TURAI: Terrestrial Unified Response to Asteroid Impacts

Version 1.0

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DOI https://doi.org/10.5281/zenodo.22950074
25 September 2026

Independent White Paper
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Suggested citation: Turai, A. L. (2026). TURAI: Terrestrial Unified Response to Asteroid Impacts (Version 1.0) [White paper]. Zenodo. https://doi.org/10.5281/zenodo.22950074

Abstract

Planetary defense has strong capabilities for discovering and tracking near-Earth objects (NEOs), but physical mitigation is generally designed for individual threats. This paper proposes TURAI (Terrestrial Unified Response to Asteroid Impacts), a research architecture for a standing international network of Earth-based response nodes. Its intended use is a subset of short-warning, small-to-medium NEO scenarios in which early deflection may no longer be practical yet a safe terrestrial-launched intervention might remain feasible. TURAI would rank candidate nodes by trajectory reachability, readiness, authorization, expected harm, and redundancy; the node nearest the projected impact point need not be the best placed to respond. The paper defines scenario-based Coverage Zones, Impact-Corridor Routing, and a Mutual-Response Principle under which participating states could make certified capabilities available across borders. It formulates node selection as a coverage problem with redundancy and regional-equity constraints. A geometry-only illustration shows the method's sensitivity to assumed access radius; it is neither an interceptor performance estimate nor a deployment plan. The proposed network would complement early detection, long-warning deflection, and civil protection. Major questions remain about actual reachability, intervention risk, authorization, sovereignty, liability, and dual-use safeguards. TURAI therefore offers a testable systems-research agenda, not an operational defense claim.

Keywords: planetary defense; near-Earth objects; short-warning response; terrestrial interception; network design; international cooperation; space law

1. Introduction

Asteroid impact is a low-frequency but potentially high-consequence natural hazard. The international planetary-defense community has built increasingly sophisticated capabilities for discovering near-Earth objects (NEOs), estimating impact probabilities, characterizing physical properties, and coordinating warning and mission planning. NASA's 2023 Planetary Defense Strategy and Action Plan treats discovery, characterization, mitigation, international cooperation, and emergency preparedness as linked elements of a single problem [1]. At the international level, IAWN and SMPAG provide recognized mechanisms for observation, warning, and cooperative mission planning [4-6].

The physical-response side of planetary defense, however, remains largely mission-specific. When a hazardous object is identified early enough, a tailored reconnaissance or deflection campaign can be designed around its orbit, size, composition, and warning time. DART demonstrated that a kinetic impactor can measurably change the motion of an asteroid system, but it did not create a standing defense against all hazardous bodies, nor was it intended to do so [2,3]. Short-warning objects present a different operational problem: scientific confirmation, political authorization, launch preparation, interception, and post-action verification all compete for a compressed timeline.

TURAI - Terrestrial Unified Response to Asteroid Impacts - addresses that architecture problem. It asks whether the international community should complement global asteroid detection with a terrestrial, globally distributed, mutually accessible physical-response network whose nodes are selected and activated according to trajectory feasibility rather than national borders. TURAI is not a proposal for a literal atmospheric dome, nor for a single universal missile. The "dome" is conceptual: overlapping access to a large share of relevant threat scenarios created by a set of prepared terrestrial nodes.

The proposal is deliberately narrower than "planetary defense" as a whole. TURAI focuses on a possible standing terrestrial response layer for small-to-medium, short-warning NEO threats. For Version 1.0, the principal study band is approximately 50-150 m in diameter. This is a research band rather than a formal astronomical category; it spans objects capable of severe urban or regional consequences and overlaps earlier very-short-warning terrestrial-interception studies [1,7,8]. Larger objects may require long-warning, mission-specific strategies, while much smaller meteoroids often undergo substantial atmospheric ablation or disruption. Neither boundary is absolute, and impact energy, composition, entry angle, warning time, and uncertainty matter as much as diameter.

