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Nuclear Thermal and Electric Propulsion

Physics, performance, and the path to flight after DRACO's cancellation

Engines of Tomorrow — Research Desk
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ABSTRACT

Does nuclear propulsion still have a credible path to flight after the U.S. cancelled its flagship demonstrator? This report quantifies the physics and techno-economics of nuclear thermal (NTP) and nuclear-electric (NEP) propulsion against chemical and solar-electric incumbents, then traces the program wreckage left by DRACO's FY2026 termination. The governing finding: NTP roughly doubles chemical specific impulse (~900 s vs ~450–465 s) but its thrust-to-weight of only ~3–5 and reactor/shield mass erode much of that advantage for departure burns, while NEP offers 3,000–7,000 s Isp at a crippling ~20 kg/kWe specific mass that no flight system has yet demonstrated. With DRACO's $499 M program zeroed and no FY2026 line for NTP or NEP, the gating constraint is no longer physics but ground-test infrastructure, HALEU fuel qualification, and sustained funding. Engines of Tomorrow estimates a credible crewed-relevant NTP flight demonstration slips to the early-to-mid 2030s at best. The near-term equity exposure is narrow and indirect — BWXT's fuel and reactor franchise, with LMT and RTX as integrators.

Keywords: nuclear thermal propulsion, nuclear electric propulsion, DRACO, specific impulse, HALEU, BWXT, Mars transit, cislunar, NERVA, Hall thruster, specific power, space nuclear

Executive Summary

Nuclear in-space propulsion splits into two physically distinct families. **Nuclear thermal propulsion (NTP)** heats liquid hydrogen in a fission reactor and expels it through a nozzle, delivering roughly double the specific impulse of the best chemical stages — about 800–900 s versus ~450–465 s — while retaining high thrust [6][7]. **Nuclear-electric propulsion (NEP)** uses a reactor to generate electricity that feeds ion or Hall thrusters at 3,000–7,000 s Isp, but at vanishingly low thrust [9][12]. The two are not competitors so much as tools for different mission segments: NTP for fast, high-thrust departure burns; NEP for patient, fuel-efficient deep-space cruise.

The physics is favorable; the engineering and the politics are not. In June 2025 DARPA confirmed the cancellation of **DRACO** — the Demonstration Rocket for Agile Cislunar Operations, the U.S. flagship NTP demonstrator — and the finalized **FY2026 budget zeroed both NTP and NEP**, with NASA materials stating the programs were terminated for cost savings and because nuclear was "not identified as the propulsion mode for deep-space missions" [1][2][3]. The $499 M DRACO contract (DARPA/NASA, Lockheed Martin prime, BWXT reactor/fuel) ended without a flight [10][14].

NTP's headline weakness is **thrust-to-weight (T/W) of only ~3–5**, an order of magnitude below a chemical core stage; combined with reactor and radiation-shield mass, gravity losses on a departure burn erode much of the Isp advantage for some trajectories [7]. NEP's weakness is **specific mass**: NASA Mars architecture studies assume ~20 kg/kWe at megawatt scale [8], meaning a multi-MWe powerplant weighs tens of tonnes before any propellant — and no such system has flown.

BOTTOM LINE:

After DRACO, the binding constraint on space fission propulsion is no longer the physics — NTP's ~900 s Isp and NEP's ~3,000–7,000 s Isp are real and bounded by well-understood limits — but **ground-test infrastructure, HALEU fuel qualification, and sustained funding**. Engines of Tomorrow estimates a credible, crewed-relevant NTP flight demonstration now slips to the **early-to-mid 2030s at the earliest**, with the only near-term public-market exposure being narrow and indirect (BWXT fuel/reactor; LMT and RTX as integrators).

1. Context and Scope

This report covers two of our core coverage domains — **nuclear thermal and electric propulsion** and the **engineering path to flight / TRL** — with a downstream **defense and commercial programs and economics** lens. The system boundary is the in-space propulsion stage: the reactor, the energy-conversion or direct-heating path, the thruster, and the propellant feed, from low Earth orbit (LEO) outward. Launch from the ground (a chemical problem) is out of scope; reactors are launched cold and started only above a nuclear-safe orbit [14].

The question is timely because the field just lost its anchor program. For two decades, NTP and NEP advanced on study contracts and component work; DRACO (2021–2025) was the first funded path to an actual in-space firing. Its cancellation, confirmed in mid-2025 and ratified by the FY2026 budget, forces a reset: what is physically true about these systems, what was actually demonstrated, what the cancellation removed, and what — if anything — survives to carry the technology to flight [1][2][3].

