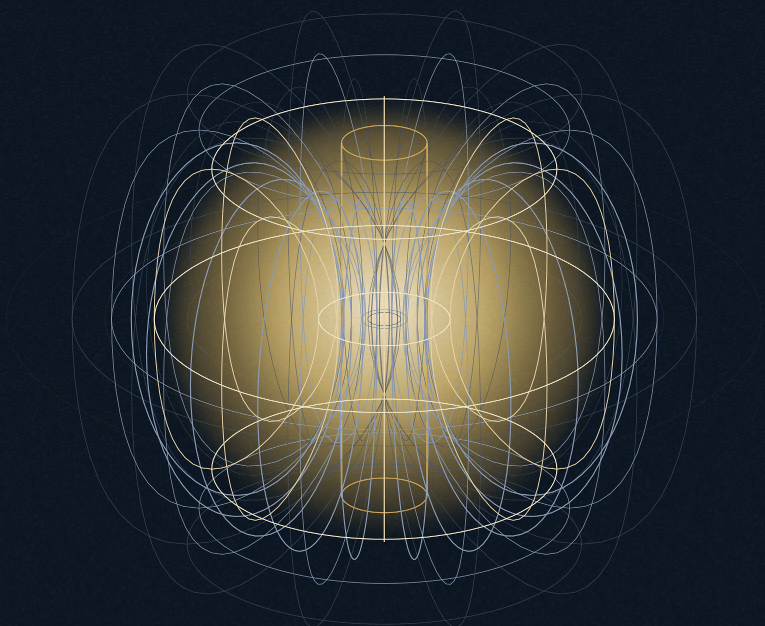
KRONOS FUSION ENERGY



THE 2026 DESIGN SERIES · WEB EDITION

The Complete Volume

A Breeder, a Burner, and the Science that Closes Both

Nine editorials in one bound volume: the five foundational papers and four companion studies of the Kronos platform — a spherical-tokamak breeder that makes strategic materials and a deuterium–helium-3 burner that makes power.

Explore it live — 3-D model · physics validator

PREPARED BY P. I. FORD & COLLEAGUES

2026 · EDITORIAL

KRONOS FUSION ENERGY · 2026

The Kronos Fleet

Fuel follows purpose, not platform.

Hyperion · Aegis · MetroVolt

THE OFFICIAL RECORD

What this document is, and how to read its numbers

This is a combined editorial. It gathers, in one volume, the two design studies Kronos Fusion Energy released in 2026 — a compact spherical-tokamak tritium/helium-3 breeder and a deuterium–helium-3 tandem-mirror generator — together with the intellectual-property estate, the people, and, in the internal edition, the full commercial case. The scientific text is the same text that appears in the arXiv preprints and the journal submissions; the editorial adds the apparatus a reader needs to hold the whole program at once, and nothing in the physics is altered to fit it.

THE HONESTY STANCE IS THE ASSET

Every headline quantity carries an **evidence class** — DERIVED RECOMPUTED MEASURED REQUIREMENT — and, where a number is a modelled extrapolation rather than a demonstrated value, it is labelled as such and its downside is shown next to it. Several quantities in the underlying corpus moved after first publication; where a value has been withdrawn or restated, the record says so plainly. This is deliberate: a diligence team will find the load-bearing assumptions, so the document surfaces them first.

TITLE	The Kronos Fleet — Hyperion · Aegis · MetroVolt: A Combined Design & Commercialization Study
AUTHOR	Priyanca Ford, Founder & CEO, on behalf of Kronos Fusion Energy
EDITION	2026 Combined Editorial · first issue
COMPANION WORKS	The five-paper arXiv drop — (1) Breeder, (2) Burner, (3) REBCO magnet & tape, (4) Direct Energy Conversion, (5) AI/ML/Quantum control — with matching numbered Zenodo deposits, plus the IOP journal and IAEA-FEC submissions. Patents were filed before the drop.
NAMING	Hyperion = the breeder; Aegis (defense) and MetroVolt (data-center) = one generator in two housings. Internal mode letters (D1, L) do not appear on public surfaces.
STATUS	Conceptual design & simulation study. Nothing herein is a construction commitment.

HOW TO READ THIS VOLUME

The fleet at a glance, and the way its numbers are marked

This volume opens with *Orientation*, presents the five research papers as a bound sequence, and closes with the *Apparatus*. *Foundations* sets out the three general results both machines rest on. *Paper One* is the Hyperion breeder; *Paper Two* the Aegis / MetroVolt generator; *Papers Three, Four and Five* are the enabling science — high-field REBCO magnets and tape, direct energy conversion, and the AI / ML / quantum control stack. A *Digital Twin & 3-D Model* part follows, then the *Environmental* profile. The *Economics* and levelized cost and the *Business Case* and diligence record appear in the internal edition only; the *Simulations* proof record and the Apparatus — patent portfolio, team, limitations, and sources — close both editions.

THE FLEET AT A GLANCE

	HYPERION	AEGIS	METROVOLT
Role	Strategic-isotope foundry	Defense installation power	Campus power
Machine	**Spherical tokamak**	**Tandem mirror**	**Tandem mirror**
Fuel	Deuterium–tritium	Deuterium–helium-3	Deuterium–helium-3
Delivers	Tritium · ^{3}He · 14 MeV n	Resilient installation power	Firm campus power
Physics bar	**Fusion gain only**	Closure (gates named)	Closure + lunar ^{3}He
In the fleet	Breeds the fuel	Proves the generator	Commercial destination

HOW THE NUMBERS ARE MARKED

Every headline quantity carries an evidence class — DERIVED from first principles, RECOMPUTED from raw data, MEASURED in hardware, or a REQUIREMENT yet to be met. Financial figures carry a case label and are confined to the internal (confidential) edition. Values that moved after first publication are shown as withdrawn or restated rather than quietly changed. A capability you can evaluate is one whose limits are on the page.

FOREWORD

One platform, in nine papers

This volume collects the 2026 Kronos editorials as one bound web edition. The five foundational papers describe the platform's machines and enabling science; the four companion studies develop the tritium fuel cycle, the integrated platform, the advanced-fuel choice, and the safety case. Every number is drawn from a single frozen physics record, and closure is stated in two tiers throughout — closed-on-model versus closed-demonstrated — never "closed" unqualified. Economics are excluded; honest gates are carried.

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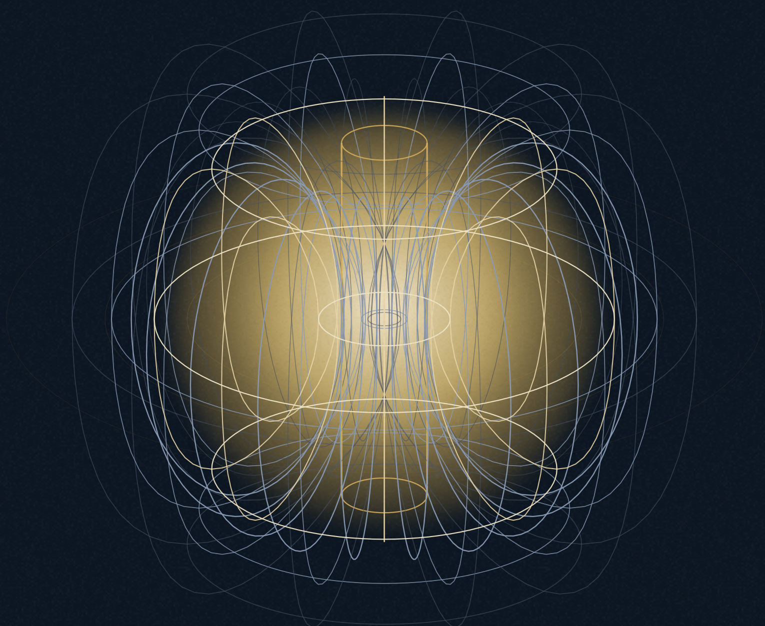
NOMENCLATURE

Symbols, units, and the names of things

Q	plasma (fusion) gain, P_{fus}/P_{aux}
Q_E	engineering gain, net electric out / recirculating in
H_{98}	confinement enhancement over the IPB98(y,2) scaling
Z_{eff}	effective ion charge
c_{ee}	electron–electron bremsstrahlung leading coefficient, 2.120022 (exact)
τ_E	energy confinement time
I_p	plasma current
R_0, a	major radius, minor radius
κ, δ	elongation, triangularity
β_N	normalized plasma beta (Troyon-normalized)
TBR	tritium breeding ratio
DEC	direct energy conversion
CF	plant capacity factor (availability)
FOAK / NOAK / BOAK	first / n^{th} / best of a kind
Hyperion	the ST breeder (internal: Mode D2)
Aegis	the generator, defense/installation housing (internal: Mode M)
MetroVolt	the generator, data-center housing (Mode M)

Part One — The Five Foundational Papers

KRONOS FUSION ENERGY



PAPER 1.1 OF THE 2026 KRONOS SET

Hyperion

The Tritium Foundry

A compact negative-triangularity spherical-tokamak breeder, sized to a national strategic-materials requirement rather than to a power rating.

Spherical tokamak · D–T · Q 3.0763 · 85.04 MW_{fus} · ~2.0 kg-T/yr/unit

Explore it live — 3-D model · physics validator · film series

PREPARED BY P. I. FORD · G. L. KULCINSKI

2026 · EDITORIAL

§ 1

Why a breeder, and why it can be small

United States tritium supply is structurally fragile: weapons-stockpile tritium is produced through a *single* commercial reactor, and the federal replacement requirement — tritium decays at **5.5% per year** — has been met by increasing irradiation loading rather than by adding a second source. Helium-3 is rationed. A domestic, non-reactor capability to produce both isotopes is of strategic interest independently of whether it is inexpensive.

The obstacle to a *fusion* isotope source has never been the nuclear physics, which is textbook, but the perceived need for a power-plant-scale machine. Hyperion removes that obstacle with one observation: **a breeder needs fusion *gain* — reactions — not net electricity.** Demanding net electricity is what forced every prior breeder concept into a large plasma, a large blanket, and a dangerous standing tritium inventory. Freed from that requirement, the machine is sized to a national supply requirement of order kilograms per year — and the size that results is small.

THE THESIS IN ONE LINE

Size the breeder to a named national requirement, not to a power rating, and the two obstacles that defeated every prior fusion-breeder proposal — machine scale and tritium inventory — both fall below their binding thresholds. The physics never forbade a small breeder; it forbade a large one.

The fusion helium-3/tritium breeder has been proposed before and rejected in print — Wittenberg on a licensing/inventory basis, Greenspan & Miley on the merchant-breeder economics — but every prior study sizes the breeder to a *fusion fleet's* support ratio, where the inventory objection bites. Hyperion sizes to a named non-fusion requirement, at which the objection inverts.

§ 2

The design point and the power balance

The zero-dimensional power balance fixes the gain. At the frozen operating point (config **22021**, gate BR-L1-A1) the compact spherical tokamak reaches a plasma gain of **Q = 3.0763** at a fusion power of $\mathbf{P_{fus}}$ = **85.04 MW** and a plasma current of $\mathbf{I_p}$ = **9.66 MA**, at negative triangularity δ = -0.3. This is a driven, sub-ignition target — it does not need to close the electrical loop, only to run reactions at a useful rate. COMPUTED · FROZEN

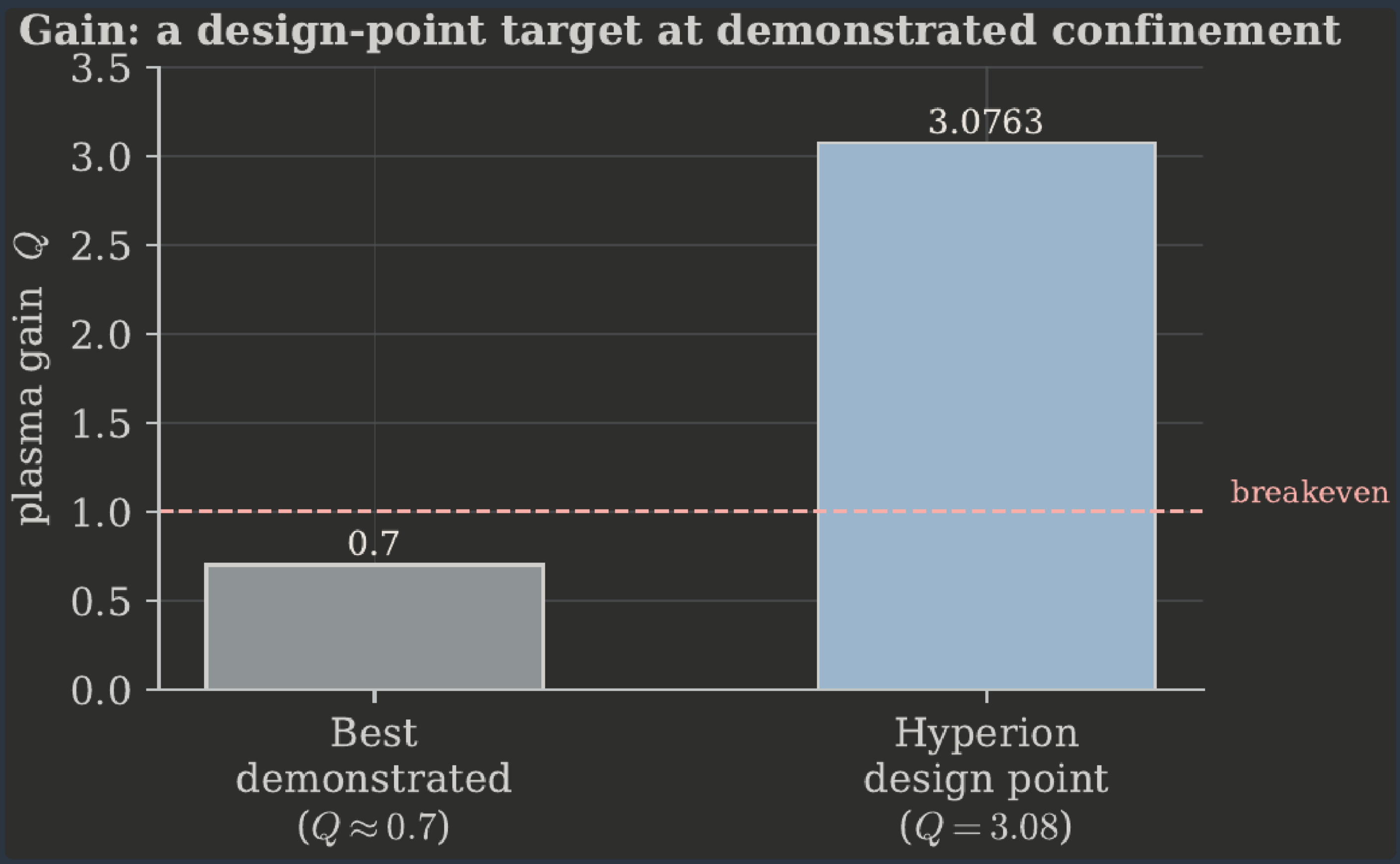


FIGURE 1. The power balance at the frozen operating point: fusion gain Q = 3.0763 at 85.04 MW, a driven sub-ignition breeder, not a power reactor. RECOMPUTED

§ 3

Negative triangularity — the confinement lever

Negative triangularity is the design's confinement lever, established at both turbulence scales with nonlinear gyrokinetics. At the operating gradient it cuts the combined ITG+TEM ion transport by **40–45%** relative to a positive-triangularity twin (gate BR-L2-A1c), and suppresses electron-scale ETG transport by **79–80%** — leaving the operating point quiet and subcritical. The direction is corroborated against the TCV and DIII-D negative-triangularity campaigns; the magnitude is a design-target caveat carried openly.

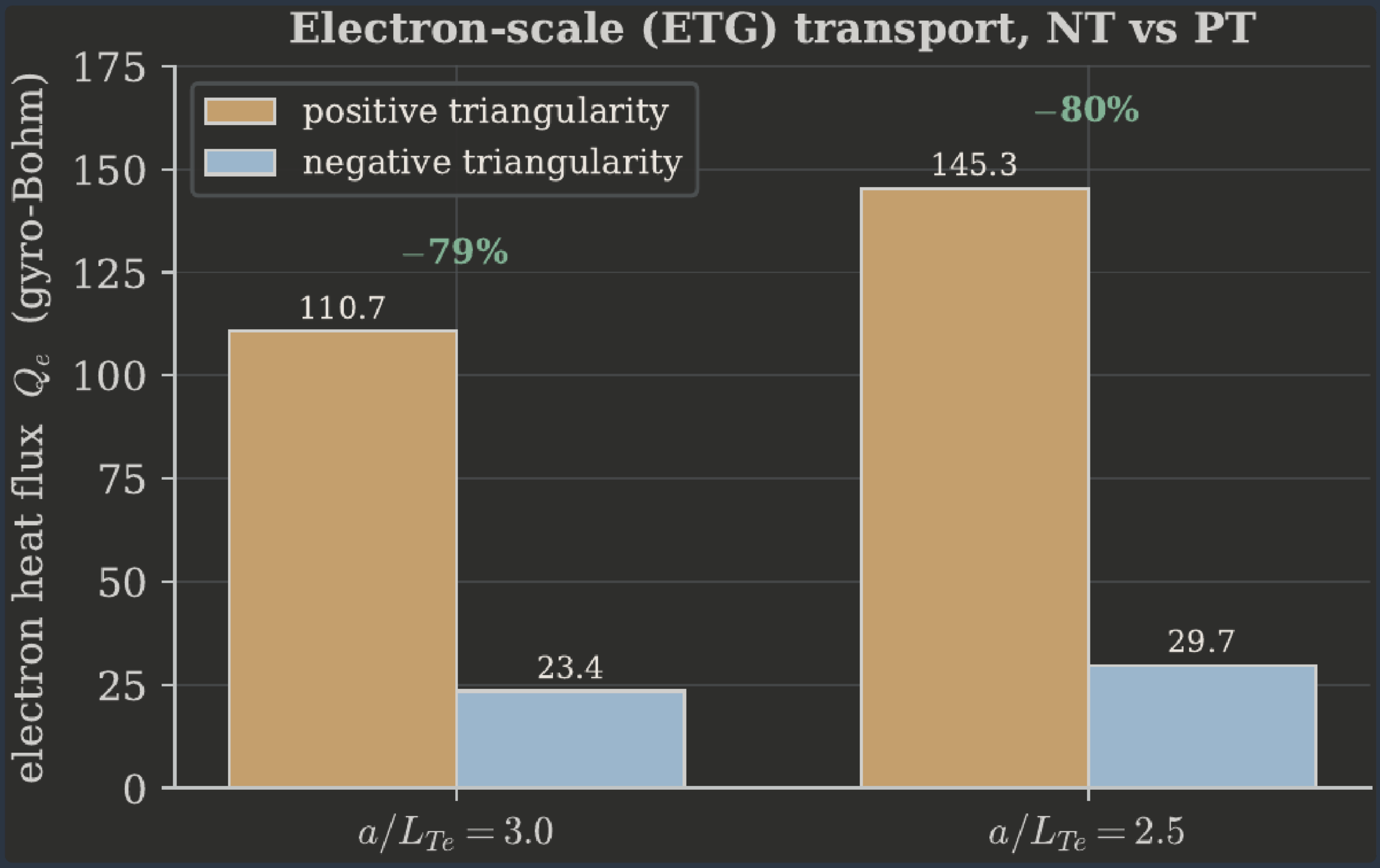


FIGURE 2. Negative triangularity suppresses turbulent transport at both the ion and electron scale relative to a positive-triangularity twin. NONLINEAR CGYRO

§ 4

The tritium breeding ladder

The breeder's product is tritium, and its credibility rests on an honest mass balance. Each deuterium–tritium fusion consumes one triton, so the per-unit burn rate follows from the fusion power: $\mathbf{\Lambda_T = 4.76}$ **kg-T fpy^{-1}**. The net surplus is a confirmed *ladder*: three-dimensional neutronics on ENDF/B-VIII.0 raise it from 0.29 kg-T yr^{-1} (literal recipe) through 0.9 (solid-beryllium blanket) to **~2.0 kg-T yr^{-1} per unit** at the advanced blanket — net TBR 1.42, the confirmed per-unit ceiling across twelve configurations.

PER UNIT VERSUS FLEET

A single advanced unit is a tritium **exporter** at the ~2.0 kg-T yr^{-1} scale. A national-scale 4 kg-T yr^{-1} supply is a *fleet* property — two advanced units, or four-to-five solid-beryllium units, with helium-3 aggregating to 3.6-4.5 kg yr^{-1} — never a single-unit claim, because the spherical-tokamak centrepost caps the per-unit ceiling.

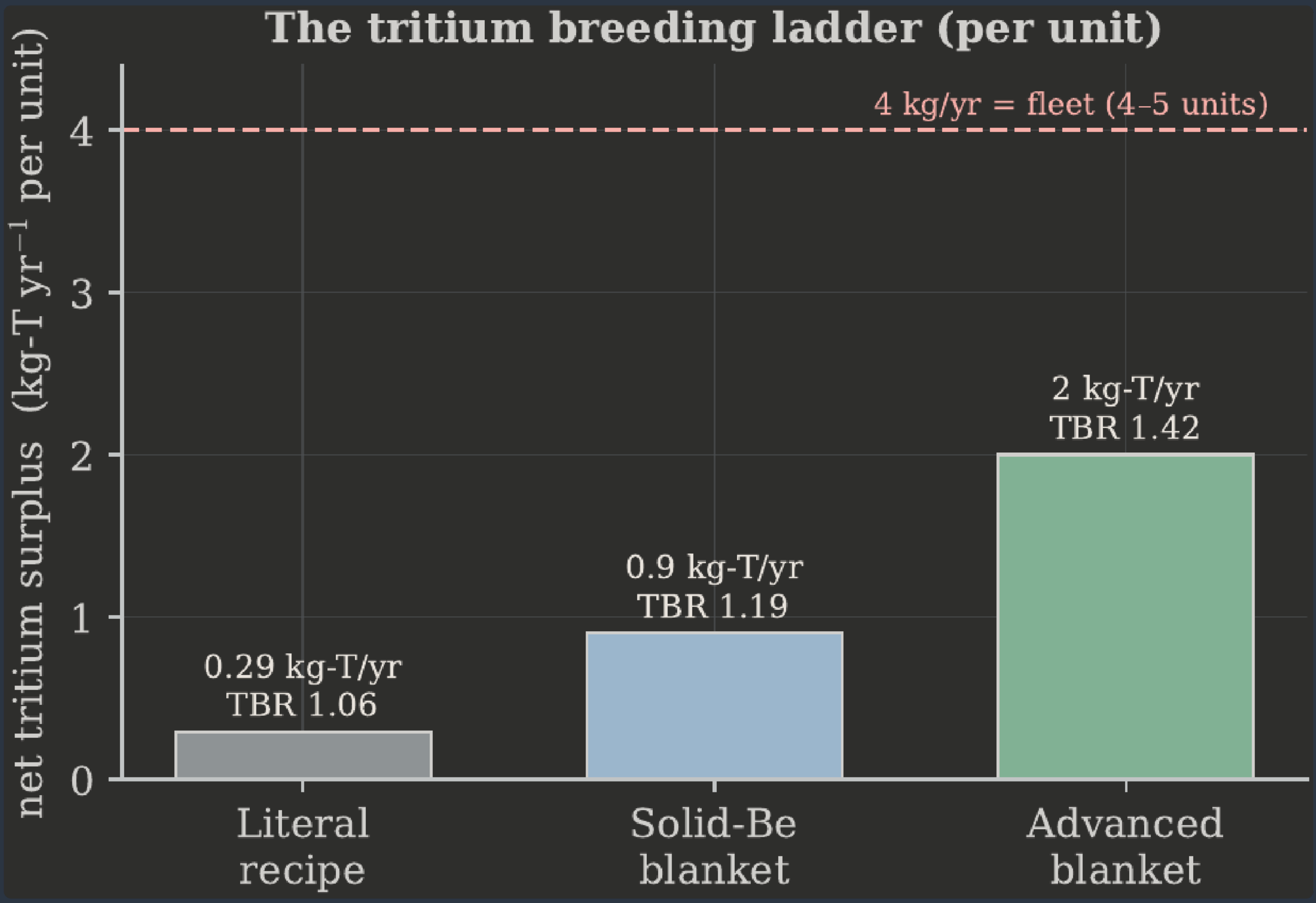


FIGURE 3. The per-unit tritium breeding ladder: net surplus at the literal, solid-beryllium, and advanced blankets. OPENMC / ENDF-B-VIII.0

§ 5

The centrepost, as a quantified consumable

The inboard centrepost is the defining vulnerability of a normal-conductor spherical tokamak, and the design does not argue it away: it is a consumable, scheduled-replacement cartridge with a best-case life of **0.58 full-power-years**, tunable against a tungsten-carbide shield that trades directly with breeding coverage. The materials-lifetime problem is converted into a maintenance-interval problem, which is the tractable one.

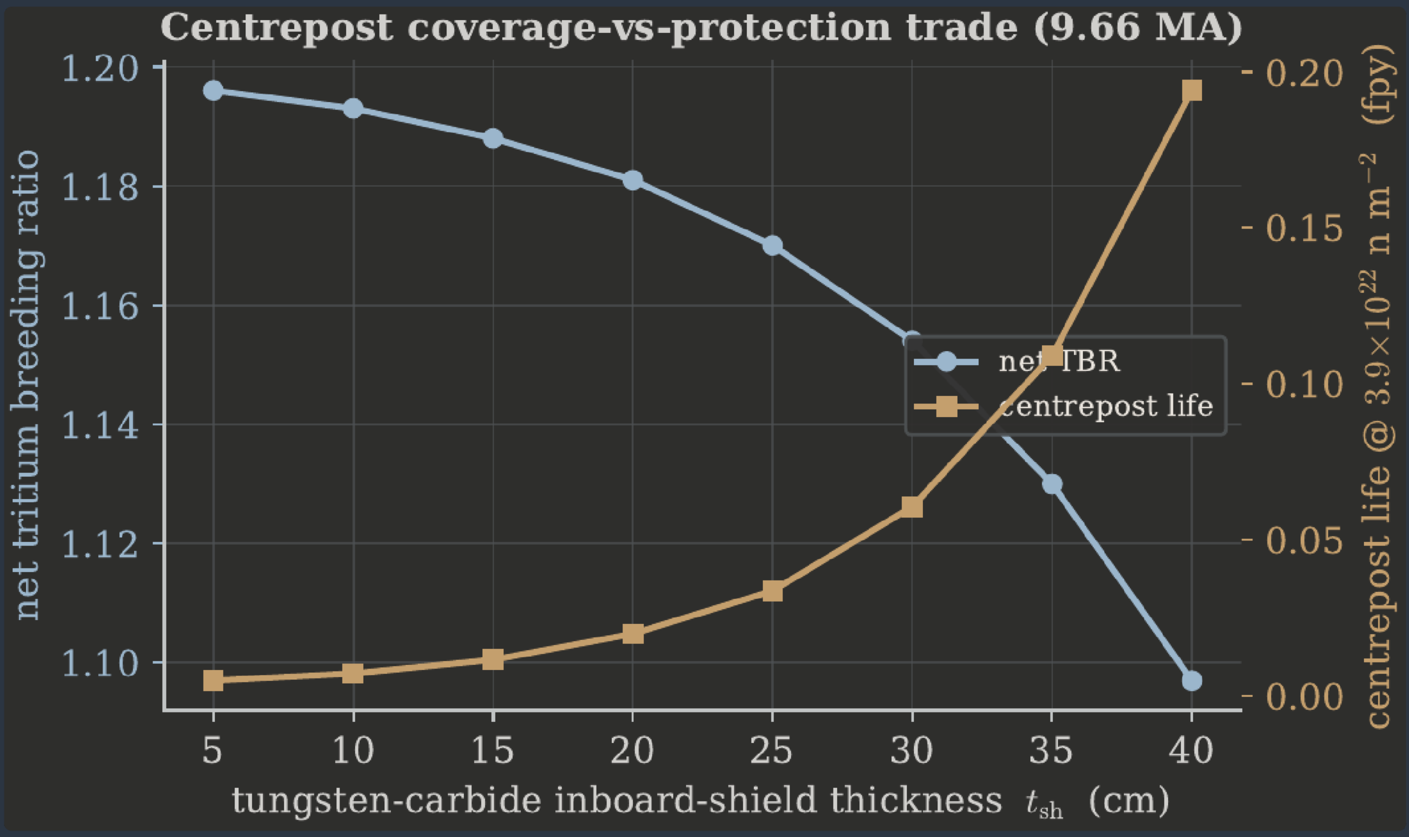


FIGURE 4. Centrepost damage and consumable-cartridge life against shield thickness; the shield trades against breeding coverage. RECOMPUTED

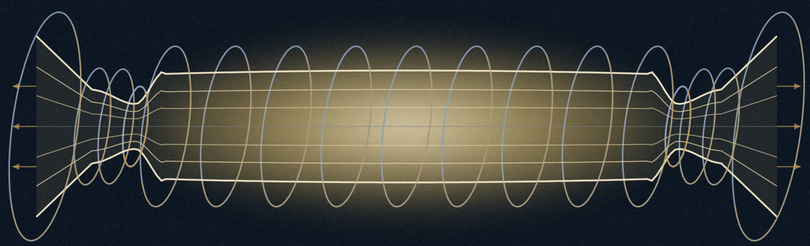
§ 6

Disruptions, answered directly

The disruption response is answered rather than assumed negligible, and it is demanding. On a NIMROD-verified equilibrium the current-quench time is 7-19, the runaway-electron avalanche is *severe* ($E/E_c \approx$ SEVERE), and the halo current reaches 35 of the plasma current. The honest conclusion is a hard design requirement: shattered-pellet-class disruption mitigation, triggered inside the current-quench window. The risk is stated as a requirement, not waved away. DESIGN REQUIREMENT

Net electricity is a category error for this machine and is excluded. Hyperion succeeds by gain, breeding ratio, helium-3, and neutrons — the materials a fusion economy needs — and the burner, its companion, carries the power story.

KRONOS FUSION ENERGY



PAPER 1.2 OF THE 2026 KRONOS SET

Aegis & MetroVolt

The Generator

A deuterium–helium-3 tandem-mirror generator that closes on measured efficiencies — two housings, one machine.

Tandem mirror · $D\text{–}^{3}He$ · Q_E 1.318 · f_n 5.44% · plug-gated

Explore it live — 3-D model · physics validator · film series

PREPARED BY P. I. FORD · G. L. KULCINSKI

2026 · EDITORIAL

§ 1

One machine, two housings

Aegis and MetroVolt are two application housings of one deuterium–helium-3 tandem mirror — fixed defence installations and data-centre generation — sharing the mirror physics and the direct-energy-conversion train. The machine burns an advanced fuel that is *low-neutron, never aneutronic*: at the design point it reaches an engineering gain of $\mathbf{Q_E = 1.318}$ at a neutron fraction of only **5.44%**, an order of magnitude below deuterium–tritium.

THE HONEST GATE, UP FRONT

Closure is *requirement-class*, not demonstrated. The machine closes on the frozen physics, but it needs an end-plug density ratio of **16** — far above the GDT-measured value — which is the design's largest open item, retired by a named plug-scale potential experiment, not by a hoped-for breakthrough.

§ 2

The size-scaling result

The paper's principal new result concerns synchrotron reabsorption: it is not a fixed fraction of fusion power but *scales with machine size*, an analytic consequence of a harmonic cutoff that grows with minor radius. That single observation reframes the mirror's power balance and sets where on the device-length ladder the engineering gain crosses unity.

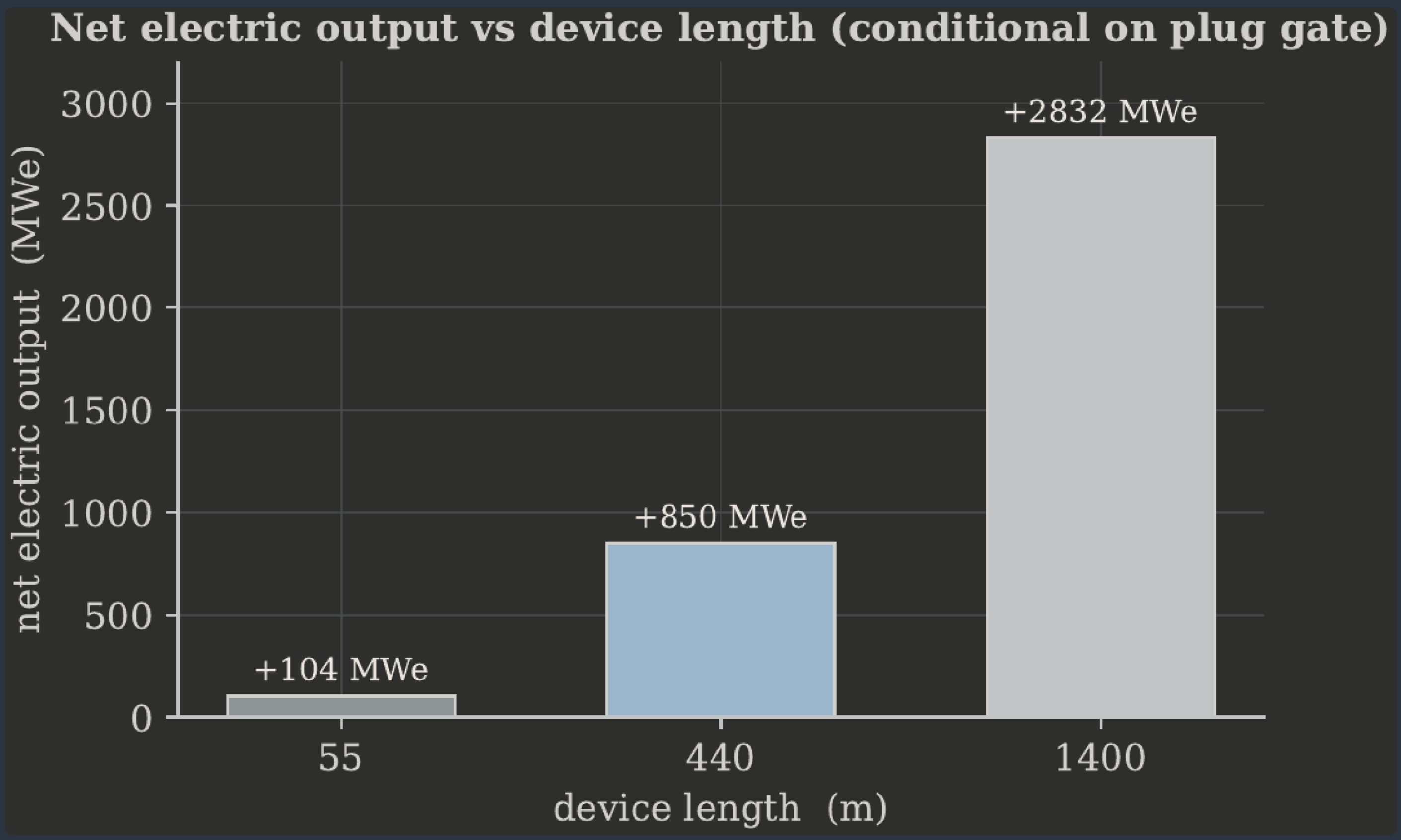


FIGURE 5. Engineering gain across the device-length ladder: net electric output grows with length as the recirculating burden is amortised. RECOMPUTED

§ 3

The plug, and the uncertainty

The end plug is where the machine lives or dies. It confines the central-cell ions electrostatically, and the potential it must hold sets the density ratio that is the design's binding gate. We do not present a single flattering number: the engineering gain is reported as a *band* under uncertainty quantification, with its probability of exceeding unity stated honestly rather than a point estimate asserted.

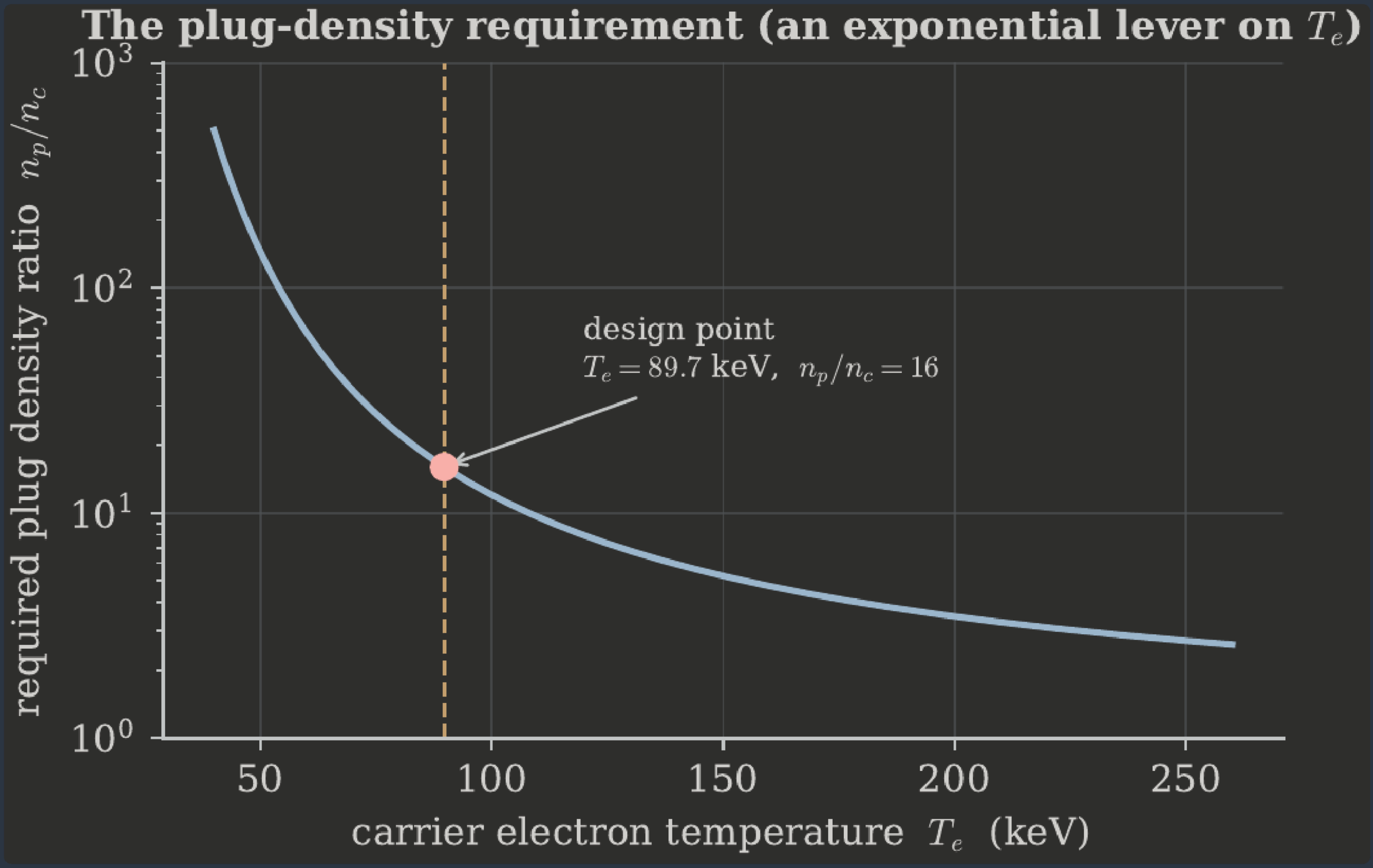


FIGURE 6. The end-plug field and potential structure that sets the confining density ratio — the machine's largest open item. REQUIREMENT-CLASS

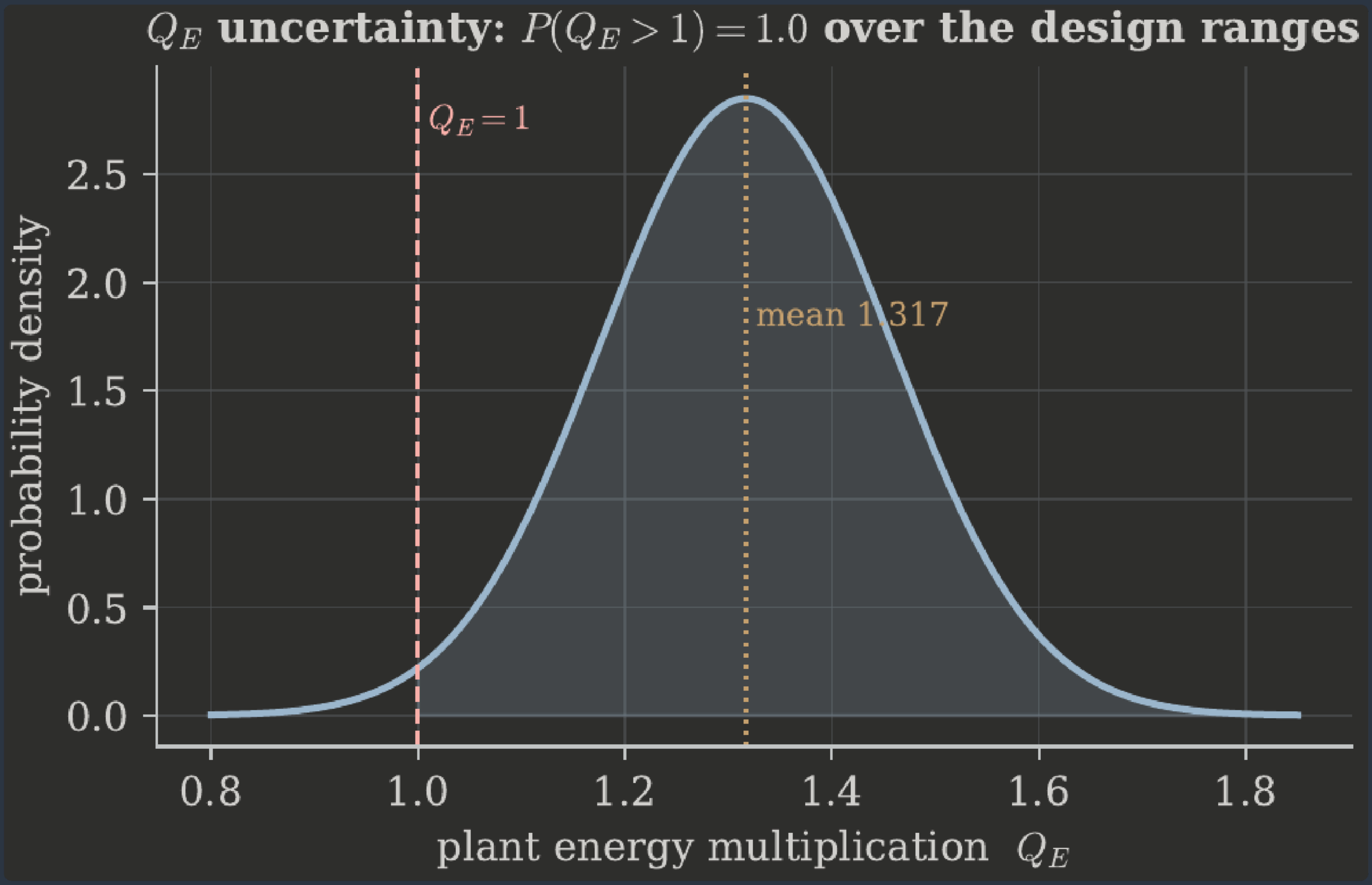


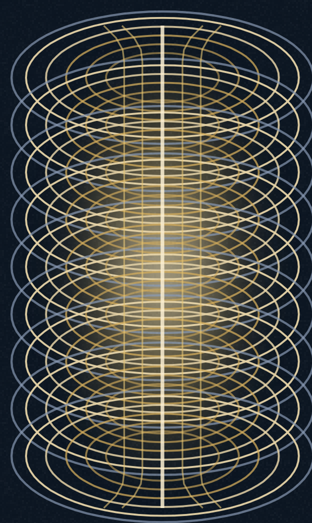
FIGURE 7. The engineering gain as a band under uncertainty quantification, not a point estimate. UQ ENSEMBLE

§ 4

Why deuterium–helium-3

The fuel is chosen on the physics, not the aneutronic ideal. Where the product is power and neutrons are a liability to shield and a source of activation, deuterium–helium-3 is correct because 5.44% is the lowest neutron burden among fuels with accessible reactivity. Its one honest cost — helium-3 availability — is met by the breeder's co-product helium-3 and, at fleet scale, lunar supply. The magnet that makes the plug is buildable within demonstrated practice; the magnet is not the gate. The generator improves with direct energy conversion, but its closure is governed by the plug potential, stated plainly.

