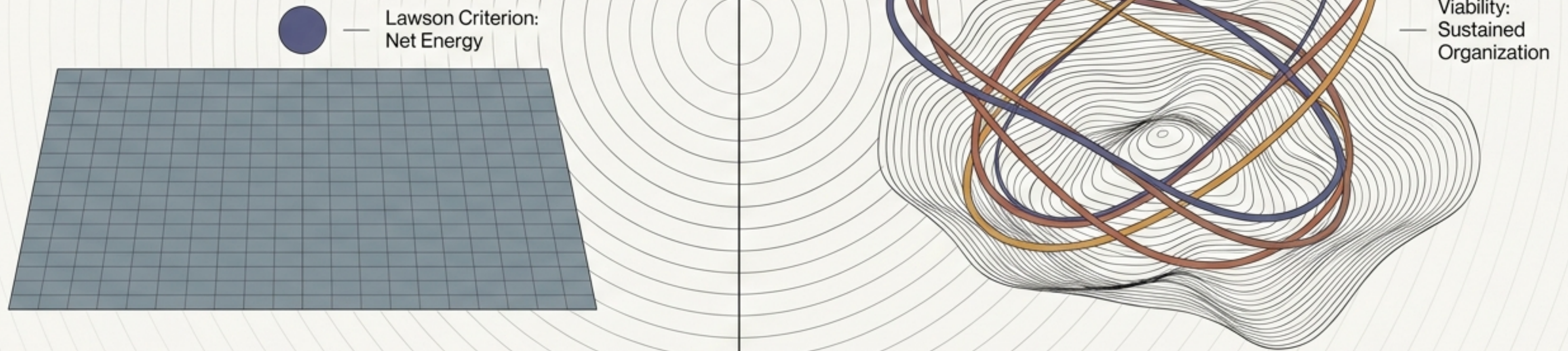


A Viability Theory of Fusion Reactors

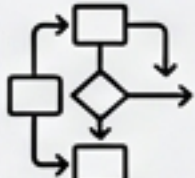
Reframing fusion from a physics performance problem to a multi-decade organizational persistence problem.



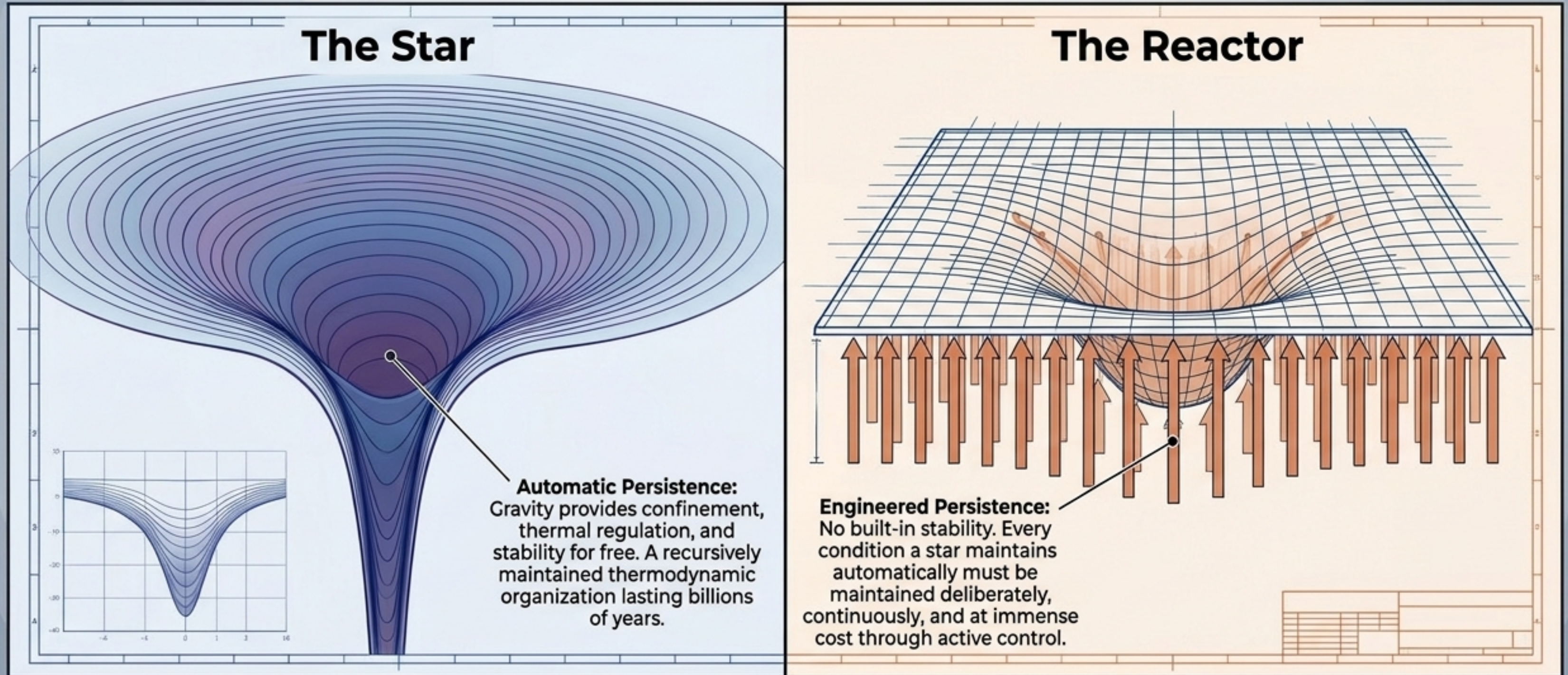
SYS_STATE: INITIATING BOUNDARY EXPANSION

