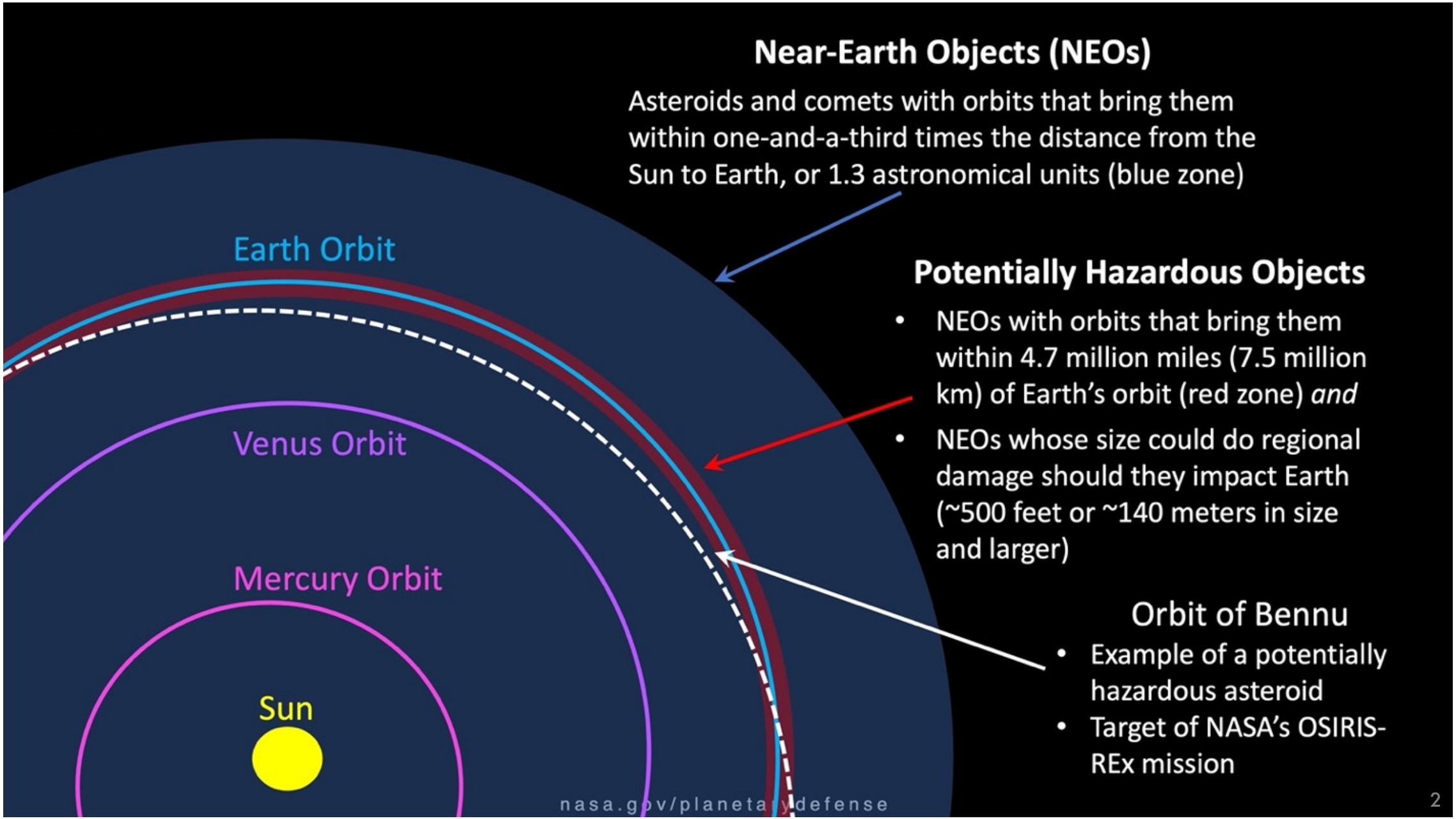
Protocols for Use of Nuclear Explosive Devices in Hazardous Asteroid Deflection