KRONOS FUSION ENERGY



PAPER 1.3 OF THE 2026 KRONOS SET

High-Field REBCO Magnets & Tape

Bore-Resolved Mechanics

One bore-resolved mechanics applied to two machines — a strain-first conductor architecture and an honest feasibility map that moves the gate off the coil.

REBCO · bore-resolved hoop stress · plug coil resolved by structural shield

Explore it live — 3-D model · physics validator · film series

PREPARED BY P. I. FORD · R. J. WEGGEL · D. K. WEGGEL

2026 · EDITORIAL

§ 1

One mechanics, applied twice

The magnet paper does one thing carefully and applies it to both machines: *bore-resolved* hoop stress, which scales with the winding bore — exactly what worst-case derating hides. Resolving the stress by bore rather than assuming a single conservative bound changes which coil is the binding constraint, and it does so in the design's favour.

THE RESULT IN ONE LINE

The breeder's centre-post is stress-comfortable at its operating field. The burner's small-bore plug coil — once feared infeasible as a bare winding — is **resolved** by a stress-managed structural shield that closes the full plug field at a healthy strain margin. The magnet is *not* the gate.

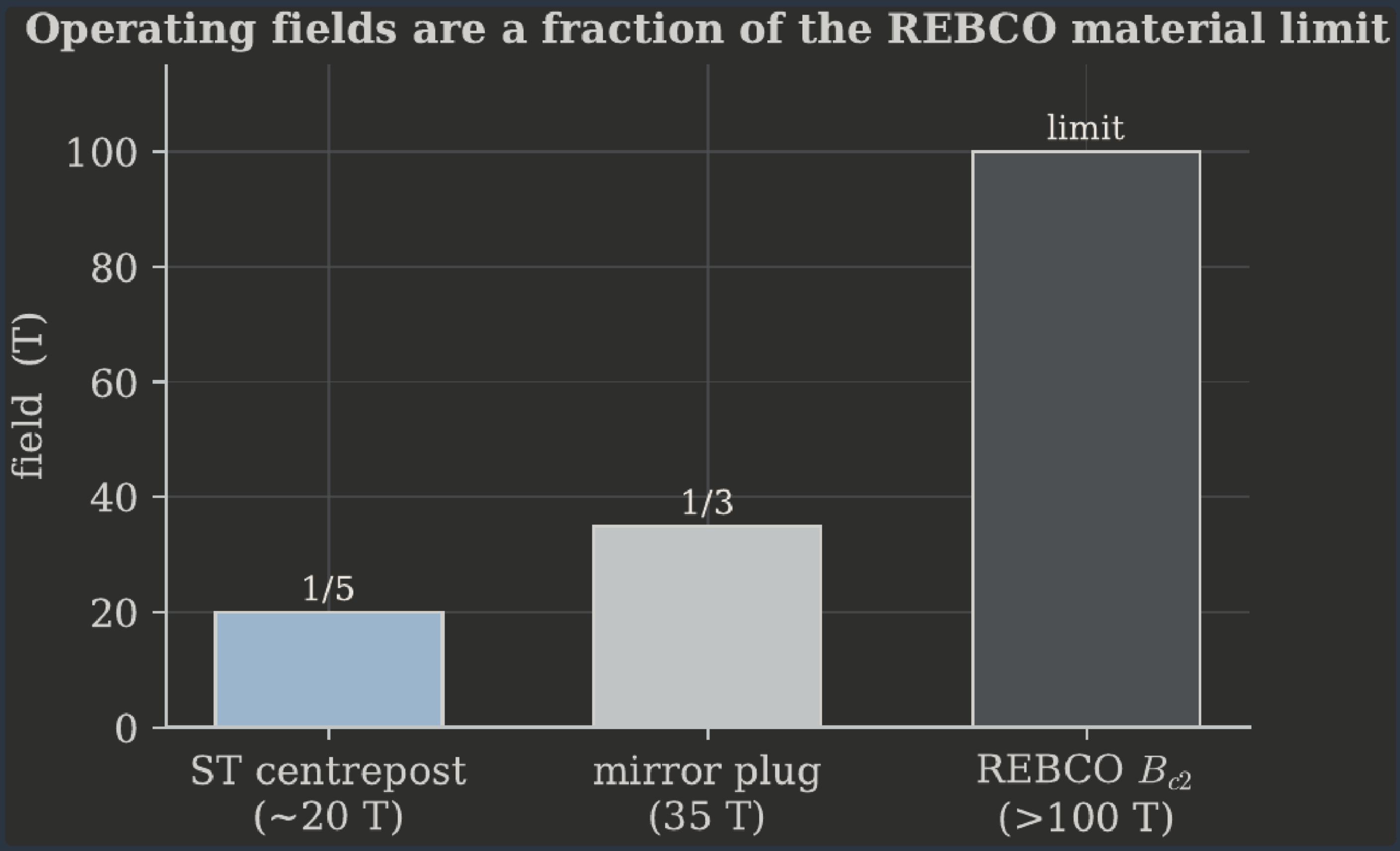


FIGURE 8. The REBCO field-capability envelope for the two machines; a conductor-capability claim, kept strictly apart from any coil record. RECOMPUTED

§ 2

The stress profile, resolved by bore

Hoop stress in a high-field winding grows with the bore radius, so a small-bore, very-high-field coil and a large-bore, moderate-field coil are not interchangeable at the same nominal field. Resolving the profile turns a single worst-case “infeasible” verdict into a map: where the bare winding is stress-limited, and where a structural shield carries the load. The burner plug sits in the second regime, and the shield closes it.

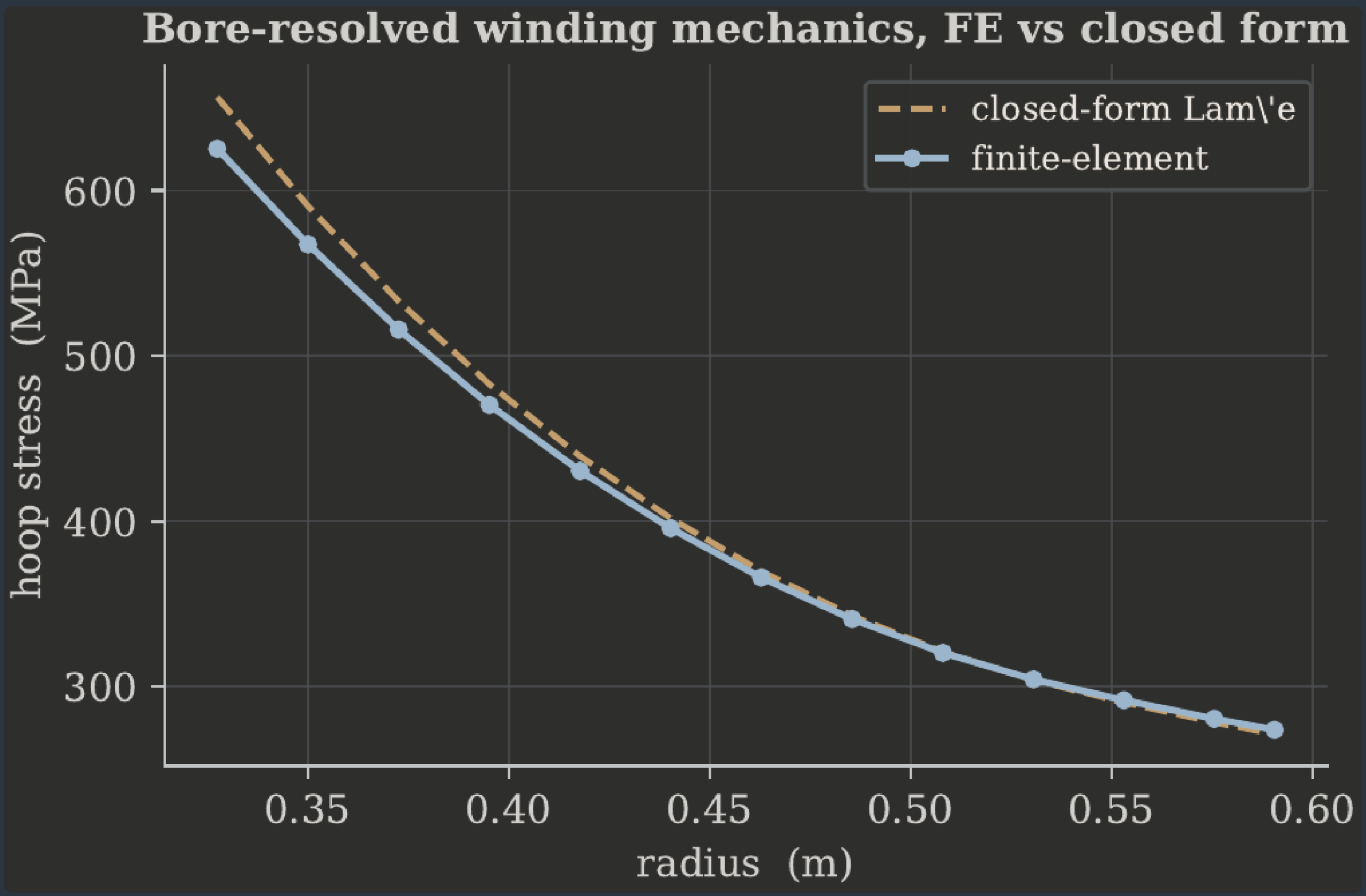


FIGURE 9. Bore-resolved hoop stress through the winding: the structural shield brings the small-bore plug coil inside its strain margin. RECOMPUTED

§ 3

Two claims, kept apart

Honesty here is a matter of not conflating two different statements. A field-capability claim about the *conductor* — what the REBCO tape can carry — is not a coil record, and we never present it as one. The feasibility map states, per coil, whether it is stress-comfortable as a bare winding, or feasible only with a structural shield, or pending a finite-element confirmation. The plug coil is the last-resolved case, and its resolution retires what had been the design's magnet gate.

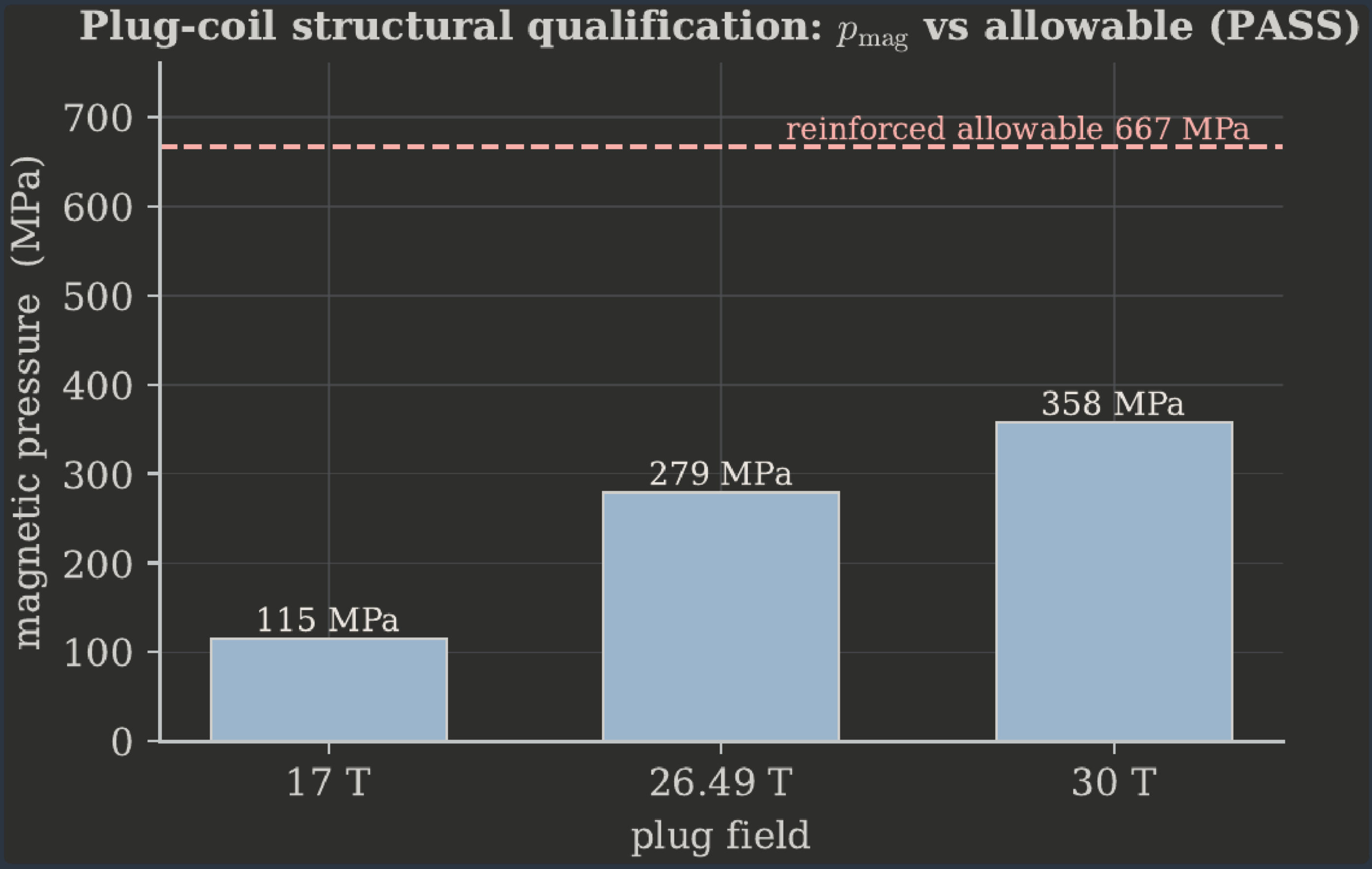
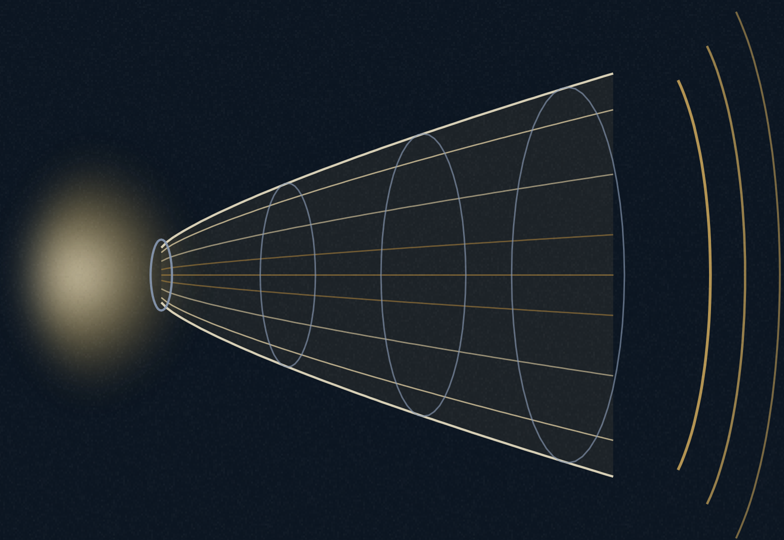


FIGURE 10. Magnet operating margin across the two machines after the structural resolution of the plug coil. FEASIBILITY MAP

The consequence for the platform is direct: with the plug coil resolved, the burner's one remaining gate is the plug *potential* — a plasma-physics experiment — not the plug *magnet*. The magnet science moved the gate off the coil.

KRONOS FUSION ENERGY



PAPER 1.4 OF THE 2026 KRONOS SET

Direct Energy Conversion

A Quasineutral Expander

For a D–^{3}He mirror: the electron channel is the larger axial stream, and a quasineutral expander can recover it.

D–^{3}He mirror · axial split 55.5 / 44.5% · expander ×20 · η 0.7

Explore it live — 3-D model · physics validator · film series

PREPARED BY P. I. FORD · G. L. KULCINSKI

2026 · EDITORIAL

§ 1

The loss channel is not the birth channel

The case for direct energy conversion in a deuterium–helium-3 mirror is usually made about the 14.66 MeV proton, which carries about 80% of the charged birth energy and invites a high-efficiency ion converter. That framing describes the *birth* spectrum, not the axial loss channel. At a reactor ion temperature the proton is born far above its Stix critical energy and thermalizes predominantly on the electrons before it can escape.

THE INVERSION

Booked against a finite axial-confinement time, the axial exit carries a *thermalized* split in which the electron/thermal stream (≈**55.5%**) is larger than the residual directed-ion stream (≈**44.5%**) — an inversion of the received picture that holds across 20–200 keV. The dominant recovery target is a directed *electron* stream, and no published converter recovers directed electrons.

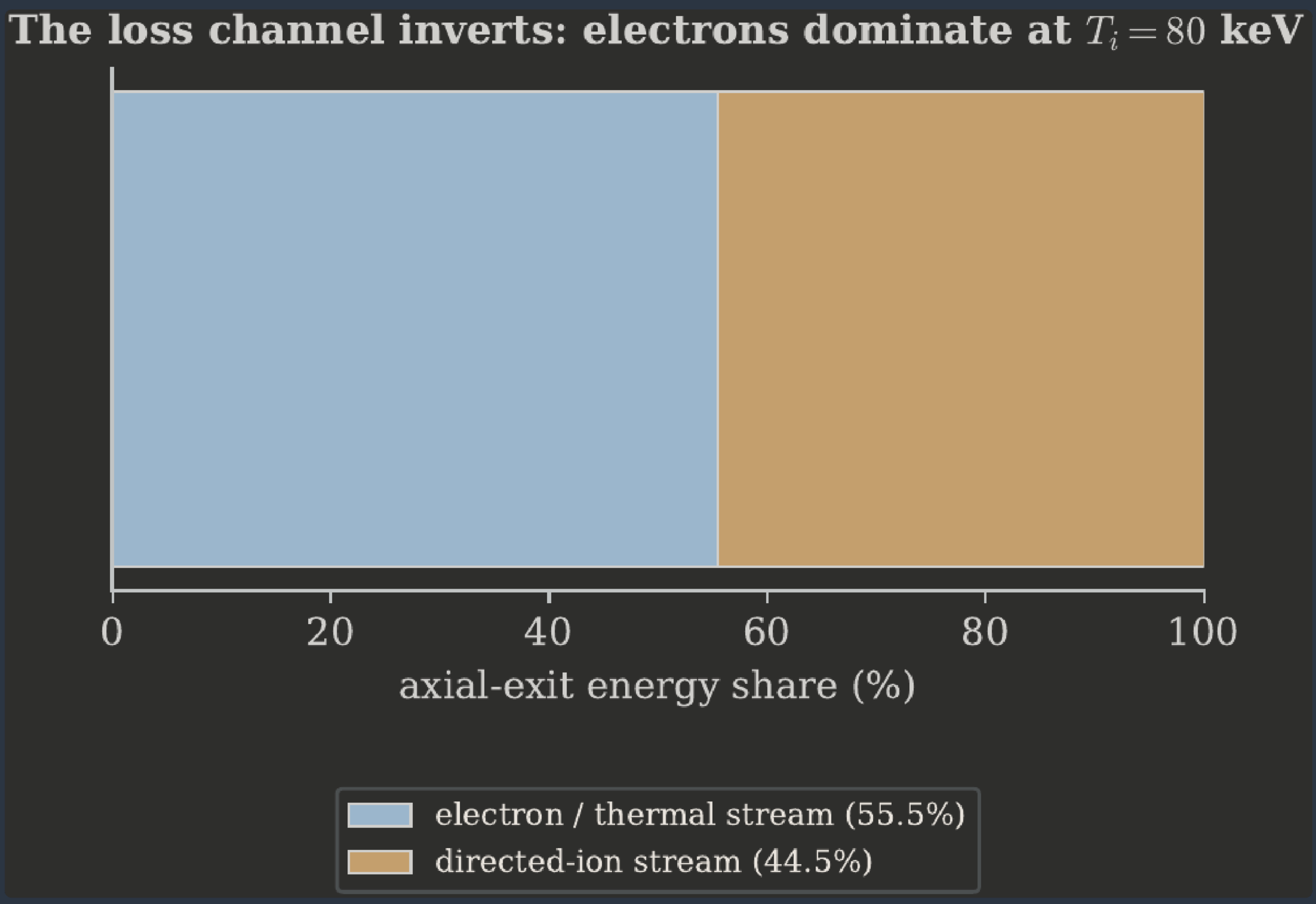


FIGURE 11. The thermalized axial-exit split at reactor temperature: the electron/thermal channel dominates the directed-ion channel. RECOMPUTED

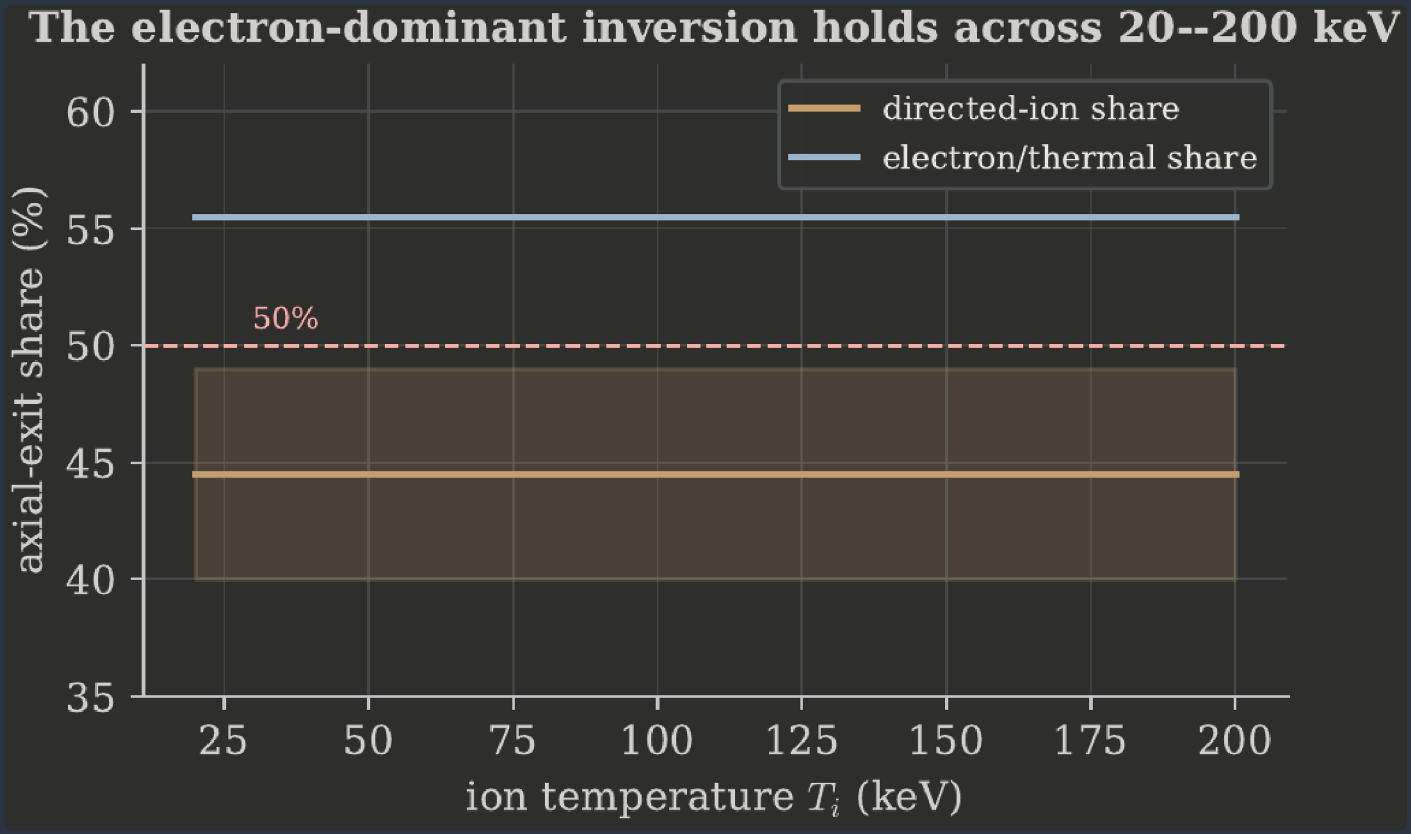


FIGURE 12. The electron-dominant inversion holds across 20–200 keV: the directed-ion share stays below 50% throughout. RECOMPUTED

§ 2

The quasineutral expander

We propose the inverse of the usual magnetic-nozzle usage: a quasineutral, two-species *expander* that recovers the electron channel against the ambipolar potential of the expansion, so the space-charge wall never forms. One worked embodiment (expansion ratio 20, 5 T → 0.25 T) recovers a bounded ≈28% of the electron channel after realistic losses, lifting the axial electric recovery by ≈13% (≈97 MW_e), at a converter module efficiency of 0.7.

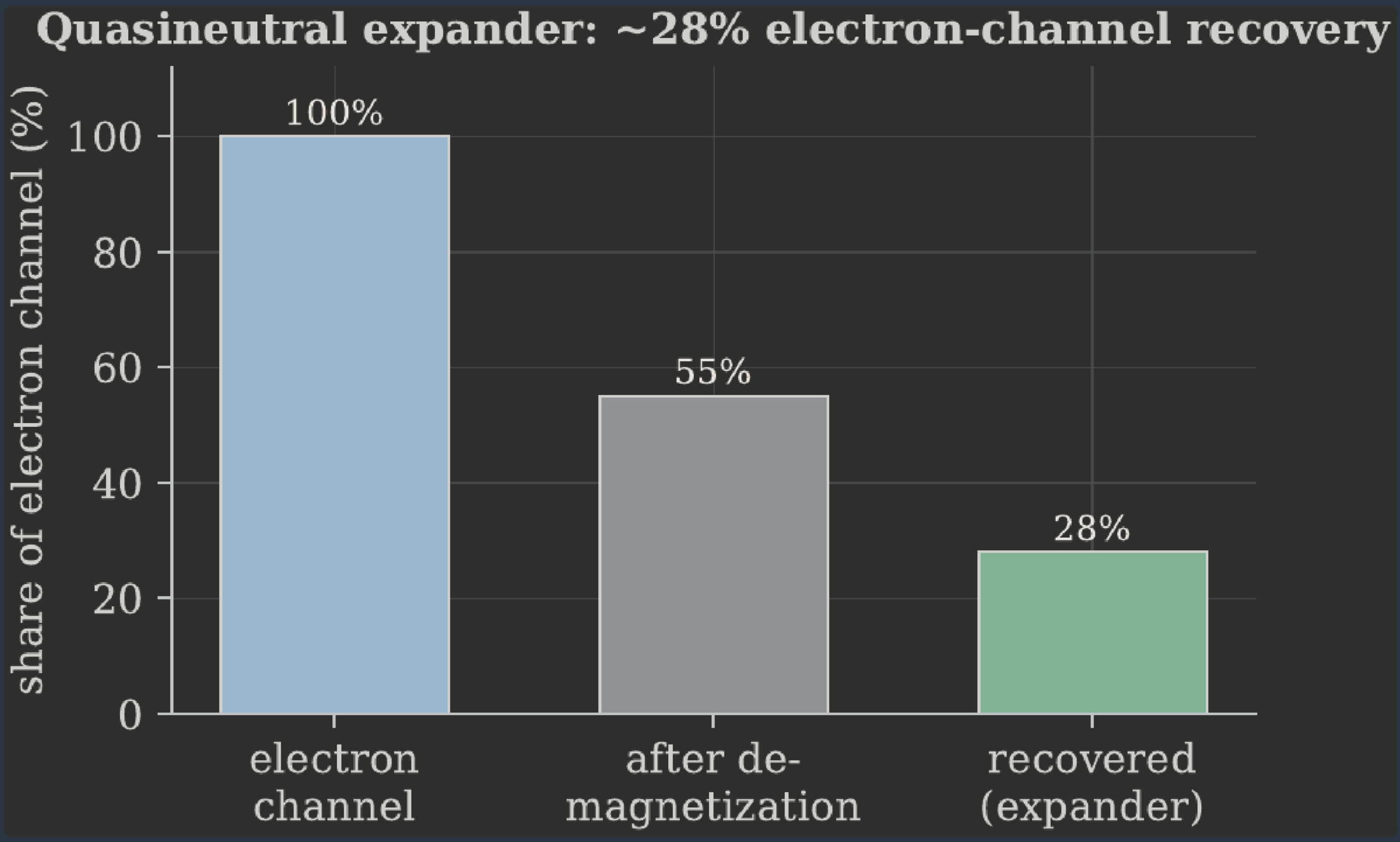


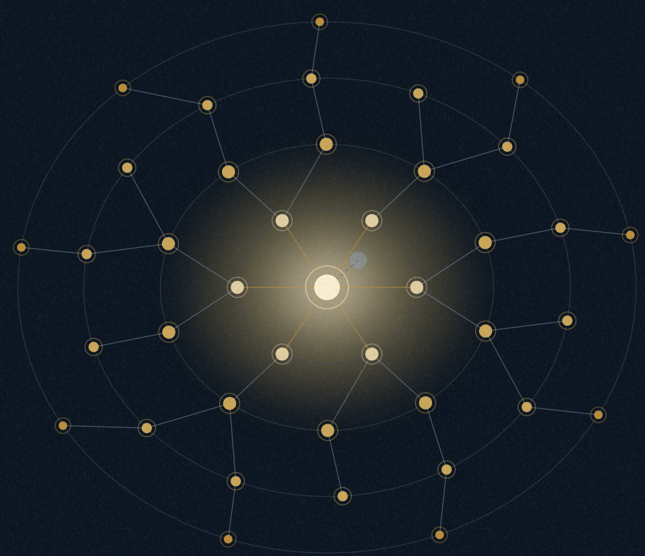
FIGURE 13. The quasineutral expander recovers a bounded ≈28% of the electron channel after modelled demagnetization and detachment losses. WORKED EMBODIMENT

§ 3

A bounded lever, not the closure mechanism

We place direct energy conversion correctly in the plant balance: the generator's energy multiplication is gated by the recirculating plug and thermal-barrier power, not by conversion efficiency. The expander is a bounded upside — it improves the generator without being what makes it close. Kronos has built no converter; every number is a design target, a model output, or an open-risk inference. Even a bounded-negative experimental result on the expander closes a named open problem in advanced-fuel energy conversion. BOUNDED LEVER

KRONOS FUSION ENERGY



PAPER 1.5 OF THE 2026 KRONOS SET

AI, ML & Quantum Control

Certifiable Real-Time Control

Physics-informed AI and quantum technologies for certifiable real-time control of compact fusion generators — three tiers, held apart.

Layered twin · 0/5000 escapes clamped · quantum: no crossover this decade

Explore it live — 3-D model · physics validator · film series

PREPARED BY P. I. FORD

2026 · EDITORIAL

§ 1

Three tiers, held apart

A nuclear-regulated fusion generator must be controlled across ten orders of magnitude in time — microsecond magnet protection through month-scale fuel logistics — and every automated actuation must be bounded, auditable, and reproducible. Machine learning and quantum technologies are often invoked for this without saying what is deployable now versus what is a decade away. We hold three technology-readiness tiers strictly apart, and report each with its evidence *and* its misses.

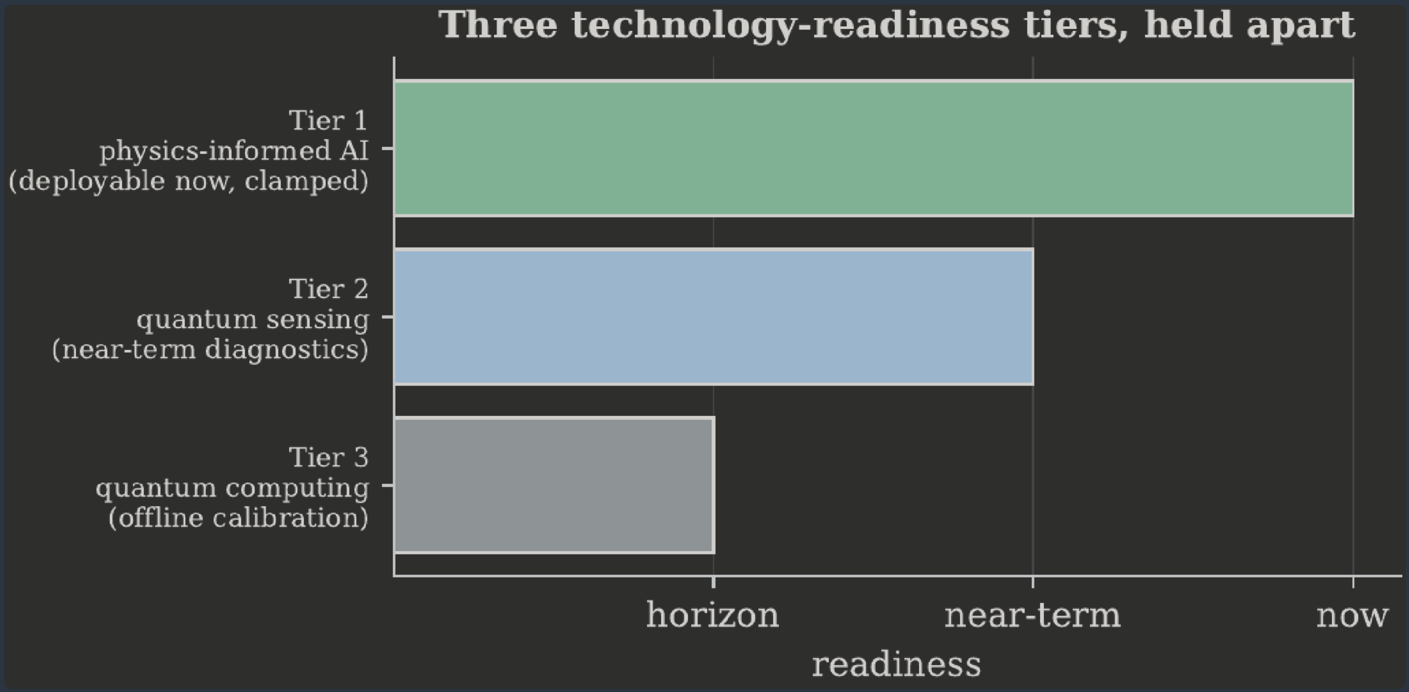


FIGURE 14. The three tiers: physics-informed AI (deployable now, clamped), quantum sensing (near-term diagnostics), quantum computation (offline calibration). ARCHITECTURE

§ 2

Tier 1 — physics-informed AI, deployable now if clamped

The load-bearing requirement is that a learned controller cannot drive the machine out of its safe operating envelope. A robust control-barrier-function filter provides this with an analytic forward-invariance guarantee: over 5000 Monte-Carlo trajectories, **0** escape the safe set with the filter against **5000** of 5000 without it. Around it, a Bayesian-optimization surrogate reaches leave-one-out R^2 = 0.987. Physics-informed AI is deployable in the loop *because* its error is bounded and deterministically clamped.

WHY THIS IS THE LOAD-BEARING RESULT

A learned controller can pursue performance while a proven clamp guarantees the machine stays in the safe envelope — zero safety-set escapes with the filter, backed by proof, not by a training score.

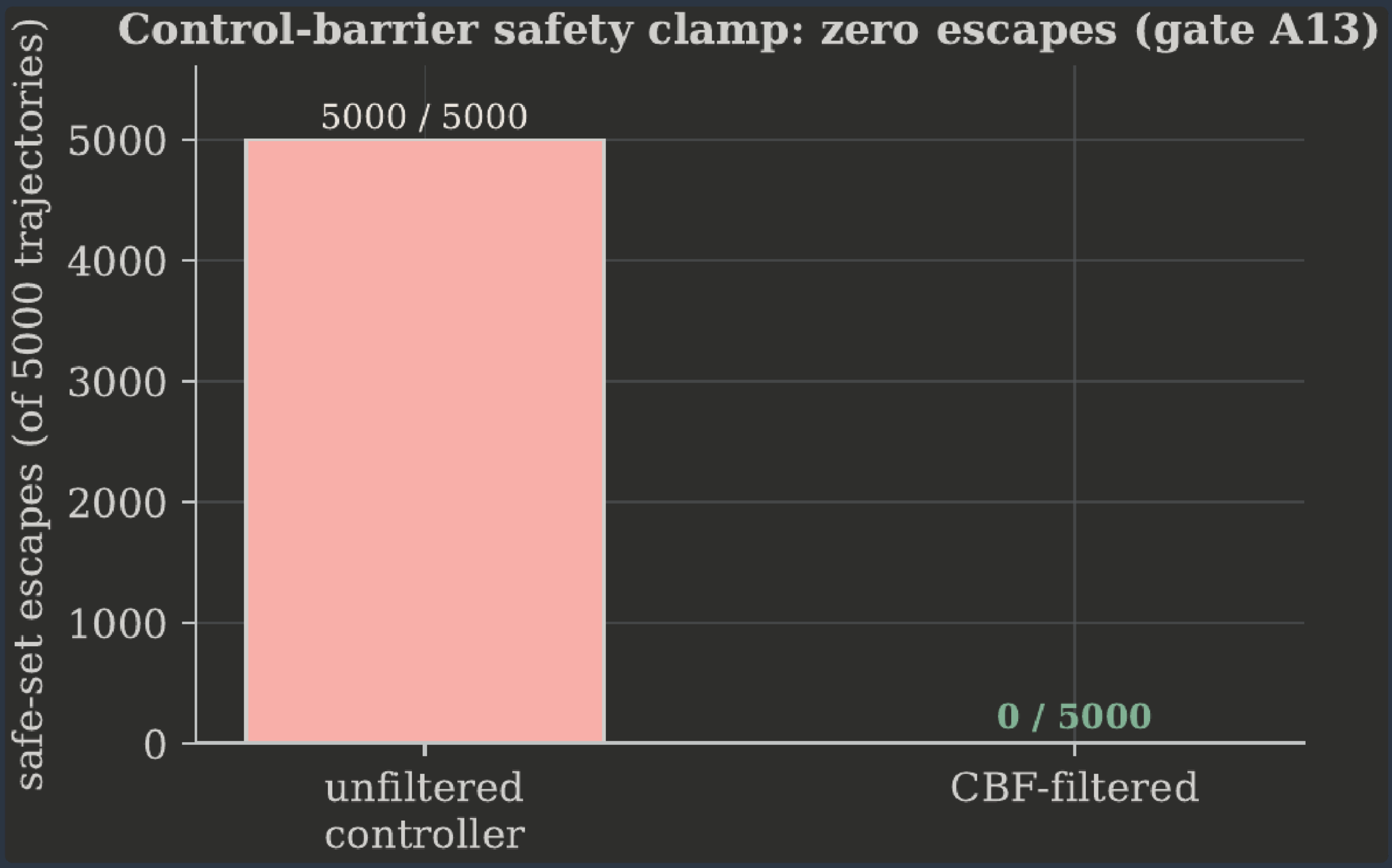


FIGURE 15. The control-barrier safety clamp: 0 of 5000 trajectories escape the safe set with the filter, against 5000 unfiltered. MONTE-CARLO

§ 3

Tier 3 — quantum computation, an offline calibration tier

For fusion, quantum computation is an offline calibration tier with no resource crossover this decade. Landau damping reproduces on a 5-qubit circuit to a few percent, and variational quantum chemistry reaches chemical accuracy on the fusion-alloy fragments — but the honest resource split is load-bearing: the linear kinetic operator needs 11–19 logical qubits, and the nonlinear gyrokinetic problem that would most help the machine is fault-tolerant-horizon. Noisy hardware today shows no advantage; the classical baseline is cheaper at every demonstrated scale.

