Orbital-Debris Removal PPPs: Pricing Public Benefit and Performance Risk

An Outcome-Payment, Liability and Verification Framework for Publicly Sponsored Active Debris Removal

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Abstract

Orbital-debris removal produces a dispersed public benefit while concentrating mission, technology, liability and financing risk in a small number of contracting parties. Satellite operators, governments and citizens benefit when collision probability, avoidance manoeuvres, service disruption and long-run orbital congestion decline. A private removal provider cannot normally charge every beneficiary. Public procurement must therefore convert a shared benefit into an enforceable payment stream without paying for activity that fails to reduce risk.

This paper develops an outcome-payment, liability and verification framework for publicly sponsored active debris removal. It treats the arrangement as a public-private partnership in economic substance: the public authority defines the required outcome and affordability envelope; the private partner integrates mission design, technology, suppliers and capital; independent evidence determines whether payments are earned; and contracts allocate risks to the party best able to manage them. The proposed structure separates target selection, mission preparation, launch and commissioning, rendezvous, capture, disposal, data delivery and claims closeout. Each gate has a defined evidence package, payment consequence and cure route.

The policy need is current. The European Space Agency reported in September 2026 that more than 4,000 payloads launched during 2025, that more than three intact objects re-entered each day while ten payloads were launched each day, and that active removal is required alongside prevention and end-of-life disposal to stop self-sustaining debris growth. ESA's current statistics report roughly 46,950 regularly tracked objects, more than 68,000 objects larger than ten centimetres and more than 660 fragmentation events. NASA's cost-benefit work shows that the economic ranking of remediation methods depends on target, timing, collision risk and cost; in some cases, nudging a large object may create value faster than full removal. The UK Space Agency's 2025 competitive procurement seeks removal of at least two unprepared, uncooperative UK-licensed satellites under a five-year research and development contract. These programmes establish policy and procurement direction; they do not establish the cost, probability of success or value of an unidentified mission. [1][2][3][4][5][6]

The worked case is wholly hypothetical. A public authority procures a five-year programme to capture and dispose of two unprepared low-Earth-orbit objects. The nominal service envelope is USD 96 million, funded by USD 18 million of sponsor equity, USD 22 million of senior programme debt, USD 46 million of public milestone and outcome payments and USD 10 million of retained contingent payment. Illustrative gross public benefit is USD 112 million, comprising avoided collision-loss equivalent, avoided operator cost, protected service continuity, demonstration spillover and environmental option value. The resulting illustrative net public value is USD 16 million before distributional, strategic and unpriced environmental effects. Every amount and probability requires mission-specific evidence.

The framework is intended for space agencies, ministries, procurement authorities, satellite regulators, mission providers, lenders, insurers, export-credit institutions, strategic investors and infrastructure funds. It directs public payment toward verified risk reduction, keeps mission and liability exposure visible, and preserves funded recovery and disposal obligations when performance deviates from plan.

JEL Classification: G28, G31, G32, H43, H54, L32, L93, Q58

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Introduction

Orbital debris is a shared-infrastructure problem. A non-functional object can threaten commercial satellites, public services and future missions owned by parties that had no role in creating it. Collision avoidance, tracking and shielding reduce exposure, yet they do not remove the object. Active debris removal can reduce the stock of hazardous mass and demonstrate technologies needed for a more circular orbital economy.

The financing problem begins with a missing direct customer. Many beneficiaries cannot be individually charged, while the provider must finance engineering, licensing, launch, rendezvous and capture before the public outcome exists. Mission failure may leave little reusable value. Liability can cross national borders and treaty relationships. Verification must distinguish a completed removal from an attempt, a temporary nudge from a durable reduction in collision risk, and useful mission data from proprietary claims that cannot be audited.

A credible PPP structure converts the policy objective into a measurable service. It identifies the target and baseline risk, specifies the required end-state, prices each mission gate, allocates controllable risks, funds the risks that cannot be transferred efficiently and appoints an independent verifier. The public authority pays for defined evidence. The private partner earns returns through delivery, disciplined cost management and reusable capability. Lenders rely on contracted payments after objective conditions rather than speculative orbital value.

1. Define the public service

The decision concerns the exact orbital-risk reduction to be purchased, including target, acceptable final orbit or re-entry state, evidence date and public-service period. The authority should assemble current technical, legal, commercial and financial evidence at one controlled cut-off date. Every assumption should have an owner, source, confidence range and review trigger.

The required output is a procurement specification that links public purpose to observable performance. The analysis should show the base case, correlated downside, control owner, cash consequence and cure route. Public benefit, mission success and payment certainty should remain separate measures because each answers a different approval question.

The authority should avoid buying an undefined mission attempt. A service definition should state what must change in the orbital environment and how long the resulting risk reduction must remain valid. The contract should state who can observe the evidence, who decides acceptance, how disagreement is resolved and which payment or remedy follows. A financing model should apply the same definitions so that drawdown, debt service and distributions move with verified performance.

The board should also test interactions. A technically successful mission can deliver weak value if the selected target has low marginal risk. A high-value target can remain unsuitable if legal authority, capture feasibility or insurance is unresolved. A low bid can become unaffordable if change, liability and delay risks return to the authority through claims.

2. Select targets through transparent risk ranking

The decision concerns mass, orbit, conjunction history, fragmentation potential, ownership, legal authority, capture feasibility and network criticality. The authority should assemble current technical, legal, commercial and financial evidence at one controlled cut-off date. Every assumption should have an owner, source, confidence range and review trigger.

The required output is a target-ranking score with documented policy weights and sensitivity tests. The analysis should show the base case, correlated downside, control owner, cash consequence and cure route. Public benefit, mission success and payment certainty should remain separate measures because each answers a different approval question.

ESA and NASA both emphasise that target choice matters. The largest or most visible object is not automatically the highest-value removal when probability, feasibility and opportunity cost are considered. The contract should state who can observe the evidence, who decides acceptance, how disagreement is resolved and which payment or remedy follows. A financing model should apply the same definitions so that drawdown, debt service and distributions move with verified performance.

The board should also test interactions. A technically successful mission can deliver weak value if the selected target has low marginal risk. A high-value target can remain unsuitable if legal authority, capture feasibility or insurance is unresolved. A low bid can become unaffordable if change, liability and delay risks return to the authority through claims.