The Paradigm Shift

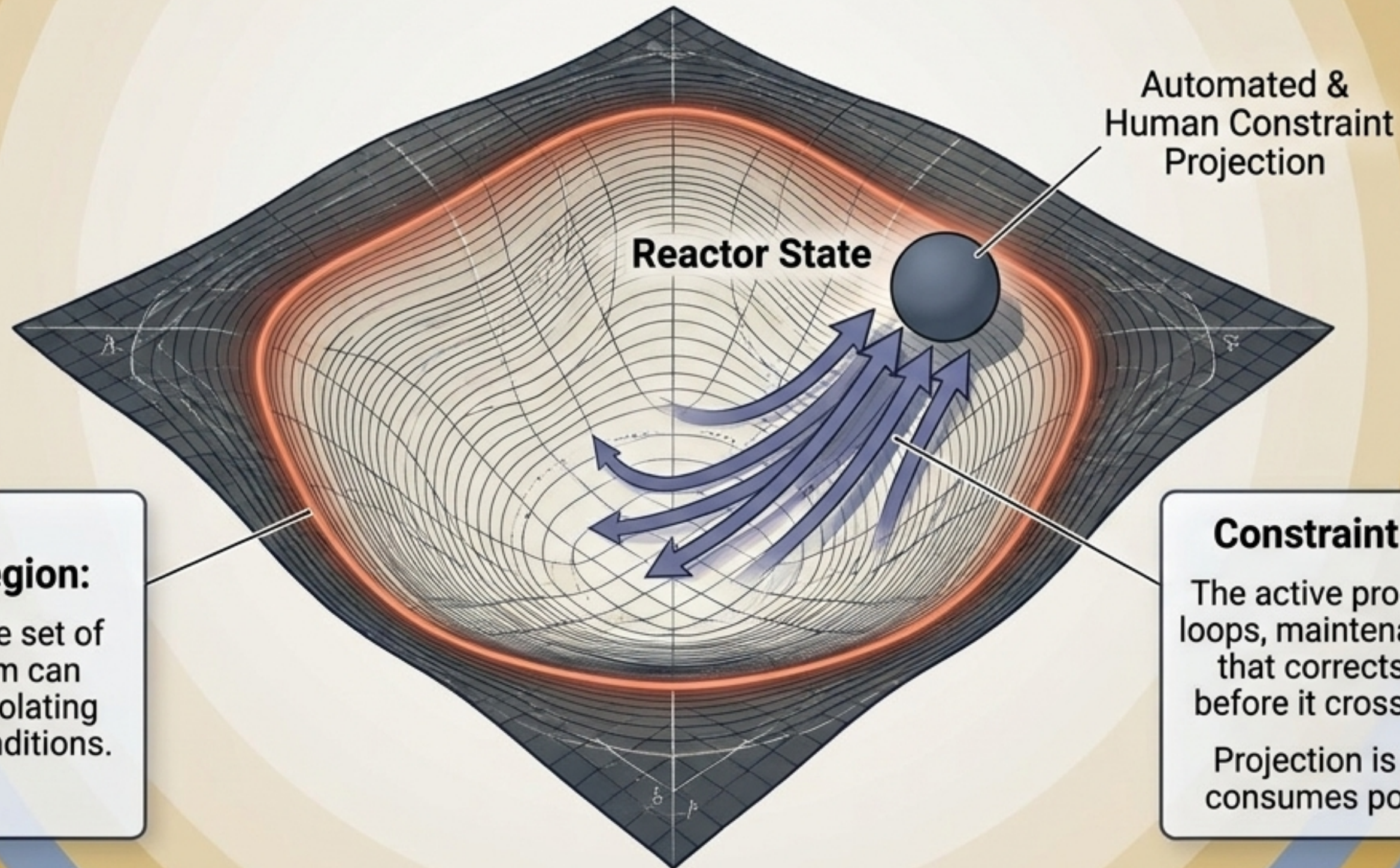
Peak performance and long-term persistence are not the same target. Optimizing for a record-setting laboratory shot often sacrifices the margins, redundancies, and slack that multi-decade persistence requires.

The Performance Paradigm (The Wrong Scale)		The Persistence Paradigm (The Global Condition)	
	Goal: Ignition		Goal: Viability
	Metric: Net Energy (Lawson Criterion)		Metric: Throughput & Negative Entropy
	Identity: Machine (Fixed)		Identity: Organization (Dynamic)
	Focus: Plasma Physics		Focus: Coupled Systems
	Failure Mode: Binary (Works / Doesn't Work)		Failure Mode: Continuous drift and degradation

Stars solve the persistence problem automatically; human reactors must construct it deliberately.



Viability requires continuous Constraint Projection to keep the reactor within its Admissible Region.



Admissible Region:

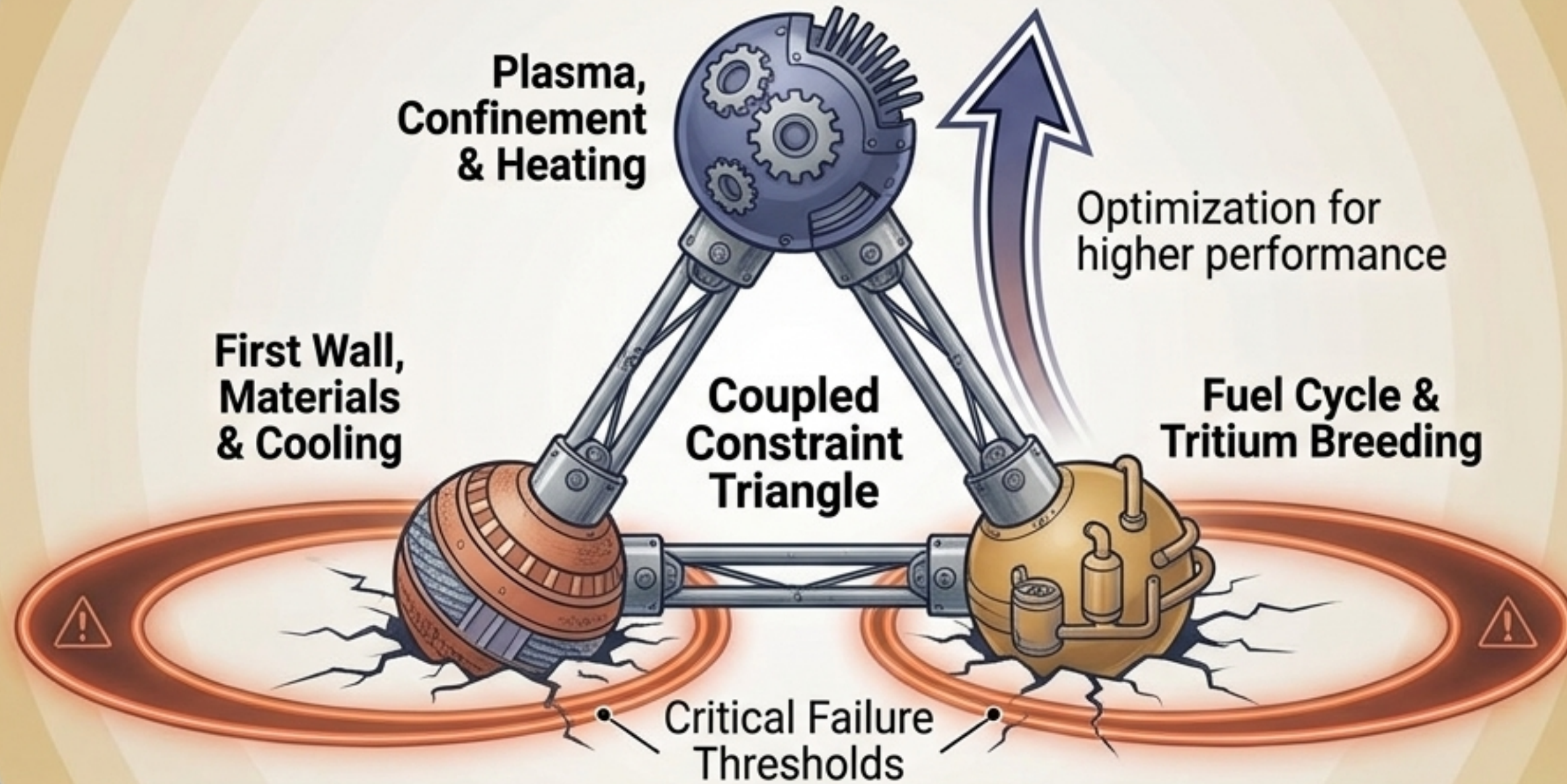
The non-factorable set of states the system can occupy without violating its persistence conditions.

