detection of a significant impact threat. There are two components to such a threat: Reconnaissance and Mitigation.

Detection of a potential impact threat triggers worldwide observational efforts to precisely determine the orbit of the threat. However, it is difficult to obtain sufficiently accurate information to predict the location or even the exact probability of impact far in advance of the actual event based on ground-based, or even earth orbiting observatories. The most accurate method for determination of impact probability and impact location is the use of a Reconnaissance Spacecraft.

If an impact threat is imminent, the faster a Mitigation Mission can be implemented, the more likely it will be to succeed. This is because a small change in the velocity of an impact threat propagates over time. The longer the time until impact, the smaller the velocity change (Delta V) needed to ensure that the threat crosses the Earth's orbit when the Earth is not at that precise location. It is much easier to deliver a small Delta V than a large Delta V. It is also easier to deliver a large Delta V to a small threat than to a larger one. Therefore, the more time available for a mitigation effort to act on the threat, the more massive a threat can be successfully mitigated.

The Requirement for Rapid Response: Many potential threats will ultimately miss the Earth. In most PDC exercises, when the probability of earth-impact reaches or exceeds ~10% a mitigation mission is seriously considered. However, it is not uncommon for the probability of impact to exceed this 10% threshold, but then to decrease as more observations eventually become available. For impacts that will occur decades or even centuries in the future, waiting to acquire the observations needed to determine if an impact will occur should not be a problem. However, for an impact that could occur in less than a decade a rapid response is required due to the long lead times needed to build and launch reconnaissance and mitigation spacecraft. This problem is exacerbated by the potential for a long cruise phase to reach the potential threat.

Following threat detection, characterization of the threat is the highest priority for the Planetary Defense community. Characterization includes determining the exact position of the threat in its orbit, determining the size, shape and composition of the threat, determining the rotation state of the threat, and determining the mass of the threat. If the threat will not impact the Earth, the other characteristics are irrelevant. If impact will occur, the sooner this is determined, the more likely a mitigation mission will succeed. The most accurate method to determine if impact will occur, and to pinpoint the most likely impact site is to survey the impactor using a reconnaissance spacecraft that can determine the exact location of the potential impactor.

If the threat will not hit the Earth, then no action is necessary. If the threat will impact the Earth, then mitigation efforts can begin immediately. In addition, the reconnaissance mission will have returned important information needed to plan a mitigation mission such as the size, shape and composition of the threat (leading to a more accurate mass estimate), an estimate of the rotation state if the threat is shown to be nonspherical (essential for planning mitigation that imparts Delta V to the threat), and, if rendezvous is possible, a direct measurement of the mass as well as other, less important details of the threat.

Building Spacecraft: NASA, ESA, JAXA and other space agencies have spent decades to find the most efficient methods to build reliable spacecraft. NASA has experimented with the concept of "faster, better, cheaper" and has rejected such techniques due to the higher probabilities of mission failures. Building typical research spacecraft using proven methodology requires approximately four to five years, depending on the complexity and reliability class of the mission. This is after the considerable preliminary design efforts have been applied to define the mission objectives, the instruments required to achieve those objectives, and the trajectory that most efficiently positions the spacecraft to achieve those objectives within approved cost constraints that lead to mission approval.

When we are faced with a potential, imminent, impact threat, does it seem reasonable to cut design reviews, rush construction and greatly reduce spacecraft testing when such actions are well known to decrease the probability of mission success? I suggest that any spacecraft built to respond to such a scenario should be designed and constructed to the highest standards possible. This philosophy precludes a "rushed, emergency" response. It demands that spacecraft requirements be well defined prior to need, and that spacecraft be designed, constructed, and tested at least as carefully as current standards dictate.

The next priority for Planetary Defense: There are at least two steps that can be taken to significantly increase the reliability and decrease the response time for spacecraft reconnaissance and threat mitigation [1]. The first, and lowest cost effort would be to conduct a thorough design study to define the requirements for both a reconnaissance and a mitigation spacecraft, and design both spacecraft using all currently mandated review processes. These requirements and designs would be subject to review and possible modification on some defined cadence to ensure that they remain current, avoid parts obsolescence and take advantage of the latest developments in spacecraft technology. Such designs could be implemented as soon as an imminent threat is detected, and mission approval is obtained, though several years would still be required before the first spacecraft launch could occur.

A much faster response can be achieved if both the reconnaissance and mitigation spacecraft discussed above have already been designed, built, constructed, tested and reside in storage when the threat is detected. Depending on the launch windows available to get to the threat, launch could occur within 3 – 6 months of receiving mission approval and with a high probability of mission success.

A Planetary Defense Threat Response Program: If we posit that it is essential that we respond to impact threats as rapidly as possible, with the highest possible probability of mission success, then we require prebuilt spacecraft prior to the detection of the threat [2]. In order to mitigate the potential for launch failure or other mishaps that could occur during cruise, two each of the reconnaissance and migration spacecraft should be in storage at any given time. These spacecraft should be replaced on a regular schedule in order to ensure use of the latest technology and to avoid parts obsolescence.

There is no need for both reconnaissance or mitigation spacecraft to be identical, though the initial construction would be less expensive and could be done on a shorter schedule if they were. Once all four spacecraft are in storage, the next priority is to replace the first spacecraft with a new model. A plan to update each stored spacecraft in turn on a set cadence would ensure a system that could rapidly respond to any new impact threat with the highest possible probability of mission success.

Retired spacecraft could be scrapped, but a better solution would be to release them to the scientific community, much as retired ICBMs were released for use as scientific launch vehicles. The community could respond to an Announcement of Opportunity to use the retired spacecraft similar to the program that redirected the Stardust and Deep Impact spacecraft to new targets to obtain new observations.

How do we justify such a program? Though an impact could destroy a city, a continent or even render the Earth uninhabitable, there is currently no imminent threat that such an event will occur within our lifetime. There is no precedent for mitigating such an enormous threat that has such a low probability of occurrence. There are however, precedents for the mitigation of much less catastrophic threats of higher probability. As an example, we mandate the installation of fire suppression systems in many buildings, even though such buildings are designed to prevent or contain fires. In practical terms, only a very small percentage of such buildings actually catch fire. However, given the relatively small expense of the fire suppression system relative to the cost of the building, the additional costs are justified based on the value of the building and its contents that would be destroyed in a fire as well as the human lives saved due to the fire suppression system.

Based on the above argument, ***the cost of the suggested Planetary Defense Threat Response System is a very small percentage of the value of a typical city, continent or even of Earth itself.*** The greatest incremental costs occur as the program is established and the initial complement of spacecraft are built and placed in storage. Annual costs are mitigated to some extent as stored spacecraft are released for scientific missions.

Does it make sense to cut corners and rush to build spacecraft to potentially save all life on Earth only after a threat has been identified? The greatest benefit of such a program is the ability to rapidly respond to a potential impact threat using spacecraft that have the highest probability of mission success, even if such a threat never materializes.

References

[1] **Spacecraft Design, Integration, & Test / Rapid Response Launch,** Benji Donitz, JPL & Joe Nuth, GSFC, for NEOWARP Final Report to PDCO. [2] **Defending the Earth from Long-Period Comets and Sneaky Asteroids: Short Term Threat Response Requires Long Term Preparation**" Joseph A. Nuth, Brent Barbee, Ronald Leung, Journal of Space Safety Engineering, https://doi.org/10.1016/j.jsse.2018.07.002.