The smart-cartridge hierarchy and μ-band control disclosed herein are equally applicable to non-therapeutic continuous-flow processes. Unless explicitly limited, all preceding claims, descriptions and figures shall be construed as applying mutatis mutandis to industrial fluids in place of a human subject.

Identical cartridge architecture applies to a chemical skid.

FIG 1 – Exploded Smart-Cartridge Hardware

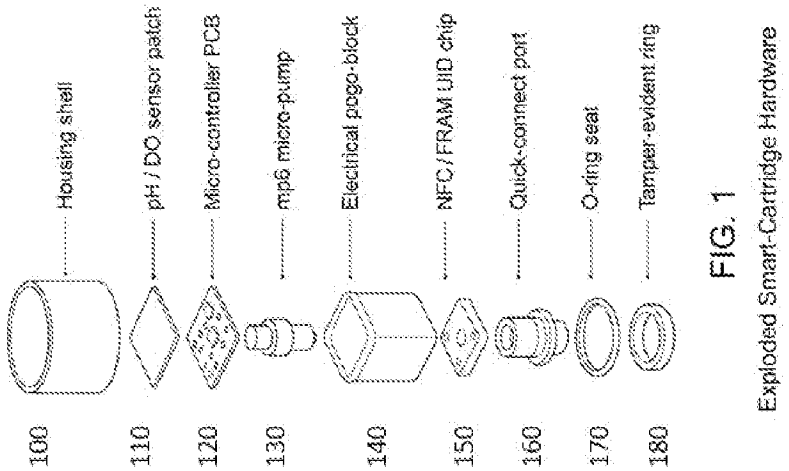


FIG 2 – Control-Loop Swim-Lane Sequence

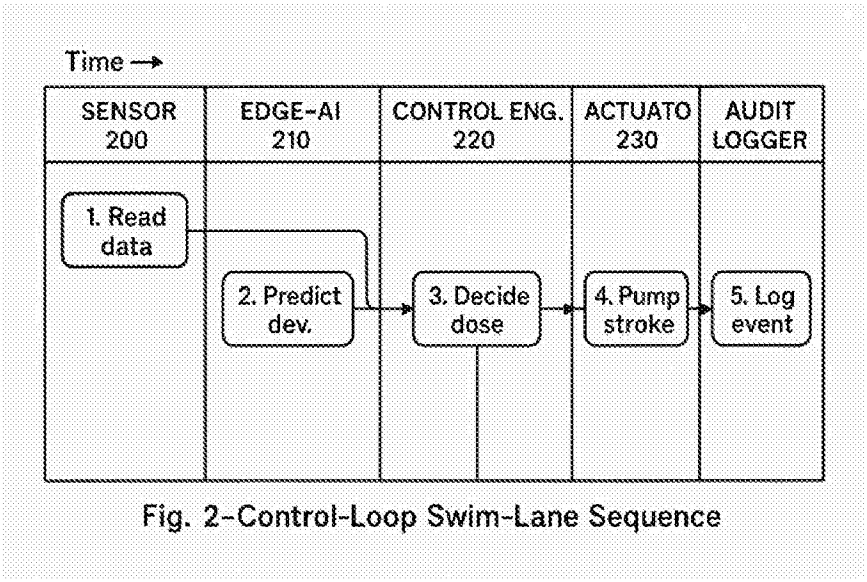


FIG 3 – Audit-Trail Hash Chain Flow