Constraint Projection:

The active process (feedback loops, maintenance, operators) that corrects the system's before it crosses a boundary.

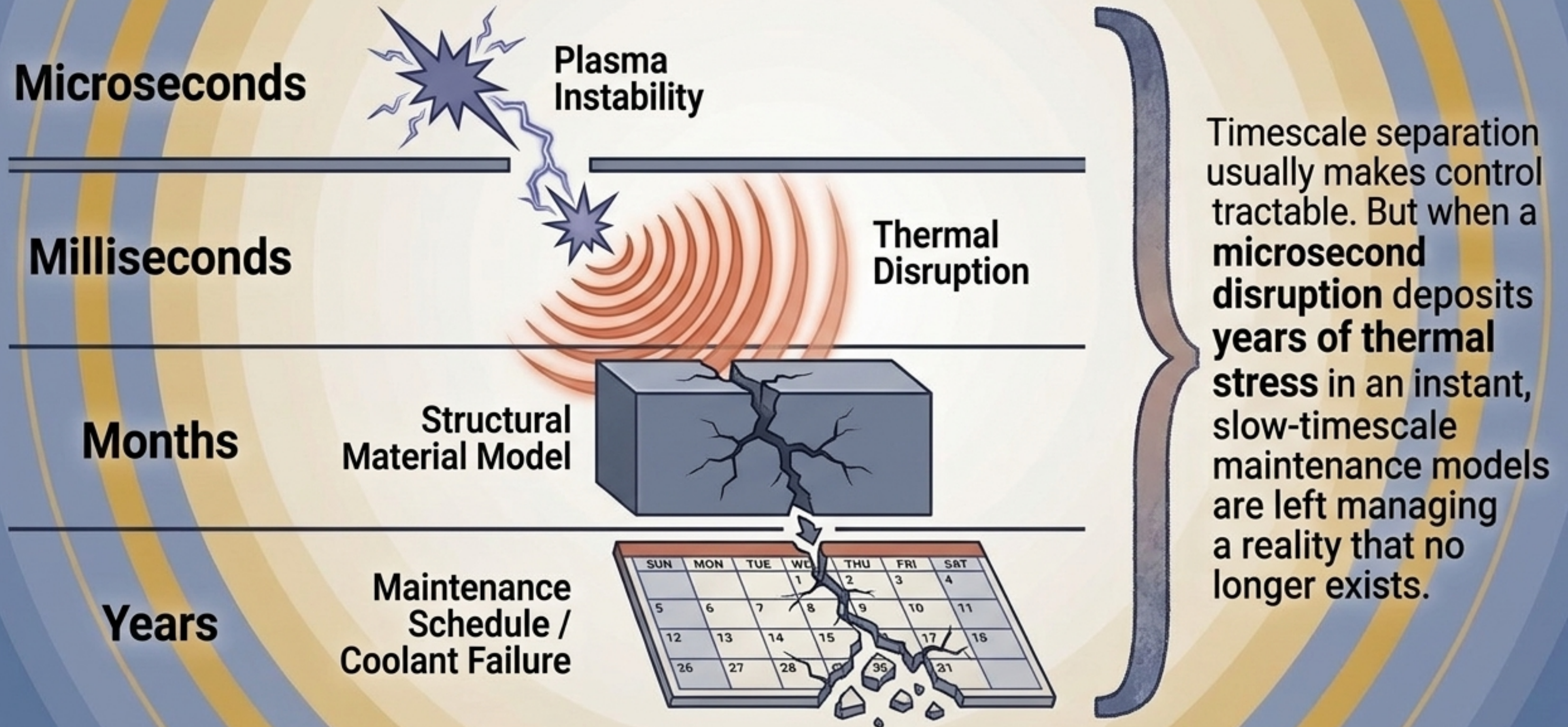
Projection is **never free**—it consumes power and wear.

The reactor's physical boundary is a tightly coupled system; subsystems cannot be optimized in isolation.



A blanket design that maximizes initial tritium breeding ratio may degrade rapidly under neutron bombardment, starving the plasma of fuel exactly when the plant is meant to reach continuous operation.

