PROJECT SPERS: TECHNICAL SPECIFICATION DOCUMENT

SECTION 3.0: SAFETY PROCEDURES & INTERLOCKS

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3.1 SAFETY PHILOSOPHY: DEFENSE IN DEPTH

The SPERS safety architecture follows the **"Power First, Not Weapon"** doctrine. It utilizes a multi-layered approach where the failure of one layer automatically engages the next.

1. **Intrinsic Safety (Physics):** The reaction physically cannot sustain itself without active input power.
2. **Hard-Wired Interlocks (Analog):** Non-programmable circuits that cut power if limits are exceeded.
3. **Active Control (Digital):** FPGA monitoring and automated shutdown sequences.
4. **Passive Containment (Physical):** Pressure vessels, burst discs, and gravity-fed cooling that require no electricity to function.

3.2 THE DEADMAN ARCHITECTURE (HARD-WIRED INTERLOCKS)

This is the "Supreme Authority" of the reactor. It is an analog control loop that operates independently of the FPGA software. It utilizes a **Series Logic Circuit** (AND Gate equivalent) where any break in the signal chain opens the **Main Power Contactor**.

3.2.1 The Triad Interlock Signals

Three conditions must be continuously met to allow the Capacitor Bank to charge.

- **Signal A: Radiological Integrity**
  - **Sensor:** Geiger-Müller (GM) Tube + Scintillation Detector located on the Blue Loop (Clean Side) output.
  - **Threshold:** $> 0.05 \mu\mathrm{Sv/h}$ (Background Radiation + 10%).
  - **Logic:** If radiation is detected in the clean steam loop, the Heat Exchanger has failed. **Action:** Immediate Trip.
- **Signal B: Thermal Envelope**
  - **Sensor:** Redundant K-Type Thermocouples bolted to the Outer Vessel (Zone B) skin.
  - **Threshold:** $> 330^\circ\mathrm{C}$.
  - **Logic:** If wall temperature exceeds limit, coolant is boiling off or pump has failed. **Action:** Immediate Trip.
- **Signal C: Physical Stability**
  - **Sensor:** Industrial MEMS Accelerometer anchored to the reactor foundation.
  - **Threshold:** $> 0.5\mathrm{g}$ (Seismic event or Turbine imbalance).
  - **Logic:** Detects earthquakes or catastrophic mechanical failure. **Action:** Immediate Trip.

3.3 EMERGENCY SCRAM PROTOCOL

(Emergency Shutdown) sequence within 100 milliseconds.

3.3.1 Electrical Isolation

- **Main Contactor:** Opens physically, disconnecting Grid/Battery power.
- **Capacitor Dump:** A normally-closed relay opens, connecting the Main Capacitor Bank to a **Bleeder Resistor Grid**.
  - **Result:** The stored energy ($50\ \mathrm{kJ}$) is dissipated as heat into a ceramic load bank within 5 seconds, preventing any further magnetic pulses.

3.3.2 Hydraulic Lockdown

- **Feed Valve:** The Tesla Valve inlet supply pump cuts off. The Waste Isolation Valve (Pneumatic Spring-Return) slams shut.
- **Isolation:** The Red Loop is isolated from the Heat Exchanger to prevent potential contamination migration.

3.3.3 The Quench (Thermal Arrest)

- If **Signal B (Thermal)** was the cause of the trip:
  - **Gravity Flood Valve:** A "Fail-Open" Solenoid valve on the roof-mounted water tank de-energizes and opens.
  - **Action:** 5,000 Liters of cold borated water floods the reactor pit, submerging the Outer Vessel to provide passive conductive cooling.

3.4 FAILURE MODE & EFFECTS ANALYSIS (FMEA)

Detailed mitigation strategies for specific catastrophic scenarios.

3.4.1 Scenario: Steam Explosion (Over-Pressurization)

- **Event:** Runaway heating or failure of the Pressurizer causes Red Loop pressure to exceed the vessel rating ($> 200\ \mathrm{Bar}$).
- **Mitigation: Burst Disc Assembly**.
  - **Component:** A calibrated Inconel diaphragm located on the Red Loop manifold.
  - **Rating:** Ruptures at $180\ \mathrm{Bar} \pm 5\%$.
  - **Path:** Vents steam directly into the **Dump Tank**.
- **The Dump Tank (Sump):**
  - **Location:** Buried concrete vault below the reactor.
  - **Contents:** Filled with cold water and metal baffling.
  - **Function:** Condenses the radioactive steam release instantly, preventing atmospheric venting.

3.4.2 Scenario: Loss of Coolant Accident (LOCA)

- **Event:** A pipe fracture drains the Red Loop, leaving the Inner Sphere dry.
- **Risk:** Decay heat from the activated SiC walls could damage the coils.

- The containment pit is lined with high-density concrete. The geometry ensures that even without water, the SiC sphere can radiate heat to the concrete walls without reaching melting temperatures. The core cartridge is sacrificed, but containment holds.

3.4.3 Scenario: Heat Exchanger Breach

- **Event:** A tube inside the Heat Exchanger cracks, creating a path between the Radioactive (Red) and Clean (Blue) loops.
- **Mitigation: Pressure Differential Barrier**.
  - **Blue Loop Pressure:** Maintained at 160 Bar.
  - **Red Loop Pressure:** Maintained at 150 Bar.
  - **Physics:** In the event of a leak, the higher pressure Clean water flows *into* the Dirty loop. The radioactive water physically cannot flow upstream against the pressure gradient.
  - **Detection:** Level sensors in the Red Loop Pressurizer will detect a rising water level (Inflow), triggering a maintenance alarm.

3.5 INTRINSIC SAFETY FEATURES

Why SPERS cannot become a nuclear weapon or suffer a Chernobyl-style meltdown.

1. **Driver Dependence:** Unlike a fission reactor which has a "Critical Mass" that burns spontaneously, the SPERS fusion reaction requires a precise, nanosecond-timed "Spark Plug" (Acoustic + Magnetic).
   - **Fail-Safe:** If power is lost, the spark plug stops. The reaction ceases instantly ($t < 1 \text{ ms}$).
2. **Fuel Density:** The reactor contains only milligrams