The comparison set is deliberately broad. NTP and NEP must be judged not in isolation but against the incumbents they would displace: **advanced chemical** propulsion (the only crewed-rated in-space option today) and **solar-electric propulsion (SEP)**, which already flies high-power Hall thrusters and dominates the efficient-cruise niche inside Mars orbit [9][12].

2. Technology Landscape and State of the Art

2.1 Nuclear thermal propulsion (NTP): the physics

NTP is conceptually a heat exchanger with a fission core. Liquid hydrogen flows through a reactor operating at ~2,500–3,000 K, is heated to high temperature, and expands through a nozzle. Because thrust efficiency scales with exhaust velocity — and exhaust velocity scales with the square root of (temperature / molecular weight) — using **hydrogen (molecular weight ~2)** rather than chemical-combustion products like water vapor (~18) is the entire trick. A chemical rocket is energy-rich but stuck with heavy exhaust; NTP decouples the energy source (fission) from the propellant, letting the engineer choose the lightest possible working fluid [6][7].

The result is **specific impulse of ~800–900 s**, roughly double the ~450–465 s of the best chemical upper stages (LH_2/LOX) [6][7]. This is a real, well-bounded number — it is limited not by reactor power but by the **temperature the fuel elements can survive** before the hydrogen-rich, high-temperature environment corrodes them. The historical U.S. program proved this is the hard problem (see below).

Crucially, NTP retains **high thrust** — tens to hundreds of kilonewtons — unlike electric systems. But its **thrust-to-weight ratio is only ~3–5** [7], compared with ~70+ for a chemical core engine, because the reactor, the pressure vessel, the turbopumps, and the radiation shield are heavy. For an impulsive departure burn from LEO, low T/W means the burn takes longer, the spacecraft spends more time climbing out of the gravity well, and **gravity losses can exceed 3,500 m/s**, eroding much of the Isp advantage on some trajectories [7]. NTP wins decisively on missions where the burn can be done at high altitude or where total ΔV, not burn duration, dominates.

2.2 The historical baseline: Rover/NERVA

NTP is not speculative at the component level — the U.S. ran a serious, well-funded ground program from 1955 to 1973. The **Rover** program (Los Alamos) and **NERVA** (Nuclear Engine for Rocket Vehicle Application, from 1963) built and hot-fired a series of reactors [4]:

- The **KIWI-B4** design was adopted as the NERVA baseline at ~825 s Isp [4].
- The **Phoebus-2A** reactor reached ~4,100 MW for 12 minutes and a peak thrust of **~930 kN** — still the most powerful nuclear rocket reactor ever operated [4].
- In the summer of 1972, the **NF-1 nuclear furnace** tested composite uranium-zirconium-carbide fuel elements at 44 MW over multiple 90-minute runs, demonstrating improved corrosion resistance — directly addressing the fuel-durability bottleneck [4].

Rover/NERVA was cancelled in 1973 for budget and mission reasons (Mars was deprioritized), not technical failure [4]. The lesson for 2026 is sobering: the technology has been "nearly ready" for over fifty years, and every revival has died on funding and ground-test logistics rather than physics.

2.3 Nuclear-electric propulsion (NEP): the physics

NEP severs heat from thrust entirely. A reactor generates thermal power; a power-conversion system (typically a closed Brayton cycle) turns it into electricity; that electricity drives **electric thrusters** (gridded ion, Hall, or magnetoplasmadynamic). Because the propellant is accelerated electromagnetically rather than thermally, exhaust velocity is far higher: **3,000–7,000 s Isp for argon-plasma systems, roughly 3–7× hydrogen NTP** [9][12].

The penalty is thrust. Electric thrusters produce millinewtons-to-newtons, so NEP accelerates continuously over months. The architecture is dominated by **specific mass (α, in kg/kWe)** — the dry mass of the powerplant per kilowatt of electrical output. NASA Mars architecture studies assume NEP at **~20 kg/kWe** for crewed-relevant systems [8]; the bulk is not the reactor but the **heat-rejection radiators**, which must dump waste heat from a multi-MWe plant in vacuum. A 2 MWe system at 20 kg/kWe implies ~40 tonnes of powerplant before propellant or payload [8]. Advanced concepts target ~2 kg/kWe above 10 MWe, but those remain paper systems [9].

2.4 What actually flies — and the small-reactor state of the art

No fission propulsion system has flown. The nearest hardware is at the **kilowatt** scale: NASA's surface-power and small-reactor work, and the **SR-1 Freedom** design targeting ~20 kWe from a HALEU-fueled, heat-pipe reactor with a closed Brayton converter [8]. The Defense Innovation Unit funded **Ultra Safe Nuclear** and **Avalanche Energy** for small nuclear power-and-propulsion demonstrations aimed at cislunar maneuvering [11]. These are power demonstrators, not the multi-MWe propulsion reactors crewed Mars NEP would require — a gap of two-to-three orders of magnitude in power.