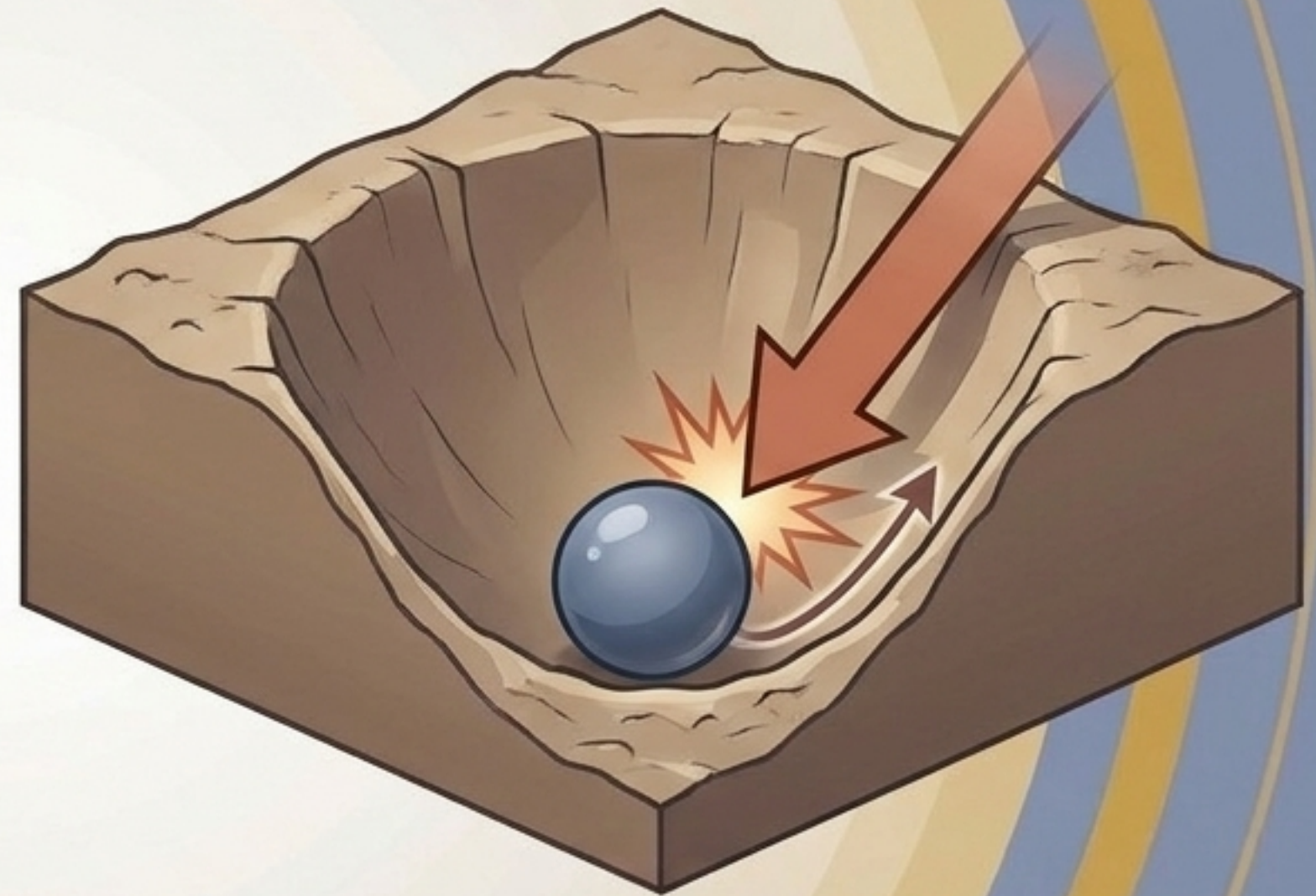
The Failure Cascade: Timescale separation breaks down when fast shocks violate slow assumptions.



Attractor Basins: A marginally lower-performance state in a deep basin is vastly more viable than a peak-performance state in a shallow basin.



High Optimization / Brittle Viability



Sub-optimal Peak / Robust Viability

An operating point is not just “admissible or not.” Its viability depends on its resistance to being pushed out. Deep attractor basins require less active constraint projection.

Energy as Throughput: Accounting for the entropy cost of recursive repair.

Energy Input

Reactor System

Useful Entropy Production
(Power Generation, Tritium Breeding)

Negative Entropy / Internal Repair
(Cryogenics, Controls, Cooling)

Net Energy asks:
Did we cross the threshold once?

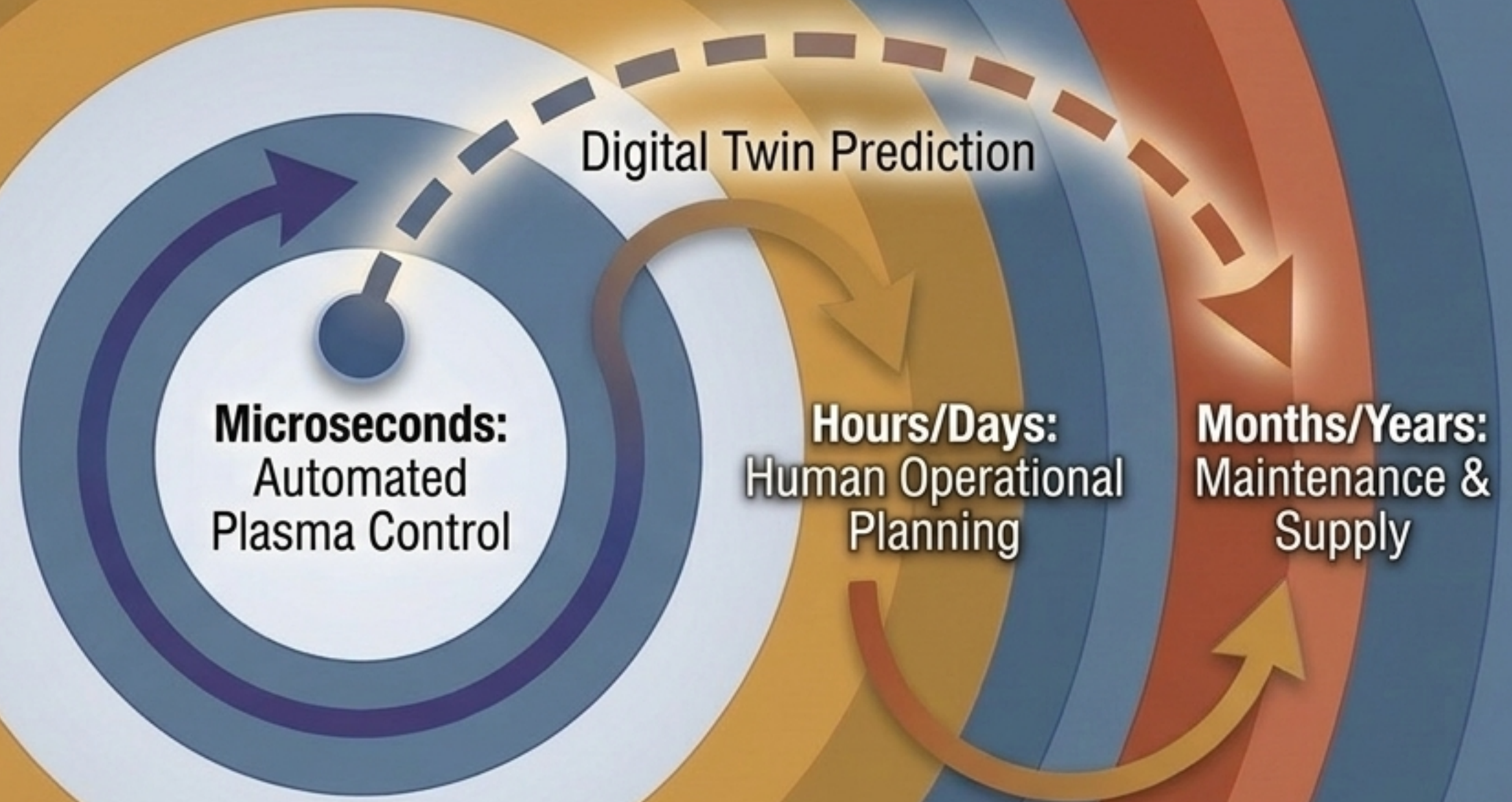
Throughput asks:
Can we sustain useful entropy production while continuously paying the thermodynamic cost of projecting the system back into its admissible region?

