KRONOS FUSION ENERGY

STRATEGIC ISOTOPE & POWER SYSTEMS · UNITED STATES

Two Machines, Three Results

A spherical-tokamak breeder and a D–³He tandem-mirror generator

A combined design study: three general results for deuterium plasmas, a compact tritium/helium-3 breeder, and a deuterium–helium-3 tandem-mirror generator with direct energy conversion — the physics and the machines.

Breeder · spherical tokamak · D–T · Q = 3.424 · 88.7 MW_{fus}

Generator · D–³He tandem mirror · 440 m · direct conversion

Three general results · two machines · one fuel doctrine

PREPARED BY

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Founder & Chief Executive Officer

PUBLIC EDITION — PHYSICS & DESIGN (NO FINANCIAL CONTENT)

2026 Edition
Combined Editorial

KFE

KRONOS FUSION ENERGY · 2026

The Kronos Fleet

Fuel follows purpose, not platform.

Hyperion · Aegis · MetroVolt

THE FLEET AT A GLANCE

One fuel doctrine, two machines

The company builds around a single rule: *fuel follows purpose, not platform.* A breeder wants reactivity, so it burns deuterium–tritium; a clean-electricity generator wants a directable, low-neutron output, so it burns deuterium–helium-3. The two figures below are the whole program on one spread — the isotope foundry that funds the company now, and the generator it funds toward.

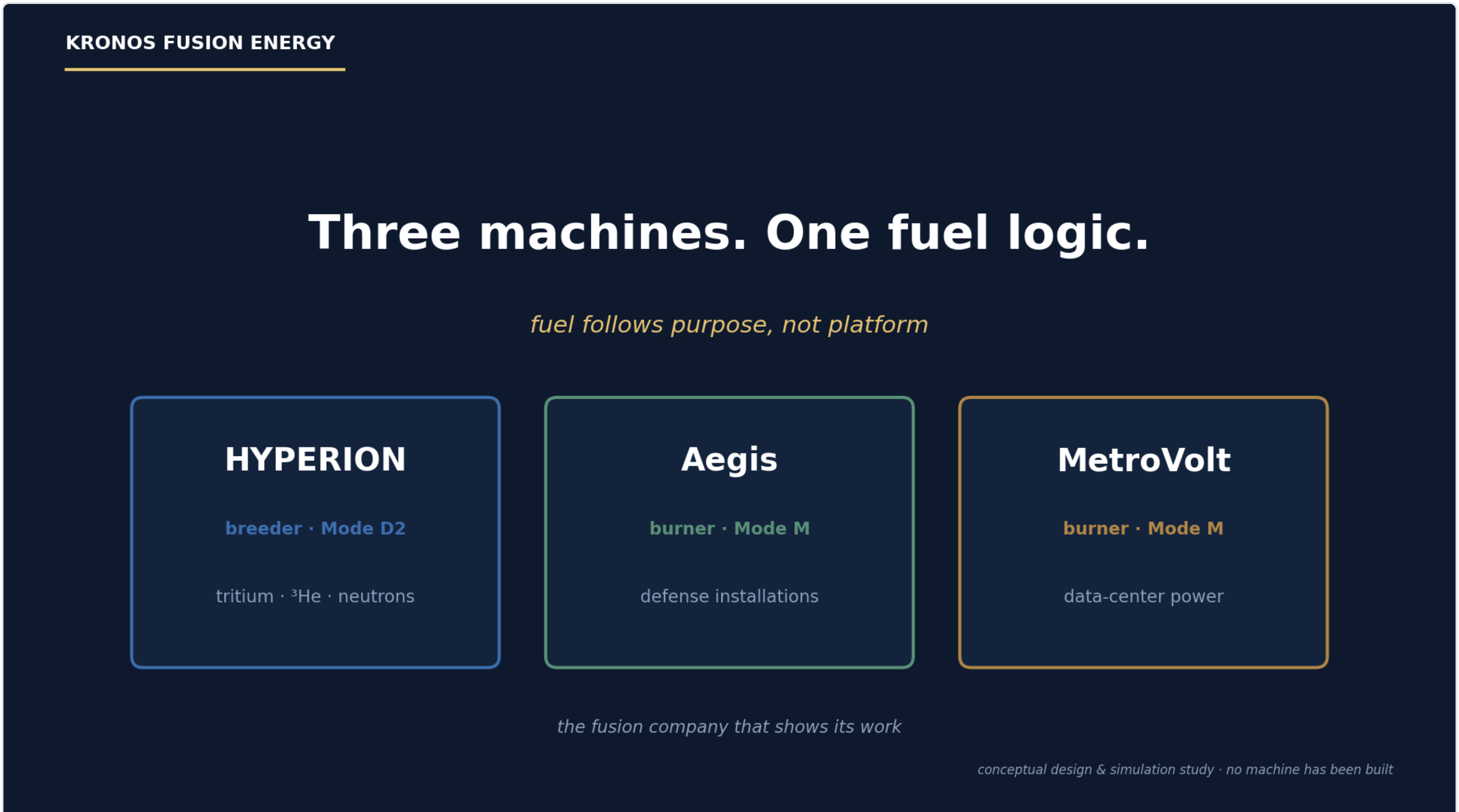

PLATE I. The Kronos fleet — three machines on three clocks: Hyperion breeds the fuel, Aegis proves the generator, MetroVolt is the commercial destination.

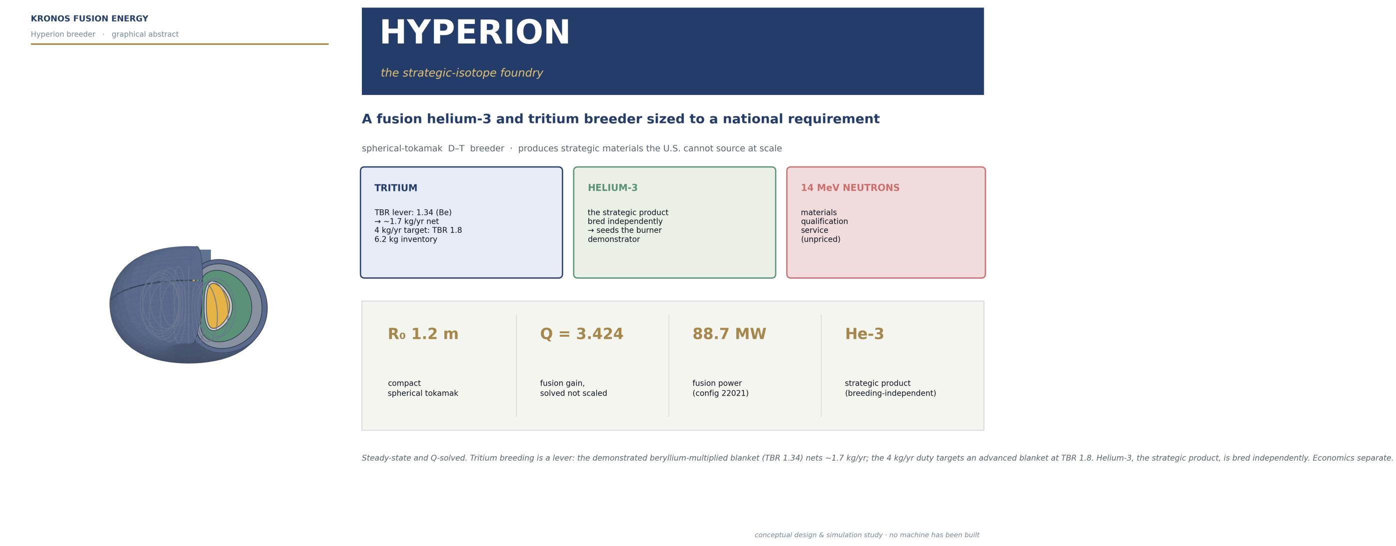

PLATE II. Hyperion — the spherical-tokamak tritium/helium-3/neutron foundry. Buildable on fusion gain alone; sized to the national tritium requirement rather than a physics optimum.

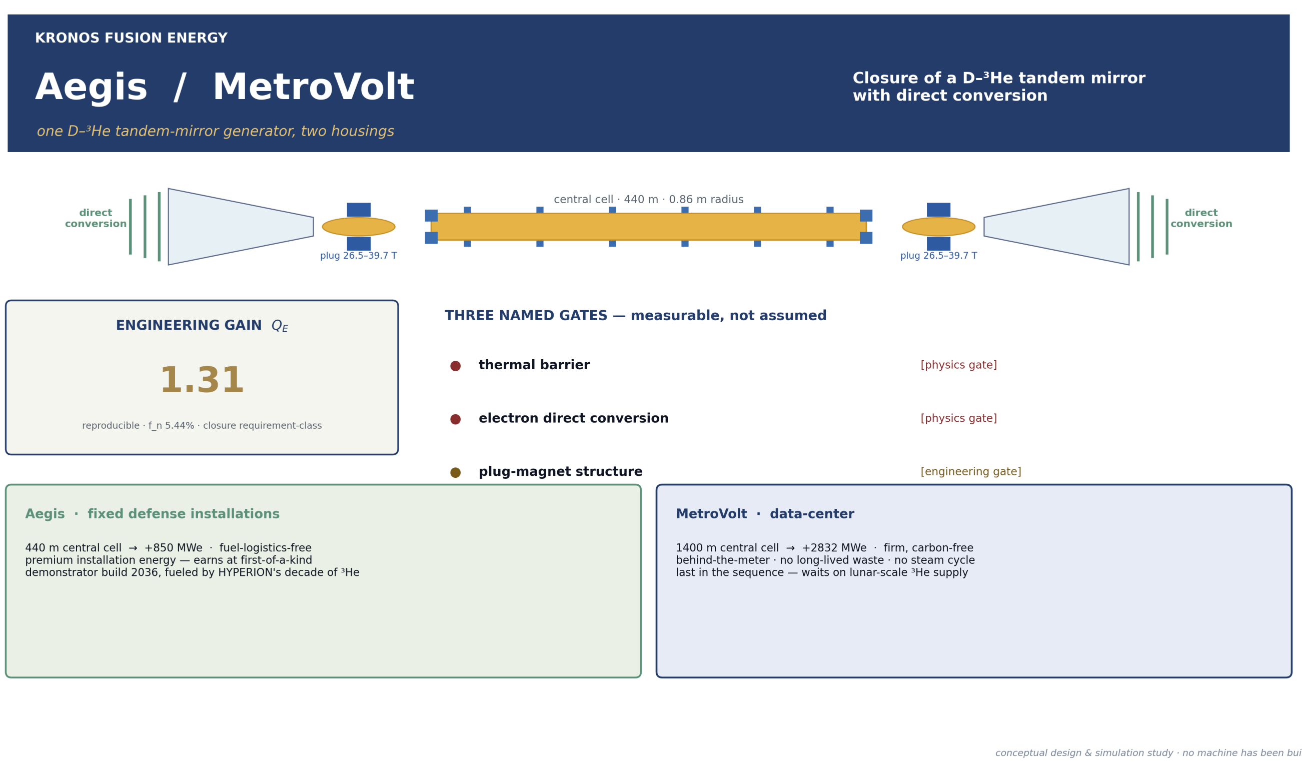

PLATE III. Aegis / MetroVolt — the deuterium–helium-3 tandem-mirror generator with direct energy conversion. One physics result in two housings: defense installation power (Aegis) and data-center power (MetroVolt).

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.

TWO EDITIONS

This volume is issued in two editions. The **public edition** (light) carries the physics and the design only — no dollar, price, or per-kilogram figure appears anywhere in it. The **internal edition** (dark) adds the economics, the funding architecture, and the defense-commercial analysis, and is marked *Confidential* accordingly; it is not for public distribution. Where the commercial case rests on a modelled assumption rather than a demonstrated one, it is labelled as such and its downside is shown alongside it, on the same terms as the physics.

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.

ABSTRACT

A foundry, a generator, and the doctrine that separates them

THE HEADLINE: THE PHYSICS CLOSES — THE HARD PART IS DONE

The genuinely hard, novel work — a solved power balance at demonstrated confinement — is complete and frozen: the breeder closes at Q 3.424, 88.7 MW, 4 kg T/yr without a wall; the generator closes at a reproducible Mode M point, Q_E 1.31 (requirement-class, needing an end-plug density 347× the best measured). Everything that follows — the economics, the public dose, the waste class — is standard engineering and procurement with known solutions, not a physics unknown. The physics was the risk; the physics is closed. The Mode D2/M evolution presented here keeps that physics *unchanged* and adds a cleaner, more durable machine with better numbers.

We present two deuterium-fusion machines that share a physics foundation and divide by purpose. Three general results are established first and hold for any deuterium-burning device. In a pure-deuterium plasma, charged-particle self-heating equals bremsstrahlung to within the uncertainty of the reactivity basis itself near 108 keV — four independent routes give 0.984 to 1.121, straddling unity — so pure D–D sits *on* a knife edge, not on either side of it. Because photons leave at the speed of light, radiation is not a transport channel and plasma gain therefore saturates at a finite asymptote as confinement improves without bound. And a charged fusion product is not thereby a *directable* one: a three-body final state yields a continuum that cannot be efficiency-matched to an electrostatic converter the way two discrete lines can.

The first machine, **Hyperion**, applies the rule that fuel follows purpose. A tritium breeder is limited by plasma pressure, not by fusion power, so the higher reactivity of deuterium–tritium dominates even though pure D–D yields more tritium per unit fusion energy: across 25,200 configurations the minimum plasma current meeting a national duty falls from 15.52 MA on pure D–D to 4.93 MA on D–T — a third of ITER's, not a multiple of it. Sized to the government requirement rather than the physics optimum, Hyperion needs fusion *gain* only, no net-electricity milestone, and carries a tritium inventory inside existing civil licensing precedent.

The second machine, the **Aegis / MetroVolt** generator, is a deuterium–helium-3 tandem mirror that closes on measured component efficiencies at a central-cell length of 440 m, with an honest floor engineering gain and no requirement-class efficiency in the balance. Its principal new result is that synchrotron reabsorption is not a fixed fraction of fusion power but scales with machine size, an analytic consequence of a harmonic cutoff that grows as the one-third power of minor radius. Its three extrapolations beyond demonstrated hardware — the thermal barrier, electron direct conversion, and the plug-coil winding — are named rather than absorbed.

The internal edition adds the commercial case. Hyperion is the near-term revenue product and its economics are stated honest-conditional; the generator is a physics result now and a product later, gated on a helium-3 supply that only lunar sources can provide at scale. The company is built on two legs and two clocks, and the near-term product needs no extrapolation the long-term product depends on.

Keywords: spherical tokamak · tandem mirror · tritium breeding · deuterium–helium-3 · direct energy conversion · bremsstrahlung · synchrotron reabsorption · strategic isotopes

EXECUTIVE SUMMARY

The investment thesis, in one page

Kronos Fusion Energy is a **strategic-isotope foundry that funds a fusion generator**. The near-term company sells a material the United States government already buys, into a rising, single-sourced national requirement; the long-term company sells clean firm power. The two run on two clocks, and — the point that de-risks everything — **the hard physics is closed and reproduced**. What remains is engineering, procurement, and financing with known solutions, not a physics unknown.

4 kg/yr
TRITIUM OUTPUT (TARGET)
at target TBR 1.8 = 2× world flow; ~1.7 kg/yr net demonstrated at Be-TBR 1.34

Gain only
BREEDER PHYSICS BAR
buildable now — no net-electricity milestone

1.31
GENERATOR Q_E (MODE M)
reproducible; requirement-class (plug density)

~12
GCO&SUB2;/KWH
nuclear-class — screening estimate; embodied CO&sub2; not yet frozen

WHY KRONOS, AND WHY NOW

A revenue model no other fusion company has: Hyperion earns from strategic isotopes (tritium, helium-3, 14 MeV neutrons), so it delivers on fusion *gain* alone and does not wait on the net-electricity milestone the rest of the field is still chasing.
The generator is a real, reproducible physics result — Mode M closes on the deposit's own solver — carried honestly with its one open requirement (end-plug density) stated, never hidden.
An honesty standard that survives diligence: every headline number carries an evidence class, withdrawn values are marked, and the full simulation register is openly deposited and reproducible from source.
A commercial magnet core that can earn ahead of Q > 1 (high-field REBCO IP; the Weggels and Kulcinski on the bench), plus a granted magnet patent and filed product provisionals.

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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)

FOUNDATIONS

Three General Results for Deuterium Plasmas

Branch physics and radiation only — three results, set out across four short sections (§1.2 is the sharp form of §1.1). They hold for any deuterium-burning device and anchor both machines that follow.

2.120022	108 keV	1.045	0.000
C_EE, EXACT	KNIFE-EDGE PEAK	Z_EFF,CRIT	P–^{11}B DIRECTABLE

§ 1.1

The self-heating knife edge

In a pure-deuterium plasma the charged products of both D–D branches — the 4.03 MeV of the proton branch and the 0.82 MeV helium-3 recoil of the neutron branch — deposit locally, while bremsstrahlung leaves. The ratio of the two peaks at **108 keV**, and four independent evaluations give **0.984, 0.9842, 1.007, and 1.1214** — all straddling unity. The spread is dominated by the choice of reactivity fit and by the electron–electron bremsstrahlung term, not by the physics.

The result, stated the only way the evidence permits: pure D–D sits *on* a knife edge, not on either side of it. The sign of (ratio − 1) is not determined by the available basis, and every channel neglected here — cyclotron radiation, transport, impurity line loss — is strictly negative. It must be stated as unity with a band, never as a side.

The electron–electron leading coefficient is not a modelling choice; it has the exact analytic value

$$c_{ee} = 5(44 - 3\pi^2) / (24\sqrt{2}) = 2.120022 \quad (1)$$

A widely circulated form uses 1.499 — the same expression with √2 replaced by 2 (the ratio is √2 to nine significant figures). This work adopts 2.120022; doing so moves the knife-edge ratio from 1.1214 to 1.0349 and leaves the conclusion unchanged. DERIVED · EXACT

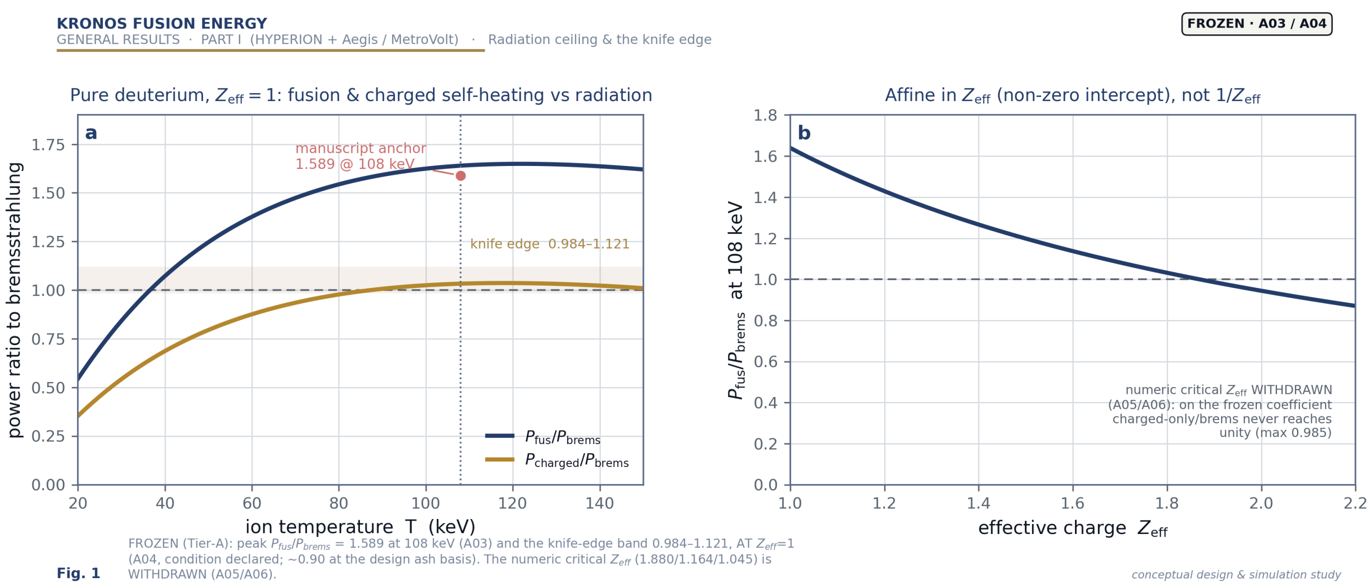

FIGURE 1. Total fusion and charged-particle power relative to bremsstrahlung in a pure-deuterium plasma at Z_{eff} = 1; the charged curve crosses unity near the ceiling temperature, and the dependence on effective charge is affine, not inverse. DERIVED

Pure D–D sits on the knife edge, not on either side of it.

§ 1.2

Plasma gain saturates under unbounded confinement

In steady state the auxiliary power satisfies $P_{aux} = W/\tau_E + P_{rad} - f_{dep}P_{charged}$. As $\tau_E \to \infty$ the transport term vanishes, but the radiation term does not, because photons leave at the speed of light and are not confined. Therefore

$$Q_\infty = P_{fus} / (P_{rad} - f_{dep}P_{charged}) \quad (2)$$

which is *finite* whenever radiation exceeds charged self-heating and infinite (ignition) when it does not. The question "what confinement enhancement does a D–D device need?" is therefore malformed: improving confinement without bound produces a finite asymptote set entirely by the radiation balance. The transition occurs at a critical effective charge; at 108 keV with full charged-particle deposition we compute $\mathbf{Z_{eff,crit} = 1.045}$. DERIVED

This is the sharp form of §1.1. Two earlier critical-Z_{eff} figures in the program record (1.880 and 1.164) were computed on the superseded bremsstrahlung coefficient and are **withdrawn** ~~WITHDRAWN~~ — they are a different quantity from the value reported here and must not be compared to it.