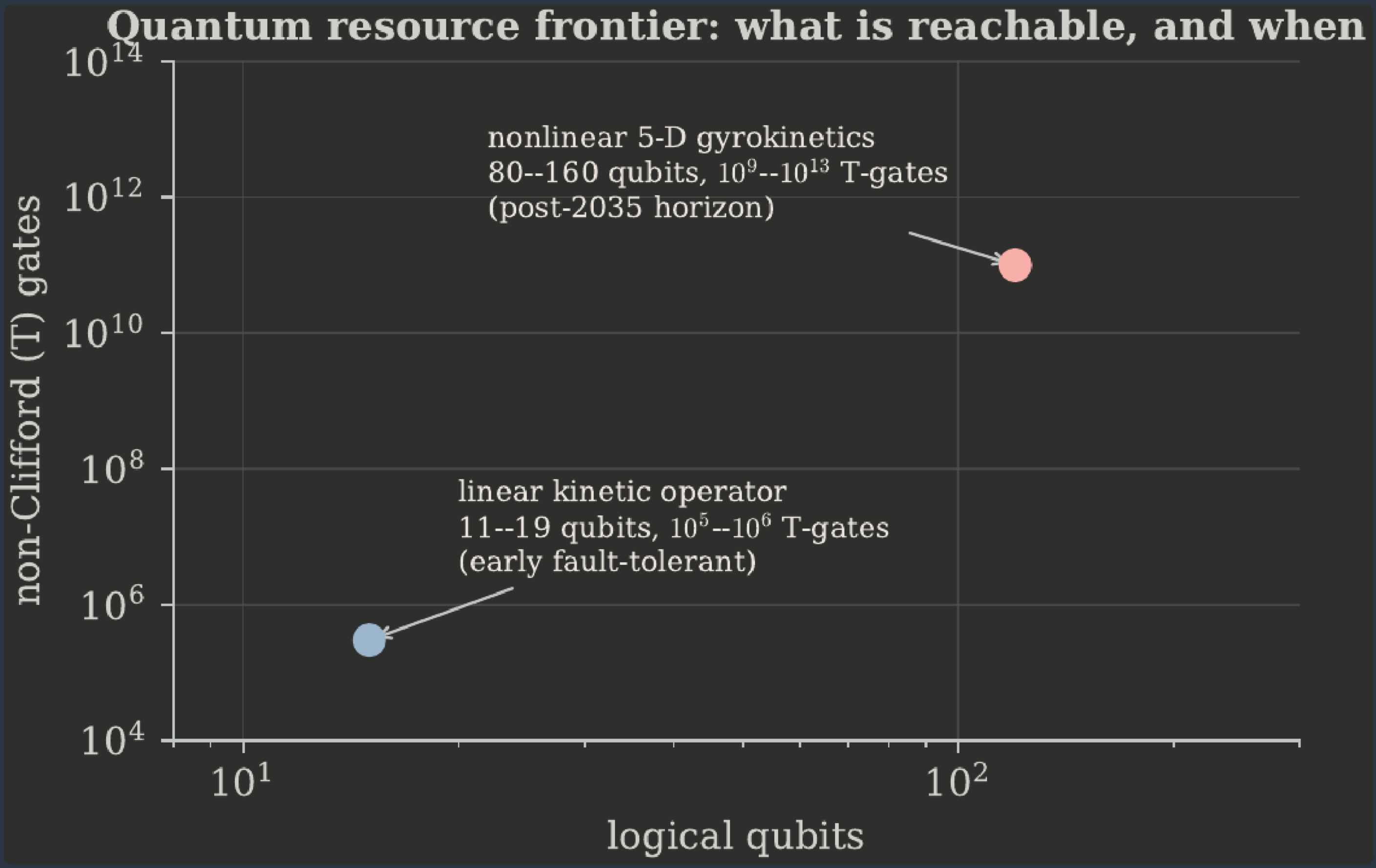


FIGURE 16. The quantum resource frontier: the linear kinetic operator is an early-fault-tolerant target; the nonlinear gyrokinetic problem is a post-2035 horizon. RESOURCE ESTIMATE

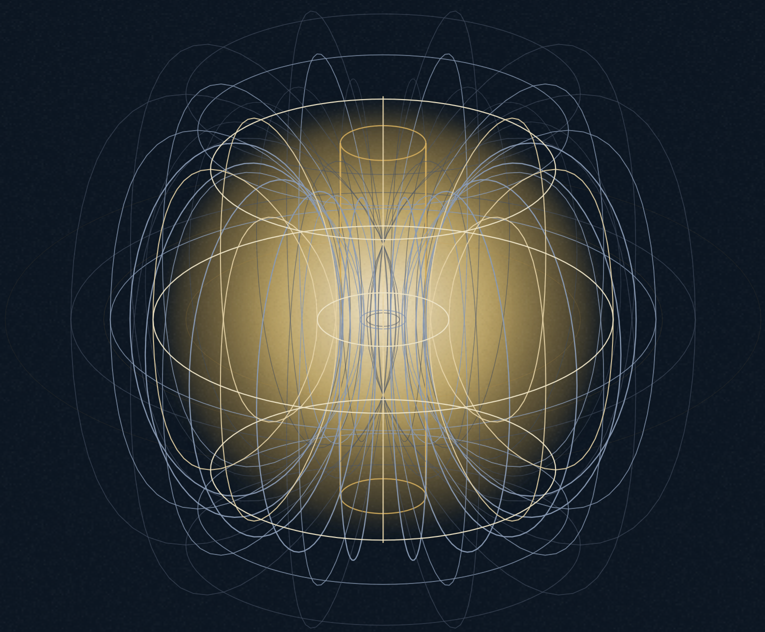
§ 4

Reporting the misses

We report every missed pre-registered target rather than reframing it. The physics-informed equilibrium network was intended to become a fast native solver and did not: it reached **1.4%** relative-L^2 error against a 1% goal. Keeping this negative in the record is part of the method. The contribution is a certifiable, resource-honest system and method for compact-fusion control — not new plasma physics. REPORTED, NOT REFRAMED

Part Two — The Companion Papers

KRONOS FUSION ENERGY



PAPER 2.1 OF THE 2026 KRONOS SET

The Consumable Centrepost

A Maintenance Line Item, Not a Barrier

The inboard centrepost’s finite life is handled as a scheduled-replacement cartridge, closed by four coupled analyses.

Coverage-vs-protection neutronics · FEA vs Lamé · fused quench · RAMI cadence

Explore it live — 3-D model · physics validator · film series

PREPARED BY P. I. FORD · R. J. WEGGEL · D. K. WEGGEL

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§ 1

The vulnerability, met head-on

A spherical tokamak buys its high beta and compactness with a slender inboard centrepost that no thick shield can protect without defeating the geometry. The honest response is not to claim a long-lived centrepost, but to make it a consumable and prove the maintenance architecture around it.

THE RESULT IN ONE LINE

The centrepost's finite life is converted from a materials-lifetime *barrier* into a scheduled-replacement *line item*, closed by four coupled analyses on the frozen design point.

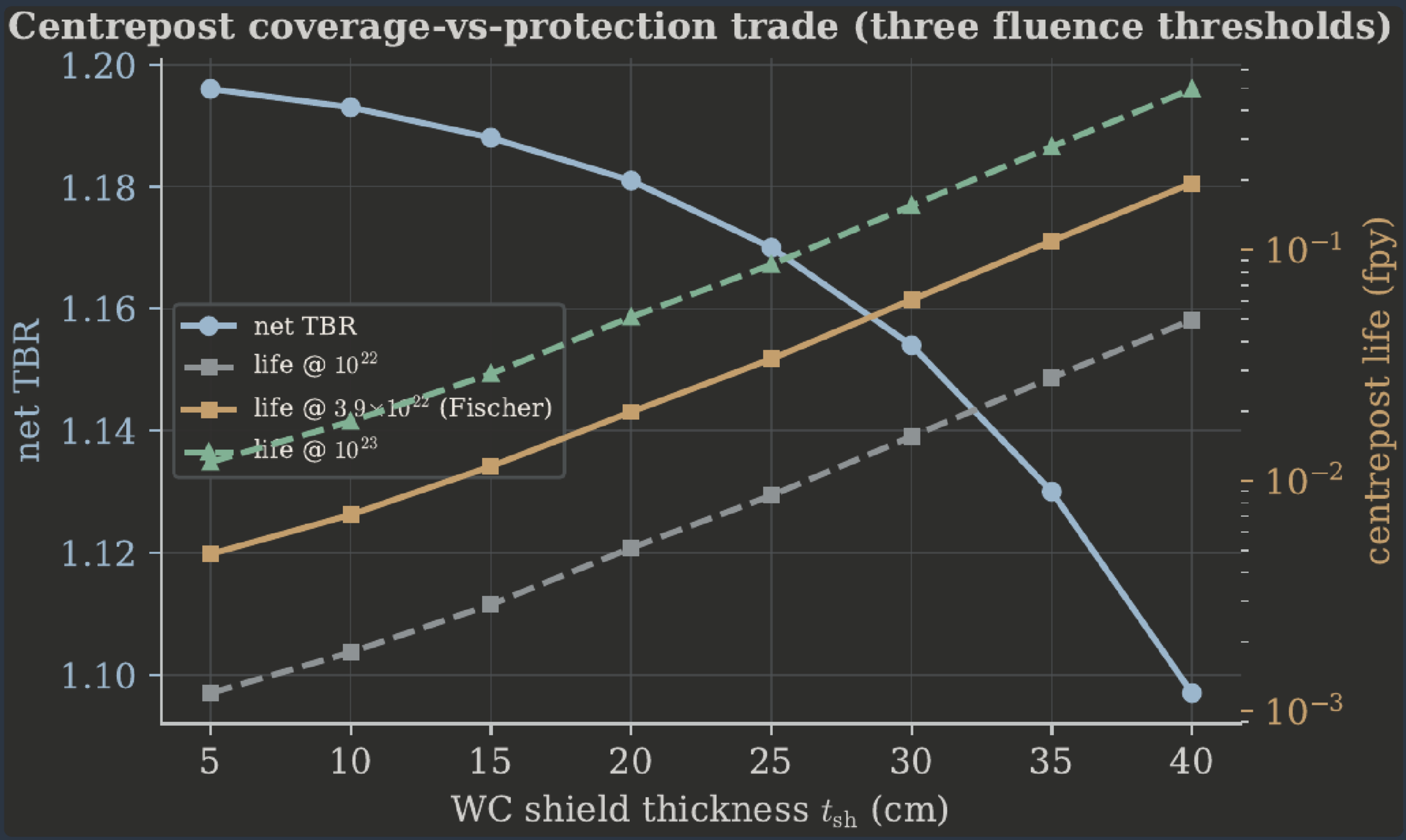


FIGURE 17. The coverage-versus-protection trade: shield thickness against breeding coverage and centrepost life. RECOMPUTED

§ 2

Four analyses, one architecture

The structural check confirms the coil stress against the analytic Lamé solution; the fused strain-rate-plus-magnetization detector catches a quench well ahead of the terminal voltage; and the reliability/maintainability model sets the cadence at which a cartridge swap keeps availability whole.

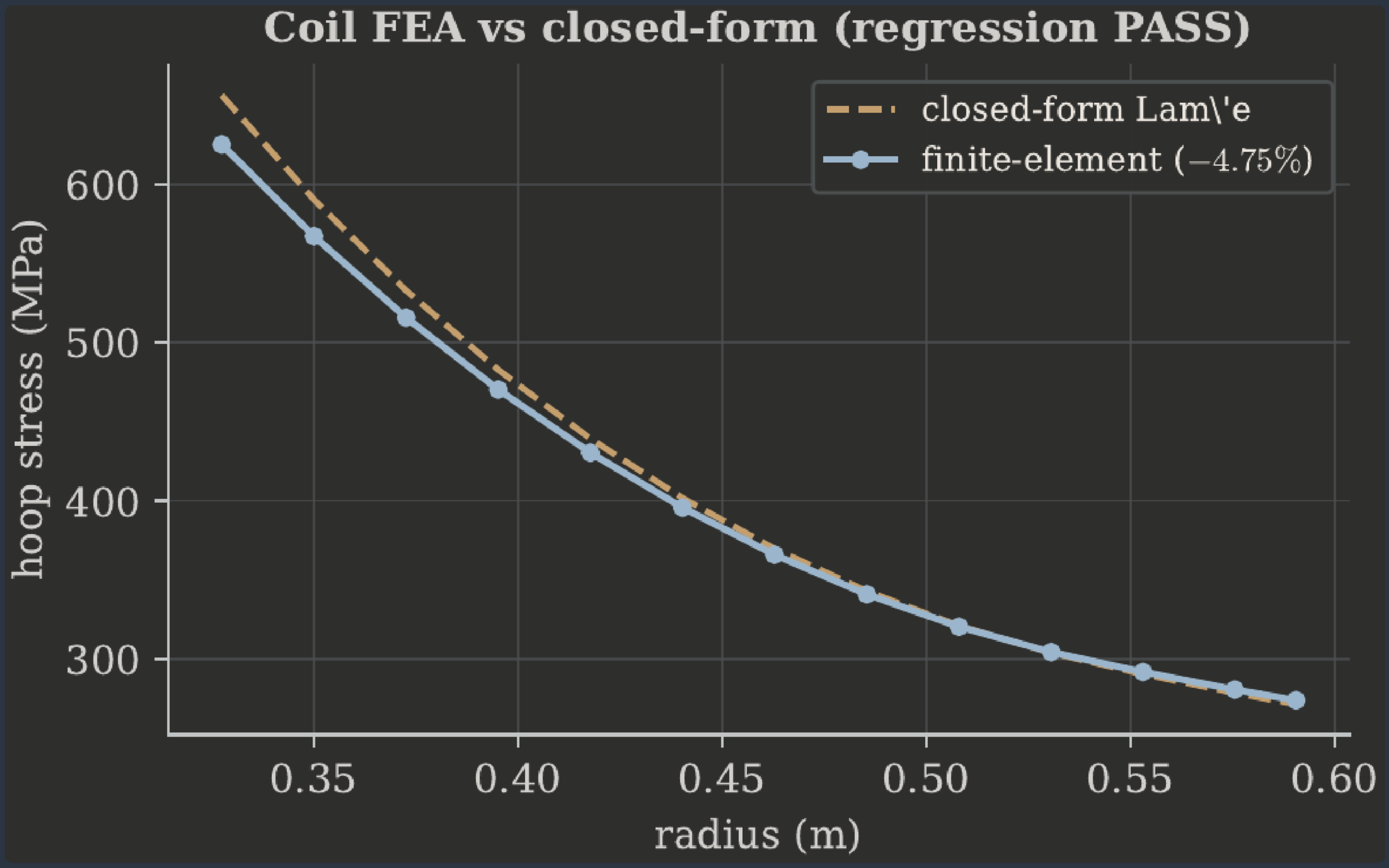


FIGURE 18. Coil structural finite-element stress against the analytic Lamé solution. RECOMPUTED

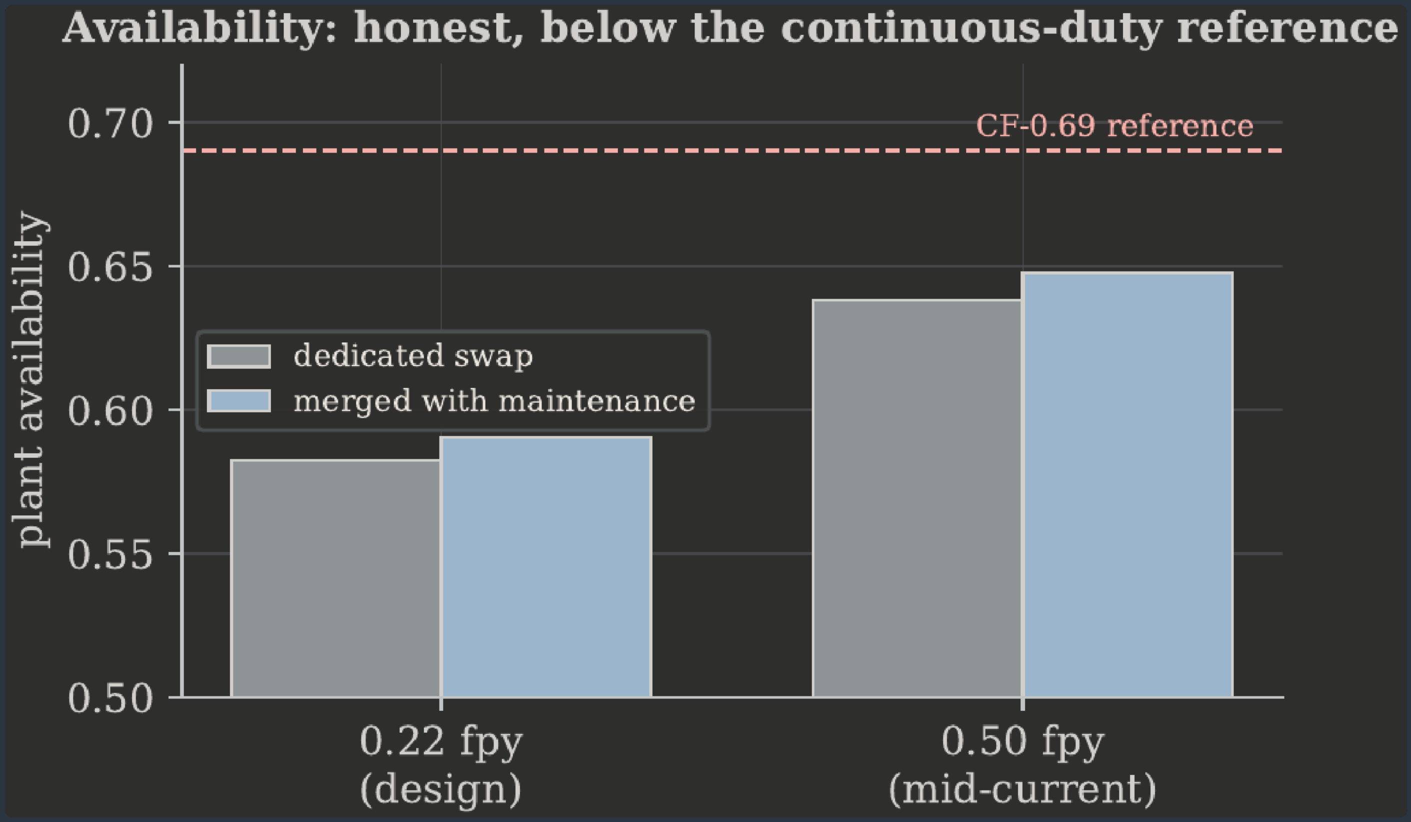
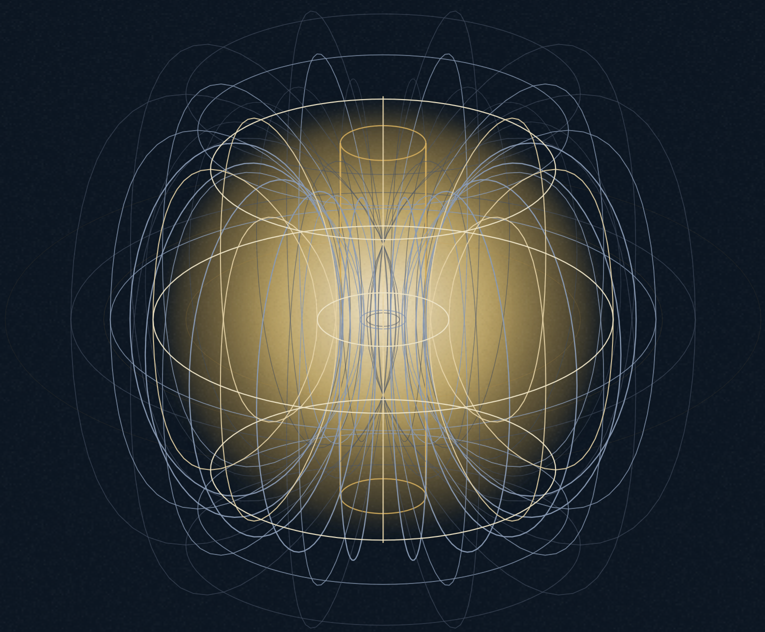


FIGURE 19. The maintenance-cadence / availability model that turns the swap into a scheduled line item. RECOMPUTED

KRONOS FUSION ENERGY



PAPER 2.2 OF THE 2026 KRONOS SET

The Blanket Breeding Lever

From 0.86 to the Confirmed Ceiling

The tritium breeding ratio is a design lever, not a fixed number — placed by 3-D neutronics that reproduce across nuclear-data libraries.

Net TBR 0.86 (bare) → solid-Be → 1.42 (advanced) · <0.3% cross-library

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Breeding is a lever, not a constant

A breeder's blanket must return more than one triton per fusion neutron, net of parasitic absorption and leakage. In a compact spherical tokamak the inboard coverage is capped by the centrepost, so the lever must be characterized honestly and its ceiling identified rather than assumed.

THE LEVER, PLACED

Net TBR rises from ~0.86 (bare lithium) through the low-1.1s (solid-beryllium multiplier) to 1.42 (advanced blanket) — the confirmed per-unit ceiling across twelve configurations, reproducing across ENDF/B-VIII.0 and FENDL-3.2 to under 0.3%.

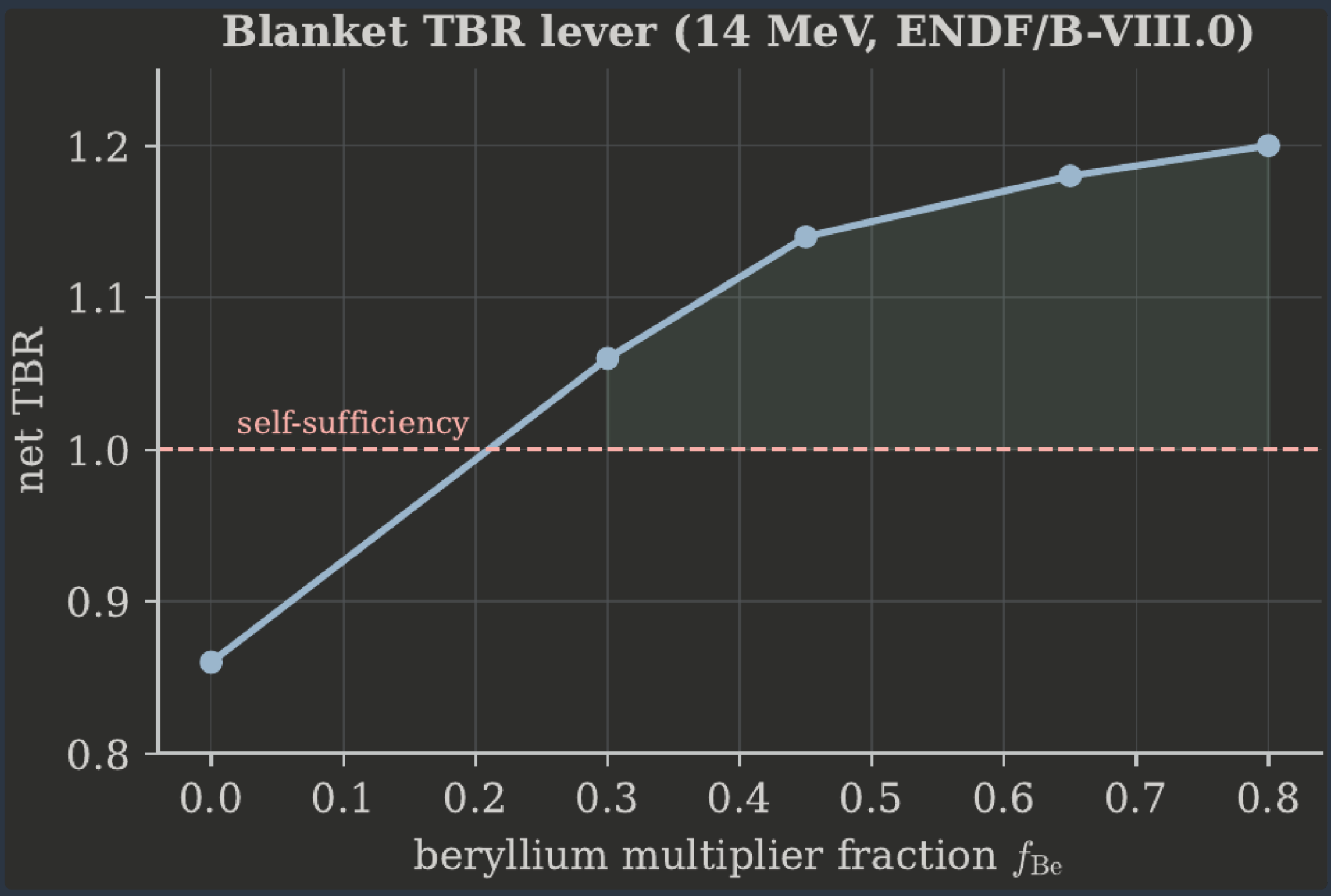
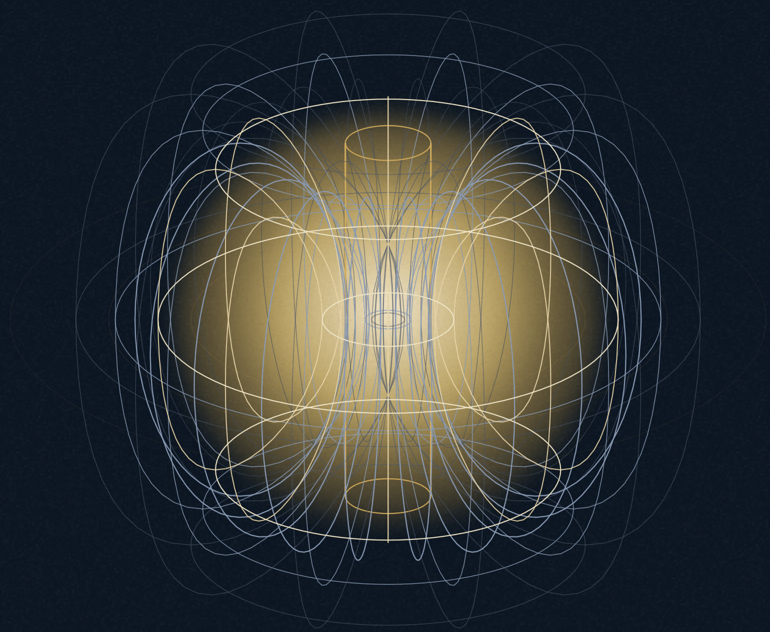


FIGURE 20. Net TBR versus beryllium-multiplier fraction: the lever crosses self-sufficiency and reaches the advanced-blanket ceiling. OPENMC / ENDF-B-VIII.0

KRONOS FUSION ENERGY



PAPER 2.3 OF THE 2026 KRONOS SET

Centrepost Fluence & Cartridge Life

Shielding Traded Against Coverage

Fast-neutron fluence, displacement damage, and cartridge life booked against a tungsten-carbide shield that trades directly with breeding coverage.

18.85 dpa/fpy · life tunable by shield · mid-current extends it

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The shield trade, quantified

The centrepost sits closest to the 14 MeV source and cannot be thickly shielded without growing the machine. Rather than argue this away, the design books the fluence and damage against the shield, and reads the cartridge interval off the result.

THE TRADE

The damage rate is 18.85 dpa/fpy at the design shield; a thin shield shortens the cartridge life and a thick shield lengthens it but displaces breeding blanket. The design point balances life against coverage rather than maximizing either.

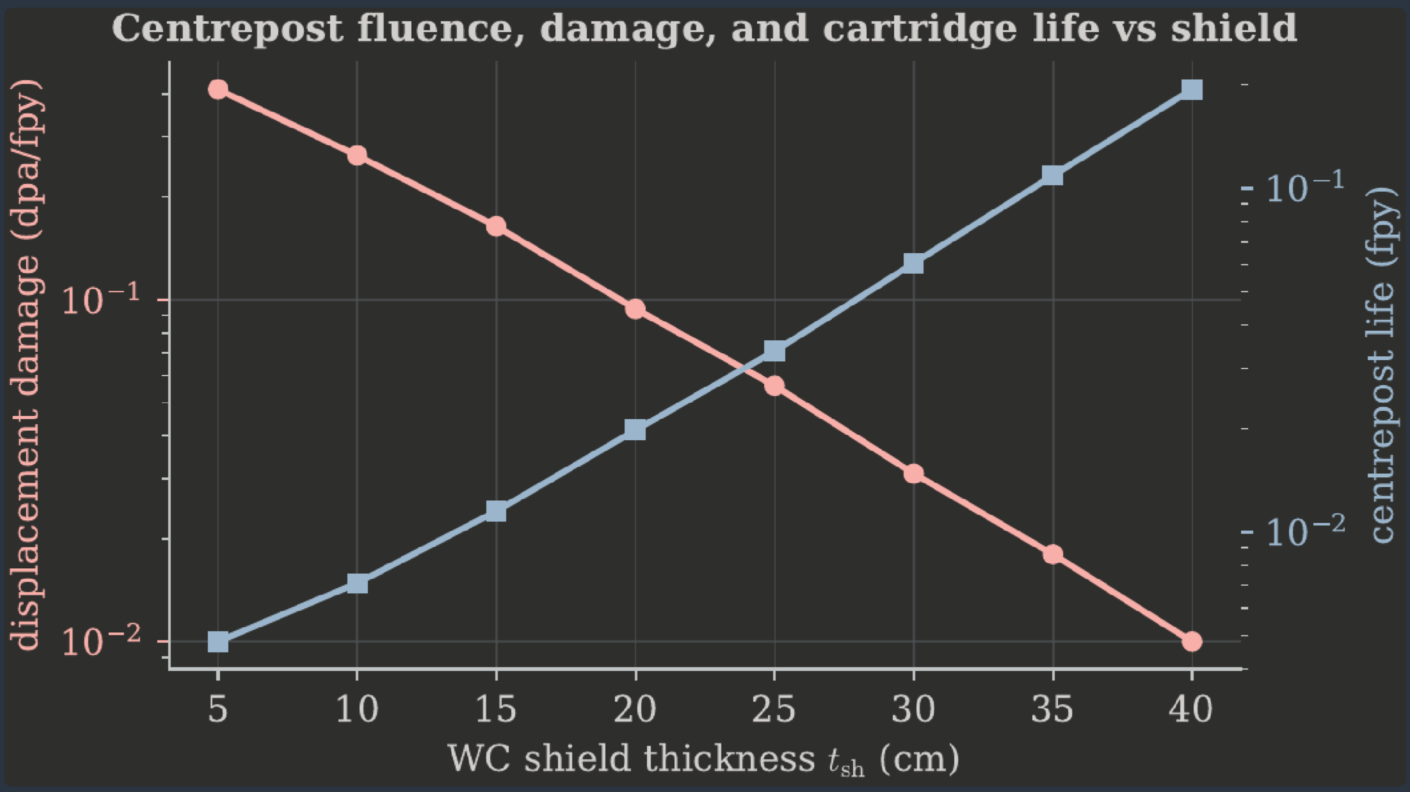
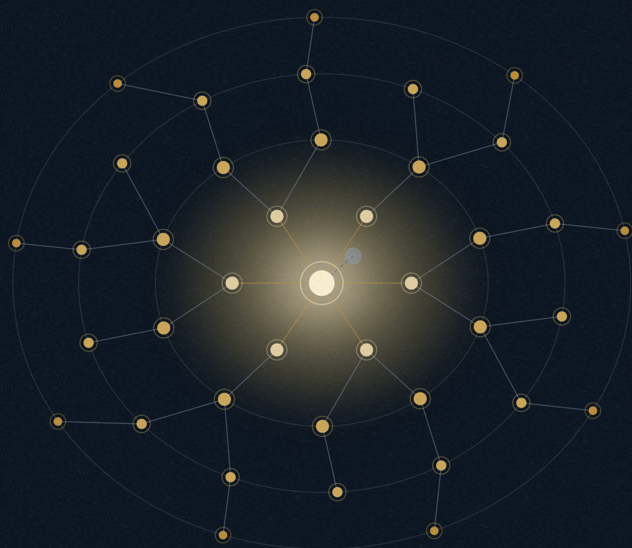


FIGURE 21. Centrepost damage rate and cartridge life versus tungsten-carbide shield thickness. RECOMPUTED

KRONOS FUSION ENERGY



PAPER 2.4 OF THE 2026 KRONOS SET

Verification & Validation

Frozen Anchors, Independently Reproduced

The V&V discipline behind the series: evidence-tagged frozen anchors regenerable from deposited code, and a load-bearing result reproduced across independent nuclear data.

Frozen anchors · two-tier reproducibility · TBR reproduces <0.3% cross-library

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Numbers you can check, not trust

A design series is only as credible as its weakest unverifiable number. The discipline here is that every headline quantity is a frozen anchor with an evidence class, regenerable from named, deposited code — so a reader can reproduce it rather than take it on faith.

THE LOAD-BEARING CHECK

The breeding ratio — the number the whole breeder case rests on — reproduces across two independent nuclear-data evaluations to under 0.3%. The result is a property of the geometry and cross-sections, not of one code path.

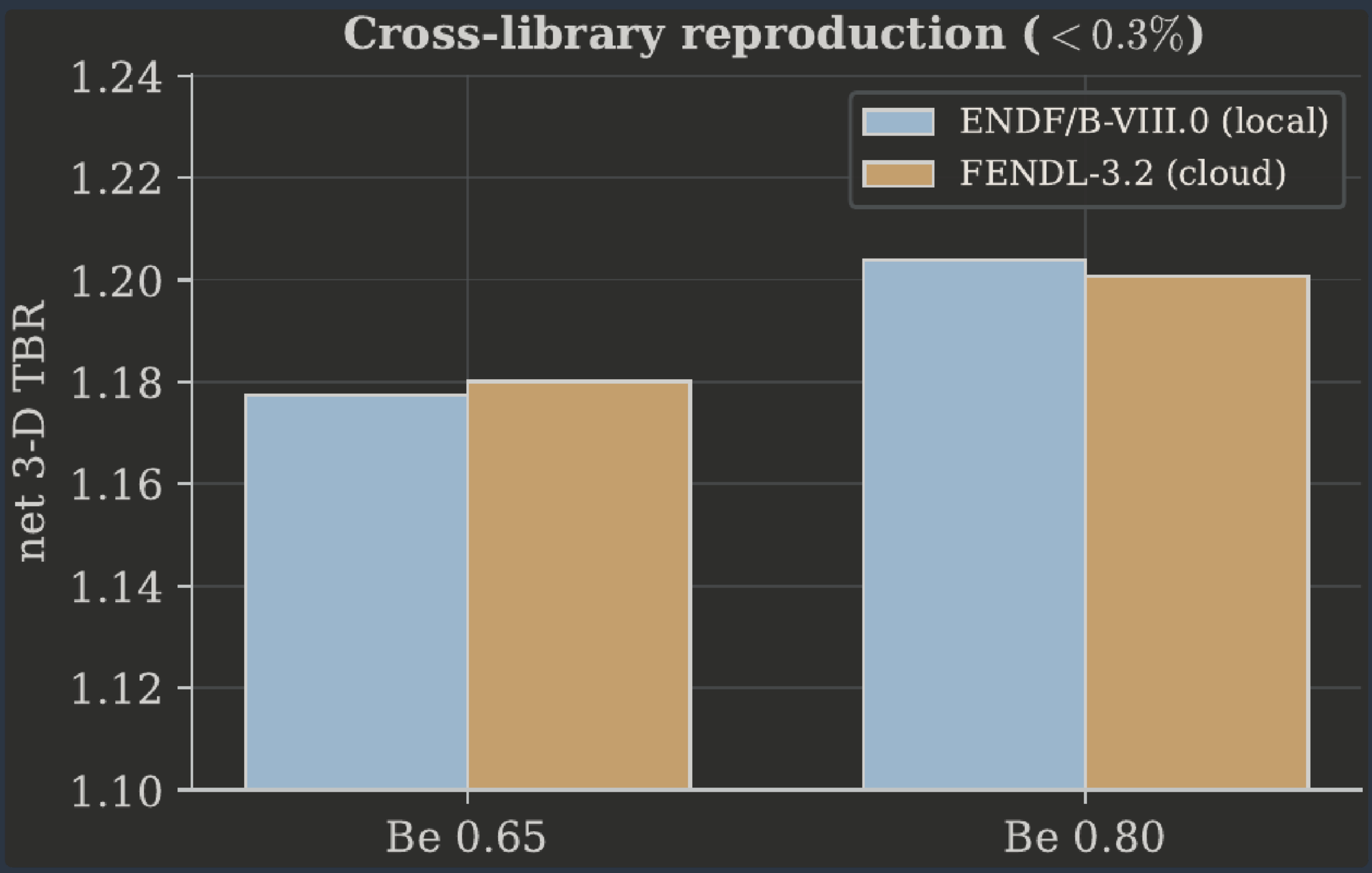
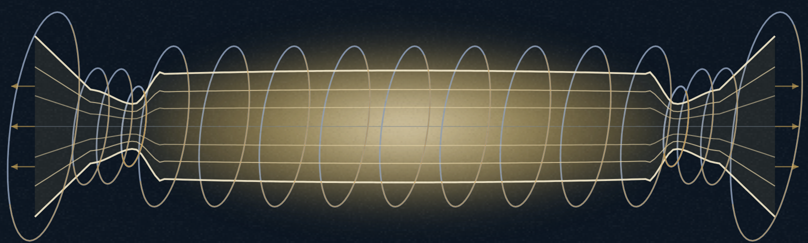


FIGURE 22. The load-bearing TBR reproduced across independent nuclear-data libraries to under 0.3%. CROSS-LIBRARY

KRONOS FUSION ENERGY



PAPER 2.5 OF THE 2026 KRONOS SET

RF Alpha-Channeling

A Bounded Power Lever

Resonant waves that hand fast-ion energy to the fuel while expelling the ash — booked as a bounded lever, not a closure mechanism.

Recoverable fraction ~8% → ~80% · eases the plug-gated power balance

Explore it live — 3-D model · physics validator · film series

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A loss turned into a gain

The advanced-fuel mirror's charged products are a resource, not just a loss. If their energy can be redirected into the fuel ions rather than lost as heat through the loss cone, the recirculating power the mirror must supply falls, and the net electric gain rises.

THE LEVER

A mode-converted channeling wave raises the recoverable charged fraction from ~8% (collisional baseline) to ~80% in the worked embodiment — a bounded upside that eases the power balance without being what makes the machine close.

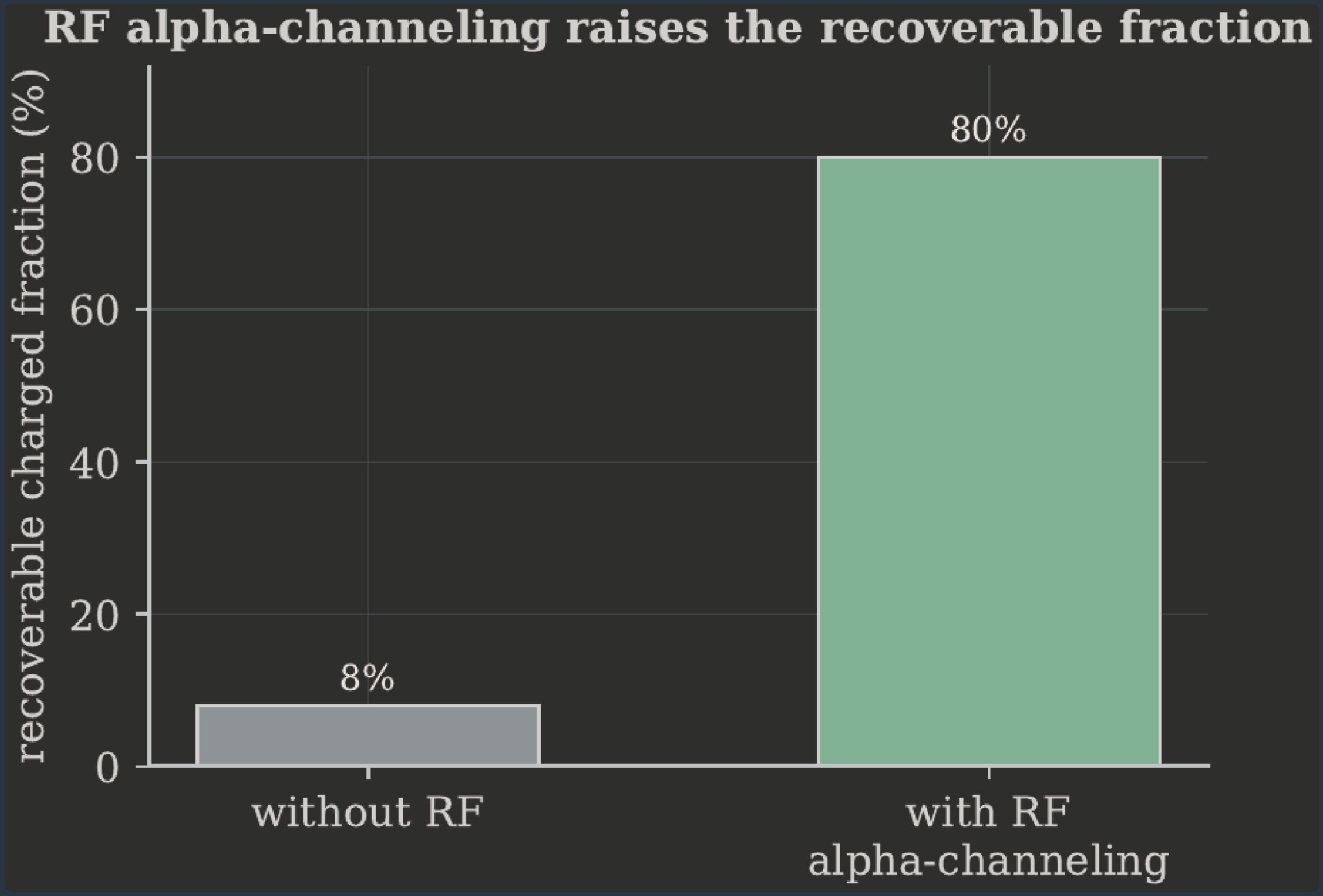
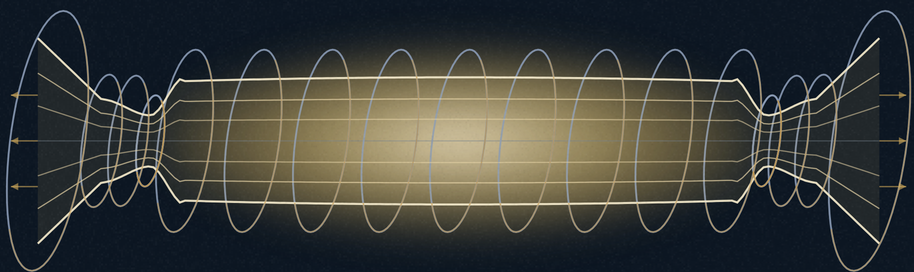


FIGURE 23. RF alpha-channeling raises the recoverable charged fraction from ~8% to ~80% in the worked embodiment. MODEL OUTPUT

KRONOS FUSION ENERGY



PAPER 2.6 OF THE 2026 KRONOS SET

Loss-Cone Microstability

On the Stabilization Knee

The drift-cyclotron loss-cone microstability of the tandem-mirror plug, mapped to its exact marginal boundary — marginal but bounded.

Flute-mode dispersion · warm-ion fill on the knee · weak residual mode

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Marginal, and honest about it

The end plug lives or dies on its microstability. Rather than assert a comfortable margin, the paper maps the exact marginal-stability boundary and places the design point on it — on the knee, cleared only for sufficiently broad edge gradients.

WHERE THE DESIGN SITS

On the stabilization knee: DCLC is cleared for broad plug-edge gradients, with a weak residual cyclotron mode carried openly. Marginal but bounded and quantified, not claimed comfortable.