Matthew Daniels, Benjamin Bahney, Brent Barbee, Michael Markey

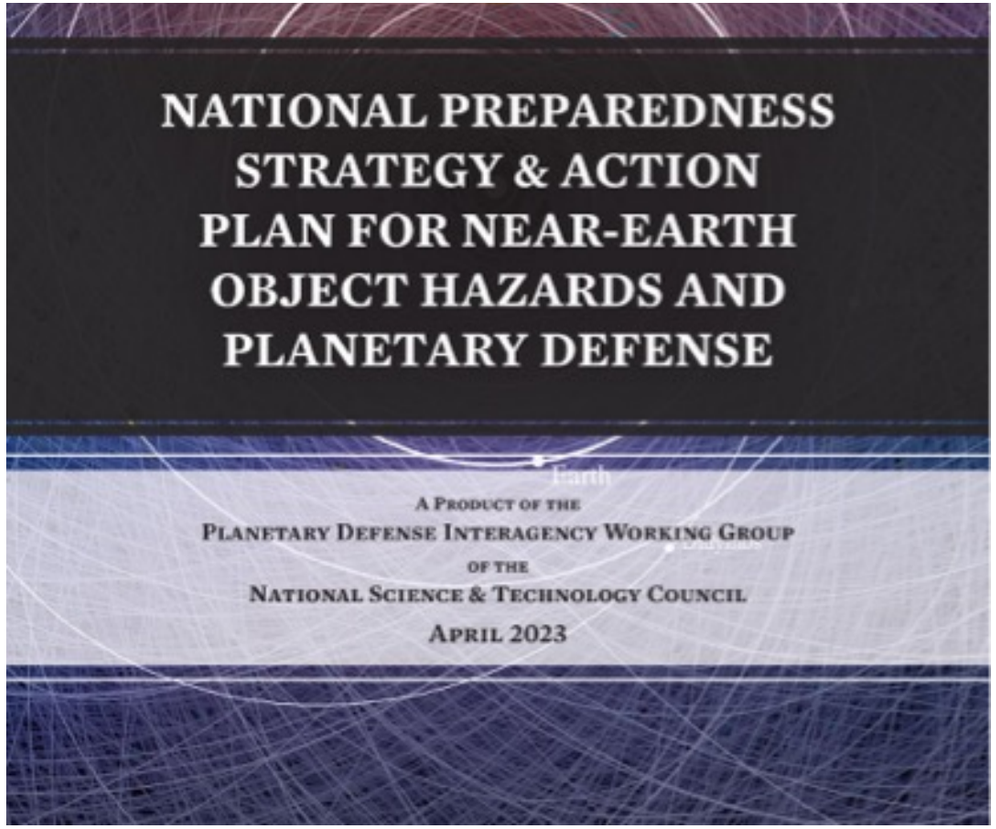
9th IAA Planetary Defense Workshop
Stellenbosch, Cape Town, South Africa
May 2025


Near-Earth Objects (NEOs)
Asteroids and comets with orbits that bring them within one-and-a-third times the distance from the Sun to Earth, or 1.3 astronomical units (blue zone)
Earth Orbit
Venus Orbit
Mercury Orbit
Sun
Potentially Hazardous Objects
• NEOs with orbits that bring them within 4.7 million miles (7.5 million km) of Earth's orbit (red zone) *and*
• NEOs whose size could do regional damage should they impact Earth (~500 feet or ~140 meters in size and larger)
Orbit of Bennu
• Example of a potentially hazardous asteroid
• Target of NASA's OSIRIS-REx mission
nasa.gov/planetarydefense

Page 16:

"3.4 Continue the study of circumstances when only use of a nuclear explosive device would provide the necessary capability to mitigate an impending NEO impact threat, and the technologies, capabilities, international coordination, and other considerations required for such contingencies. Assess the legal and national policy implications of such an option."

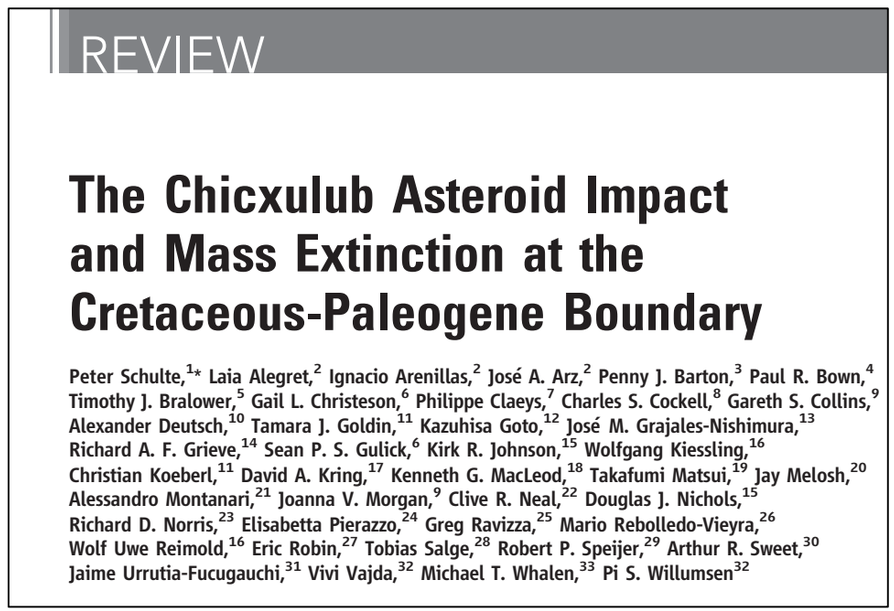
Text online here:
https://assets.science.nasa.gov/content/dam/science/psd/planetary-science-division/2025/2023-NSTC-National-Preparedness-Strategy-and-Action-Plan-for-Near-Earth-Object-Hazards-and-Planetary-Defense.pdf