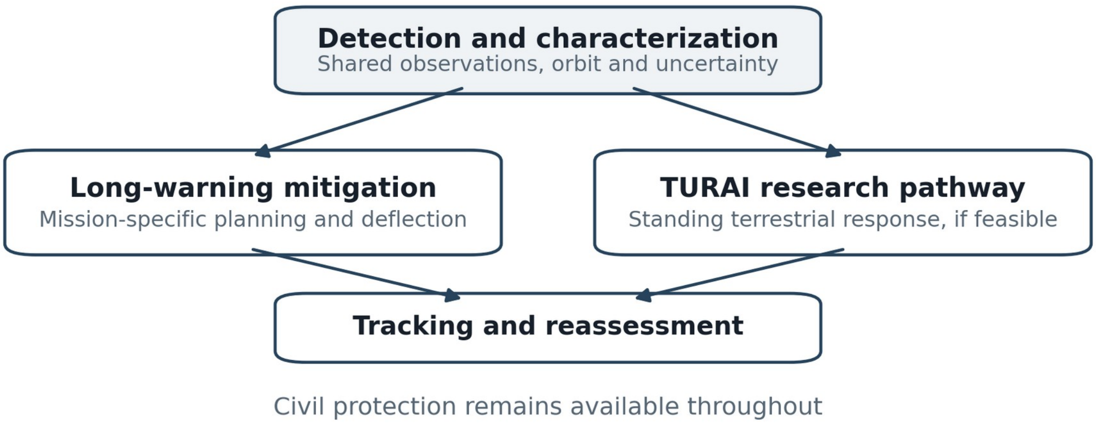

Figure 1. TURAI as a proposed pathway within the broader planetary-defense system.

2. Terminology, Scope, and Design Principles

2.1 Terrestrial-only basing

In TURAI, "terrestrial" describes the location of persistent infrastructure. Response nodes are stationed, maintained, governed, and inspected on Earth. A terrestrial-launched interceptor may necessarily travel above the atmosphere or through an exo-atmospheric trajectory; that does not make TURAI a permanently space-based defense network. TURAI Version 1.0 does not require orbiting weapons, permanently stationed interceptor spacecraft, or a global constellation of defensive platforms.

2.2 Correct impact terminology

A near-Earth object (NEO) is an asteroid or comet whose orbit brings it into Earth's neighborhood. This paper focuses on incoming asteroid-like bodies. A meteor is the luminous phenomenon during atmospheric entry; a meteorite is material that survives to the ground. TURAI addresses natural objects before or during entry, not meteorites after impact [16,17].

2.3 The threatened location is not automatically the responding location

A defining design principle is that geographic proximity to the projected impact point does not determine the best response node. An object predicted to affect one country may be more safely or effectively engaged from another because launch azimuth, Earth rotation, warning time, interceptor energy, target approach geometry, airspace constraints, and debris risk can make a distant node preferable. TURAI therefore routes the threat globally rather than assigning each city a local defensive battery.

2.4 Net-risk reduction

TURAI does not assume that intervention is always safer than non-intervention. Even technically successful fragmentation could produce an unacceptable debris or airburst pattern. Any authorized action should reduce expected loss by a predefined safety margin, with uncertainty assessed separately. Let L denote loss and let δ be that margin in the same units as L:

$$\mathbb{E}[L \mid \text{intervene}] + \delta \leq \mathbb{E}[L \mid \text{no intervention}], \qquad \delta > 0$$

3. Existing Planetary-Defense Architecture and Prior Art

TURAI builds on extensive planetary-defense science, engineering, and international coordination. The proposed contribution is the integration of a global network-design and governance framework, not any claim to have invented asteroid interception, kinetic impact, fragmentation, or directed energy.

Precedent	Established contribution	Relationship to TURAI
IAWN	International observation and warning network; persistent and globally distributed sensing/analysis.	Provides detection and warning layer, not physical interception.
SMPAG	Space-agency forum for cooperative planetary-defense mission planning and recommendations.	Governance and mission-planning precursor, not a standing response grid.
DART	Full-scale kinetic-impact technology demonstration at Dimorphos.	Demonstrates momentum-transfer principle; not a standing global defense system.
Very-short-warning terrestrial interception studies	Pre-built or suborbital terrestrial interceptors studied for small NEOs and compressed warning times.	Closest technical ancestor of TURAI; shows terrestrial interception is not novel by itself.
PI / Pulverize It	Terminal disruption/fragmentation concept intended to reduce consequences under suitable conditions.	Potential capability class; requires fragment and atmospheric risk modeling.
DE-STAR / directed-energy concepts	Laser-ablation concepts for asteroid deflection or disruption.	Relevant physics precedent; major DE-STAR concepts are not TURAI terrestrial deployments.

