MITIGATION OF THE IMPACT HAZARD: POLICY-LEVEL PERSPECTIVES
What can we do? What should guide our actions?

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Introduction

Thank you Dr. Remo, other distinguished members of this panel, Dr. Loret, President of the Explorers Club, and Mr. Secretary General. It is an honor to be here speaking to you on the issue of impact hazard mitigation, and to a lesser degree on the related issue of detection. Mitigation is the act of protecting Earth from catastrophic NEO impacts, while detection is finding those same NEOs before they impact. I shall provide some perspectives through a posed series of questions and answers.

What are near-Earth objects, or NEOs?

NEOs are the comets and asteroids which frequent our part of the solar system. They are the natural building block materials of our solar system which have played a prominent role in Earth's evolution. They range in size from minute particles to massive mountain-sized objects 10+ kilometers in characteristic dimension. They are of course influenced by the laws of nature to wander through space in somewhat predictable orbits. Sometimes NEOs collide with other orbiting bodies and, as a result, either coalesce or fragment. It is by virtue of their mass and high orbital velocities relative to other bodies with which they might collide that give them their pervasive ability to most intrusively and destructively interact. But NEOs are more than just dangerous

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flotsam in space, they are objects of beauty worthy of continued scientific study to unlock the secrets buried within.

What is the impact hazard?
The impact hazard is the threat of Earth impact by these comets or asteroids. It is the massive amounts of kinetic energy the larger NEOs possess, with the resultant potential to cause massive damage to the Earth's biosphere, that has us so concerned.

Are all possible impacts of equal concern?
No. Some impacts are inconsequential - like the "shooting stars" we see in the sky at night, while other impacts are serious enough to threaten our very existence on Earth - like the K-T (Cretaceous-Tertiary) impact some 66 million years ago. Fortunately, the more serious threats posed by the larger objects, generally those objects greater than 10's of meters (for iron meteors) to a couple hundred meters in diameter (for comets), don't occur very often. They have a very low probability of occurrence; assessed to be in the one-in-hundreds of thousands to one-in-millions of happening in any given year. The smaller ones have a very high probability of occurrence; but, again, are of little to no consequence. Generally, we are concerned only by those objects which can significantly penetrate our protective atmosphere and cause substantial damage to the ground below. Over the past two days of this conference, we have heard of the tremendous damage potential caused by such massive impacts. And who of us can ever forget the awesome celestial fireworks display put on by comet Shoemaker-Levy 9 fragments impacting Jupiter last July.

What is mitigation of the impact hazard?
Mitigation refers to collective measures taken by people of the Earth to prevent large near-Earth objects from impacting the Earth. Naturally, the consequences of some particular impact would have to be unacceptable in terms of loss of life and property damage, or long term consequences to the Earth's biosphere in terms of its ability to sustain life as we know it, in order to justify mitigation efforts.

What would mitigation entail?
Mitigation would involve the delivery of an appropriate amount of mass, momentum and/or energy to an approaching NEO either to gently deflect the body or to disruptively deflect all or a significant amount of the body's mass away from an Earth impact.

What considerations and principles should guide how we address the mitigation issue?

Simply put, they are: detection, definition and understanding, safety and safeguards, accountability and affordability, peer review and consensus, openness and public awareness, balance, and cooperation and teamwork. I will briefly describe each of these, and then provide some more perspectives in succeeding questions.

Detection: Obviously, the most important consideration - by far - is detecting threatening NEOs which might need to be deflected. How do we know what to mitigate or how to mitigate it if we can't detect them approaching Earth on an apparent collision trajectory? The mitigation community's best advice to the detection community is to maximize the amount of provided warning time. Doing so will help maximize our chances of successfully defending the Earth.

Definition and Understanding: Through dedicated research, we must first seek scientific knowledge about and understanding of the impact problem and potential solutions before we can make rational decisions about mitigation schemes. How can we proclaim we know the "best" mitigation scheme when we know very little about comets and asteroids? We have not yet landed on one in space. We know few details about their surface and internal micro- and macroscopic characteristics, which will define how well one mitigation scheme compares against another. Not only is more and better detection capability necessary, but more exploratory missions to comets and asteroids are needed, like the planned NEAR and Rosetta missions.

Safety and Safeguards: Safety must play a key role in our mitigation research and planning activities in avoiding accidents or unintended outcomes. We cannot allow any potential mitigation "cures" to be worse than the "malady". Formal accountability back to the people and the peoples governmental representatives are the checks and balances which will help ensure safety is met, and the risks minimized. The burden of proof must be on us to show that mitigation can be researched, planned, and conducted safely. Precautionary measures, or safeguards, may also be required to protect some particular mitigation technologies or schemes against accident or misuse. These could involve certain barriers and procedures and perhaps be governed by formal international protocols.