Origins of planetary defense

- The previous dominant form of life on Earth was likely eradicated by an asteroid impact about 66M years ago.[1][2] Humanity's growing awareness of this planetary history has shaped our thinking about the future: scientific surveys of asteroids have evolved into mandated searches for potentially hazardous near-Earth objects (NEOs), and from there into planetary defense programs encompassing searches and technologies to avert cataclysm.[3]

- There are several commonly discussed potential means of deflecting a hazardous asteroid, including: kinetic impactors (as demonstrated with NASA's DART Mission), gravity tractors, ion beam concepts, and nuclear explosive devices (NEDs).[4][5]



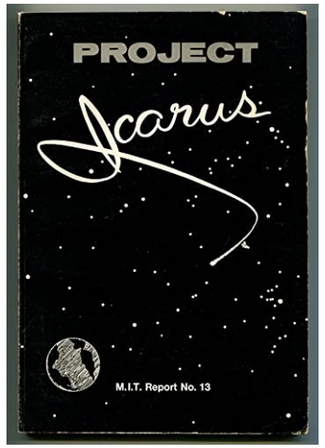
REVIEW

The Chicxulub Asteroid Impact and Mass Extinction at the Cretaceous-Paleogene Boundary

Peter Schulte,[1*] Laia Alegret,[2] Ignacio Arenillas,[2] José A. Arz,[2] Penny J. Barton,[3] Paul R. Bown,[4] Timothy J. Bralower,[5] Gail L. Christeson,[6] Philippe Claeys,[7] Charles S. Cockell,[8] Gareth S. Collins,[9] Alexander Deutsch,[10] Tamara J. Goldin,[11] Kazuhisa Goto,[12] José M. Grajales-Nishimura,[13] Richard A. F. Grieve,[14] Sean P. S. Gulick,[6] Kirk R. Johnson,[15] Wolfgang Kiessling,[16] Christian Koeberl,[11] David A. Kring,[17] Kenneth G. MacLeod,[18] Takafumi Matsui,[19] Jay Melosh,[20] Alessandro Montanari,[21] Joanna V. Morgan,[9] Clive R. Neal,[22] Douglas J. Nichols,[15] Richard D. Norris,[23] Elisabetta Pierazzo,[24] Greg Ravizza,[25] Mario Rebolledo-Vieyra,[26] Wolf Uwe Reimold,[16] Eric Robin,[27] Tobias Salge,[28] Robert P. Speijer,[29] Arthur R. Sweet,[30] Jaime Urrutia-Fucugauchi,[31] Vivi Vajda,[32] Michael T. Whalen,[33] Pi S. Willumsen[32]

https://www.science.org/doi/10.1126/science.1177265

50 years of analyses of NEDs in planetary defense



- **The use of NEDs is widely considered to be a last-resort potential means of deflecting or disrupting hazardous asteroids/NEOs**—to be used when they are the only option possible (such as large asteroids and long-period comet impactors). Analyses of NEDs in planetary defense span across over 50 years, though primarily have been done since *Alvarez & Alvarez* proposed an asteroid impact as the probable cause of the Cretaceous–Paleogene extinction event.[4][5][6][7][8][9][10][11]
- Teller-Sagan disagreement: does a nascent human ability to rearrange matter in the solar system pose more risks than the natural hazards of NEOs? [12][13][14][15]
  - Morrison presented counterarguments to the deflection dilemma in 2010: it's much easier to deflect an asteroid away from Earth than it is to steer one onto a predetermined course.[16]
- **Here we briefly outline a set of notional protocols for NEDs in a future and hypothetical planetary defense mission** to help address studies on goal 3.4 of the published US planetary defense strategy.[3]
  - The notional protocols can be read as steps to follow <u>after</u> a decision for NED-use in a hazardous NEO contingency: how could a state(s) that has chosen to carry out the NED-based mission proceed so as to maximize subsequent nuclear and space security? The responsible government(s) carrying out the NED deflection mission is referred to simply as the "mission provider" in the protocols.
  - *The notional protocols are meant to be simple and understandable.*
  - Stipulation: Everything will be done consistently with international law.

