Aspects of evacuating a NEO impact area

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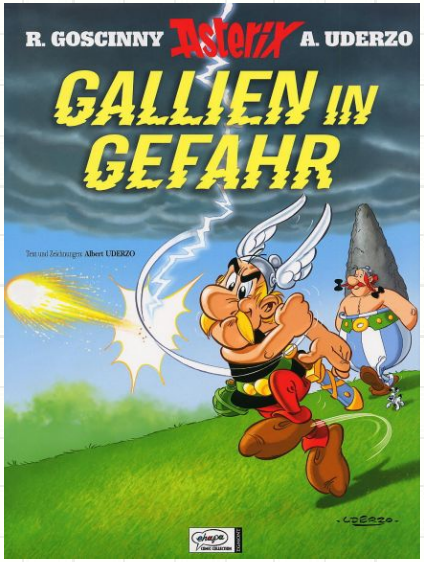

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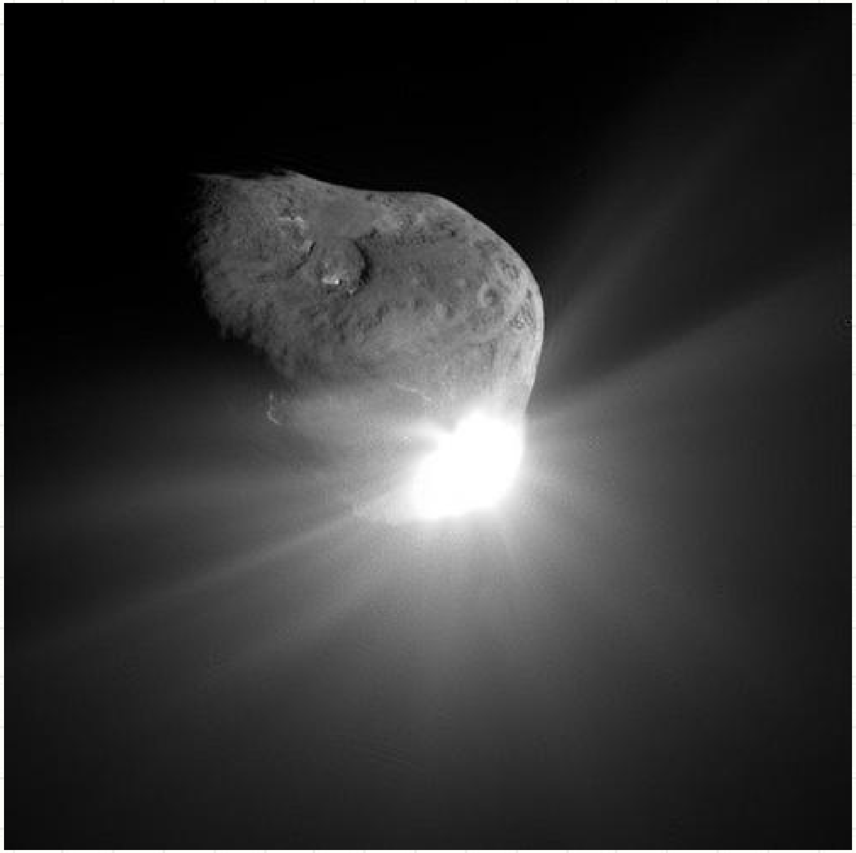
Overview

