

PROJECT SPERS: TECHNICAL SPECIFICATION DOCUMENT

SECTION 1.0: HARDWARE ARCHITECTURE & SPECIFICATIONS

System Designator: SPERS-MK1 (Self-Powered Environmental Remediation System) Document ID: SPERS-HW-SPEC-v2.0 Date: November 24, 2025 Classification: Engineering Control / Pilot Fabrication

1.1 ZONE A: THE REACTOR CARTRIDGE (CORE-A1)

The CORE-A1 is the central reaction chamber. It is designed as a modular, replaceable "cartridge" unit to facilitate maintenance of irradiated components. It operates under extreme conditions of thermal shock ($> 1000^{\circ}\text{C/ms}$), high pressure transients (1000 Bar), and high neutron flux.

1.1.1 Inner Vessel (The Crucible)

The crucible serves as the plasma facing component and the acoustic resonator.

- **Geometry:** Perfect Sphere.
 - **Internal Diameter (ID):** $300\text{ mm} \pm 0.05\text{ mm}$.
 - **Sphericity Tolerance:** Grade 10 (High precision ball bearing standard) to ensure uniform acoustic wave convergence.
- **Base Material:** Sintered α -SiC (Alpha Silicon Carbide).
 - **Density:** $> 3.15\text{ g/cm}^3$ ($> 98\%$ theoretical density).
 - **Thermal Conductivity:** $120\text{ W/(m} \cdot \text{K)}$ at 200°C .
 - **Flexural Strength:** 450 MPa.
- **Internal Coating:** h-BN (Hexagonal Boron Nitride).
 - **Deposition Method:** CVD (Chemical Vapor Deposition).
 - **Layer Thickness:** $50\text{ }\mu\text{m}$.
 - **Function:** Provides a "Sanitary" lubricious surface (Coefficient of Friction < 0.2) to prevent adhesion of transmutation products.

Abbreviations & Definitions (1.1.1):

- **ID (Internal Diameter):** The measurement of the straight line passing through the center of the sphere, terminating at the inner walls.
- **SiC (Silicon Carbide):** A semiconductor ceramic compound of silicon and carbon. Chosen for its ability to withstand thermal shock and its transparency to magnetic fields (unlike metals).
- **h-BN (Hexagonal Boron Nitride):** Often called "White Graphite." An isoelectronic analog to graphite with excellent thermal stability and chemical inertness.
- **CVD (Chemical Vapor Deposition):** A vacuum deposition method used to produce high quality, high-performance solid materials.

1.1.2 The Active Matrix (Embedded Drivers)

This layer contains the electromagnetic and acoustic drivers, buried within the wall to prevent contact with the waste stream.

- **Conductor Type:** Litz Wire (Type 8, Silk Served).
- **Composition:** 5000 strands of 44 AWG Copper.
- **Reasoning:** Mitigates the **Skin Effect** at high frequencies (> 20 kHz), ensuring current flows through the entire cross-section of the wire for maximum magnetic flux density.
- **Circuit Topology:** 3x Redundant Parallel Circuits (Pentagonal winding geometry).
- **Acoustic Drivers:**
 - **Type:** High-Power PZT (Lead Zirconate Titanate) Stacks.
 - **Placement:** 12 units arranged at dodecahedral vertices.
 - **Bonding:** Vacuum brazed directly to the SiC substrate.
- **Encapsulation (Potting):**
 - **Material:** Alumina-Silicate Ceramic Paste.
 - **Dielectric Strength:** > 15 kV/mm.
 - **Function:** Mechanically secures wires against Lorentz forces and prevents voltage breakdown.

Abbreviations & Definitions (1.1.2):

- **Litz Wire (Litzendraht):** A type of cable used in electronics to carry alternating current. The wire is designed to reduce the skin effect and proximity effect losses in conductors used at frequencies up to about 1 MHz.
- **AWG (American Wire Gauge):** A standardized wire gauge system used for the diameters of round, solid, nonferrous, electrically conducting wire.
- **Skin Effect:** The tendency of an alternating electric current (AC) to become distributed within a conductor such that the current density is largest near the surface of the conductor.
- **PZT (Lead Zirconate Titanate):** A piezoelectric ceramic material that changes shape when an electric field is applied, used to generate the acoustic shockwaves.

1.1.3 Structural Armor (Outer Shell)

The SiC liner is brittle. The outer armor provides tensile strength to contain the pressure pulse without shattering.

- **Material:** C/SiC (Carbon Fiber Reinforced Silicon Carbide).
 - **Process:** Filament Winding followed by Polymer Impregnation and Pyrolysis (PIP).
- **Wall Thickness:** 10.0 mm.
- **Burst Pressure Rating:** $> 2,500$ Bar (Static).
- **Fatigue Life:** Rated for 10^9 cycles (approx. 18 months at 60 Hz).

Abbreviations & Definitions (1.1.3):

- **C/SiC (Carbon-Silicon Carbide):** A ceramic matrix composite (CMC) consisting of carbon fibers embedded in a silicon carbide matrix. It combines the hardness of ceramic with the toughness of carbon fiber.
- **PIP (Polymer Impregnation and Pyrolysis):** A manufacturing process for ceramics where a preform is infiltrated with a liquid polymer and then heated to decompose the polymer into a ceramic matrix.