3.1 Warning and international coordination

UNOOSA describes IAWN and SMPAG as central elements of the international response to the NEO hazard [4,5]. IAWN coordinates observations and warning information, while SMPAG brings space agencies together to exchange information, develop collaborative work, and build consensus on possible mission responses [5,6]. These arrangements demonstrate that planetary defense is already treated as a transnational problem. TURAI proposes an additional standing physical-response layer; it does not claim endorsement from IAWN, SMPAG, UNOOSA, NASA, ESA, or any national government.

3.2 Kinetic deflection

NASA's DART spacecraft struck Dimorphos on 26 September 2022 and altered the moonlet's orbital period, validating kinetic impact as a real planetary-defense technology class [2,3]. The result is foundational for TURAI because it demonstrates controlled momentum transfer to a natural body. It does not imply that the same architecture can simply be scaled to every short-warning object: target structure, relative velocity, lead time, launch geometry, and acceptable post-impact uncertainty remain decisive.

3.3 Terrestrial interception and short-warning research

The closest prior art to TURAI is previous work on terrestrial or suborbital interception of small NEOs. Hupp, DeWald, Wie, and Barbee examined suborbital intercept and fragmentation for approximately 50-150 m objects in very-short-warning scenarios [7]. A later Aerospace Corporation presentation hosted by NASA's NESC Academy considered pre-built ground-based interceptors and explored local, regional, and national protection requirements [8]. These studies directly preclude any claim that TURAI invented the idea of launching an interceptor from Earth against an incoming asteroid.

The research gap addressed by TURAI is instead architectural: whether multiple terrestrial response capabilities can be organized as one persistent international grid, optimized for global scenario coverage, dynamically routed by incoming trajectory, and governed by a pre-agreed mutual-response framework.

3.4 Terminal disruption and directed energy

Lubin and Cohen's "Pulverize It" research investigates terminal interception and disruption as a means of changing how an incoming object deposits energy in the atmosphere [9]. Such concepts are relevant to TURAI because a node may eventually support more than one intervention mode. Fragmentation, however, is not automatically a successful outcome; the fragment-size distribution, dispersion, entry timing, and atmospheric energy deposition determine whether expected harm falls or rises.

Directed-energy planetary-defense work, including DE-STAR-related research, has explored laser ablation as a way to modify asteroid motion [10]. TURAI treats terrestrial directed energy only as a future or experimental capability class. Atmospheric propagation, pointing, range, power, target coupling, thermal response, and legal constraints would have to be demonstrated before such a system could be certified as an operational TURAI node capability.

3.5 Defensible novelty statement

TURAI proposes to combine four elements in one research architecture: (1) a standing network of geographically distributed, Earth-based response nodes; (2) explicit optimization of global threat-scenario coverage; (3) trajectory-dependent routing among national nodes; and (4) a pre-agreed multinational mutual-response commitment. The proposed contribution lies in this combination, not in an individual intervention technology.

This review is scoped rather than exhaustive. Stronger novelty or patentability claims would require a systematic scholarly and patent prior-art search.

4. The TURAI Architecture

4.1 TURAI Grid

The TURAI Grid is the complete multinational system: terrestrial response nodes; interfaces to warning organizations and national authorities; shared threat-state data; readiness and certification standards; routing algorithms; primary and backup assignment; authorization procedures; consequence modeling; liability rules; and post-action verification. The Grid is therefore as much an institutional system as a hardware network.

4.2 TURAI Node

A TURAI Node is an abstract capability unit rather than a synonym for a missile base. It may combine launch or directed-energy infrastructure, local tracking and communications, secure interfaces to national and multinational authorities, certified response technologies, civil-protection coordination, and defined readiness levels. Different nodes may possess different technology classes. Interoperability is achieved by common data, safety, authorization, and verification requirements rather than by forcing all countries to buy the same hardware.