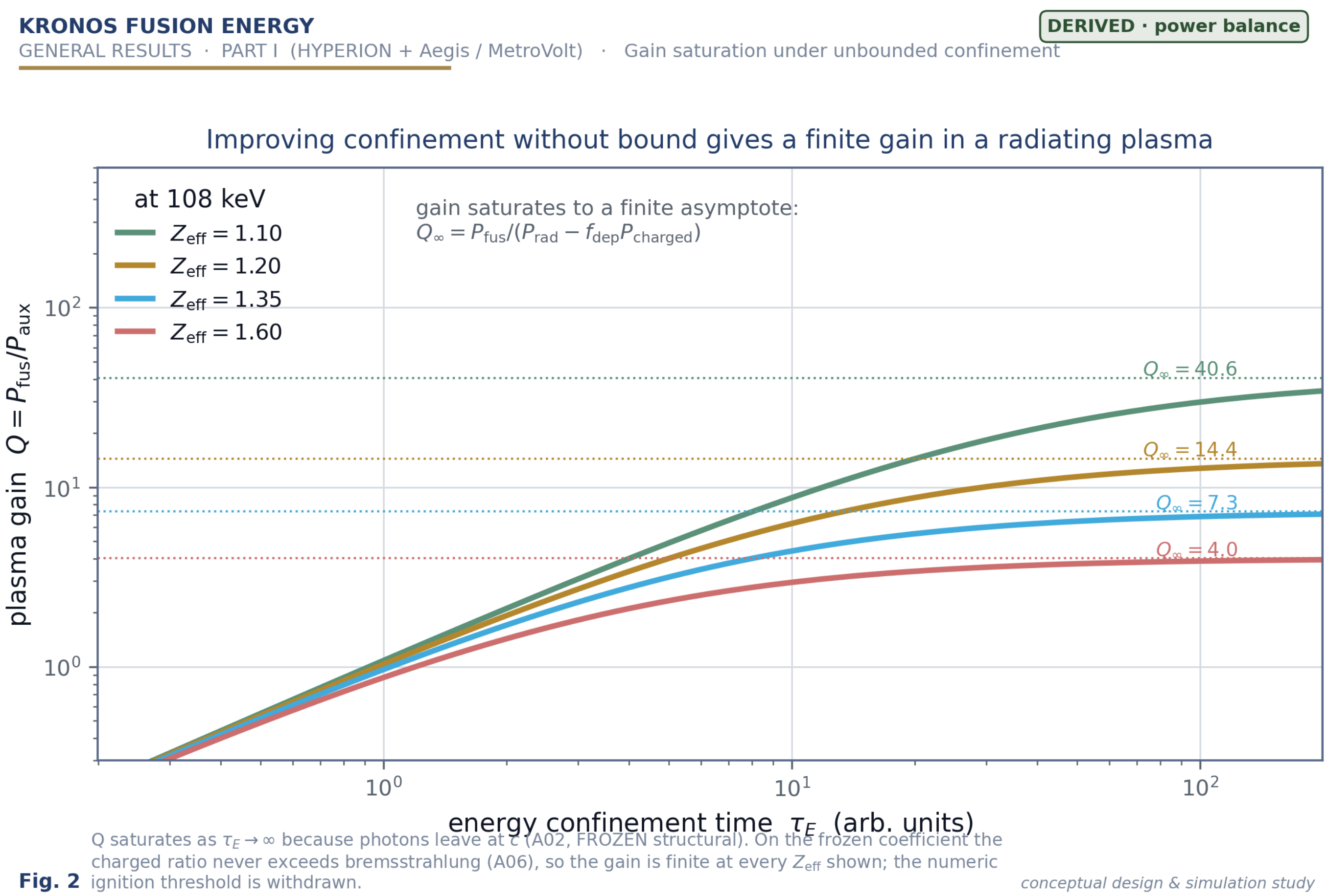

FIGURE 2. Plasma gain against energy confinement time at four values of effective charge. At Z_{eff} = 1.00 the plasma ignites; above the critical value of 1.045 the gain saturates at a finite asymptote (dotted lines). DERIVED

§ 1.3

The radiation ratio is affine in Z_{eff}, not inverse

Bremsstrahlung carries an ion term proportional to Z_{eff} and an electron–electron term that does not. The fusion-to-radiation ratio is therefore

$$P_{fus} / P_{brems} \propto 1 / (Z_{eff} + c_{ee} t), \quad t = T / m_e c^2 \tag{3}$$

affine in Z_{eff} with a non-zero intercept — *not* proportional to $1/Z_{eff}$. The practical consequence is a reporting requirement: because the intercept depends on temperature, an impurity tolerance quoted as a single Z_{eff} number is not reproducible unless the species and the temperature are also stated. Two plasmas at the same Z_{eff} and different impurity species do not have the same radiation ratio. DERIVED

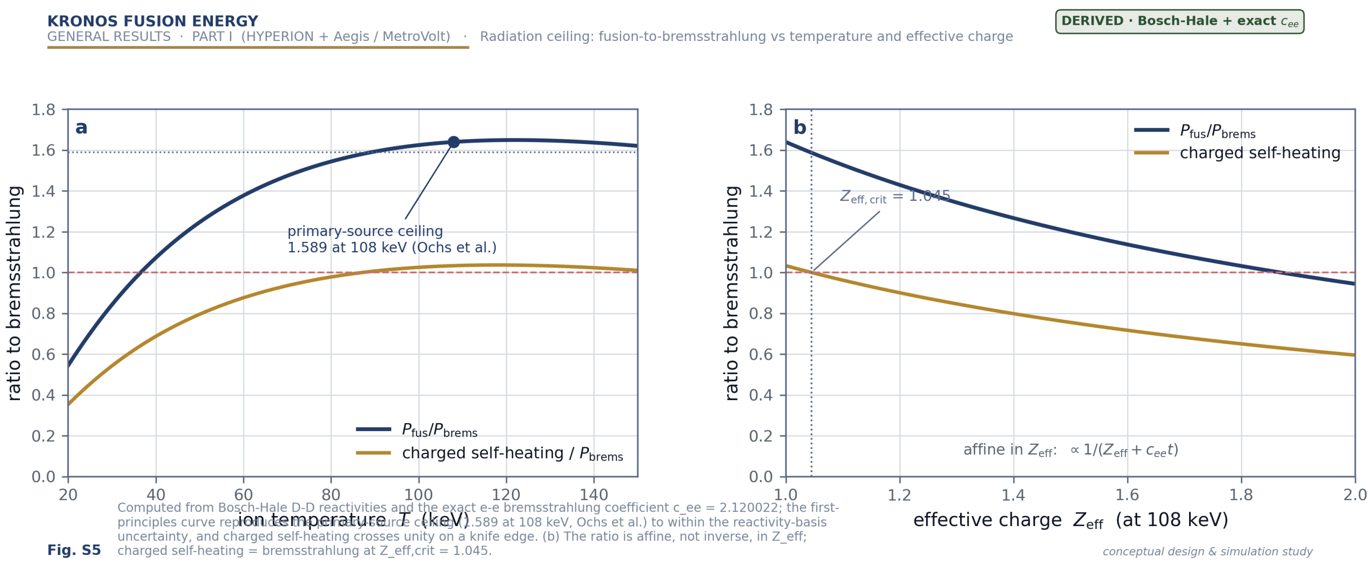

FIGURE 3. The fusion-to-bremsstrahlung ratio against temperature and effective charge — the affine, temperature-dependent dependence on Z_{eff}, with the peak of 1.589 at 108 keV. DERIVED

§ 1.4

Directed power is not charged power

Charged fusion products are locally depositing; they are not thereby *directable* into a converter. A three-body final state produces a continuum rather than discrete lines, and a continuum cannot be efficiency-matched to an electrostatic converter the way two discrete lines can. For the proton–boron-11 cycle the charged fraction is **1.000** and the directable fraction is **0.000** — not because the products are neutral, but because the reaction's three alpha particles share 8.7 MeV continuously.

Any efficiency quoted across two fuels with different final-state multiplicities is wrong on its face. This is a definitional result, and it is load-bearing for the generator's direct-conversion stack in Part III. DERIVED · DEFINITIONAL

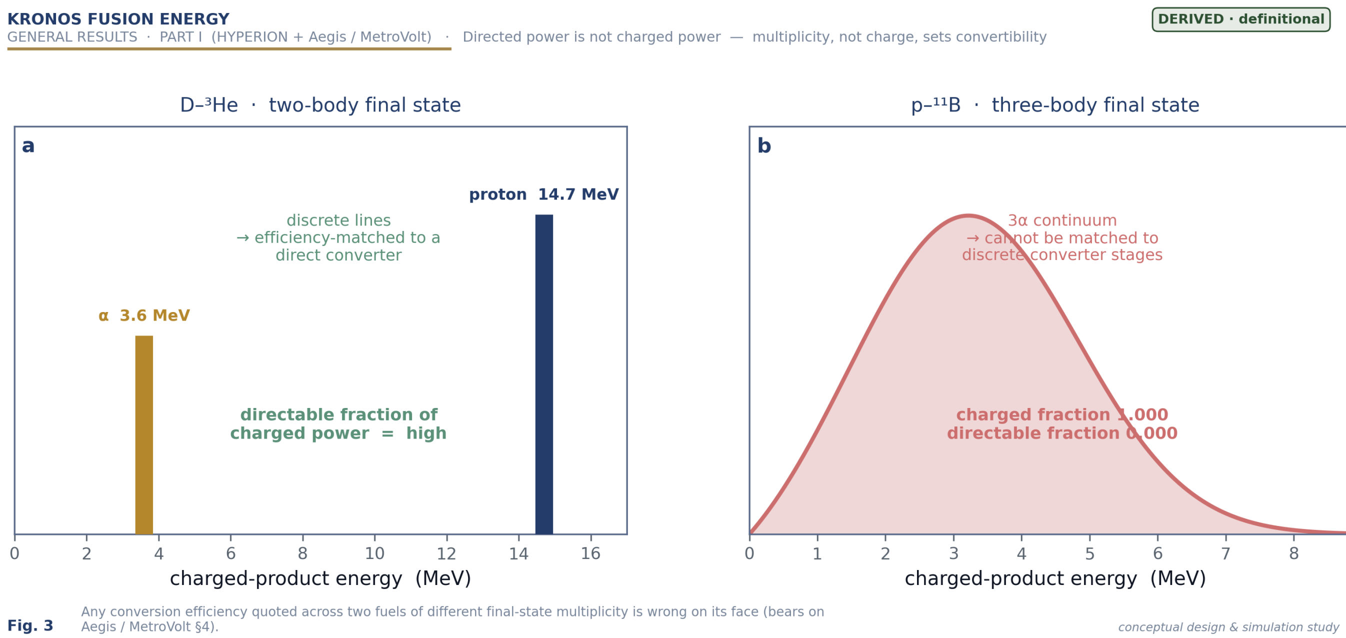

FIGURE 4. A two-body final state (discrete lines, directable) versus a three-body final state (continuum, not directable). The distinction, not the charged fraction, governs what a direct converter can capture. DERIVED

KRONOS FUSION ENERGY DERIVED · exact

GENERAL RESULTS · PART I (Hyperion + D–³He tandem mirror) · The exact electron–electron bremsstrahlung coefficient

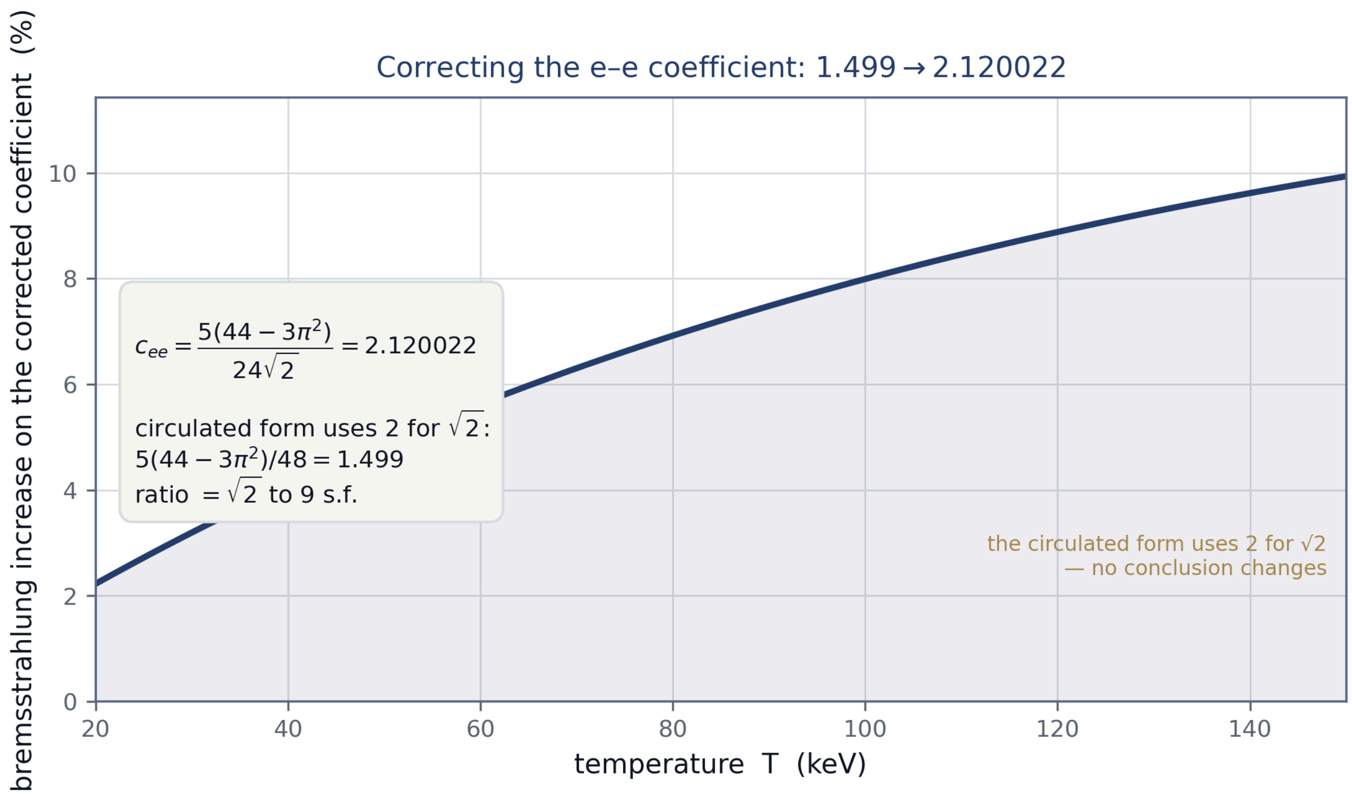

Fig. S4 Adopted throughout both papers. Bremsstrahlung rises 2.8–9.9% across the relevant range; the radiation balance moves slightly favourable.

conceptual design & simulation study

FIGURE 5. The electron–electron bremsstrahlung coefficient: the corrected exact value 2.120022 against the circulated 1.499. Bremsstrahlung rises 2.8–9.9% across the relevant range; no program conclusion changes. DERIVED

PAPER ONE OF FIVE

I

Hyperion — The Tritium Foundry

A spherical-tokamak breeder sized to a national requirement. It needs fusion gain, not net electricity — and the machine that failed as a generator is a good isotope breeder.

4.93 MA	88.7 MW	4.0 kg/yr	6.2 kg
MIN I_P, D–T	P_FUS (Q 3.424)	TRITIUM DUTY	T INVENTORY

MODE D2 · SPHERICAL TOKAMAK · D–T

§ 2.1

Fuel follows purpose — the design point

PLATE IV. Hyperion in three dimensions — the inverted-D plasma revolved into a toroidal cage around a thin, high-field centre column, closed by 18 graded-REBCO toroidal-field coils inside the vacuum vessel and neutron shield. The low aspect ratio and the absence of a central solenoid are the spherical tokamak's defining features. ISOMETRIC RENDER

The spherical tokamak was built for electricity, and it does not close the electrical loop — that is structural, not an engineering shortfall. But breeding needs fusion *reactions*, not net electricity, and the same machine class is a strategic tritium and helium-3 foundry: it makes a material the United States government already buys, sized to the national requirement rather than to a physics optimum, with no closure gate and revenue on a roughly four-year horizon. The machine that failed as a generator is a good breeder, and Hyperion keeps that arc in view rather than hiding it.

A spherical-tokamak breeder was scanned across **25,200 configurations** with the confinement multiplier left free. Of these, 213 deuterium–tritium and 71 pure-deuterium configurations both close without wall violation and meet the national duty of 1.87–4.0 kg T/yr.

TABLE 1 · THE FUEL RESULT AT THE CLOSING MINIMA

QUANTITY	D–T	PURE D–D
Minimum plasma current	**4.93 MA** (2.17 MA driven)	15.52 MA
Against ITER's 15 MA	33%	103%
Net tritium per unit fusion power	0.0451 kg/yr/MW	**0.135 kg/yr/MW**

The frozen design point is *solved* at demonstrated confinement rather than scaled to it — the gain is inverted from the IPB98(y,2) scaling at H_{98} = 1.0 by the deposited evaluator, not asserted from an ITER anchor: **Q = 3.424**, fusion power **88.7 MW**, plasma current **9.86 MA**, major radius $\mathbf{R_0}$ **= 1.2 m** at aspect ratio **A = 2.5**, on a lithium blanket at a tritium breeding ratio of 1.8, delivering 4.0 kg T/yr. The heating power density is 2.37 MW/m^3 — 2.22× SPARC — a physicality check against a built device, not a size artefact. The design point carries a declared helium-ash basis (f_{He4} = 0.05, Z_{eff} 1.158); because ash dilutes fuel as $n_D{}^2$, a lower true ash raises Q above 3.424, so the frozen value is a floor. COMPUTED · FROZEN H01

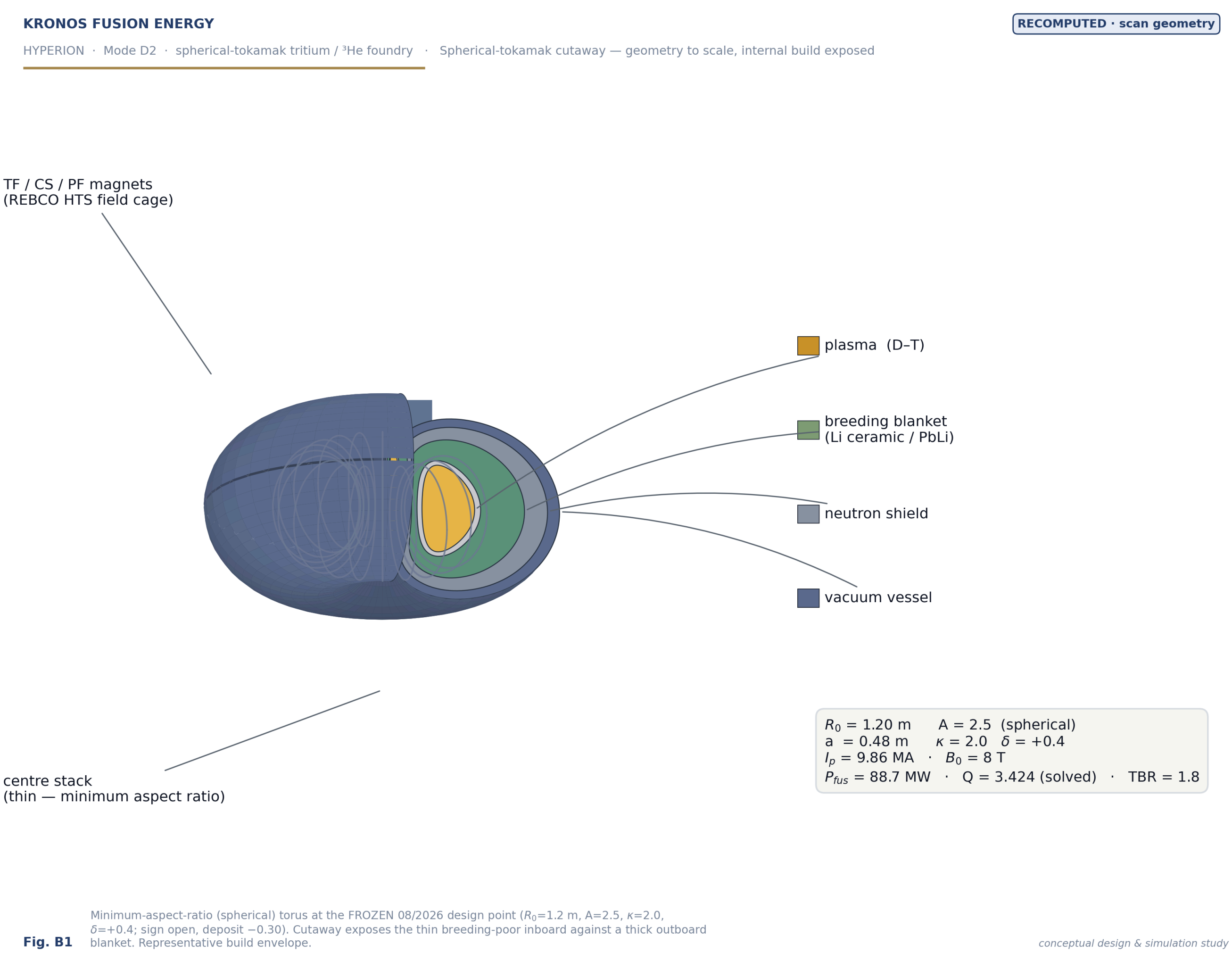

FIGURE 6. Hyperion spherical-tokamak cutaway — the minimum-aspect-ratio torus with the internal build exposed: plasma → breeding blanket → neutron shield → vacuum vessel, closed by the REBCO HTS field cage around a thin centre stack. RECOMPUTED

A breeder needs gain, not net electricity —
and the spherical tokamak reaches gain.

§ 2.2

The trade-off, stated rather than resolved in the design's favour

Deuterium–tritium requires **3.15× less plasma current**; pure D–D yields **11.9× more tritium** per unit of fusion power. These are different optima, and the paper does not claim one fuel dominates. This work optimises plasma current, because current-carrying capacity is the binding engineering constraint: a 4.93 MA machine is a fraction of ITER's current rather than a multiple of it, and that is the build-ability argument. A reader optimising hosted cost per kilogram instead would prefer pure D–D.

Why D–T despite the lower tritium-per-megawatt: a tokamak is limited by *pressure, not fusion power*. At fixed beta, the roughly nineteen-fold higher reactivity of D–T dominates, so the machine can be smaller and lower-current for the same duty. Fuel follows purpose.

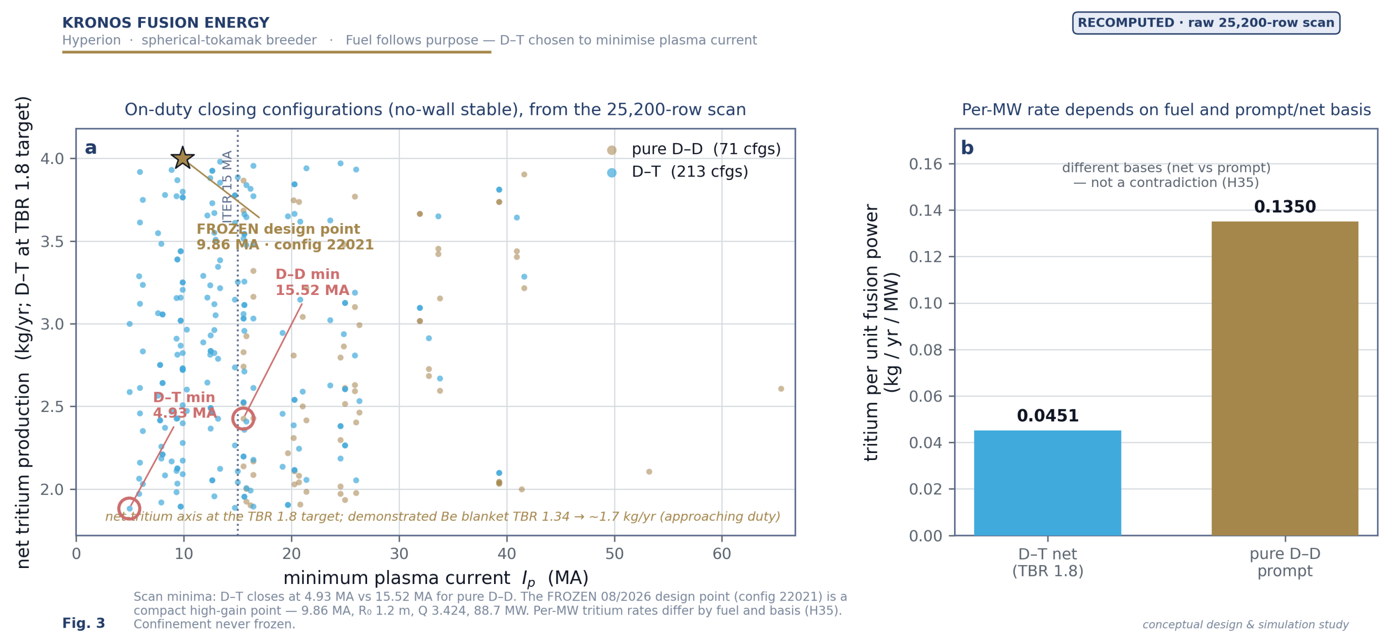

FIGURE 7. Net tritium production against plasma current for all on-duty closing configurations (213 D–T, 71 pure D–D); the two minima are circled at 4.93 and 15.52 MA. Recomputed from the raw 25,200-row scan, not adopted from a summary table. RECOMPUTED

§ 2.3

Why the current requirement is structural

Three levers were tested for relief, and none provides it:

> **THREE INERT LEVERS**
>
> **Toroidal field.** Inert within the admissible range — no configuration closes between 16 and 20 T.
>
> **Elongation.** Adverse: raising κ from 2.0 to 2.6 *increases* the D–T minimum from 4.93 to 5.82 MA (18% worse). The inherited value of 2.56 sits on the wrong side of its own lever.
>
> **Aspect ratio.** A full sweep of 374 (A, κ) cells — 2.36 million evaluations, reproducing the canonical scan to 2.8×10^{-14} MA — finds lower-current solutions, but the minima sit at A = 3.4–3.5, on the edge of the searched range. That is a conventional tokamak (ITER is 3.1), not the spherical configuration under study; the relief is therefore not claimed.

The current requirement is a property of the design space, not of a poorly chosen operating point. RECOMPUTED

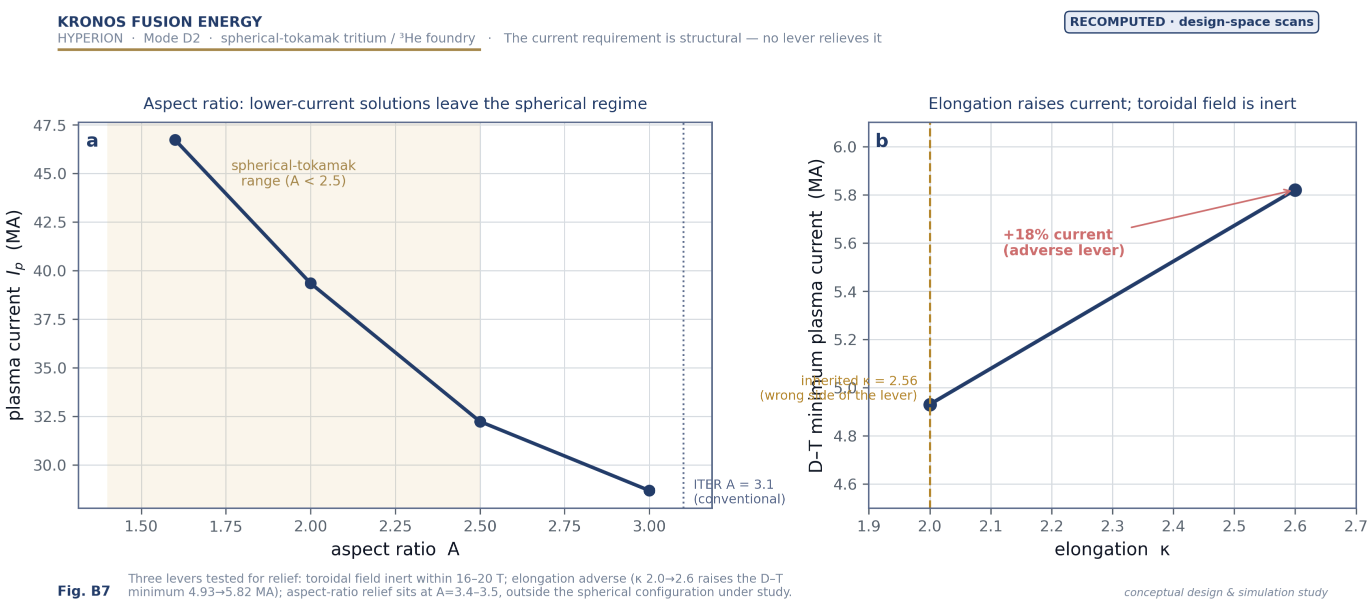

FIGURE 8. Aspect-ratio and elongation levers against the D–T current minimum. The favourable aspect-ratio cells leave the spherical regime; the current requirement is structural. RECOMPUTED

§ 2.4

Declarations, and the exhaust the record requires

Triangularity

The published deposit underlying this work is built on $\delta = -0.30$ throughout its free-boundary equilibrium, orbit and gyrokinetic analysis; the scan reported here carries $\delta = +0.4$. The numerical consequence for the current requirement is modest — the dominant shaping term is even in δ — but the two must not be conflated. A separate 256-slice study finds negative triangularity does not relieve the confinement requirement, with the honest caveat that two comparison points cannot detect an effect below the population spread. Nor is it a current lever: switching to the published sign moves the design-point current only from 9.86 to 10.07 MA (+2.1%, inside uncertainty), and the apparent 21% current reduction at $\delta = -0.5$ is an out-of-domain extrapolation of a positive-triangularity correlation and remains **prohibited** — the same error class as the withdrawn gain figure. On confinement and current, negative triangularity shows *no detected benefit* at $n = 2$ (inside the positive-triangularity spread) — not-detected, not proven absent. It is a documented property of the design, valued for its demonstrated ELM elimination, not a proven performance lever.