2.5 Competing Pathways

Pathway	Principle	Isp (s)	Thrust class	T/W	Specific power / mass	TRL	Status
Chemical (LH_2/LOX)	Combustion, hot heavy exhaust	~450–465 [6]	High (MN)	~70+	n/a	9	Operational; crewed-rated
Solar-electric (Hall)	PV power -> ion/Hall thruster	~1,600–1,800 flight; to ~5,000 demo [12]	Low (mN)	<0.001	~10–100 kW PV demonstrated [12]	7–9	Operational (flight Hall thrusters)
NTP	Reactor heats H_2, nozzle expansion	~800–900 [6][7]	High (10s–100s kN)	~3–5 [7]	n/a	~3–5 (component-tested historically)	No flight; DRACO cancelled 2025 [1]
NEP	Reactor -> electricity -> electric thruster	~3,000–7,000 [9][12]	Low (N)	<0.001	~20 kg/kWe assumed; ~2 kg/kWe aspirational [8][9]	~2–3	No flight; FY2026 funding zeroed [2]

KEY TAKEAWAY

TRL is our assessment synthesizing the cited program status; NTP/NEP TRLs reflect that component and subscale work exists but no integrated flight system has been built or flown.

3. Techno-Economic Analysis

Space fission propulsion has no levelized "cost per unit" in the energy sense; the relevant economics are **program cost to first flight** and **mission-level mass/time savings** versus chemical and SEP. The analysis below is built transparently from public program figures and labeled estimates.

3.1 Cost Model and Assumptions

Parameter	Value	Unit	Basis / Source
DRACO program value (Phases 2–3)	499	USD M	DARPA/NASA, 2023 [10][14]
— NASA commitment	up to 300	USD M	NASA, 2023 [10]
— of which engine design/development	up to 250	USD M	NASA, 2023 [10]
DRACO target demo	FY2027 (cancelled)	year	DARPA [14]; cancelled 2025 [1]
FY2026 NTP/NEP appropriation	0	USD	NASA FY2026 budget materials [2]
NTP reactor temperature	~2,500–3,000	K	NTP physics [6][7]
NTP Isp	~800–900	s	DOE/NASA [6][7]
Chemical (LH_2/LOX) Isp	~450–465	s	comparison baseline [6]
NEP assumed specific mass	~20	kg/kWe	NASA Mars architecture [8]
Small reactor demonstrator	~20	kWe	SR-1 Freedom / HALEU [8]
Mars transit time, NTP-class	~500 (vs ~900 chemical)	days	NTP studies [7]

3.2 Program economics and unit economics

DRACO is the only recent number with a verified price tag: **$499 M for a single in-space demonstration**, split between DARPA and NASA, with NASA committing up to $300 M [10][14]. That buys one reactor, one fuel load, one integrated stage, and one firing — and it still did not survive to flight. A crewed-relevant NTP stage, with ground-test facilities, multiple fuel iterations, and qualification, is a **multi-billion-dollar program** (Engines of Tomorrow estimate: a full NTP development-to-crew-rating effort is plausibly **$5–10 B** over a decade, scaling DRACO's demonstrator cost by the gap from a one-shot demo to a qualified, reusable, crew-rated stage — an order-of-magnitude-plus uplift consistent with historical flagship propulsion programs).

The mission-economic case rests on two levers:

1. **Transit time.** NTP-class propulsion is cited as cutting a crewed Mars transit from ~900 days to ~500 days, reducing crew radiation dose, consumables, and life-support mass [7]. This is the strongest argument and is genuinely hard to replicate chemically.
2. **Propellant mass / launch count.** Higher Isp means less propellant per unit ΔV, reducing the number of heavy-lift launches to assemble a Mars stack — a direct cost saving if launch remains the dominant line item.

3.3 Sensitivity

The answer is governed by a small number of drivers. In descending order of leverage on whether nuclear beats the incumbents:

Driver	Low case	High case	Effect on the nuclear case
Sustained annual funding	$0 (current)	$0.5–1 B/yr	Decisive — at $0 the program does not exist [2]
NEP specific mass (α)	~20 kg/kWe [8]	~2 kg/kWe aspirational [9]	A 10× α improvement is the difference between unflyable and competitive
NTP fuel durability (run time at temp)	minutes (historic) [4]	hours, many restarts	Sets reusability and crew-rating credibility
Ground-test availability	none operational	exhaust-capture facility	Gates any U.S. full-scale hot fire
Launch cost	high	low	Erodes the propellant-saving argument for nuclear

The two that dominate are **funding** (currently zero) and, for NEP, **specific mass** (currently ~10× too heavy). Neither is a physics problem; both are engineering-and-budget problems.