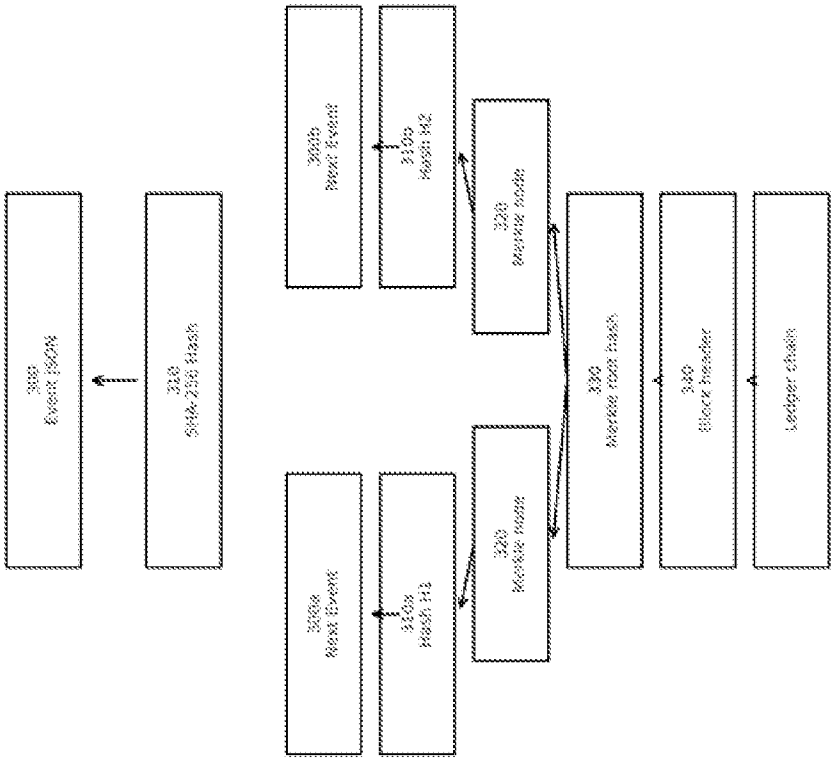


FIG 4 – Hot-Swap Cartridge Removal/Insertion Sequence

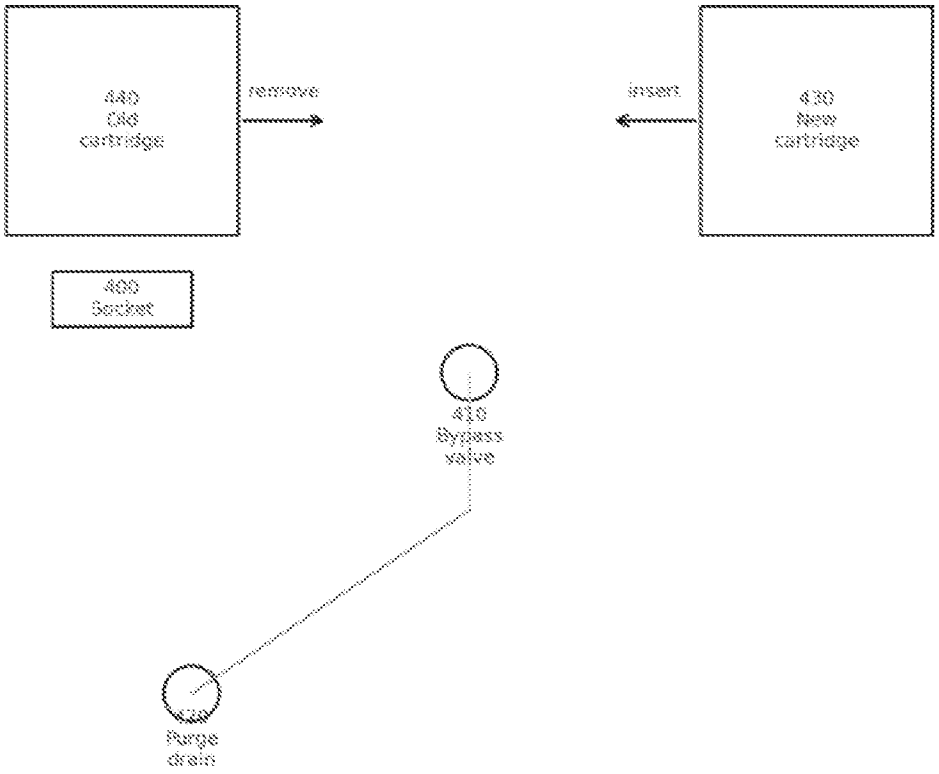


FIG 5 – Five-Slot Manifold / Kit Assembly

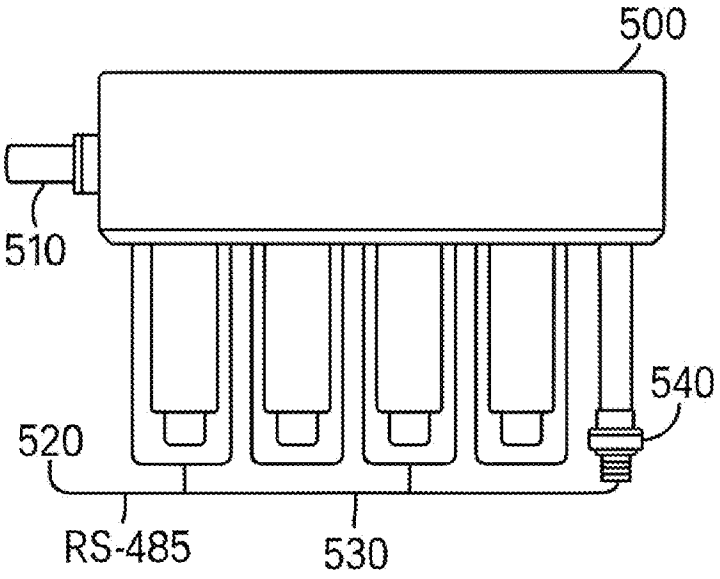


FIG 6 – Digital-Twin Model-Validation Flow