4.3 Coverage Zones

A node's Coverage Zone is defined in scenario space, rather than by a circle on a map. Let S be the set of relevant threat scenarios, U_i the authorized actions at node i, and F(i,s,u) an indicator that action u satisfies technical, timing, legal, and safety constraints for scenario s. Then:

$$C_i = \{\, s \in S : \exists\, u \in U_i \text{ such that } F(i,s,u) = 1 \,\}$$

4.4 Impact-Corridor Routing

Impact-Corridor Routing is the dynamic assignment process that converts a validated threat estimate into a ranked set of terrestrial response options. As observations refine the orbit, the predicted impact corridor and uncertainty region evolve. TURAI continually re-evaluates feasible nodes, identifies a primary response node, preserves backup and redundant options, and reports when physical intervention is not justified. The decision is made from trajectory and risk, not from political symbolism or city-level proximity.

4.5 Mutual-Response Principle

TURAI's institutional center is a mutual-response principle: a qualifying natural NEO threat to any participating state is treated as a shared planetary-defense emergency, and participating states agree in advance to make suitable certified capabilities available when their node offers a safer or more feasible intervention opportunity. This is distinct from military collective defense. The adversary is a natural object, and TURAI authority should explicitly exclude use against states, persons, aircraft, satellites, launch vehicles, or other human-made targets.

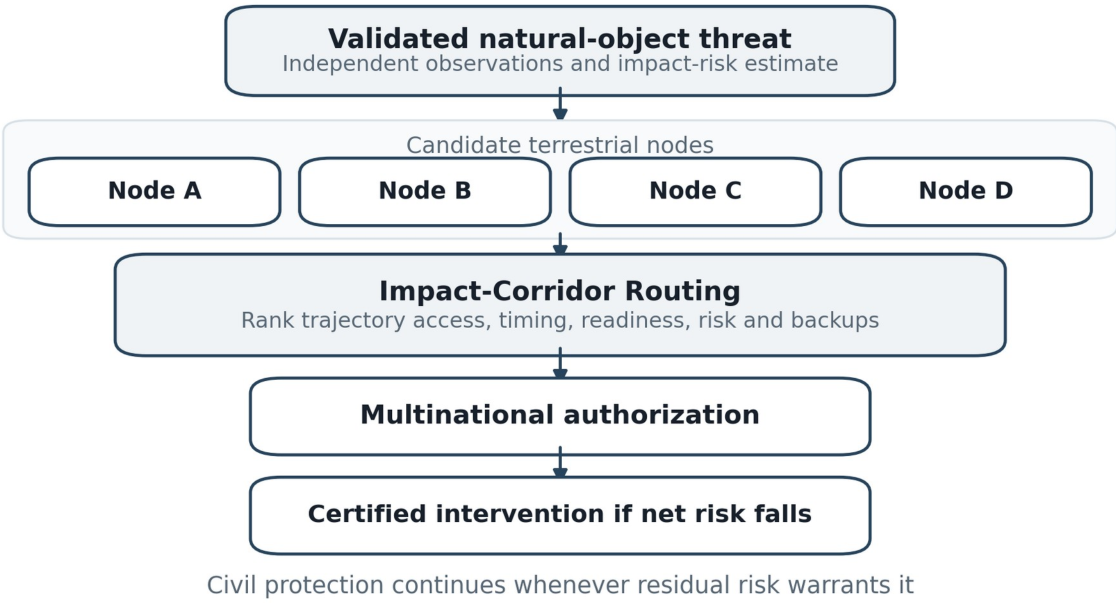

Figure 2. Conceptual TURAI routing and authorization. Node selection depends on feasibility and risk, not the nationality of the threatened location.