4. Market and Demand Outlook

There is no commercial market for space fission propulsion today; demand is **agency-driven and program-contingent**. The addressable pull comes from three sources: crewed Mars exploration (NASA), responsive cislunar maneuvering (DoD/Space Force, the original DRACO rationale), and outer-planet science where SEP runs out of sunlight [9][14]. With FY2026 funding at zero for both NTP and NEP, near-term U.S. demand is effectively **suspended**, not merely slowed [2].

our analysis frames the path to a flight demonstration as three scenarios to ~2035:

Scenario	Probability (Engines of Tomorrow estimate)	Path	First in-space nuclear-propulsion firing
Reauthorization	~30%	A future budget restores an NTP demonstrator (DRACO-like or successor); HALEU pipeline already exists	~2031–2033
Quiet continuity	~45%	No flagship; kilowatt-class reactor and fuel work continues via DoD/DIU and small-reactor lines; propulsion deferred	Power demo possible ~2027–2029; **propulsion** firing slips past 2035
Dormancy	~25%	Funding stays zero; NTP/NEP revert to study-only as in 2000–2015	No firing this decade

The probability-weighted read is that a **full-scale NTP propulsion firing is more likely after 2033 than before**, and a crewed-relevant qualified stage is a 2040s proposition (Engines of Tomorrow estimate). The small-reactor *power* demonstrations (≤20–100 kWe) are far more likely to occur this decade than any propulsion firing, because they ride defense and surface-power demand that survives the propulsion cuts [8][11].

5. Feasibility, Scale-Up, and Risk

The honest go/no-go: the technology is feasible in principle and was component-validated historically, but the U.S. has just removed the only funded path to flight, and the supporting infrastructure does not currently exist at full scale.

The gating risks, in order:

- **Funding (the binding constraint).** FY2026 zeroed NTP and NEP [2]. Without a sustained line, no facility gets built and no fuel gets qualified.
- **Ground testing.** A full-scale NTP hot fire exhausts hot hydrogen that has passed through a reactor; the U.S. has no operational facility to capture and scrub that exhaust to modern environmental standards. This was a real DRACO friction point and is a multi-hundred-million-dollar capital item on its own [1][14].
- **Fuel qualification.** NTP requires fuel elements that survive ~2,500–3,000 K in flowing hydrogen for the full burn and multiple restarts. NF-1 (1972) proved composite UZrC could resist corrosion, but modern **HALEU**-based fuel must be re-qualified from a cold start; DOE-supplied HALEU feedstock to BWXT was part of DRACO and the HALEU pipeline itself runs on extended contracts [4][5][13].
- **Reactor/shield mass (NTP) and radiator mass (NEP).** These are the physics-rooted penalties — T/W ~3–5 for NTP [7], ~20 kg/kWe for NEP [8] — that no amount of money removes, only engineering chips away at.
- **Thermal management.** NEP's multi-megawatt heat rejection in vacuum is the single largest

mass and reliability driver and remains unproven at scale [8].
- **Regulatory/launch safety.** Launching fissile material (even cold, un-started HALEU) carries an inter-agency safety and approval burden that contributed to DRACO's schedule slips [1][14].

5.1 Risk Register

Risk	Likelihood	Impact	Mitigation
Funding stays zero (no flagship)	High	Critical — no flight path	Ride DoD/DIU small-reactor demand; keep fuel/reactor IP warm
No full-scale ground-test facility	High	High — blocks NTP hot fire	Subscale/element testing; international or shared facility
HALEU fuel-element re-qualification slips	Medium	High — sets NTP schedule	Leverage NF-1 heritage + existing HALEU contracts [5][13]
NEP specific mass stays ~20 kg/kWe	High	High — keeps crewed NEP unflyable	Radiator and Brayton R&D; start kW-class flight data
Launch-safety/regulatory delay	Medium	Medium — schedule	Cold-launch, start above nuclear-safe orbit [14]
Workforce/IP erosion after DRACO	Medium	Medium — restart cost	Retain BWXT/lab teams via adjacent reactor work

6. Market and Equity Implications

The investable surface here is **small, indirect, and dominated by diversified primes** — not a pure-play opportunity. The thesis (nuclear propulsion is real but funding-gated and post-DRACO dormant) cuts against any near-term revenue narrative and in favor of optionality on franchises that survive on adjacent demand.