3. Establish the counterfactual

The decision concerns the expected risk, operator cost and service exposure if the authority does not procure the mission. The authority should assemble current technical, legal, commercial and financial evidence at one controlled cut-off date. Every assumption should have an owner, source, confidence range and review trigger.

The required output is a baseline against which avoided loss and incremental benefit can be measured. The analysis should show the base case, correlated downside, control owner, cash consequence and cure route. Public benefit, mission success and payment certainty should remain separate measures because each answers a different approval question.

Historical conjunctions and modelled collision probability inform the counterfactual. They do not create a guaranteed loss forecast. The appraisal should retain ranges and show which assumption drives the ranking. The contract should state who can observe the evidence, who decides acceptance, how disagreement is resolved and which payment or remedy follows. A financing model should apply the same definitions so that drawdown, debt service and distributions move with verified performance.

The board should also test interactions. A technically successful mission can deliver weak value if the selected target has low marginal risk. A high-value target can remain unsuitable if legal authority, capture feasibility or insurance is unresolved. A low bid can become unaffordable if change, liability and delay risks return to the authority through claims.

4. Price dispersed public benefit

The decision concerns avoided collision-loss equivalent, avoided manoeuvres, protected service continuity, demonstration value, environmental option value and strategic resilience. The authority should assemble current technical, legal, commercial and financial evidence at one controlled cut-off date. Every assumption should have an owner, source, confidence range and review trigger.

The required output is a public-benefit account that separates monetised, quantified non-monetised and qualitative effects. The analysis should show the base case, correlated downside, control owner, cash

consequence and cure route. Public benefit, mission success and payment certainty should remain separate measures because each answers a different approval question.

Combining all effects into a single precise number can conceal weak evidence. The decision record should show the metric, beneficiary, time horizon and confidence attached to each category. The contract should state who can observe the evidence, who decides acceptance, how disagreement is resolved and which payment or remedy follows. A financing model should apply the same definitions so that drawdown, debt service and distributions move with verified performance.

The board should also test interactions. A technically successful mission can deliver weak value if the selected target has low marginal risk. A high-value target can remain unsuitable if legal authority, capture feasibility or insurance is unresolved. A low bid can become unaffordable if change, liability and delay risks return to the authority through claims.

5. Choose the procurement form

The decision concerns whether the authority needs a grant, cost-reimbursement contract, fixed-price service, milestone contract, availability payment or outcome-based PPP. The authority should assemble current technical, legal, commercial and financial evidence at one controlled cut-off date. Every assumption should have an owner, source, confidence range and review trigger.

The required output is a form matched to technical maturity, information asymmetry and public risk tolerance. The analysis should show the base case, correlated downside, control owner, cash consequence and cure route. Public benefit, mission success and payment certainty should remain separate measures because each answers a different approval question.

A novel capture concept may require development risk sharing. A mature repeat mission may support firmer pricing. Contract form should evolve with evidence rather than force early certainty. The contract should state who can observe the evidence, who decides acceptance, how disagreement is resolved and which payment or remedy follows. A financing model should apply the same definitions so that drawdown, debt service and distributions move with verified performance.

The board should also test interactions. A technically successful mission can deliver weak value if the selected target has low marginal risk. A high-value target can remain unsuitable if legal authority, capture feasibility or insurance is unresolved. A low bid can become unaffordable if change, liability and delay risks return to the authority through claims.

6. Build the mission work breakdown

The decision concerns target characterisation, design, licensing, manufacture, launch, commissioning, rendezvous, capture, disposal, data delivery and closeout. The authority should assemble current technical, legal, commercial and financial evidence at one controlled cut-off date. Every assumption should have an owner, source, confidence range and review trigger.

The required output is a costed and scheduled mission tree with accountable owners. The analysis should show the base case, correlated downside, control owner, cash consequence and cure route. Public benefit, mission success and payment certainty should remain separate measures because each answers a different approval question.

Programme finance depends on the interfaces between stages. A delay in target data, launch integration or regulatory consent can consume liquidity before any outcome payment becomes available. The contract should state who can observe the evidence, who decides acceptance, how disagreement is resolved and which payment or remedy follows. A financing model should apply the same definitions so that drawdown, debt service and distributions move with verified performance.

The board should also test interactions. A technically successful mission can deliver weak value if the selected target has low marginal risk. A high-value target can remain unsuitable if legal authority, capture feasibility or insurance is unresolved. A low bid can become unaffordable if change, liability and delay risks return to the authority through claims.

7. Design objective payment gates

The decision concerns the evidence required before each public payment becomes irrevocably earned. The authority should assemble current technical, legal, commercial and financial evidence at one controlled cut-off date. Every assumption should have an owner, source, confidence range and review trigger.

The required output is a milestone and outcome-payment schedule aligned with cost, value and risk retirement. The analysis should show the base case, correlated downside, control owner, cash consequence and cure route. Public benefit, mission success and payment certainty should remain separate measures because each answers a different approval question.

Early payments should fund necessary development and public dependencies. Later payments should remain conditional on independently verified capture, disposal and data delivery. Retention supports claims closeout and final evidence. The contract should state who can observe the evidence, who decides acceptance, how disagreement is resolved and which payment or remedy follows. A financing model should apply the same definitions so that drawdown, debt service and distributions move with verified performance.

The board should also test interactions. A technically successful mission can deliver weak value if the selected target has low marginal risk. A high-value target can remain unsuitable if legal authority, capture feasibility or insurance is unresolved. A low bid can become unaffordable if change, liability and delay risks return to the authority through claims.

8. Separate activity from outcome

The decision concerns engineering effort and launch expenditure versus durable reduction in orbital risk. The authority should assemble current technical, legal, commercial and financial evidence at one controlled cut-off date. Every assumption should have an owner, source, confidence range and review trigger.

The required output is two payment classes with different acceptance tests and termination rights. The analysis should show the base case, correlated downside, control owner, cash consequence and cure route. Public benefit, mission success and payment certainty should remain separate measures because each answers a different approval question.

Some activity payments are justified because the public authority requests novel research and owns resulting data. Outcome payments should remain reserved for completed risk reduction. The contract should state who can observe the evidence, who decides acceptance, how disagreement is resolved and which payment or remedy follows. A financing model should apply the same definitions so that drawdown, debt service and distributions move with verified performance.

The board should also test interactions. A technically successful mission can deliver weak value if the selected target has low marginal risk. A high-value target can remain unsuitable if legal authority, capture feasibility or insurance is unresolved. A low bid can become unaffordable if change, liability and delay risks return to the authority through claims.

