NOMAD HP-4

Nuclear Microreactor Concept Note

4 MWe Heat-Pipe-Cooled Modular Reactor
Conceptual Design & Applications Framework

UCDPForge Research Initiative | 2025

This document was prepared using publicly available data with the assistance of commercially available AI software.

4 MWe	**~100 MWe**	**~8 Years**	**~33%**	**Walk-Away**
Per Module	Max Site Scale	Core Life	Efficiency	Safety

A Non-Technical Summary

The Nomad HP-4 is a compact, factory-built nuclear microreactor that generates 4 megawatts of electricity per unit using heat-pipe technology to transfer heat passively from a sealed core. Each module relies on robust TRISO fuel enriched to HALEU levels (under 20% uranium-235) in a graphite structure, eliminating the need for pumps, coolant loops, or water. Designed for the 2030s, it acts as a "nuclear battery" that can be transported by truck, rail, ship, or aircraft and scaled by adding identical modules to reach up to 100 megawatts at a single site, making it suitable for locations where traditional power grids or large reactors are not feasible.

Key Benefits

- Walk-away safety: the reactor shuts down and cools itself passively during emergencies without human intervention, relying on natural air circulation and built-in physics to prevent meltdowns.
- Operates approximately 8 years without refueling, requiring minimal staffing (1–2 technicians per shift with remote monitoring) and producing no ongoing fuel transport needs.
- Potentially 40–60% lower cost than diesel generators in remote areas by eliminating fuel logistics.
- Low-pressure design avoids high-pressure failure modes; reduced safety zone minimizes off-site emergency planning requirements.
- Waste heat (~150°C) available for absorption chillers, liquid cooling loops in AI/HPC data centers, hospital steam/hot water, chilled-water production, and district heating. Cogeneration heat is drawn from the Brayton cycle recuperator/heat-rejection loop (~90–160°C), not directly from the 600–700°C core outlet.

Primary Use Cases

AI / HPC Data Centers (60–100 MWe)	Reliable power with redundancy; waste heat for cooling.
Hospital / Medical Campuses	Uninterruptible electricity plus heat for water or chillers, outperforming diesel backups.
Community Energy Independence (~5,000 homes)	Microgrid islanding during outages with optional district heating.
Military Bases	Hardened, fail-safe 20–40 MWe setups with EMP-hardening options.
Forward / Disaster-Relief Camps	Rapid 5 MWe deployment in 3–5 days with minimal site preparation.

Scope Boundary: Nomad HP-4 is optimized for edge and regional AI/HPC sites in the 20–100 MWe range. It is not intended for single-site 300–1,000 MWe hyperscale training campuses. Future hybrid architectures combining Nomad HP-4 with larger SMRs or a conceptual Nomad HP-10 class could address those larger requirements.

Key Risks and Mitigation

Primary risks include heat-pipe reliability at sustained high temperatures, fuel performance under transients, and HALEU supply chain availability. Regulatory pathways for transportable fueled units and siting approvals in non-traditional locations represent the principal licensing challenges. Staged demonstrations address these systematically: non-nuclear heat-pipe testing (2026–2027), nuclear prototype validation (2028–2029), and integrated microgrid demonstration (2030).

B Technical Concept Note

1 Concept Overview

The Nomad HP-4 is a factory-built, heat-pipe-cooled nuclear microreactor designed for rapid deployment in the 2030s, delivering 4 MWe of reliable, carbon-free power per module using proven technologies analogous to Westinghouse's eVinci and Oklo's Aurora. It emphasizes passive safety, transportability, and scalability to address critical energy needs in remote or high-reliability settings, with minimal operational complexity and no water requirements.

Nomad HP-4 draws primarily from eVinci as the technology analog for a heat-pipe-cooled nuclear battery microreactor, while Oklo Aurora serves as a business model and licensing pathway precedent. The design provides transportable, walk-away safe 4 MWe modules that scale to 20–100 MWe microgrids for remote or high-reliability loads, with cogeneration options and minimal water dependence.