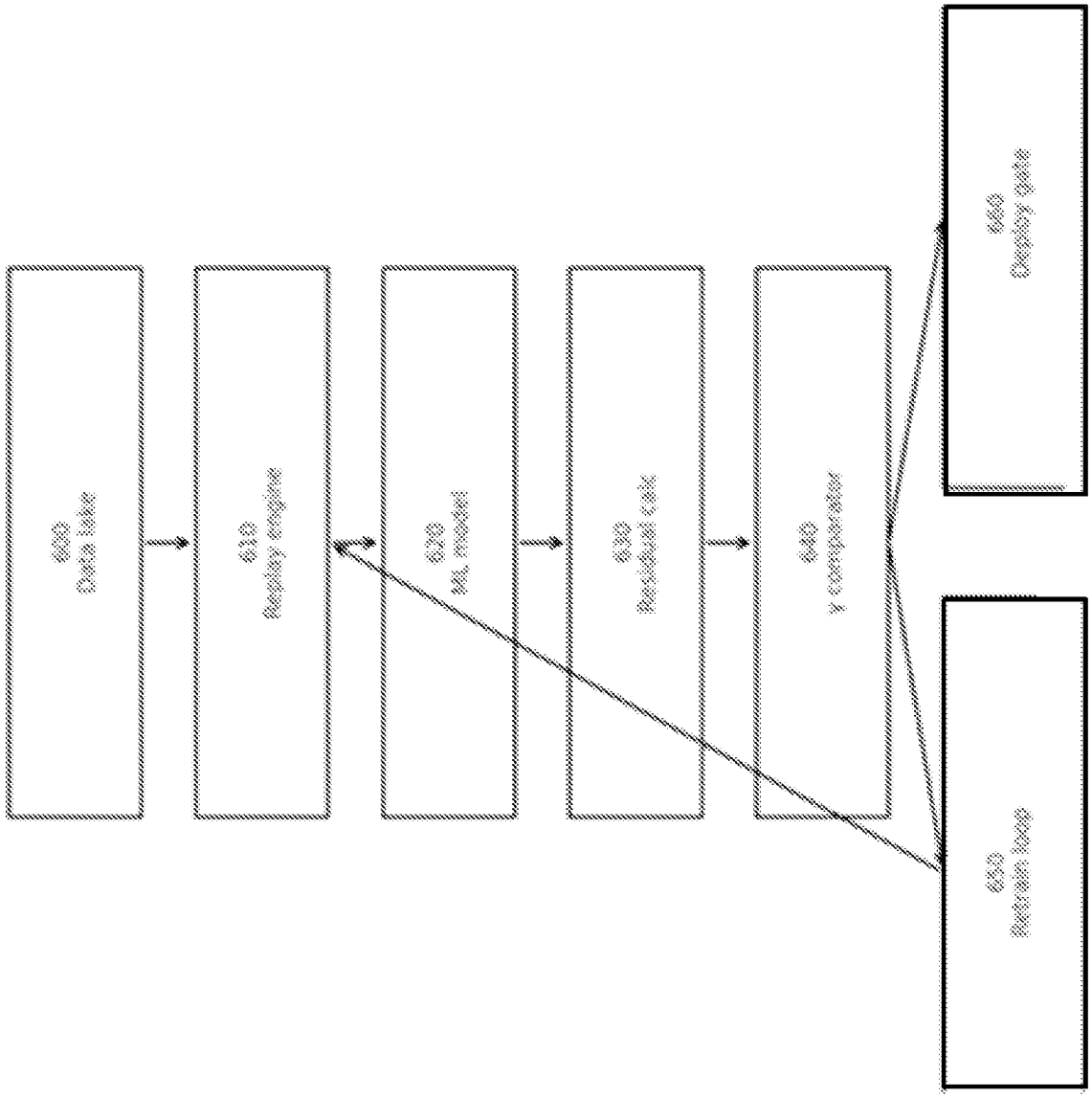


FIG 7 – Physical Tamper-Evidence Mechanism

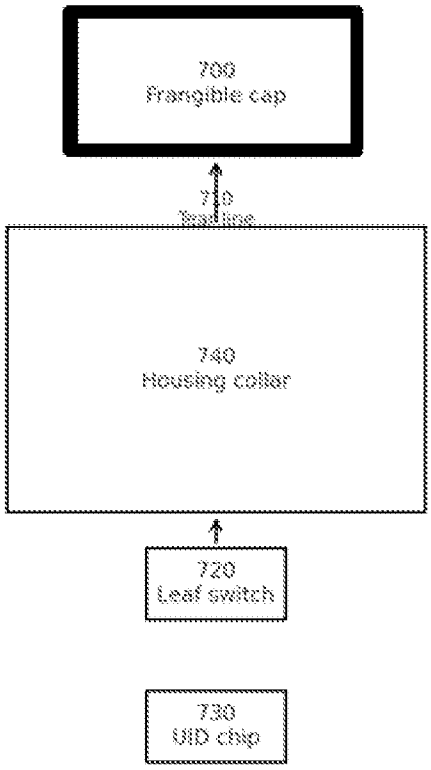


Fig 8: Chelator Counter-measure Reservoir & Pump-5 Hook-up

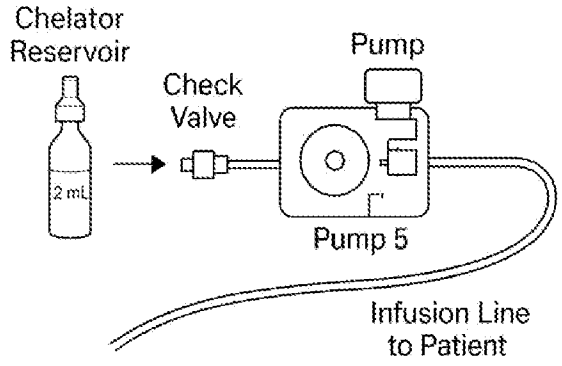
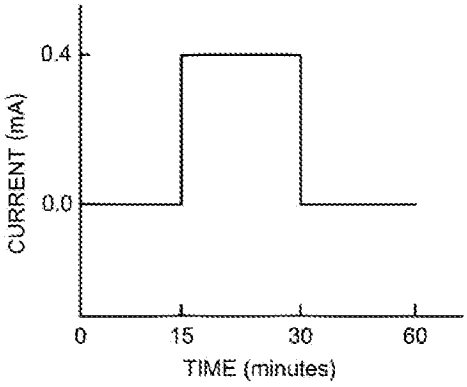