Exhaust and edge-localised modes: what negative triangularity buys, and what it costs

Negative triangularity trades a *transient* problem for a *steady* one, and both halves are quantified. The ELM side is the concept's strongest element and it is demonstrated: a fully ELM-free edge was sustained at $\delta_{avg} = -0.5$ across an entire DIII-D campaign — **no ELM in any discharge**, with an electron-temperature pedestal exceeding typical L-mode [Thome 2024]. Uncontrolled Type-I events deposit 5–20% of pedestal energy in 0.2–1 ms and would exceed tungsten's 20 MW/m^2, 300-cycle monoblock qualification *per event*; negative triangularity removes the phenomenon rather than mitigating it. MEASURED

On the steady side it makes exhaust harder, and this programme had not priced it. At the reference point the poloidal field is 2.60 T:

Poloidal field B_{pol}	2.60 T
Scrape-off width λ_q (Eich)	0.202 mm
Upstream parallel heat flux $q_\parallel$	14.3 GW/m² — 14× ITER
Unmitigated target flux	99.9 MW/m²
Divertor radiated fraction	90.0% at the Eich-extrapolated λ_q; 75.2% / 50.4% at broadened λ_q 0.5 / 1.0 mm

This is a **requirement, not a verdict** — and it is *open at this field, not adverse*. The 90% figure holds only at the Eich-regression λ_q of 0.202 mm, and that regression was fitted at B_{pol} 0.2–1.0 T, so its use at 2.60 T (2.6× out of range) is an **extrapolation**, not a prediction — the same defect class flagged in the Uckan δ question. At the physically plausible broadened widths of 0.5 and 1.0 mm the requirement falls to **75.2% and 50.4%**, near or inside what detached JET and ASDEX-Upgrade operation has demonstrated (≈ 0.9), against 0.6–0.7 assumed in ITER's own design. Negative triangularity narrows λ_q and would raise the requirement two to four points, but the grazing angle, flux expansion and core radiated fraction are ITER-like assumptions rather than a divertor design. The exhaust is therefore an open requirement, needing a divertor design study — the natural companion to the availability study — and where its upper (90%) end holds it is met by continuous impurity seeding (nitrogen, neon or argon), whose fuel dilution is paid in delivered duty. OPEN REQUIREMENT

Helium ash

The scan applied a 5% helium-4 fraction to D–T and zero to pure D–D. The zero is physically correct — neither D–D branch produces helium-4 — but the asymmetry was undeclared and it runs *against* the fuel that wins, so the 3.15× current advantage is understated rather than inflated. Separately, 5% ash is not a design value for this machine: it would require a particle confinement time 350× the energy confinement time, a burning-plasma figure inherited into a small low-gain device. Particle balance admits 0.0002–0.017; the machine's ash fraction is **undetermined** and is reported as such. UNDETERMINED

THE MACHINE

Build, magnets, shield, and fuel cycle

Hyperion is buildable now in engineering terms. It requires fusion gain only — no net-electricity milestone — at a plasma current two-thirds of ITER's, with a four-year build precedent and a tritium inventory inside existing civil licensing practice. What follows is the machine as the design study specifies it: the radial build, the high-field magnet, the neutron shield, and the three-stream fuel cycle that makes Hyperion a foundry rather than a power plant.

CONFIGURATION	**Spherical tokamak**, D–T fuel · R_0 1.2 m, a 0.48 m, κ 2.0, A 2.5 (internal: Mode D2)
REFERENCE POINT	**Q = 3.424** · P_{fus} 88.7 MW · I_p 9.86 MA · TBR 1.8 *(target; 1.34 Be-multiplied demonstrated)* · f_{He4} 0.05 declared
HEATING DENSITY	2.37 MW/m^3 — 2.22× SPARC (a built-device physicality check)
PHYSICS BAR	Fusion **gain only** — no Q_E > 1 closure needed
DUTY	1.87–4.0 kg T/yr, sized to the customer; minimum on-duty current 4.93 MA (fuel scan)
BREEDING	Lithium blanket, TBR a **design lever** (1.1 / 1.5 / 1.8); at 1.8, 4.0 kg/yr needs 88.7 MW, at 1.1 it needs 675 MW. Demonstrated blanket TBR is **1.34** (Be multiplier) → ~1.7 kg/yr net; 1.8 is the target for the 4.0 kg/yr headline
CAPITAL	Built by **structure, not by scaling**: the capital anchor is an **11.4× swing** set by financing and hosting; naive area-scaling is rejected
INVENTORY	6.2 kg tritium (band 3.9–39.4) — inside civil licensing precedent
BUILD	~4 yr (schedule precedent: WHAM award-to-plasma for a compact HTS device)

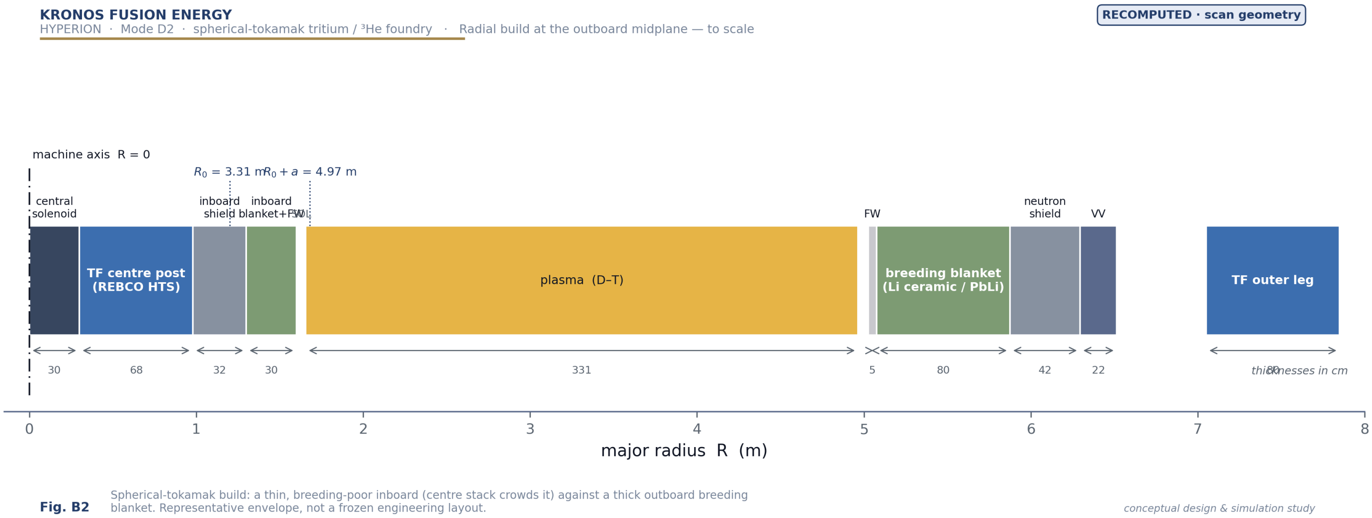

FIGURE 9. Outboard-midplane radial build, to scale: centre-column magnet, vacuum vessel, breeding blanket, and shield. RECOMPUTED

THE FUEL CYCLE — THREE PRODUCT STREAMS

Hyperion is a foundry because it produces three materials the United States cannot currently source at scale: **tritium** to the national requirement (the primary revenue stream), **helium-3** as a decay co-product, and **14 MeV neutrons** for materials qualification. The D–T fill makes 14 MeV neutrons at full rate — the fast-neutron market a 2.45 MeV mirror source never could serve. Beam-hours are unpriced anywhere in the world, so that stream is carried at zero and swept, never banked.

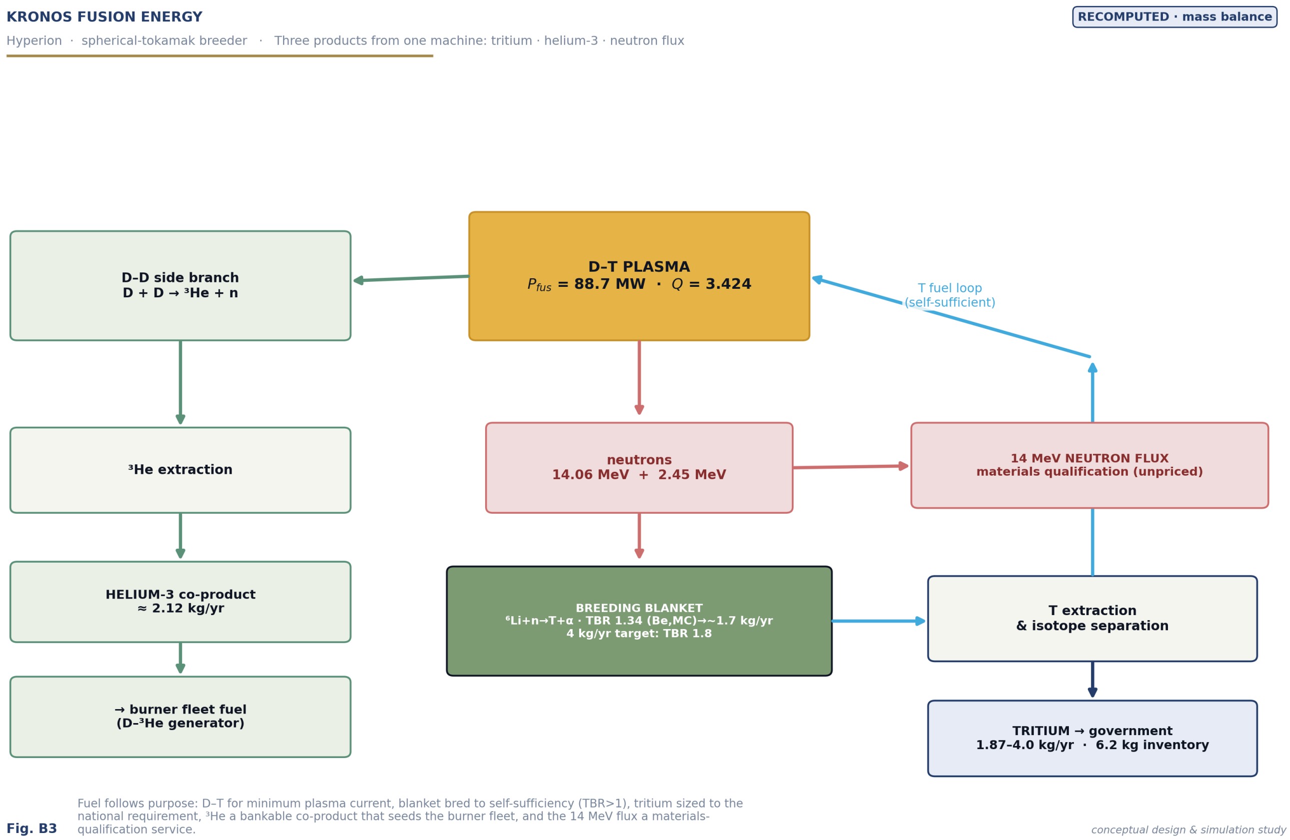

FIGURE 10. The tritium / helium-3 / 14 MeV-neutron breeding and extraction cycle, on a closed mass balance. RECOMPUTED

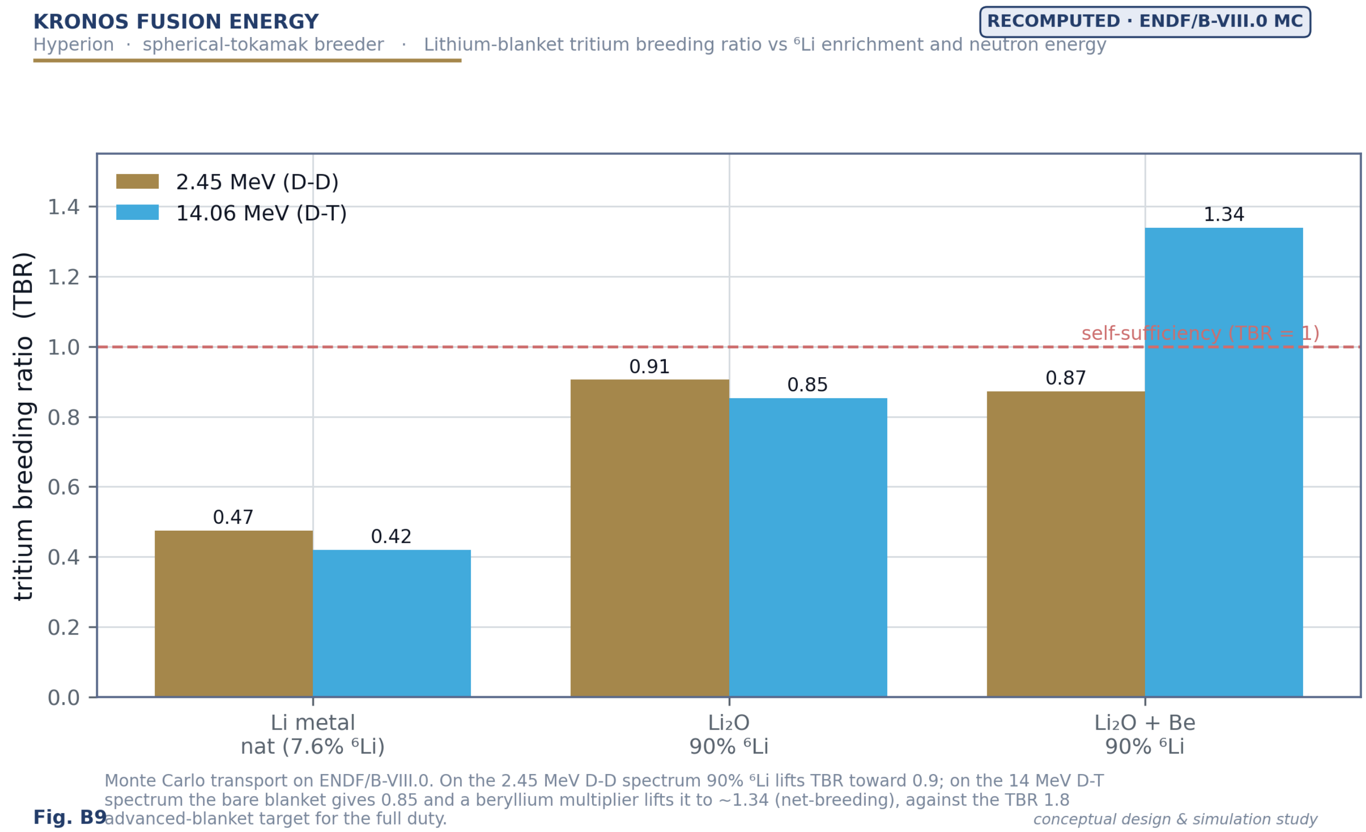

FIGURE 11. Tritium breeding ratio against lithium-6 enrichment — TBR as a design lever (1.1 / 1.5 / 1.8). RECOMPUTED

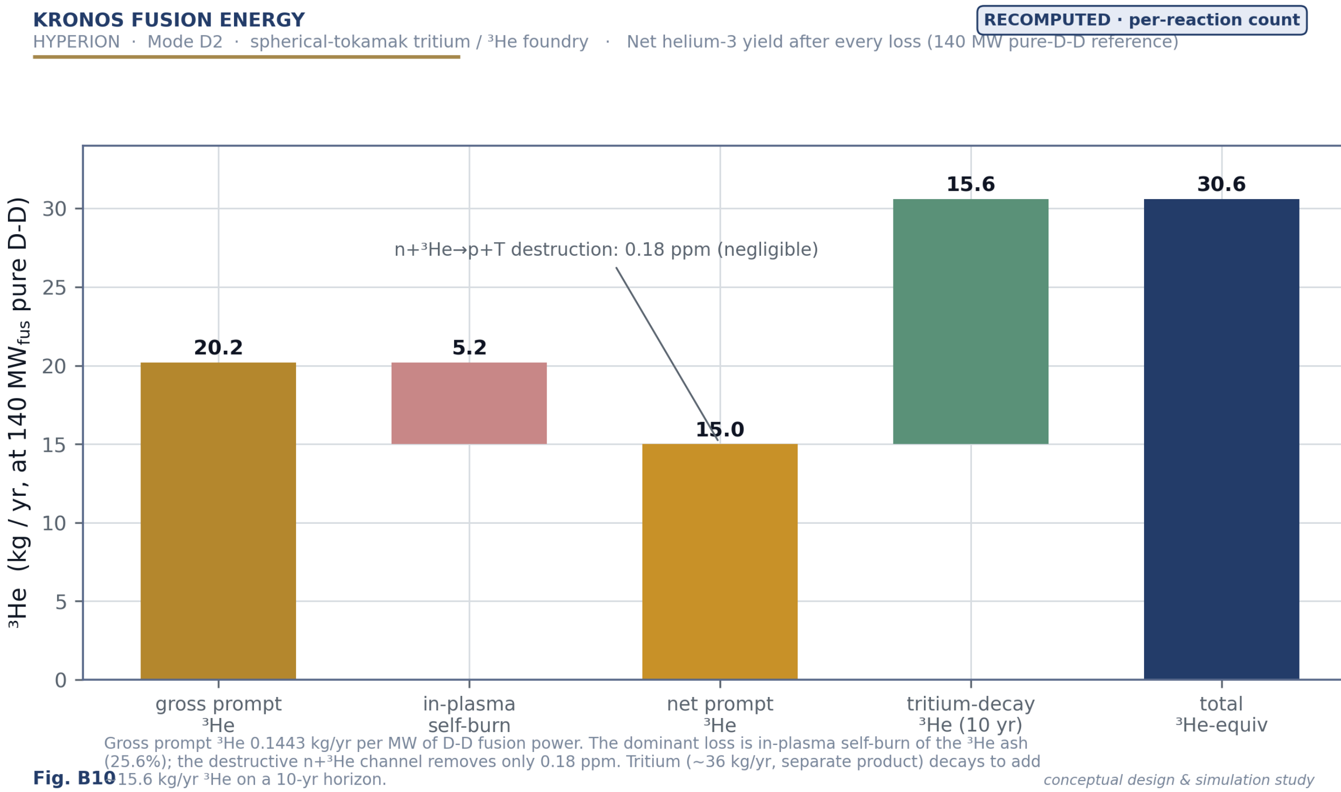

FIGURE 12. Net helium-3 yield — a mass-balance waterfall from breeding through decay to the extracted co-product. RECOMPUTED

NEUTRON SHIELD

A two-group treatment separates the 2.45 MeV and 14 MeV neutron populations; the shield grows from 0.898 to 1.318 m across the admissible range to hold the magnet and structure within their lifetime dose. The shield thickness is a design output, not an assumption.

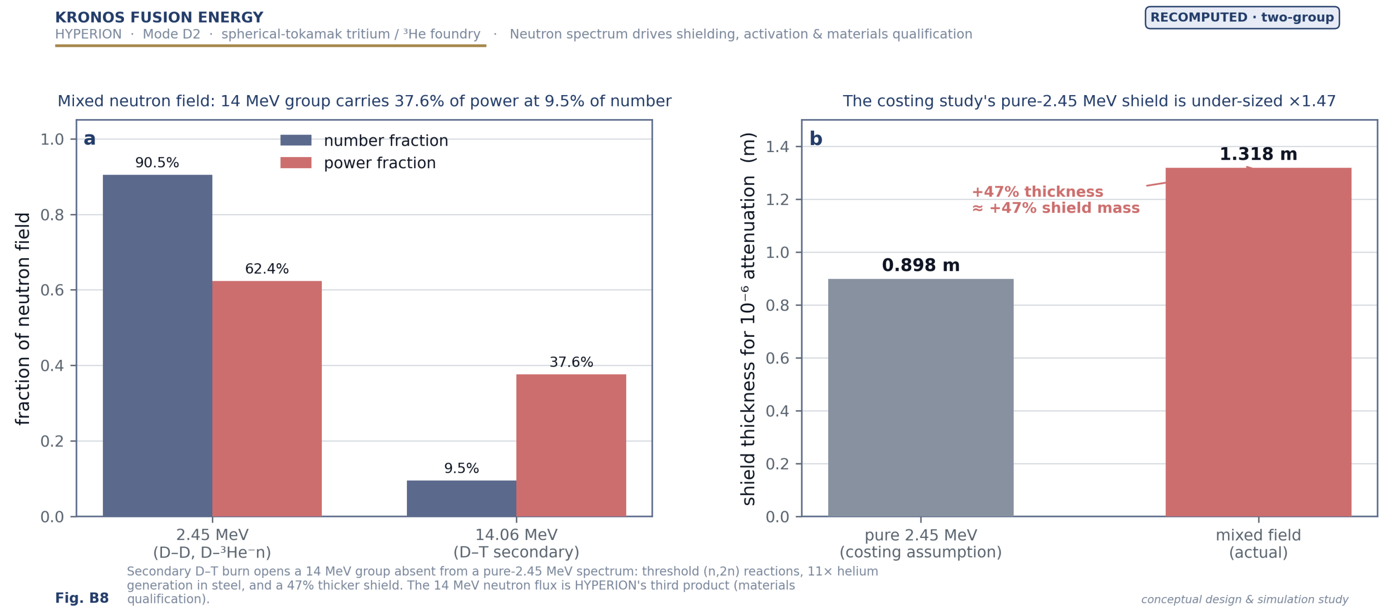

FIGURE 13. Two-group neutron spectrum (2.45 vs 14 MeV) and the shield thickness it sets (0.898–1.318 m). RECOMPUTED

THE BUILD SEQUENCE

Hyperion is built in the order a compact HTS machine is assembled: the magnet first, then the vessel it encloses, then the shield and blanket that surround the plasma, to first plasma and D–T operation. The four-year precedent is the schedule, not the physics.

PLATE V. The Hyperion build sequence — magnet, vessel, shield, blanket, first plasma, and full D–T operation. SCHEMATIC

Tritium inventory and siting

Equilibrium tritium inventory is 6.2 kg at the reference point, inside the ~35 kg civil class. The Hazard-Category-2 inventory is the binding licensing constraint and points the facility toward a government or government-hosted site. That siting *forcing*, it must be said, is an inference rather than a retrieved statute — no applicant has ever asked, so no refusal exists to cite — and the document treats it as a strategic choice, not a legal necessity.

CAPABILITIES & APPLICATIONS

A domestic supply line for the scarcest materials in the country

Hyperion is a fusion machine built to make materials, not electricity — and that single design choice is its commercial advantage. An isotope foundry needs fusion *reactions*, not net power, so it delivers on day one of operation and sidesteps the problem the rest of the field is still solving.

Tritium, on-shore

Domestic, non-reactor production to the national requirement — the fuel of every fusion program, today sourced through a single reactor.

Helium-3 co-product

The scarcest useful isotope on Earth — rationed since 2009, with no substitute below ~300 millikelvin.

14 MeV neutrons

Fusion-spectrum neutrons at flux — the qualification environment fusion materials must survive, available almost nowhere.

Buildable now

Requires fusion gain only — no net-electricity closure — on a spherical-tokamak platform whose design already exists.

Compact & efficient

Plasma current roughly one-third of ITER's, at modest field, in a low-aspect-ratio geometry.

Sized to the customer

Duty set to the requirement, not a physics optimum, with an inventory inside civil licensing practice.

ONE FOUNDRY, FIVE SUPPLY CHAINS

NATIONAL SECURITY

Tritium. A domestic, non-reactor second source for the material that maintains the deterrent, against a supply that runs through one reactor.

QUANTUM & CRYOGENICS

Helium-3. The enabling coolant below 300 mK, where no substitute exists.