Nomad HP-4 serves as a capable power backbone for distributed architectures where compute nodes are spread across highly secure, latency-sensitive regional sites, enabling energy independence from vulnerable legacy grids.

2 Key Parameters

Parameter	Value	Annotation
Electrical output	4 MWe	*Aligned with eVinci-class data*
Thermal power	12 MWth	*Estimate – conservative*
Fuel type	TRISO particles in graphite matrix	—
Enrichment	≤19.75% U-235 (HALEU-class)	*Aligned with SMR/microreactor literature*
Core life	~8 years at rated power	*Aligned with eVinci-class data; FOAK conservative*
Dimensions	~10m L × 3m W × 4m H	*Estimate – conservative*
Weight	~40–50 tons	*Estimate – conservative*
Efficiency	~33%	*Aligned with eVinci-class data*
Turndown ratio	20% (~0.8 MWe minimum)	*Estimate – conservative*
Ramp rate	5% per minute	*Estimate – conservative*
Core outlet temperature	600–700°C	*Uncertain range per eVinci prototypes; aligned with literatur*

3 Reactor Technology and Safety Concept

The Nomad HP-4 employs a heat-pipe-cooled reactor class, chosen for its passive heat transfer without pumps, valves, or coolant loops, enabling low-pressure (~1 atm) operation and inherent safety. The core configuration is a graphite-moderated monolith with embedded sodium heat pipes for radial heat conduction to an open-air Brayton cycle power conversion unit. TRISO fuel in graphite matrix operates normally at 600–700°C core outlet temperature, well below the typical steady-state TRISO integrity limit of ~1,200–1,300°C.

Walk-Away Safety Mechanisms

- Passive decay-heat removal via heat pipes conducting heat radially to air-cooled condensers with natural convection.
- Strong negative temperature coefficients from Doppler broadening in fuel and graphite expansion.
- Low-pressure design eliminating high-energy failure modes (no Loss-of-Coolant Accident scenario).
- Gravity-inserted shutdown rods and rotatable control drums per module.
- Target exclusion zone ~100m radius (Estimate – conservative; subject to regulator review).

Accident Scenario Peak Fuel Temperatures (Estimated – Conservative)

Scenario	Peak Temp.	Safe Duration	Notes
Long-term loss of off-site power / forced cooling	~1,100°C	14–21 days	Below TRISO limit of ~1,600°C
Loss of heat-sink / impaired airflow	~1,050°C	5–7 days	Before optional venting
Reactivity insertion or control failure	~1,250°C	>10 days	No cascading failures assumed

All scenarios assume no cascading failures and require modeling validation. Peak temperatures remain well below the TRISO design limit of ~1,600°C in all cases.

Heat-Pipe Operational Constraints

Sodium heat pipe operational limits constrain the design to approximately 500–1,000 heat pipes per module with thermal power per pipe of ~12–24 kW to remain below sonic and enboilment thresholds. Core geometry is a compact monolith (~1–2m diameter) to minimize pipe length and ensure radial heat flux below 50 kW/m². Key material challenges at 600–700°C for ~8 years include superalloy creep and fatigue, sodium corrosion compatibility, and long-term wick integrity.

4 Packaging, Transport, and Deployment

The fueled module (~10m L × 3m W × 4m H; ~40–50 tons) is packaged as an ISO-like skid including core, heat pipes, power conversion, shielding, and controls. It is transportable by truck, rail, ship, or cargo aircraft (e.g., C-17).