I. Diplomacy and technical expertise

1. Dynamical data on all known NEOs will continue to be shared with all nations on an ongoing basis, as it currently is via the Minor Planet Center.*
2. Warning of the current NEO hazard and opportunity for information sharing on possible mitigation approaches, including based on information from any flyby or rendezvous reconnaissance missions, is available through international bodies (almost certainly IAWN and SMPG), which provide ongoing updates to national governments.**
3. Mission provider commits not to place NEDs beyond Earth for future planetary defense programs without renewed UNSC approval.***

*In the much longer term, this can also continue to mitigate the "deflection dilemma" raised by Sagan and Ostro.[14] Current data collected by the Minor Planet Center are available here: https://minorplanetcenter.net/data.

**The International Asteroid Warning Network (IAWN) and the Space Mission Planning Group (SMPG) and their histories are described in: https://www.nature.com/articles/s41467-024-48600-x

***Continued compliance with existing treaties: https://www.state.gov/outer-space-treaty and https://www.state.gov/nuclear-non-proliferation-treaty

II. Transparency and security

4. Mission provider publicizes all major mission parameters, consistent with practices of NASA civil space missions to planets and asteroids (spacecraft overview, space launch vehicle, detailed flight plan, etc.)*
5. Mission provider publicizes analysis of uncertainties around mission parameters that will impact mission effectiveness. This includes bounded uncertainties around: NEO mass & diameter; NEO bulk cohesive strength and material composition; Physics of interaction of NED with NEO materials, etc.**
6. Mission provider designs spacecraft to facilitate independent tracking to maximum extent practical (such as tracking aids like those used on some NASA spacecraft+), comparable to humanitarian ships and aircraft.
7. Data about the NED(s)–including design, mass, volume, and other specific technical factors–will **not** be shared by the NED supplier.
8. Mission provider implements specific "transparency and confidence building measures (TCBMs)" around the NED package(s), including: declaration of number of NEDs, inspection/monitoring measures, international chain of custody until launch, assured command/control.

* For example: https://science.nasa.gov/mission/juno/

** These are the types of information already presented in analyses like [4][10][11].

+ See for example online here: https://www.nasa.gov/smallsat-institute/sst-soa/identification-and-tracking-systems/

III. Verification and safety

9. Mission provider uses trajectory for NED planetary defense mission with direct departure from Earth-Moon system via space launch vehicle.*
10. Mission provider uses trajectory design that provides high confidence of non-return of NEDs to the Earth-Moon system or any tracked planetary body for at least 50 years.**
    - For example, since the hazardous NEO itself is (by definition) on a trajectory back toward Earth, this protocol would require non-rendezvous intercept trajectories or rendezvous trajectories that maintain a continuous non-gravitationally-captured drift-away posture while in the NEO's vicinity—either way, precluding the possibility of inadvertently returning to Earth with the NEO.
11. No NEDs launched as part of the mission are left undetonated after the mission. For example, any NEDs unused in deflection to be detonated in disposal trajectories.
12. Mission provider facilitates independent observations and data sharing on NED detonations.***
13. Mission provider develops and shares contingency plans for launch vehicle and spacecraft failure scenarios, including launch and orbital trajectories to enable disposal plans.+

* Standard for some NASA interplanetary missions: https://www.nasa.gov/history/50-years-ago-pioneer-10-launches-to-explore-jupiter/

** Analogous to NASA Planetary Protection protocols, e.g., section 4.5: https://standards.nasa.gov/sites/default/files/standards/NASA/Baseline/0/NASA-STD-871927_Baseline.pdf

*** International observations might resemble the observation campaign for NASA's DART mission: https://www.sciencedirect.com/science/article/pii/S0094576524002005

+ Analogous to relevant NASA interplanetary missions: https://ntrs.nasa.gov/api/citations/20230008641/downloads/NASA-NFS-Handbook-Inaugural-2023-06-30.pdf

Full discussion in forthcoming paper:

- **Additional Treaty Considerations**

- **Mission Design considerations**
  - When is an NED required for Earth impact prevention?
  - When might an NED be preferred even if not required?
  - Considerations for NED deployment/trajectory options?

In summary:

- Theoretical studies have considered the use of NEDs to deflect hazardous asteroids for decades. Questions about how this would work in international relations have lingered, however, complicating planning and discussions. Many discussions simply conclude that if a NEO deflection scenario arose which could not be achieved through non-nuclear means, then use of a NED(s) would hinge on endorsement by the United Nations Security Council—but additional details are not explored.