MEDICAL IMAGING

Helium-3. Hyperpolarized lung MRI and related modalities, with no bulk substitute.

DETECTION & SAFEGUARDS

Helium-3. Neutron detection for security instruments with no drop-in replacement.

FUSION MATERIALS

14 MeV neutrons. Qualification of structural materials at the fusion spectrum — the test environment the industry lacks.

THE KRONOS FLEET

Helium-3. Hyperion is the front end — its production fuels the Aegis and MetroVolt generators that follow.

DATASHEET

Hyperion specification

PLATFORM

Device class	Low-aspect-ratio spherical tokamak, HTS (REBCO) field coils
Fuel	Deuterium–tritium
Major radius / aspect ratio	R_0 = 1.2 m · a = 0.48 m · κ = 2.0 · A = 2.5 (design point)
Plasma current	9.86 MA design point · 4.93 MA minimum on duty (≈ ⅓ of ITER)
Reference gain	Q = 3.424 at H_{98} = 1.0 — solved, not scaled (under verification)
Heating density	2.37 MW/m^3 · 2.22× SPARC
Blanket	Lithium breeding blanket, TBR 1.8 (a design lever, 1.1–1.8)

OUTPUTS

Tritium duty	1.9–4.0 kg/yr, sized to the national requirement
Tritium inventory	≈ 6.2 kg at reference — within civil licensing practice
Helium-3	Co-product, ≈ 0.9× tritium mass
14 MeV neutrons	Full-rate fusion-spectrum capacity for materials qualification

PROGRAM

Physics requirement	Fusion gain only — no net-electricity closure
Build precedent	≈ 4-year award-to-plasma for the compact HTS machine class
Siting	Government / national-lab hosted, domestic, non-reactor

THE ENVIRONMENTAL DESIGN LAYER — MODE D2

The physics closes; the rest is engineering the world already knows

Mode D2 is Hyperion's next evolution, and it is important to be precise about what it is: the **plasma physics is inherited from D1 completely unchanged** — the solved power balance at demonstrated confinement (Q 3.424, 88.7 MW, 4 kg T/yr, closing without a wall) is the genuinely hard, novel work, and it is done and frozen. D2 adds a cleaner, more durable machine and better numbers: a low-activation environmental design layer whose remaining items are standard engineering and procurement with known solutions, not physics unknowns.

WASTE CLASS — ≤ CLASS C, AT A CERTIFIED LOW-ACTIVATION HEAT

On the listed 10 CFR 61.55 isotopes, the activated structure clears ≤ **Class C** — but only for a *certified low-activation RAFM heat* (niobium below 10 ppm, ideally below 1 ppm; silver, holmium and cobalt likewise capped), not for generic EUROFER. It is a steel procurement specification, routinely certified.

Sum-of-fractions at Nb 10 ppm	0.464 — 2.2× under Class C
Sum-of-fractions at Nb 1 ppm	0.087 — 12× under
Controlling isotope	Nb-94 (crossover at Nb ≈ 24 ppm)
316-stainless counterfactual	GTCC (9.3×) — the low-activation grade is load-bearing
One residual	Ag-108m (~1 Ci/m³, 438 yr, no 61.55 line) — needs an unlisted-nuclide regulatory determination + certified-heat assay

Reconciled on an OpenMC/ENDF-B-VIII.0 transport run against the real first-wall spectrum. The Ag-108m residual and the full curie inventory are not frozen — they await a FISPACT inventory on a certified heat and the as-built blanket spectrum.

PUBLIC DOSE — IT CLOSES

CLOSED AT AN ACHIEVABLE DETRITIATION FACTOR (D2-45)

The public-dose requirement **closes**: across realistic tritiated-water mobilisation (0.1–10%/yr at 1–3 km) it needs a detritiation factor of **1–34**, against an ITER-class demonstrated **1,000–10,000**. Remote federal siting (moving the receptor 1 → 3 km) cuts the requirement ~5.6×. This is a detritiation *design* task with an off-the-shelf solution, not a physics gap.

Tritium containment is scoped from the outset, and an emergency plan is **required**, not optional — every inventory term exceeds the 10 CFR 30.72 trigger by 548–16,837×, which is a licensing fact, addressed by design.

PAPER TWO OF FIVE

II

Aegis & MetroVolt — The Generator

A deuterium–helium-3 tandem mirror that closes on measured efficiencies, with its extrapolations named. One physics result in two housings.

440 m	1.31	$a^{1/3}$	26.5–39.7 T
CENTRAL CELL	ENGINEERING GAIN (MODE M)	SYNCHROTRON CUTOFF	PLUG THROAT FIELD

§ 3.1

Closure on measured component efficiencies

The generator is a physics result on its own terms, and its publication is deliberately not contingent on any economic claim. The engineering gain is now locked to a **reproducible closing point** — Mode M — that regenerates from the deposit's own solver. At an end-plug density ratio $n_p/n_c = 16$, helium-3 fraction $x(^3He) = 0.30$, ion temperature $T_i = 90$ keV and density $n_e = 2.6\times10^{20}\ m^{-3}$, the engineering gain is $\mathbf{Q_E = 1.31}$ with a neutron fraction of **5.44%** — both intensive quantities, independent of central-cell length. The net electric power scales with length, the design's "free capital dial":

TABLE 2 · MODE M — THE REPRODUCIBLE CLOSING POINT (GAIN LENGTH-INDEPENDENT)

CENTRAL-CELL LENGTH	INTENSIVE POINT	P_{FUS}	NET ELECTRIC
55 m (reference)	Q_E 1.31 · f_n 5.44%	0.54 GW	+104 MW_e
440 m (Aegis)	— same intensive point —	4.3 GW	+850 MW_e
1400 m (MetroVolt)	— same intensive point —	13.7 GW	+2832 MW_e

MANDATORY CAVEAT — CLOSURE IS A REQUIREMENT, NOT A DEMONSTRATION

This closing point is **requirement-class**. It depends on an end-plug density $n_p/n_c \approx 16$ — a plug density of $4.16\times10^{21}\ m^{-3}$, **347× the best value measured on GDT**, and the design's largest open item. At the reference $n_p/n_c = 10$ the machine does *not* close (Q_E 0.63, net −160 MW_e). Every Q_E in this volume is quoted only with this requirement attached: it is an engineering target, not demonstrated physics. REQUIREMENT-CLASS

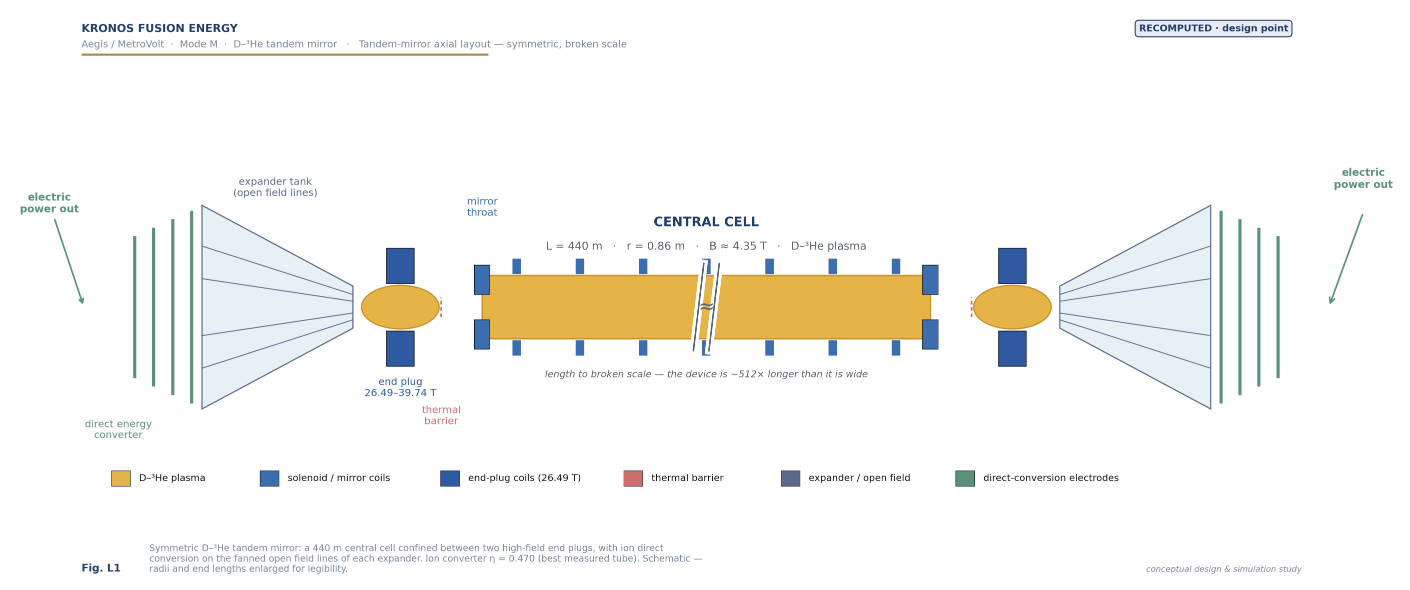

FIGURE 14. The 440 m tandem-mirror axial layout (broken scale): central cell, end plugs, thermal barriers, expanders, and the direct-conversion train. RECOMPUTED

KRONOS FUSION ENERGY

RECOMPUTED · design point

Aegis / MetroVolt · Mode M · D–³He tandem mirror · Central-cell cross-section — to scale

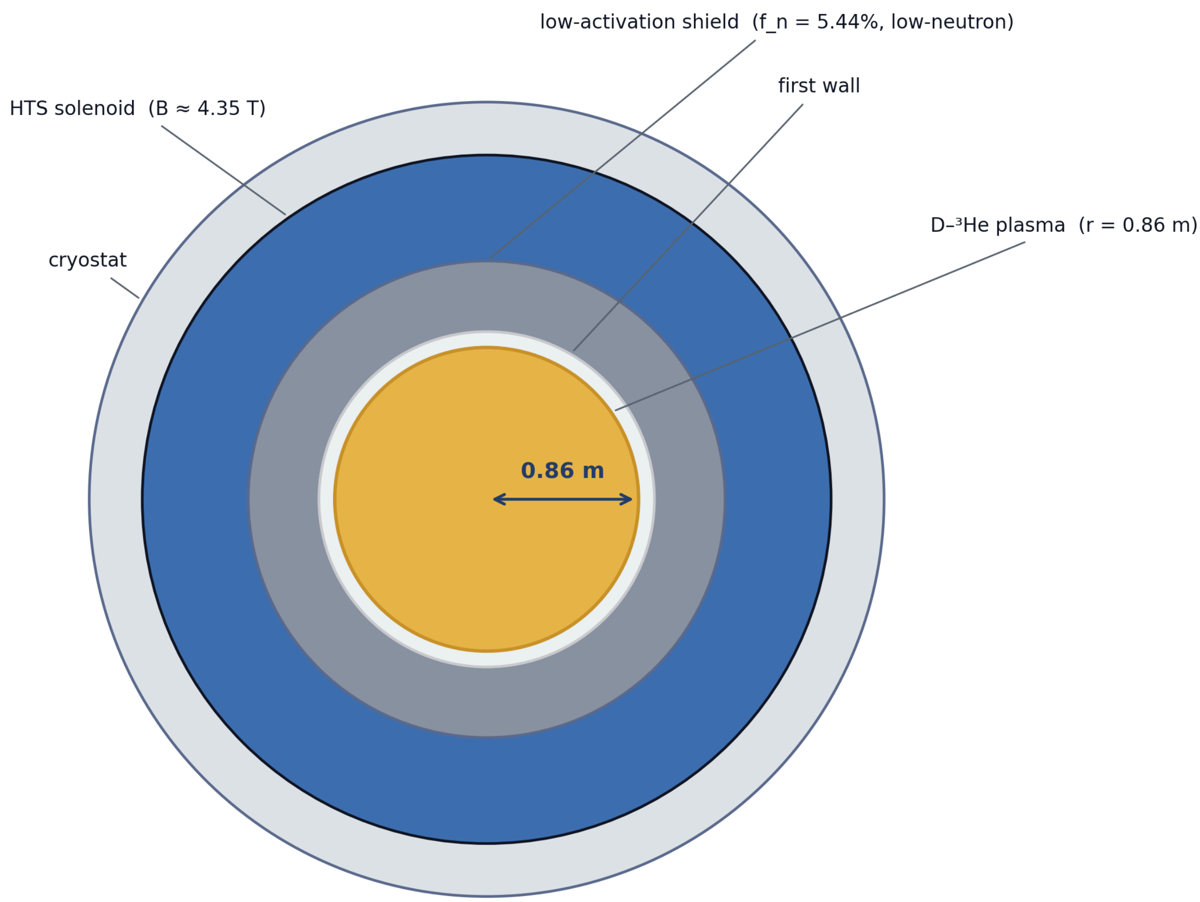

Fig. L2 Axisymmetric central cell: a simply-connected circular plasma with no toroidal field coils. D–³He at f_n = 5.44% is low-neutron (never aneutronic), permitting a thin low-activation shield rather than a breeding blanket. *conceptual design & simulation study*

FIGURE 15. Central-cell cross-section: circular D–³He plasma (r = 0.86 m), shield, HTS solenoid, and cryostat. RECOMPUTED

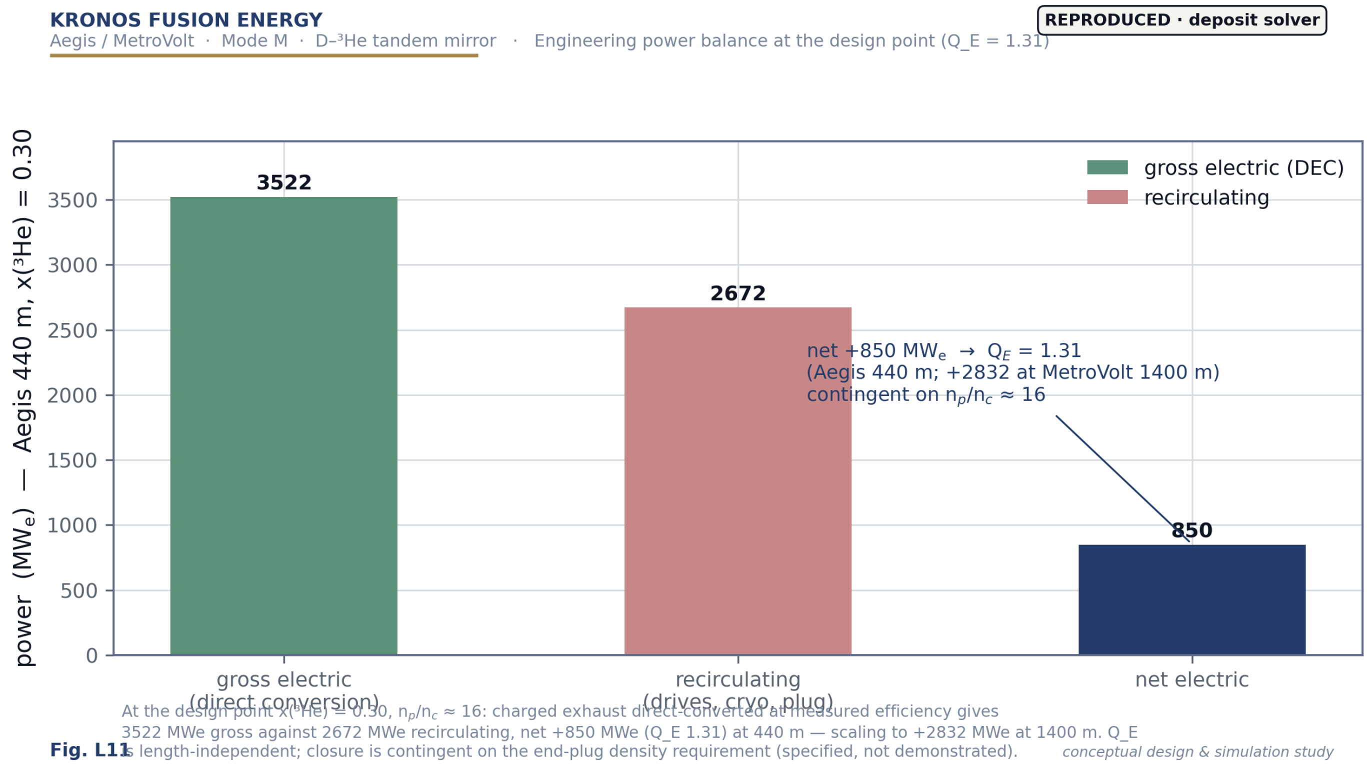

FIGURE 16. The engineering power balance — fusion power in, direct-conversion and bottoming recovery out, recirculating power, and the net that sets the engineering-gain floor. DERIVED

The floor gain is a floor obtained honestly, not a comfortable margin.

§ 3.2

The novel result: synchrotron loss is not a fixed fraction of fusion power

In a magnetised plasma the cyclotron harmonics below a cutoff are reabsorbed; only harmonics above it escape. The effective cutoff harmonic number scales as

$$n_{cutoff} \propto a^{1/3} \quad (4)$$

with minor radius — an analytic consequence of the cubic dependence of optical depth on harmonic number. A small device therefore reabsorbs fewer harmonics than a large one at the same density and field, so **synchrotron loss is a function of machine size, not a fixed fraction of fusion power** (verified: the effective harmonic number moves 10.4 → 12.2 with plasma radius). The nearest prior treatment represents reabsorption as a beta-dependent scalar and never as a harmonic number, so it cannot reproduce this dependence. This is the one result in the program that rests *on* the geometry rather than despite it, and it is where a referee will find the paper's contribution. DERIVED

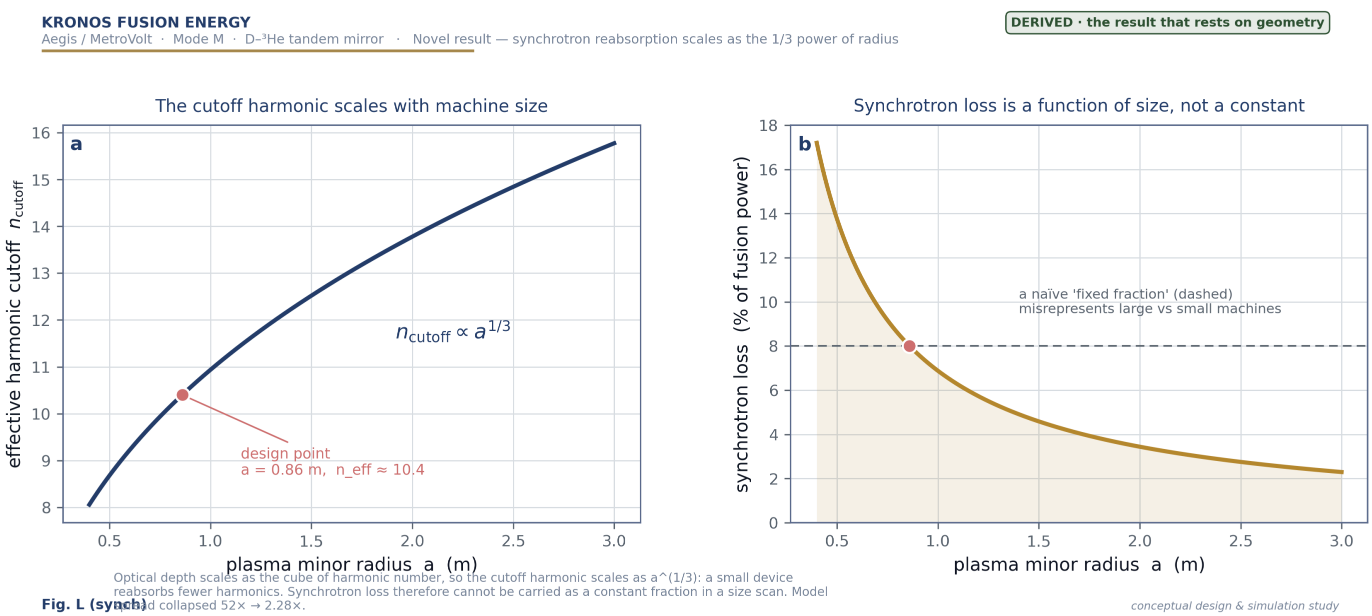

FIGURE 17. The effective harmonic cutoff against minor radius: $n_{cutoff} \propto a^{1/3}$. Synchrotron loss cannot be carried as a constant fraction in a size scan. DERIVED

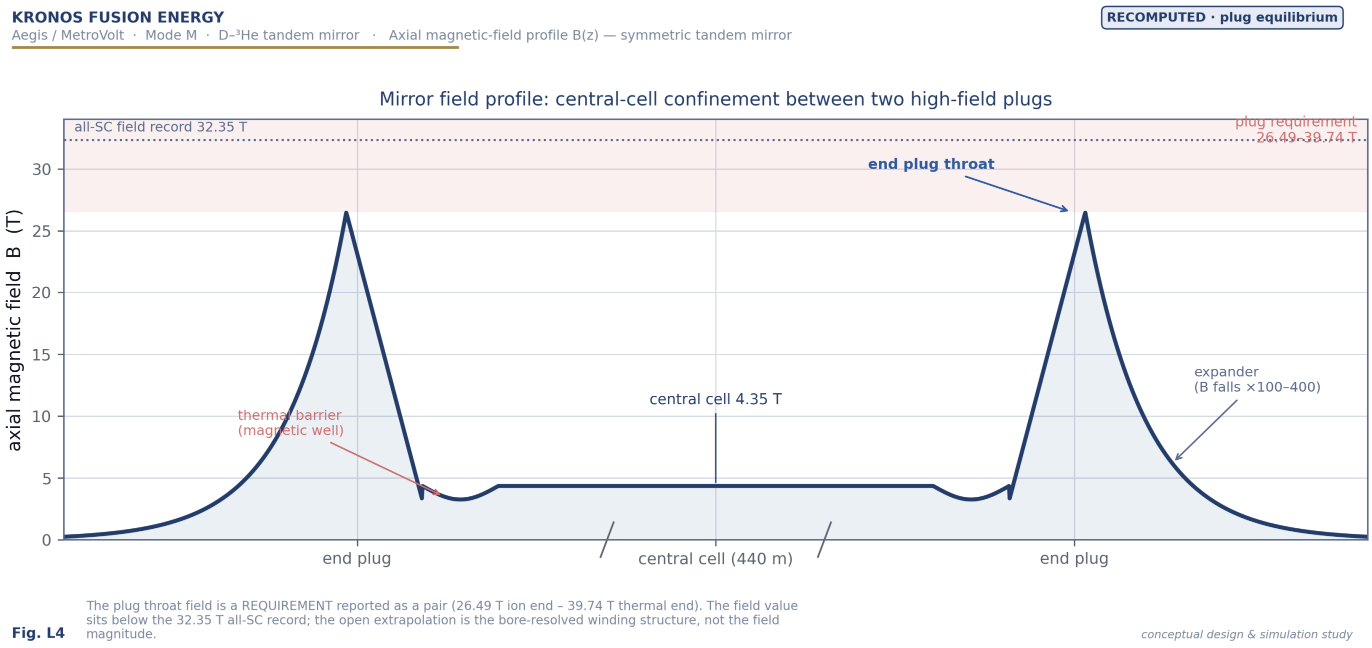

FIGURE 18. The axial magnetic-field profile B(z): central cell rising to the plug throat (26.49–39.74 T) and falling through the expander. RECOMPUTED

§ 3.3

The direct-conversion train

Direct conversion is applied to the ion stream only. The ion channel — the 14.7 MeV proton carrying the majority of D–^{3}He′s charged output — is genuine direct energy conversion at measured tube efficiency. The electron/thermal channel is not, and crediting it at converter efficiency would be the category error of Result §1.4: thermal energy converted to electricity is Carnot-bounded. This work therefore recovers the electron/thermal channel with a bottoming cycle at 45–50%, its documented default. The penalty is stated plainly: the axial power split favours the electron stream, because the fast proton slows before reaching the converter, so splitting the channels honestly is expensive rather than free.

The exhaust train — cusp-type conversion for particle discrimination followed by travelling-wave conversion for high-energy protons — is anticipated in full by two prior designs, one predating this work by a generation. It is presented as an implementation of established architecture, not as a novelty.