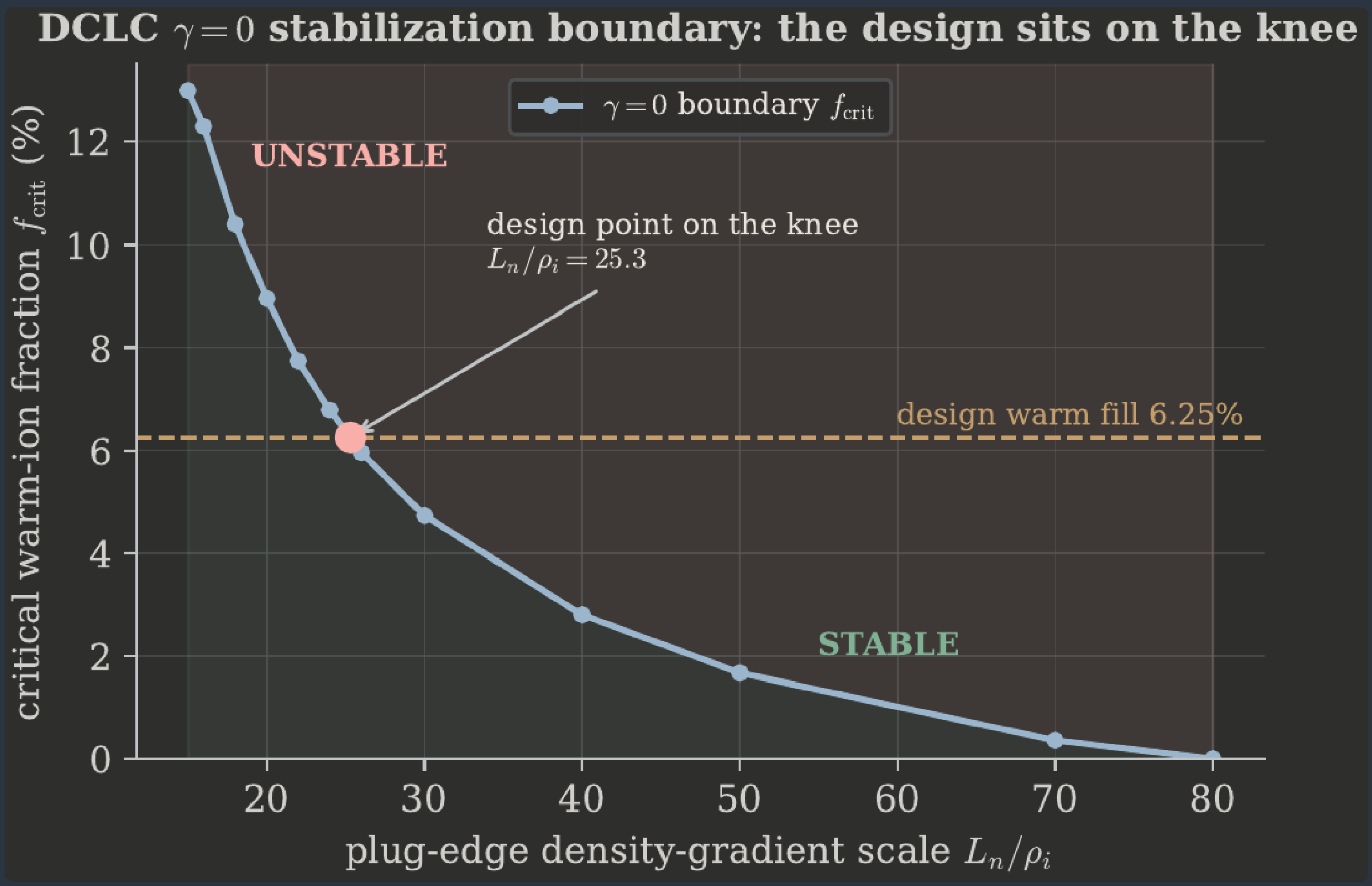


FIGURE 24. The marginal-stability boundary: the warm-ion fill sits on the stabilization knee. RECOMPUTED

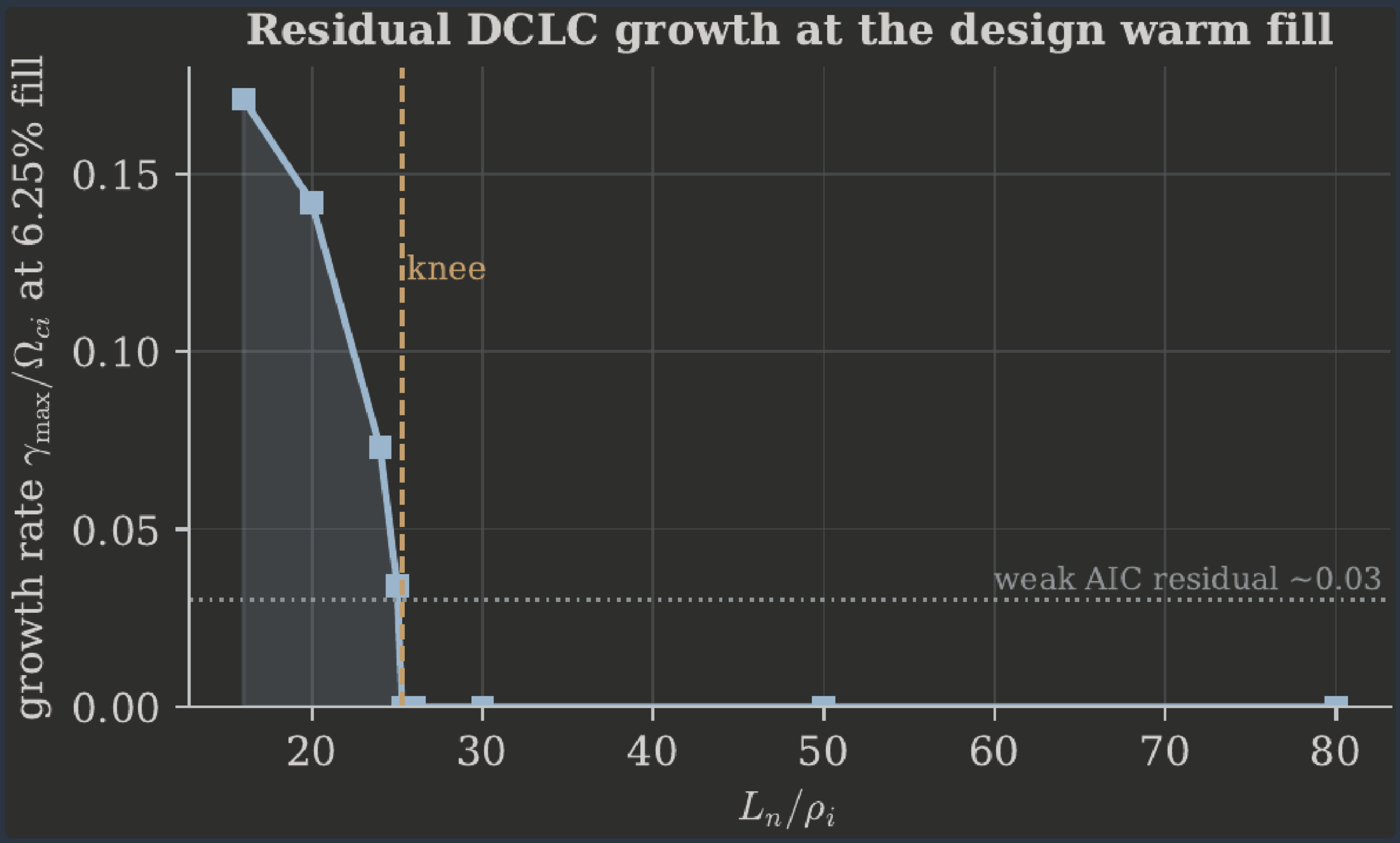
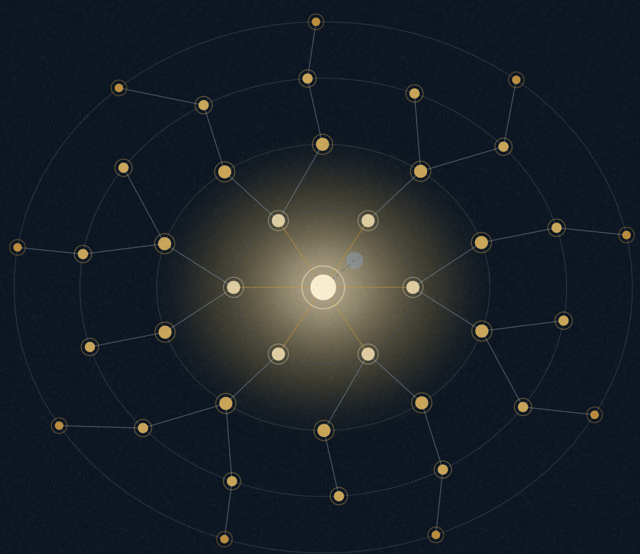


FIGURE 25. Residual mode growth: weak and bounded across the plug-edge gradient range. RECOMPUTED

KRONOS FUSION ENERGY



PAPER 2.7 OF THE 2026 KRONOS SET

The Safety Clamp

A Provable Zero-Escape Guarantee

A control-barrier-certified safety filter that wraps any controller with a provable zero-escape guarantee on the operating envelope.

0/5000 escapes clamped vs 5000/5000 · analytic proof

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Performance inside a proof

A learned or optimization-based controller cannot be allowed to drive a nuclear-regulated machine out of its safe envelope. The clamp guarantees it cannot: a control-barrier filter with a closed-form solution wraps any controller and enforces forward invariance of the safe set.

THE GUARANTEE

0 of 5000 trajectories escape the safe set with the clamp, against 5000 of 5000 without it — backed by an analytic forward-invariance proof, not a training score. Scope is stated openly: the reduced-order model and a declared disturbance bound.

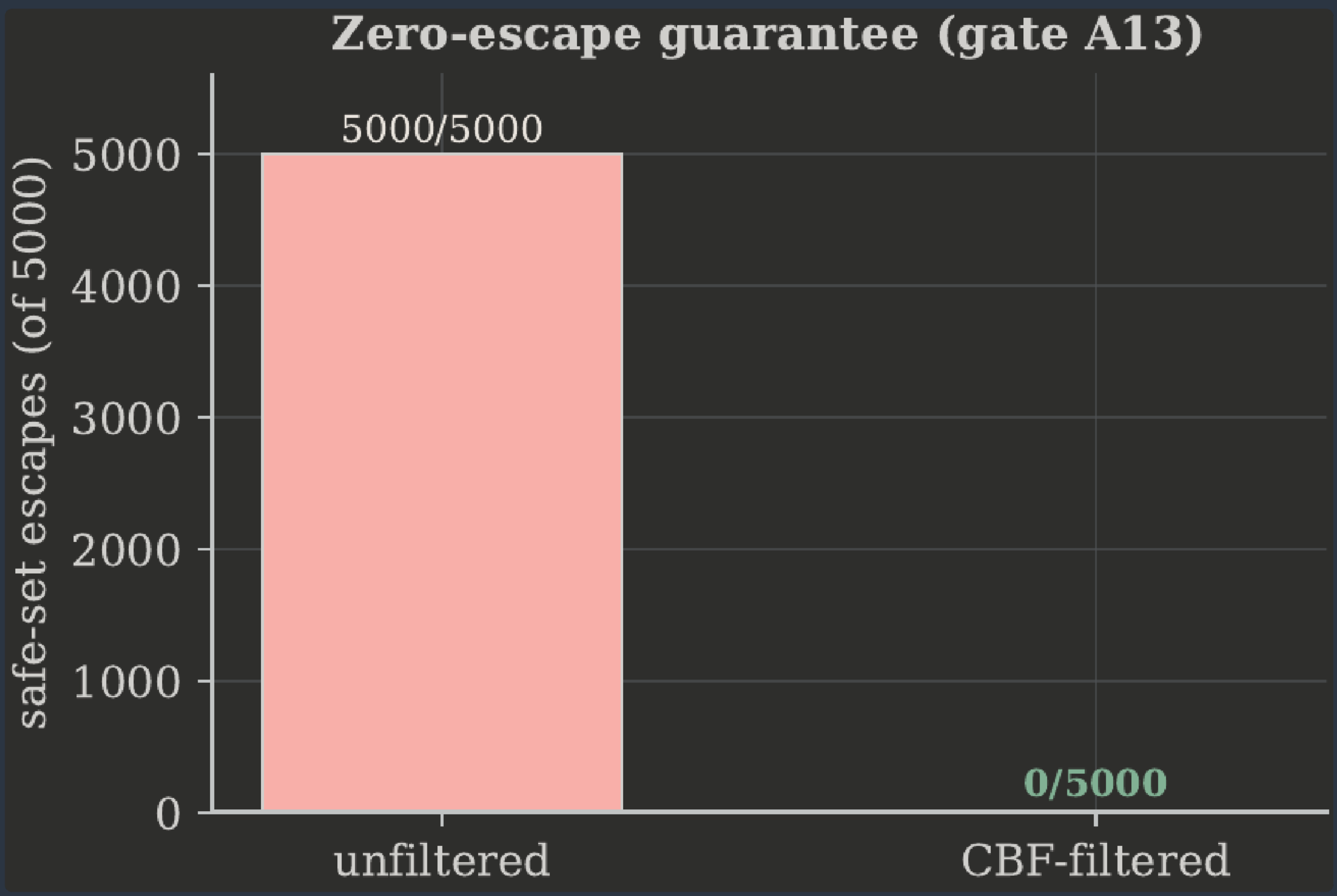


FIGURE 26. Safe-set escapes with and without the clamp over 5000 Monte-Carlo trajectories. MONTE-CARLO

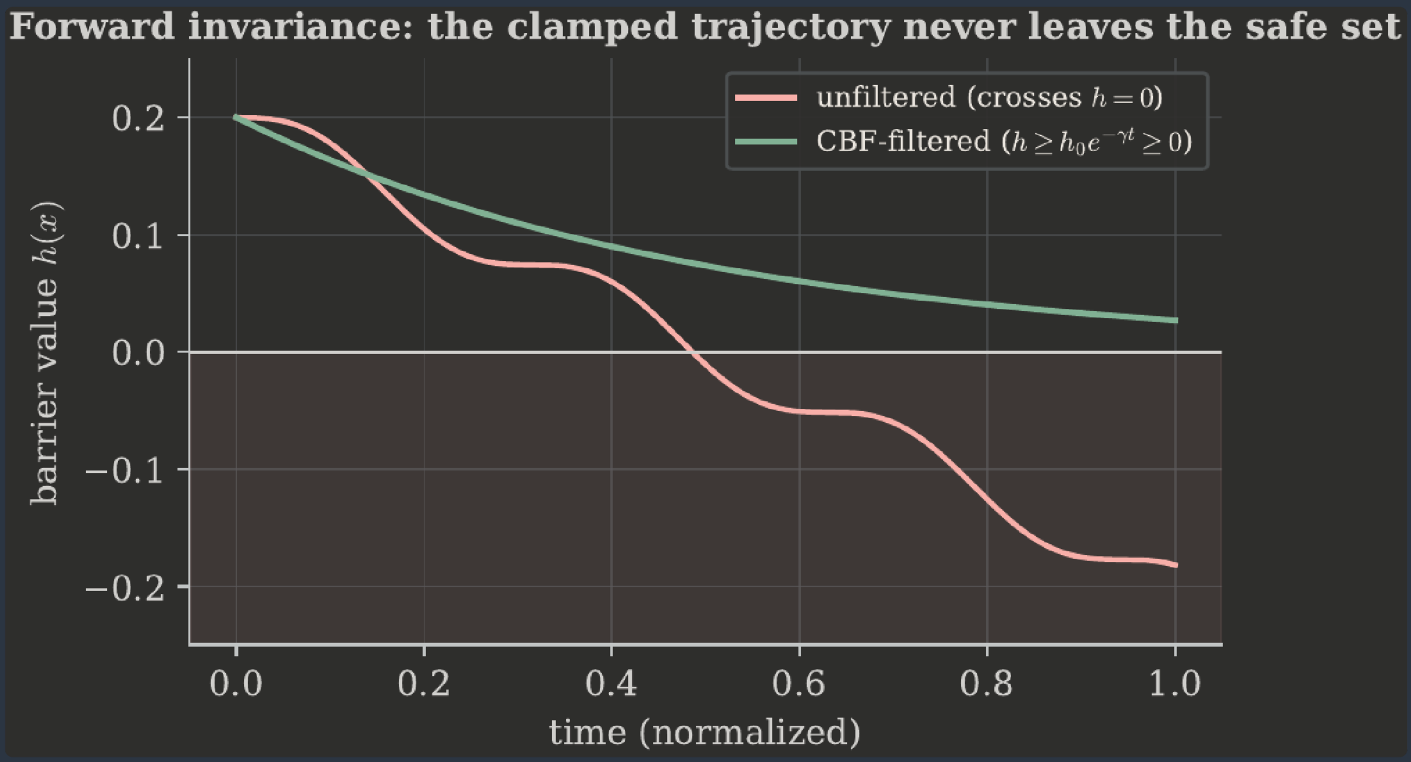
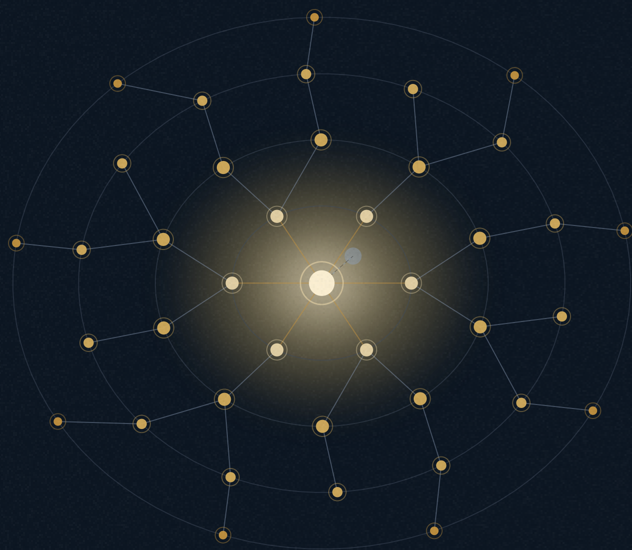


FIGURE 27. The control-barrier filter: forward invariance of the safe set, in closed form. RECOMPUTED

KRONOS FUSION ENERGY



PAPER 2.8 OF THE 2026 KRONOS SET

Quantum Computing for Fusion

With Honest Resource Estimates

Quantum simulation of fusion kinetics and materials — and a resource frontier that says plainly where the crossover is not.

Landau on 5 qubits · VQE chemical accuracy · no crossover this decade

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§ 1

What quantum can do — and can't, yet

Quantum computing is often invoked for fusion without a resource budget. Here it comes with one. Landau damping reproduces on a small circuit and variational chemistry reaches chemical accuracy on the alloy fragments — genuine, but far from the problem that would move the machine.

THE HONEST FRONTIER

The linear kinetic operator is an early-fault-tolerant target (11-19 logical qubits); the nonlinear gyrokinetic problem that would most help is fault-tolerant-horizon. Noisy hardware shows no advantage today — the classical baseline is cheaper at every demonstrated scale.

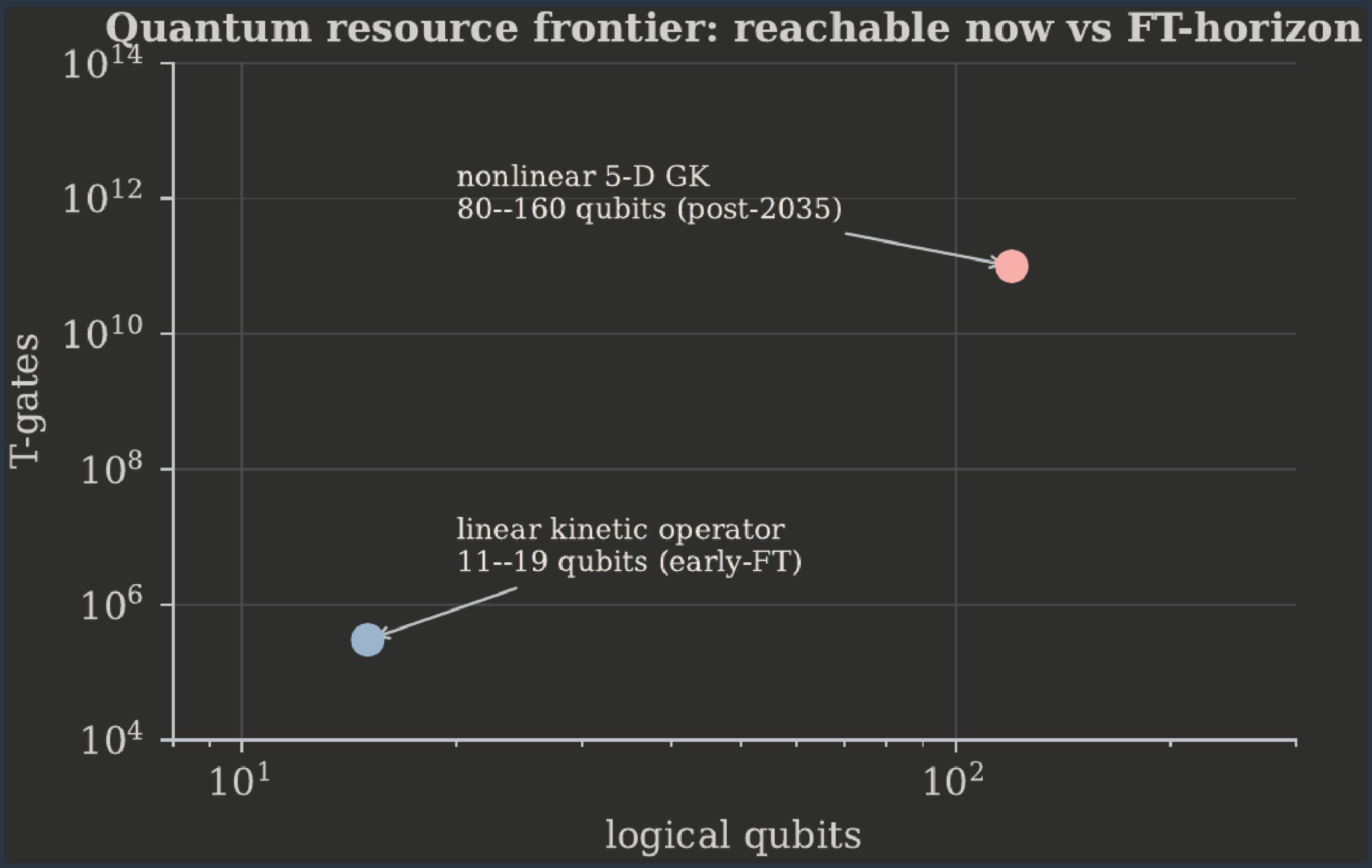

FIGURE 28. The quantum resource frontier: tractable linear operator versus fault-tolerant-horizon gyrokinetics. RESOURCE ESTIMATE

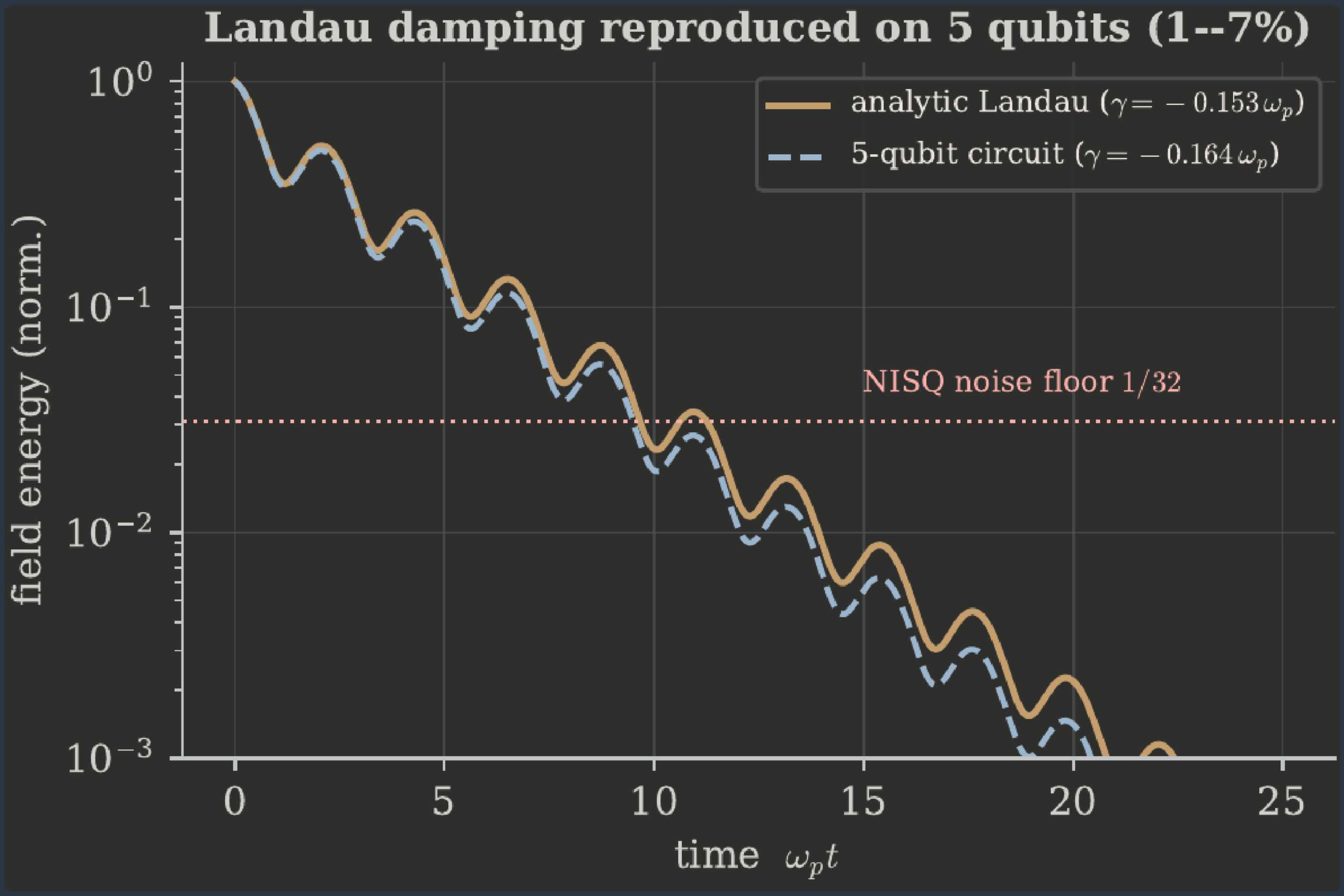

FIGURE 29. Landau damping reproduced on a 5-qubit Hamiltonian-simulation circuit. RECOMPUTED

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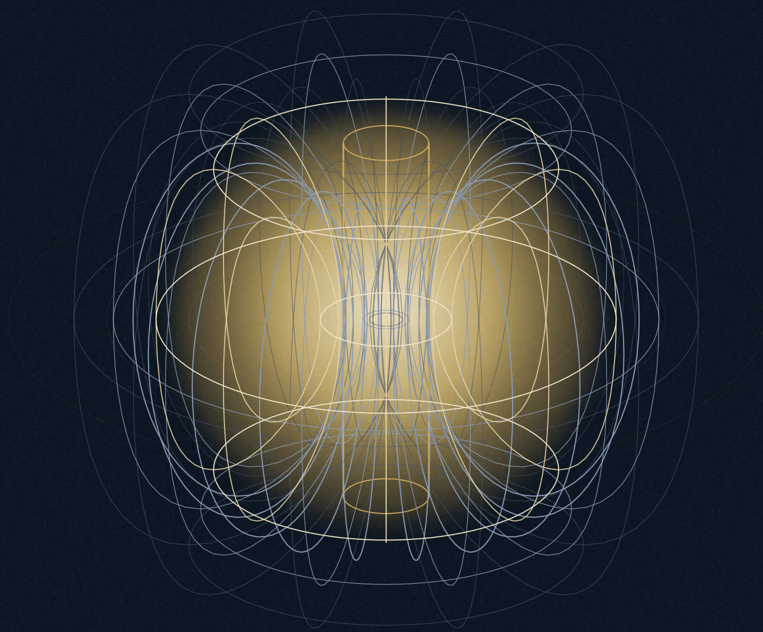

PAPER 2.9 OF THE 2026 KRONOS SET

Red-Teaming the Gates

Attacking the Binding Constraints

A reduced-order red-team of the binding gates — for each honest negative, alternatives brainstormed, bounded, ranked, and only the promising ones promoted.

Current-drive burden −58% · tritium closure restored · plug attacked

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§ 1

Attack your own gates first

The most valuable thing a design team can do is red-team its own binding constraints before a reviewer does. For each honest negative in the platform, this paper brainstorms alternatives, bounds them, ranks them, and promotes only the promising ones — screening bounds, explicitly not banked results.

WHAT THE RED-TEAM FOUND

The current-drive burden falls 58% below fusion power inside unused pressure headroom; tritium closure is restored independent of the multiplier; and the burner plug-density gate is attacked by a thermal barrier and a centrifugal architecture. Directions, ranked — not claimed closed.

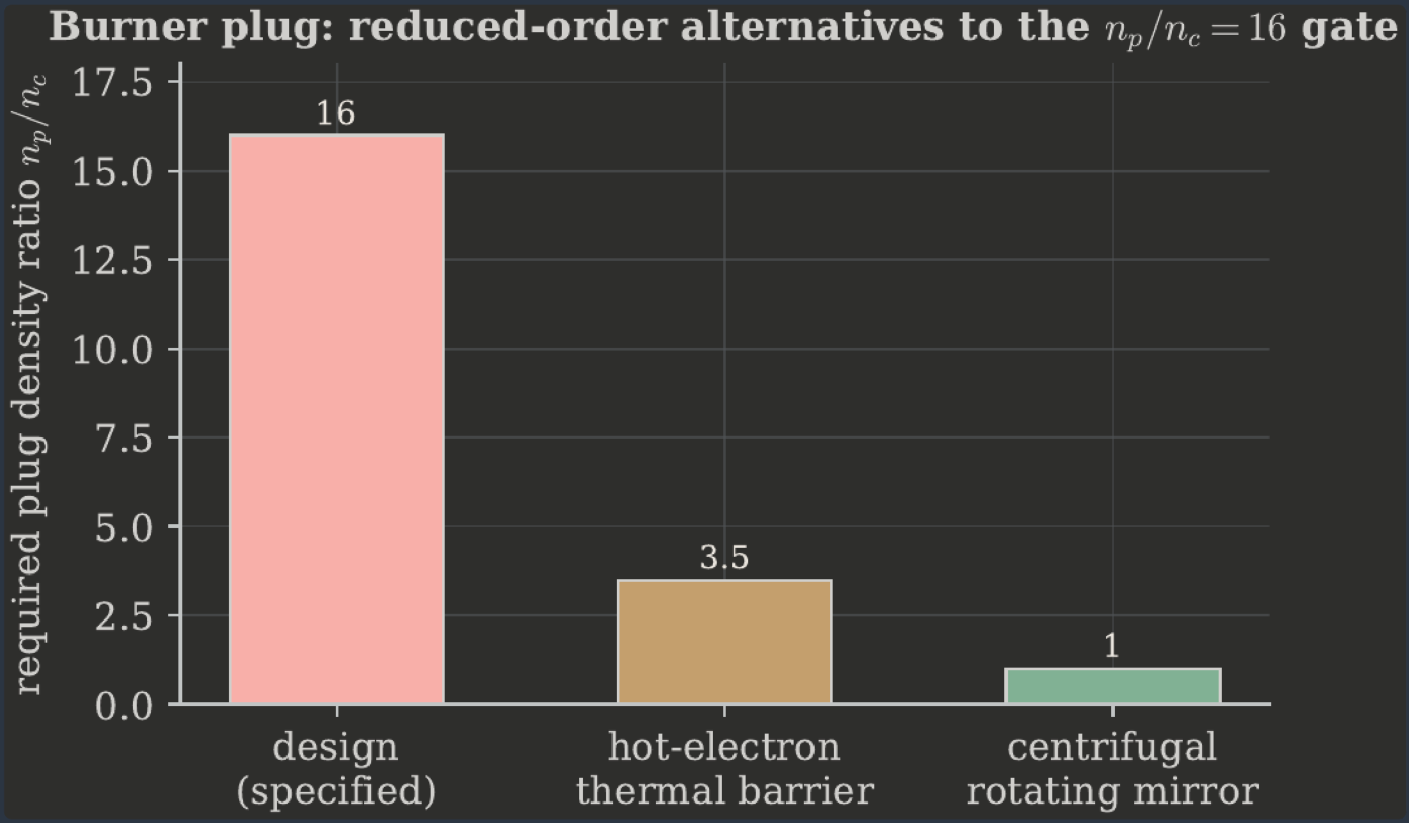


FIGURE 30. Ranked alternatives for the burner plug-density gate: thermal-barrier and centrifugal architectures. SCREENING BOUNDS

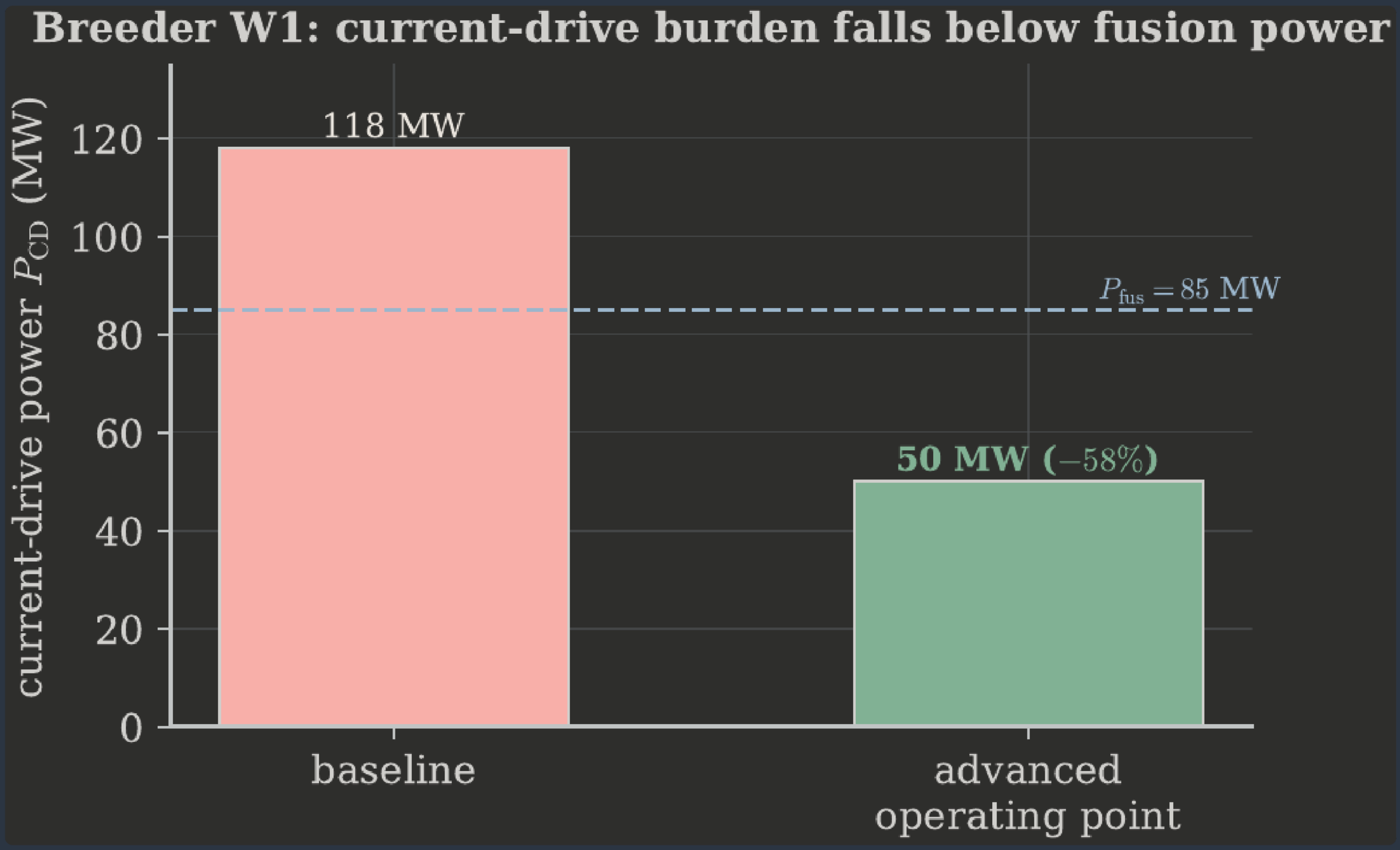
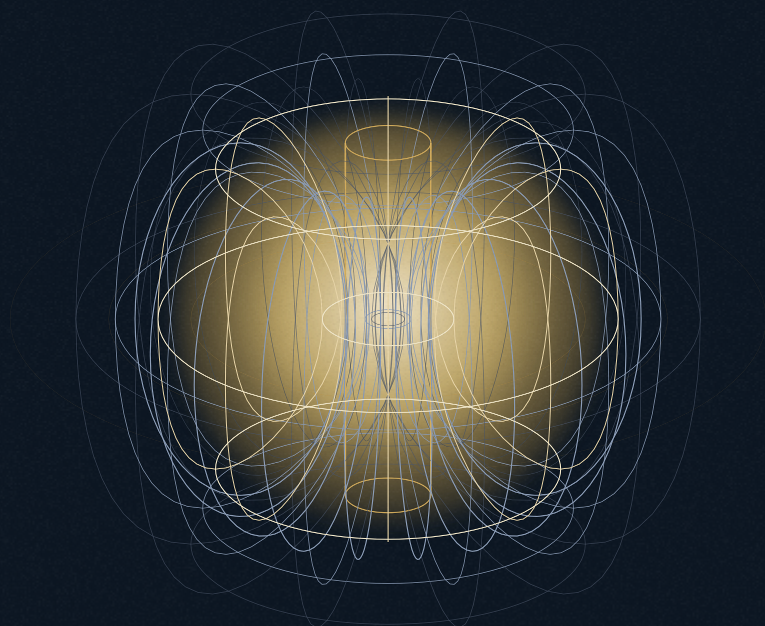


FIGURE 31. The current-drive relief lever inside unused pressure headroom. RECOMPUTED

KRONOS FUSION ENERGY



PAPER 2.11 OF THE 2026 KRONOS SET

Negative-Triangularity Confinement

A Quiet, Subcritical Core

Nonlinear gyrokinetics at the frozen negative-triangularity point — turbulence cut at both scales, corroborated against TCV and DIII-D.

Ion transport −40–45% · ETG −79–80% · quiet subcritical

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§ 1

The confinement lever, at both scales

Negative triangularity is the breeder's confinement lever, and the claim is established where it counts: nonlinear gyrokinetics at both the ion and electron scale, not a reduced-order scaling.

WHAT THE TURBULENCE DOES

Negative triangularity cuts ion-scale transport by 40–45% and electron-scale ETG by 79–80% versus a positive-triangularity twin, leaving the operating point quiet and subcritical — corroborated against TCV and DIII-D.

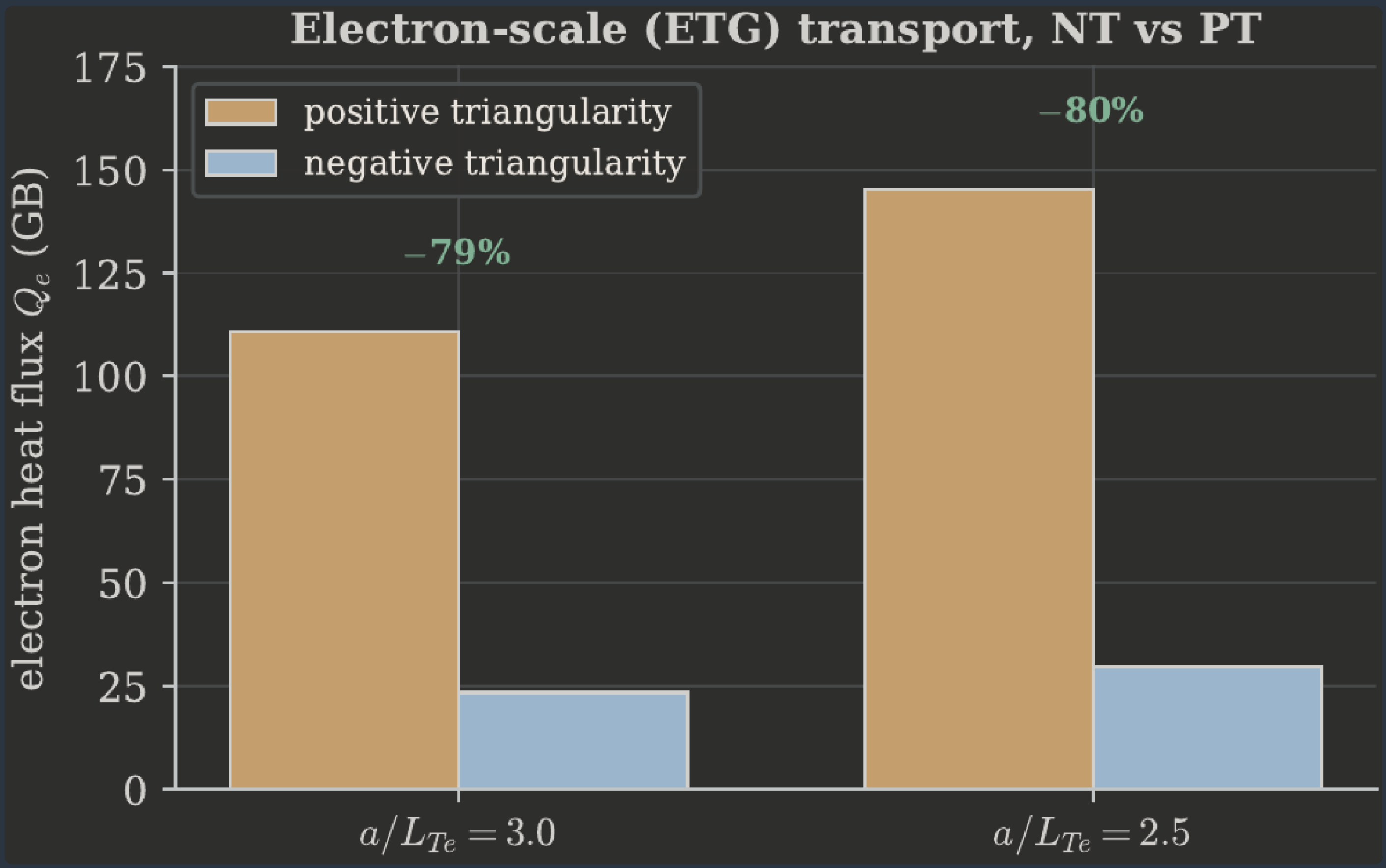
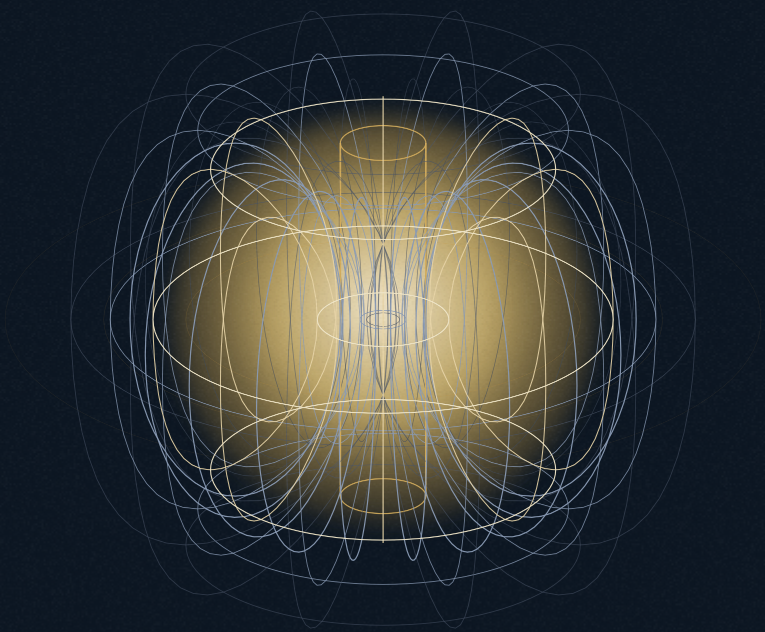


FIGURE 32. Turbulent transport suppression at the electron scale under negative triangularity. NONLINEAR CGYRO

KRONOS FUSION ENERGY



PAPER 2.12 OF THE 2026 KRONOS SET

Disruptions & Runaway Electrons

A Hard Requirement, Not a Footnote

A reduced-order assessment on a verified equilibrium — the runaway risk is severe, and the mitigation requirement is stated as a requirement.