9. Appoint an independent verifier

The decision concerns who observes tests, mission telemetry, tracking data, disposal evidence and contract compliance. The authority should assemble current technical, legal, commercial and financial

evidence at one controlled cut-off date. Every assumption should have an owner, source, confidence range and review trigger.

The required output is a verification protocol with access rights, standards, dispute escalation and audit trail. The analysis should show the base case, correlated downside, control owner, cash consequence and cure route. Public benefit, mission success and payment certainty should remain separate measures because each answers a different approval question.

The verifier requires sufficient technical access without taking operational control. The contract should resolve conflicts between provider telemetry, public tracking and third-party catalogues. The contract should state who can observe the evidence, who decides acceptance, how disagreement is resolved and which payment or remedy follows. A financing model should apply the same definitions so that drawdown, debt service and distributions move with verified performance.

The board should also test interactions. A technically successful mission can deliver weak value if the selected target has low marginal risk. A high-value target can remain unsuitable if legal authority, capture feasibility or insurance is unresolved. A low bid can become unaffordable if change, liability and delay risks return to the authority through claims.

10. Allocate design and integration risk

The decision concerns whether the provider can control system design, suppliers, interfaces and qualification. The authority should assemble current technical, legal, commercial and financial evidence at one controlled cut-off date. Every assumption should have an owner, source, confidence range and review trigger.

The required output is provider responsibility supported by relief for authority-directed changes and deficient public data. The analysis should show the base case, correlated downside, control owner, cash consequence and cure route. Public benefit, mission success and payment certainty should remain separate measures because each answers a different approval question.

Risk transfer has value only when the provider can manage the risk and price it. Unbounded transfer can raise bids, weaken competition or produce claims after award. The contract should state who can observe the evidence, who decides acceptance, how disagreement is resolved and which payment or remedy follows. A financing model should apply the same definitions so that drawdown, debt service and distributions move with verified performance.

The board should also test interactions. A technically successful mission can deliver weak value if the selected target has low marginal risk. A high-value target can remain unsuitable if legal authority, capture feasibility or insurance is unresolved. A low bid can become unaffordable if change, liability and delay risks return to the authority through claims.

11. Allocate target-condition risk

The decision concerns uncertainty in tumbling, geometry, structural integrity, residual energy, materials and unrecorded modifications. The authority should assemble current technical, legal, commercial and financial evidence at one controlled cut-off date. Every assumption should have an owner, source, confidence range and review trigger.

The required output is a baseline target dossier, data-room warranty and change mechanism. The analysis should show the base case, correlated downside, control owner, cash consequence and cure route. Public benefit, mission success and payment certainty should remain separate measures because each answers a different approval question.

An unprepared, uncooperative object may differ from historical records. The authority should define the information standard, provider inspection duty and consequences of material deviation. The contract should state who can observe the evidence, who decides acceptance, how disagreement is resolved and which payment or remedy follows. A financing model should apply the same definitions so that drawdown, debt service and distributions move with verified performance.

The board should also test interactions. A technically successful mission can deliver weak value if the selected target has low marginal risk. A high-value target can remain unsuitable if legal authority, capture feasibility or insurance is unresolved. A low bid can become unaffordable if change, liability and delay risks return to the authority through claims.

12. Allocate launch and schedule risk

The decision concerns launcher availability, rideshare priority, integration, weather, regulatory slots and mission-window effects. The authority should assemble current technical, legal, commercial and financial evidence at one controlled cut-off date. Every assumption should have an owner, source, confidence range and review trigger.

The required output is a schedule regime with long-stop dates, substitute launch rights and delay liquidity. The analysis should show the base case, correlated downside, control owner, cash consequence and cure route. Public benefit, mission success and payment certainty should remain separate measures because each answers a different approval question.

Schedule risk can sit outside the removal provider's control. The finance plan should distinguish excusable delay from provider delay and keep debt service aligned with payment timing. The contract should state who can observe the evidence, who decides acceptance, how disagreement is resolved and which payment or remedy follows. A financing model should apply the same definitions so that drawdown, debt service and distributions move with verified performance.

The board should also test interactions. A technically successful mission can deliver weak value if the selected target has low marginal risk. A high-value target can remain unsuitable if legal authority, capture feasibility or insurance is unresolved. A low bid can become unaffordable if change, liability and delay risks return to the authority through claims.

13. Allocate capture and disposal risk

The decision concerns failed approach, collision, partial capture, loss of control, incomplete deorbit and post-capture fragmentation. The authority should assemble current technical, legal, commercial and financial evidence at one controlled cut-off date. Every assumption should have an owner, source, confidence range and review trigger.

The required output is mission-specific performance standards, abort rules, reserves and remedy hierarchy. The analysis should show the base case, correlated downside, control owner, cash consequence and cure route. Public benefit, mission success and payment certainty should remain separate measures because each answers a different approval question.

The contract should prioritise orbital safety over rigid schedule compliance. Safe abort, re-attempt and alternative disposal routes require predefined authority and funding. The contract should state who can observe the evidence, who decides acceptance, how disagreement is resolved and which payment or remedy follows. A financing model should apply the same definitions so that drawdown, debt service and distributions move with verified performance.

The board should also test interactions. A technically successful mission can deliver weak value if the selected target has low marginal risk. A high-value target can remain unsuitable if legal authority, capture

feasibility or insurance is unresolved. A low bid can become unaffordable if change, liability and delay risks return to the authority through claims.

14. Map international liability

The decision concerns launching-state relationships, registration, control, fault, third-party damage, cross-waivers and recourse. The authority should assemble current technical, legal, commercial and financial evidence at one controlled cut-off date. Every assumption should have an owner, source, confidence range and review trigger.

The required output is a treaty-to-contract liability matrix supported by jurisdiction-specific legal opinions. The analysis should show the base case, correlated downside, control owner, cash consequence and cure route. Public benefit, mission success and payment certainty should remain separate measures because each answers a different approval question.

Government responsibility under international space law cannot be replaced by a private indemnity. Contractual allocation can define recourse between parties, subject to enforceability and counterparty capacity. The contract should state who can observe the evidence, who decides acceptance, how disagreement is resolved and which payment or remedy follows. A financing model should apply the same definitions so that drawdown, debt service and distributions move with verified performance.