FIG-9 Iontophoresis Extraction Timing Diagram



IONTOPHORESIS EXTRACTION TIMING

FIG-10 Critical-Factor Sensor Daughterboard & Extra Pump Cassettes

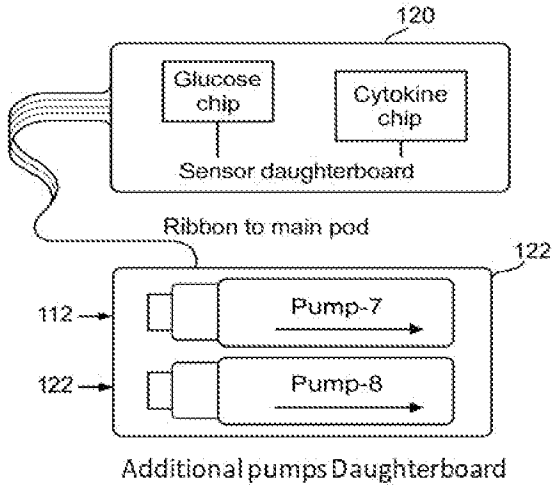


FIG-11 Pump-Bay Map (Slots 1-16)

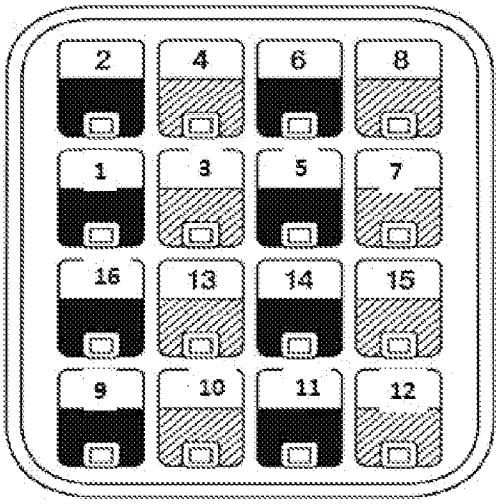


FIG. 11

FIG-12 Multi-Analyte Sensor Daughtercard

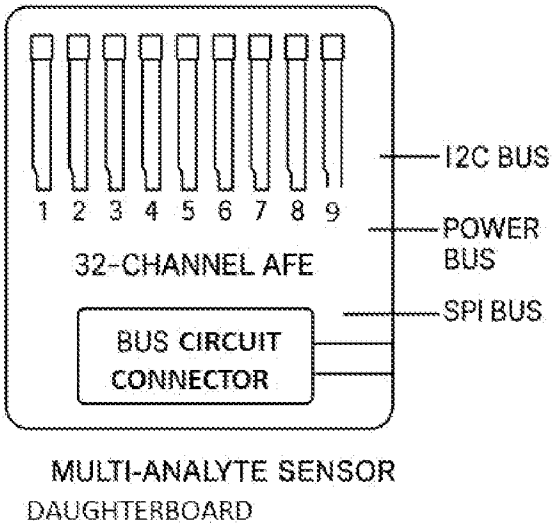


FIG-13 Flex-Pump Manifold (Slots 21-36)