The Degradation & Repair Matrix

Degradation is the reactor's default behavior; viability is the active, continuous process of counteracting it across three distinct domains.

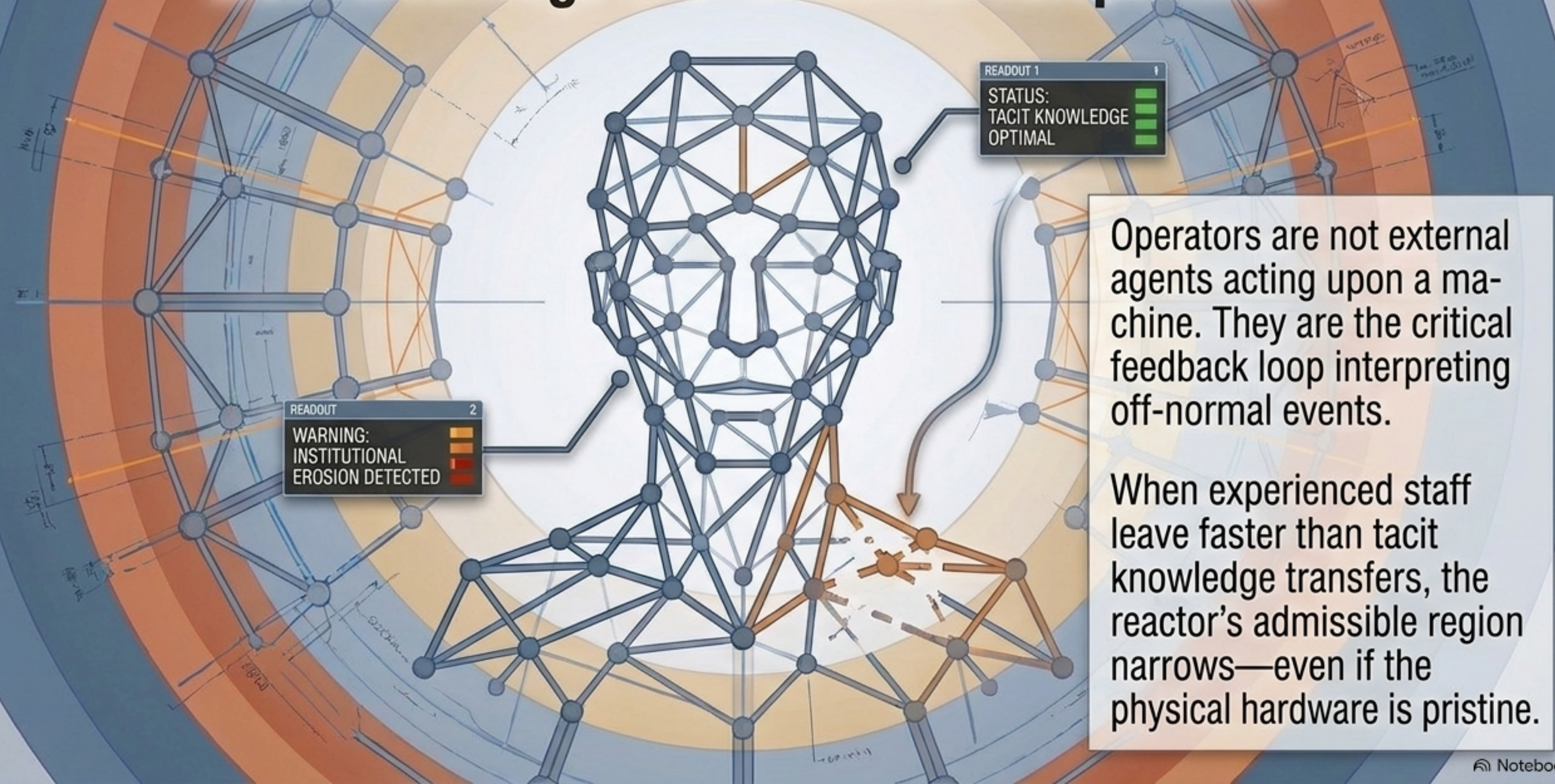
Degradation Domain	Repair Strategy	Economic Expression
Gradual / Predictable Wear (e.g., Radiation damage to first wall)	Scheduled Replacement	Predictable CapEx
Sudden / Off-Normal Events (e.g., Unplanned thermal excursion)	Reserved Capacity (Spares/Standby)	Risk Capital / Financial Slack
Slow / Institutional Erosion (e.g., Loss of tacit operator knowledge)	Deliberate Transfer / Active Culture	OpEx (Invisible until failure)

Layered Feedback: Stabilization is recursive.

