Literature relevant to the nuclear option of near-Earth object (NEO) deflection ("blast deflection")

Reports on the blast deflection method from NEOShield:

Assessment of blast deflection and other mitigation concepts, NEOShield, D7.3, 2014, TsNIImash, Russia

Two concepts are presented. The first addresses a scenario in which the warning time is long and it is possible to use a nuclear blast of comparatively low energy in order to avoid fragmentation of the target body. In the second concept it is assumed that the available time is very short. Hence a powerful blast is used in an attempt to break up the body. Numerical codes were developed for
- calculation of the thermodynamic characteristics of silicates,
- solution of the transport problem of X- radiation,
- estimation of the momenta from stand-off nuclear explosions and conventional chemical explosions.

http://www.neoshield.net/wp-content/uploads/2015/02/NEOShield_D7.3__Assessment-of-blast-deflection.pdf

Trade offs of viable alternative mitigation concepts, NEOShield, D7.5, 2013, Airbus DS, UK

This document assesses and evaluates trade-offs of NEO mitigation concepts that may present viable alternatives to the kinetic impactor method, depending on circumstances. The core mitigation concepts traded off are as follows
- the gravity tractor and the "multiple gravity tractor" concept,
- blast deflection,
- the human missions concept.

However, in the interests of a more holistic trade-off and greater insight into the main drivers and constraints, assessments of additional alternative mitigation concepts, as well as the results from an internal analysis of a kinetic impactor, were also carried out and included:
- the ion beam shepherd,
- laser ablation,
- electrostatic deflection

Some of the mitigation concepts in the trade-off were further broken down (e.g. stand-off and surface/sub-surface blasts) to cover sub-variants which are different enough from a trade-off point of view to warrant an independent assessment.
http://www.neoshield.net/wp-content/uploads/2015/02/NEOShield_D7.5__Trade-Offs-of-Viable-Alternative-Mitigation-Concepts.pdf

NEOShield blast deflection demonstration mission detailed design, NEOShield, D8.4, 2015, TsNIImash, Russia

The concept and scenario of the demonstration mission scheme include
- trajectory to the target asteroid;
- precision control of the S/C close approach to the target asteroid and maneuvering near the asteroid;
- S/C receding to a safe distance from the blast;
- S/C trajectory for prolonged tracking of the asteroid with a programme of onboard observations of the asteroid to assess the results of blast. (Not available online)

Global response campaign roadmap design, NEOShield, D9.5, 2015, Airbus DS, UK

This document describes a detailed mitigation strategy based on the example of 2011 AG5 (<150m) assuming impact on the Earth in 2040. Reconnaissance and mitigation missions are studied and compared, based on the results of NEOShield studies of the gravity tractor, kinetic impactor, and blast deflection. On the basis of the NEOShield results, the most promising mitigation techniques are the nuclear blast, the kinetic impactor, and the latter combined with a gravity tractor. A deflection campaign is proposed based on a combination of these techniques, with nuclear blast as a last resort. An impact in 2040 provides the time needed to develop critical technologies necessary for the successful deployment of the selected mitigation techniques.
http://www.neoshield.net/wp-content/uploads/NEOShield_D9.5__Global-Response-Campaign-Roadmap-Design.pdf

Technical Papers on blast deflection from the peer-reviewed literature:

Korycansky, D. G., Plesko, C. S. (2012) *Effects of stand-off bursts on rubble-pile targets: Evaluation of a hazardous asteroid mitigation strategy.* Acta Astronautica, 73, 10–22.

Abstract: "We explore the aftereffects of stand-off burst mitigation on kilometer-scale rubble pile asteroids. We use a simple model of X-ray energy deposition to calculate the impulse transferred to the target, in particular to burst-facing blocks on the target surface. The impulse allows us to estimate an initial velocity field for the blocks on the outer side of the target facing the burst. We model the dynamics using an N-body polyhedron program built on the Open Dynamics Engine, a "physics engine" that integrates the dynamical equations for objects of general shapes and includes collision detection, friction, and dissipation. We tested several different models for target objects: rubble piles with different mass distributions, a "brick-pile" made of closely fitting blocks and zero void space, and a non-spherical "contact binary" rubble pile. Objects were bound together by self-gravity and friction/inelastic restitution with no other cohesive forces. Our fiducial cases involved objects of $m=3.5\times10^{12}$ kg (corresponding to a radius of 0.7 km for the bulk object), an X-ray yield of 1 megaton, and stand-off burst distances of R=0.8-2.5 km from the target center of mass. Kilometer-scale rubble piles are robust to stand-off bursts of a yield (Y~1 megaton) that would be sufficient to provide an effective velocity change (Δv~$0.05 ms^{-1}$). Disaggregation involving some tens of percent of the target mass happens immediately after the impulse; the bulk of the object re-accretes on a few gravitational timescales, and the final deflected target contains over 95% (typically, 98-99%) of the original mass. Off-center components of the mitigation impulse and the target mass distribution cause a small amount of induced spin and off-axis components of velocity change. The off-axis velocity component amounts to an angular deviation of ~0.05-0.1 radians from the nominal impulse vector, which may be important for mitigation planning."
https://www.sciencedirect.com/science/article/pii/S0094576511003213?via%3Dihub

