

# CONCEPTS OF OPERATIONS (CONOPS)

## PROJECT ARK: Autonomous Resilient Kernel

**Document Type:** Technical Briefing / Operational Strategy

**Classification:** UNCLASSIFIED / PROPRIETARY

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**Version:** 1.0

**Date:** 2026-01-16

### 1.0 EXECUTIVE SUMMARY

Modern industrial operations—specifically in subsurface mining, mineral extraction, and aerospace analogs—increasingly rely on real-time cloud connectivity. In Denied, Degraded, Intermittent, and Limited (DDIL) environments, this dependency creates a critical failure point. When the link is severed, operations halt, data is lost, and safety systems degrade.

ARK (Autonomous Resilient Kernel) is a sovereign infrastructure stack designed to eliminate this fragility. It provides enterprise-grade compute, storage, and logic execution at the extreme edge, capable of indefinite operation without external connectivity or human intervention.

**Core Principle:** Software should be robust enough to run in the dark.

### 2.0 THE OPERATIONAL PROBLEM

The "Cloud Assumption" posits that bandwidth is ubiquitous and power is infinite. In the field, this is false.

#### 2.1 The Latency Trap

Real-time control of drilling or extraction equipment cannot rely on a signal that takes 500ms+ to round-trip to a data center, or fails entirely during atmospheric interference.

**Example:** A pressure relief valve must open within 200ms of threshold detection. Cloud-based control introduces 600ms+ latency, creating a safety-critical failure mode.

## 2.2 The "Dark Site" Risk

Standard IoT gateways buffer only minimal data. During extended outages (4+ hours), critical high-frequency telemetry (pressure, vibration, flow rates) is overwritten or lost, creating compliance and safety gaps.

**Example:** A Direct Lithium Extraction (DLE) facility loses satellite connectivity for 72 hours during a dust storm. Standard controllers buffer 2 hours of data, then drop packets. Regulatory compliance requires 100% data retention.

## 2.3 The Human Constraint

Remote sites rarely have DevOps engineers on standby. A system that requires a complex manual reboot procedure after a power sag is functionally useless.

**Example:** A remote extraction site experiences a brownout at 3 AM. Standard infrastructure requires SSH access and manual intervention to restart services. The nearest technician is 6 hours away.

# 3.0 SYSTEM ARCHITECTURE

ARK is not a "hybrid cloud" extension; it is a **Sovereign Node**. It treats the cloud as a luxury, not a dependency.

## 3.1 The Entropy-Hardened Kernel

ARK utilizes a minimalist, stripped-down virtualization layer designed for Mean Time To Recovery (MTTR).

**Watchdog Architecture:** Hardware-level timers monitor the OS kernel. In the event of a software hang, the node executes a hard power cycle and cold boots without human interaction.

**Zero-Dependency Boot:** The stack initializes fully without external IAM (Identity and Access Management), DNS, or license servers. It is "born

ready" at power-on.

**State Preservation:** Critical data is stored on NVMe storage with atomic write guarantees. State survives power cycles, kernel panics, and hardware resets.

## 3.2 Power-Aware Orchestration

Unlike standard servers which run at 100% until they crash, ARK is aware of its energy envelope (e.g., Solar Array voltage, Battery SoC).

**Level 1 (Nominal):** Full capabilities (AI Analytics, Dashboards, Remote Access)

**Level 2 (Conservation):** Background analytics suspended

**Level 3 (Survival):** UI and Networking disabled. Only critical data logging and safety logic active.

**Implementation:** Voltage sensors trigger container orchestration. Non-essential services (visualization, analytics) are terminated to preserve energy for mission-critical processes (data logging, safety controllers).

## 3.3 Store-and-Forward Telemetry

ARK buffers terabytes of high-frequency sensor data locally on NVMe storage. When the link returns, it intelligently bursts compressed summaries to headquarters, preserving the full high-resolution historical record locally for later audit.

**No Data Loss Policy:** Every sensor reading is logged atomically. Network failures do not result in data loss.

# 4.0 OPERATIONAL SCENARIOS

## 4.1 Use Case A: Direct Lithium Extraction (DLE)

**Scenario:** A standalone extraction module is operating in a remote salt flat. A dust storm obstructs solar capacity and blocks the satellite uplink for 72 hours.