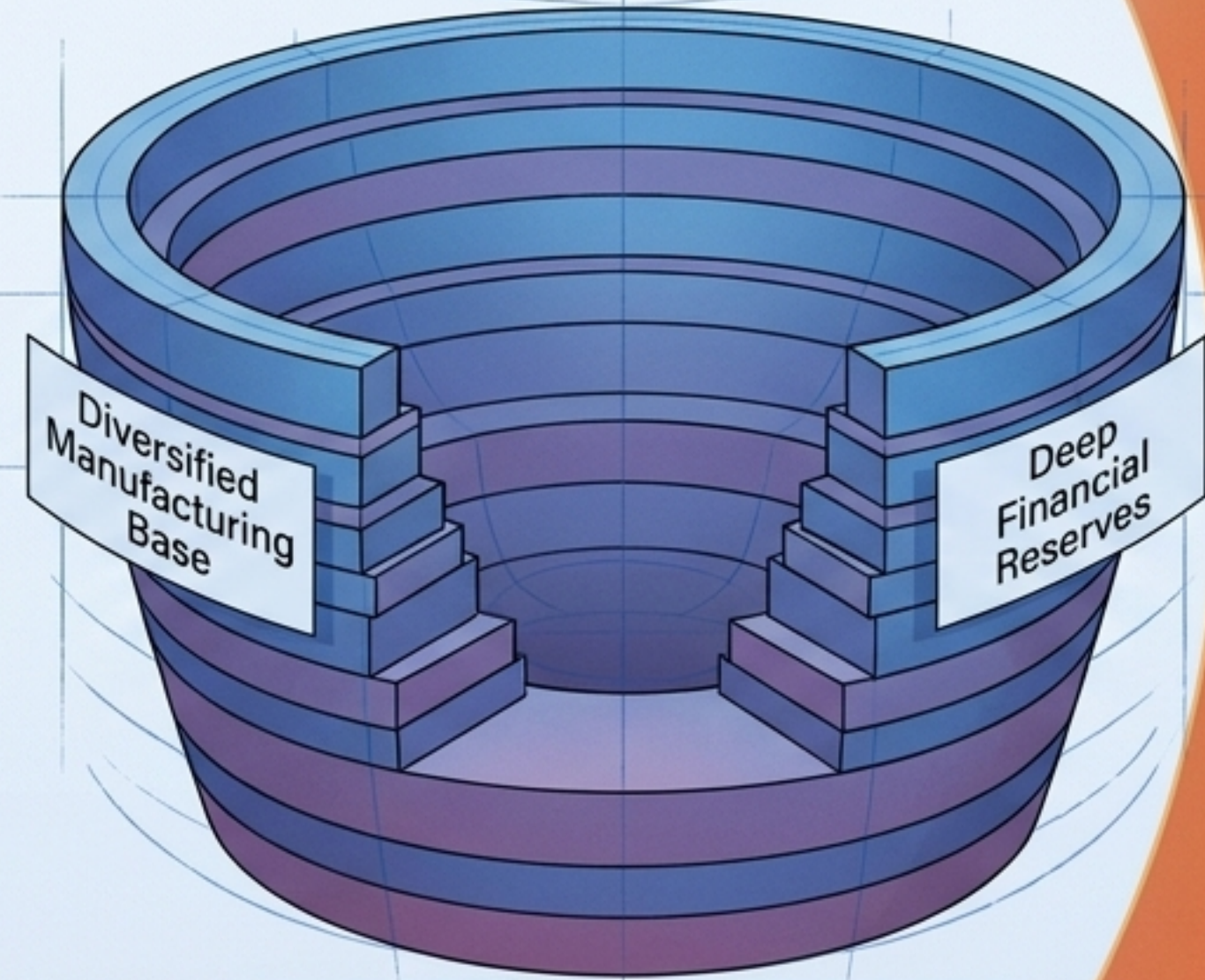
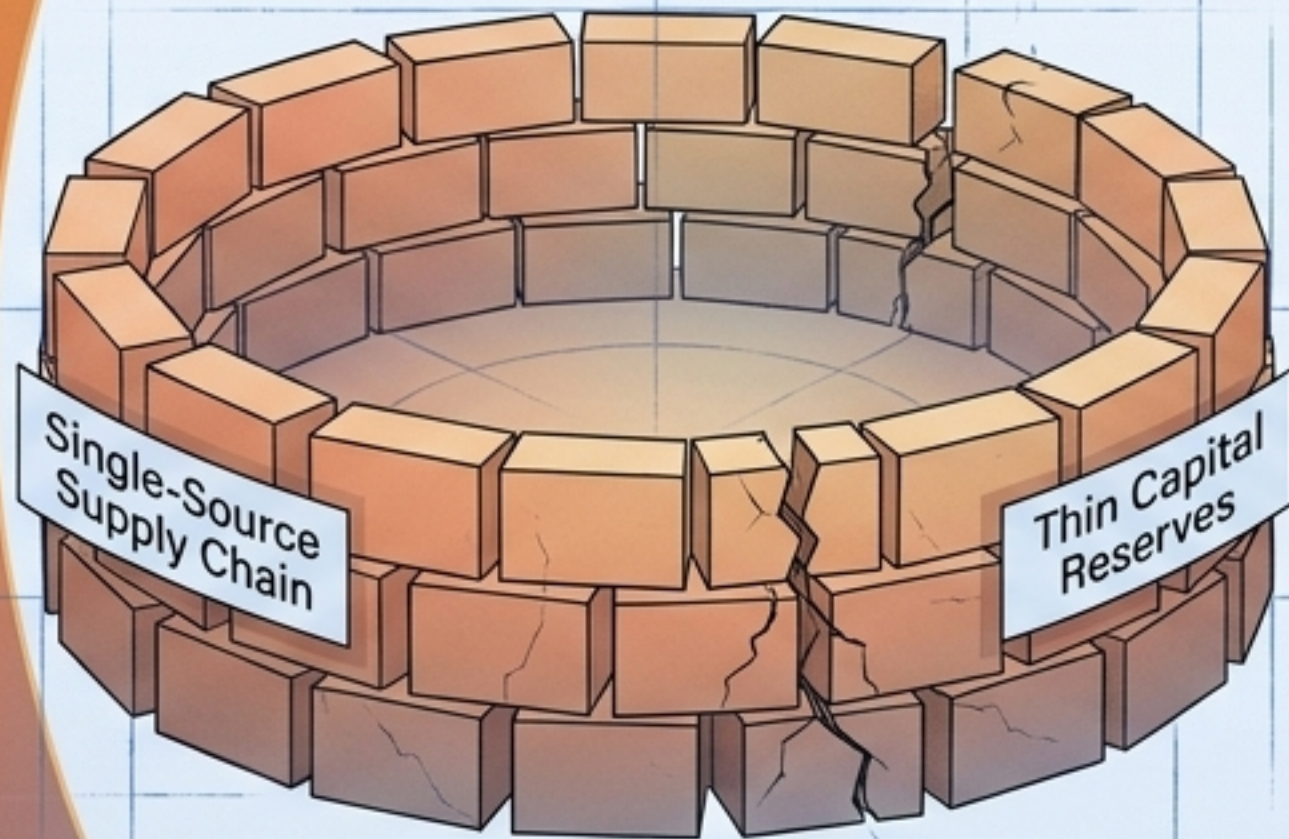


There is no single external controller; each feedback layer stabilizes the conditions the next layer depends upon. A digital twin extends a layer's response time, turning prediction into a form of continual repair.