1. NEO Hazard Mitigation Methods
2. Reasons for Evacuation
3. Costs and Risks of Evacuation
4. Conclusions



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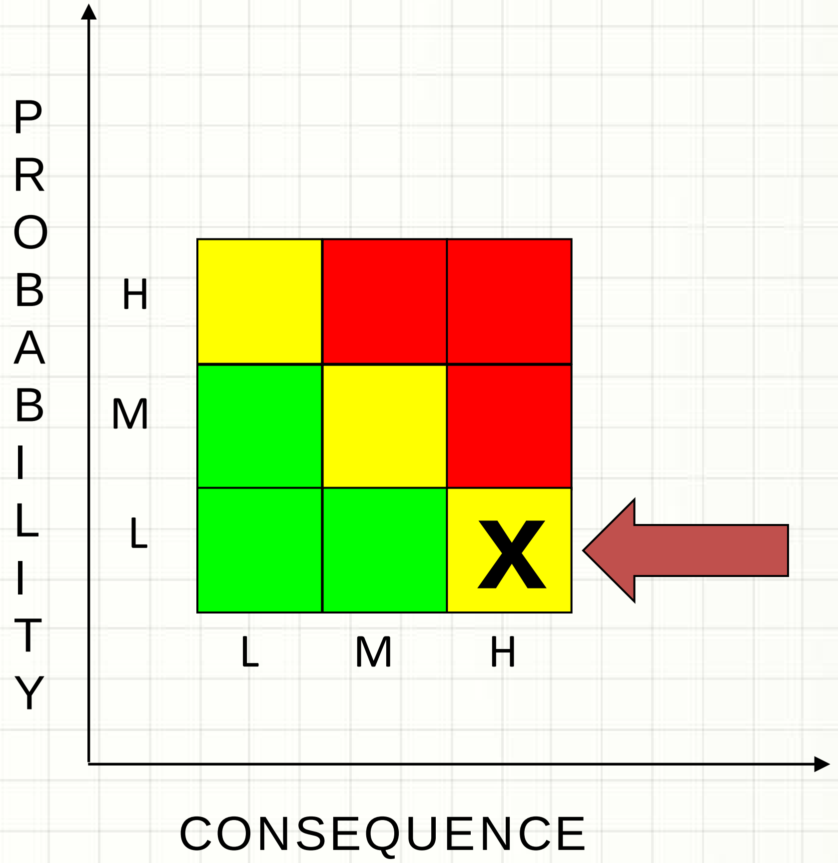
NEO Hazard Mitigation Methods

Risk management strategies to oppose the NEO impact hazard:

- Risk mitigation –> NEO hazard mitigation measure
- Risk avoidance –> n.a.
- Risk delegation –> n.a.
- Risk assumption –> evacuation



NEO Hazard Mitigation Methods

NEO impacts are the only major natural catastrophes that can be predicted **and** avoided (compared to earthquakes, tsunami, volcanoes)!

Basically there are two NEO hazard mitigation strategies:

- Destruction
- Deflection

Basic problems with these NEO mitigation methods are:

- Destruction
  - Resulting fragments may be large enough to still cause damages on Earth,
  - It highly depends on the NEOs internal structure which is unknown in most cases,

    -> size limit about 100 m.

- Deflection
  - Required energy (impulse) defined mainly by NEO mass, (cruise) time, and P/L capacity,
  - The “optimal” deflection system has to be determined in each case,
  - 100% success rate is mandatory!

NEO Hazard Mitigation Methods

NEO deflection systems with possible near-term availability:

- Chemical propulsion systems (I sp rel = 1), -> small NEOs only
- Ion propulsion systems (GT), (I sp rel = <100), -> very long operation time
- Impactors (I sp rel = <1,000), -> high rel. velocity required
- Nuclear explosives (I sp rel = <100,000), -> efficiency uncertain.

NEO deflection systems with possible mid-term availability:

- Solar mirror system (I sp rel = <1,000), -> limited by dust, long op. time
- High energy chemical propulsion systems (I sp rel = 2), -> expensive
- Nuclear propulsion systems (I sp rel = 2), -> development risks.

Other systems are too remote, too weak or too complex, e.g. laser systems, in-situ propellant extraction, solar sails, painting (Yarkovski effect), antimatter, etc…

Reasons for Evacuation

Operational reasons

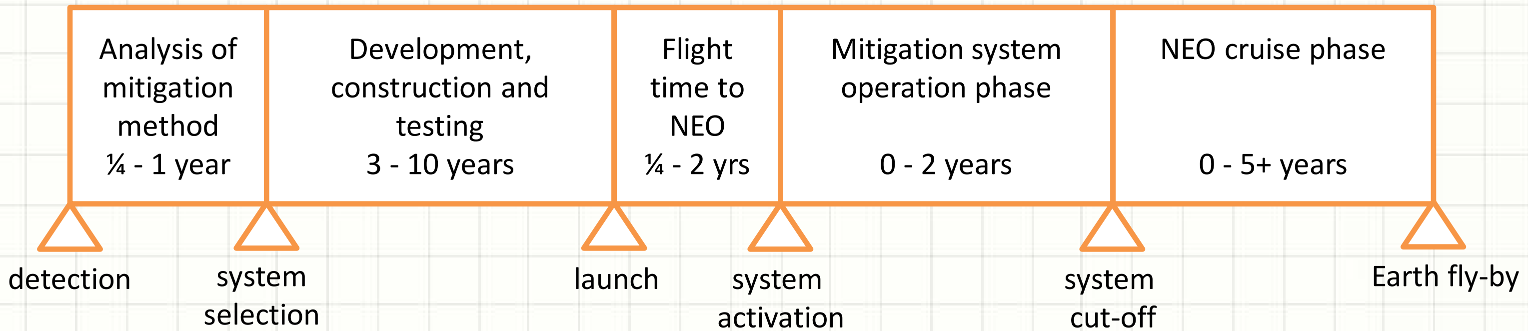
- Warning time too short (for mitigation measures) due to late detection (at least about 4 to 15 years required).