The board should also test interactions. A technically successful mission can deliver weak value if the selected target has low marginal risk. A high-value target can remain unsuitable if legal authority, capture feasibility or insurance is unresolved. A low bid can become unaffordable if change, liability and delay risks return to the authority through claims.

15. Structure insurance and retained risk

The decision concerns launch, in-orbit operations, collision, third-party liability, professional risk, cyber events and unavailable coverage. The authority should assemble current technical, legal, commercial and financial evidence at one controlled cut-off date. Every assumption should have an owner, source, confidence range and review trigger.

The required output is a coverage map, deductibles, exclusions and funded retained-risk account. The analysis should show the base case, correlated downside, control owner, cash consequence and cure route. Public benefit, mission success and payment certainty should remain separate measures because each answers a different approval question.

Insurance markets may exclude novel capture phases or price them heavily. The affordability model should show uninsured exposure and avoid assuming that future cover will be available on historical terms. The contract should state who can observe the evidence, who decides acceptance, how disagreement is resolved and which payment or remedy follows. A financing model should apply the same definitions so that drawdown, debt service and distributions move with verified performance.

The board should also test interactions. A technically successful mission can deliver weak value if the selected target has low marginal risk. A high-value target can remain unsuitable if legal authority, capture feasibility or insurance is unresolved. A low bid can become unaffordable if change, liability and delay risks return to the authority through claims.

16. Define data rights and cyber controls

The decision concerns mission telemetry, imagery, tracking observations, software, trained models, security restrictions and publication rights. The authority should assemble current technical, legal, commercial and financial evidence at one controlled cut-off date. Every assumption should have an owner, source, confidence range and review trigger.

The required output is a data architecture supporting verification, future procurement and protected commercial know-how. The analysis should show the base case, correlated downside, control owner, cash consequence and cure route. Public benefit, mission success and payment certainty should remain separate measures because each answers a different approval question.

Public value can include reusable mission evidence. Data rights should support learning and accountability while protecting security-sensitive information and legitimate intellectual property. The contract should state who can observe the evidence, who decides acceptance, how disagreement is resolved and which payment or remedy follows. A financing model should apply the same definitions so that drawdown, debt service and distributions move with verified performance.

The board should also test interactions. A technically successful mission can deliver weak value if the selected target has low marginal risk. A high-value target can remain unsuitable if legal authority, capture feasibility or insurance is unresolved. A low bid can become unaffordable if change, liability and delay risks return to the authority through claims.

17. Finance development and construction

The decision concerns equity, grants, advance payments, senior debt, guarantees and contingent supplier terms before operating evidence exists. The authority should assemble current technical, legal, commercial and financial evidence at one controlled cut-off date. Every assumption should have an owner, source, confidence range and review trigger.

The required output is a fully funded sources-and-uses plan through downside commissioning. The analysis should show the base case, correlated downside, control owner, cash consequence and cure route. Public benefit, mission success and payment certainty should remain separate measures because each answers a different approval question.

Senior debt should enter after technical and contractual conditions reduce uncertainty. Sponsor equity and public development payments should absorb earlier design and integration risk. The contract should state who can observe the evidence, who decides acceptance, how disagreement is resolved and which payment or remedy follows. A financing model should apply the same definitions so that drawdown, debt service and distributions move with verified performance.

The board should also test interactions. A technically successful mission can deliver weak value if the selected target has low marginal risk. A high-value target can remain unsuitable if legal authority, capture feasibility or insurance is unresolved. A low bid can become unaffordable if change, liability and delay risks return to the authority through claims.

18. Size senior programme debt

The decision concerns the contracted payments that remain available after operating cost, reserves, taxes and downside delay. The authority should assemble current technical, legal, commercial and financial evidence at one controlled cut-off date. Every assumption should have an owner, source, confidence range and review trigger.

The required output is a debt schedule based on payment certainty, timing and termination compensation. The analysis should show the base case, correlated downside, control owner, cash consequence and cure route. Public benefit, mission success and payment certainty should remain separate measures because each answers a different approval question.

Debt capacity depends on enforceable public payment and accepted performance. Expected public benefit does not itself repay lenders. The contract should state who can observe the evidence, who decides acceptance, how disagreement is resolved and which payment or remedy follows. A financing model

should apply the same definitions so that drawdown, debt service and distributions move with verified performance.

The board should also test interactions. A technically successful mission can deliver weak value if the selected target has low marginal risk. A high-value target can remain unsuitable if legal authority, capture feasibility or insurance is unresolved. A low bid can become unaffordable if change, liability and delay risks return to the authority through claims.

19. Construct the payment waterfall

The decision concerns the order of taxes, mission operations, safety reserves, debt service, cure funding, retention and sponsor distributions. The authority should assemble current technical, legal, commercial and financial evidence at one controlled cut-off date. Every assumption should have an owner, source, confidence range and review trigger.

The required output is controlled accounts and distribution tests linked to mission status. The analysis should show the base case, correlated downside, control owner, cash consequence and cure route. Public benefit, mission success and payment certainty should remain separate measures because each answers a different approval question.

Cash should remain trapped when technical, schedule, insurance or liability evidence deteriorates. Safety-critical recovery should rank before discretionary distribution. The contract should state who can observe the evidence, who decides acceptance, how disagreement is resolved and which payment or remedy follows. A financing model should apply the same definitions so that drawdown, debt service and distributions move with verified performance.

The board should also test interactions. A technically successful mission can deliver weak value if the selected target has low marginal risk. A high-value target can remain unsuitable if legal authority, capture feasibility or insurance is unresolved. A low bid can become unaffordable if change, liability and delay risks return to the authority through claims.

20. Test affordability and value for money

The decision concerns whole-life public cost, risk retained by the authority, competitive tension, financing cost, flexibility and expected benefit. The authority should assemble current technical, legal, commercial and financial evidence at one controlled cut-off date. Every assumption should have an owner, source, confidence range and review trigger.

The required output is a public-sector comparator and risk-adjusted bid evaluation. The analysis should show the base case, correlated downside, control owner, cash consequence and cure route. Public benefit, mission success and payment certainty should remain separate measures because each answers a different approval question.

Private finance may add discipline and capacity while increasing financing and transaction cost. Appraisal should compare realistic delivery models on the same scope and risk basis. The contract should state who can observe the evidence, who decides acceptance, how disagreement is resolved and which payment or remedy follows. A financing model should apply the same definitions so that drawdown, debt service and distributions move with verified performance.