5. Conceptual Operational Sequence

A mature TURAI response would separate scientific validation, political authorization, and technical execution. No single automated system or national operator should both declare a threat and authorize an intervention with cross-border consequences. A conceptual sequence is:

1. Detection and validation: observations establish an object, orbit, uncertainty distribution, and credible impact risk.
2. Characterization: size, composition, rotation state, entry geometry, and other properties are estimated to the extent time permits.
3. Scenario generation: a probabilistic ensemble of possible trajectories and impact outcomes is produced rather than relying on one nominal impact point.
4. TURAI routing: the Grid evaluates which terrestrial nodes have at least one technically feasible and legally authorized response opportunity.
5. Risk comparison: intervention and non-intervention outcomes are compared, including fragmentation, corridor shift, atmospheric effects, and uncertainty.
6. Multinational authorization: a pre-agreed authority confirms whether the risk threshold for physical intervention has been met.
7. Execution: the selected primary node acts within certified limits while backup nodes remain available where time permits.
8. Post-action tracking: independent observations immediately update the orbit and residual impact probability.
9. Re-routing or stand-down: if risk remains, TURAI re-runs the scenario; if risk is acceptably removed, the physical-response layer stands down.
10. Civil protection: evacuation, warning, infrastructure protection, and emergency response remain active whenever residual risk justifies them.

6. Technology-Agnostic Capability Classes

TURAI is an architecture, not a commitment to a single interceptor. This distinction is essential because the technology appropriate for one threat class may be unsuitable for another. Version 1.0 therefore classifies candidate technologies by function and evidence level.

Capability class	Function	2026 evidence base	TURAI v1.0 treatment
Kinetic trajectory modification	Momentum transfer intended to alter trajectory.	Demonstrated as a principle by DART; terminal terrestrial implementation still requires dedicated design.	Baseline mature principle; scenario dependent.
High-altitude terrestrial interception	Engage an incoming small NEO on a rapidly prepared trajectory.	Prior NASA/NESC-hosted and conference studies; no standing global system.	Core TURAI research pathway.
Controlled disruption / fragmentation	Break an object into a fragment distribution intended to reduce expected harm.	Peer-reviewed terminal-defense research exists.	Conditional; only if fragment modeling shows net risk reduction.
Terrestrial directed energy	Remote energy deposition for ablation, disruption, or trajectory change.	Strong conceptual literature; terrestrial operational feasibility not established for TURAI.	Future / experimental class.
Future non-prescribed technology	Any later method meeting common interface and safety requirements.	Unknown by definition.	Permitted by architecture after certification.
Civil protection / non-intervention	Reduce consequences when physical mitigation is unavailable or unsafe.	Established emergency-management function.	Mandatory fallback, not failure.

Nuclear planetary-defense approaches are not part of the TURAI Version 1.0 baseline. Their technical, strategic, treaty, security, and escalation implications require separate specialist analysis. Excluding them keeps the initial architecture focused on civilian, internationally verifiable response classes.

7. A Quantitative Global Coverage Problem

7.1 Formal formulation

A central research component of TURAI is an explicit network-design problem. Let I be the set of candidate terrestrial nodes and S the set of threat scenarios. Let x_i indicate whether node i is selected, and let y_s indicate whether scenario s is credited as covered. Set a_{is} to 1 only when node i has a safe, technically feasible, authorized response for scenario s. Let $w_s \geq 0$ be the scenario weight, α the required weighted coverage fraction, and k the required number of distinct feasible nodes per credited scenario.

A minimal node-count formulation is:

$$
\begin{aligned}
\min_{x,y} \quad & \sum_{i\in I} x_i \\
\text{subject to} \quad & \sum_{i\in I} a_{is} x_i \ge k y_s, \qquad \forall s \in S, \\
& \sum_{s\in S} w_s y_s \ge \alpha \sum_{s\in S} w_s, \\
& x_i, y_s \in \{0,1\}.
\end{aligned}
$$

This constraint counts distinct feasible nodes. It does not by itself rule out common-cause failures; a higher-fidelity model would need explicit reliability or failure-domain constraints.

Regional-equity constraints may additionally require a minimum weighted coverage fraction α_r for each regional or socioeconomic scenario subset S_r. Such constraints prevent a nominally efficient global solution from systematically underserving particular regions.

7.2 What a physically meaningful scenario must contain

A high-fidelity threat scenario should include an estimated NEO state vector and covariance; diameter, density, shape, spin, and composition assumptions; warning time; an impact corridor; atmospheric conditions; and a consequence model. The value a_{is} should be 1 only when a mission-design analysis finds at least one response satisfying preparation, energy, timing, intercept geometry, target uncertainty, safety, and legal constraints.