Technical reasons

- Deflection system developed not 100% functional.

Economical / political reasons

- Deflection costs far higher than expected damages,
- Minor, regional damages expected (sub-Tunguska size and/or remote location).



Costs and Risks of Evacuation

General risks / problems in case of evacuation:

- Evacuation only of persons, animals, moveable goods,
- Irretrievable loss of infrastructure, buildings, nature preserve, etc.,
- Additional risks due to possible destruction of chemical plants, nuclear power stations, etc.

Efficiency of evacuation depends on:

- Location of impact area – a densely populated area could possibly not be evacuated completely,
- Precise prediction of the impact area - may be too inaccurate due to poor orbital data (short warning time),
- Warning time available - long lead time allows for (nearly) complete evacuation.

Costs and Risks of Evacuation

Costs of search, evacuation, and mitigation measures:

Measure	Estimated costs [million Euro]
Search program (ground)	5 – 100
Search mission (Venus orbit)	300 – 2,000
Evacution (NEO 150 m)	100 – 5,000
Evacuation (NEO 750 m)	4,000 – 40,000
Mitigation mission (simple)	500 – 5,000
Mitigation mission (complex)	5,000 – 100,000

Costs and Risks of Evacuation

Prediction of impact area depends on accuracy of orbital data and available lead time.

Predicted destruction and evacuation area shrink with time, but evacuation success sinks due to short time to act.

Expected damages strongly depend on impact location.

Inhabitants / km²	% of Earth's surface
2,500	0.1
50	15.7
10	13.5
0	70.7
Average: 12	100

dpa

Costs and Risks of Evacuation

Example:

Discovery of a stony NEO at 40 lunar distances (LD) or about 10.5 days in advance (warning time).

A mean continental population density of 40 people / km² is considered, as well as a radar position determination uncertainty of 0.1", orbital eccentricity e = 1.7 (impact angle ≈75°), and a relative NEO velocity of 20 km/s (Duerfeld, 2004, and Kasper, 2004).

NEO diameter [m]	Detruction area [km²]	Evacuation area [km²]	Evacuation costs [million Euro]
60	300-3,000 (airblast)	4,000	90
150	2,000-7,000 (airblast)	20,000	500
400	12,500	120,000	3,500
750	45,000	410,000	13,200

Costs and Risks of Evacuation

Comparison of costs of evacuation, mitigation missions, damages (Duerfeld, 2004, Kasper, 2004, Gritzner et al., 2006). The values given may vary by an order of magnitude, depending on impact site, warning time, etc…!

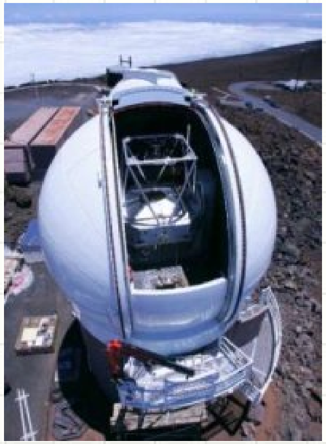
-> Evacuation is cheaper than mitigation (about a factor of 2 to 10),

-> Damages are higher than mitigation costs (about a factor of 4 to 45).

NEO diameter [m]	Evacuation costs [million Euro]	Mitigation costs [million Euro]	Average impact damages [million Euro]	Average impact casualties
60	90-2,200	500-5,000	20,000	16,700
150	100-5,000	1,000-10,000	45,000	37,500
400	3,500-15,000	10,000-50,000	120,000	100,000
750	4,000-40,000	25,000-100,000	650,000	540,000

Conclusions

- Evacuation of the impact area should be the last option in NEO mitigation (only if NEO deflection/destruction is impossible),
- Due to the current detection rates evacuation will be the most probably case for the next decades (short warning time),
- Evacuation plans should be developed and updated,
- Mitigation studies and tests have to be carried out,
- NEO search activities have to be intensified!



PS1 telescope by Brett Simison

Don Quijote study by ESA/AOES Medialab

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