- **Inlet Valve:** Solid-State Tesla Valve.
 - **Material:** Inconel 718 (Nickel-Chromium-based superalloy).
 - **Manufacturing:** DMLS (Direct Metal Laser Sintering).
 - **Diode Ratio:** 12:1 (Fluid resistance is 12x higher in reverse).
 - **Design:** 4-Stage Loop geometry.
- **Outlet Valve:** Active Flap Valve.
 - **Body Material:** 316L Stainless Steel.
 - **Sealing Face:** WC (Tungsten Carbide) coating.
 - **Actuator:** High-Speed Solenoid (< 2 ms response).

Abbreviations & Definitions (1.1.4):

- **DMLS (Direct Metal Laser Sintering):** A 3D printing technology that melts metal powder with a high-power laser. Essential for creating the complex internal channels of the Tesla Valve which cannot be machined.
- **WC (Tungsten Carbide):** An extremely hard chemical compound containing equal parts of tungsten and carbon atoms. Used on the valve seal to crush any solid waste particles that might prevent closure.

1.2 ZONE B: PRIMARY CONTAINMENT (VESSEL-B1)

This vessel acts as the pressure boundary, radiation shield, and thermal transfer medium. It fully encapsulates Zone A.

1.2.1 Pressure Vessel Assembly

- **Standard:** ASME BPVC Section III, Class 1 (Rules for Construction of Nuclear Facility Components).
- **Geometry:** Spherical vessel, 600 mm Internal Diameter.
- **Wall Material:** SS 316L (Stainless Steel).
 - **Grade:** Nuclear Grade (Low Cobalt, $< 0.05\%$).
 - **Thickness:** 25 mm.
- **External Shielding:**
 - **Material:** Cast Lead (Pb).
 - **Thickness:** 50 mm bonded cladding.
 - **Function:** Gamma ray attenuation.

Abbreviations & Definitions (1.2.1):

- **ASME BPVC (American Society of Mechanical Engineers Boiler and Pressure Vessel Code):** The global standard for the design, fabrication, and inspection of boilers and pressure vessels.
- **SS 316L:** A molybdenum-bearing austenitic stainless steel. The "L" stands for "Low Carbon," which improves corrosion resistance after welding.
- **Pb (Plumbum/Lead):** A heavy metal used for radiation shielding due to its high atomic density.

- **Base Fluid:** Demineralized Light Water (H_2O).
- **Additive:** Boric Acid (H_3BO_3).
 - **Concentration:** 2000 ppm (Parts Per Million).
 - **Isotope:** Enriched Boron-10 (^{10}B).
- **Operating Conditions:**
 - **Pressure:** 150 Bar (maintained by an external Pressurizer).
 - **Temperature:** 280°C (Inlet) to 310°C (Outlet).

Abbreviations & Definitions (1.2.2):

- **ppm (Parts Per Million):** A unit of concentration. 2000 ppm means 0.2% of the solution is Boric Acid.
- **Pressurizer:** A vessel connected to the primary loop that maintains the system pressure to prevent the water from boiling (voiding) at operating temperatures.

1.3 ZONE C: BALANCE OF PLANT (THE BLUE LOOP)

This zone handles the safe extraction of energy and the processing of transmutation products.

1.3.1 Heat Exchanger (HX-1)

The barrier between the radioactive (Red) and clean (Blue) loops.

- **Type:** TEMA Class R Shell & Tube Exchanger.
- **Tube Side (Red Loop Fluid):**
 - **Material:** Titanium Grade 2.
 - **Reasoning:** Superior corrosion resistance to borated water and high temperature.
- **Shell Side (Blue Loop Fluid):**
 - **Material:** Carbon Steel (SA-516 Grade 70).
 - **Function:** Steam Generation.

Abbreviations & Definitions (1.3.1):

- **TEMA (Tubular Exchanger Manufacturers Association):** The authority that sets standards for shell and tube heat exchanger design. Class R is for severe requirements (petroleum/nuclear).

1.3.2 Exhaust Processing System

Designed to separate gas, liquid, and solid phases from the reactor discharge.

- **Component 1: Cyclone Flash Tank.**
 - **Design:** Tangential Inlet high-velocity separator.
 - **Function:** Flashes pressurized slurry to steam; centrifugal force drives solids to the bottom.
- **Component 2: Magnetic Drum.**
 - **Magnet Type:** NdFeB (Neodymium Iron Boron) Rare Earth Permanent Magnet.
 - **Surface Field:** 1.2 Tesla.
 - **Function:** Removes paramagnetic isotopes (e.g., Transmuted Iron/Nickel).

- **Technology:** PSA (Pressure Swing Adsorption).
- **Sorbent:** Activated Carbon / Zeolite molecular sieve.
- **Purity Target:** 99.9% Helium-4.

Abbreviations & Definitions (1.3.2):

- **NdFeB:** The strongest type of permanent magnet commercially available, composed of Neodymium, Iron, and Boron.
- **PSA (Pressure Swing Adsorption):** A technology used to separate some gas species from a mixture of gases under pressure according to the species' molecular characteristics and affinity for an adsorbent material.

End of Section 1.0