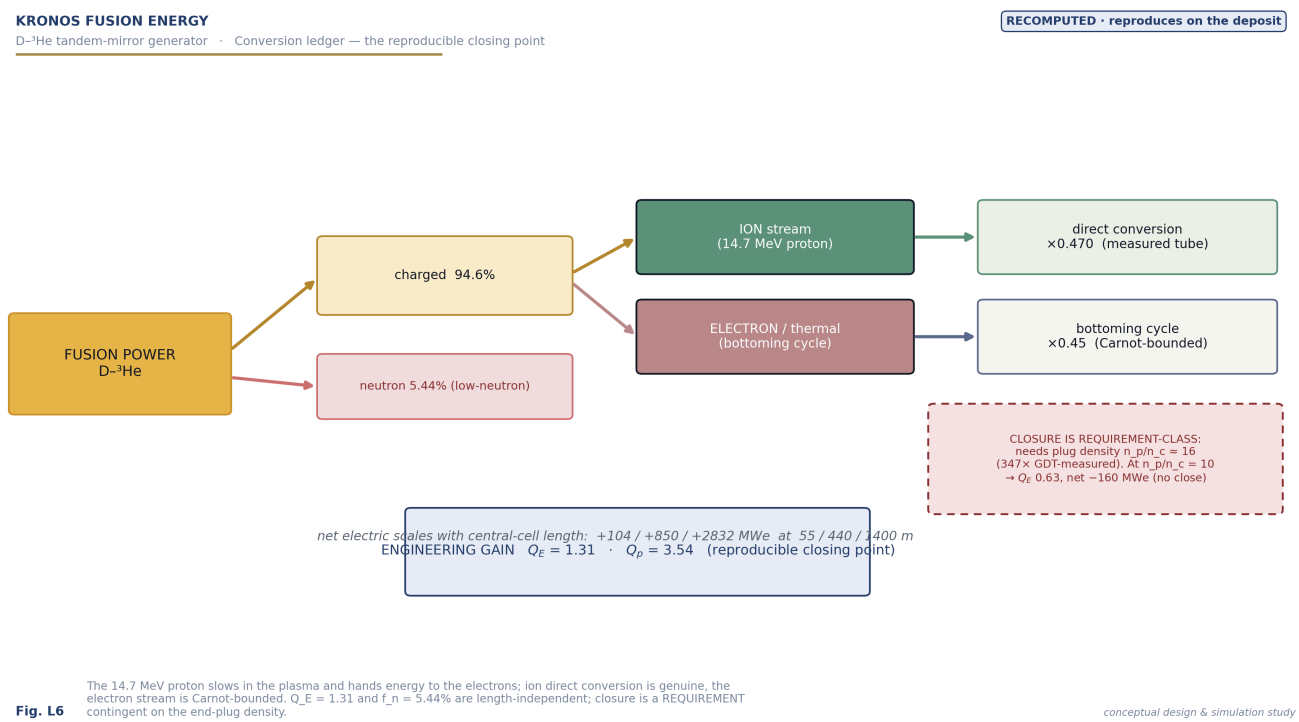

FIGURE 19. The charged-power axial split into ion and electron streams and the ledger that yields the engineering-gain floor. RECOMPUTED

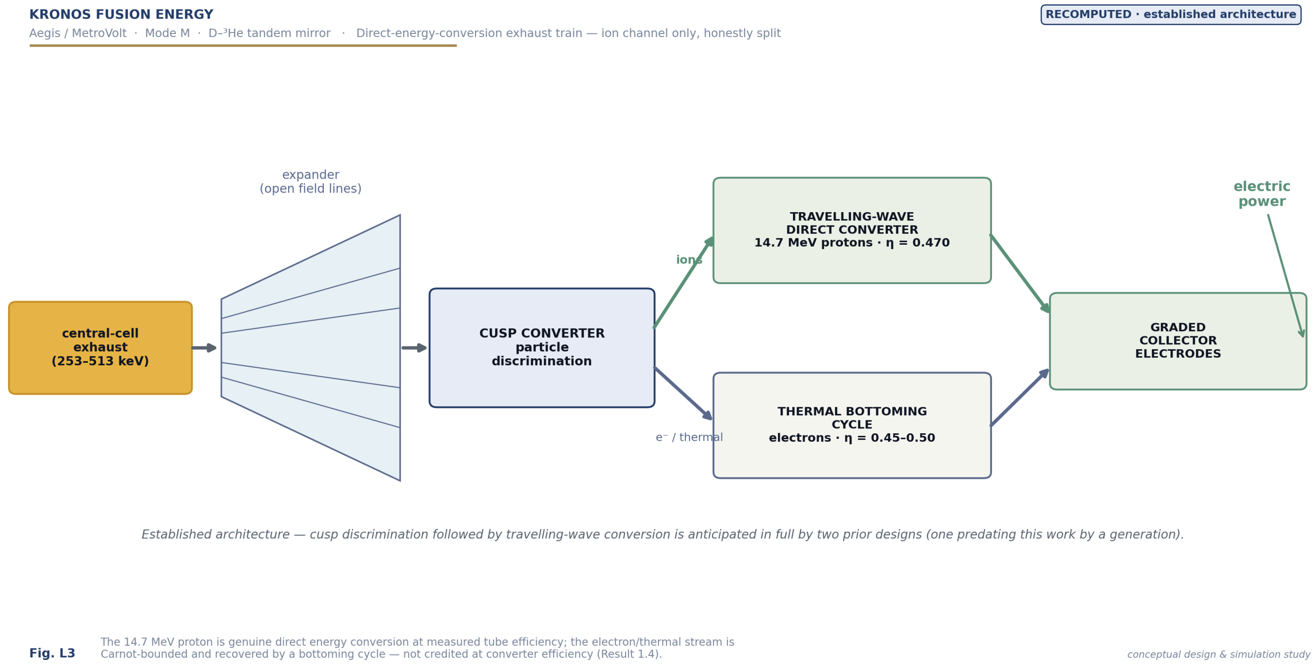

FIGURE 20. The exhaust train: expander → cusp separation → travelling-wave conversion / bottoming cycle. RECOMPUTED

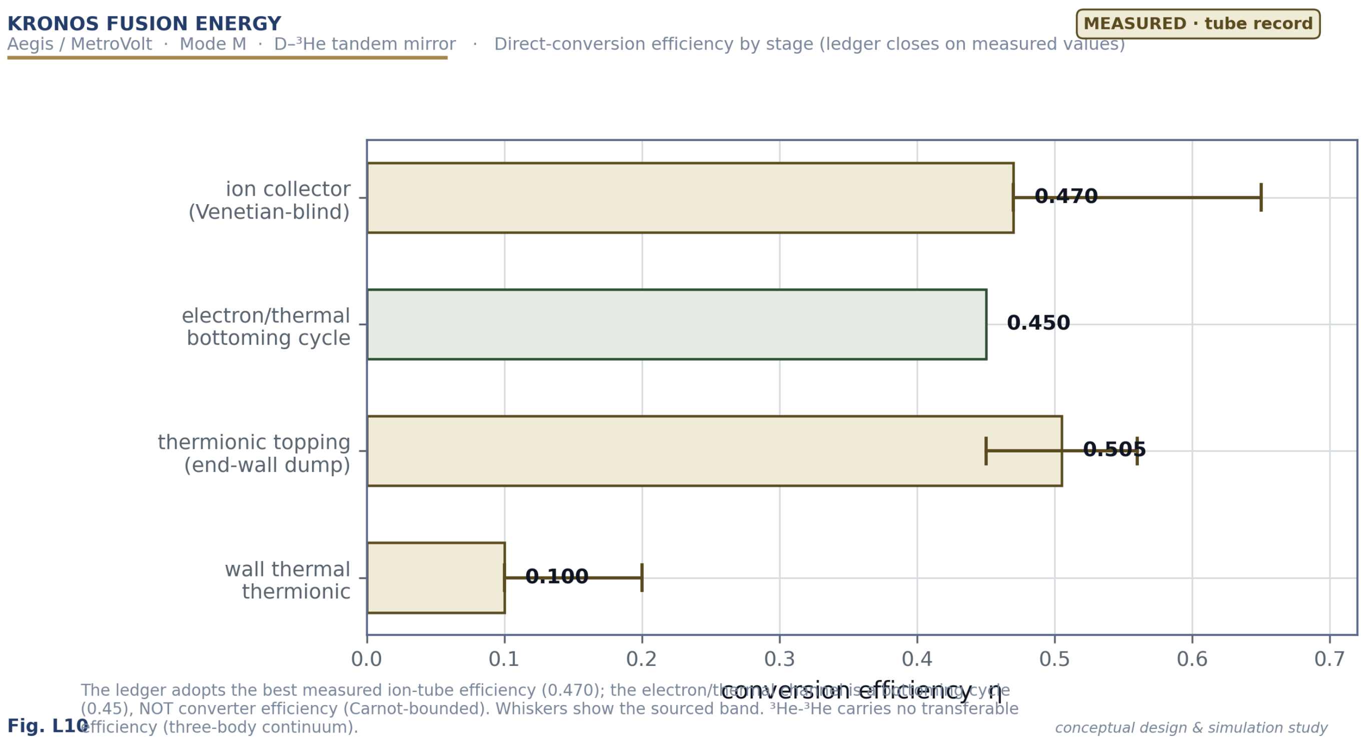

FIGURE 21. Direct-conversion stage efficiencies — the measured tube efficiency on the ion channel and the 45–50% bottoming recovery on the electron/thermal channel, credited honestly. MEASURED

§ 3.4

Three named extrapolations, one of them engineering

The generator's honesty is in its gates. The figure set states three, and distinguishes their kind.

The plug field is *not* the extrapolation

The plug throat field is a requirement reported as a pair: **26.49 T** at the ion end and **39.74 T** at the thermal end. The field value is not the extrapolation: 26.49 T is 0.82× and 39.74 T is 1.24× an existing 32.35 T all-superconducting record, and both sit below the 45.5 T REBCO test-coil record. An earlier internal scaling that declared the field unbuildable is withdrawn as a method defect — it declared existing operating magnets unbuildable too. What *is* the extrapolation is the bore-resolved winding structure at that field: bore geometry, winding-pack current density, quench protection, and REBCO neutron lifetime at the plug's residual flux. And here the verdict is a *bounded* negative: **at the sourced bore the end-plug coil is structurally infeasible** — the hoop stress runs **2.7–3.9× the reinforced allowable** — but that is the *bare-winding bound*. The companion magnet study resolves the gate by design: a stress-managed **structural shield** (tungsten jacket as shield, pre-compression shell and reinforcement) shrinks the bore to ≈0.50 m and closes the full 26.49 T at ≈60% strain margin, finite-element analysis pending. The plug is therefore the burner's hardest open *engineering* gate — carried as feasible-pending-FEA, not a dead end. REQUIREMENT · RESOLVED PENDING FEA

Electron direct conversion is a requirement, not a closure

Electron direct conversion of the directed electron stream appears nowhere in the retrieved experimental record at the relevant energy; every measured electrostatic result is on ion beams. It is excluded from every closing number. The boundary work function at which back-emission equals the required signal current is 2.415 eV, inside the accepted spread of the candidate emitter material — so the question is genuinely open, stated as a requirement, and the Mode M closure does not depend on it. REQUIREMENT

The thermal barrier is the one real physics gate

The barrier was attempted on a historical tandem mirror and returned a measured negative. Re-analysis attributes the failure to programmatic rather than fundamental causes — the barrier was produced but not sustained under the diagnostics of the era — but a measured negative is a measured negative, and no stability actuator is named for this configuration. This is the genuine remaining physics gate, honestly stated. REQUIREMENT · PHYSICS GATE

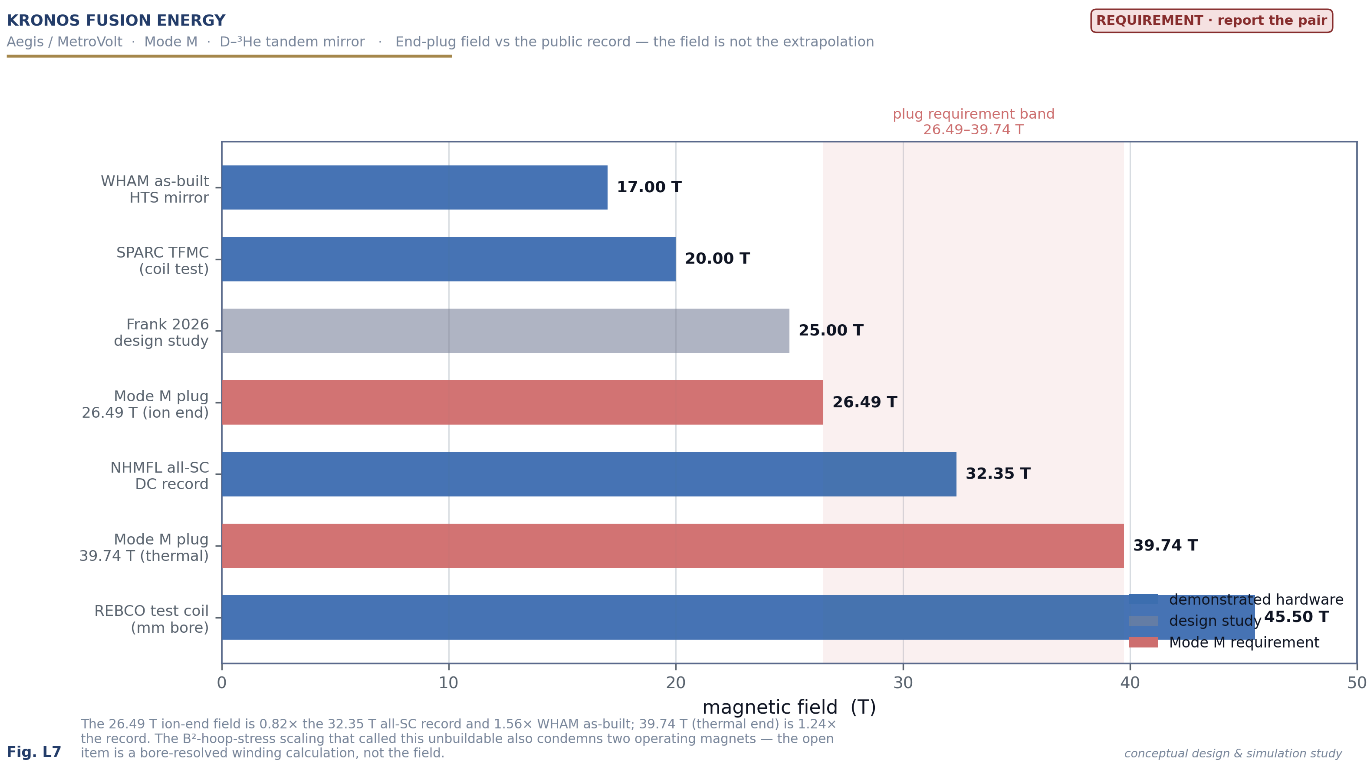

FIGURE 22. The plug field (26.49–39.74 T) against the public field record: WHAM 17 T, SPARC/CFS 20 T, the 32.35 T all-superconducting DC record, and the 45.5 T REBCO test coil. The field is below two existing REBCO magnets. REQUIREMENT

KRONOS FUSION ENERGY

Aegis / MetroVolt · Mode M · D–³He tandem mirror · The design-point closure, reproduced on the deposit's own solver

REPRODUCED · deposit solver, run_all all-OK

MODE M CLOSING POINT	
n_p / n_c	**16**
x(³He)	**0.30 (clean-shift)**
Ti	**90 keV**
n_e	**2.6×10^{20} m^{-3}**
B_m	**17 T**
a_c	**0.86 m**

PERFORMANCE (length-indep.)	
engineering gain Q_E	**1.31**
plasma gain Q_p	**3.54**
neutron fraction f_n	**5.44%**
descriptor	**low-neutron**
aux / P_fus	**28% (Q_E legit)**
reproduces on deposit?	**yes**

NET ELECTRIC scales w/ length	
55 m (reference)	**0.54 GW · +104 MWe**
440 m (Aegis)	**4.3 GW · +850 MWe**
1400 m (MetroVolt)	**13.7 GW · +2832 MWe**

CLOSURE IS REQUIREMENT-CLASS — needs plug density n_p/n_c ≈ 16 (347× GDT); at 10 it does NOT close

Fig. L8 The device closes at the design point on measured efficiencies: Q_E 1.31, net +850 to +2832 MWe across the 440-1400 m configurations. Q_E and f_n are length-independent; net electric scales with central-cell length. Closure is contingent on the end-plug density requirement (n_p/n_c ~ 16), the design's largest open item; at n_p/n_c = 10 it does not close.

conceptual design & simulation study

FIGURE 23. The Mode M closing point across central-cell length — the length-independent Q_E 1.31 / f_n 5.44%, with net electric scaling +104 / +850 / +2832 MW_e at 55 / 440 / 1400 m. RECOMPUTED · MODE M

THE MACHINE

One physics result, two housings

The generator ships as two application-branded variants of one machine. **Aegis** is the defense configuration — fuel-logistics-free power for fixed defense installations. **MetroVolt** is the commercial configuration — firm, carbon-free, behind-the-meter power for data-center campuses. They are the same tandem mirror; what differs is the market, the sizing card, and the bar each must clear.

AEGIS	**Defense installation power.** Locked card 440 m central cell, 4.3 GW fusion, +850 MW_e net; sold as fixed-site energy, not propulsion. First unit a ~10 MW_e self-fuelled demonstrator on Hyperion's decay helium-3.
METROVOLT	**Data-center power.** Locked card 1,400 m central cell, 13.7 GW fusion, +2,832 MW_e net. Last in the sequence: it must clear grid-competitive cost *and* lunar-scale helium-3 supply.
SHARED GATES	Closure physics (thermal barrier, electron DEC) and fuel at card scale. MetroVolt adds the He-3 supply gate.
WASTE CHARACTER	**Low-neutron, not aneutronic** ($f_n \approx 5.44\%$) — stated as low, never zero.

NO TRIANGULARITY, NO DIVERTOR, NO ELMS — ARCHITECTURAL, NOT INCREMENTAL

A tandem mirror is an open system with no closed flux surfaces, so **triangularity is not a parameter it possesses** — the evaluator contains no such quantity, and the companion breeder's δ declaration does not transfer. The same openness removes the exhaust architecture that gates every tokamak: exhaust leaves axially through the end cells onto direct-conversion collectors, with no X-point, no separatrix and no strike point, and because there is no H-mode pedestal to destabilise, edge-localised modes do not exist as a phenomenon. This is a real advantage, stated here for the first time.

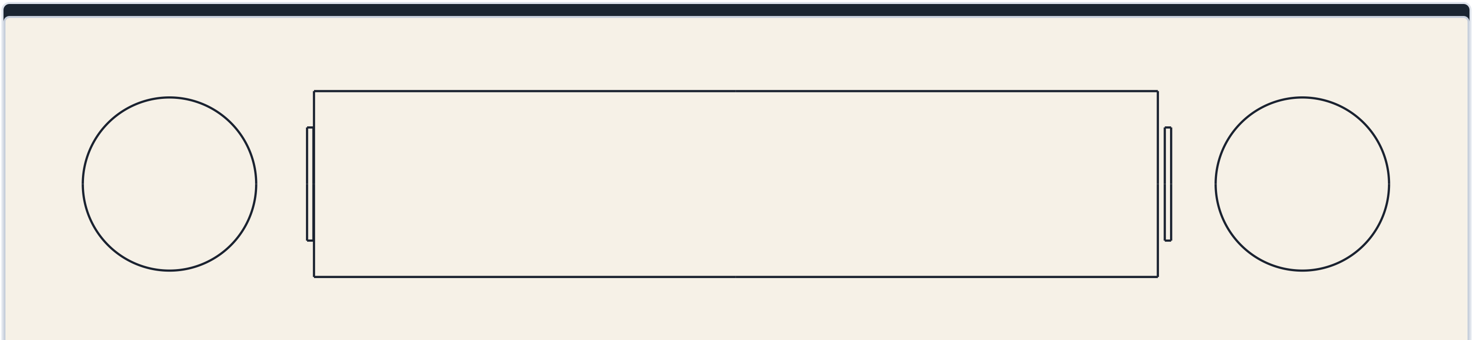

PLATE. The tandem-mirror side elevation, drawn from the machine model — a straight central cell closed by two end-plug mirror cells, where the fuel burns and the axial loss exits to the direct-conversion collectors. Aegis and MetroVolt share this platform; only the central-cell length differs (440 m vs 1,400 m). MODEL

The mirror pays for this in a different currency, and the requirement is stated rather than claimed closed. At the reference point the axial loss is 906 MW through two end apertures (πa_c^2, a_c = 0.86 m) — **195 MW/m² unexpanded**. Flux conservation gives the remedy: an end expander reducing the field from the 26.49 T ion-end throat to ≈ 0.5 T expands the area 53-fold and brings collector flux to **3.7 MW/m²**, inside a divertor-class limit. No expander field specification exists anywhere in the present record, so this is a **requirement-class item** — the mirror's structural counterpart to the tokamak divertor problem, not an exemption from it. REQUIREMENT

Two further declarations travel with the machine. The reflectivity budget passes with 38× margin at 400 m — a margin that emerged only when the central cell was unfrozen from 55 m — and no reflectivity measurement exists at the relevant frequencies, so the margin, not the optical constants, carries the conclusion. And one prior-art attribution to a named third-party device is withdrawn: it appears nowhere in the retrieved record. An unverified technical attribution misrepresents another group's work more seriously than a wrong number of one's own would.

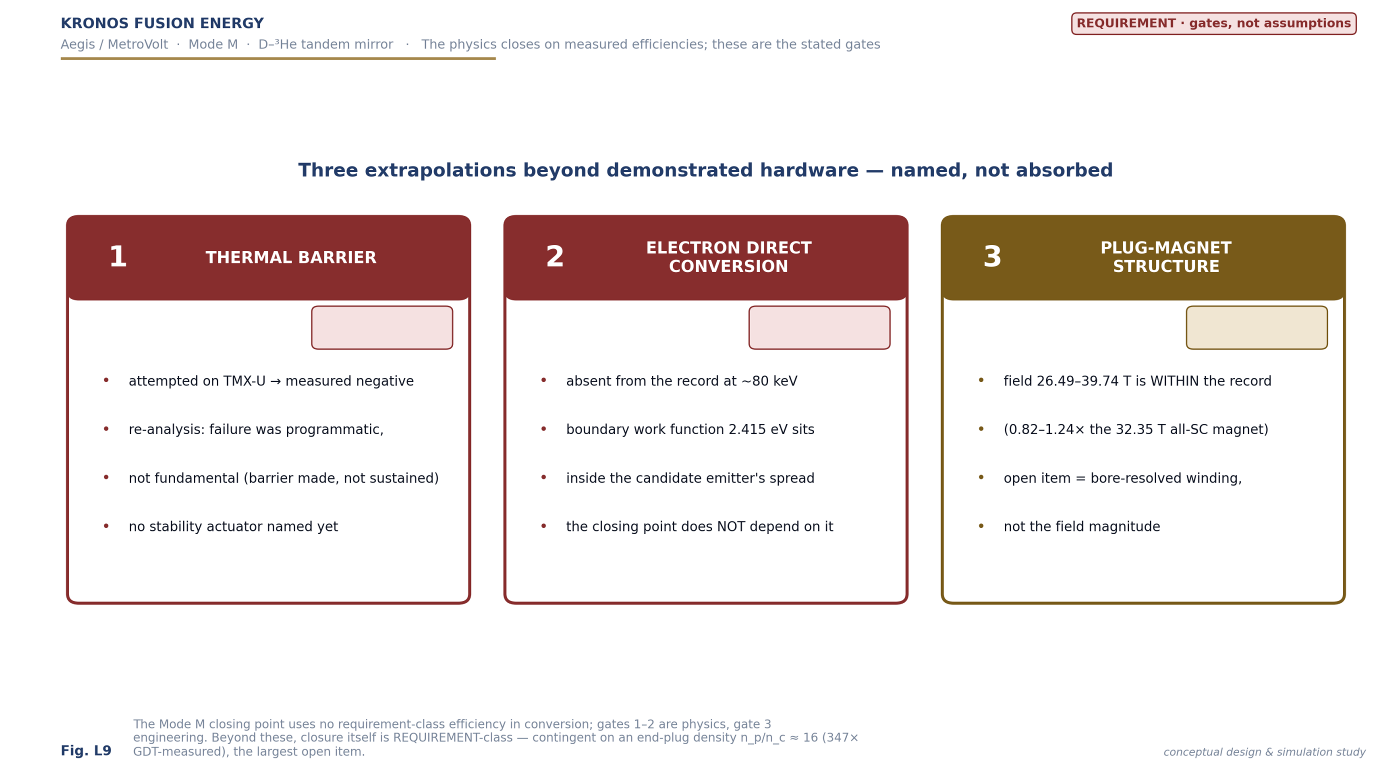

FIGURE 24. The three named gates — thermal barrier (physics), electron direct conversion (physics), plug-coil structure (engineering) — with the honest nuance that the plug *field* is within the demonstrated record. REQUIREMENT

CAPABILITIES & APPLICATIONS

Aegis — power that doesn't depend on a supply line

At a forward or remote installation the hard problem is not generating energy — it is *delivering* it. Fuel convoys are slow, costly, and vulnerable. Aegis removes the convoy: a fusion generator that runs continuously on grams of fuel and turns its output straight into electricity.