Phase	Activity	Timeline
Site Preparation	Simple concrete pad (~0.5 acres)	Prior to delivery
Transport & Placement	Crane installation on pad	Day 1–2
Connections & Testing	System integration and checkout	Day 3–7
Commissioning	Criticality and power export	Week 2
Relocation / Decommission	Shutdown, cool-down (2–3 days), transport to defueling facility	As required

5 Multi-Module ~60–100 MWe Site Configuration

For scaling to ~100 MWe (e.g., 25 modules at 4 MWe each), modules connect via a medium-voltage (4,160V) common bus with per-module breakers, feeding a step-up transformer to site HV feeders. An integrated 10–20 MWh battery bank provides black-start capability and ride-through stability. Target site footprint: ~2–3 hectares (~5–7 acres), arranged in 5×5 rows with 10–15m spacing, each module in independent concrete vaults for fault containment.

For a 60 MWe AI data-center configuration: 18 modules total (15 active at ~80–90% utilization factor, 3 standby); N-2 reliability (site maintains >60 MWe with 2 module failures); 10 MWh battery ride-through; 4,160V interface with waste heat (up to 150°C) piped for liquid cooling.

6 Application Templates

AI / HPC Data Center (~60–100 MWe)	15 modules in N+2 redundancy (13 active, 2 spare); 10 MWh batteries for 10-minute ride-through; 4,160V interface. Waste heat (~90–160°C from Brayton recuperator) suitable for absorption chillers and liquid cooling loops, improving site PUE. Supports distributed, latency-sensitive compute nodes with energy independence from legacy grids.
Hospital / Medical Campus (8–10 MWe)	3 modules (N+1); 2 MWh batteries replace diesel for seamless UPS; cogeneration provides 4–6 MWth for steam/hot water or absorption chillers. No fuel deliveries required for ~8 years.
Community / Commercial District (~8 MWe avg., ~5,000 homes)	3 modules at 90%+ capacity factor; microgrid islanding during outages; optional district heating from ~90–160°C waste heat stream.
Military Base / Logistics Hub (~20–40 MWe)	8 modules; bermed or semi-buried siting for hardening; passive shutdown isolates any damaged module without cascade. Microgrid controller and electrical infrastructure designed with EMP hardening in mind. Diffuse thermal signature manageable via berming or below-grade siting.
Forward / Disaster-Relief Camp (~5 MWe)	2 modules (N+1); simple concrete pad, road access, small crane; target deployment 3–5 days, removal 7 days. Auto-shutdown on seismic/tamper sensors; passive cooling in adverse conditions.

7 Fuel Cycle, Logistics, and Lifecycle

Core life: ~8 years at rated power. Sealed, swap-out core design enhances proliferation resistance and eliminates on-site refueling (per Aurora model). Fresh and spent modules transported by licensed carriers in shielded casks via truck or rail, handled by fuel fabricators or DOE-equivalent under safeguards. Waste form: irradiated graphite/TRISO assemblies for central dry cask storage and eventual repository disposition.

HALEU Supply Consideration: Each module requires approximately 100–200 kg of HALEU. A 25-module, 100 MWe site would therefore require on the order of 2,500–5,000 kg of HALEU in total, which must be reconciled with projected U.S. and allied HALEU production capacity in the 2030s.

Phase	Target Period	Key Activity
R&D / Design	2020s	Technology development and concept refinement
Pre-Application / Licensing	Early–mid 2030s	NRC Part 52 topical reports; combined license
FOAK Demonstration	Late 2030s	First-of-a-kind nuclear prototype and microgrid demo
NOAK Production	2040s	Factory scaling; 10–20 modules/year target

8 Economics and Key Risks

Metric	Range	Basis
CAPEX – FOAK single module	$5,000–8,000/kWe	*Aligned with SMR/microreactor literature*
CAPEX – NOAK single module	$2,000–4,000/kWe	*Estimate – optimistic*
CAPEX – Multi-module ~100 MWe site	$1,500–3,000/kWe	*Estimate – optimistic; shared infrastructure savings*
LCOE vs. diesel + logistics	40–60% lower	*Remote diesel ~$0.20–0.50/kWh*
LCOE vs. grid + diesel backup	20–30% lower	*High-reliability grid ~$0.10–0.15/kWh*

Illustrative Economics: A remote 20 MWe installation currently powered by diesel at an all-in cost of approximately $0.25–0.40/kWh (fuel, transport, maintenance) could achieve meaningful cost reduction over an 8-year core life by replacing diesel with Nomad HP-4 modules, even at FOAK CAPEX of $5,000–8,000/kWe, primarily by eliminating fuel logistics costs (illustrative, order-of-magnitude only).

