Independent and dependent claims

1. **A radiation-shielding cartridge *comprising*:**
   - **a rigid housing (710) sized to mount on a spacecraft bulkhead;**
   - **an internal flexible bladder (712) that holds a radiation-absorbing gel containing 20 – 50 wt % boron carbide;**
   - **at least one gamma-dose sensor (722) and at least one neutron-dose sensor (724) operably fixed to the housing;**
   - **an electrically driven pump (730) fluidly coupled to the bladder;**
   - **an inflatable shield pillow (740) positioned between the housing and a protected volume; and**
   - **a controller (730) that, when dose rate exceeds a threshold and/or cumulative dose exceeds a threshold, automatically (i) inflates the shield pillow and (ii) meters the gel into the pillow until a predetermined gel thickness is achieved.**
2. **The cartridge of claim 1, wherein the gel comprises a silicone matrix loaded with 30 ± 5 wt % B_4C powder having a mean particle size ≤ 10 µm.**
3. **The cartridge of claim 1 or 2, wherein the pump is a two-stage piezoelectric micro-pump that first inflates the pillow to at least 30 kPa and thereafter delivers the gel at 5 – 15 mL s^{-1}.**
4. **The cartridge of any of claims 1-3, wherein the controller is further configured to halt gel delivery when gel temperature measured by a gel-embedded thermistor falls outside −30 °C to +60 °C.**
5. **The cartridge of any preceding claim, wherein the controller logs the time stamp, dose rate, cumulative dose and volume dispensed and transmits the log over a vehicle data bus.**
6. **The cartridge of any preceding claim, wherein the housing, bladder and pillow collectively weigh ≤ 2 kg.**

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7. **An electrostatic-neutralising cartridge *comprising*:**
   - **a rigid housing (810) mountable inside an electronics bay;**
   - **a reservoir (812) containing an electrically conductive fluid having a surface resistivity ≤ 1×10^6 Ω $□^{-1}$;**
   - **an electrostatic field sensor (820) configured to measure field strength within the bay;**
   - **a humidity sensor (822);**
   - **a micro-nozzle (840) fluidly coupled to the reservoir; and**
   - **a controller (830) programmed to, when field strength exceeds a preset magnitude and humidity is below a preset magnitude, actuate the micro-nozzle to disperse the conductive fluid as an aerosol toward one or more circuit boards.**
8. **The cartridge of claim 7, wherein the conductive fluid is a water-free glycol ether formulation having a kinematic viscosity of 3–5 cP at 20 °C and producing droplets with a median aerodynamic diameter of 40 – 80 µm.**
9. **The cartridge of claim 7 or 8, wherein the preset magnitude is ±10 kV m^{-1} and the micro-nozzle is actuated in bursts of 50 – 150 ms.**

10. **The cartridge of any of claims 7-9, further comprising a fluid-level sensor (814) and a feedback channel (860) that transmits burst-duration, volume-dispensed and remaining-fluid data to the controller after each burst.**
11. **The cartridge of any of claims 7-10, wherein the controller communicates burst count and remaining fluid volume to a spacecraft telemetry bus at intervals no greater than 60 s.**
12. **The cartridge of any of claims 7-11, wherein the housing, reservoir and electronics together weigh < 450 g.**

Method claims

13. A method of providing adaptive radiation shielding, the method comprising:

- **monitoring ionising-radiation dose rate inside a spacecraft;**
- **inflating a flexible pillow adjacent to crew habitat surfaces when the dose rate exceeds a first threshold; and**
- **pumping a boron-enriched gel into the pillow until integrated dose is reduced below a second threshold.**

14. **A method of dissipating electrostatic charge in a sealed electronics compartment, the method comprising:**

- **sensing local electric-field strength;**
- **comparing the sensed strength to a preset magnitude; and**
- **upon the sensed strength exceeding the preset magnitude and relative humidity being below a preset limit, actuating a nozzle burst that imparts an electrically conductive aerosol to the compartment atmosphere.**

System-Level Independent Claim

15. An autonomous maintenance system for an aerospace or defense platform, *comprising*:

- (a) a plurality of adaptive maintenance cartridges, each cartridge including:
  - (i) at least one condition sensor configured to monitor a platform parameter;
  - (ii) a reservoir containing a consumable corrective medium; and
  - (iii) a locally controlled actuator configured to deliver the consumable into or onto a platform subsystem in response to signals from the condition sensor;
- (b) a vehicle data bus;
- (c) at least one edge controller operatively coupled to the vehicle data bus and to each adaptive maintenance cartridge, the edge controller being programmed to:
  - (i) receive data streams from the condition sensors;
  - (ii) execute a predictive-maintenance algorithm that identifies an anomaly or predicts an impending anomaly;
  - (iii) issue a command over the vehicle data bus that triggers the actuator of a selected cartridge to deploy the consumable corrective medium; and

- ○ (iv) receive a verification signal from the selected cartridge confirming that deployment occurred, and log the deployment with a time stamp and residual capacity of the selected cartridge.

Dependent System Claims

16. The system of claim 15, **wherein** the plurality of cartridges comprises at least:

- (a) a hydraulic-fluid purification cartridge configured to maintain NAS 1638 class ≤ 6 in a 5 000 psi hydraulic circuit;
- (b) a thermal-spike mitigation cartridge containing a phase-change slurry; and
- (c) a radiation-shielding gel cartridge containing ≥ 20 wt % boron carbide.

17. The system of claim 15 or 16, **wherein** the vehicle data bus is selected from MIL-STD-1553B, Ethernet-AVB, CAN-FD, or SpaceWire.

18. The system of any of claims 15-17, **wherein** each adaptive maintenance cartridge further comprises a capacitive or ultrasonic level sensor configured to measure a remaining quantity of the consumable corrective medium with ±10 % accuracy.

19. The system of any preceding system claim, **wherein** the predictive-maintenance algorithm executes a machine-learning model trained on at least one month of historical sensor data collected during flight or mission operation of the same platform type.

20. The system of any preceding system claim, **wherein** the edge controller is further configured to transmit the time-stamped deployment log and residual capacities to a ground-station server via a secure IP or CCSDS telemetry link no less frequently than every 60 seconds.

21. The system of any preceding system claim, **wherein** at least two cartridges are mounted redundantly in parallel flow paths such that a first cartridge can be serviced or replaced while a second cartridge remains active, thereby maintaining continuous protection.

22. The system of any preceding system claim, **wherein** the edge controller disables further deployment of the consumable corrective medium from a cartridge if the verification signal indicates a fault condition or if the residual capacity falls below a preset reserve threshold.

Method Claim

23. A method of autonomously maintaining a mission-critical platform, the method comprising:

- continuously acquiring sensor data from a plurality of adaptive maintenance cartridges mounted on the platform;

- predicting, with a predictive-maintenance algorithm executed on an edge controller, that a parameter of the platform will exceed an operational limit;
- selecting one of the adaptive maintenance cartridges;
- commanding an actuator of the selected cartridge to deploy a dose of a consumable corrective medium;
- receiving a verification signal from the selected cartridge confirming the dose was deployed; and
- logging, in non-volatile memory, (i) the parameter values that triggered the deployment, (ii) the time stamp of the deployment, and (iii) a remaining capacity of the selected cartridge.