- This talk develops a set of notional protocols for employing NEDs to deflect a hazardous asteroid, which could provide a foundation for NED-use decisions in these extraordinary circumstances. We begin by summarizing previous analyses of NED use for planetary defense. We then propose notional protocols that incorporate three kinds of elements. These include approaches to multilateral diplomacy and technical coordination, design and trajectory factors to meet transparency and security requirements, and operational measures to provide for independent verification and safety.

- We develop these notional protocols to facilitate future technical and international discussions, and we invite continued improvement. Ultimately, these notional NED planetary defense protocols could help clarify planning for NEDs as part of planetary defense strategies–and in the much longer term, help chart a continued path toward peaceful use of nuclear technologies for human expansion in the solar system.

SOURCES

[1] Alvarez, Luis W., W. Alvarez, F. Asaro, and H. V. Michel. "Extraterrestrial cause for the Cretaceous-Tertiary extinction." Science 208, no. 4448 (1980): 1095-1108.

[2] Schulte, Peter, Laia Alegret, Ignacio Arenillas, José A. Arz, Penny J. Barton, Paul R. Bown, Timothy J. Bralower et al. "The Chicxulub asteroid impact and mass extinction at the Cretaceous-Paleogene boundary." Science 327, no. 5970 (2010): 1214-1218.

[3] "National Preparedness Strategy and Action Plan for Near-Earth Object Hazards and Planetary Defense," Planetary Defense Interagency Working Group, April 2023, https://assets.science.nasa.gov/content/dam/science/psd/planetary-science-division/2025/2023-NSTC-National-Preparedness-Strategy-and-Action-Plan-for-Near-Earth-Object-Hazards-and-Planetary-Defense.pdf

[4] National Research Council, *Defending planet earth: Near-Earth-Object surveys and hazard mitigation strategies*. National Academies Press, 2010. https://nap.nationalacademies.org/catalog/12842/defending-planet-earth-near-earth-object-surveys-and-hazard-mitigation

[5] Reinhardt, Jason, Matthew Daniels, and M. Elisabeth Paté-Cornell. "Probabilistic analysis of asteroid impact risk mitigation programs." In *Proceedings Probabilistic Safety and Management (PSAM)*. 2014.

[6] MIT Student Project in Systems Engineering, Project Icarus, MIT Press, 1968.

[7] Ahrens, Thomas J., and Alan W. Harris. "Deflection and fragmentation of near-Earth asteroids." Nature 360, no. 6403 (1992): 429-433.

[8] NASA, "Near-Earth Object Survey and Deflection Analysis of Alternatives," Report to Congress, March 2007. https://www.nasa.gov/wp-content/uploads/2015/01/171331main_NEO_report_march07.pdf

[9] Syal, Megan, David SP Dearborn, and Peter Schultz. "Limits on the use of nuclear explosives for asteroid deflection." *Acta Astronautica* 90, no. 1 (2013): 103-111.

[10] Dearborn, David, Megan Bruck Syal, Brent W. Barbee, Galen Gisler, Kevin Greenaugh, Kirsten M. Howley, Ronald Leung et al. "Options and uncertainties in planetary defense: Impulse-dependent response and the physical properties of asteroids." Acta Astronautica 166 (2020): 290-305.

[11] King, Patrick, Megan Syal, David Dearborn, Robert Managan, J. Michael Owen, and Cody Raskin. "Late-time small body disruptions for planetary defense." Acta Astronautica 188 (2021): 367-386.

[12] Conway, Erik M., Donald K. Yeomans, and Meg Rosenburg. A history of near-earth objects research. NASA SP-2022-4235, 2022. https://www.nasa.gov/history/history-publications-and-resources/nasa-history-series/a-history-of-near-earth-objects-research/

[13] Teller, Edward. "The need for experiments on comets and asteroids." In Proceedings of the Planetary Defense Workshop, pp. 5-6. 1995.

[14] Sagan, Carl, and Steven J. Ostro. "Long-range consequences of interplanetary collisions." Issues in Science and Technology 10, no. 4 (1994): 67-72.

[15] Morrison, David. "Carl Sagan and Edward Teller: an uneasy alliance over defending the earth." Skeptic (Altadena, CA) 13, no. 1 (2006): 47-50.

[16] Morrison, David. "Impacts and Evolution: Protecting Earth from Asteroids." Proceedings of the American Philosophical Society 154, no. 4 (2010): 439-450.