Accountability and Affordability: In all our actions as professional researchers, we have to be absolutely accountable to the people for all our mitigation efforts. They are our customers. They support our activities with their hard-earned financial resources. And, they (and all of us!!) are affected ultimately by the outcome(s) of our collective mitigation activities. Should some type of formal mitigation protocol or deployment ever be required, it must be justifiable, reasonable, and affordable when balanced against the risks of not doing it. We must also be good stewards of the environment; not just here on Earth, but in near-Earth space as well. How many times have we belatedly learned about the "effect" part of cause-and-effect regarding the consequences of science & technology on a global scale, for example, ozone depletion, acid rain, orbital debris, DDT, and so forth.

Peer Review and Consensus: This is necessary to ensure that all related mitigation issues (and impact hazard issues, too) have been considered, addressed, reviewed, and accepted by all qualified and cognizant researchers, and by a majority of the general public as well. The mitigation consensus could consist of a hierarchy of viable and accepted mitigation solutions which are dependent on the amount of warning time, physical characteristics of the approaching NEO, and availability of mitigation technologies.

Openness and Public Awareness: Since the impact threat affects all people equally, it is appropriate that people and governments have the ultimate responsibility to decide on what mitigation actions, if any, and at what level of support, should be taken. Rational decisions can only be made to the extent that information on the issue flows to them openly, accurately, and with honest intent. It is reasonable to expect, however, that some information on mitigation technologies and safeguards cannot be widely shared.

Balance: Detection and mitigation are inseparable. Obviously, any mitigation technique first requires detection of NEO impactors. The fact that detection is considered important enough to merit additional study, and very possibly additional support, suggests that mitigation is important. Conversely, if mitigation is not important, then why do detection? It makes no sense to detect and catalog potential NEO impactors if there is no plan to mitigate detected threats. Ongoing

scientific inquiry and discovery related to NEOs is not simply detection. There exists a natural synergism in jointly addressing the detection and mitigation issues.

Cooperation and Teamwork: As professional researchers, we should always be guided by our own search for scientific and technical truth and knowledge. We must cast aside debilitating differences we might have, be they national, ideological, and/or organizational, and work cooperatively to generate detection and mitigation solutions to this NEO problem of utmost consequence. This is a complex problem and it will require much effort by multi-disciplinary international teams to generate acceptable solutions. No one group can credibly proclaim to "have all the answers," nor should they.

What things could we be doing now to help us understand how to mitigate the impact threat?

There are a number of actions we could take now to start preparing ourselves to mitigate the threat of a NEO on an Earth-collision trajectory. We can study the problem and identify issues and potential solutions, based on what the detection and mitigation communities already know. We can conduct laboratory research, specifically, energy coupling experiments into surrogate NEO materials, using what is already known about NEOs and existing mitigation technologies. We can plan contingency mitigation missions on paper. And, finally, we can practice by conducting missions of deflection against nearby NEOs on benign trajectories using a number of existing mitigation technologies. Whatever prudent mitigation actions we undertake now will give us an advantage in being able to respond safely and effectively someday when a real impact threat is detected; especially if the warning time is short.

Can we decide to do nothing about the impact threat?

Of course, that is certainly our prerogative. The odds are that we'll get away with it for some period of time by human time-scales; maybe centuries, millennia, or even longer. Perhaps even longer than our own ability as a species to survive on this planet. But, we need to keep in mind that there's an equal probability of a catastrophic impact now, as there was 100 years ago, and as there will be 100 or even a 1,000 years from now. A catastrophic impact can happen at any time. And, if I'm not mistaken, our current understanding is that we are about overdue for another K-T class impact. At a minimum, we should at least consider how we would address the shortest warning of an impending

NEO impact. If our mitigation plans can handle that scenario, then we could have an increased level of confidence that we could handle most other impact scenarios with more warning time.

Why is warning time so important?
Warning time is the advance notice we'd get of a predicted impending NEO impact, based on initial detection and subsequent tracking information. Warning time is important because the more we have, the greater the number of options which could be available to deflect the approaching NEO and thus the greater our probability of success. More warning time also allows lower energy deflection technologies to be used. The shorter the warning time, the fewer the deflection technology options available to deflect the body and the lower the probability of success. Some long-period comets, which are believed to comprise a significant percentage of the impact flux, could provide warning times as short 6 months. It should not be assumed that existing deflection technologies can be quickly marshaled, nor that they will even exist in the future, to deflect an approaching threat on such a short timescale. It should be noted that our ability right now to detect small NEOs is literally hours, days, and perhaps weeks. Clearly, a better detection capability is needed to detect objects much further out than is possible now.