The human operating crew has its own Admissible Region; tacit knowledge is a structural component.

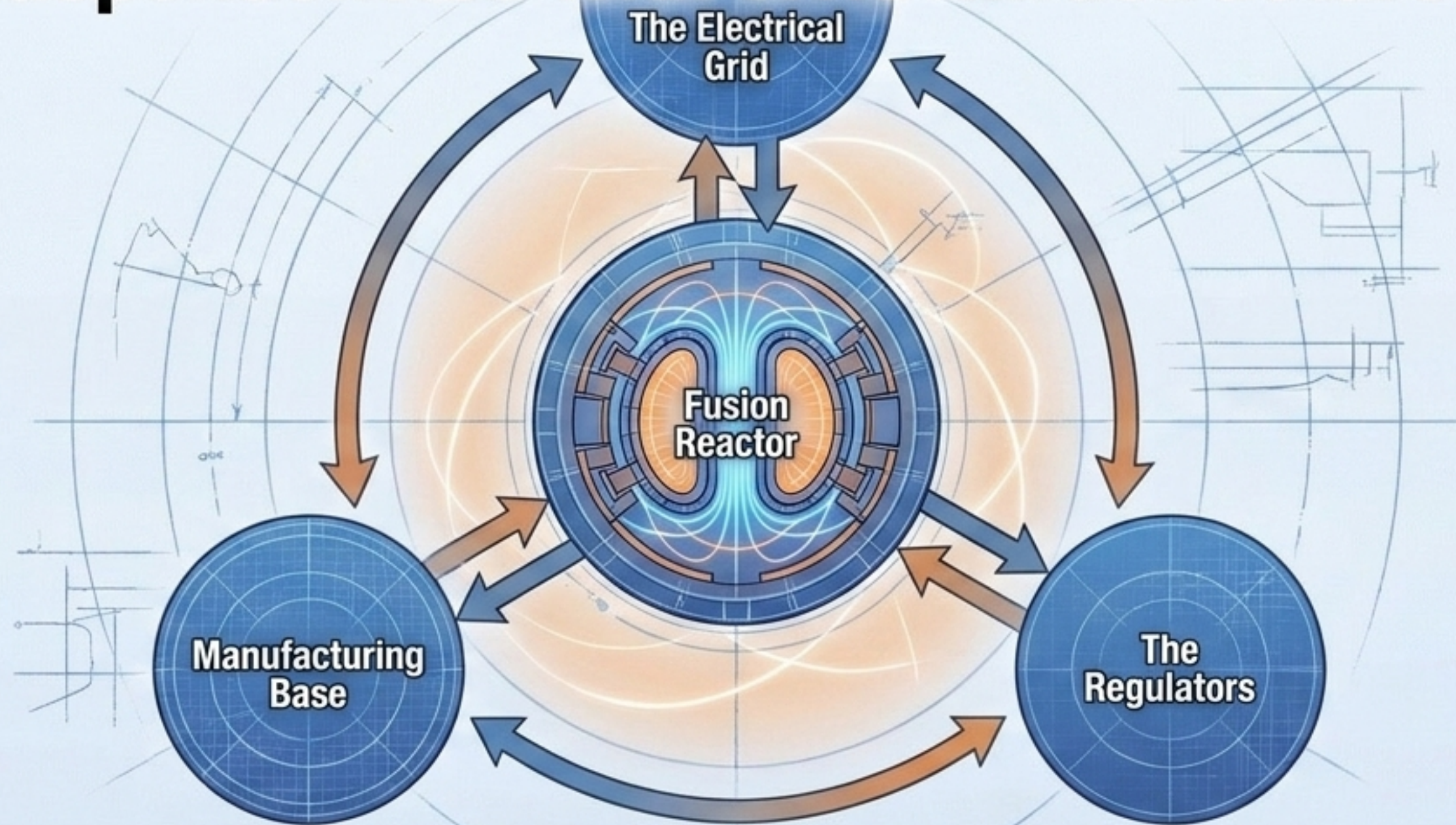


Financial capital and supply chain diversity act as literal, physical bounds on resilience.



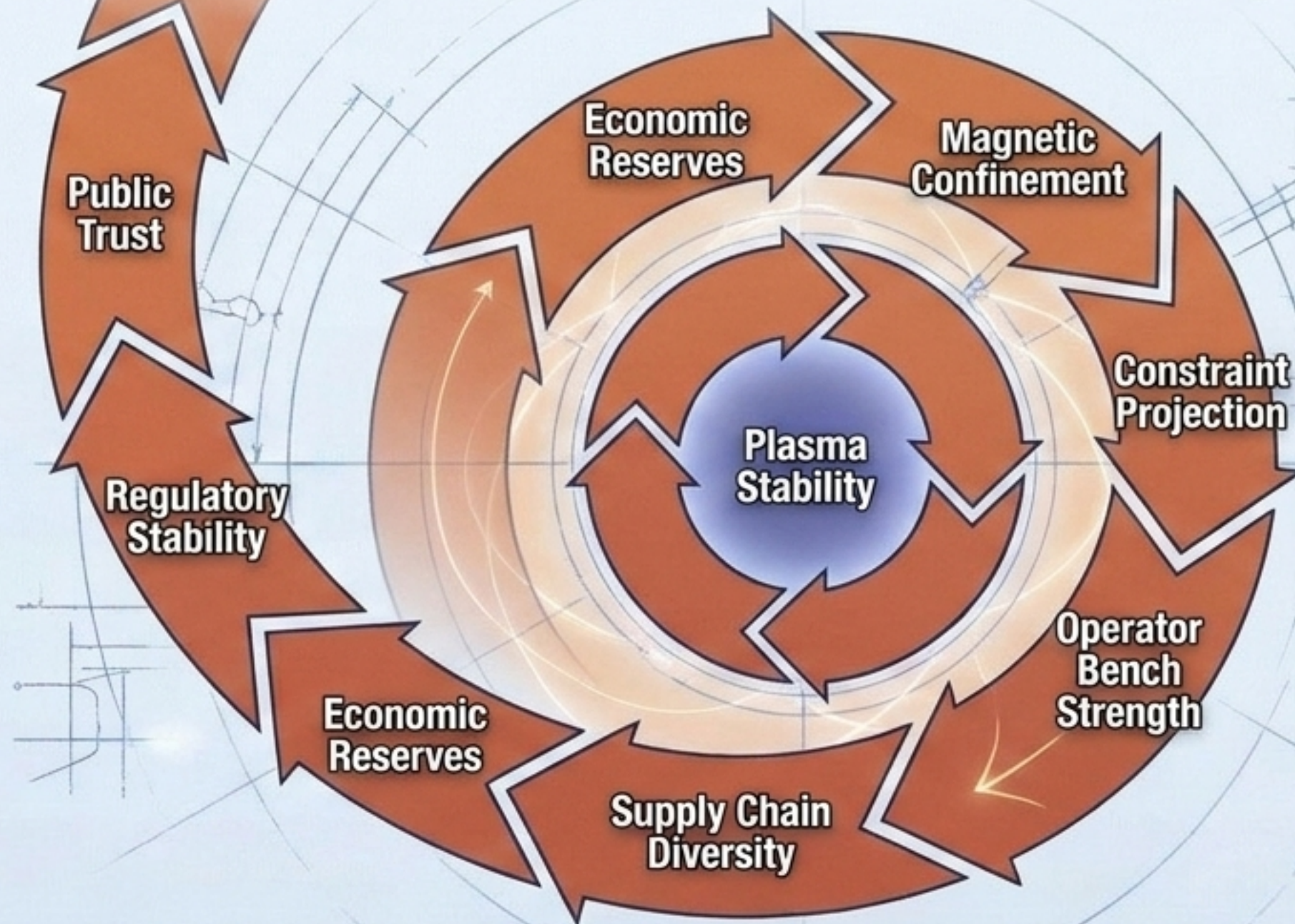
Economics is not a downstream consequence of good engineering; it is an Admissibility Condition.
A plant with thin financial reserves cannot absorb an unplanned shutdown, triggering a cascade of deferred maintenance that guarantees future physical failure.