Economic Sensitivities

- HALEU pricing: accounts for 20–30% of LCOE if above ~$100/kg.
- Factory throughput: NOAK cost drops require 10+ modules/year production.
- Site work scope: minimal civil vs. hardened military siting adds 10–20% variability.
- FOAK SMR precedent (e.g., NuScale cost revisions): supply chain immaturity and regulatory delays could push CAPEX to upper bound.

Physical Security and Guard-Force Considerations

HALEU use implies 24/7 armed security requirements under current regulatory practice, which can challenge economics for small civilian deployments. Defense and major base deployments ride on existing armed security with minimal incremental cost. For civilian/community sites, proposed design-time mitigations include below-grade hardened vaults, tamper-indicating enclosures, and automated seismic/tamper lockouts providing response time for off-site law enforcement.

Nomad HP-4 is intended to comply with applicable physical protection requirements (e.g., 10 CFR Part 73) and to support a graded safeguards case for applicable deployments. This remains a regulatory and policy negotiation topic under active development.

Key Design Trade-offs

- **Heat-pipe vs. gas-cooled:** Prioritizes simplicity and passivity (no pumps, low pressure) for remote deployability. Trades lower power density (~10–20 kW/liter vs. gas-cooled's 50+ kW/liter), acceptable at micro-scale.
- **4 MWe module size:** Balances capital cost (~$20–32M FOAK) and siting flexibility against economies of scale; enables numbering-up to 100 MWe without site overload.
- **Sealed 8-year core:** Enhances proliferation resistance; eliminates on-site refueling. Increases full-module logistics burden and HALEU dependency (~100–200 kg/module).
- **High-temperature Brayton (~33% at 600–700°C):** Improves compactness vs. lower-temperature Rankine. Adds materials qualification burden; addressed via conservative operating temperatures.
- **Passive safety emphasis:** Enables walk-away capability and reduced EPZ. Trades slower load-following vs. active systems, mitigated by battery integration.

9 Risk Reduction Path and Staged Demonstrations

Nomad HP-4 fits NRC Part 52 licensing via pre-application topical reports or DOE demonstration paths analogous to Aurora at INL, targeting a combined license by mid-2030s.

Top Technical Risks

- Heat-pipe reliability at operating temperatures: superalloy creep and fatigue; sodium corrosion; long-term wick integrity.
- Fuel performance under transients: TRISO particle integrity.
- HALEU supply chain: production ramp timing for commercial deployment.

Top Regulatory / Public-Acceptance Risks

- Licensing timelines for factory-fueled transportable units.
- Siting approvals in non-traditional locations.
- Public concerns over microreactor proliferation.

Stage	Period	Objective	Key Gate
1 – Non-Nuclear Heat-Pipe Test Bed	2026–2027	Retire heat-pipe reliability risk via accelerated life-cycle testing (multi-decade equivalent)	No unexpected creep, corrosion, or wick degradat
2 – Nuclear Test Reactor	2028–2029	3–5 MWth prototype; validate safety systems and fuel performance under transients.	Demonstrated passive shutdown and TRISO integ
3 – Integrated Microgrid Demo	2030	1–2 module demonstration; confirm application integration and regulatory path.	Contingent on Stage 1 and 2 results; Stage 3 date

The FOAK demonstration program is well-suited for joint public-private funding via mechanisms such as the Defense Innovation Unit (DIU), DARPA, or DOE/ARPA-E, which specifically target early-stage deep technology with dual-use applications. The overall program schedule is gated by the HALEU production ramp; the reactor design is technically feasible without new fuel breakthroughs, but commercial deployment timing is constrained by supply chain readiness.