The board should also test interactions. A technically successful mission can deliver weak value if the selected target has low marginal risk. A high-value target can remain unsuitable if legal authority, capture feasibility or insurance is unresolved. A low bid can become unaffordable if change, liability and delay risks return to the authority through claims.

21. Design termination and continuity

The decision concerns provider default, authority default, prolonged force majeure, mission impossibility, target change and security direction. The authority should assemble current technical, legal, commercial and financial evidence at one controlled cut-off date. Every assumption should have an owner, source, confidence range and review trigger.

The required output is termination payments, data handover, step-in, asset control and safe-state obligations. The analysis should show the base case, correlated downside, control owner, cash consequence and cure route. Public benefit, mission success and payment certainty should remain separate measures because each answers a different approval question.

Termination should preserve orbital safety and mission records. Lender protection should remain subordinate to lawful safety intervention. The contract should state who can observe the evidence, who decides acceptance, how disagreement is resolved and which payment or remedy follows. A financing model should apply the same definitions so that drawdown, debt service and distributions move with verified performance.

The board should also test interactions. A technically successful mission can deliver weak value if the selected target has low marginal risk. A high-value target can remain unsuitable if legal authority, capture feasibility or insurance is unresolved. A low bid can become unaffordable if change, liability and delay risks return to the authority through claims.

22. Govern change without destroying incentives

The decision concerns new conjunction data, target deterioration, regulation, launch substitution, technology improvement and authority scope change. The authority should assemble current technical, legal, commercial and financial evidence at one controlled cut-off date. Every assumption should have an owner, source, confidence range and review trigger.

The required output is a transparent change-control and price-adjustment mechanism. The analysis should show the base case, correlated downside, control owner, cash consequence and cure route. Public benefit, mission success and payment certainty should remain separate measures because each answers a different approval question.

A frozen specification can become unsafe or obsolete. An unlimited change mechanism can remove cost discipline. Decisions require evidence, valuation rules and independent review. The contract should state who can observe the evidence, who decides acceptance, how disagreement is resolved and which payment or remedy follows. A financing model should apply the same definitions so that drawdown, debt service and distributions move with verified performance.

The board should also test interactions. A technically successful mission can deliver weak value if the selected target has low marginal risk. A high-value target can remain unsuitable if legal authority, capture feasibility or insurance is unresolved. A low bid can become unaffordable if change, liability and delay risks return to the authority through claims.

23. Operate a public-benefit dashboard

The decision concerns target risk, mission status, spend, forecast payments, verified outcomes, residual liabilities and learning outputs. The authority should assemble current technical, legal, commercial and financial evidence at one controlled cut-off date. Every assumption should have an owner, source, confidence range and review trigger.

The required output is a board and public-authority control record with defined disclosure levels. The analysis should show the base case, correlated downside, control owner, cash consequence and cure route.

Public benefit, mission success and payment certainty should remain separate measures because each answers a different approval question.

Operational transparency supports accountability. Security, export-control and commercial restrictions still require a controlled public-versus-confidential reporting boundary. The contract should state who can observe the evidence, who decides acceptance, how disagreement is resolved and which payment or remedy follows. A financing model should apply the same definitions so that drawdown, debt service and distributions move with verified performance.

The board should also test interactions. A technically successful mission can deliver weak value if the selected target has low marginal risk. A high-value target can remain unsuitable if legal authority, capture feasibility or insurance is unresolved. A low bid can become unaffordable if change, liability and delay risks return to the authority through claims.

24. Make the investment and award decision

The decision concerns whether benefits, affordability, deliverability, competition, liability and verification support procurement. The authority should assemble current technical, legal, commercial and financial evidence at one controlled cut-off date. Every assumption should have an owner, source, confidence range and review trigger.

The required output is approve, resize, redesign, stage or decline with an evidence register. The analysis should show the base case, correlated downside, control owner, cash consequence and cure route. Public benefit, mission success and payment certainty should remain separate measures because each answers a different approval question.

A strong decision identifies the target, counterfactual, mission outcome, payment gates, retained public risk, financing source, verification method and termination path. The contract should state who can observe the evidence, who decides acceptance, how disagreement is resolved and which payment or remedy follows. A financing model should apply the same definitions so that drawdown, debt service and distributions move with verified performance.

The board should also test interactions. A technically successful mission can deliver weak value if the selected target has low marginal risk. A high-value target can remain unsuitable if legal authority, capture feasibility or insurance is unresolved. A low bid can become unaffordable if change, liability and delay risks return to the authority through claims.

Conclusion

An orbital-debris removal PPP is financeable when public purpose is converted into a measurable service, mission risks are assigned to capable parties, payments follow verifiable evidence and residual liabilities remain funded. The authority should buy a defined change in orbital risk rather than a loosely specified mission attempt. The provider should control design and integration risks that it can manage. The public sector should retain or share risks that depend on sovereign authority, deficient public information or policy change.

Outcome payments create discipline when milestones are objective and independently observable. Development payments remain necessary where the authority commissions novel capability or requires data that has wider public value. The balance should evolve as flight heritage, standards, insurance and competition mature. Financing should follow the same sequence: early risk-bearing capital supports development; debt enters against contracted payments after conditions precedent; retention remains available until disposal evidence and claims closeout are complete.

The hypothetical programme shows the logic. USD 96 million of nominal service funding supports a two-target mission through sponsor equity, senior debt, milestone payments and retained contingent value. The

public-benefit account totals USD 112 million and leaves USD 16 million of illustrative net value. These figures are decision mechanics rather than market evidence. A real procurement requires target-specific probability, mission design, competitive pricing, treaty and licensing analysis, insurer terms and independent verification.

Governance completes the structure. The public authority should maintain one integrated record of target risk, mission progress, payment eligibility, financing, retained liability and public benefit. Technical and financial definitions should remain aligned from procurement through closeout. A disciplined PPP can then produce capability, competition and verified risk reduction while preserving safety and public accountability.

Appendix A. Hypothetical programme assumptions

The programme covers two unprepared, uncooperative objects in low Earth orbit over five years. The service envelope is USD 96 million. Funding comprises USD 18 million of sponsor equity, USD 22 million of senior programme debt, USD 46 million of public milestone and outcome payments and USD 10 million of retained contingent payment. Illustrative public benefit totals USD 112 million: USD 34 million of avoided collision-loss equivalent, USD 18 million of avoided avoidance and operating cost, USD 31 million of protected service continuity, USD 17 million of demonstration and industrial spillover, and USD 12 million of environmental option value. All amounts are illustrative.