The Reactor Ecosystem: Bidirectional dependencies with civic infrastructure.



A reactor cannot survive in a vacuum; it is recursively dependent on the infrastructure, industry, and institutions that surround it. The grid relies on the plant's power, but the plant relies on massive grid power for controlled startups and cryogenics.

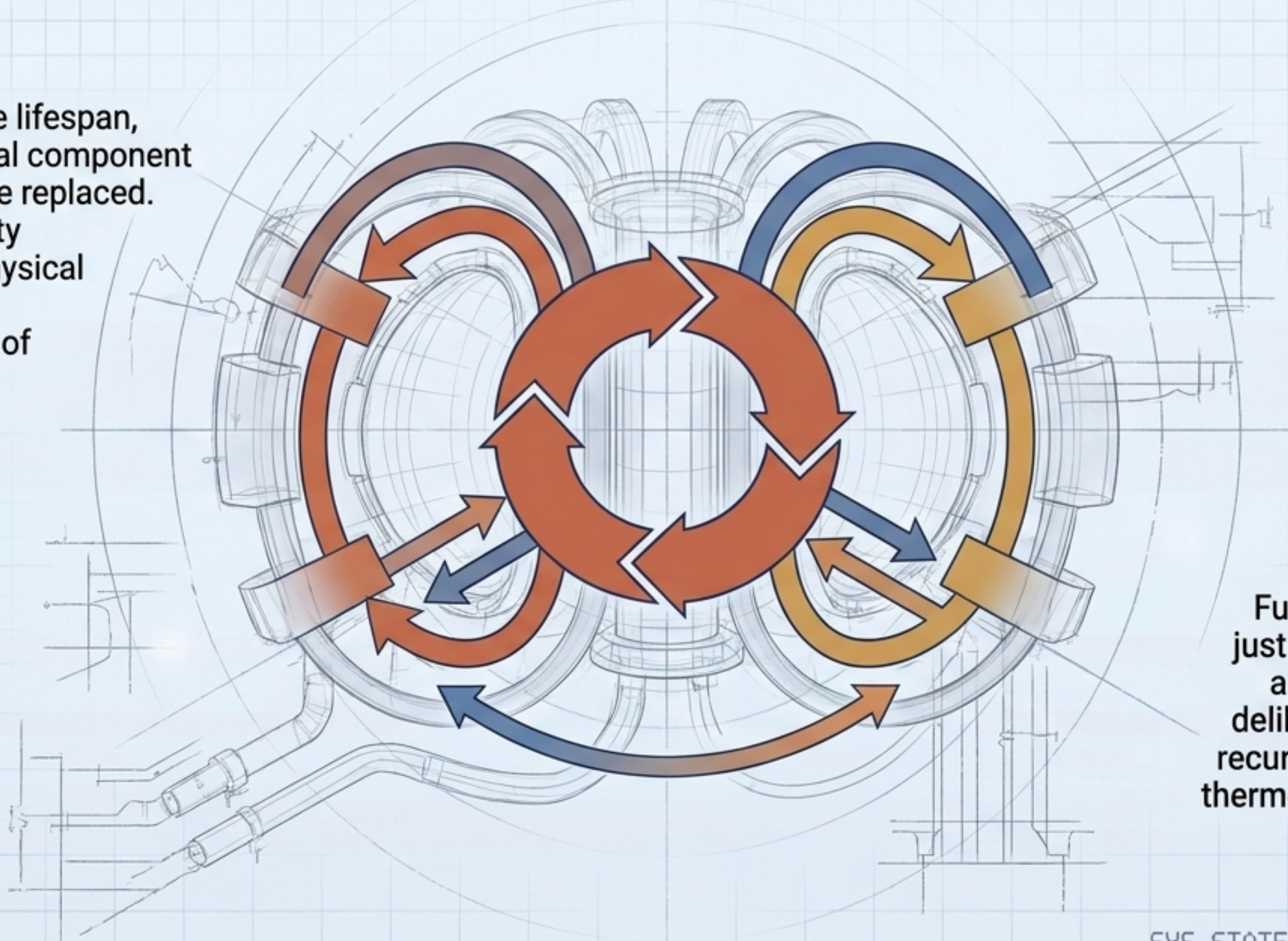
The Synthesis: Social and economic constraints are literal components of the reactor's physics engine.



A loss of public trust tightens regulatory timelines, which strains financial reserves, which forces single-source supply chains, which degrades operator training, which delays constraint projection, which drops the plasma. The loop is absolute.

Identity Without Matter: Conservation of Organization.

Over a multi-decade lifespan, nearly every physical component of the reactor will be replaced. The reactor's identity resides not in its physical matter, but in its maintained pattern of relationships.



Fusion engineering is not just about making a star in a jar. It is the conscious, deliberate engineering of a recursively self-maintaining thermodynamic organization.

SYS_STATE: PERSISTENCE ACHIEVED