τ_{CQ} 7-19 ms · RE avalanche SEVERE · halo 35% I_p · SPI required

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Naming the worst case

A credible design names its worst case rather than assuming it away. On a verified equilibrium, the disruption picture is demanding: a fast current quench, a severe runaway-electron avalanche, and a substantial halo current.

THE REQUIREMENT

The runaway avalanche is severe and the halo current reaches 35% of plasma current, so the conclusion is a hard requirement — shattered-pellet-class mitigation triggered inside the current-quench window — not a hope that the risk is small.

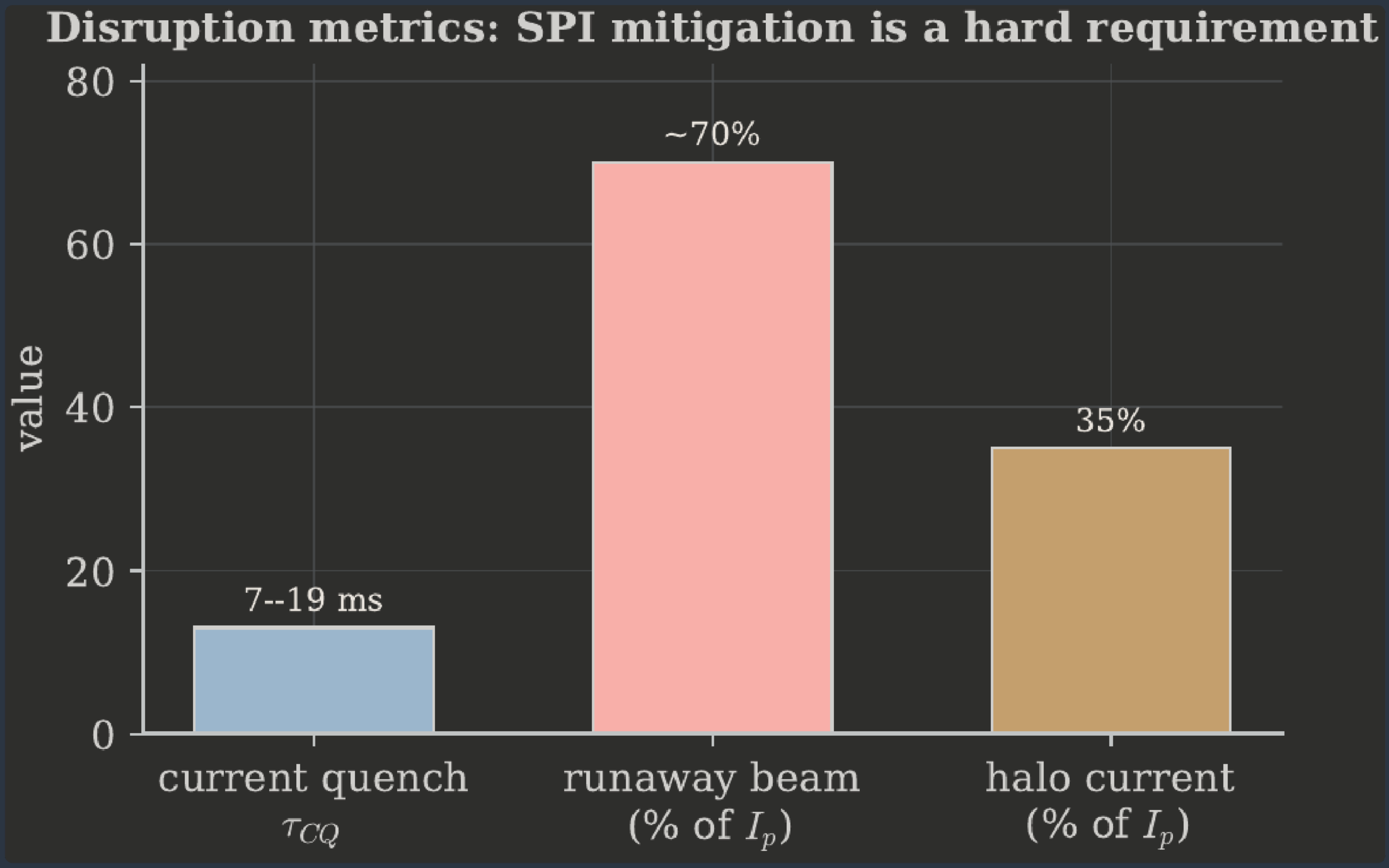
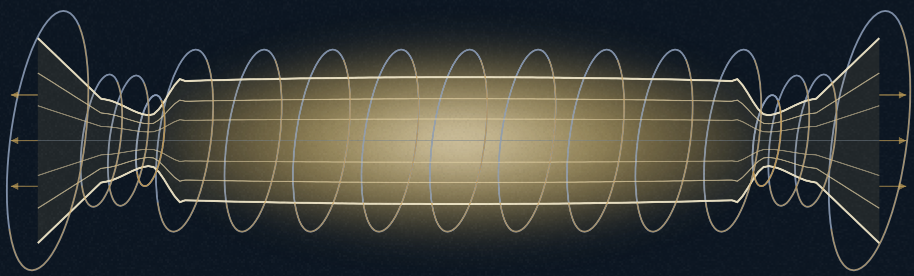


FIGURE 33. Current-quench, runaway-electron, and halo-current loads driving the mitigation requirement. NIMROD-VERIFIED

KRONOS FUSION ENERGY



PAPER 2.13 OF THE 2026 KRONOS SET

Fast-Product Confinement

Where the Charged Power Goes

Fast-alpha and fusion-product confinement in the tandem-mirror burner — the ash accumulation and axial power the conversion train must handle.

Mirror-trapped products · loss-cone dynamics · ash + axial power

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§ 1

The charged products, tracked

In a mirror the fusion products are trapped and their fate is set by loss-cone dynamics. Tracking them is what tells the conversion train how much ash accumulates and how much axial power it must recover.

WHY IT MATTERS

The confinement of the fast products sets both the ash the machine must exhaust and the directed axial power the direct-energy-conversion and alpha-channeling systems recover — the input to the whole power balance.

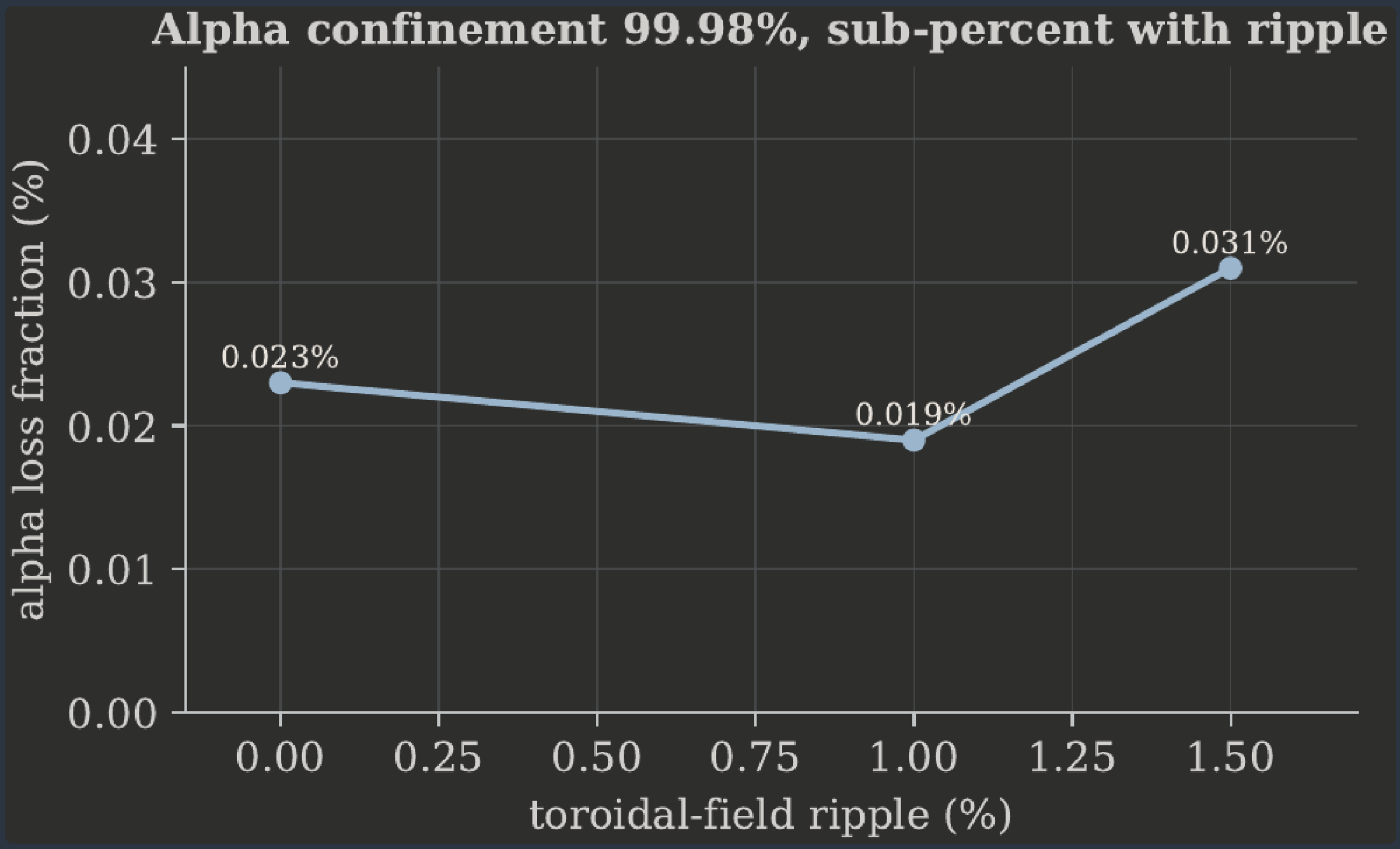
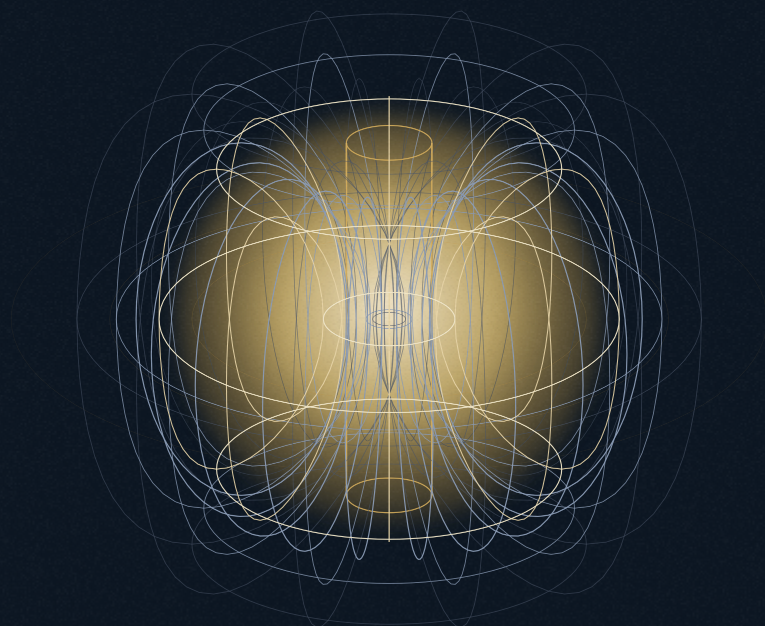


FIGURE 34. Fast-product confinement and the axial power it delivers to the conversion train. RECOMPUTED

KRONOS FUSION ENERGY



PAPER 2.14 OF THE 2026 KRONOS SET

The Helium-3 Fuel Cycle

A Co-Product, Honestly Gated

Helium-3 bred as a co-product of surplus-tritium decay — strategic, distinct from bulk fuel, and lunar-gated at fleet scale.

Co-product of T decay · ~192/105/45 breeders/burner · lunar-gated 2038–40

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§ 1

Strategic value is not fuel supply

Helium-3 links the two machines but does not close between them, and the paper is careful to say so. The breeder's helium-3 is a co-product of the tritium inventory's decay — strategically valuable, but not a bulk fuel source for a burner fleet.

THE HONEST GATE

The tritium half-life makes decay-sourced helium-3 far too slow to fuel a fleet (~192/105/45 breeders per burner), so burner-scale supply is lunar-gated around 2038–40. The breeder's helium-3 is strategic co-product value, distinct from fuel and from revenue.

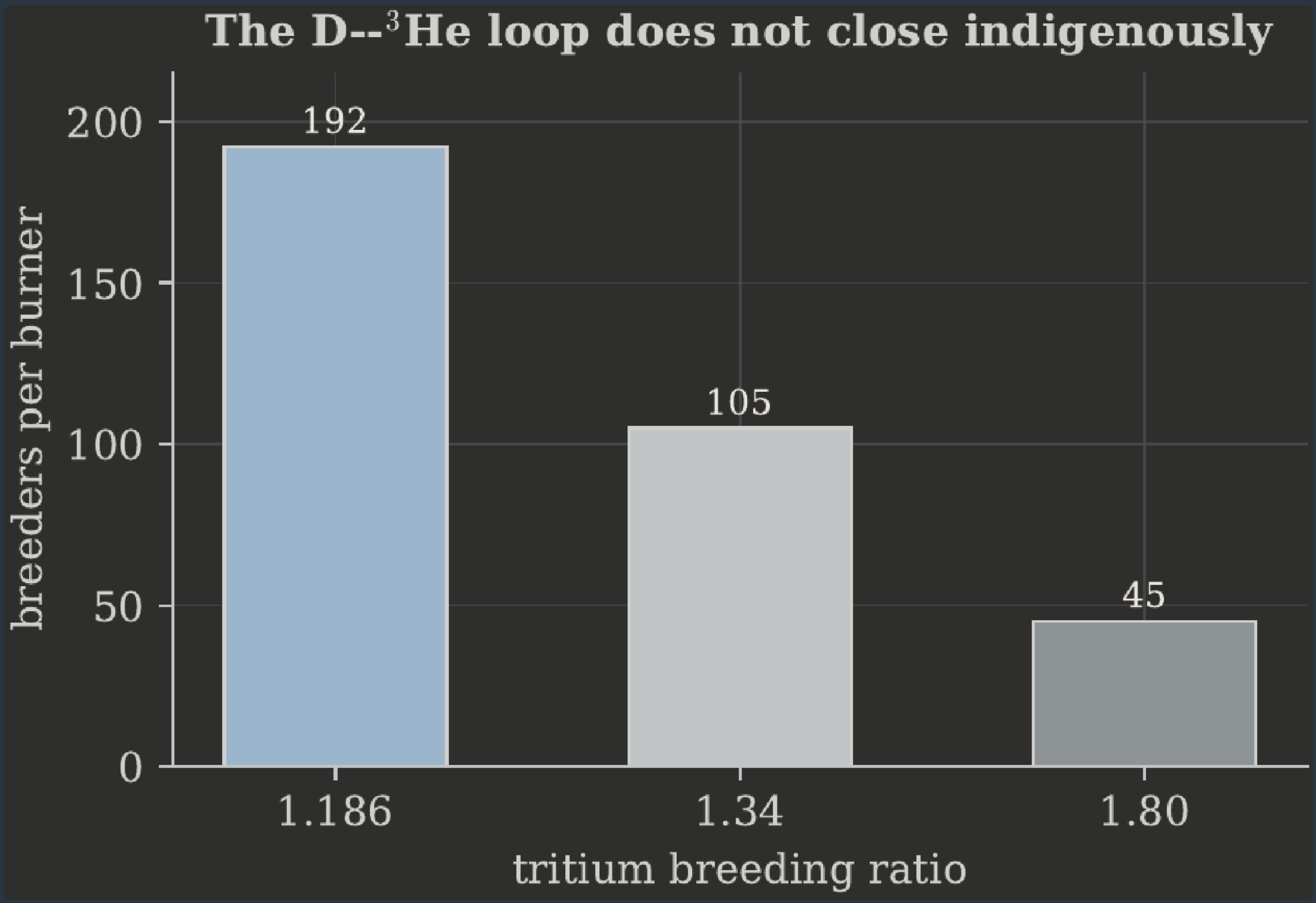
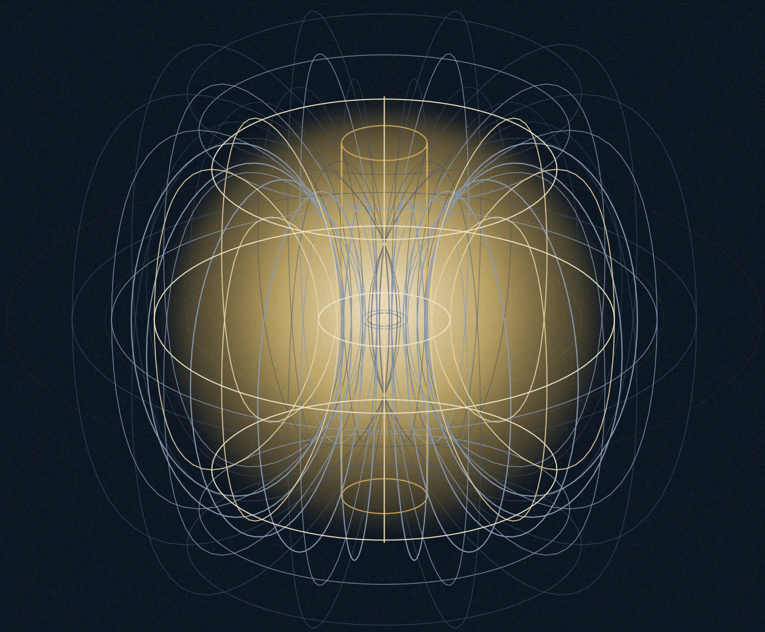


FIGURE 35. The helium-3 loop: co-product supply versus burner-fleet demand, and the lunar gate. DERIVED

KRONOS FUSION ENERGY



PAPER 2.15 OF THE 2026 KRONOS SET

Ideal-MHD Stability

Margins Carried Openly

Ideal-MHD stability of the compact negative-triangularity breeder at the frozen point, with quantified margins against the binding limits.

Ideal-MHD stable · kink and ballooning margins quantified

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§ 1

Stable, with the margins shown

A design point is only usable if it is stable, and the honest way to report stability is with the margin, not a binary pass. At the frozen point the equilibrium is ideal-MHD-stable, and the margins against the binding limits are quantified.

THE MARGINS

The equilibrium clears the kink and ballooning limits with quantified margin — reported as numbers to check, not a claim to trust.

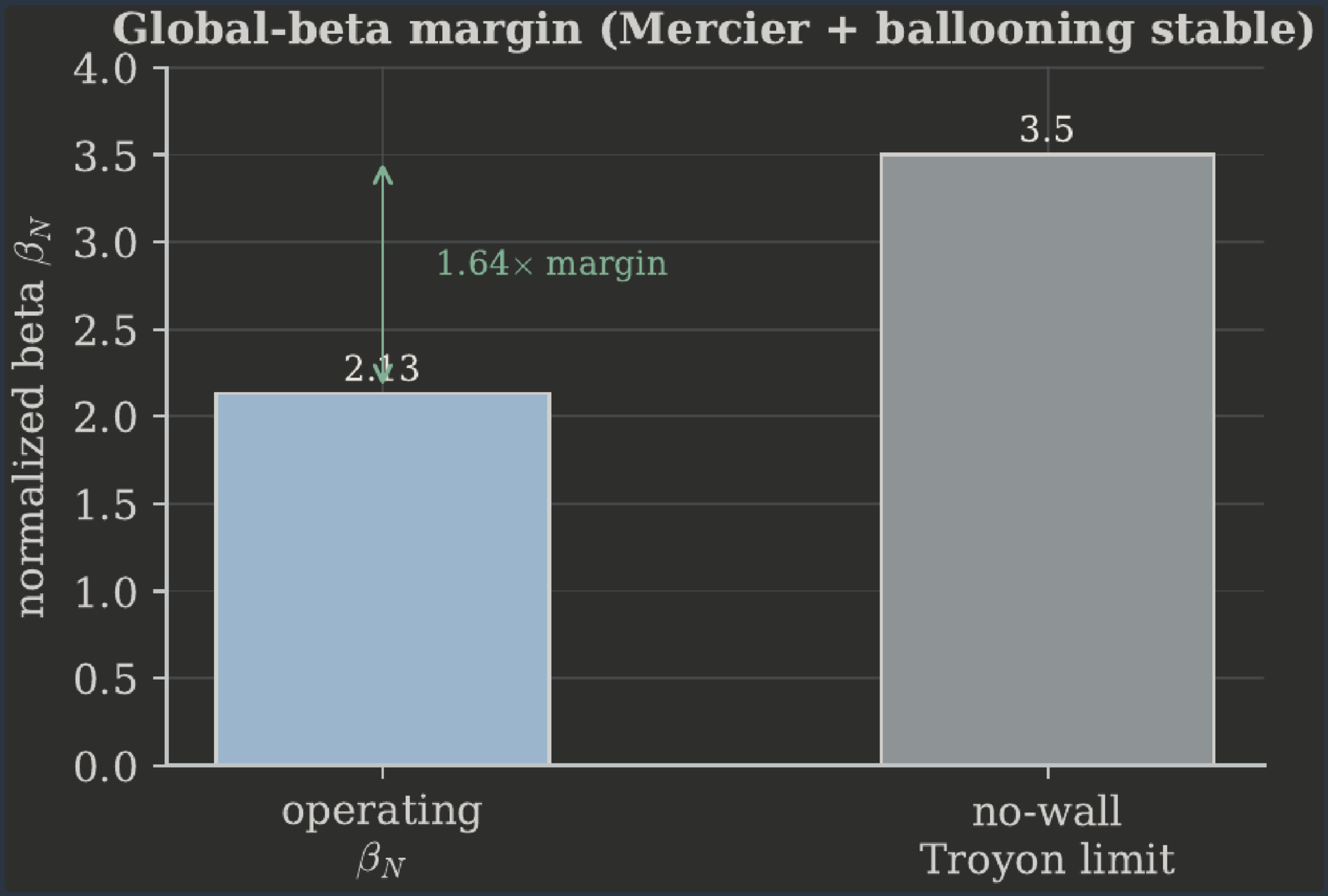
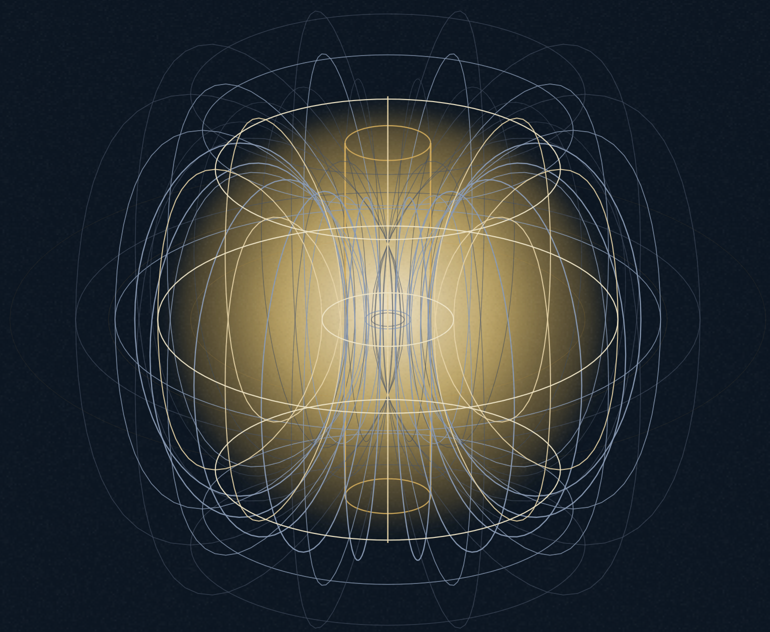


FIGURE 36. Ideal-MHD stability margins against the binding kink and ballooning limits. RECOMPUTED

KRONOS FUSION ENERGY



PAPER 2.16 OF THE 2026 KRONOS SET

The Divertor Portfolio

Options Ranked Against the Load

A portfolio assessment of divertor and heat-exhaust options ranked against the concentrated exhaust power of a compact machine.

Conventional / advanced-magnetic / liquid-metal · detachment ranked

Explore it live — 3-D model · physics validator · film series

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§ 1

The hardest power-handling problem, scoped

A compact machine concentrates its exhaust power on a small divertor area, which is where power-handling is sharpest. The portfolio ranks the options — conventional, advanced-magnetic, and liquid-metal — against that load rather than picking one by preference.

THE READING

Each option is ranked on detachment and power handling against the compact machine's concentrated load; the flowing-lithium vapor-box option, developed in a companion, couples heat exhaust to the fuel cycle.

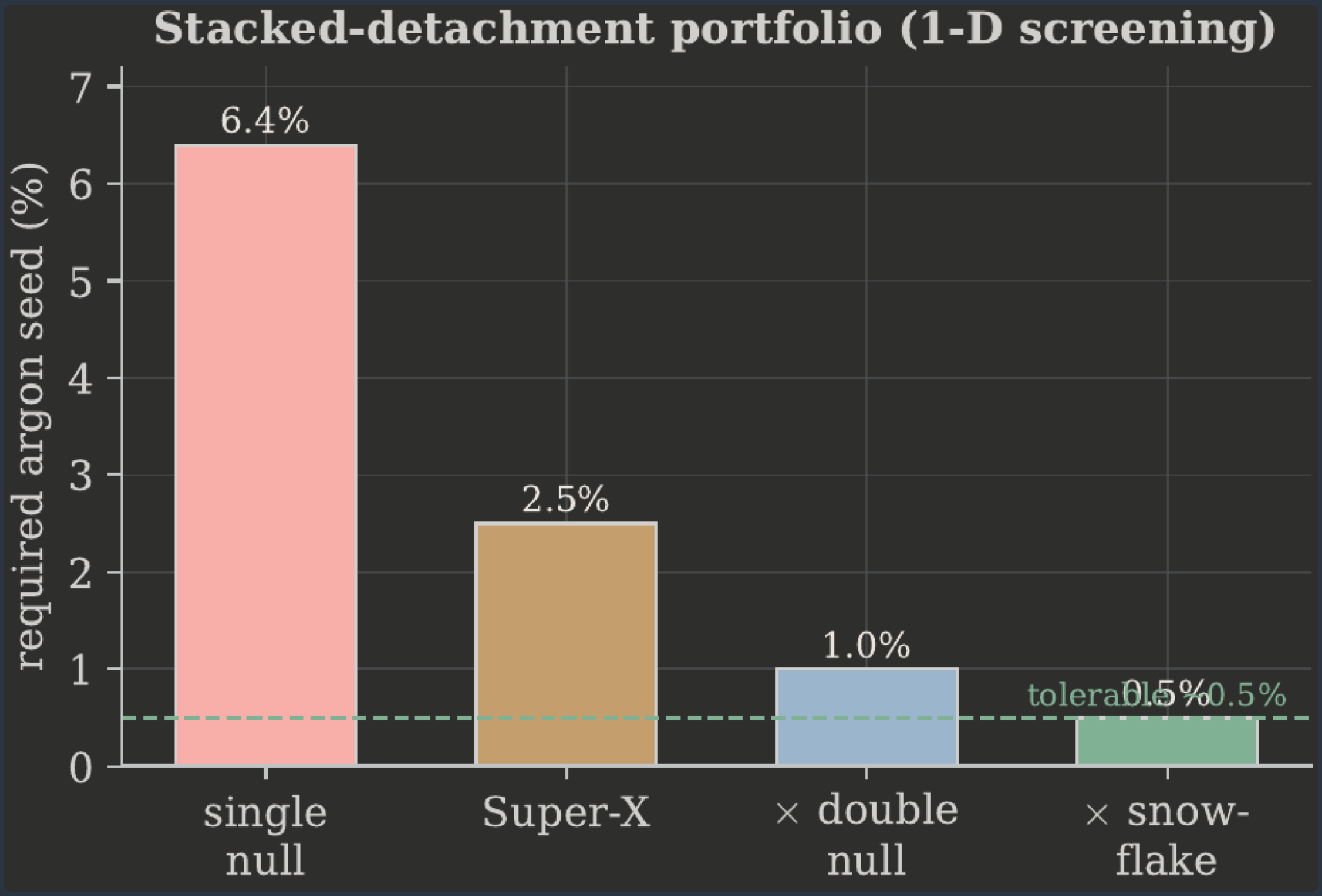

FIGURE 37. Divertor options ranked on detachment against the compact machine's exhaust load. RECOMPUTED

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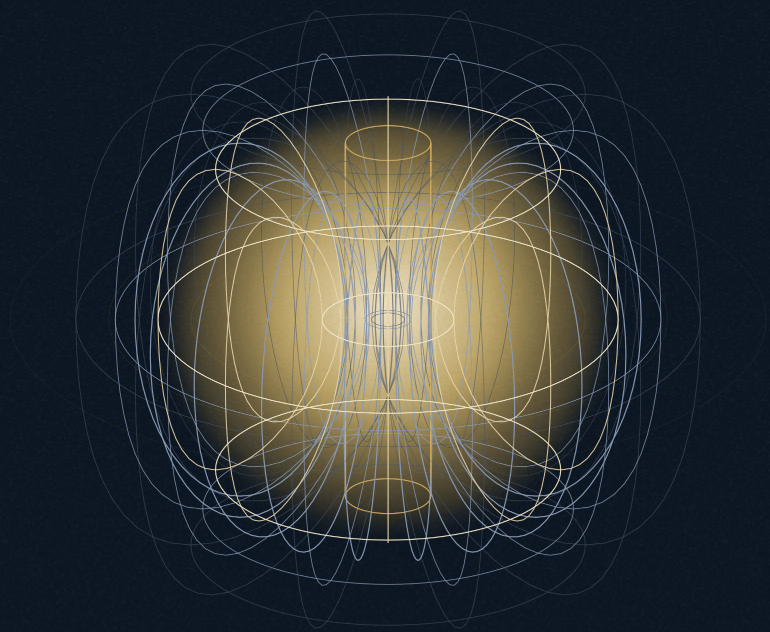

PAPER 2.17 OF THE 2026 KRONOS SET

Low-Activation Materials

A Low-Level-Waste Target

Reduced-activation structural steels and their activation, decay-heat, and waste behaviour under the 14 MeV spectrum.

RAFM steels · activation + decay heat · low-level-waste class target

Explore it live — 3-D model · physics validator · film series

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§ 1

Choosing the structure for its afterlife

What a fusion structure becomes after irradiation — its activation, decay heat, and waste class — is a design choice made at material selection. Reduced-activation steels are chosen to keep the retired structure in a low-level-waste class.

THE TARGET

Reduced-activation steels target a low-level-waste classification and short-cooldown or hands-on maintenance where practical — material-selection targets carried openly, pending qualification.

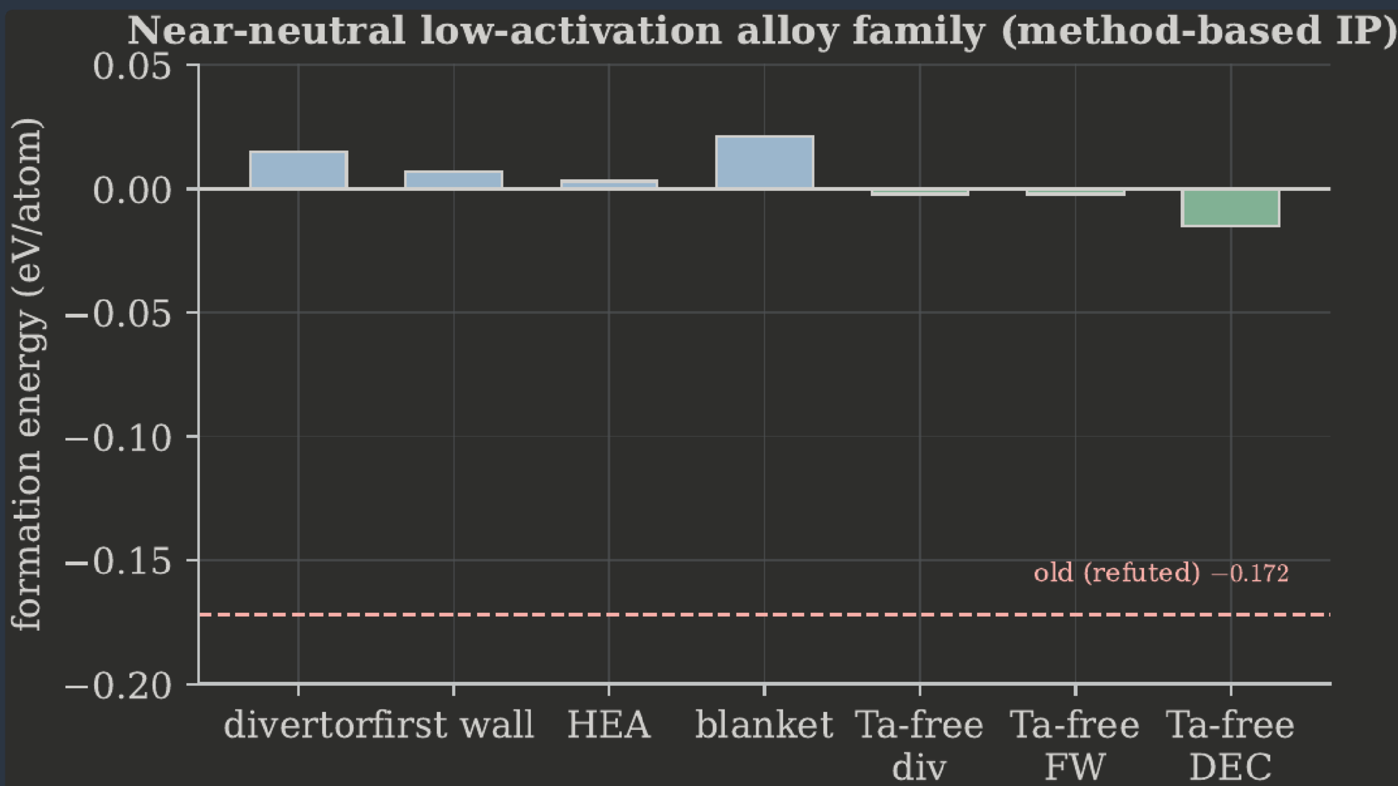
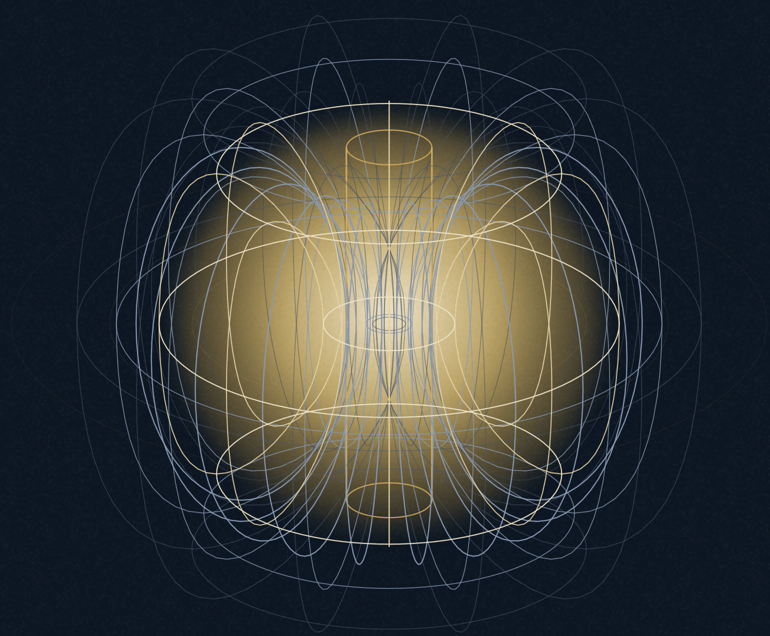


FIGURE 38. Activation and decay-heat behaviour of the candidate low-activation steels under the 14 MeV spectrum. RECOMPUTED

KRONOS FUSION ENERGY



PAPER 2.18 OF THE 2026 KRONOS SET

The Tritium Fuel Cycle

A Breeding Ladder, Not a Number

The breeder’s product is tritium, and its credibility rests on an honest mass balance — developed here as a confirmed ladder.

Burn 4.76 kg-T/fpy · net TBR to 1.42 · ~2.0 kg-T/yr/unit

Explore it live — 3-D model · physics validator · film series

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§ 1

A breeder is only as credible as its mass balance

A fusion breeder's product is tritium, and the temptation, historically, has been to quote a single flattering breeding ratio and move on. We do the opposite. We develop the tritium fuel cycle as a confirmed *ladder* of design points, derive the burn rate from first principles, and separate what a single unit delivers from what a fleet delivers — because conflating the two is how prior breeder concepts overstated themselves.

THE CLAIM, STATED HONESTLY

A single advanced unit is a tritium **exporter** at the ~2.0 kg-T yr^{-1} scale. A national-scale **4 kg-T yr^{-1}** supply is a *fleet* property — never a single-unit claim, because the spherical-tokamak centrepost caps the per-unit ceiling at net TBR 1.42.

§ 2

The burn rate, and the surplus

Each 17.59 MeV deuterium–tritium fusion consumes one triton, so the per-unit burn rate follows directly from the fusion power: **Λ_T = 4.76 kg-T per full-power-year** at 85.04 MW. The net surplus available for export is then **$S = (TBR - 1)\,\Lambda_T$**. The breeding ratio, not the burn rate, is therefore the design lever — and it is a lever, not a constant. DERIVED FROM P_{FUS}

§ 3

The breeding ladder

Three-dimensional OpenMC neutronics on ENDF/B-VIII.0 place the ladder. The literal frozen recipe gives net TBR ~1.06 and a surplus of 0.29 kg-T yr^{-1}; a dedicated 5 cm solid-beryllium multiplier raises it to ~1.19 and 0.9; and the advanced blanket — a void-reduced breeder with a solid-beryllium multiplier and a steel reflector — reaches net TBR **1.42** and about **2.0 kg-T yr^{-1} per unit**.

This TBR 1.42 is the confirmed per-unit ceiling across twelve blanket configurations; a lithium–lead alternative was explored and does not beat it, and the result reproduces across an independent nuclear-data evaluation to under 0.3%. CROSS-LIBRARY REPRODUCED

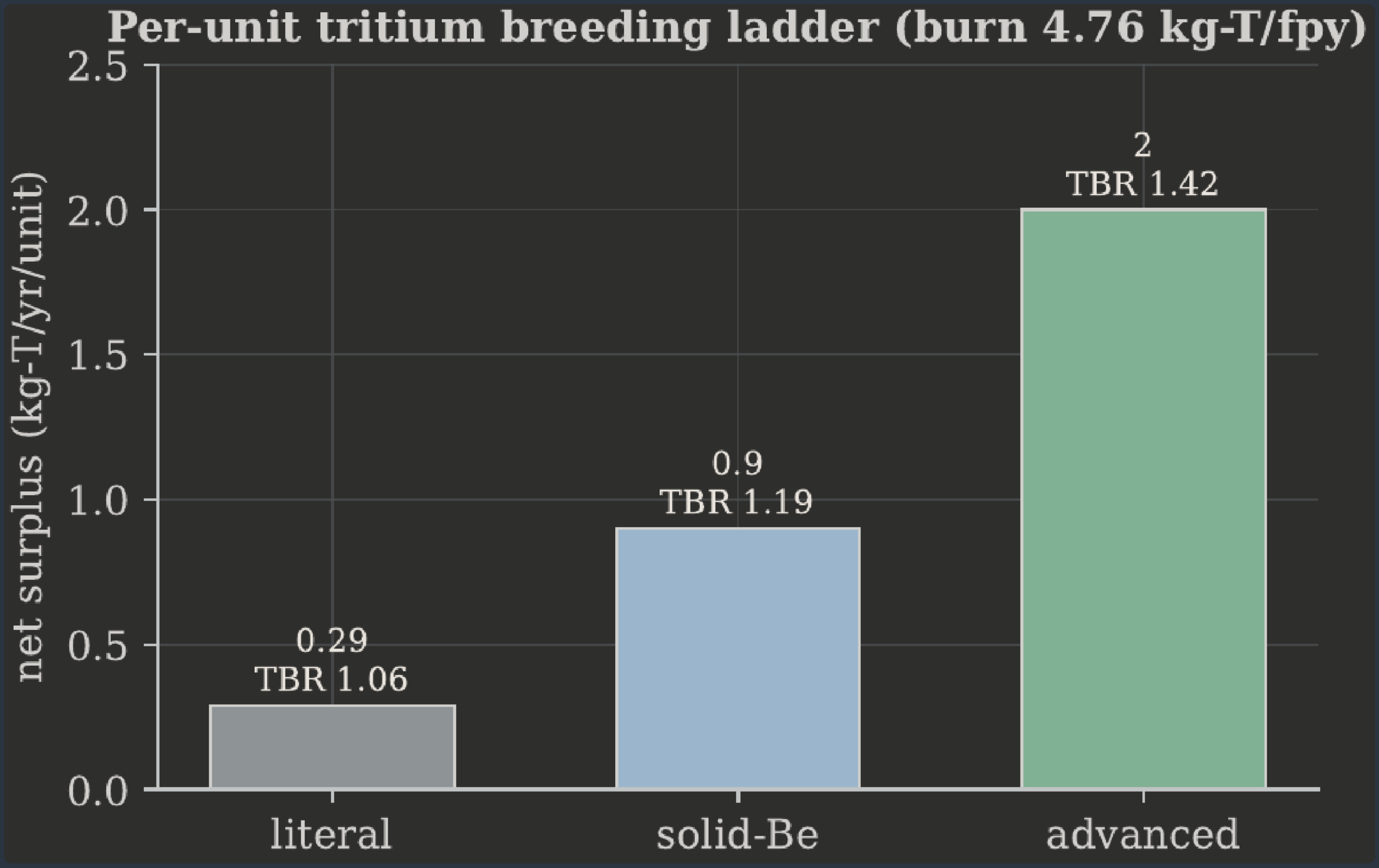

FIGURE 39. The per-unit tritium breeding ladder: net surplus at the literal, solid-beryllium, and advanced blankets, with the corresponding net breeding ratio. OPENMC / ENDF-B-VIII.0

§ 4

Per unit versus fleet

The distinction is load-bearing. A single advanced unit exports tritium at the ~2.0 kg-T yr^{-1} scale. A national-scale 4 kg-T yr^{-1} supply is reached by two advanced units, or four-to-five solid-beryllium units — and the co-produced helium-3 aggregates the same way, to 3.6-4.5 kg yr^{-1} across the fleet. We never claim 4 kg-T yr^{-1} from one unit.