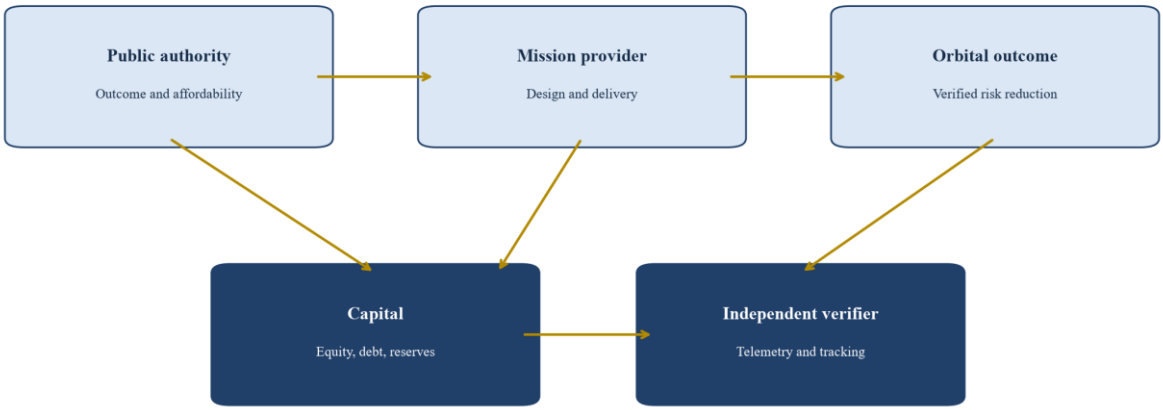
Appendix B. Evidence request

Request the target catalogue record, ownership and registration evidence, conjunction and fragmentation analysis, target attitude and structural data, mission concept, capture analysis, abort logic, launch plan, licensing path, international-liability opinions, insurance indications, supplier contracts, cost-to-complete model, funding commitments, payment schedule, verification protocol, data-rights matrix, cyber plan, security restrictions, environmental analysis, disposal evidence standard, termination model and public-sector comparator. Reconcile every item to the same target set, mission configuration and valuation date.

Appendix C. Red-flag tests

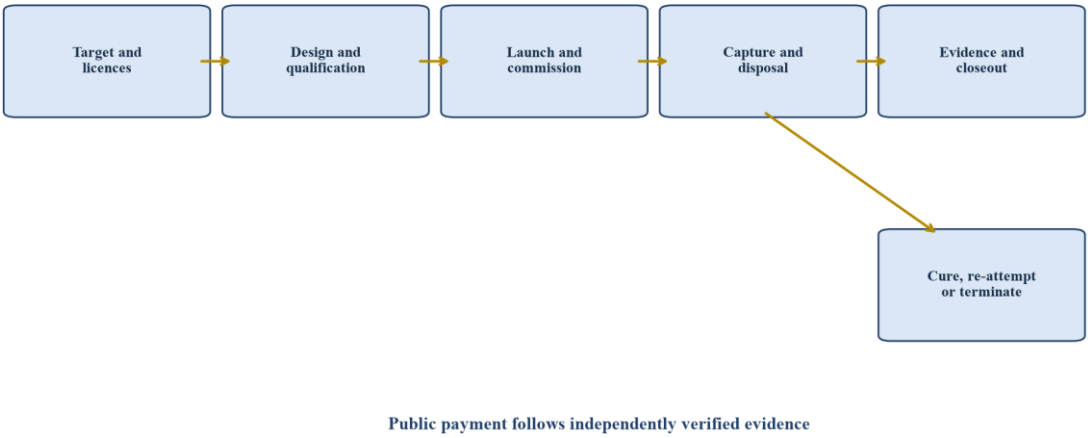
Red flags include a target selected without comparative risk ranking; public benefit presented as a guaranteed loss avoided; payments tied only to expenditure; a verifier lacking telemetry or tracking access; unlimited provider liability unsupported by capital or insurance; target-condition risk transferred without a reliable baseline; senior debt drawn before material licences and interfaces are secured; termination compensation that rewards provider default; disposal evidence defined only by provider telemetry; public data rights omitted; residual liabilities unfunded; and public value presented without a counterfactual.

Figure 1. Orbital-debris removal PPP architecture



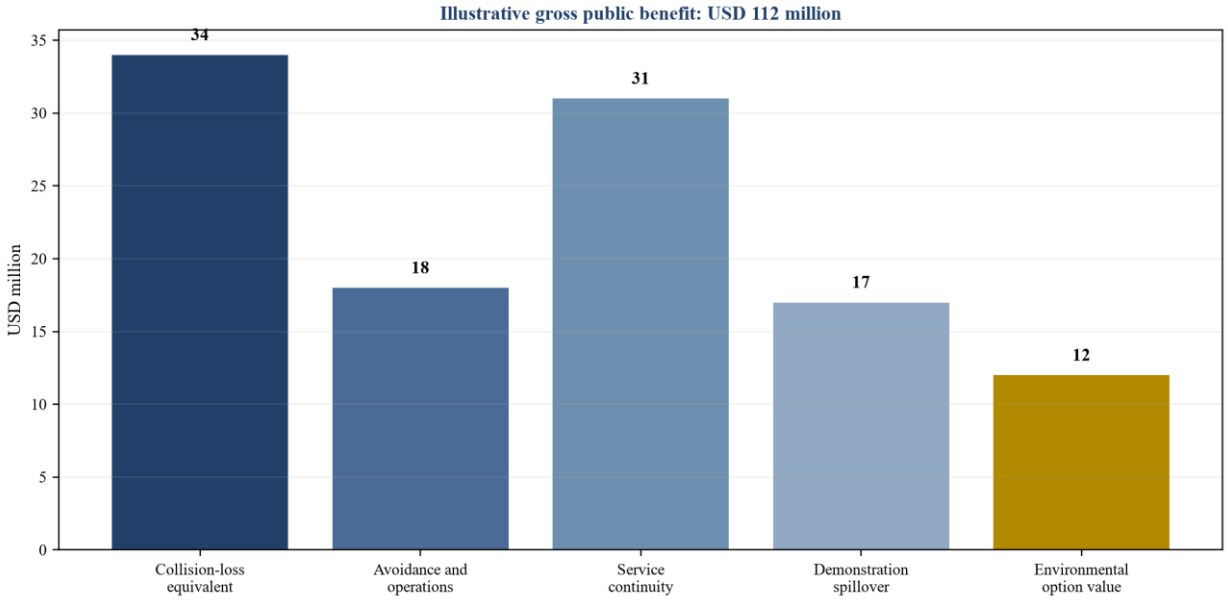
Proposed separation of public purpose, mission delivery, verification and payment.