7.3 Illustrative Version 1.0 proxy

Version 1.0 uses a deliberately simplified geometric proxy to illustrate the optimization without assuming an unvalidated interceptor specification. Candidate terrestrial anchors cover a synthetic surface scenario when their great-circle distance is no larger than an assumed access radius. A greedy set-cover procedure selects anchors toward a target geometric coverage fraction.

The assumed radius is not an interceptor range, and the node counts are not deployment recommendations. This proxy omits approach direction, launch energy, Earth rotation, warning time, target uncertainty, atmospheric consequences, sovereignty, infrastructure, and reliability. It illustrates how sensitive a node-selection result is to its underlying reachability assumptions.

Proxy access radius	Coverage target	Nodes selected	Achieved geometric coverage
4,500 km	90%	13	90.8%
4,500 km	95%	18	92.8% (target unmet)
5,000 km	90%	9	93.3%
5,000 km	95%	10	95.4%
5,500 km	90%	7	92.0%
5,500 km	95%	8	96.3%
6,000 km	90%	6	93.9%
6,000 km	95%	7	96.9%

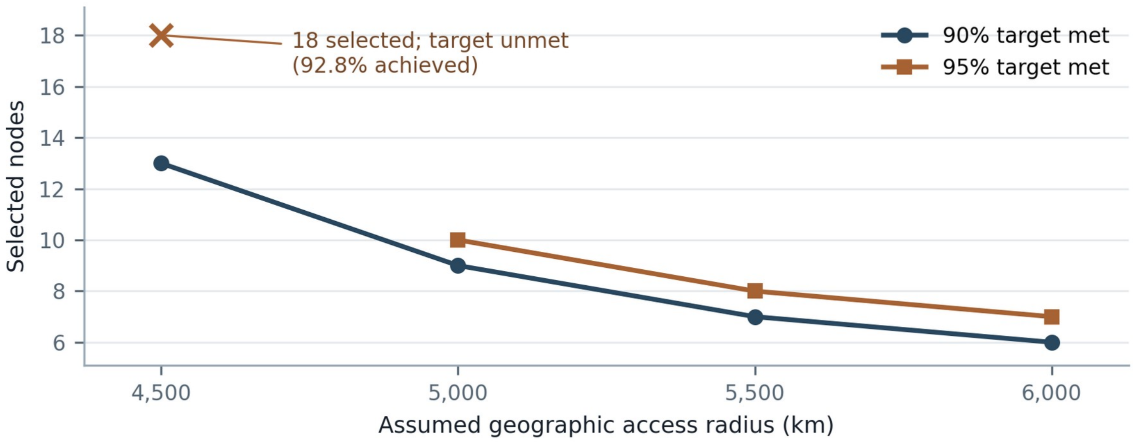

Figure 3. Sensitivity of selected node count to a synthetic geographic-access assumption. The 95% target was not reached at 4,500 km; these results do not predict operational performance.

7.4 Research progression

The next technical step is to replace the geographic proxy with a vehicle-independent trajectory-reachability model. Rather than asking whether a site lies within a fixed distance of a surface point, the analysis should ask whether node i can place an approved response system on an admissible intercept trajectory for scenario s before a defined terminal boundary. The optimization framework can then use a physically defensible a_{is} matrix.

Four testable hypotheses follow: H1, a finite terrestrial network can provide useful redundancy across a meaningful subset of short-warning NEO scenario space; H2, trajectory-optimized node locations differ materially from population-center-based locations; H3, cross-border routing increases feasible-response coverage relative to national-self-defense-only architectures; and H4, a pre-agreed authorization framework reduces decision latency enough to enlarge the feasible intervention set in time-critical cases.

8. Governance and International Cooperation

8.1 Integration with existing institutions

TURAI should be designed to fit beneath, not compete with, existing international planetary-defense mechanisms. A practical division of functions is: IAWN - detect, characterize, and warn; SMPAG - coordinate and advise on possible mission responses; TURAI - investigate whether a standing terrestrial response layer can be maintained, routed, and activated under pre-agreed rules. This framing recognizes the legitimacy of existing institutions while identifying a capability they do not presently provide as an operational grid [4-6].