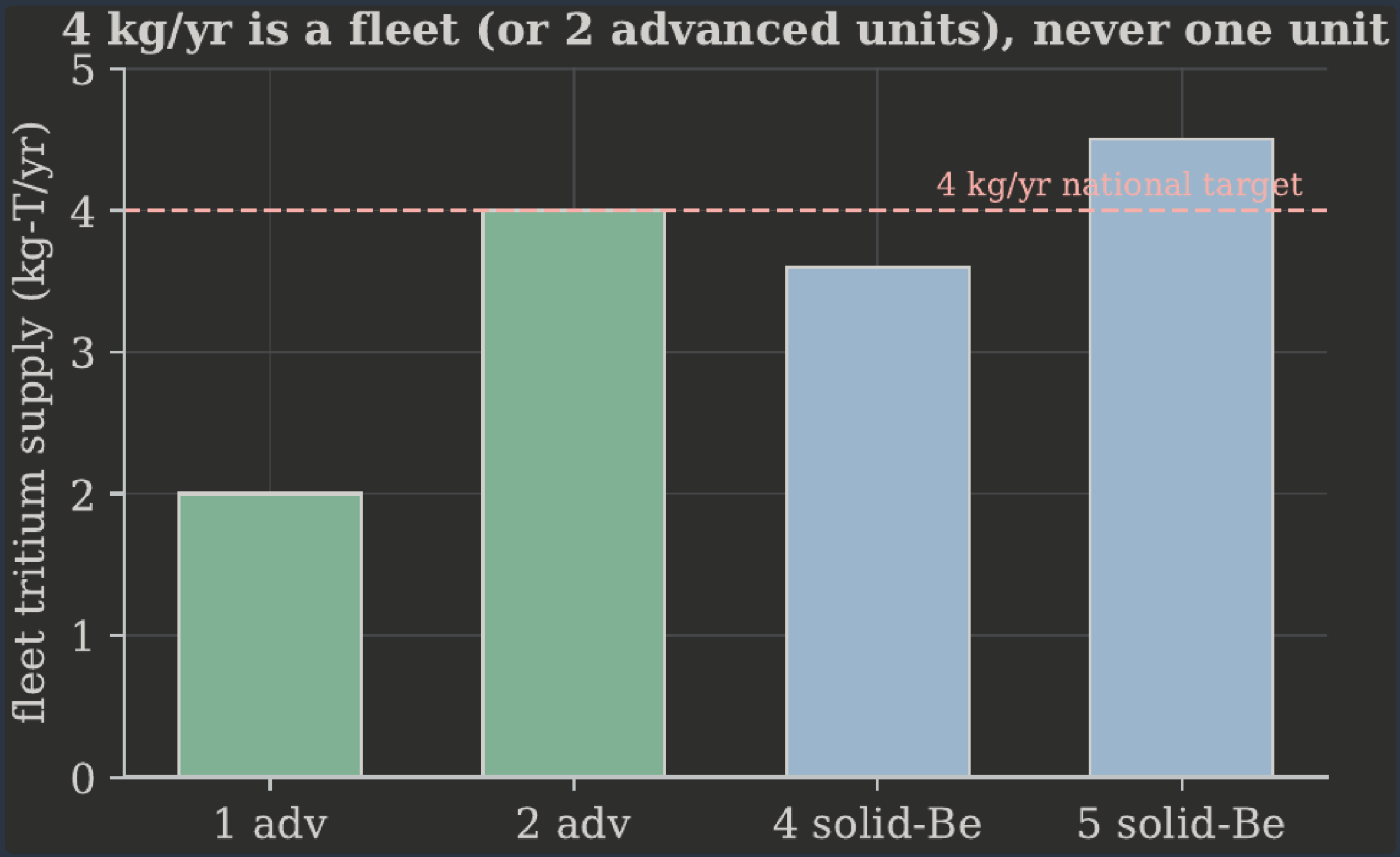

FIGURE 40. Fleet aggregation to the national target: 4 kg-T yr^{-1} is reached by two advanced units or four-to-five solid-beryllium units. FLEET ARITHMETIC

§ 5

The closed loop

The fuel cycle closes through direct internal recycling of unburned tritium from the exhaust, blanket tritium extraction, detritiation of process streams, and permeation control at the blanket–coolant boundary. Direct internal recycling minimizes the standing inventory — and the standing inventory, not the breeding ratio, is what the safety case turns on — by returning unburned fuel promptly rather than through a large buffered store.

Helium-3, bred by the decay of surplus tritium at equilibrium, is a co-product of that inventory rather than an independent channel. The standing-inventory value that sets the accident source term is computed in the fuel-cycle model and carried to the safety companion — flagged as the governing safety quantity, not asserted here. COMPUTED DOWNSTREAM

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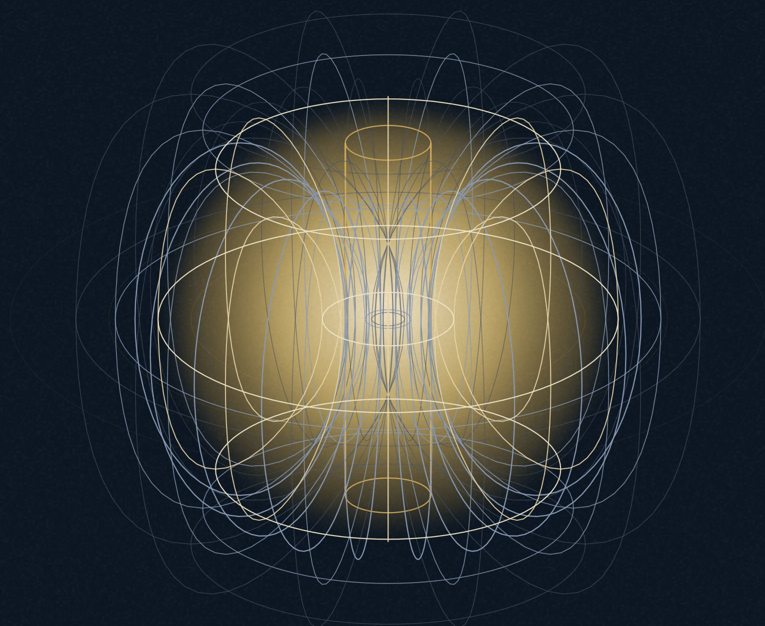

PAPER 2.19 OF THE 2026 KRONOS SET

The Flowing-Lithium Divertor

Heat Exhaust Meets the Fuel Cycle

A flowing-lithium vapor-box divertor where the best power-handling surface is also the best tritium-inventory surface.

Li optimal for T retention by 3-6 orders of magnitude · vapor-box exhaust

Explore it live — 3-D model · physics validator · film series

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§ 1

One surface, two problems solved

A flowing liquid-metal surface solves the erosion and thermal-fatigue problems of a solid divertor by renewal, and a vapor box dissipates the incident power by radiation. The remaining question — which metal — is answered by tritium retention, because the divertor is also part of the fuel cycle.

WHY LITHIUM

Coupled permeation-retention modelling ranks lithium optimal by three to six orders of magnitude over lithium-tin, lead-lithium, and tin — so the surface that best dissipates the exhaust power also best minimizes the tritium it holds and leaks.

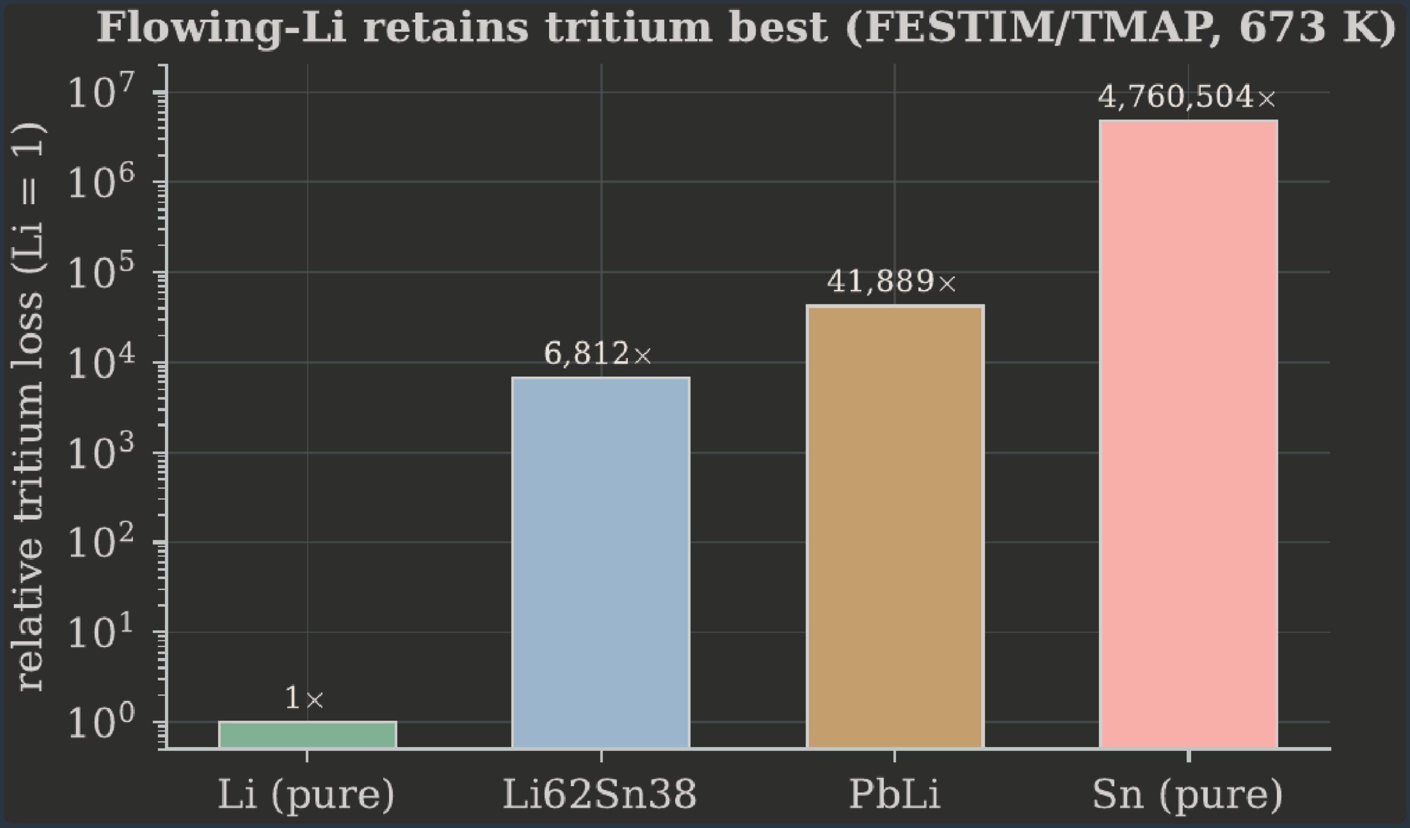
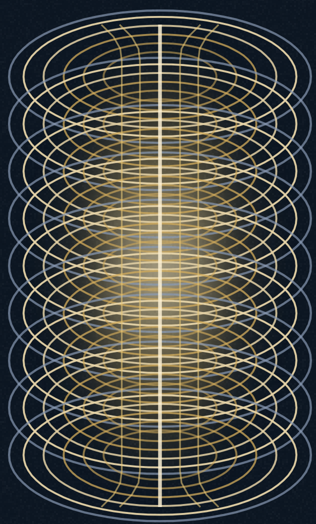


FIGURE 41. Relative tritium loss of four liquid-metal divertor candidates: flowing lithium is optimal. FESTIM/TMAP

KRONOS FUSION ENERGY



PAPER 2.20 OF THE 2026 KRONOS SET

Early Quench Detection

Firing Before the Voltage

Fused strain-rate and magnetization sensing detects a REBCO quench well ahead of the terminal voltage, cutting the winding's MIITs.

Fused detector 0.089 s · lead 2.935 s · SNR 322.5 · NV margin 39

Explore it live — 3-D model · physics validator · film series

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§ 1

Detect the quench, not the voltage

REBCO magnets store enormous energy and quench slowly — exactly the wrong combination for voltage-based protection, which acts only after a small resistive voltage has built along a slowly spreading zone. The answer is to detect something that changes early.

THE LEAD

A fused strain-rate-plus-magnetization detector fires at 0.089 s, 2.935 s ahead of the voltage threshold (SNR 322.5), cutting the current-time integral the winding must absorb. An in-winding nitrogen-vacancy magnetometer supplies the magnetization channel and tolerates the neutron environment at margin 39.

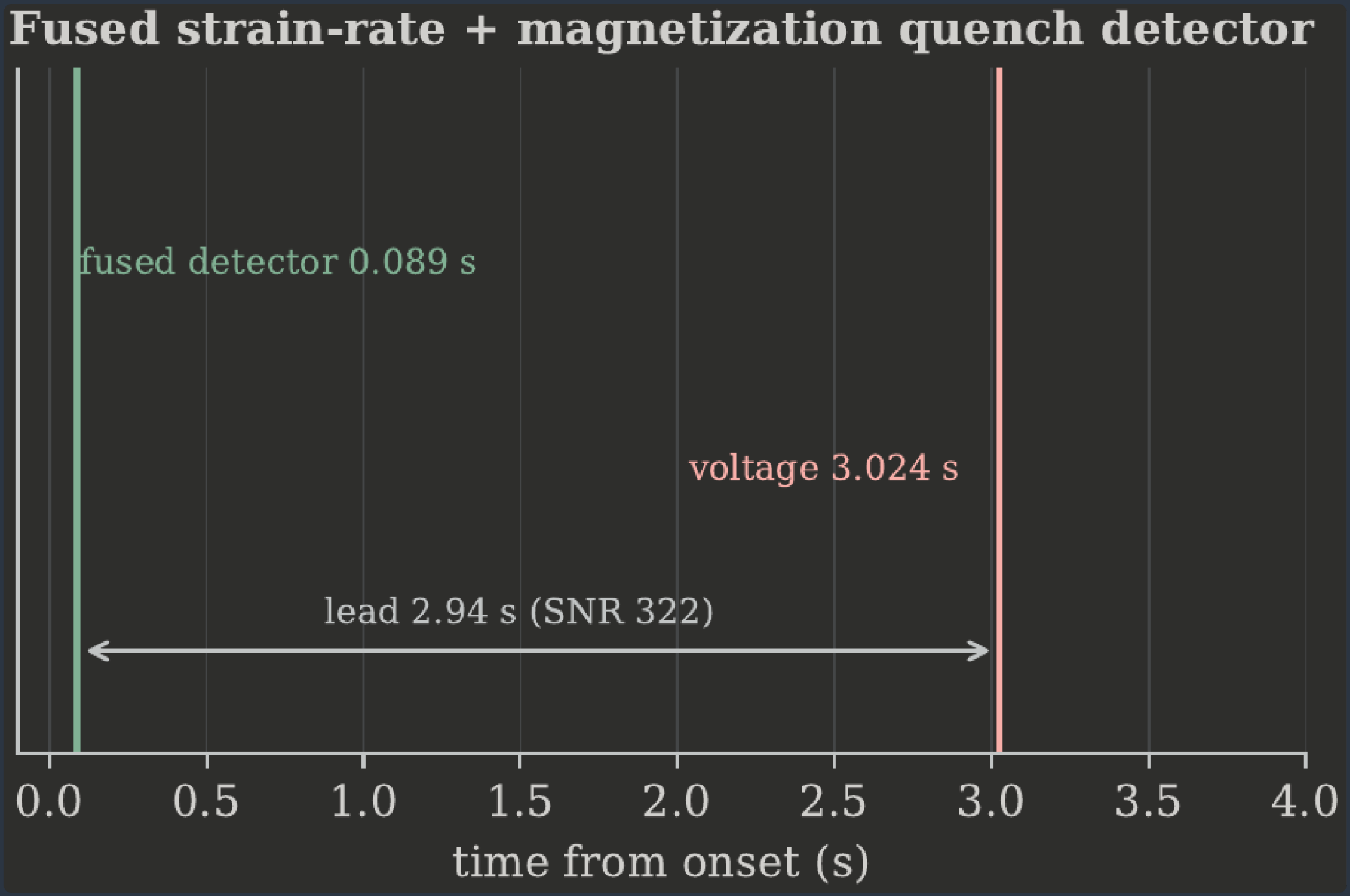
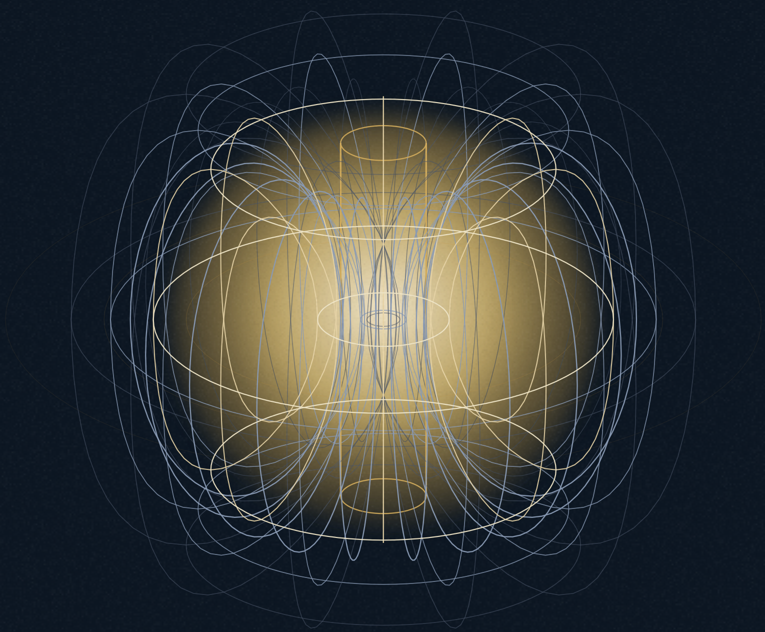


FIGURE 42. Fused strain-rate + magnetization detection fires well ahead of the voltage threshold. RECOMPUTED

KRONOS FUSION ENERGY



PAPER 2.21 OF THE 2026 KRONOS SET

The Safety Case

Bounded Hazards, Stated Plainly

Fusion's safety advantages are real but often asserted; here they are bounded against the platform's actual hazards.

Mobilizable tritium minimized · no meltdown by construction · low-activation waste target

Explore it live — 3-D model · physics validator · film series

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§ 1

A credible safety case names the hazards

Fusion's safety advantages are real, but they are too often *asserted* rather than bounded. A credible case names the hazards and bounds each one. Fusion's inherent advantages — no fission-product inventory, no criticality, a small driven plasma — are genuine; but the tritium inventory and the activated structure are real hazards that must be quantified, not waved away.

THE POSTURE IN ONE LINE

A **minimized mobilizable-tritium source term**, **no criticality or meltdown mechanism by construction**, and a **low-activation-waste target** — with the governing quantity, the standing tritium inventory, *computed, not asserted*.

§ 2

The dominant hazard: mobilizable tritium

The accident source term is set by the mobilizable tritium inventory. The design minimizes it through direct internal recycling of unburned fuel, which avoids a large buffered store, and through permeation control at the blanket–coolant boundary and detritiation of process streams. The standing-inventory value is computed in the fuel-cycle model and is the governing safety quantity; we carry it rather than assert a figure, and we flag it as the load-bearing input to the source term. COMPUTED (FUEL-CYCLE)

§ 3

No meltdown, by construction

There is no fission-product decay-heat inventory and no chain reaction. The fusion plasma requires several simultaneous conditions — confinement, heating, fuelling, field — and the loss of any one quenches it on a short timescale. An unmitigated loss of control therefore *terminates* the reaction rather than escalating it; there is no physical mechanism for a runaway or a core melt. The decay heat that remains is from activated structure, not fuel, and is bounded by the material selection.

§ 4

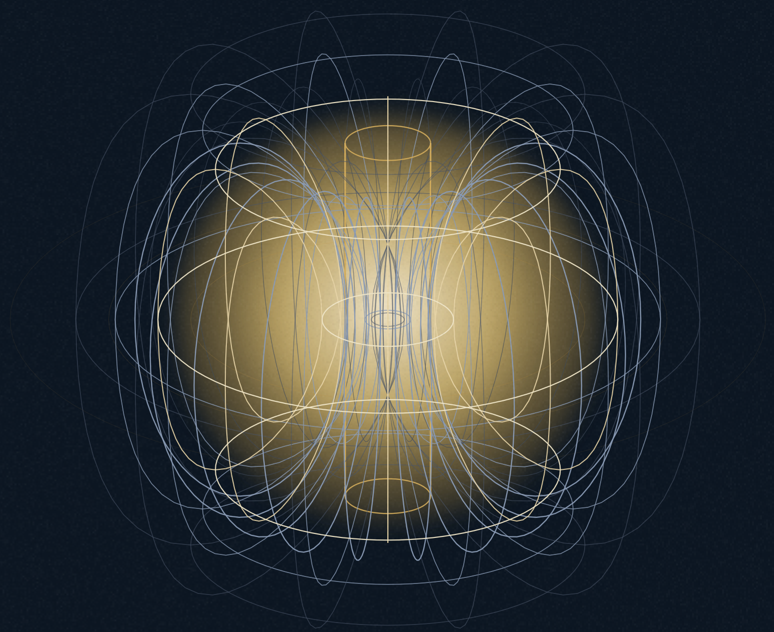
Waste, activation, and the safety basis

Structural activation is minimized by low-activation steel selection, targeting a low-level-waste classification of the retired structure and, where practical, short-cooldown or hands-on maintenance. The consumable centrepost cartridge is designed for scheduled handling within this waste class, and the burner's 5.44% neutron fraction — an order of magnitude under deuterium–tritium — further reduces activation at the power plant.

MOBILIZABLE TRITIUM	Minimized by direct internal recycling · *computed* (fuel-cycle companion)
CRITICALITY / MELTDOWN	None — no fissile, no chain reaction · *inherent*
DECAY HEAT	Activated structure only, bounded · *requirement* (materials)
STRUCTURAL WASTE	Low-activation steel, low-level-waste target · *requirement* (materials)
POWER-PLANT ACTIVATION	Reduced by the burner's 5.44% neutron fraction · *computed* (burner)

This is a design-basis safety argument, not a licensed safety analysis report: the source term depends on the computed standing inventory carried from the fuel-cycle companion, and the waste classification is a material-selection target pending qualification. Regulatory treatment is developed in the licensing companion. What the case establishes is that every hazard is *bounded*, and the one that governs is computed. DESIGN-BASIS

KRONOS FUSION ENERGY



PAPER 2.22 OF THE 2026 KRONOS SET

Licensing as Byproduct Material

A Framework That Fits

Licensing the platform under the U.S. byproduct-material framework — a graded, hazard-proportionate path that fits a low-source-term machine.

10 CFR Part 30 · ADVANCE Act · Agreement-State graded path

Explore it live — 3-D model · physics validator · film series

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§ 1

The path fits the hazard

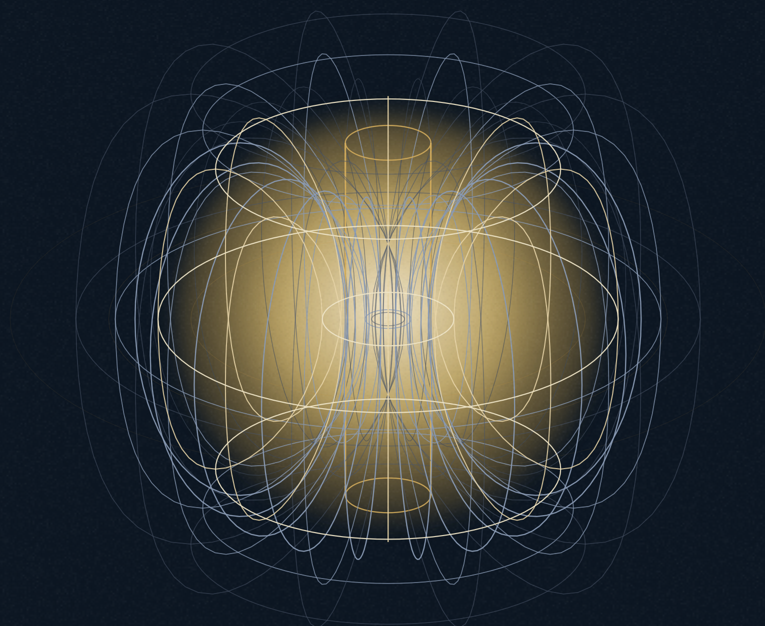
A program that ignores its regulatory path can build a working machine it cannot deploy. The United States settled fusion's path in a direction that suits a compact, low-source-term platform: byproduct material, not the reactor framework.

WHY IT FITS

The byproduct-material framework is materials-oriented, Agreement-State-administrable, and graded — the correct lens for a machine whose only significant source term is a bounded tritium inventory, with no criticality mechanism. The strategy is early pre-application engagement.

FRAMEWORK	10 CFR Part 30 (byproduct material), confirmed for fusion 2023 + ADVANCE Act
FIT	Dominant hazard = bounded tritium inventory; no fission products, no criticality
PATH	Agreement-State-administrable, graded, hazard-proportionate; pre-application engagement

KRONOS FUSION ENERGY



PAPER 2.23 OF THE 2026 KRONOS SET

Current Drive & Bootstrap

The Recirculating Cost, Stated

Non-inductive current drive and bootstrap fraction — the drive power booked openly in the recirculating budget.

I_p 9.66 MA · bootstrap ~15.5% · driven 8.16 MA

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§ 1

No transformer, no hidden power

Steady-state operation means no ohmic transformer to renew the plasma current, so the current must be sustained by bootstrap and external drive. The external share costs recirculating power, and an honest design states it rather than assuming a high bootstrap fraction.

THE BALANCE

Of the 9.66 MA total, the bootstrap current self-generates ~15.5% and external drive supplies 8.16 MA, whose wall-plug power is a named line in the recirculating budget — booked openly, not hidden. The bootstrap fraction is a lever, stated modestly.

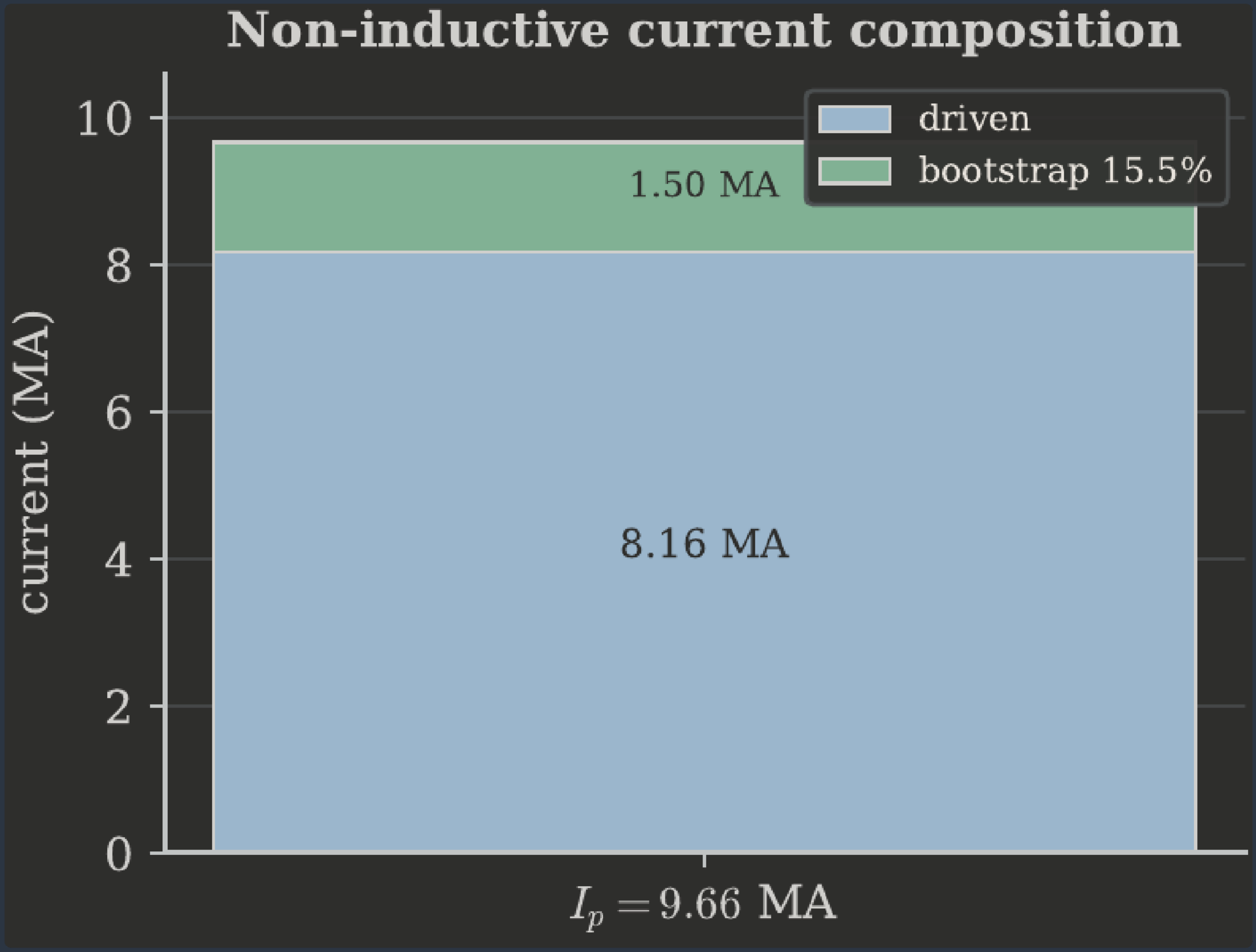

FIGURE 43. Non-inductive current composition: bootstrap and external drive of the total plasma current. DESIGN POINT

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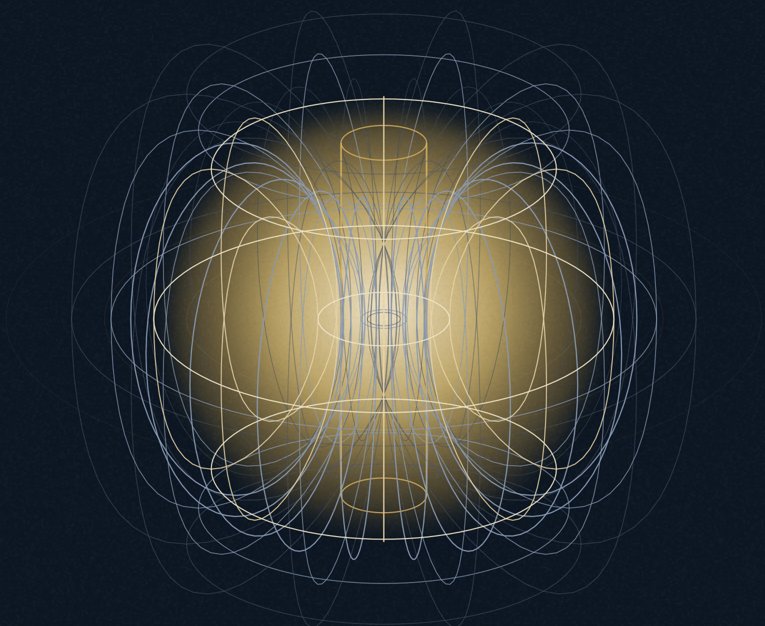

PAPER 2.24 OF THE 2026 KRONOS SET

Solenoid-Free Startup

Growing the Current Without a Transformer

A spherical tokamak has no room for a central solenoid, so the current is initiated and ramped without one — a strategy and a risk register.

Outboard induction + ECH + helicity seed → non-inductive flat-top

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§ 1

A defining constraint, not a detail

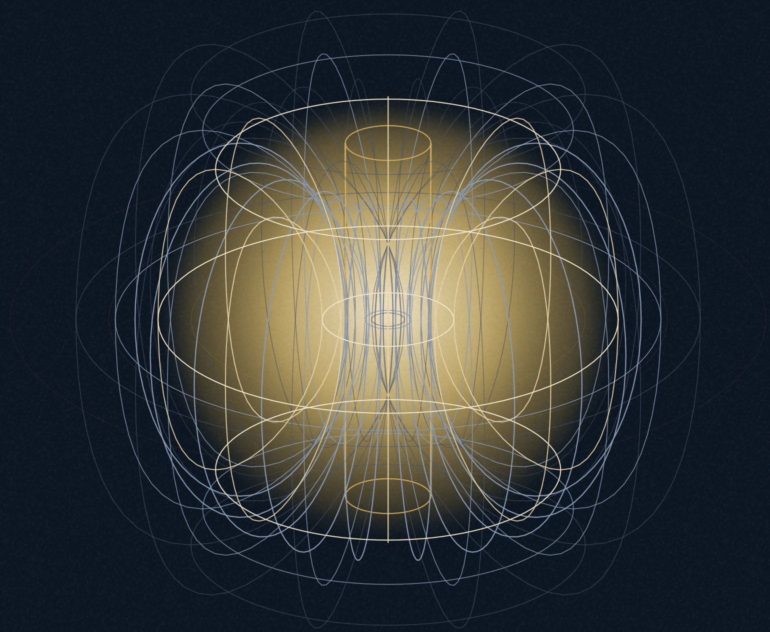
The central solenoid a conventional tokamak uses to induce its current does not fit in a spherical tokamak's slender centrepost. Startup is therefore a defining problem: the current must be born and grown without a transformer.

THE STRATEGY

Outboard induction, electron-cyclotron heating, and a helicity or beam seed grow the current to the flat-top, where the non-inductive and bootstrap currents sustain it. The ramp auxiliary power and the profile-control hand-off are flagged as carried engineering risks, not a solved sequence.

INITIATION	Outboard poloidal-field induction + electron-cyclotron pre-ionization/heating
SEED	Helicity injection or beam-driven seed current
HAND-OFF	Non-inductive drive + bootstrap hold the flat-top · ramp power + profile control = carried risks

KRONOS FUSION ENERGY



PAPER 2.25 OF THE 2026 KRONOS SET

Isotopes & Materials Qualification

The Neutron, Put to Work

The breeder's 14 MeV source as a co-production platform — a fusion-spectrum materials facility and a fission-free route to medical isotopes.

~59× reference materials facility · Mo-99 without a reactor

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§ 1

The neutron a breeder already makes

The 14 MeV neutron a breeder makes to breed tritium is a resource with more than one use. The same source can qualify materials in a true fusion spectrum and breed medical isotopes in target stations — co-products of the neutron economy.

TWO CO-PRODUCTS

A fusion-spectrum materials-qualification volume about 59× the reference dedicated facility — a capability the field has lacked — and a fission-free route to shortage-prone isotopes like molybdenum-99. Booked as strategic-material capability, not revenue.

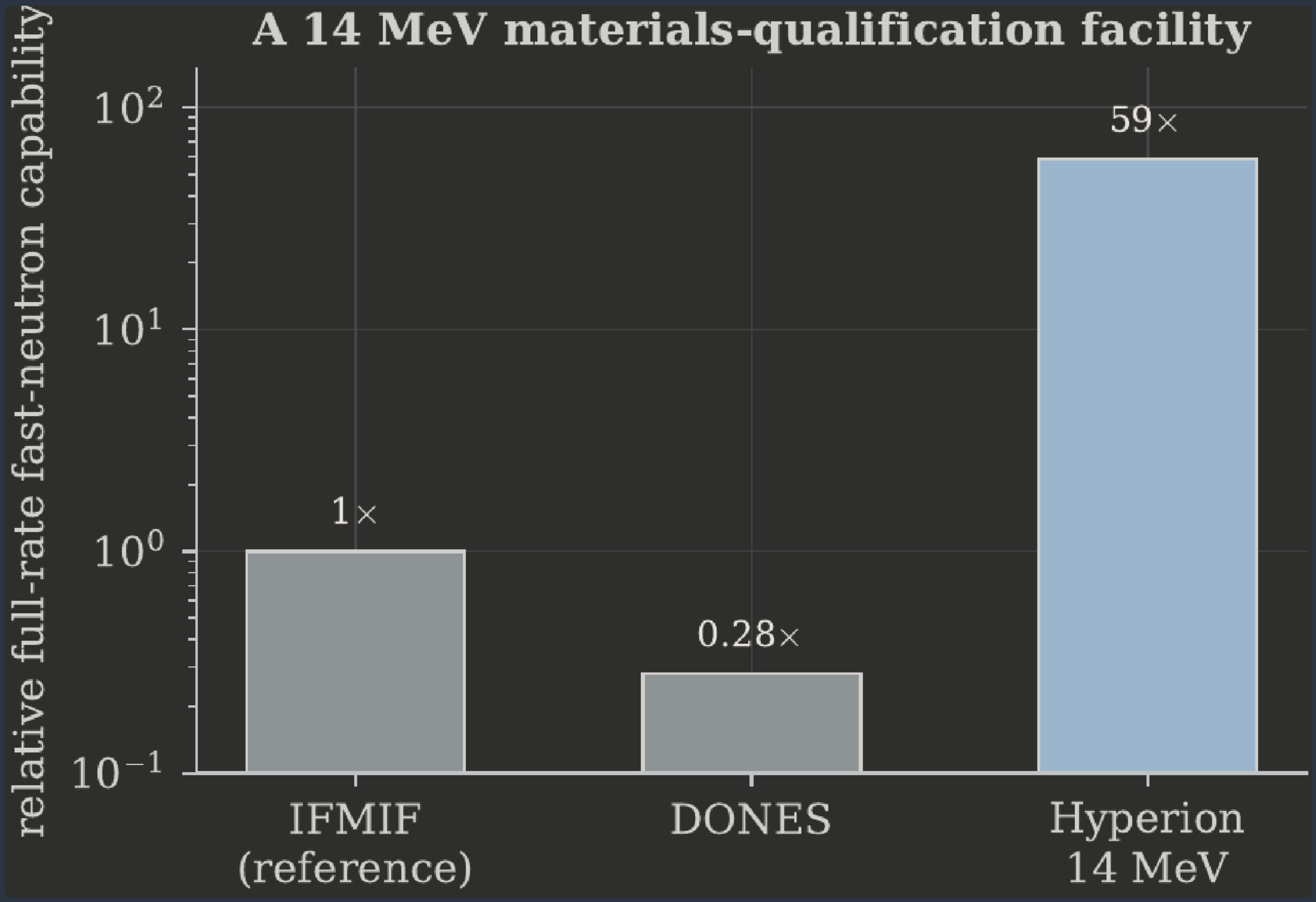
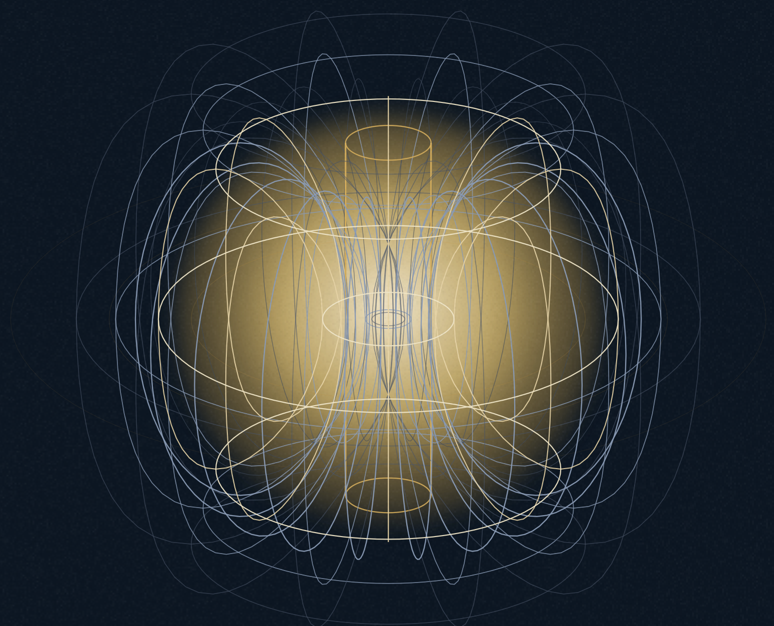


FIGURE 44. Relative full-rate fast-neutron capability: the breeder's 14 MeV volume against reference facilities. CAPABILITY PROJECTION

KRONOS FUSION ENERGY



PAPER 2.26 OF THE 2026 KRONOS SET

The Integrated Platform

One Architecture, Two Machines

A spherical-tokamak breeder that makes strategic materials and a deuterium–helium-3 burner that makes power — sharing a magnet basis and a single physics record.