Figure 2. Mission and payment gate tree



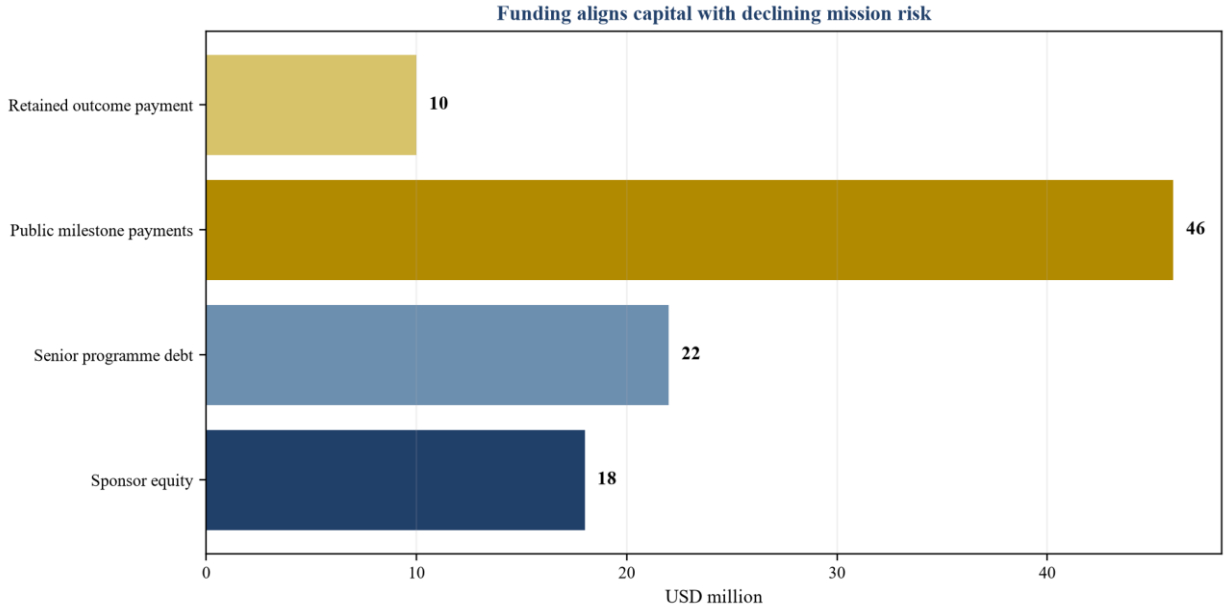
Illustrative sequence; payments require evidence at each gate.

Figure 3. Hypothetical public-benefit bridge



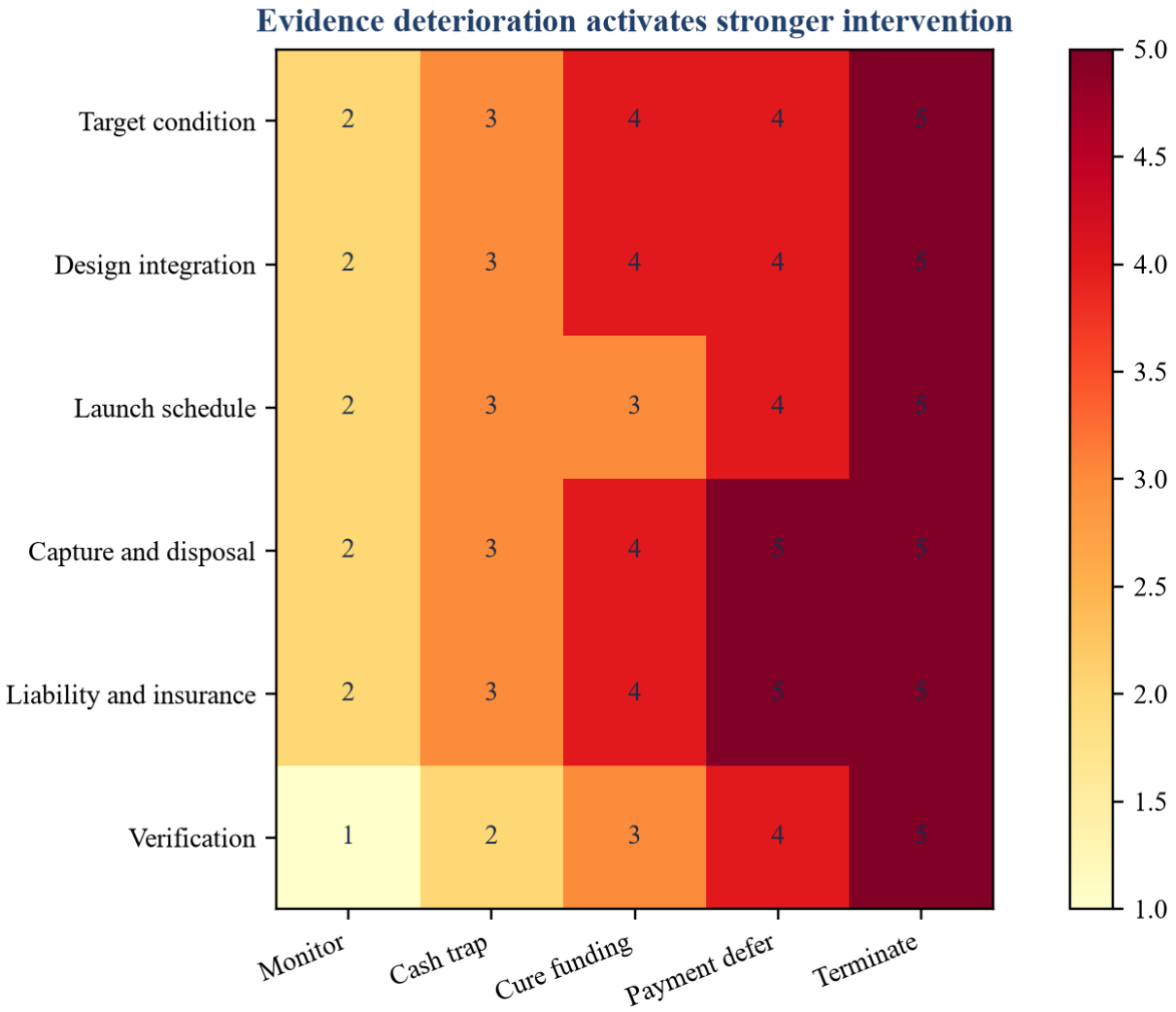
Illustrative USD millions; categories require mission-specific evidence.