8.2 Authorization

TURAI requires an ex-ante decision framework agreed before a real emergency. Scientific bodies should validate what is happening; a designated multinational authority should decide whether intervention is permitted; and certified nodes should execute only within approved technical limits. The authorization threshold should depend on impact probability, consequence severity, warning time, confidence in the intervention model, residual risk, and the possibility of transferring risk to third states.

8.3 Risk transfer and sovereignty

A deflection or disruption campaign may change the geographic distribution of risk before it removes the threat entirely. A state that was initially safe may temporarily enter a projected corridor as the object's trajectory evolves. Earlier UN work on international NEO response explicitly recognized this political problem [11]. TURAI therefore treats risk transfer as a core design constraint rather than an afterthought. A future agreement should define what level of temporary transferred risk is acceptable, how affected states are consulted, and how urgent action proceeds when unanimous consent is impossible.

8.4 Liability and responsibility

The Outer Space Treaty establishes state responsibility for national activities in outer space and contains liability and due-regard principles relevant to launched objects and potentially harmful activities [12]. The Liability Convention develops the international liability regime for damage caused by space objects [13]. Depending on the trajectory and legal characterization of a particular TURAI intervention, registration obligations may also be relevant [14]. Existing law does not provide a turnkey compensation mechanism for a multinational planetary-defense operation involving a facility state, launching state, technology supplier, threatened state, and collective decision authority. A TURAI accord should therefore study pooled indemnification, cross-waivers among participants, and compensation for third-party victims.

8.5 Dual-use safeguards

Rapid-launch interceptors and high-power directed-energy systems are inherently dual-use and may be perceived as strategic weapons even if intended only for natural hazards. Contemporary scholarship on planetary-defense law and ethics emphasizes that security, responsibility, and legitimacy are inseparable from technical capability [15]. TURAI should therefore require independent confirmation that the target is a natural object, multinational authorization, shared mission telemetry for approved operations, declared capability classes, post-mission reporting, and verification measures appropriate to participating states. The agreement should explicitly prohibit activation against human-made targets.

9. Why a TURAI-Like Network Does Not Already Exist

The absence of a standing global terrestrial interception grid is not evidence that the idea is useless. Several structural reasons explain why planetary-defense work has developed differently.

- Early discovery is more efficient. Long warning times permit smaller trajectory changes and more deliberate mission development, so survey and characterization capability correctly receive major attention [1].
- Terminal interception is technically difficult. The relevant research remains highly scenario-dependent and has not matured into a globally certified operational capability [7,8].
- Fragmentation can create new hazards. Breaking an object apart is beneficial only when the resulting fragment and atmospheric-entry distribution lowers expected harm [9].
- Global deployment is politically sensitive. Interceptor-like and directed-energy infrastructure raises sovereignty, verification, arms-control, and dual-use concerns [12,15].
- International institutions coordinate warning and planning but are not a supranational launch authority. Creating a standing execution network would require new legal commitments and financing [4-6].
- The optimization problem is nontrivial. Real coverage is a function of trajectory geometry, warning time, vehicle capability, reliability, and risk - not a simple map of circles around cities.

10. Safety, Failure Modes, and Limits

TURAI Version 1.0 is a research architecture, not an operational defense plan. Its credibility depends on identifying failure modes openly.

- Orbit and impact uncertainty: a false positive, a rapidly changing impact corridor, or insufficient characterization can make premature intervention more dangerous than waiting.
- Launch or response failure: a standing node can still be unavailable because of maintenance, weather, airspace, range safety, command failure, or technical fault.
- Fragmentation failure: disruption may create large surviving fragments, a broader damage footprint, or multiple atmospheric bursts.
- Insufficient warning time: some objects may be discovered too late for any physical response, leaving civil protection as the only rational option.
- Insufficient energy or poor geometry: a node may be geographically close yet unable to reach a viable intercept state.
- Risk transfer: a partial deflection can move probability mass into another state or region.
- Political delay: a technically feasible response may become infeasible if authorization is improvised during the emergency.