Breeder Q 3.0763 · Burner Q_E 1.318 · f_n 5.44% · two-tier closure

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§ 1

A platform, not a machine

Kronos is usually described one machine at a time — the breeder, or the burner — and that framing undersells what has actually been built. Kronos is a *platform*: a compact negative-triangularity spherical-tokamak breeder that makes strategic materials, and a deuterium–helium-3 burner that makes power, sharing a magnet basis, a control architecture, and a single frozen physics record. The two machines are not a portfolio bet placed twice; they are one architecture that produces the materials a fusion economy needs and the power it will run on.

THE PLATFORM IN ONE LINE

All three products — breeder, and burner in two housings — **close on the frozen physics**; every component is buildable within demonstrated practice; and the distance to *demonstrated* closure is **three named experiments, not open physics**.

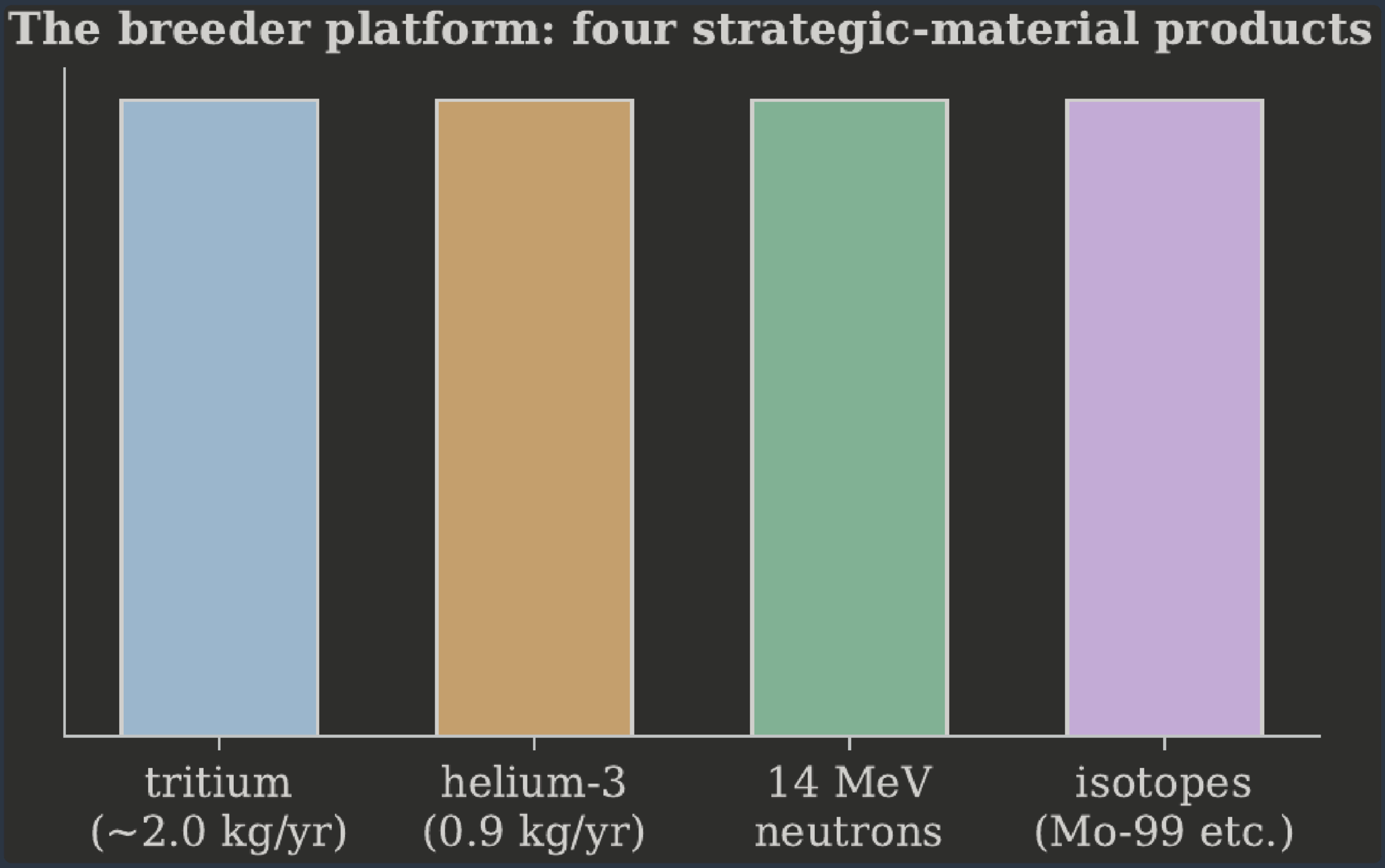


FIGURE 45. The breeder platform's four strategic-material products — tritium, helium-3, 14 MeV neutrons, and co-produced isotopes; the burner adds power in two housings. DESIGN SYNTHESIS

§ 2

The breeder — a strategic-materials platform

The compact spherical tokamak reaches **Q = 3.0763** at **85.04 MW** of fusion power and supplies four products: tritium along a confirmed breeding ladder to about **2.0 kg-T yr^{-1} per unit** (net TBR ceiling 1.42); helium-3 at about 0.9 kg yr^{-1} per unit; 14 MeV neutrons for materials qualification; and co-produced medical and industrial isotopes.

Negative triangularity (δ = -0.3) suppresses turbulence into a quiet subcritical core; the equilibrium is ideal-MHD-stable; and the inboard centrepost is a consumable, scheduled-replacement cartridge rather than a lifetime component. Net electricity is a *category error* for the breeder and is excluded — the breeder's success is measured in gain, breeding ratio, and the materials it makes, not in megawatts to the grid. FROZEN ANCHOR

§ 3

The burner — power in two housings

The deuterium–helium-3 tandem-mirror burner reaches **Q_E = 1.318** at a neutron fraction of only **5.44%** — an order of magnitude below deuterium–tritium, low-neutron but never aneutronic. It is deployed in two housings, Aegis (fixed defence installations) and MetroVolt (data-centre generation), that share the mirror physics and the direct-energy-conversion train.

Its one residual physics gate is the plug potential — an end-plug density ratio of 16 — and the high-field plug coil qualifies structurally, so the *magnet* is not the gate. The honest open item is a plug-scale potential experiment, named and scoped, not a hoped-for breakthrough. REQUIREMENT-CLASS

§ 4

The strategic helium-3 loop

Helium-3 links the two machines but does not close between them. The 12.3-year tritium half-life makes the breeder's decay-sourced helium-3 far too slow to fuel a burner fleet — of order ~192/105/45 breeders per burner — so burner-scale helium-3 is honestly *lunar-gated*, around 2038–40. The breeder's helium-3 is a strategic co-product with national-security, cryogenic, and quantum value: distinct from bulk fuel supply, and distinct from revenue.

§ 5

The programme timeline

The build canon is founder-locked. Construction begins Q2 2027; first-of-a-kind tritium follows in 2030–31; the ~100 MW test burner in 2032; and lunar helium-3 gates the burner fleet around 2038–40.

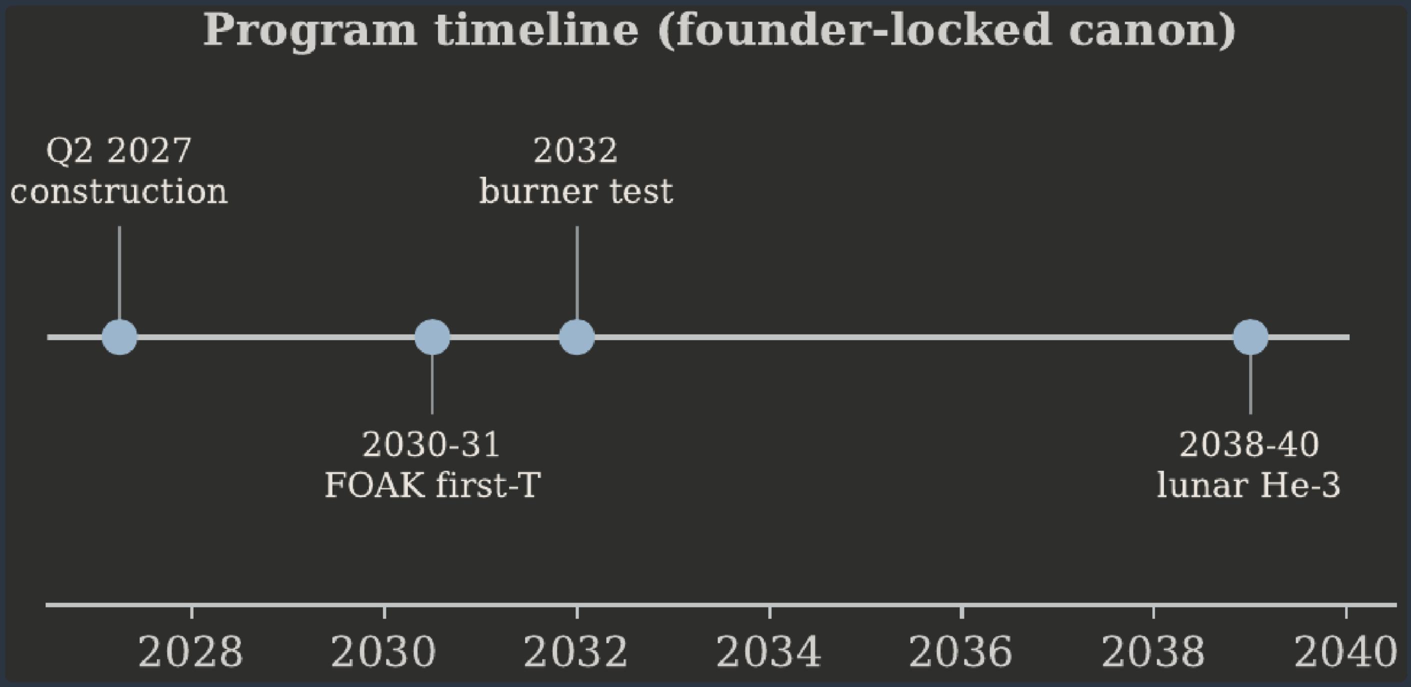


FIGURE 46. The founder-locked programme timeline: construction, first-of-a-kind tritium, the test burner, and the lunar-helium-3 fleet gate. PROGRAMME CANON

§ 6

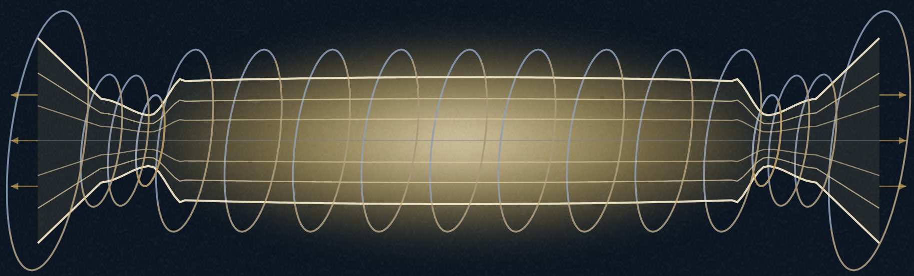
Closure, in two tiers

We state closure in two tiers throughout and never say “closed” unqualified: *closed-on-model* (what the frozen physics delivers) versus *closed-demonstrated* (the named experiment that retires each residual gate).

BREEDER (HYPERION)	Closed-on-model as a **platform**, net-TBR ceiling 1.42 · demonstrated by the measured breeding ratio at first-of-a-kind operation (2030–31)
BURNER (AEGIS / METROVOLT)	Closed-on-model at **Q_E 1.318** with a buildable coil · demonstrated by the plug-potential experiment (~2028–30)
HELIUM-3 FLEET	Co-product loop · demonstrated by lunar helium-3 supply (2038–40)

The defensible headline is not that Kronos has finished, but that it knows exactly what remains: each product closes on the frozen physics, every component is buildable within demonstrated practice, and what stands between on-model and demonstrated is three named experiments. That is the honest statement of where the platform stands.

KRONOS FUSION ENERGY



PAPER 2.27 OF THE 2026 KRONOS SET

The Advanced-Fuel Scorecard

Physics, Not the Aneutronic Ideal

Grading D–T, D–D, D–^{3}He, and p–^{11}B on one ruler — and letting the Kronos architecture fall out of the grades.

D–T breeding · D–^{3}He power (f_n 5.44%) · p–^{11}B not chosen

Explore it live — 3-D model · physics validator · film series

PREPARED BY P. I. FORD · G. L. KULCINSKI

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§ 1

Fuel choice is the decision

Every fusion company implicitly picks a fuel, and the pick determines everything downstream: the neutron load, the tritium logistics, the required temperature, the conversion strategy. The choice is too often made emotionally — toward the aneutronic ideal — rather than on the physics. We grade all four candidate fuels on the same ruler and let the Kronos architecture fall out of the grades.

THE RESULT IN ONE LINE

No fuel wins on every axis. Kronos runs **deuterium–tritium where the product is the neutron and the bred material** (the breeder) and **deuterium–helium-3 where the product is power** and neutrons are the liability (the burner, only 5.44% neutronic) — with helium-3 honestly lunar-gated. Proton–boron is *not* chosen.

§ 2

The scorecard

The single most decisive axis is the neutron fraction of the fusion power — it sets the shielding, the activation, and whether the machine can sit near people and hardware. Deuterium–tritium is ~80% neutronic; deuterium–deuterium ~66%; deuterium–helium-3 only 5.44%, and even those neutrons come from an unavoidable D–D side reaction; proton–boron is effectively aneutronic at under 1%.

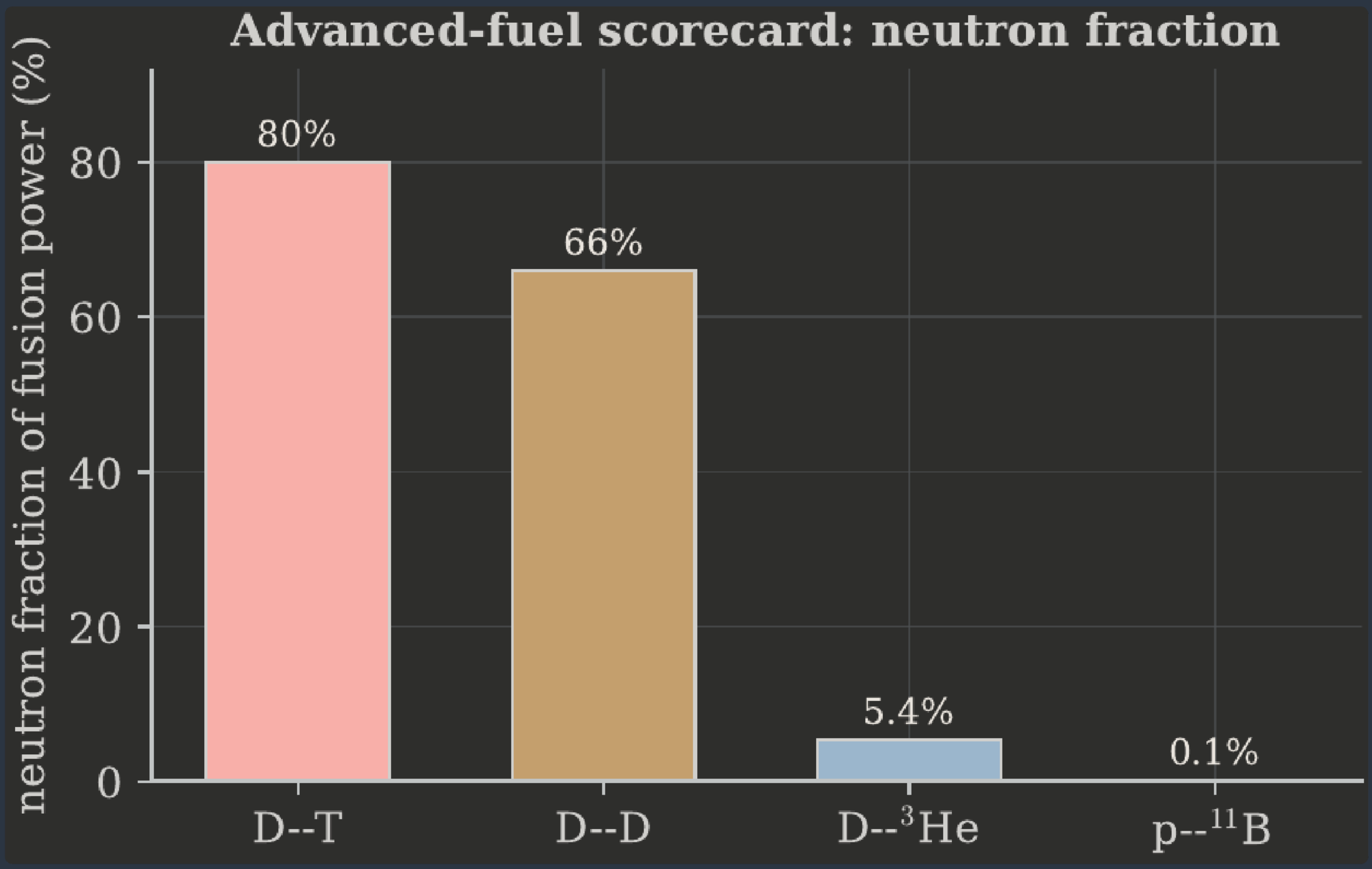


FIGURE 47. The decisive axis: neutron fraction of fusion power across the four fuels. Deuterium–helium-3 combines a low neutron burden with accessible reactivity. PUBLIC REACTION PHYSICS

D–T	Highest reactivity, lowest temperature · but ~80% neutronic and consumes tritium · *demonstrated net gain (NIF)*
D–D	No tritium needed · but ~66% neutronic and low reactivity
D–^{3}HE	Only 5.44% neutronic, reactivity still accessible · but requires helium-3 Earth lacks in bulk
P–^{11}B	Effectively aneutronic · but highest temperature, radiates hardest, *no device has reached net gain*

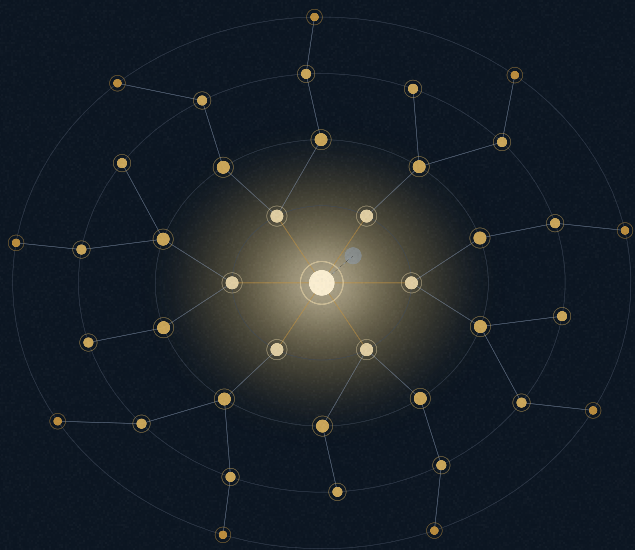
§ 3

The Kronos reading of the scorecard

The architecture follows the grades rather than the ideal. Where the product is the *neutron and the bred material* — tritium, helium-3, isotopes, materials qualification — deuterium–tritium is correct, because its high neutron output is the whole point; this is the breeder. Where the product is *power* and neutrons are a liability to shield and a source of activation, deuterium–helium-3 is correct, because 5.44% is the lowest neutron burden among fuels with accessible reactivity; this is the burner.

Proton–boron is not chosen: its temperature, its radiation, and the absence of any demonstrated gain outweigh its aneutronic appeal *today*. And the one honest cost of the deuterium–helium-3 choice — fuel availability — is met by the breeder's co-product helium-3 and, at fleet scale, lunar supply gated around 2038–40. The scorecard, not the aneutronic ideal, drew the architecture. DESIGN RATIONALE

KRONOS FUSION ENERGY



PAPER 2.28 OF THE 2026 KRONOS SET

The Tensor-Network Kinetic Solver

Classical, Deployable Today

The fusion distribution function is low-rank — a matrix-product-state solver runs today where a quantum one is a decade away.

rank-8 ≈ 0.19× dense · exponential error decay · classical hardware

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§ 1

The curse of dimensionality, sidestepped

A kinetic distribution on six-dimensional phase space is hopeless on a dense grid. Learned surrogates trade fidelity for speed and quantum solvers are a fault-tolerant-horizon prospect. We take a third route: exploit the low-rank structure the distribution actually has.

THE RESULT

On the BGK test the relative-L^2 error falls exponentially with rank — to 2×10^{-4} at rank 8 — while storage grows only linearly to ~0.19× the dense grid. A handful of singular modes capture the distribution to engineering accuracy.

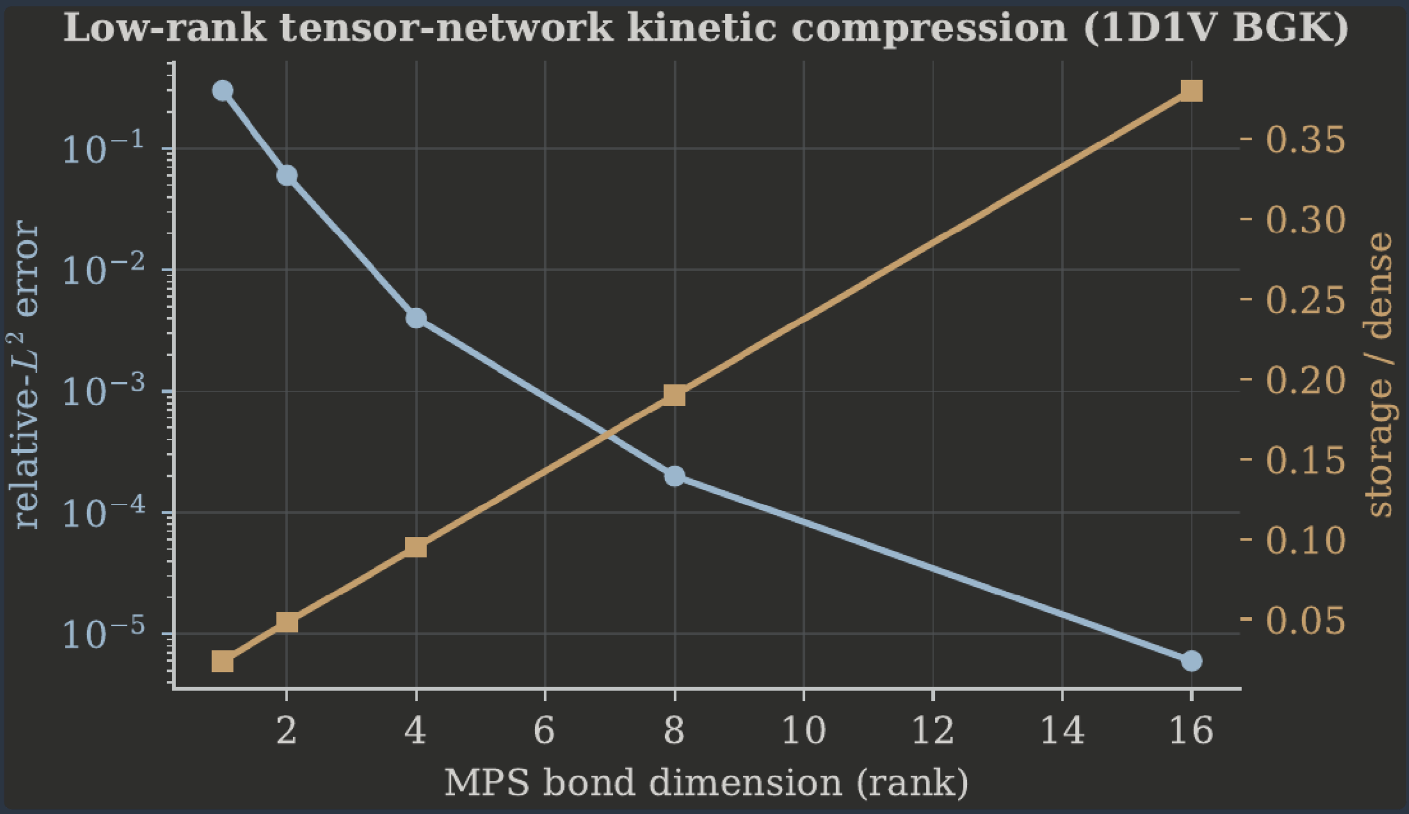


FIGURE 48. Low-rank tensor-network compression of the BGK distribution: exponential error decay and storage vs bond dimension (gate KX-L1-A16). MPS / SVD

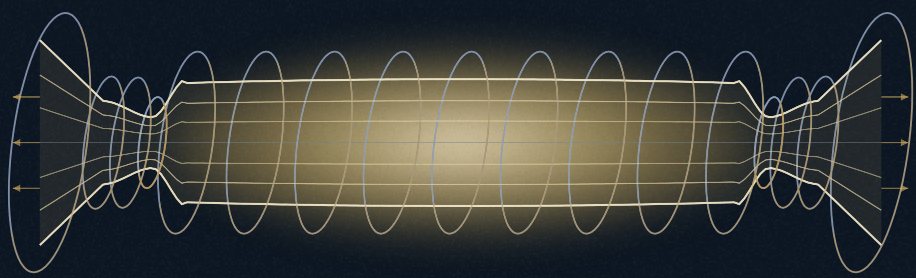
§ 2

A solver, not a storage trick

Because the streaming and collision operators act directly on the compressed representation, the low rank reduces the cost of *advancing* the solution, not merely of holding it — the difference between a solver and post-hoc compression. It runs on classical hardware available now; the compressibility of the full nonlinear gyrokinetic distribution is the honest open question.

CLASSICAL, TODAY

KRONOS FUSION ENERGY



PAPER 2.29 OF THE 2026 KRONOS SET

Synchrotron Radiation Transport

What Pins the Burner Temperature

The D–^{3}He burner is radiation-dominated; a first-principles transport calculation, not an estimate, sets its operating temperature.

P_{-k} 1803 MW (reabsorbed) vs 66,677 optically-thin · 37× band collapsed

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§ 1

Getting the dominant loss right

The case against advanced fuels has always centred on radiation. Whether the burner closes depends on computing the synchrotron loss correctly — not on an order-of-magnitude estimate that can be off by 37×.

THE MODEL SPREAD IS THE PROBLEM

Against a 2546 MW radiated scale, synchrotron loss ranges from 919 MW (Trubnikov) to 1803 MW (reabsorbed transport) to 66,677 MW optically-thin. The last is unphysical — the plasma is optically thick at the harmonics that carry the power. A design adopting any single estimate without the transport calculation is off by up to 37× in its dominant channel.

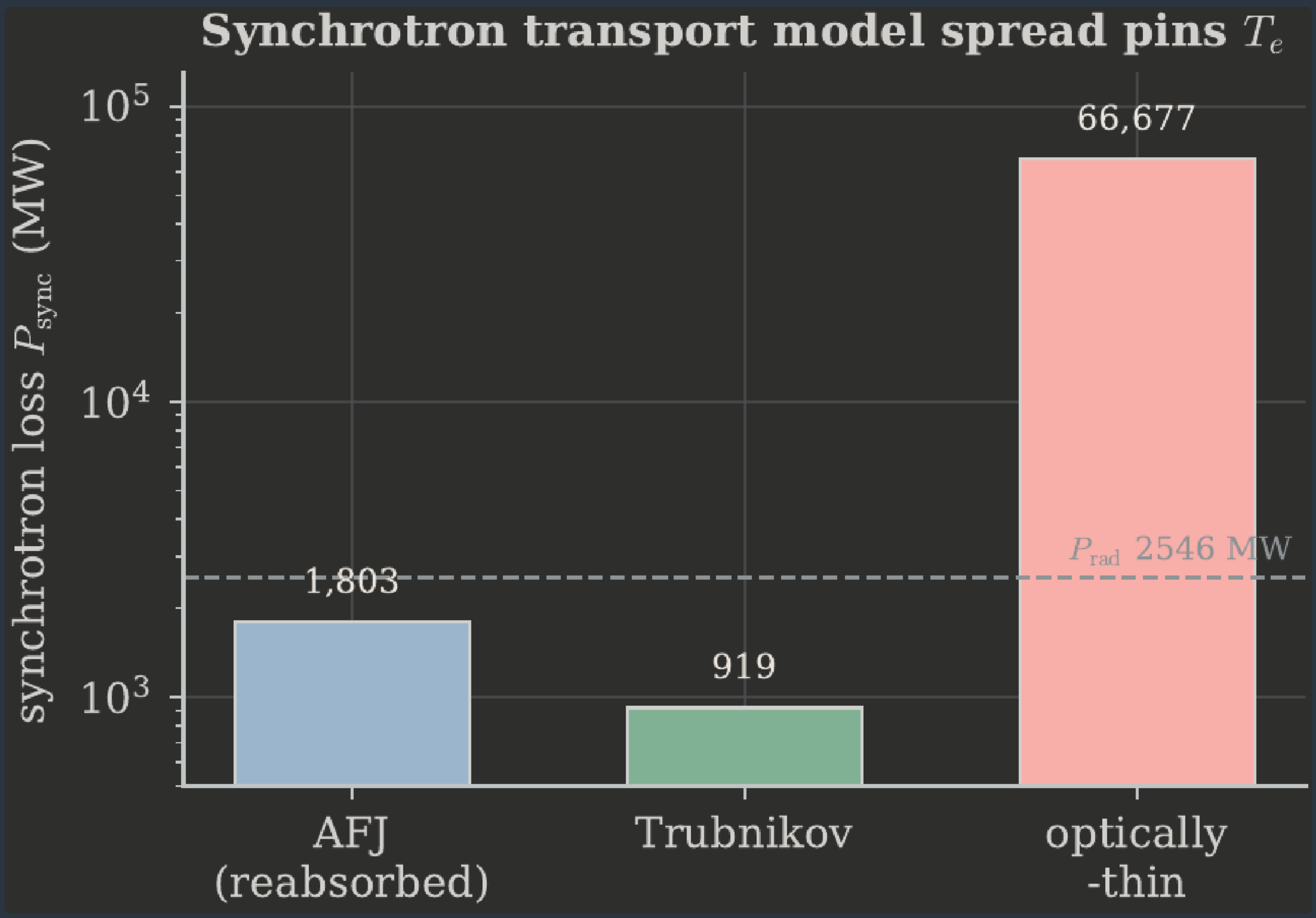


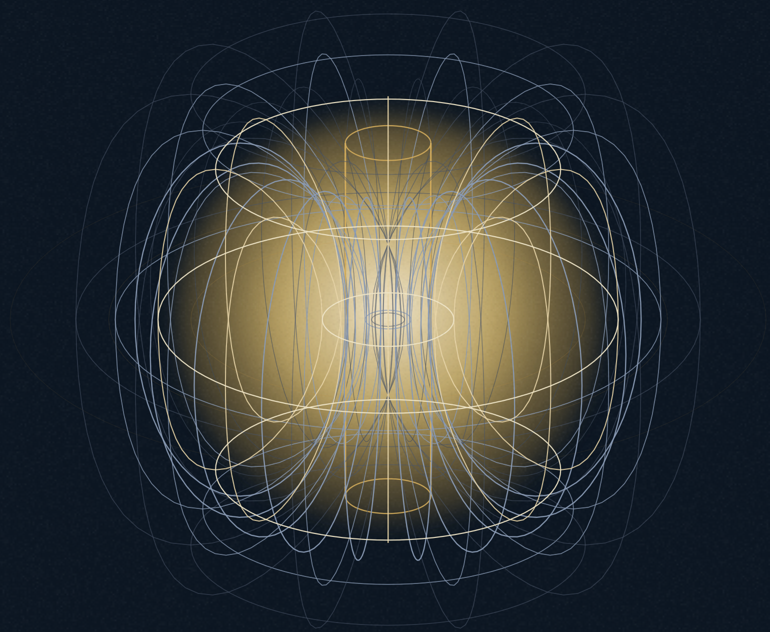
FIGURE 49. Synchrotron loss by model against the radiated-power scale (gate KX-L1-A3-BU). EC TRANSPORT

§ 2

Optical depth, and why size helps

The plasma is optically thick to harmonic $n^*\approx 10.4$; above it the emission escapes. Because that cutoff grows as the one-third power of minor radius, the synchrotron loss *fraction* falls as the machine grows — the analytic origin of the burner's size-scaling. Synchrotron loss rises steeply with electron temperature while fusion power saturates, so there is a maximum-Q_E temperature, and the transport calculation locates it. FIRST-PRINCIPLES

KRONOS FUSION ENERGY



PAPER 2.30 OF THE 2026 KRONOS SET

First-Wall Damage Lifetime

How Long the Wall Survives

Activation tells you what the wall becomes; this tells you how long it lasts — dpa, swelling, erosion, permeation.

9.78 dpa/fpy behind armor · displacement-limited · scheduled replacement

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§ 1

The survival question, answered directly

The first wall sees the full 14 MeV flux and the plasma edge, and it is a consumable. The question is how long it lasts before displacement damage, gas swelling, erosion, or hydrogen uptake forces replacement. We compute all four and identify the binding one.

THE LIFE-LIMITER

Displacement damage accumulates at ~9.78 dpa/fpy behind the armor, reaching replacement-class damage within a few full-power-years — the governing limit. Gas swelling, erosion, and permeation are quantified and subdominant.

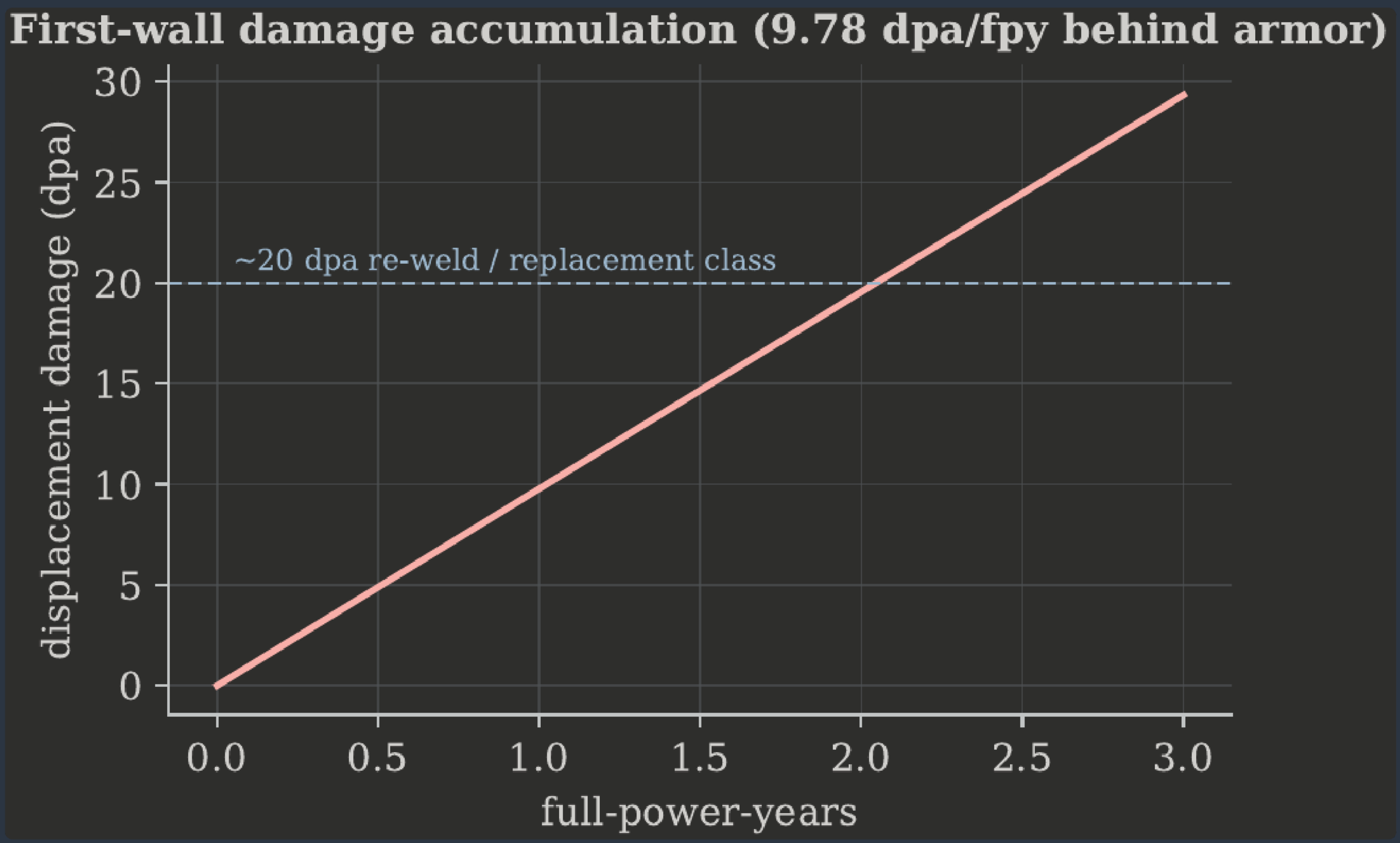


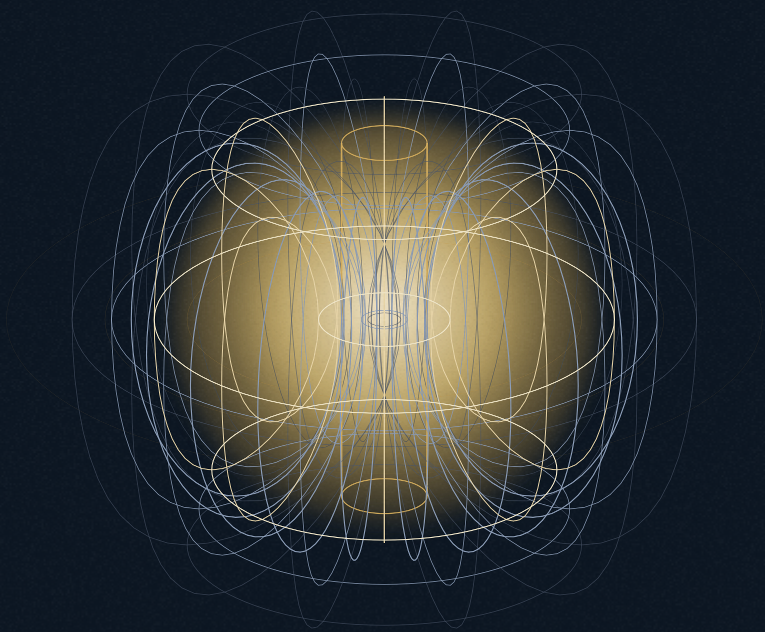
FIGURE 50. First-wall displacement-damage accumulation at 9.78 dpa/fpy (gate BR-L2-A24). SPECTRA-PKA / MD

§ 2

The other three channels, bounded

Helium/hydrogen bubbles (kinetic Monte Carlo on DFT binding energies) accumulate but do not reach life-limiting swelling; sputtering/erosion (binary-collision transport) is manageable within the displacement-limited interval; and hydrogenic permeation (finite-element transport) sets the tritium-inventory boundary condition the fuel-cycle and safety papers carry. The wall is a scheduled-replacement component on a defined damage budget. INDEPENDENT CODES

KRONOS FUSION ENERGY



PAPER 2.31 OF THE 2026 KRONOS SET

The TBR Error Bar

Which Cross-Sections Actually Matter

A breeding ratio without a tolerance is a point without an error bar — and the light channels dominate it.

light channels 55–66% spread · heavy structural ~15% · a data requirement

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§ 1

A point needs a tolerance

The breeding ratio is the number the whole breeder case rests on, and its credibility depends on the light-element cross-sections behind it. A responsible design states not just the TBR but its nuclear-data tolerance, and identifies which channels drive it.

THE LIGHT CHANNELS DOMINATE

The breeding-carrying light channels diverge 55–66% between evaluated and model data at 14 MeV — an order of magnitude more than the ~15% spread of the heavy structural channels. Because the TBR is near-linear in the light rates, those channels are the error bar; the voluminous structural data contributes little.

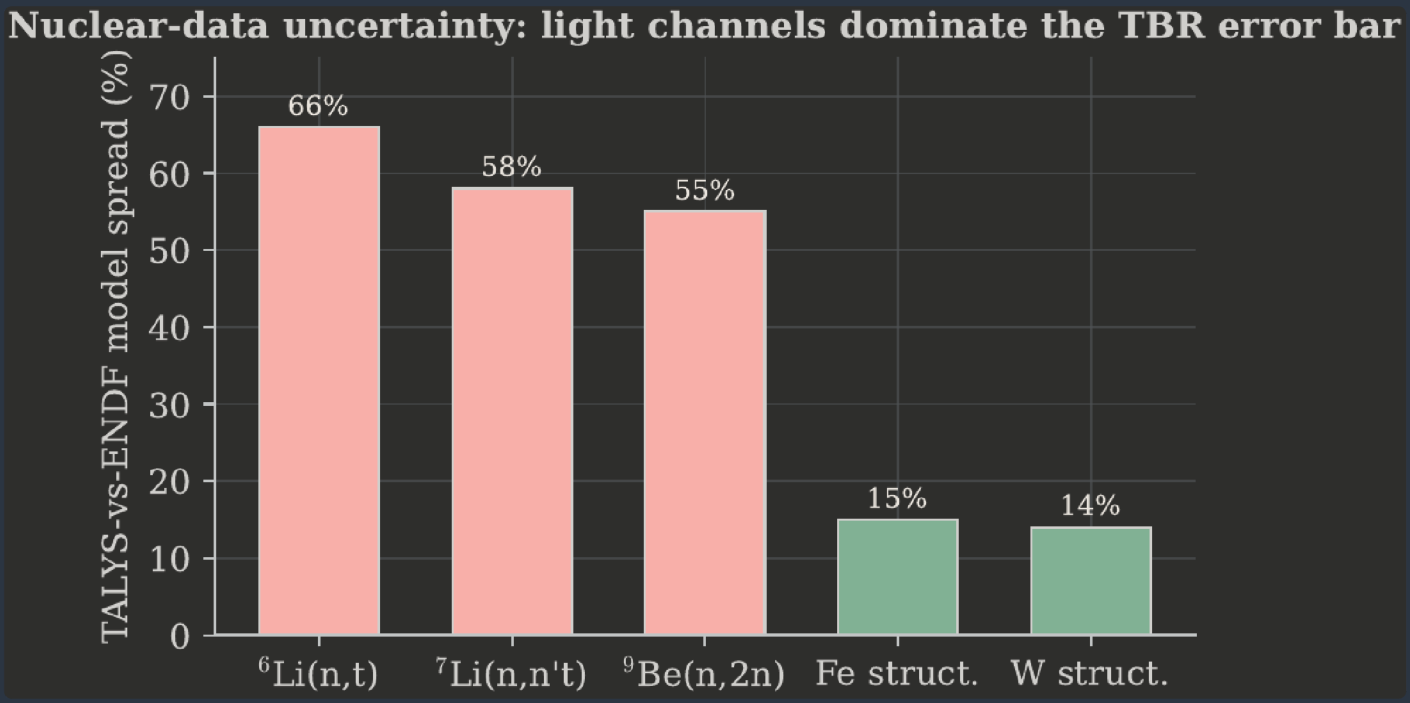


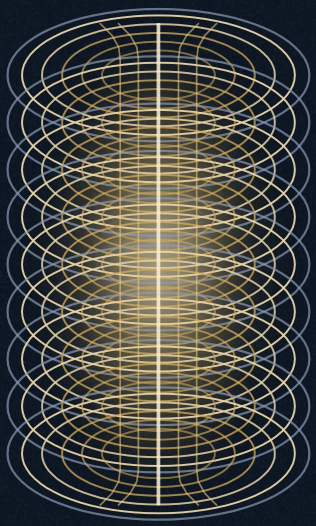
FIGURE 51. TALYS-vs-ENDF model spread by channel at 14 MeV: light breeding channels dominate the TBR error bar (gate BR-L2-A28). ENDF / TALYS

§ 2

The requirement

The consequence is a data requirement, not a caveat: the light breeding channels must be taken from evaluated covariances and, where the field's evaluations disagree, targeted by measurement. Reporting a TBR without propagating these covariances understates the tolerance on the most load-bearing number in the design. DATA REQUIREMENT

KRONOS FUSION ENERGY



PAPER 2.32 OF THE 2026 KRONOS SET

Conductor Materials Under Irradiation

The Neutron Environment Selects the Tape

In a neutron environment the conductor spec changes: un-doped tape wins, and two new materials protect the coil.

un-doped > doped for fluence life · graphene-Al stabilizer · V_2O_3 interlayer

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§ 1

The tape you want changes

A fusion magnet's conductor is chosen for field and stress, but it must survive years of fast-neutron fluence at cryogenic temperature — and the irradiation environment selects a different tape than a room-temperature optimization would.