Company (Ticker)	Exposure	Reasoning (tied to the thesis)	Horizon
BWX Technologies (BWXT, NYSE)	Neutral-to-Positive	The closest thing to a pure space-fission franchise: DRACO reactor and HALEU-derived fuel supplier [10][14]. DRACO revenue is gone, but the naval-reactor and microreactor/HALEU-fuel core is intact and benefits from any future restart; the propulsion line is upside optionality, not the base case.	3–7 yr
Lockheed Martin (LMT, NYSE)	Neutral	DRACO prime/integrator [10][14], but the program is immaterial to a company of its scale; cancellation is not a financial event. Optionality only if a successor flagship appears.	5–10 yr
RTX Corp. (RTX, NYSE)	Neutral	Aerojet Rocketdyne (now within RTX) has propulsion/integration heritage cited in space-nuclear teaming [11]. Exposure is diffuse and dominated by its core chemical-propulsion and defense business.	5–10 yr

Most of the actual builders are **agencies, national labs, or private/non-listed** (NASA, DOE, DARPA/DIU, Ultra Safe Nuclear, Avalanche Energy, Blue Origin) [8][11] — there is no clean public-equity way to express a "space nuclear" view. The listed names are diversified primes for whom this technology is a rounding error today.

THE TAKE:

The correct way to read BWXT here is **not** as a space-propulsion stock — DRACO's death proves that line is uninvestable on a near-term basis. Its space-nuclear value is a **free option** riding on a business (naval reactors, terrestrial microreactors, HALEU-adjacent fuel) that is funded for reasons that have nothing to do with Mars. The non-obvious implication: the *power*-reactor side of space fission (≤20–100 kWe demonstrators for cislunar and surface use) is where 2026–2030 dollars and contracts will actually land — propulsion is downstream of power, and the market is mispricing how long the propulsion firing is still away. Anyone underwriting "nuclear propulsion by 2030" is, in our read, underwriting a *power* demonstration and mislabeling it.

7. Outlook and Strategic Implications

The physics verdict is settled and favorable: NTP roughly doubles chemical Isp at usable thrust, and NEP delivers 3–7× NTP Isp for patient cruise [6][7][9][12]. The program verdict is bleak. DRACO — the first funded path to a firing in fifty years — is cancelled, and FY2026 carries no NTP or NEP line [1][2][3]. The binding constraints are now institutional: money, a ground-test facility, and fuel qualification, in that order.

For an operator or investor, the decision-grade takeaways are:

- **Treat a near-term flight as a low-probability event.** our probability-weighted estimate puts a full-scale NTP propulsion firing more likely after 2033 than before, and a crewed-rated stage in the 2040s.
- **Follow the power, not the propulsion.** Kilowatt-class space reactors (≤20–100 kWe) ride defense and surface-power demand and are far more likely to fly this decade [8][11]; they are the leading indicator that the fuel and reactor supply chain stays alive.
- **The equity expression is optionality, not exposure.** BWXT carries the only meaningful franchise, but as a free option on top of a self-funding reactor business; the primes are immaterial-but-present.

WHAT TO WATCH:

1. **FY2027 budget request (early 2026 cycle):** any restored NTP/NEP line reverses the dormancy thesis. 2. **A successor to DRACO or a DoD cislunar maneuver award:** the original responsive-space rationale could resurface under defense funding even if NASA stays out. 3. **First kilowatt-class space-reactor power demonstration (~2027–2029):** confirms the fuel/reactor supply chain survives and de-risks any later propulsion restart [8][11]. 4. **HALEU supply contracts beyond mid-2026:** the fuel feedstock pipeline is the quiet enabler; extensions signal continued government commitment [5][13].

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Methodology and Assumptions

This report synthesizes public agency, standards, and technical sources (cited inline) into a comparative techno-economic frame for nuclear thermal and nuclear-electric propulsion. Performance figures (Isp, thrust-to-weight, specific mass, temperatures) are drawn from DOE, NASA NTRS, ANS, and peer/industry sources and reported with their conditions. Program facts (DRACO value, schedule, FY2026 status) are taken from agency releases and reputable reporting. Where a figure is our own inference — full-program cost, scenario probabilities, the timing of a first firing — it is explicitly labeled "Engines of Tomorrow estimate" and its basis is shown in the surrounding text or the sensitivity/assumptions tables. No proprietary data was used and no figures were fabricated. The conclusion would change most on two inputs: a restored federal funding line (currently zero), and a step-change in NEP specific mass (currently ~10× too heavy for crewed use). Data vintage spans 1972 (NF-1 fuel testing) to 2026 (FY2026 budget); the latest year is preferred for all program-status claims.

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