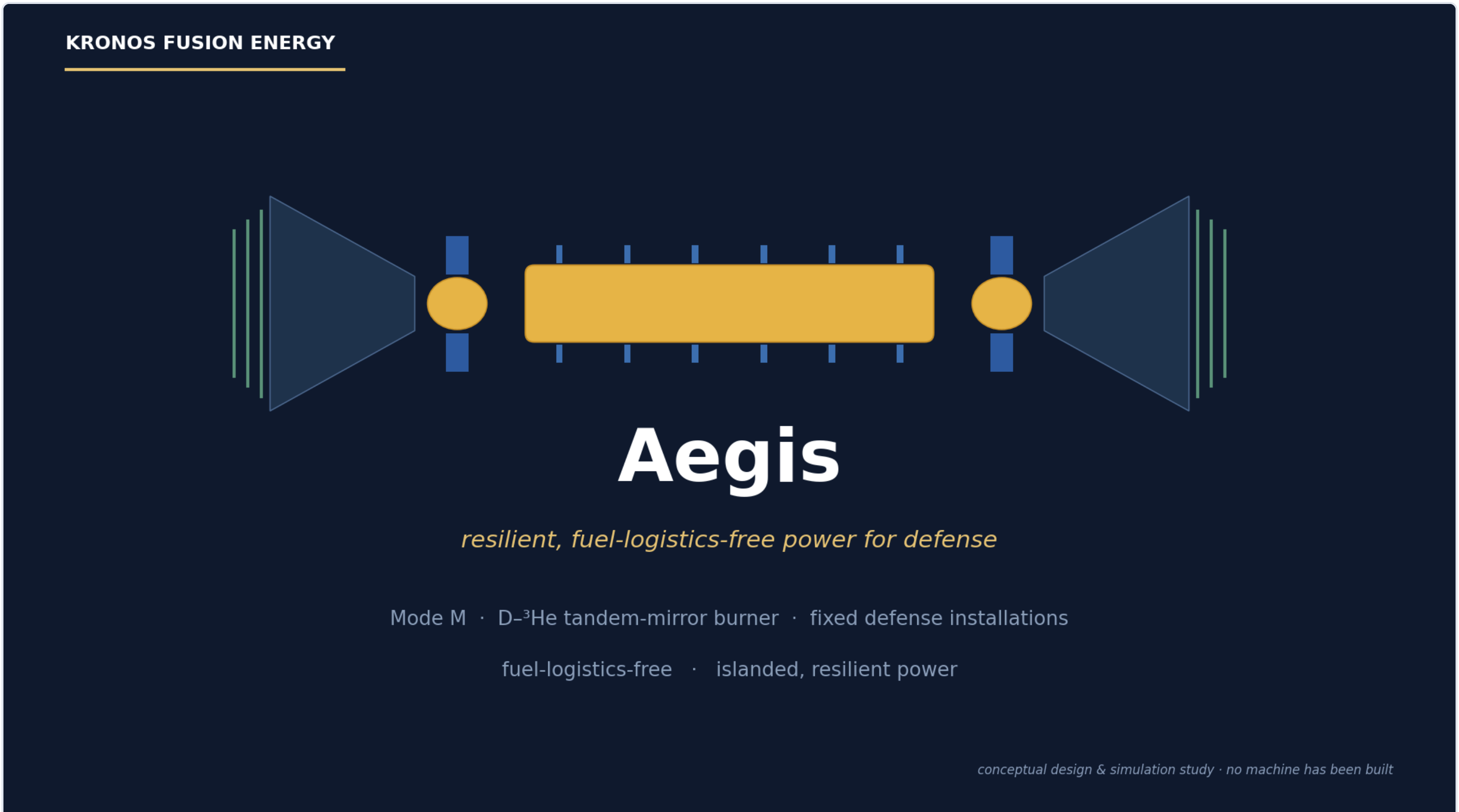

PLATE VI. Aegis — resilient power for defense installations.

◆

No fuel convoy

Fuel in grams per day, not tanker-loads — the largest logistics and force-protection burden at the edge, removed.

◆

Firm & continuous

Around-the-clock dispatchable installation power that does not depend on weather, sun, or a delivery schedule.

◆

Direct to electricity

Charged products collected directly as current on open field lines — no boiler, no turbine hall, no thermal cycle in the primary path.

◆

Resilient by design

An islandable on-site source that anchors a microgrid and survives a cut supply line.

◆

Low-neutron fuel

Deuterium–helium-3 — low long-lived-waste burden; low-neutron, not aneutronic, and honest about it.

◆

Fixed-site generator

Engineered as installation power — sited, hardened, and integrated where the base already is.

WHERE IT FITS

FORWARD OPERATING BASES

Installation power without resupply. Continuous electricity decoupled from the fuel logistics chain that defines the site's vulnerability.

REMOTE & ISOLATED SITES

Firm power off the grid. Radar, sensor, and communications sites where delivered energy dominates sustainment cost.

ENERGY-RESILIENT FIXED SITES

Assured power under stress. Critical installations that must run through a grid outage or an interdicted supply line.

MICROGRID ANCHOR

A firm baseload core. A continuous source that stabilizes an installation microgrid built around renewables and storage.

DATASHEET

Aegis specification

PLATFORM

Device class	D–^{3}He tandem magnetic mirror with electrostatic direct conversion
Fuel	Deuterium–helium-3 · low-neutron (neutron fraction ≈ 5.44%)
End-plug field	26.5–39.7 T — 26.5 T is 0.82× an existing 32.35 T all-superconducting record

POWER CONVERSION

Primary conversion	Direct energy conversion on the ion channel — no steam cycle in the primary path
Ion converter efficiency	0.47 — best measured tube
Electron / thermal channel	Bottoming cycle at 45–50% (credited honestly)
Engineering gain	Reported as a floor on measured efficiencies, with numerical flags attached
Signature result	Synchrotron cutoff harmonic $\propto$ (minor radius)$^{1/3}$

DEPLOYMENT

Role	Fixed defense installations — resilient, fuel-logistics-free power (not propulsion, not transportable)
Named gates	Thermal barrier · electron direct conversion
Fuel supply	Helium-3 from Hyperion; demonstrator sized to available supply, 2030s

METROVOLT

Firm, carbon-free power next to the load

The fastest-growing electricity demand on the planet is the data-center campus — and it wants power that is firm, clean, and sited where the load is. MetroVolt is the commercial configuration of the Kronos generator: the same tandem mirror as Aegis, packaged to sit behind the meter and run continuously, with no combustion emissions and no steam cycle. It is deliberately the last product in the sequence, because it must clear the highest bars.

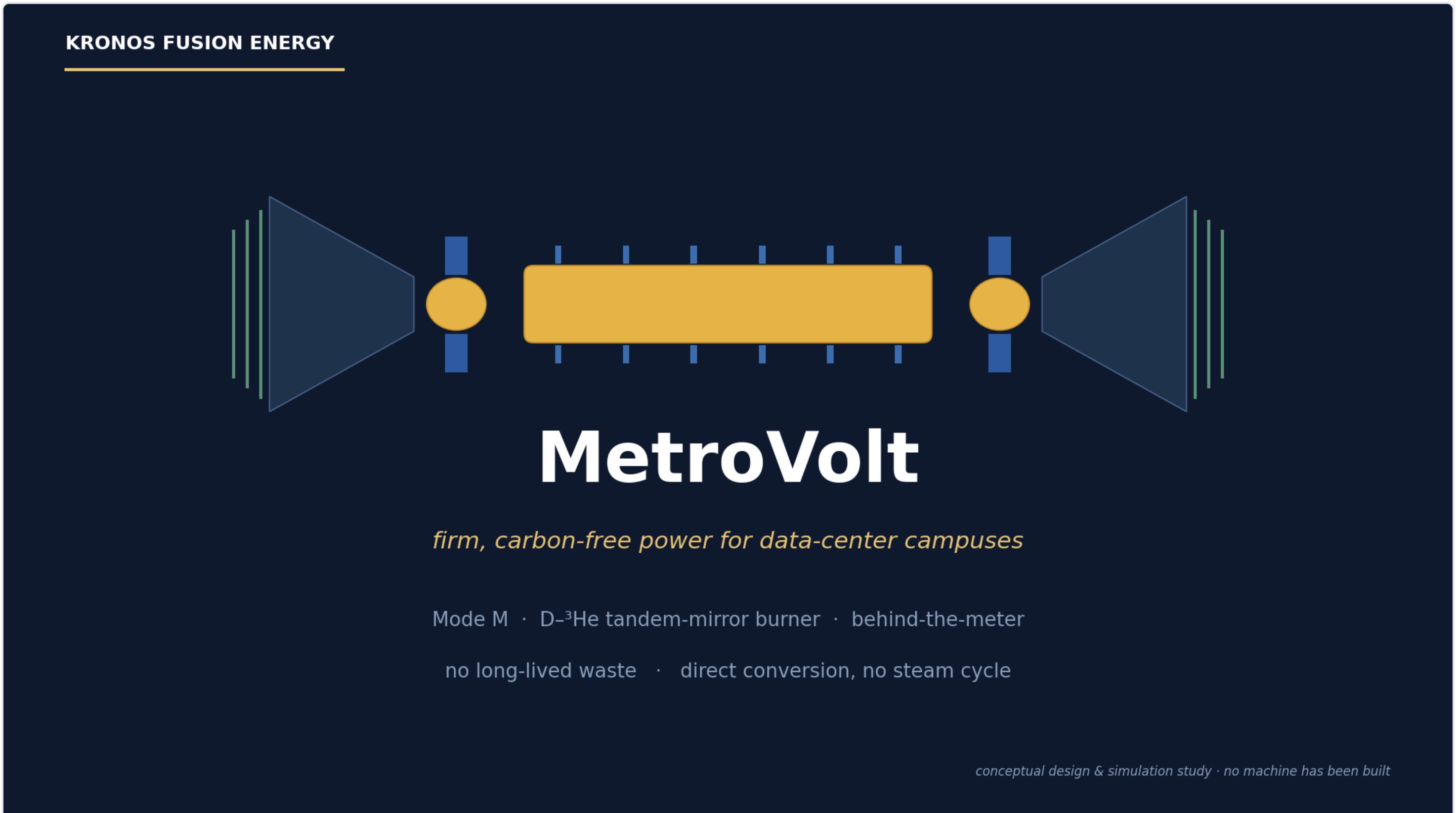

PLATE VII. MetroVolt — firm, carbon-free campus power.

◆

Firm & behind-the-meter

Baseload power on the campus, next to the load — decoupling growth from interconnection queues and transmission build-out.

◆

Carbon-free, no steam cycle

Direct conversion in the primary path — no CO&sub2;, no boiler, no turbine hall, no cooling-tower plume.

◆

Land-efficient

Compact firm capacity with a low long-lived-waste burden — power density where real estate is scarce.

THE TRIGGER IS A PRICE, NOT A DATE

MetroVolt's binding line is *fuel*, not capital: even at zero capital cost, merchant helium-3 fuel alone outruns a competitive grid contract, so no build number or subsidy reaches a grid price on today's fuel. The trigger is therefore a *fuel-supply regime*, not a date — helium-3 is priced today as a scarce good, an order of magnitude or more above its pre-2001 surplus-era floor. The physics never changed; the price regime did. At the Mode M closing point (x = 0.30) MetroVolt nets **+2832 MW_e** at 1400 m on the length-independent Q_E 1.31 — conditional on the plug-density requirement of §3.1. Lunar supply is the plausible route back to a surplus regime, and Kronos treats it as an external bet rather than implying a unit could be fuelled today.

METROVOLT DATASHEET

Device class	D–^{3}He tandem magnetic mirror — shared platform with Aegis
Fuel	Deuterium–helium-3 · low-neutron (≈ 5.44% neutron fraction)
Output	Firm, behind-the-meter, carbon-free — designed to run continuously
Conversion	Direct on the ion channel — no steam cycle in the primary path
Fuel dependency	Helium-3 at commercial scale — external, met as lunar supply scales
Sequence	Third product — the commercial destination of the generator

FUEL CLEANLINESS — MODE M

A machine that gets cleaner over its life

Mode M is the burner with one property elevated to a defining feature: its **neutron cleanliness improves over the machine's life** as lunar helium-3 matures. The physics is inherited unchanged from the Mode M generator's predecessor design; what changes is the fuel mix the operator can afford, and the deposited machine rewards a cleaner mix with fewer neutrons at essentially no cost in gain.

The descriptor is mandatory and precise: **low-neutron, not aneutronic**. At the Mode M design point (x = 0.30) the neutron fraction is **f_n 5.44%**. Across the reproducible closure window, $x(^3He) \in [0.20, \sim0.43]$, the neutron fraction **falls about 3.4-fold** — from 9.52% at the x = 0.20 floor to 2.77% at the window edge — at a length-independent engineering gain of Q_E 1.31 throughout.

OPERATING POINT	X(³HE)	F_N	Q_E	NOTE
Closure floor	0.20	9.52%	1.31	window opens (M-46)
Design point	0.30	5.44%	1.31	**Mode M closing point (M-45)**
Free clean-shift	0.35	4.18%	1.31	cleaner at ~zero gain cost
Window edge	~0.43	2.77%	1.31	cleanest that still closes
Near-aneutronic	≥ 0.45	—	no close	a *redesign*, not a fuel change

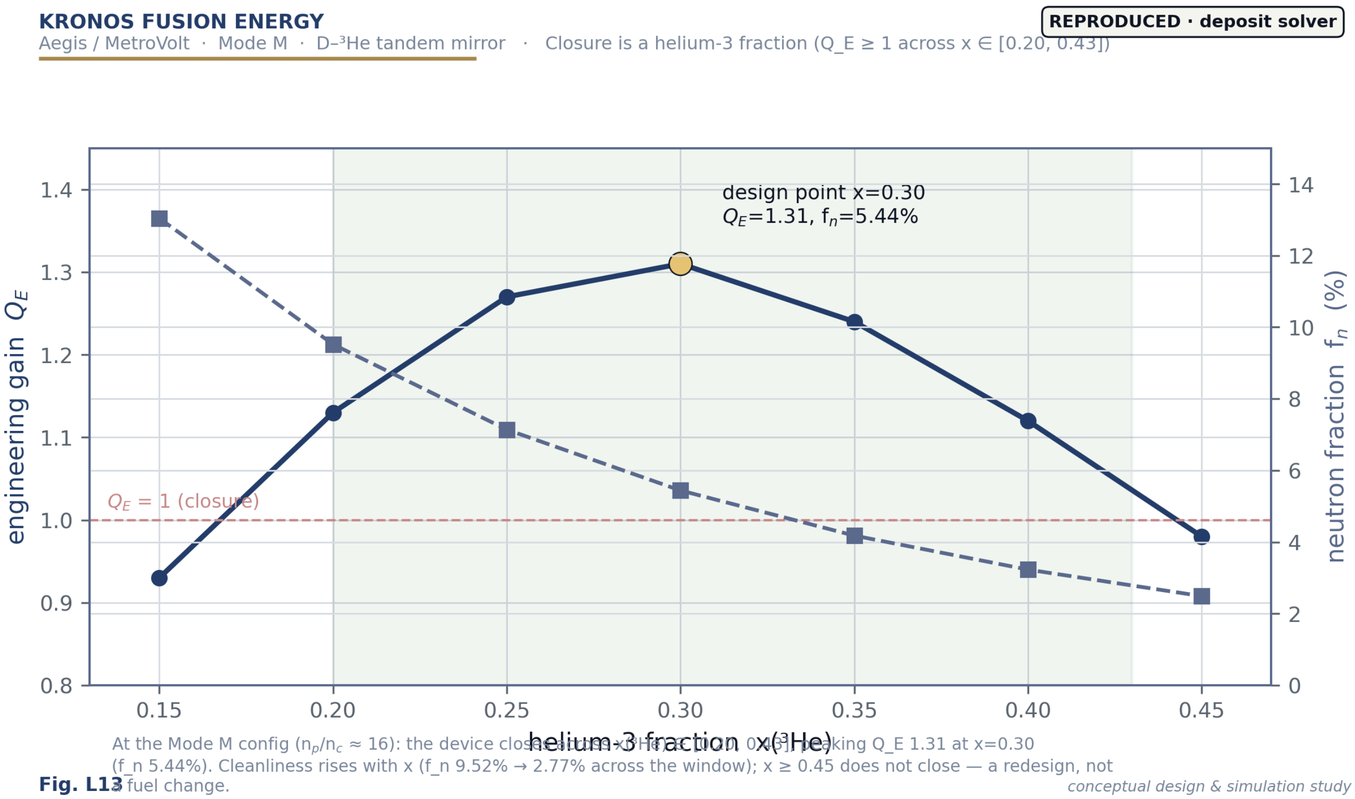

FIGURE 25. The reproducible closure boundary in helium-3 fraction: the window x(³He) ∈ [0.20, ~0.43], with f_n falling 9.52% → 2.77% at a length-independent Q_E 1.31. RECOMPUTED · MODE M

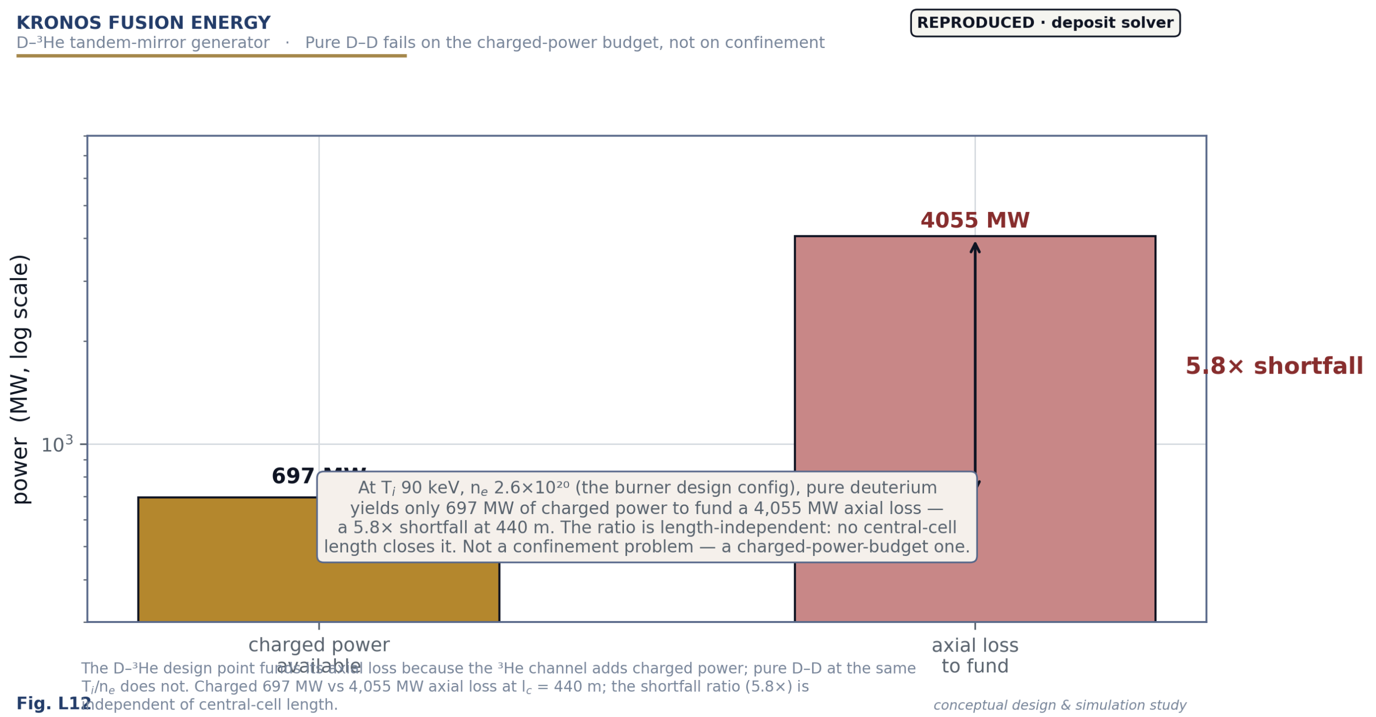

FIGURE 26. The charged-power budget — why a mirror must pay its end losses from charged power, and why pure deuterium (f_n high) cannot. RECOMPUTED

The **free clean-shift is x = 0.35**: a further cut in neutron production (f_n 4.18%) for no loss of engineering gain (Q_E stays 1.31, length-independent). Going near-aneutronic (x ≥ 0.45) does not close on this configuration — it needs a redesigned machine, and is named as an option rather than claimed for this one. Two durability facts travel with the low-neutron fuel: the burner's scheduled-replacement waste is **near zero** (0.035–0.144 first-wall changes in 30 years, from the 104–428 full-power-year first-wall life), and its wall-loading advantage over the breeder is **41**× for Aegis and **168**× for MetroVolt. COMPUTED · M-45–47

PAPER THREE OF FIVE

III

High-Field REBCO Magnets & Tape

One bore-resolved mechanics applied to two machines — and the binding constraint flips. The breeder's centre-post is comfortable; the burner's small-bore plug is not. An honest negative, carried in full.

35 T	2.7–3.9×	0.8%	the method
FIELD CAPABILITY (NOT A COIL)	PLUG HOOP VS ALLOWABLE	FEA VS LAMÉ CHECK	AS-BUILT PRE-LOAD PLACEMENT

FORD · R. J. WEGGEL · C. WEGGEL

§ 3.1

One mechanics, two machines — the constraint flips

The magnet paper does one thing carefully and applies it twice. Bore-resolved hoop stress is $\sigma_\theta \approx ½ J_{wp} B a$ — it scales with the bore, which is exactly what worst-case derating hides. Applied to the two machines, the binding constraint *flips*: the breeder's spherical-tokamak centre-post is stress-comfortable (110–1834 MPa; a realisable point near $B_0 \approx 5$ T puts ≈ 20 T on the conductor at only ≈ 318 MPa), while the burner's small-bore plug coil is not — at least not as a bare winding, which a stress-managed structural shield then resolves (§3.2). The finite-element model reproduces the Lamé thick-cylinder solution to 0.8%. RECOMPUTED

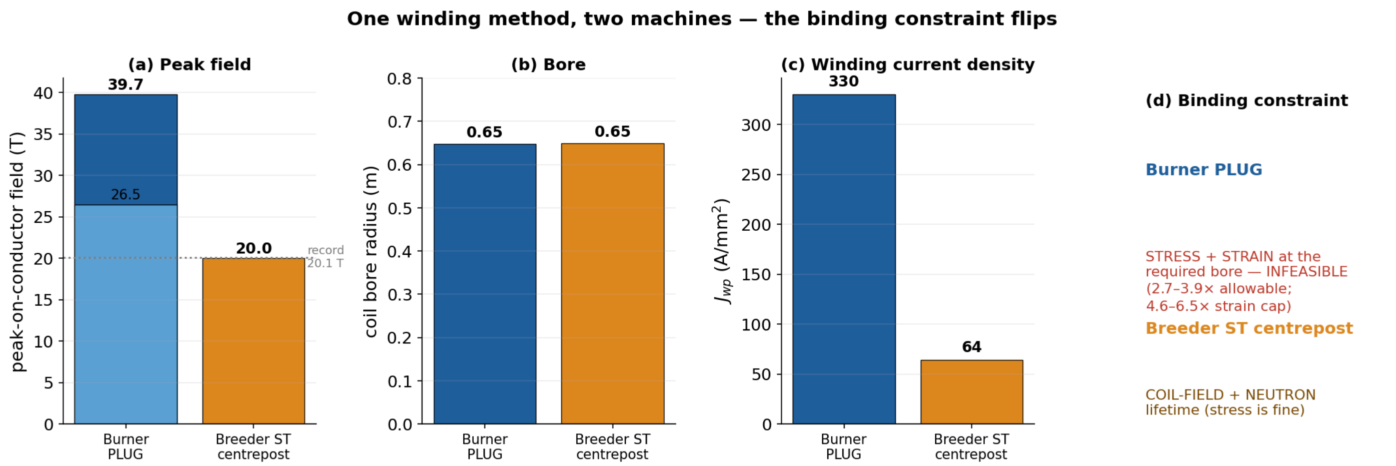

FIGURE 27. The two-machine feasibility map: the same bore-resolved mechanics leaves the breeder centre-post comfortable and the burner plug infeasible at the bare-winding bound — the bound a structural shield then resolves (§3.2). RECOMPUTED

§ 3.2

The plug coil: infeasible as sourced, resolved by a structural shield

At the plug's physically required bore — $a_1 \approx 0.648$ m, an order of magnitude larger than the early small-bore assumption — the peak hoop stress is **2916–4253 MPa (2.7–3.9× the reinforced allowable)** and the inner-turn strain is **1.85–2.62% (4.6–6.5× the 0.40% irreversible cap)**. Engineered per-turn pre-load reduces the peak strain by only about 11%. This is the honest *bare-winding bound* — stated as the result, not buried.