THE UN-DOPED RULE

Artificial-pinning-centre tapes raise the in-field critical current but reach their irradiation-damage knee sooner. For fusion fluence the plain un-doped tape retains a longer service life, because neutron irradiation supplies its own pinning — an inversion of the usual selection, with a J_c-onset-knee surrogate to screen candidates.

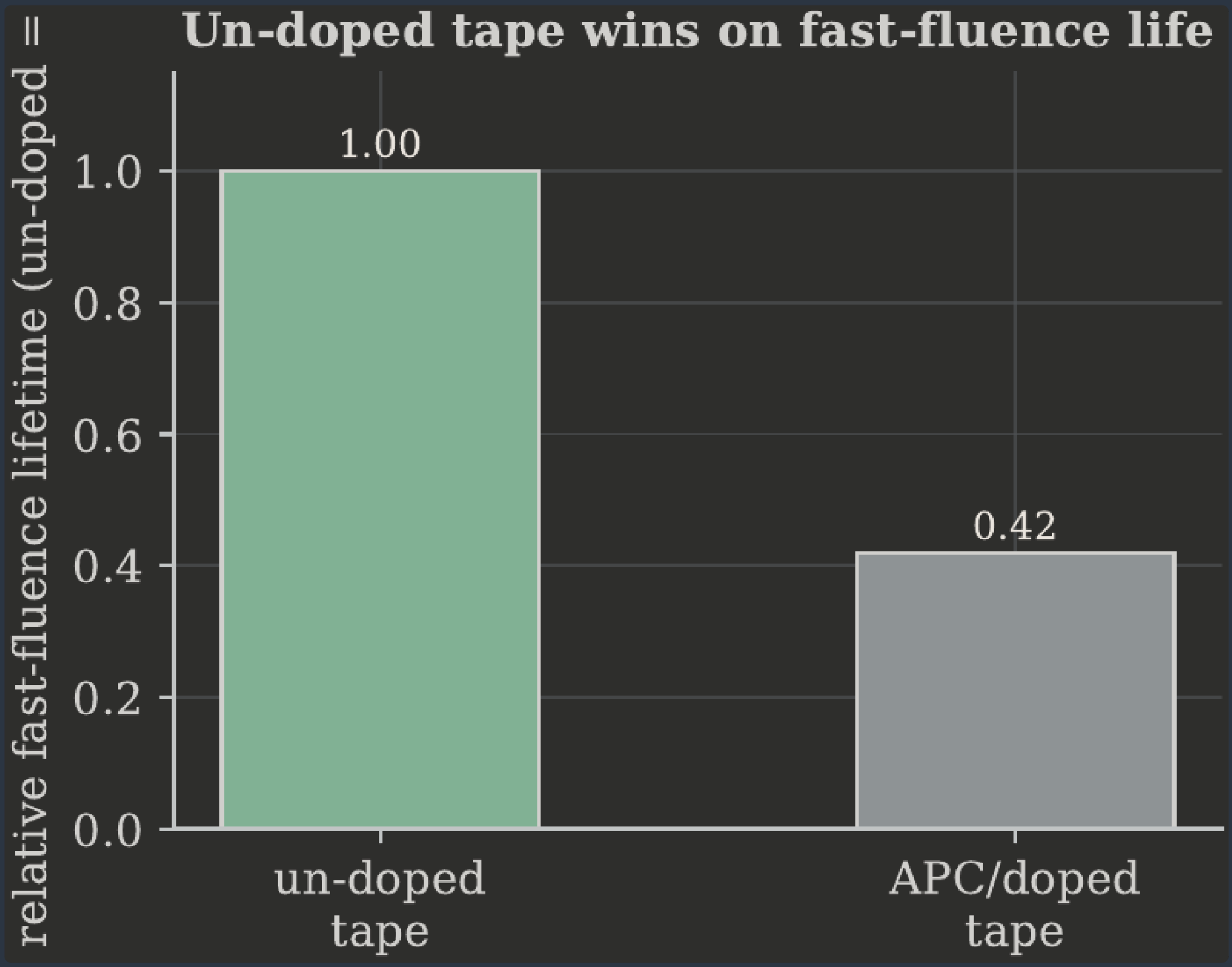


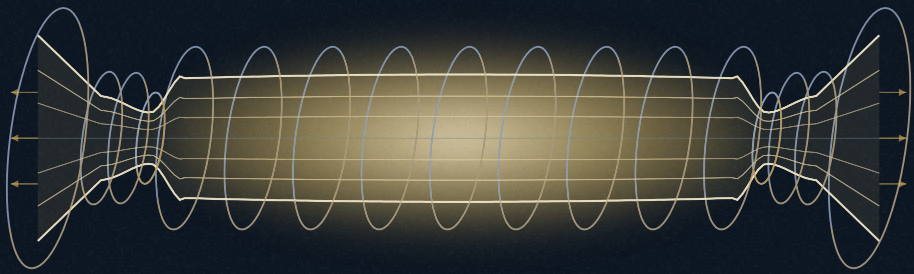
FIGURE 52. Relative fast-fluence lifetime: un-doped tape outlasts the doped tape (gates #33/46/66/68). SCREENING

§ 2

Stabilizer and self-protection

A graphene-reinforced ultra-pure aluminum stabilizer retains ~2×10^4 S/cm at cryogenic temperature in 30–35 T, a lighter, lower-loss bypass than copper; and a vanadium-sesquioxide (V_2O_3) interlayer gives *passive* quench protection — insulating in normal operation, conducting to shunt current turn-to-turn once a turn heats. A conductor architecture for a neutron environment, distinct from the magnet's field/stress design. MATERIALS ARCHITECTURE

KRONOS FUSION ENERGY



PAPER 2.33 OF THE 2026 KRONOS SET

Thermal-Barrier Decoupling

The Cornerstone Plug Mechanism

The thermal barrier lets the plug hold a big potential without a hot central cell — the lever that lifts Q_E.

ϕ_i 248.75→167.9 keV (33% gate cut) · Q_E 1.3→3–5

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§ 1

Breaking the coupling

A tandem mirror plugs its central cell with a potential, and the hotter the central-cell electrons, the more potential (and power) the plug must supply. The thermal barrier breaks this coupling — letting the plug hold a large ion-confining potential while keeping the central-cell electrons cool.

> **THE GATE CUT**
>
> Booking the barrier, the confining-potential requirement falls from 248.75 to 167.9 keV — a 33% cut in the binding gate. Heating the barrier hot electrons rather than the whole central cell removes ~1093 MW of ECH, and in the aggressive limit lifts Q_E from ~1.3 toward 3–5.

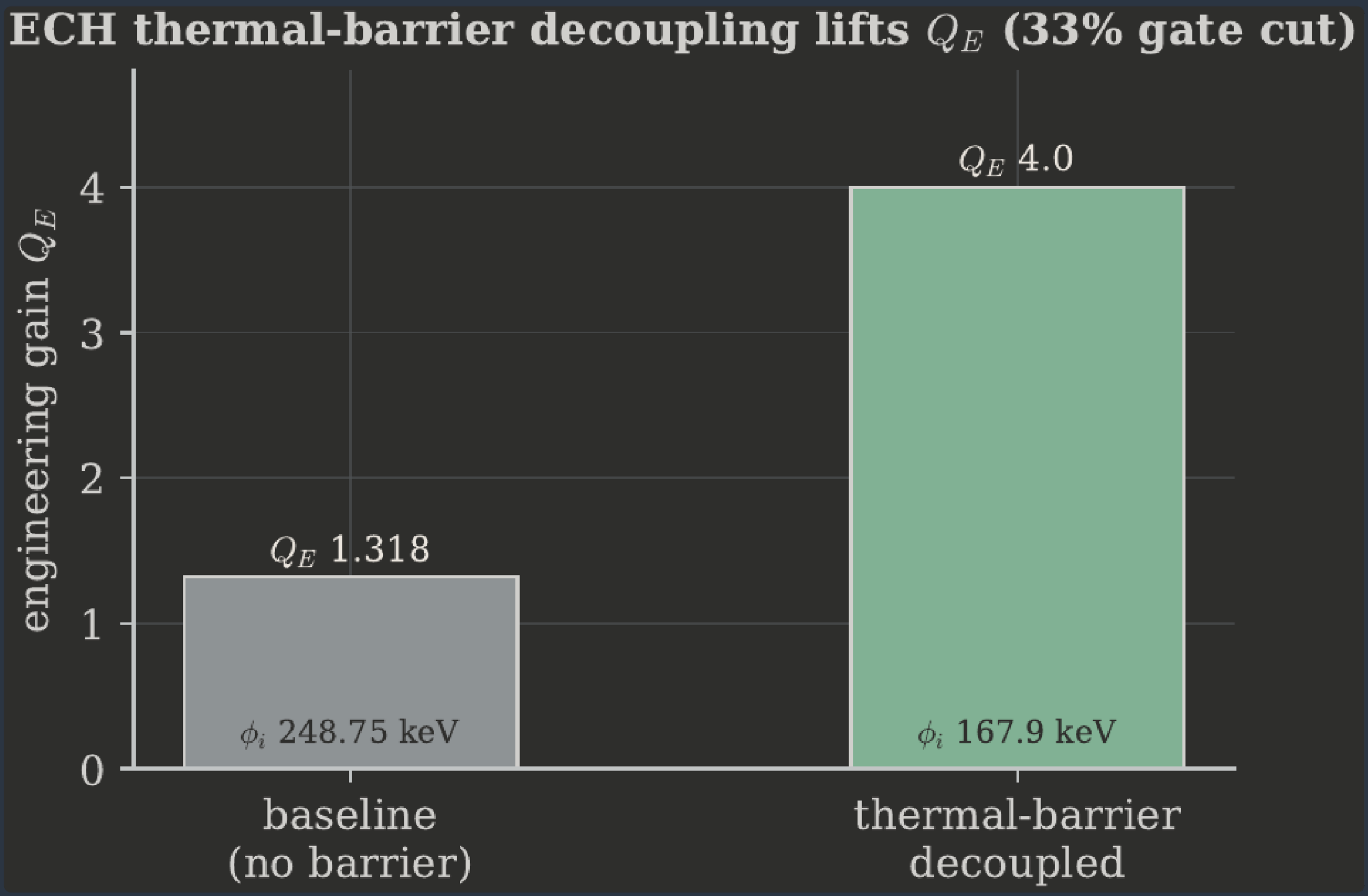

FIGURE 53. Thermal-barrier decoupling lifts Q_E and cuts the confining-potential requirement 33% (gate KX-L1-A13-BU). MODEL

§ 2

One named experiment

The barrier is the burner's cornerstone claim, and its distance to demonstrated closure is a single WHAM-scale thermal-barrier experiment that establishes the sustained depression and the decoupling at accessible field and density — a plasma-physics experiment, not a materials or magnet gate. CORNERSTONE CLAIM

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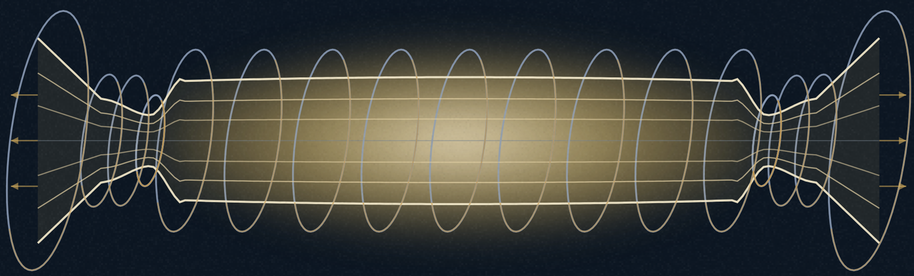

PAPER 2.34 OF THE 2026 KRONOS SET

The HVDC-Native Power Interface

MetroVolt to the Data-Center Bus

A direct-energy-conversion machine is intrinsically an HVDC source — a shorter, different electrical interface.

~54% DC-native at 50–250 kV · 800 VDC in 2–3 stages · ms load-following

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§ 1

Not an AC machine in disguise

Most fusion power-plant studies assume an AC turbine hall. A direct-energy-conversion machine does not have one: its converters produce DC at high voltage. When the load is a data center — itself a DC bus — the interface is shorter and different.

AN HVDC-NATIVE SOURCE

About 54% of gross output is delivered as DC at 50–250 kV, with no synchronous generator and no grid-frequency stage. Reaching an 800 V rack bus takes 2–3 stages, against 4–5 for a conventional AC plant that must synchronize then rectify.

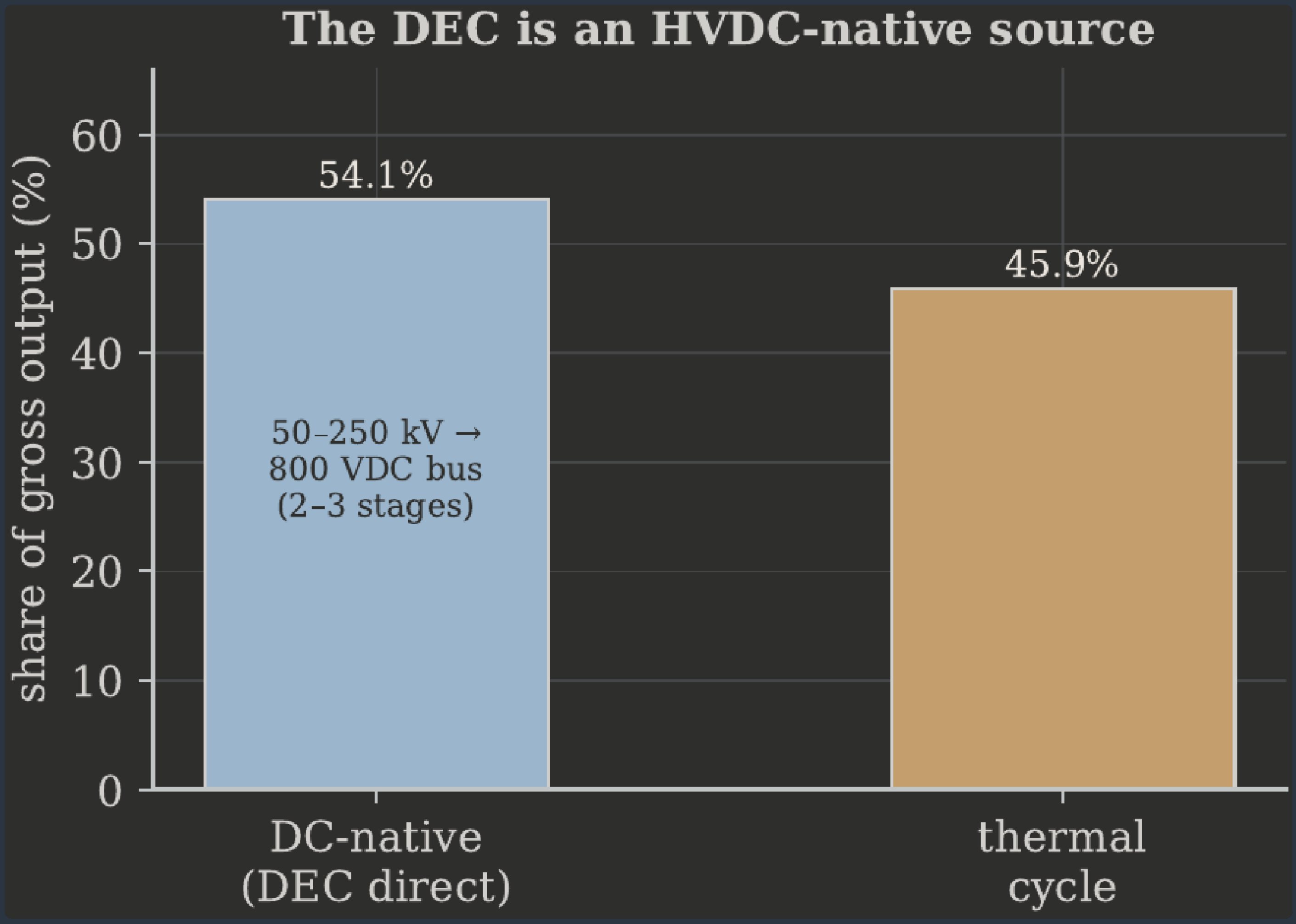

FIGURE 54. The direct-energy converter delivers ~54% of gross output as HVDC (gate MV-L1-A3). ARCHITECTURE

§ 2

Follow the load with electronics, not plasma

A direct converter modulates at ms scale. Following the load by throttling the plasma is far more costly: the gross-to-net amplifier is 4.14, so a 10% plasma dip cuts net export ~41%. Load-following is done on the electronic path with dump and storage, holding the plasma at its efficient point. Economics, siting, and service-level content are internal and excluded. POWER ELECTRONICS

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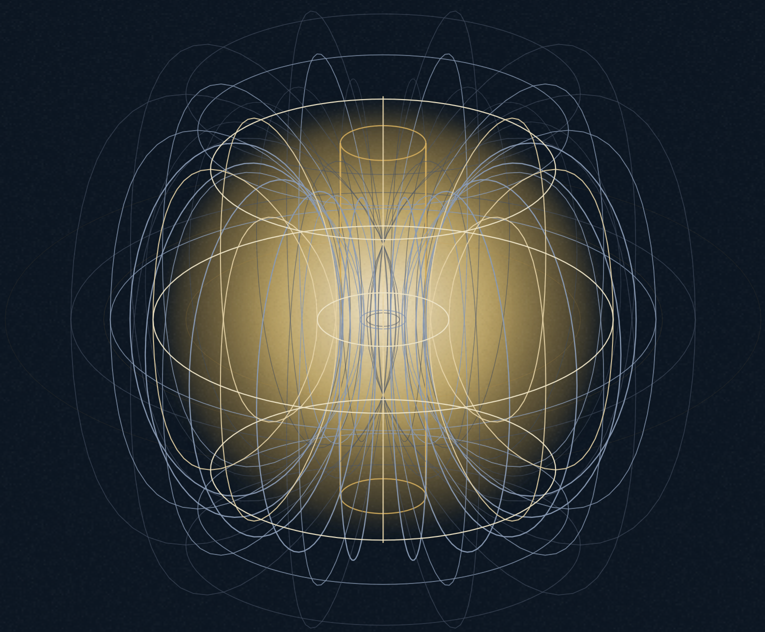

PAPER 2.35 OF THE 2026 KRONOS SET

Supply Chain & Buildability

Can It Be Built at Fleet Rate

A machine that closes on physics can still fail to be built — unless its longest-lead item is relaxed.

^{6}Li 90% = #1 long-lead, relaxable to 30–60 at% · consumable-cartridge line

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§ 1

Buildability is de-risking too

A breeder fleet needs enriched lithium, nuclear-grade beryllium, and long REBCO tape in quantities and on timelines that must be checked. We rank the bottlenecks and report the relaxations that move them, keeping cost out of scope.

THE ENRICHMENT RELAXATION

The longest-lead item is 90%-enriched lithium-6 — but the neutronics meet the breeding target at 30–60 at%, because the compact geometry and multiplier recover the breeding the lower enrichment would cost. Relaxing the spec moves the single hardest item off the critical path, with no physics penalty.

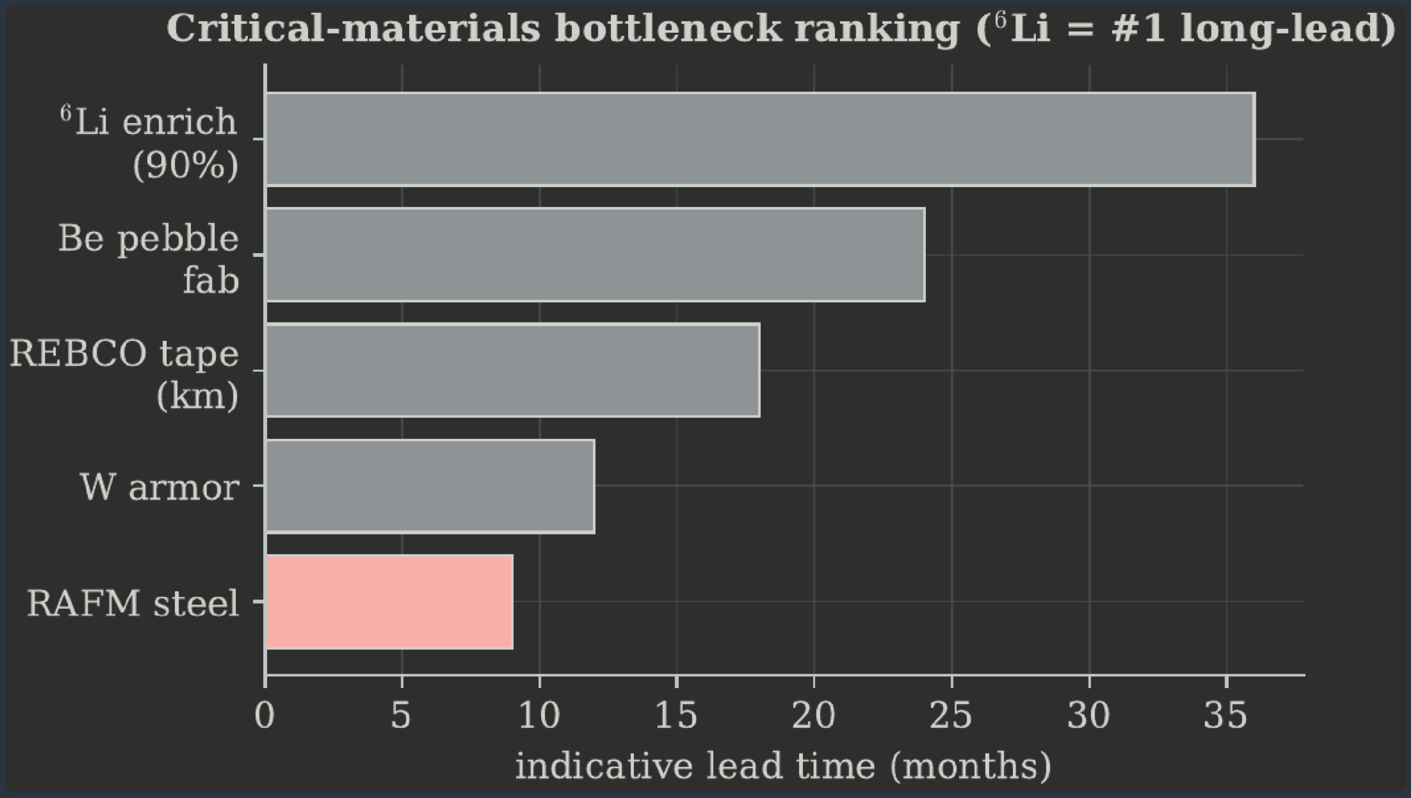


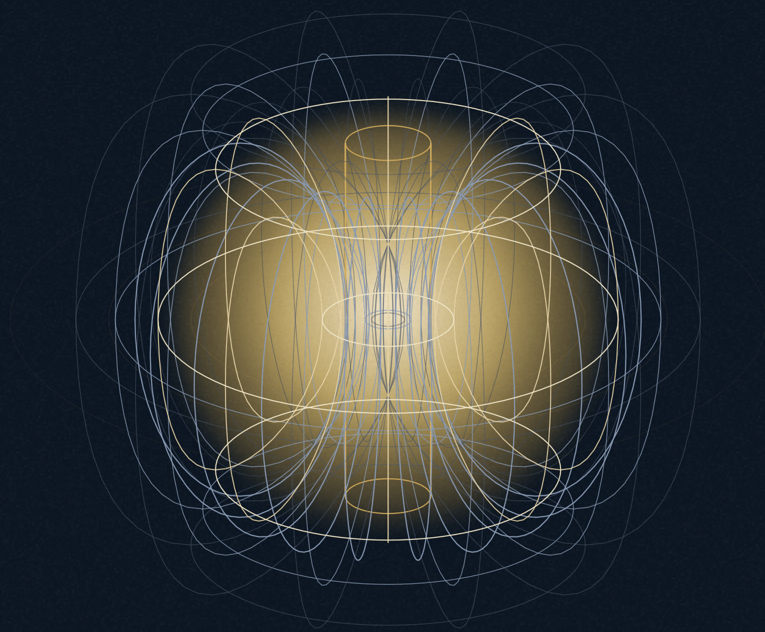
FIGURE 55. Critical-materials lead-time bottleneck ranking; enriched lithium-6 is the binding long-lead item (gate SC-BR-1). BOM

§ 2

A cartridge line, not a bespoke build

Because the centrepost is a consumable, it is manufactured as a cartridge on a ~10–15 unit/yr line rather than fabricated as a bespoke lifetime component — converting a single-point manufacturing risk into a production-rate specification ordinary industry can meet. All cost content stays internal. BUILDABILITY

KRONOS FUSION ENERGY



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Prognostics for the Consumable Centrepost

Knowing When to Replace It

If the centrepost is a consumable, knowing when to replace it is a control problem — that fails safe.

dual-channel RUL estimator · out-of-distribution backstop

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§ 1

A live estimate, not a fixed interval

A consumable component is only manageable if you can predict its end of life before it arrives. A dual-channel estimator fuses a physics-based fluence trajectory with a damage-correlated in-situ observable, giving a live remaining-useful-life with a confidence interval that drives the maintenance cadence — rather than a static worst-case number.

THE BACKSTOP IS THE POINT

A data-driven estimator is trustworthy only inside its trained regime; extrapolated past its support it can be confidently wrong. The framework monitors whether signals stay in-distribution and, when they do not, defaults to the conservative physics bound — the difference between a decision aid and a hazard.

PHYSICS FLUENCE MODEL	deterministic damage trajectory (guards sensor dropout)
IN-SITU OBSERVABLE	live estimate update (guards model drift)
OUT-OF-DISTRIBUTION BACKSTOP	defaults to conservative bound (guards confident extrapolation)

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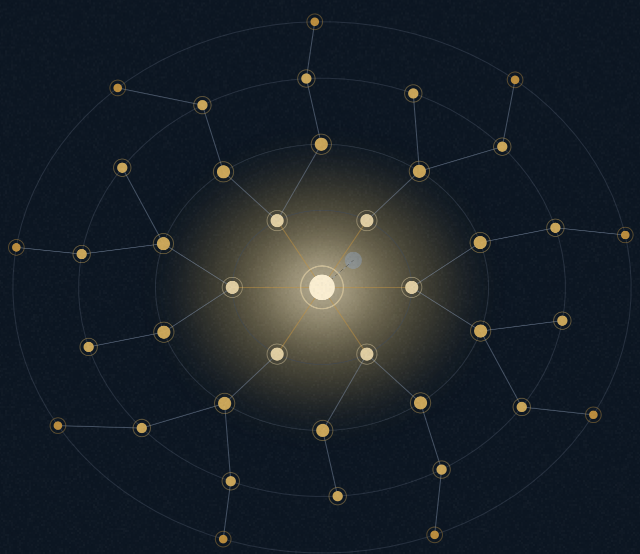

PAPER 2.37 OF THE 2026 KRONOS SET

Maturity-Gated Actuation Authority

Trust Earned by Evidence

A controller should have exactly as much authority as the evidence behind its models can justify — no more.

PCMM maturity → runtime authority · an auditable governance rule

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§ 1

Authority as a function of evidence

Automated control on a regulated machine raises a governance question usually answered by fiat: how much authority should the automation have? We answer it by tying authority to evidence. A subsystem whose models are validated has earned more autonomy than one whose models are still reduced-order.

THE PRINCIPLE

The maximum authority — magnitude, rate, irreversibility — a controller may exercise on a subsystem is a monotone function of that subsystem's maturity score. High-maturity subsystems admit wide, fast authority; low-maturity ones are clamped to a narrow, reversible band, the balance deferred to a human or a physics-bounded safe controller.

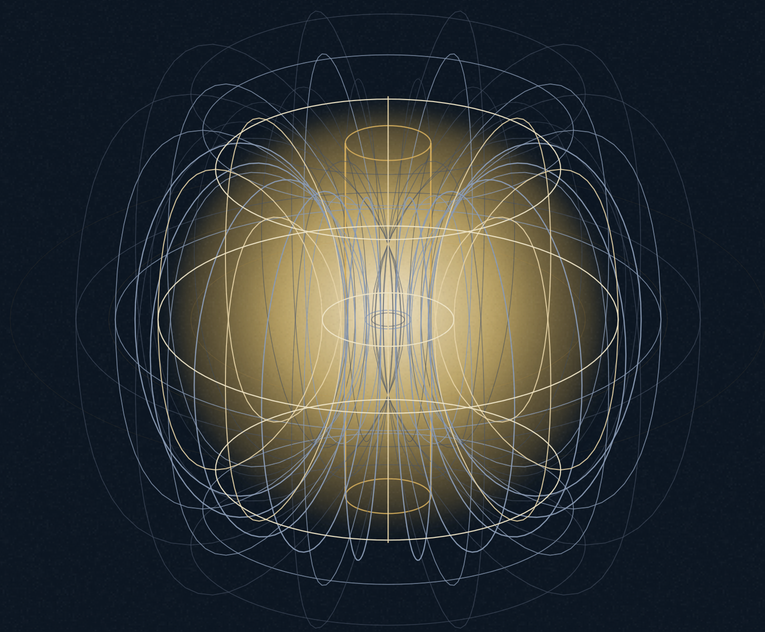
MACHINE-VALIDATED	wide, fast, includes irreversible actions · controller-led
CONVERGED	moderate, rate-limited · controller with human confirm
REPRESENTATIVE / REDUCED-ORDER	narrow, reversible only · human or physics-bounded

§ 2

An auditable rule for licensing

The principle gives a regulator an auditable governance rule rather than a promise: authority is derived from documented model maturity and expands only as that maturity is demonstrated — a property a licensing review can inspect. GOVERNANCE

KRONOS FUSION ENERGY



PAPER 2.38 OF THE 2026 KRONOS SET

The Materials-Discovery Pipeline

Activation as a First-Class Filter

An automated funnel from thousands of candidate alloys to a qualified handful — with activation screened early.

CHGNet screen → DFT confirm → activation down-select

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§ 1

An intractable search, funneled

A refractory high-entropy alloy space has more candidates than any team can evaluate by density-functional theory directly, and for fusion each must pass a stability *and* a neutron-activation test. Searching it requires a method fast enough to screen thousands and strict enough to enforce activation.

THE THREE-STAGE FUNNEL

A universal ML potential ranks thousands of compositions by formation energy at a fraction of DFT cost; DFT confirms the survivors at full accuracy; and an activation-transport down-select rejects any whose waste class or decay heat is unacceptable, regardless of mechanical merit — a qualified handful from an intractable start.

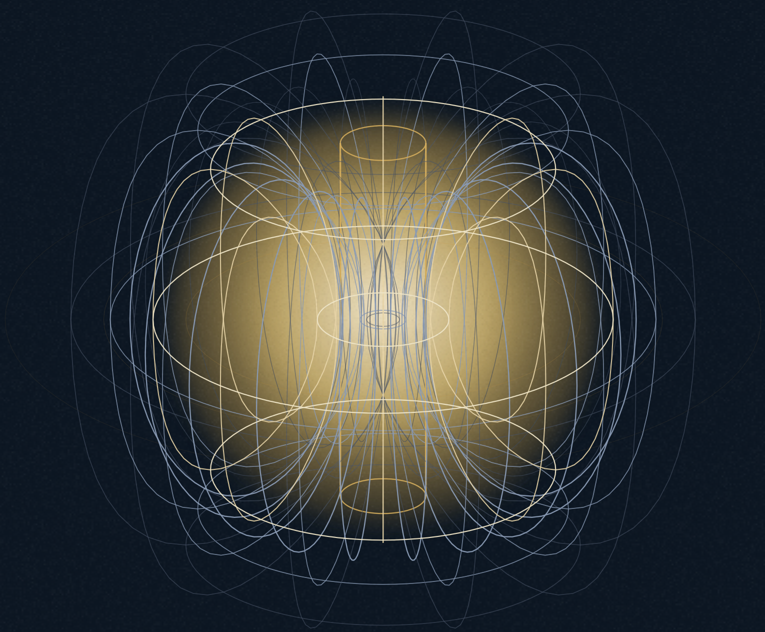
1 SCREEN	universal ML potential (CHGNet) · formation energy · thousands
2 CONFIRM	density-functional theory · stability at full accuracy · tens
3 DOWN-SELECT	OpenMC → FISPACT activation · waste class + decay heat · handful

§ 2

Why activation goes early

The novelty is not the ML potential alone — it is placing neutron activation as a co-equal filter with stability, early. A refractory alloy that is excellent but activates into a high-level-waste class is useless to a plant, and screening it out only at the end wastes the search. The alloy *results* are the materials companion; this is the *method*. MATERIALS INFORMATICS

KRONOS FUSION ENERGY



PAPER 2.39 OF THE 2026 KRONOS SET

The Admissible Operating Window

Which Constraints Actually Bind

A breeder's operating point is boxed by competing constraints — and there is no free operating-point gain.

S_n ↔ centrepost-life invariant · q95/MHD floor, fluence ceiling · startup 1.7× margin

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§ 1

No free lunch in the operating plane

Where a breeder operates is decided by the constraints that box it in, not a single figure of merit. Across the whole operating plane, source strength and wall loading trade one-for-one against centrepost life — a fixed ratio, no corner where more neutron output comes free of centrepost cost.

THE BOX, AND WHAT BINDS

The admissible current is a coupled floor/ceiling problem: the floor is the q95/MHD edge, the ceiling the centrepost fluence, and the tritium-startup requirement — often assumed binding — sits inside with ~1.7× margin. So the true floor is the MHD edge, not fuel startup; the design current 9.66 MA sits inside.

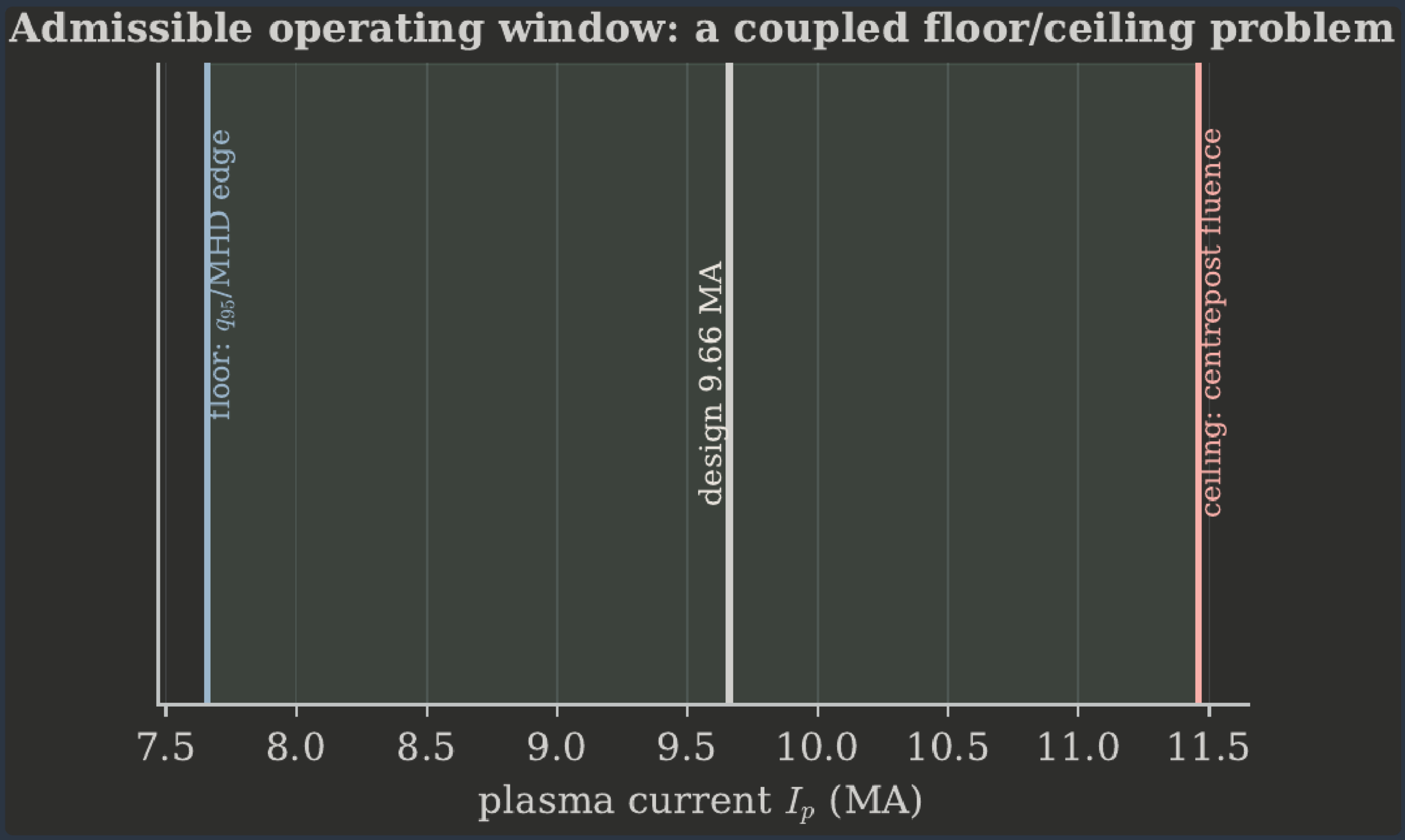

FIGURE 56. The admissible plasma-current window: q95/MHD floor, centrepost-fluence ceiling, design point inside (gate KX-L1-A21). CONSTRAINT MAP

§ 2

The actionable output

The synthesis identifies which constraints bind: the centrepost-fluence ceiling and the MHD-edge floor do; the tritium-startup floor does not. A designer moving the operating point trades centrepost life against edge stability, with fuel startup a non-issue in this window — a clearer picture than treating all constraints as co-equal. SYSTEMS SYNTHESIS

APPARATUS

Portfolio, People & Record

The intellectual-property estate, the people who built it, the limitations that gate it, and the sources it rests on.

1	4	40	27
GRANTED PATENT	2026 PROVISIONALS	TEAM MEMBERS	2022 PROVISIONALS

INTELLECTUAL PROPERTY

The patent portfolio

The estate spans a granted high-field magnet patent, pending utility and 2026 provisional filings that map to the two products, a digital-twin control provisional, a registered trademark application, and the original 2022 provisional family. Every patentable disclosure in the five-paper arXiv drop was protected **before** publication: the breeder and burner provisionals were filed 1–2 August, and a publication-gap omnibus filing the evening before the drop swept up the DEC, plasma-control, and REBCO-winding matter of the three otherwise-unprotected papers. Patent numbers and application serials are matters of public record; claim scope is summarised, not reproduced.

GRANTED & PENDING UTILITY

US 12,009,112	High-field tilted graded-REBCO magnet architecture (KRONO-002A) · *app. 17/878,550*	GRANTED
US 17/878,507	Core device / method (KRONO-001A) · *utility*	PENDING

2026 PROVISIONAL FILINGS — MAPPED TO THE PRODUCTS

64/124,209	Hyperion — spherical-tokamak tritium / helium-3 foundry · *breeder · filed Aug 2026*	FILED
64/124,220	Aegis / MetroVolt — synchrotron-cutoff, fuel-selection & plug-winding · *generator · filed Aug 2026*	FILED
64/115,167	KRONOS-CTRL digital-twin plant control · *provisional · filed Jul 2026*	FILED
64/005,440	Integrated spherical-tokamak fusion architecture · *early integrated-architecture filing · filed Mar 2026*	FILED
64/105,530	Negative-triangularity spherical-tokamak architecture · *foundational ST filing · filed Jul 2026*	FILED
64/128,097	Publication-gap omnibus — quasineutral two-species expander DEC · provenance-gated / latency-split plasma control · as-built high-field winding & conductor architecture · *filed 7 Aug 2026, the evening before the arXiv drop*	FILED

TRADEMARK & ORIGIN

FTK-98801894	Kronos Fusion Energy — trademark application	FILED
KR-2022-*	Original provisional family (KR-2022-00001 … 00027) · *27 filings, 2022*	PRIORITY

The narrow, defensible magnet novelty — the specific conductor and the digital-twin winding optimisation, not high-field REBCO as a category — is the commercial core that can earn ahead of any Q > 1 milestone, with markets in fusion magnet supply, MRI/NMR, accelerators, and proton therapy. The claim is scoped honestly: the high field is a *system field* result, not a stand-alone-coil record; the small-bore plug coil is structurally infeasible as a bare winding but resolved by a stress-managed structural shield (feasible-pending-FEA); and the winding-tape experiment returned a *null result*. The value is the method, not a field record.

THE TEAM

Founding partners, board, advisors & auditors

Kronos is built by a bench of advanced-fuel-fusion, high-field-magnet, direct-conversion, and materials specialists, with a board and operations team drawn from defense, national laboratories, and industry. Dates are shown as ranges; where a tenure has ended or is term-ending, the range says so.

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List of Figures

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