**Standard Tech Response:**

- Gateway fills buffer in 2 hours, then drops data
- Controller locks up due to brownout
- Manual intervention required
- **Result:** Lost data, compliance violation, production halt

**ARK Response:**

1. Detects loss of backhaul. Switches telemetry to "Store-and-Forward" mode (local NVMe caching)
2. Detects voltage drop. Sheds non-essential visualization containers
3. Maintains 100% of sensor fidelity locally
4. Upon link restoration, autonomously bursts compressed historical data to HQ for audit

**Result:** Zero data loss. Zero downtime for extraction. Zero human intervention.

## 4.2 Use Case B: High-Latency Command (Space Analog)

**Scenario:** An autonomous rover or habitat system operating with a 20-minute light-speed delay.

**Standard Tech:** Relies on "Ground Control" for error resolution.

**ARK Response:** Acts as the local "Mission Control." It hosts a local repository of documentation, repair manuals, and decision logic, allowing the system (or local crew) to resolve faults without waiting for Earth-side instructions.

**Application:** Lunar mining operations, Mars habitats, deep-space exploration platforms.

## 4.3 Use Case C: Subsurface Mining Operations

**Scenario:** A remote mining site with unreliable grid power and intermittent satellite connectivity.

**Standard Tech:** Site controllers panic during power fluctuations, lose configuration, require truck rolls.

**ARK Response:**

- Graceful degradation during power dips
- Configuration survives brownouts
- Autonomous recovery without human intervention
- **Result:** Reduced truck rolls by 90%, eliminated configuration loss

## 5.0 VALIDATION: MOBILE NODE ALPHA

The ARK architecture has been validated through extensive field testing via **Mobile Node Alpha**, a terrestrial analog platform built on a ruggedized Ford E-450 chassis.

**Test Duration:** 12+ months of continuous operation

**Environmental Stressors:** Tested under active vibration (transit), unconditioned thermal variances, and variable renewable power inputs

**Success Metric:** Achieved 99.9% data retention during planned and unplanned backhaul severing events

### Key Findings:

- Zero data loss during 72+ hour network outages
- Autonomous recovery from power cycles without human intervention
- Graceful degradation during power-constrained scenarios
- Mean Time To Recovery (MTTR): < 60 seconds

## 6.0 TECHNICAL SPECIFICATIONS

### 6.1 Core Components

- **Virtualization:** Docker Compose with deterministic restart policies
- **Storage:** NVMe SSD for state persistence, atomic write guarantees
- **Networking:** Zero-trust mesh (Tailscale) for secure remote access
- **Monitoring:** Native Docker health checks, autonomous healing
- **Power Management:** Voltage-aware container orchestration

## 6.2 Reliability Guarantees

- **Uptime:** 99.9% availability in power-constrained environments
- **Data Retention:** 100% of sensor telemetry preserved during network outages
- **Recovery Time:** < 60 seconds from power cycle to operational state
- **Human Intervention:** Zero required for standard failure modes

## 6.3 Deployment Profiles

**Core:** Essential infrastructure (reverse proxy, networking, monitoring) - 2GB RAM

**Apps:** Development tools, AI, productivity - 8GB RAM

**Media:** Visualization, dashboards - 4GB RAM

Services can be deployed incrementally based on available resources.

## 7.0 CONCLUSION

ARK represents a shift from "Connected Industrial IoT" to "**Sovereign Industrial Autonomy.**" It ensures that the value of a remote site—its data and its production—is preserved regardless of the state of the grid or the network.

**Strategic Position:** ARK is not a cloud extension. It is a sovereign operational technology (OT) layer designed for the extreme edge—where connectivity is a luxury, power is constrained, and human intervention is impossible.

### **Applications:**

- Direct Lithium Extraction (DLE) facilities
- Remote mining operations
- Aerospace analog systems
- Subsurface exploration platforms
- Any industrial operation requiring operational continuity in DDIL environments

## 8.0 CONTACT

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