Barbee, B. W., Wie, B., Steiner, M., and Getzandanner, K. (2015) *Conceptual design of a flight validation mission for a Hypervelocity Asteroid Intercept Vehicle*. Acta Astronautica, 106, 139–159.

From the abstract: "The Hypervelocity Asteroid Intercept Vehicle (HAIV) is a two-body vehicle consisting of a leading kinetic impactor and trailing follower carrying a Nuclear Explosive Device (NED) payload. The HAIV detonates the NED inside the crater in the NEO's surface created by the lead kinetic impactor portion of the vehicle, effecting a powerful subsurface detonation to disrupt the NEO. For the flight validation mission, only a simple mass proxy for the NED is carried in the HAIV. Ongoing and future research topics are discussed following the presentation of the detailed flight validation mission design results.” https://doi.org/10.1016/j.actaastro.2014.10.043

Aleksandrova, A.G., Galushina, T.Y., Prishchepenko, A.B., et al. (2016) *The preventive destruction of a hazardous asteroid.* Astron. Rep., 60:611.

From the abstract: “The destruction of the hazardous object using a nuclear charge is discussed. “The explosion of such an asteroid shortly before its predicted collision would have catastrophic consequences, with numerous highly radioactive fragments falling onto the Earth. The possibility of exploding the asteroid several years before its impact is also considered. Such an approach is made feasible because the vast majority of hazardous objects pass by the Earth several times before colliding with it. Computations show that, in the 10 years following the explosion, only a negligible number of fragments fall onto the Earth, whose radioactivity has substantially reduced during this time. In most cases, none of these fragments collides with the Earth. Thus, this proposed method for eliminating a threat from space is reasonable in at least two cases: when it is not possible to undergo a soft removal of the object from the collisional path, and to destroy objects that are continually returning to near-Earth space and require multiple removals from hazardous orbits.”
https://doi.org/10.1134/S1063772916040016

Barbee, B. W., Syal, M. B., Dearborn, D., et al. (2018) *Options and uncertainties in planetary defense: Mission planning and vehicle design for flexible response.* Acta Astronautica, 143, 37–61.

From the abstract: “This paper is part of an integrated study by NASA and the NNSA to quantitatively understand the response timeframe should a threatening Earth-impacting near-Earth object (NEO) be identified. The two realistic responses considered are the use of a spacecraft functioning as either a kinetic impactor or a nuclear explosive carrier to deflect the approaching NEO. The choice depends on the NEO size and mass, the available response time prior to Earth impact, and the various uncertainties. Whenever practical, the kinetic impactor is the preferred approach, but various factors, such as large uncertainties or short available response time, reduce the kinetic impactor's suitability and, ultimately, eliminate its sufficiency. We examine response time and the activities that occur between the time when an NEO is recognized as being a sufficient threat to require a deflection and the time when the deflection impulse is applied to the NEO…. We further present a vehicle design capable of either serving as a kinetic impactor, or, if the need arises, serving as a system to transport a nuclear explosive to the NEO.” https://doi.org/10.1016/j.actaastro.2017.10.021

Dearborn, D. S. P., Bruck Syal, M., Barbee, B. W., et al. (2020) *Options and uncertainties in planetary defense: Impulse-dependent response and the physical properties of asteroids.* Acta Astronautica, 166, 290-305.