Should we do nothing about the threat?
Most of us would probably not recommend it. Sooner or later we will be faced with a significant impact threat. It has happened, and it will happen again on Earth. These are the fundamental laws of nature at work in our solar system. Faced with such a threat in the future we will of course chose and attempt to mitigate it in the best way we know how. Why? Because survival is our most basic human instinct. But, it could be a losing race to see if we can marshal up the level of defenses required to mitigate that particular threat in the given period of warning time provided. A little bit of mitigation planning and laboratory experimentation now is an inexpensive insurance policy which could generate effective, affordable, and safe mitigation options for future use.

Should we mitigate smaller NEOs (like the Tunguska impactor), which have a higher impact probability, but which only cause local damage, or should we wait for the K-T impactors?
For the smaller impactors, it depends. If the impact is over water or remote land areas, which is likely to be the case - like Tunguska, we don't have to do anything, except perhaps evacuate the area for a short period of time. And provided, of course, that we have ample warning time, accurate tracking

capability, and are confident in our trajectory and impact point calculations. If it's predicted to impact in a location where the resultant damage would be unacceptable to us, for example, at population or resource centers, then - yes, obviously - we will attempt to mitigate it. The time for debate will promptly end and someone or some group will make the decision to mitigate the threat as best we can. Whether we're successful or not will depend on how well prepared we were to mitigate it. And, of course, we must be prepared to defend against the K-T class impactors. The consequences of inaction in this case are unimaginable.

Should we build and deploy a mitigation system for Earth?
No, not right now. Premature deployment could be dangerous and expensive. Besides, what's the hurry? We don't even understand the problem yet. Therefore, how can we proclaim to have the mitigation solution in hand? Someday, however, if required, we may wish to deploy a mitigation capability to meet the shortest warning time threats and provided that the international geopolitical climate is hospitable for doing so. Another viable future option may be to store the mitigation system as separate parts, safely and securely under national and international safeguards, with proven contingency plans to rapidly generate a viable mitigation capability and respond to any NEO impact threat emergency.

What could we do then if we don't deploy a system?
Through appropriate long-term research and study and consistent with the considerations and principles given above, we could begin systematically developing the necessary knowledge, technology, and mitigation capability to protect Earth from NEO impacts of consequence. We could generate contingency plans, based on what we learn, to address all NEO impact threat scenarios.

Should we consider precursor mitigation missions?
Yes. In fact, Dr. Allahdadi, of the US Air Force Phillips Laboratory, and I have proposed a benign mitigation mission in the poster paper session which would be fast and inexpensive, promote international cooperation, and increase our scientific understanding of NEOs. We could improve our understanding of: carrying deflection technologies long distances through the hostile environments of space, final approach and terminal homing with the target, the interaction of the mitigation technology with the NEO to deflect it, long range tracking and control, modeling and planning assumptions, and sub-scale energy coupling experiments on Earth, among others.

How might our ability to do mitigation change in the future?
Our ability to respond to future impact threats could be improved, or it could be lessened. If humankind evolves into a peaceful and balanced equilibrium on Earth, we may decide to give up on deep space travel - deciding instead to operate only in near-Earth space - and on powerful military capabilities. If such were the case, we might be unable to defend ourselves against NEO impacts except in the case where we had many years of warning. However, there is no rational reason why we could not evolve into a peaceful planet and still have a safe and effective NEO defense capability if we collectively decided to do so.

Do we care now about the detection and mitigation issues?
Yes, of course we do. All of you very talented researchers with varied backgrounds and from around the world wouldn't be here if you didn't care. The U.S. Congress cares; they've instituted several studies. The Russians care; they have proposed for consideration some interesting detection and mitigation systems. The United Nations cares, as evidenced by their sponsorship of this conference. Other international conferences have been held to promote common understanding: Snowmass, San Juan Capistrano, Tucson, Erice, and Chelyabinsk - to name a few. The public is becoming more aware; especially after the comet impacts on Jupiter last year. Many popular and scientific books and articles are being written about the subject. There will undoubtedly be more conferences, for example, a Planetary Defense Workshop is scheduled for Livermore, California next month. Through personal empowerment, individual researchers have been successful at finding the resources to continue their detection and mitigation research. As our understanding of these two issues increases, so too will support from the people and governments.

What should we do?
At a minimum, I believe that we should continue to conduct thorough detection and mitigation research and studies - to better understand the problem and potential solutions, while guided by the considerations and principles I mentioned above.

Closing Remarks
In closing, we understand that NEO impacts are a threat to all humanity. Preventive action should therefore be based on international cooperation, the level of which required has never before been witnessed in human history, but

which could be the start of an exciting new chapter in the evolution of humankind on Earth. Through appropriate preparation and timely action lives can be saved and the rich diversity of life on Earth preserved. Thank you.

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