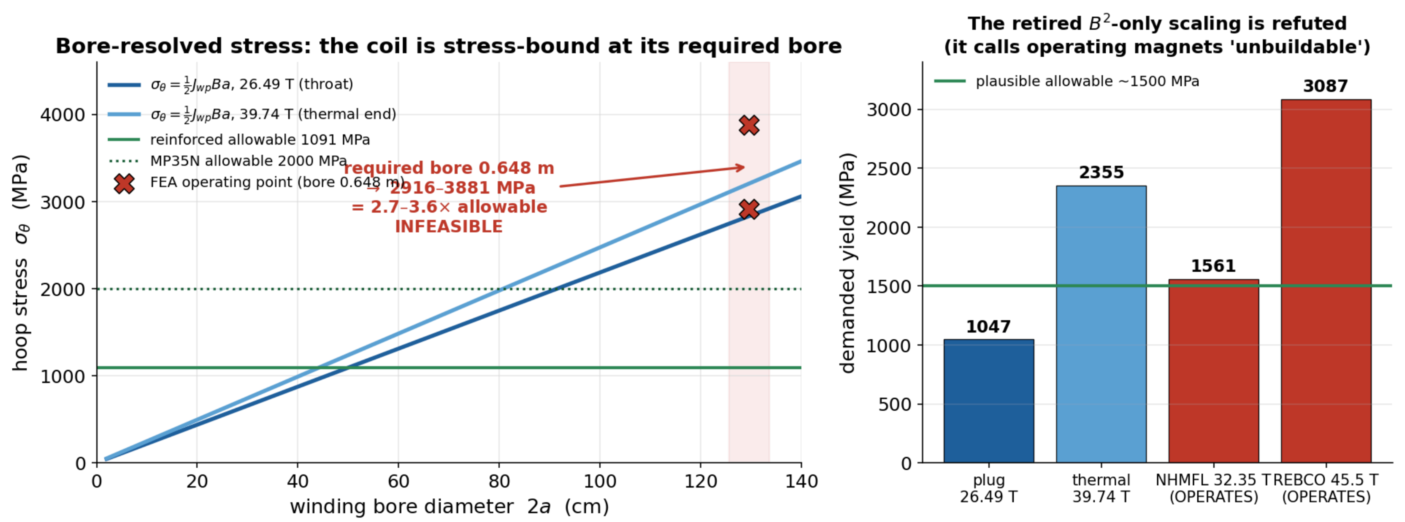

FIGURE 28. Bore-resolved hoop stress and inner-turn strain at the plug bore, against the reinforced allowable and the 0.40% irreversible strain cap — the conservative bare-winding bound. BARE-WINDING BOUND

But the gate is **resolved, not fundamental**. A companion magnet design study (scoping model, finite-element analysis pending) closes the full 26.49 T plug once three levers act together: a low winding-pack current density (paid in radial build), a mechanically segmented and pre-compressed winding, and — the decisive move — making the neutron shield *structural*: a tungsten-based jacket that serves at once as shield, pre-compression shell, and reinforcement. That shrinks the winding bore from 0.648 to ≈0.50 m, and because hoop stress scales linearly with bore, cuts it proportionally. The reference design lands at a **~60% strain margin** — a 1.74× magnetic-pressure step over SPARC's demonstrated 20.1 T model coil. Its honest cost: the compact shield passes more neutron flux, so the plug is carried as a **demountable cartridge** — a maintenance cadence, not a lifetime limit. The plug is therefore requirement-class and **feasible-pending-FEA**, not a dead end.

TABLE · REBCO PLUG-COIL FEASIBILITY TIERS AT THE 26.49 T THROAT

TIER	WINDING BORE	SHIELD	STRAIN VS. CAP	BASIS
Bare winding (published bound)	0.648 m	30 cm passive	4.6–6.5× over	**infeasible**
Stress-managed (reference)	0.50 m	15 cm *structural*	**0.4× (60% margin)**	design-study, FEA pending
Frontier (development target)	0.45 m	10 cm advanced	**0.4×**	not yet qualified

TWO CLAIMS KEPT STRICTLY APART

35 T is a field-capability claim, not a coil claim. REBCO's upper critical field exceeds 100 T at 4.2 K, so 35 T is about a third of the material limit — a statement about the *conductor*, made without qualification. What a *coil* can realise at a given bore is the separate, harder question answered above. Conflating the two is the error this paper exists to prevent.

§ 3.3

The tape study is a null result — the value is the method

On the conductor itself the paper reports negatives, honestly: an aluminium current bypass is unsupported at operating field (copper is adequate); MP35N as an epitaxial growth substrate is infeasible (defensible only as post-growth reinforcement); and the V_2O_3 smart-quench interlayer is prior art. **Kronos has fabricated and measured nothing.** What *is* new, and separately filed, is the **method**: per-turn, as-built-data-driven pre-load placement with per-coil qualification, which replaces worst-case derating and is the commercial core that can earn ahead of any reactor. The complete analysis is deposited (DOI 10.5281/zenodo.21842514).

Verdict matrix — subsystem × machine, by basis tier

Subsystem	Burner PLUG	Breeder ST centrepost
Field capability	35 T < REBCO record	~20 T @ B_0=5 T realisable
Conductor J_c	public-data proxy	public-data proxy
Bore-resolved stress	2.7–3.9× over → infeasible	under allowable (OK)
Winding strain	4.6–6.5× over cap	under cap (OK)
Pre-load method	per-turn, filed (novel)	same method transfers
Quench protection	self-protecting; slow NZPV	self-protecting
Neutron lifetime	shielded to 2 FPY	centrepost-limited
Novelty	method only (narrow)	method only (narrow)

DEMONSTRATED / OK · DESIGN-STUDY · OPEN-RISK / binding

FIGURE 29. The verdict, per machine: centre-post realisable, plug requires a redesign. RECOMPUTED

PAPER FOUR OF FIVE

IV

Direct Energy Conversion

The received picture is inverted: in a D–^{3}He mirror the electron stream is the larger axial channel, and a quasineutral two-species expander can recover it. A bounded upside, not the burner's closure.

55.5%	0.563	20×	upside
ELECTRON/THERMAL STREAM	CASCADE ELECTRON-CHANNEL H	EXPANDER RATIO (5→0.25 T)	NOT THE CLOSURE MECHANISM

FORD · KULCINSKI

§ 4.1

The electron channel is the larger axial stream

At an ion temperature of 80 keV the 14.66 MeV D–^{3}He proton is born roughly 17× above its Stix critical energy, so it thermalises onto the electrons before it can escape. The axial exit therefore inverts the received picture: **55.5% of the power leaves in the electron/thermal stream against 44.5% in the directed-ion stream**, and that split holds across 20–200 keV. No published converter recovers a *directed electron* stream — which is precisely the gap this paper addresses. DERIVED

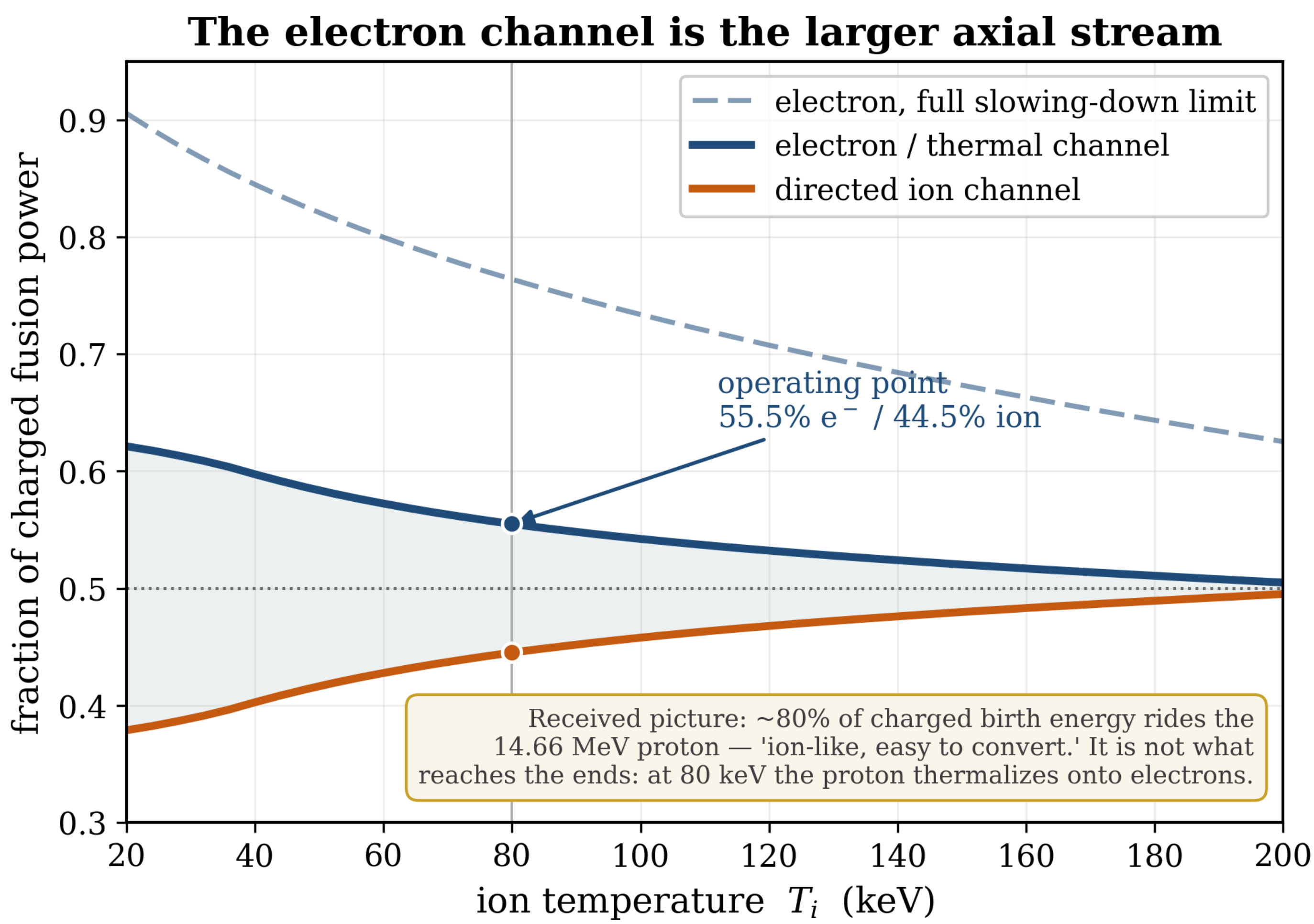

FIGURE 30. The axial power split — electron/thermal versus directed-ion — across ion temperature. DERIVED

§ 4.2

A quasineutral two-species expander

The proposed recovery is the ambipolar magnetic nozzle run *backward*: a quasineutral two-species expander on the adiabatic-invariant backbone of recent mirror theory. A worked embodiment at expansion ratio 20 (5 T → 0.25 T), with an ambipolar barrier near 240 keV, recovers about 28% of the electron channel realistically (39% ideal); across ratios 2–60 the realistic recoverable band is 16–70%. That lifts the cascade electron-channel efficiency to **0.563** against a 0.45 thermal-only baseline.

TABLE 10 · THE CONVERSION LEDGER, PER STAGE (BANDED)

STAGE	H (NOMINAL)	BAND	BASIS
Ion DEC (venetian-blind / TWDEC)	0.48	0.45–0.65	**sourced**
Electron → thermal bottoming (sCO&sub2;)	0.45	0.40–0.50	**sourced**
Electron → quasineutral expander	0.283	0.16–0.40	**derived · open-risk**

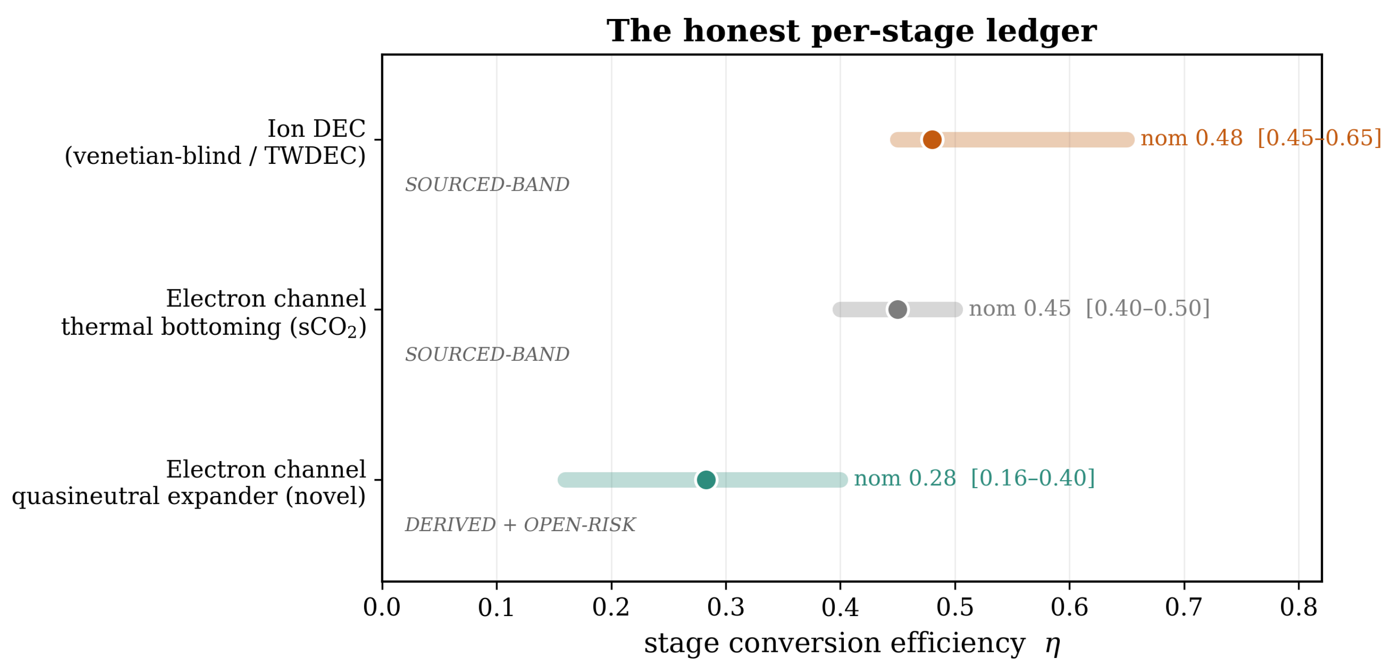

FIGURE 31. The banded conversion ledger by stage; the expander term is the novel, open-risk contribution. RECOMPUTED

§ 4.3

A bounded upside, not the closure mechanism

The honest framing matters: the expander lifts axial electric recovery by about 13% (roughly 97 MW_e), but it does *not* set the plant's engineering gain. Q_E is gated by the plug and thermal-barrier recirculating power (the Mode M requirement of Paper Two), not by direct conversion. D–^{3}He's two-line spectrum beats the ^{3}He–^{3}He three-body continuum by 10.5× (narrow) to 2.4× (wide), confirming the fuel choice. **Kronos has built no converter**; the open risks are retired by a pre-registered bench program, and every claim is tagged by evidence class. The analysis is deposited (DOI 10.5281/zenodo.21842864).

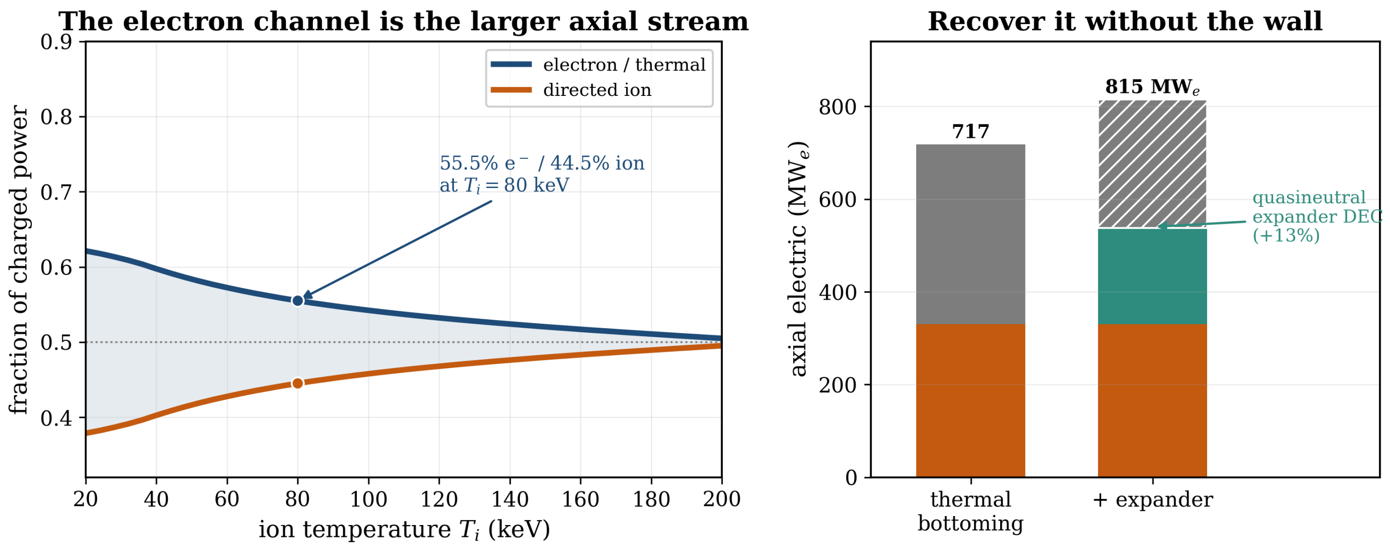

FIGURE 32. Direct energy conversion for the D–³He mirror — the electron channel and its recovery path. BOUNDED UPSIDE

PAPER FIVE OF FIVE

V

AI, ML & Quantum Control

KRONOS-CTRL — a certifiable, physics-informed control architecture with a deterministic safety floor. A system and a method, stated as such, with its limits kept in full.

0 / 150k	47.2 ms	3 tiers	+30%
CLAMP ESCAPES	QUENCH WARNING	ML · SENSING · COMPUTE	RECOVERED MAGNET J_WP

§ 5.1

KRONOS-CTRL — a certifiable control architecture

The control paper is explicit that it is *a system and a method, not new plasma physics or new algorithms*. KRONOS-CTRL is an eight-layer (L0–L7) architecture around a four-module predictive-shadow twin — MHD stability, thermomechanics, neutronics, and power systems — that integrates 50–100 ms ahead of the plant. Three technology tiers are held strictly apart: physics-informed machine learning deployable now behind a deterministic clamp; quantum sensing as a near-term diagnostic; and quantum computation confined to offline, calibration-only use with no crossover claimed this decade. ARCHITECTURE

F01 — KRONOS-CTRL L0–L7 control blueprint [SCHEMATIC]

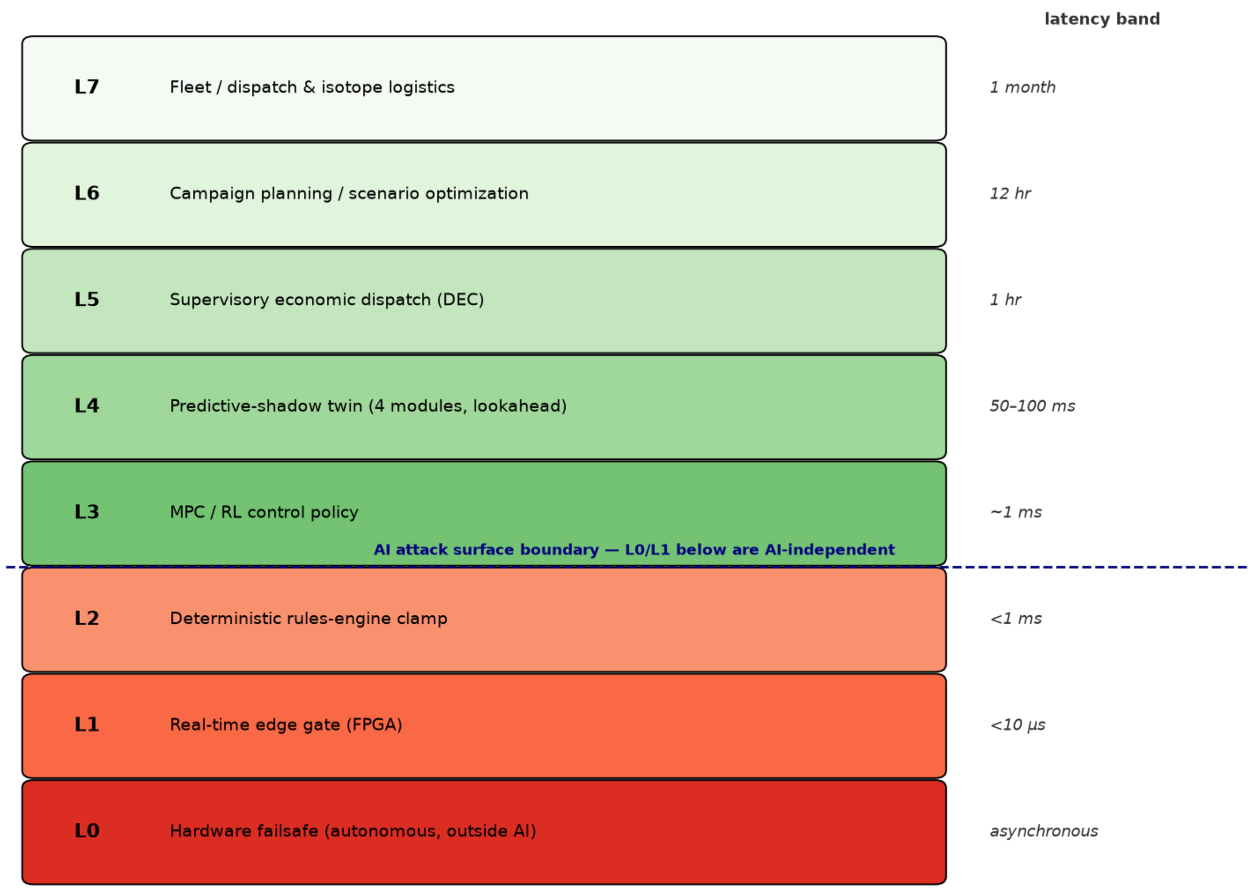

FIGURE 33. The KRONOS-CTRL blueprint — eight layers, the four-module shadow twin, and the three technology tiers. ARCHITECTURE

§ 5.2

The deterministic floor, and what the twin recovers

Certification rests on a **latency-split safety clamp**: a software tier at 42 µs, a hardware look-up-table tier at 0.055 µs, and a sub-10 µs edge tier. In test it caught **3000 of 3000** unsafe actions with **zero escapes across 150,000 steps**, and the control-barrier forward-invariance was preserved through provenance-gated calibration (10/10, against 1/10 for an ungated model). The predictive twin pays for itself elsewhere too: a per-turn magnet model recovers +30% of winding-pack current density over worst-case derating, and a fused quench precursor gives 47.2 ms of warning (AUC 0.9998) against 2.6 ms.

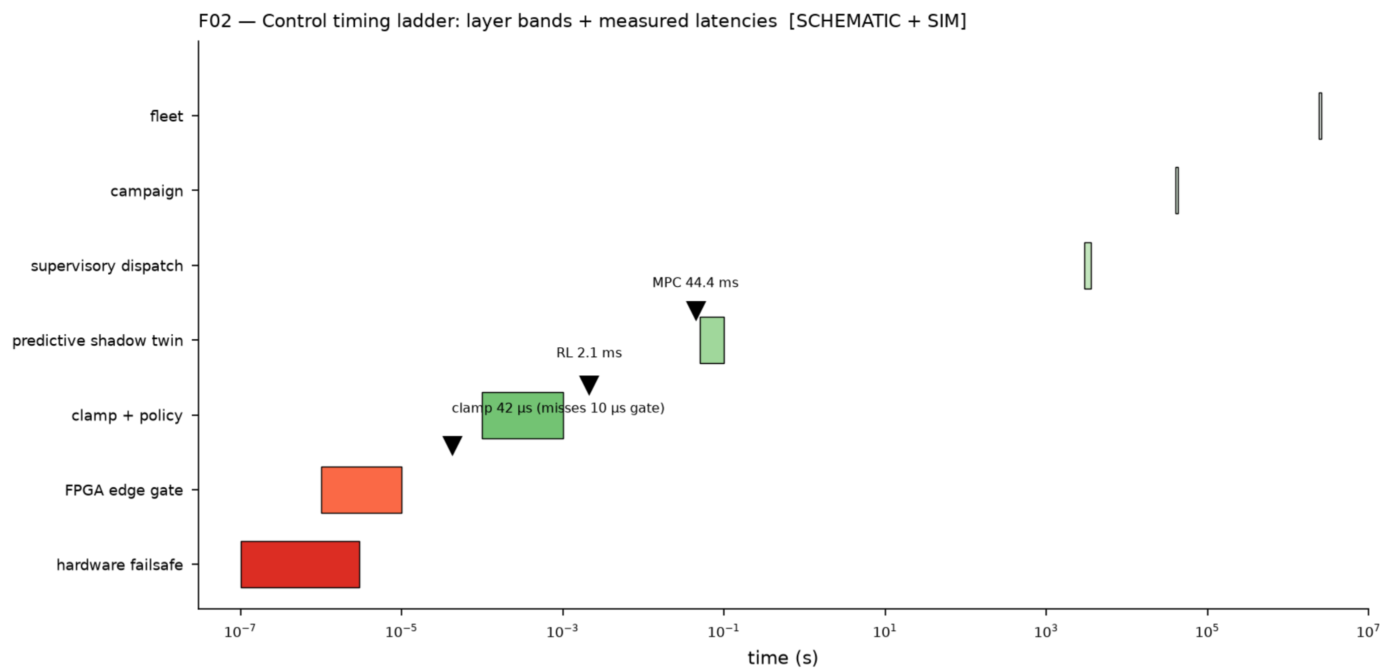

FIGURE 34. The timing ladder — every decision at its own altitude, with the deterministic clamp as the floor. MEASURED (IN SIM)

§ 5.3

The limits, kept in full

The paper's honesty section is not optional and travels here: there is **no operating-plant data** — every result is simulation or digital-twin; there is **no near-term quantum-computing advantage** (the equilibrium linear solve would need on the order of 10^{17} T-gates), and the quantum proof-of-concept is simulator-only; the physics-informed network did not become a fast native solver. The BST twin used for parameter studies (R_0 2.0 m, A 2.0, κ 2.56, B_0 10 T) is deliberately a *distinct machine* from the breeder design point — not to be conflated. The methods are deposited (DOI 10.5281/zenodo.21842371).