Abstract: “Though rare, asteroid impacts are inevitable, and with the current state of technology, kinetic impactors are the preferred but not the complete solution. If the time to impact is short, or the threatening body too large, nuclear deflection serves as a final option. This work is part of an integrated study by National Aeronautics and Space Administration (NASA) and the National Nuclear Security

Administration (NNSA) to better determine the relative efficacy of these complimentary approaches. In particular, we examine the important material properties that affect each approach, to improve critical characterization efforts, and reduce uncertainty in the limits of the impactor technology. Impact speeds for kinetic impactors on Near-Earth Object (NEO) intercept trajectories commonly range from 5 to 20 km/s, resulting in significant crater ejecta and a momentum enhancement above that carried by the impactor. This enhancement depends substantially on the strength and porosity of the asteroid, as well as the impact speed. Here simulations from different codes are presented, along with constraints from experimental measurements. The uncertainties due to ignorance of the strength and porosity of the impact point are significant in determining the limits of impactor sufficiency. The nuclear approach is considered within the context of current capabilities, posing no need to test, as extant and well-understood devices are sufficient for the largest known Potentially Hazardous Objects (PHOs). Results of x-ray sources with realistic spectra as well as blackbody spectra are given, along with some assessment on composition dependence." https://doi.org/10.1016/j.actaastro.2019.10.026

Legal Papers on blast deflection from the peer-reviewed literature:

David A. Koplow (2019) *Exoatmospheric Plowshares: Using a Nuclear Explosive Device for Planetary Defense Against an Incoming Asteroid.* UCLA Journal of International Law and Foreign Affairs, vol. 23, Spring 2019.

Abstract: "What should be done if we suddenly discover a large asteroid on a collision course with Earth? The consequences of an impact could be enormous – scientists believe that such a strike 60 million years ago led to the extinction of the dinosaurs, and something of similar magnitude could happen again. Although no such extraterrestrial threat now looms on the horizon, astronomers concede that they cannot detect all the potentially hazardous "near-Earth objects," and even more striking, they acknowledge that if such a danger were discerned, there is currently no proven capability for diverting or destroying it. One possible response to this type of incipient catastrophe could be to send into space a nuclear explosive device, hoping the massive blast could alter the asteroid's trajectory – indeed, if time were short, that might be the only effective remedy. But two major nuclear arms control treaties – which have been joined by most of the leading countries and are widely appreciated as fundamental to global security – specifically forbid that approach. This article examines that critical clash of legal, political, and technical values, and concludes that the best response would be for the U.N. Security Council to adopt a binding resolution pursuant to its powers under Chapter VII of the U.N. Charter, to deal with the emergency on an expeditious, global basis. A proposed draft of such a resolution is presented, along with explanatory annotations." https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3229382

James A. Green (2019) *Planetary Defense: Near-Earth Objects, Nuclear Weapons, and International Law*. Hastings Int'l & Comp.L., vol. 42, Rev. 1

From the abstract: "…There has been an increased focus amongst states on the possibility of using nuclear detonation to divert or destroy a collision-course NEO - something that a majority of scientific opinion now appears to view as representing humanity's best, or perhaps only, option in extreme cases. Concurrently, recent developments in nuclear disarmament and the de-militarization of space directly contradict the proposed "nuclear option" for planetary defense. In the context of significant developments that have occurred in relation to NEO impact risk over the last five years, this article analyses the question of whether a nuclear NEO response would (or could) be permissible under

international law. Potential restrictions and prohibitions under treaty law are assessed, as are a range of mechanisms that may act to preclude possible illegality. The article concludes by advancing a tentative proposal for a move towards (strictly limited and safeguarded) legal preparedness."
https://repository.uchastings.edu/hastings_international_comparative_law_review/vol42/iss1/2

Seth D. Baum (2019) *Risk-Risk Tradeoff Analysis of Nuclear Explosives for Asteroid Deflection.* Risk Analysis, vol. 39, no. 11 (Nov. 2019), p.2427-2442

Abstract: "To prevent catastrophic asteroid-Earth collisions, it has been proposed to use nuclear explosives to deflect away Earthbound asteroids. However, this policy of nuclear deflection could inadvertently increase the risk of nuclear war and other violent conflict. This article conducts risk-risk tradeoff analysis to assess whether nuclear deflection results in a net increase or decrease in risk. Assuming nonnuclear deflection options are also used, nuclear deflection may only be needed for the largest and most imminent asteroid collisions. These are low-frequency, high-severity events. The effect of nuclear deflection on violent conflict risk is more ambiguous due to the complex and dynamic social factors at play. Indeed, it is not clear whether nuclear deflection would cause a net increase or decrease in violent conflict risk. Similarly, this article cannot reach a precise conclusion on the overall risk-risk tradeoff. The value of this article comes less from specific quantitative conclusions and more from providing an analytical framework and a better overall understanding of the policy decision. The article demonstrates the importance of integrated analysis of global risks and the policies to address them, as well as the challenge of quantitative evaluation of complex social processes such as violent conflict."
https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3397559

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