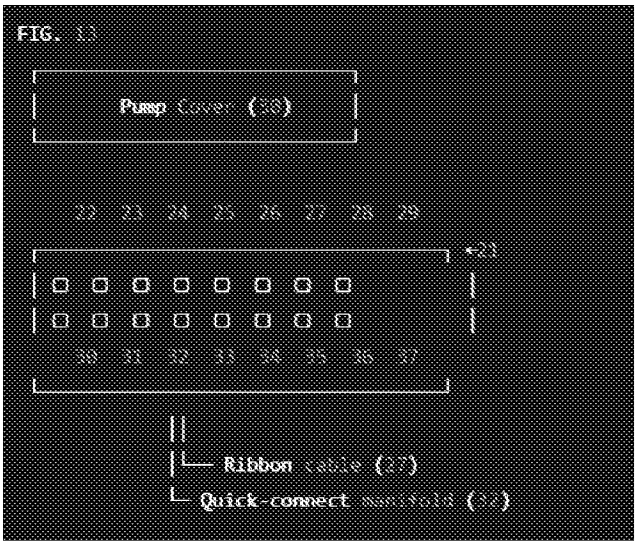


FIG-14 Multi-Infectious-Antigen Sensor Pad

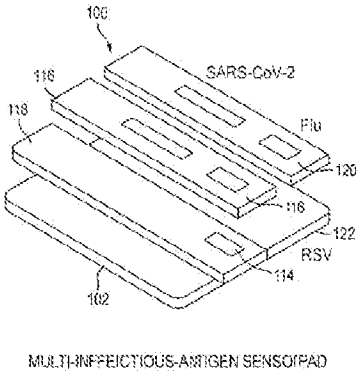


FIG. 14

FIG-15 Endotoxin & HMGB-1 Sorbent Cartridge in CRRT Loop

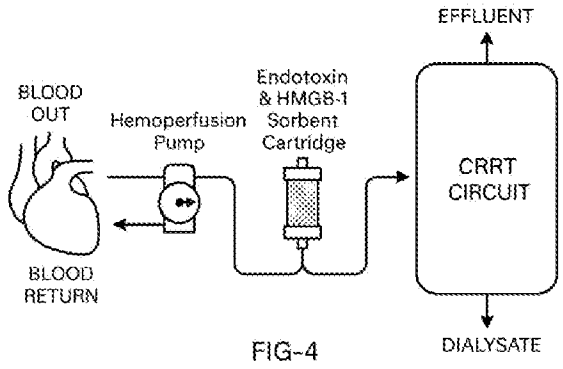
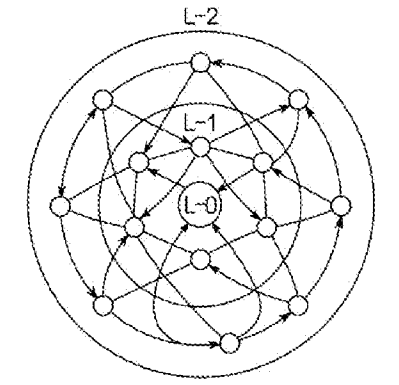


FIG-4

FIG-16 Hierarchy & Knock-Down Graph



HIERARCHY & KNOCK-DOWN GRAPH
FIG. 16

FIG-17 EEPROM Map for Smart-Cartridge Metadata (all offsets in bytes)

Offset	Length	Field
0x00	2	cart_id
0x02	1	class_code
0x03	4	concentration (float32)
0x07	4	dose_ceiling_mg_kg_day (float32)
0x0B	4	μ_band_array_pointer
0x0F	4	hard_limit_array_pointer
0x13	4	incompat_list_pointer 0x17 2 crc16

FIG-18 As shown in FIG-18, the controller injects a ±1 % probe pulse (λ_0) once every 20 minutes while the sensed variable remains inside the stored μ-LOW / μ-HIGH window. Each successful probe-response pair updates the corresponding Jacobian row via recursive least squares. When the 95 % confidence interval of that row drops below half the population standard deviation, the firmware halves λ and programmatically narrows the μ-band (dashed arrows), thereby reducing patient/process disturbance while preserving identifiability.

[0019] PART 11 MAPPING