- Dual-use mistrust: states may withhold participation or data if infrastructure is perceived as strategic weaponry.
- Cost and readiness burden: a distributed network that is rarely used must still be continuously maintained, tested, and audited.

These limitations define the research program needed to determine whether TURAI is viable. A credible study should be willing to conclude that some asteroid classes, warning times, or technologies are unsuitable for a standing terrestrial response.

11. Research Roadmap

TURAI can progress through increasingly quantitative stages rather than attempting to specify a complete global defense system in one document.

Stage	Core work	Decision value
Phase 1 - Architecture	Formal definitions, prior art, governance model, illustrative optimization.	This white paper (Version 1.0).
Phase 2 - Reachability	Monte Carlo NEO trajectories; vehicle-independent response envelopes; response-time distributions.	Replace geographic proxy with astrodynamic feasibility.
Phase 3 - Consequence coupling	Fragmentation, atmospheric entry, impact-effects, population and infrastructure risk.	Optimize expected harm, not surface geometry.
Phase 4 - Governance simulation	Authorization delays, risk-transfer rules, liability and multinational decision pathways.	Test whether policy timing changes feasible interventions.
Phase 5 - Demonstration	Table-top exercises, digital twins, hardware-in-the-loop tests, possibly non-hazardous flight demonstrations.	Validate interfaces without operational weaponization.
Phase 6 - Treaty feasibility	Negotiation of standards, inspections, financing, mutual response, and peaceful-use safeguards.	Political decision based on evidence from earlier phases.

12. Discussion

TURAI's central contribution is not a new interceptor. It is the proposition that planetary-defense preparedness can be designed as a standing global network rather than only as a sequence of bespoke missions. That proposition matters most in the narrow but consequential region where warning time is too short for conventional long-duration mission development yet long enough for a prepared terrestrial capability to create a safe intercept opportunity.

The architecture deliberately separates basing from flight. A terrestrial network can remain terrestrial even if an interceptor leaves the atmosphere. It separates geography from responsibility: the state at risk need not be the state that responds. It separates the network from the technology: kinetic, disruption, directed-energy, and future capabilities can be assessed against common performance and safety interfaces. And it separates scientific warning from political authorization: existing international institutions need not become weapon commands for TURAI to interoperate with their data and recommendations.

The central technical unknown is the true reachability matrix a_{is}. A meaningful study needs many synthetic or historical NEO approach states, realistic warning-time distributions, physically valid performance envelopes, and consequence models that compare intervention with non-intervention. The central governance unknown is whether states would accept advance cross-border response rules for infrastructure with potential dual uses.

This combination of engineering and governance is precisely why TURAI is suitable as a systems-research agenda. A network can be rejected, redesigned, or narrowed based on quantitative results. If simulation shows that short-warning reachability is too sparse, that fragmentation risk overwhelms benefits, or that authorization cannot occur safely in time, the architecture should be revised rather than defended rhetorically.

13. Conclusion

Planetary defense is inherently planetary: impact corridors do not recognize sovereignty, and the terrestrial location best positioned to support mitigation need not lie within the state most at risk. Existing international arrangements provide increasingly capable mechanisms for detection, warning, and cooperative mission planning, while individual mitigation technologies continue to advance. TURAI proposes that the next architectural question is whether these capabilities can be extended into a persistent terrestrial response network in which strategically distributed nodes collectively provide resilient access to suitable short-warning impact scenarios.

TURAI Version 1.0 introduces the TURAI Grid, scenario-based Coverage Zones, Impact-Corridor Routing, a Mutual-Response Principle, and a formal node-selection problem with redundancy and equity constraints. It intentionally avoids claiming that current missiles, lasers, or fragmentation systems already constitute a global asteroid shield. Instead, it defines a falsifiable research program: calculate real reachability, model consequences, measure how cross-border routing changes coverage, and determine whether safe multinational authorization can occur within compressed timelines.

The concept remains unvalidated and substantial technical, legal, economic, and political questions are unresolved. Those uncertainties are not arguments for assuming the architecture feasible; they define the work required to test it. TURAI's purpose is therefore not to declare that Earth already knows how to build a terrestrial planetary-defense grid, but to make the question precise enough that the scientific and international community can evaluate whether one should exist.

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