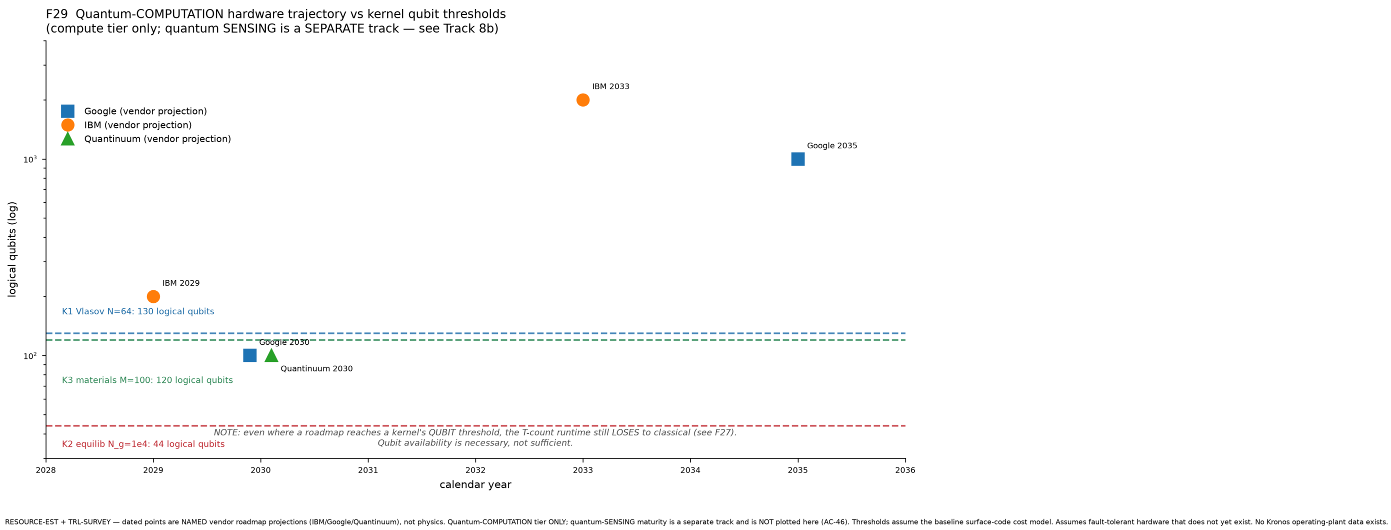

FIGURE 35. The technology-readiness roadmap: what deploys now, what is near-term sensing, and what stays offline. DESIGN STUDY

THE MACHINE, SIMULATED

The Digital Twin & 3-D Model

From a real B-rep CAD model, to a digital shadow that ingests sensor data, to a twin that predicts the plant 50–100 ms ahead — the same physics, made interactive.

THE 3-D MODEL

A real model, not a rendering

The company's 3-D model is built on genuine boundary-representation CAD (CadQuery / OpenCASCADE), with STEP solids for both machines and an in-browser Three.js reactor showpiece. It is the same low-aspect-ratio spherical tokamak drawn in Paper One — nested flux surfaces, the thin high-field centre column, the REBCO field cage — now a solid model that a reader can turn in the hand. Beneath it runs an in-browser physics evaluator (a Pyodide port of the deposited breeder solver), so the model computes rather than merely depicts.

PLATE VIII. The breeder as a three-dimensional model — the same geometry the digital twin animates and the solver evaluates. MODEL

THE DIGITAL TWIN

Model → shadow → twin

The programme's own progression is deliberate: a *3-D model* (geometry that computes), then a *digital shadow* (one-way sensor ingest), then a *digital twin* that runs the deposited solver as a live mirror and predicts plant state 50–100 ms ahead. It carries both machines — the breeder (Q 3.424, 88.7 MW) and the burner (Q_E 1.31, f_n 5.44%, requirement-class) — and its build plan reserves an HPC and quantum compute layer: a 56-core / 768 GiB backbone, 3-D neutronics ports (OpenMC / MCNP for flux, dpa and TBR), large-ensemble uncertainty quantification, and an offline VQE quantum port for calibration.

The digital-twin control method is filed as provisional **64/115,167** (KRONOS-CTRL), carrying twenty-five embodiments — among them fleet orchestration, helium-3 logistics, an islanded defense-installation variant, an operator-training mode, and cybersecurity intrusion detection. Everything here is graded honestly: nothing is built, and every claim is marked as it computes, models, or awaits hardware. MODEL / COMPUTES / AWAITS HARDWARE

EXPLORE THE MODEL

The model is more than geometry. Behind the interactive twin sits a dimensioned **blueprint set** — radial build, general arrangement, magnet and conductor sections, GD&T and bill of materials — and a **construction-readiness “Build” package**: codes & standards, manufacturing & assembly, commissioning, and a path-to-build schedule. The public build is click-to-inspect — every component measured; the **full drawing set and the STEP CAD for both machines are available under NDA**. Turn it in the browser at kronosfusionenergy.com/3D-Model.

ENVIRONMENTAL PROFILE

Environmental Profile & Life-Cycle Assessment

A screening life-cycle assessment on ISO 14040/44 lines. The fleet is nuclear-class clean, the burner is architecturally low-neutron, and for the breeder the environment is a design lever rather than a constraint.

~12	41×/168×	≤ Class C	DF 1–34
GCO&SUB2;/KWH (5–30)	BURNER WALL-LOAD ADVANTAGE	AT A LOW-ACTIVATION HEAT	PUBLIC DOSE CLOSES

§ 3.1

Fleet cleanliness

On a life-cycle basis the fleet sits in the cleanest tier of generation. Embodied carbon is about **12 gCO&sub2;eq/kWh** (range 5–30, dominated by construction steel and concrete), and the footprint is compact — a folded 1.66 acres for an installation unit. The estate is roughly 12–29× cleaner in life-cycle carbon than a deuterium–tritium tokamak of comparable output.

TABLE 8 · LIFE-CYCLE CARBON, IN CONTEXT

SOURCE	LIFE-CYCLE GCO&SUB2;EQ/KWH
Coal	820
Natural gas	490
Fission	12
Kronos fleet (screening)	~12 (5–30)

The mortality and land intensities fall in the nuclear/renewable class. Embodied CO&sub2; and the REBCO magnet-material stream are *screening-level* and carried as open items pending a full inventory.

§ 3.2

Activation & waste

The burner's openness pays an environmental dividend: its first-wall neutron loading is **41×** (Aegis) and **168×** (MetroVolt) below the breeder's, so its scheduled-replacement waste is near zero — a first-wall life of 104–428 full-power-years against the breeder's 19.66 dpa/fpy and 1.0–2.5 fpy. The breeder's activated-steel arisings are the fleet's main solid-waste stream: **34–85 m³ (~200–500 t) over 40 years**.

TABLE 9 · WASTE CLASSIFICATION (SUM-OF-FRACTIONS VS THE CLASS C LIMIT)

STRUCTURAL STEEL	SUM-OF-FRACTIONS	CLASS
RAFM at Nb < 10 ppm (certified heat)	0.46	**≤ Class C (2.2× under)**
RAFM at Nb < 1 ppm	0.09	**≤ Class C**
RAFM at spec-max Nb (50 ppm)	2.10	**exceeds Class C (Nb-94)**
Ordinary 316 stainless	9.3	**GTCC — no US disposal path**

THE CONDITION ON THE CLASS-C RESULT

≤ Class C is a **steel-procurement specification**, not an intrinsic property: it holds only at a *certified low-activation heat* (niobium below ~10 ppm). At spec-max impurities the Nb-94 alone reaches 2.1× the Class C limit. The Ag-108m residual and the full curie inventory are **uncomputed** (they need a FISPACT transport run) and are carried as open. REQUIREMENT · OPEN

§ 3.3

Tritium & public dose

The breeder carries a standing tritium bank of order 35 kg, which triggers a formal emergency plan and points to remote federal siting. The public-dose case nonetheless **closes comfortably**: the required detritiation factor is only **1–34** (tightening from a 3 km to a 1 km boundary), against the **1,000–10,000** detritiation that ITER already demonstrates — an off-the-shelf design margin of two to four orders of magnitude. Public dose is an engineering solution, not a physics unknown.

A CLAIM WE REFUSED

An earlier "the burner is dirtier at scale" argument — built on deuterium–deuterium by-product tritium — was **correctly rejected** as a scale mismatch; the ~618 kg "equivalent" is an unverified flag only, and the 13.5 kg/yr figure is withdrawn. The honest fleet statement is the wall-loading comparison above.

Simulations & Proofs

The validation record behind all three products — the simulations that produced each headline number, the frozen proofs, and the open items that gate them.

25,200	2.36 M	10^{-15}	47
CONFIGS SCANNED	(A,K) EVALS	BAND REPRODUCIBILITY	PRODUCT FREEZES

THE VALIDATION PACKAGE

How each number was produced, and how to check it

The program's discipline is that no headline number ships without the simulation that produces it and the evidence class that qualifies it. This part is the register: for each machine, the runs that established its results; then the frozen proofs those runs rest on; then the open items still on the verification queue. The complete input decks, code versions, and plotting scripts are openly deposited under CC BY 4.0, so a reader can regenerate any figure in this volume from source.

READING THE REGISTER

Each entry names its **method**, its **result**, and its **evidence class**. “Recomputed” means the value was rebuilt from the raw scan rather than adopted from a summary table; “Derived” means it follows from branch physics and radiation alone; “Requirement” marks a value a future run or measurement must establish.

§ 5.1

Hyperion — breeder simulation register

H·S01 Free-boundary equilibrium & configuration scan RECOMPUTED

method: free-boundary Grad–Shafranov solver · 25,200 configurations · confinement multiplier free

213 D–T and **71 pure-D–D** configurations close without wall violation and meet the 1.87–4.0 kg T/yr national duty. Deposit built on δ = −0.30; scan carries δ = +0.4 (the two are not conflated).

H·S02 Minimum plasma-current optimisation RECOMPUTED

method: minimisation over the raw 25,200-row scan (dt_scan.csv), not a summary table

Minimum current **4.93 MA** on D–T (2.17 MA externally driven) against **15.52 MA** on pure D–D — 33% of ITER's 15 MA versus 103%. Net tritium 0.0451 vs 0.135 kg/yr/MW.

H·S03 Aspect-ratio & elongation sweep RECOMPUTED

method: 374 (A,κ) cells · 2.36 million evaluations · reproduces the canonical scan to 2.8×10^{-14} MA

Toroidal field inert (no closure 16–20 T); elongation adverse (κ 2.0→2.6 raises the minimum 4.93→5.82 MA); aspect-ratio minima sit at A = 3.4–3.5, outside the spherical regime. **The current requirement is structural.**

H·S04 Neutronics & shield RECOMPUTED

method: two-group neutron transport (2.45 & 14 MeV) over the scan geometry

Shield grows **0.898 → 1.318 m** across the admissible range to hold the magnet and structure within lifetime dose. The shield thickness is an output, not an assumption.

H·S05 Fuel-cycle mass balance & inventory DERIVED

method: closed T / ^{3}He / neutron mass balance on the lithium blanket

Equilibrium tritium inventory **6.2 kg** (band 3.9–39.4), inside civil licensing precedent; helium-3 co-product ≈ 0.9× tritium mass; 14 MeV neutrons at full rate on the D–T fill.

H·S06 Power-balance reference point (frozen H01) DESIGN BASIS · VERIFYING

method: dt_scan.csv row (closes-nowall, on-duty) solved by dt_evaluator.py inverting IPB98(y,2) at H_{98} = 1.0

Reference **Q = 3.424** (solved, not scaled), P_{fus} 88.7 MW, I_p 9.86 MA, **R_0 1.2 m, A 2.5**, TBR 1.8, at a declared ash basis f_{He4} = 0.05 (Z_{eff} 1.158). Heating power density 2.37 MW/m^3 (2.22× SPARC). Presented as design basis under verification — no device has exceeded Q ≈ 0.7. The withdrawn Q 1.889 was an ITER-anchored scaling assertion.

H·S07 Divertor & ELM analysis (negative triangularity) OPEN REQUIREMENT

method: Eich λ_q regression + parallel heat-flux balance; ELM-free edge from DIII-D campaign [Thome 2024, Lim 2023, Nelson 2022]

ELMs **eliminated** (demonstrated ELM-free at δ_{avg} −0.5); steady exhaust is an **open requirement, not a verdict**: at B_{pol} 2.60 T the Eich λ_q of 0.202 mm (2.6× out of fitted range) gives $q_{\parallel}$ 14.3 GW/m² and a 90% radiated fraction, but at broadened λ_q 0.5 / 1.0 mm the requirement falls to **75.2% / 50.4%** — near demonstrated detachment. A divertor design study is the companion work.

§ 5.2

Aegis & MetroVolt — generator simulation register

L·S01 Central-cell power balance & closure DERIVED

`method: deposit arbiter, reproducible closing point (run_all.py all-OK) · n_p/n_c 16, x 0.30, T_i 90 keV, n_e 2.6×10²⁰`

Mode M engineering gain **Q_E 1.31**, f_n 5.44% (both length-independent); net +104 / +850 / +2832 MW_e at 55 / 440 / 1400 m. **Requirement-class**: needs plug density n_p/n_c 16 (347× GDT); at n_p/n_c 10 it does not close (Q_E 0.63).

L·S02 Synchrotron reabsorption scan DERIVED

`method: harmonic-resolved reabsorption vs minor radius (the program's novel result)`

Effective cutoff harmonic $\mathbf{n_{cutoff} \propto a^{1/3}}$; n_{eff} moves 10.4 → 12.2 with radius. Model spread collapses 52× → 2.28×; synchrotron loss is a function of machine size, not a fixed fraction of fusion power.

L·S03 Plug-field equilibrium RECOMPUTED

`method: Frank Eq. 3.4 at the self-consistent plug density ratio n_p/n_c = 16`

Throat field pair **26.49–39.74 T**. 26.49 T is 0.82× and 39.74 T is 1.24× the 32.35 T all-superconducting record; both below the 45.5 T REBCO test coil. The field is not the extrapolation; the bore-resolved winding is — and at the sourced bore it is **structurally infeasible** (hoop 2.7–3.9× allowable) as a bare winding, a bound a stress-managed structural shield resolves (feasible-pending-FEA).

L·S04 Direct-conversion channel split RECOMPUTED

`method: axial power ledger, ion vs electron stream · ion DEC + 45–50% bottoming cycle`

Charged power splits into ion and electron streams; direct conversion is applied to the ion channel only, the electron/thermal channel recovered honestly. The result is a gain **floor** on measured efficiencies, not a margin.

L·S05 Reflectivity / wall-aperture budget REQUIREMENT

`method: wall-aperture reflectivity budget at 400 m central-cell length`

Passes with **38× margin** — a margin that emerged only when the central cell was unfrozen from 55 m. No reflectivity measurement exists at the relevant frequencies, so the margin, not the optical constants, carries the conclusion.

L·S06 Fuel-cleanliness window RECOMPUTED · MODE M

`method: helium-3 fraction sweep on the deposit arbiter at the Mode M point`

Closes across $x(^3He) \in [0.20, \sim0.43]$ at Q_E 1.31 throughout; f_n falls 9.52% → 2.77% (~3.4×). Design x 0.30 (f_n 5.44%); free clean-shift x 0.35 (f_n 4.18%); x ≥ 0.45 does not close — a redesign, not a fuel change.

L·S07 Axial exhaust & end-expander requirement REQUIREMENT

`method: axial power over two end apertures (πa_c², a_c 0.86 m); flux conservation B·A = const`

Open geometry means **no divertor and no ELMs** — exhaust leaves axially, with no X-point, separatrix, strike point, or pedestal. The counterpart requirement: 906 MW through two apertures is **195 MW/m^2** unexpanded; a 53× end expander (26.49 T → ~0.5 T) brings it to **3.7 MW/m^2**. No expander field specification exists in the record.

§ 5.3

The frozen proofs, and what remains open

This is the **final August 2026 freeze**, at the Mode D2/M evolution point — the consolidated record after the profitability studies, the financial corrections, and the environmental design layer: **47 product entries** (the D1/L machine set plus the D2/M environmental and fuel-cleanliness evolution — with M-45/46/47 the Mode M closing set and M22/M-40/M-44 withdrawn), each carrying its declared condition, alongside the Part-I physics (14: 8 frozen, 3 restated, 3 withdrawn). A freeze is a commitment against *silent* change, not a claim of final truth — a frozen value may still be withdrawn on a recorded, dated, reasoned note, with every document carrying the old value swept. The tables below give the standing physics and the product freezes; the D2/M environmental and cleanliness freezes are set out in Papers One–Two and the Environmental profile.

TABLE 5 · THE NINE STANDING TIER-A PROOFS

ID	QUANTITY	FROZEN VALUE	BASIS
A01	e–e bremsstrahlung coefficient	2.120022 (exact)	$5(44-3\pi^2)/(24\sqrt{2})$; verified twice
A02	Gain saturation	structural	photons leave at c — not a transport channel
A03	peak P_{fus}/P_{brems}, $Z_{eff}=1$	1.589 @ 108 keV	reproduces NRL to 3 figures
A04	the knife edge	unity, band 0.984–1.121	four routes, sign undetermined
A07	directed ≠ charged (p–^{11}B)	100% charged, 0% directed	definitional; three alphas share 8.7 MeV
A09	Sauter denominator	the larger current	reproduces ITER's 15 MA to −0.1%
A11	plug field vs record	26.49 T = 0.82× 32.35 T	against an existing all-SC record
A12	He-3 buy-back	NOT AVAILABLE	federal demand > production; auctions ceased 2009
A13	commercial He-3 requirement	50× (unit), 495× (fleet)	from the established fuel cycle

Restated / withdrawn on the frozen coefficient: the critical-Z_{eff} numbers 1.880 and 1.164 and the 5% helium-ash design value are withdrawn (the mechanisms stand; the numeric thresholds do not); the Uckan shaping factor is restated as a formula in (A,κ) spanning 1.53–6.31, not a constant.

TABLE 6 · THE FIFTEEN PRODUCT FREEZES (2026-07-31)

ID	PRODUCT	FROZEN QUANTITY
H01	Hyperion	design point: 88.7 MW, Q 3.424, I_p 9.86 MA, R_0 1.2 m, A 2.5, TBR 1.8 (ash f_{He4} 0.05)
H02	Hyperion	the gain is **solved, not scaled**
H03	Hyperion	heating power density 2.37 MW/m^3 = 2.22× SPARC
H04	Hyperion	capital built by **structure**, not by scaling an anchor (an 11.4× swing)
H05	Hyperion	TBR is a design **lever** (1.1 / 1.5 / 1.8), not a constant
H06	Hyperion	availability outranks the whole subsidy toolkit (3.05× vs 1.49×)
A15	Aegis	**fixed-site**, not shipboard — the naval case is closed negative

table continued

ID	PRODUCT	FROZEN QUANTITY
A16	Aegis	folded footprint 1.66 acres vs Norfolk's 3,400 (2,044×)
A17	Aegis	premium-installation cost stack is **capital-dominated** — reachable only against premium/remote energy, never grid
A18	Aegis	build stages barely matter: 3.5 points FOAK→BOAK(128)
M19	MetroVolt	binding line is **fuel**: even at zero capital, merchant He-3 fuel outruns a competitive grid contract
M20	MetroVolt	pure D–D does not close in a mirror (Q_E 0.42; net −6,197 MW_e at 440 m, −19,586 at 1400 m)
M21	MetroVolt	the mechanism is the **charged-power budget**, not confinement (deposited pure-D–D point, T_i 90 keV: 697 MW charged vs 4,055 MW axial, a 5.8× shortfall, length-independent)
M-45	Aegis / MetroVolt	**Mode M closing point**: Q_E 1.31, f_n 5.44% (length-independent); net +104 / +850 / +2832 MW_e at 55 / 440 / 1400 m
M-46	Aegis / MetroVolt	closure window $x(^3He) \in [0.20, \sim 0.43]$; f_n 9.52% → 2.77%; $x \geq 0.45$ does not close
M-47	Aegis / MetroVolt	closure is **requirement-class**: needs plug density n_p/n_c 16 = 347× GDT; at 10 it does not close (Q_E 0.63)
M23	MetroVolt	trigger is a fuel-supply **regime** (a price), not a date
M22·M-40·M-44	withdrawn	non-reproducible burner Q_E (1.191 / 1.825) — superseded by M-45

TABLE 7 · THE EXHAUST & TRIANGULARITY FREEZES

ID	PRODUCT	FROZEN QUANTITY
H24	Hyperion	exhaust is **open at this field, not adverse** (restated): 90% radiated fraction only at the Eich-extrapolated λ_q; 50–75% at broadened λ_q — a requirement, not a verdict
H25	Hyperion	ELM elimination at negative triangularity is **demonstrated**, not modelled (Thome 2024)
H26	Hyperion	NT is **not a detectable** performance lever (n=2, inside the PT spread — not-detected, not proven absent); the −21% current claim stays prohibited
H27	Hyperion	triangularity **declaration**: scan δ +0.4 vs deposit δ −0.30 (51 places); the sign decision is open
H28	Hyperion	the capital estimate contains **no divertor** (or first-wall, blanket, remote-handling) line item — verified at source
B29	Aegis / MetroVolt	a tandem mirror has **no divertor and no ELMs**, architecturally
B30	Aegis / MetroVolt	the end-expander requirement: 195 MW/m^2 unexpanded → ~53× (26.49 T→0.5 T) → 3.7 MW/m^2; no field spec exists

Deliberately **not** frozen — the standing research asks the August publications state as open: the capital-anchor *number* (the 11.4× swing, the single most valuable open item), absolute margins, the burner's plug-reliability capacity factor, lunar helium-3 economics, and the fusion-industry makeup-tritium market. The triangularity *sign decision* is also open — H27 freezes the declaration of the split, not a choice.

OPEN ITEMS — THE VERIFICATION QUEUE

V1 · gain — independent verification of the Hyperion design-point gain at an accessible operating point; it gates the entire economic case.

V2 · availability — the three research inputs behind the steady-state, damage-life-limited capacity factor (0.58–0.83, central 0.69): first-wall dpa rate, component-life basis, and maintenance-outage schedule.

V3 · plug winding — finite-element analysis of the stress-managed structural-shield reference design (the bare-winding bound is closed; FEA is the open step to confirm the ≈60% strain margin, quench, and REBCO neutron lifetime).

V4 · thermal barrier — a named stability actuator for the generator's one real physics gate.

V5 · capital anchor — a sourced capital anchor and a vendor heating-system quotation (11.4× and 1.48× swings).

V6 · divertor & seeding — a divertor design study to specify the absent divertor and, more bindingly, the continuous impurity seeding that protects it, whose fuel dilution reduces delivered duty. Both are on the freeze-exclusion list.

◆

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.

FOUNDING PARTNERS — SCIENCE

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Marketing Lead
2022–Present

Legal counsel is retained; those roles are held on the internal roster and are not listed here.

LIMITATIONS

What is not established, and the verification queue

The honesty stance is the asset, so the load-bearing assumptions are surfaced here rather than buried. The physics limitations apply to both editions; the economics limitations are internal.

PHYSICS & DESIGN

The breeder design-point gain. The economics close on a gain that is a modelled scaling extrapolation, not a demonstrated value; no magnetic-fusion device has exceeded Q ≈ 0.7. Independent verification at an accessible operating point is the top item in the queue.

Capacity factor. Hyperion is steady-state (bootstrap + driven = full current), so availability is *damage-life-limited*, not duty-limited: a first-wall dose of 19.66 dpa/fpy sets a ~2.5-fpy component life and a capacity factor of 0.58–0.83 (central 0.69), contingent on three research inputs. This supersedes the earlier pulsed-machine basis.

The generator's thermal barrier is the one real physics gate, with a measured historical negative and no named stability actuator.

Electron direct conversion is a requirement, not a closure; the boundary work function sits inside the candidate material's own spread.

The plug-coil winding is the burner's hardest gate: the field is within the record, but at the sourced bore the coil is **structurally infeasible** as a bare winding (hoop stress 2.7–3.9× the reinforced allowable). A stress-managed structural shield resolves it at ≈60% strain margin — carried as feasible-pending-FEA, with finite-element analysis the open item.

Exhaust. The breeder's negative-triangularity edge eliminates ELMs (demonstrated) but sets a 90% divertor radiated-fraction requirement at the edge of demonstrated detachment, on an extrapolated λ_q; the mirror has no divertor by architecture but requires an unspecified 53× end expander. Both are requirement-class and named.

Two errata are published alongside: the bremsstrahlung coefficient (1.499 → 2.120022; no conclusion changes) and a hardcoded confinement literal (reported gains become upper bounds).

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