Figure 4. Hypothetical programme funding



Illustrative USD millions; total nominal envelope USD 96 million.

Figure 5. Risk allocation and intervention heat map



Illustrative severity score from one to five.

Table 1. Proposed mission payment gates

Gate	Evidence	USD million	Payment character
Design and licensing	approved design, licences, insurance plan	10	development milestone
Manufacture and qualification	completed qualification and launch readiness	18	milestone
Launch and commissioning	functioning servicer in required orbit	14	milestone
Target 1 disposal	verified capture and compliant disposal	20	outcome
Target 2 disposal	verified capture and compliant disposal	20	outcome
Data and programme closeout	accepted data, audit and handover	4	closeout
Retained performance value	claims closeout and final evidence	10	contingent outcome

Illustrative allocation of the USD 96 million service envelope.

Table 2. Public-benefit account

Benefit category	USD million	Primary evidence
Avoided collision-loss equivalent	34	probability model and exposed asset values
Avoided avoidance and operating cost	18	operator manoeuvre and tracking records
Protected service continuity	31	critical-service dependency and outage cases
Demonstration and industrial spillover	17	reuse plan, procurement pipeline and learning rights
Environmental option value	12	scenario analysis and policy weights
Gross public benefit	112	reconciled benefit register
Less nominal programme envelope	(96)	contracted sources and uses
Illustrative net public value	16	appraisal output

Illustrative values; a live appraisal requires target-specific evidence.

Table 3. Core risk allocation

Risk	Primary bearer	Contract control
Target-selection policy	authority	transparent ranking and approval
Design and integration	provider	specification, qualification and warranty
Deficient public target data	authority/shared	baseline dossier and change mechanism
Supplier performance	provider	flow-down terms and replacement rights
Authority-directed change	authority	priced change control
Capture execution	provider	gates, abort logic, cure and retention
International state liability	state with contractual recourse	treaty and indemnity matrix
Uninsurable systemic risk	shared/authority	cap, reserve and termination regime

Proposed starting point subject to procurement law and mission facts.

Table 4. Verification evidence matrix

Stage	Evidence	Independent check	Payment result
Qualification	test records and configuration	verifier witnesses critical tests	milestone eligibility
Commissioning	telemetry and orbit determination	tracking reconciliation	milestone eligibility
Rendezvous	proximity-operations record	safety review	continue or abort
Capture	telemetry, imagery and control state	multi-source confirmation	partial outcome eligibility
Disposal	orbit or re-entry evidence	public and third-party tracking	outcome payment
Closeout	data, claims and asset handover	final audit	retention release

Proposed evidence classes for payment approval.

Table 5. Hypothetical sources and uses

Sources	USD million	Uses	USD million
Sponsor equity	18	design, licensing and target analysis	16
Senior programme debt	22	manufacture and qualification	28
Public milestone and outcome payments	46	launch, commissioning and operations	24
Retained contingent payment	10	capture, disposal and verification	18
		reserves, insurance and closeout	10
Total	96	Total	96

Illustrative USD millions.

Table 6. Liability and insurance review

Exposure	Legal question	Financial control
Launch failure	launching-state and contract responsibility	launch cover and delay reserve
Target damage	authority to intervene and provider fault	indemnity, cap and mission cover
Third-party collision	treaty claim and private recourse	liability cover and retained-risk account
Cyber compromise	control and data responsibility	cyber cover, segmentation and incident plan
Failed disposal	continuing control and remediation duty	retention, cure funding and termination rights
Cross-border claim	forum, law and state representation	enforceability opinion and sovereign process

Counsel and brokers must confirm jurisdiction-specific treatment.

Table 7. Board and credit decision gates

Gate	Question	Evidence threshold
Public need	is incremental intervention justified?	ranked target and counterfactual
Deliverability	can the proposed system complete the mission safely?	qualified design and mission tree
Authority	can each state and regulator authorise the operation?	licences and legal opinions
Value for money	does risk-adjusted benefit exceed delivery alternatives?	comparator and competitive pricing
Financeability	can contracted cash service debt through downside?	funded model and termination regime
Verification	can performance be independently observed?	accepted protocol and data access
Residual risk	are liability, recovery and closeout funded?	insurance, reserves and retention

Frequently asked questions

Q: Why use a PPP for orbital-debris removal? A: A PPP can combine a defined public outcome, private mission integration, risk-bearing capital and independent verification. The structure is useful when the authority can specify and observe performance and when competition and risk allocation justify the added transaction and financing cost.

Q: What should the authority pay for? A: Pay for a combination of necessary development milestones and verified outcomes. Outcome payments should depend on objective evidence of capture, disposal, data delivery and final closeout.

Q: How can public benefit be priced? A: Build a transparent account covering avoided collision-loss equivalent, operator cost, protected service continuity, demonstration spillover and environmental option value. Keep monetised, quantified non-monetised and qualitative effects separate.

Q: Can collision risk be treated as a guaranteed avoided loss? A: No. Collision models produce probabilities and ranges. Appraisal should preserve uncertainty and show how target ranking changes when probability, asset value, time horizon or discount rate changes.

Q: What can support senior debt? A: Contracted public payments that become payable after objective conditions, net of mission operating cost, reserves, taxes and downside delay. Expected public benefit and target value do not directly service debt.

Q: Who should verify performance? A: An independent technical verifier with access to agreed telemetry, tracking data, test records and mission evidence. The contract should define standards, data access, acceptance authority and dispute resolution.

Q: How should international liability be handled? A: Map treaty responsibility, launching-state relationships, registration, licensing and private recourse with jurisdiction-specific legal advice. Insurance, indemnities, caps and reserves should reflect the resulting allocation.

Q: What is the central award decision? A: The authority must decide whether the selected target, mission design, risk allocation, competitive price, financing plan, verification method and residual-liability package produce an affordable and defensible public outcome.

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