PROVISIONAL PATENT APPLICATION

United States Patent and Trademark Office

TITLE OF THE INVENTION:

Consumer Battery Collection Module With Passive Thermal Containment, Multi-Modal Sensor Fusion, and Automated Lockout for a Dual-Compartment Retail Battery Node

INVENTORS:

Vedant Awasthi — Morganville, New Jersey, USA

Rehan Pagarkar — Morganville, New Jersey, USA

Akshit Gupta — Manalapan, New Jersey, USA

Aarush Shah — Morganville, New Jersey, USA

Aumrit Khanwani — Manalapan, New Jersey, USA

Classification: Provisional Utility Application

I. ABSTRACT

The PowerLoop Battery Node is a steel enclosure that combines a battery vending section with a battery collection section. These sections are divided by a fire-resistant barrier. The collection section is built around a sliding return drawer which contains a removable Collection Container. This container is pre-filled with expanded vermiculite, a granular, fire-migitating material that surrounds deposited batteries and slows heat transfer between them. A liquid suppressant reservoir and discharge are also built into the Collection Container when a fire hazard is detected and exceeds the capabilities of passive containment.

As part of the sensor suite, five sensors are used. A dust sensor is used to detect smoke emitted by batteries through thermal runaway. This is paired with dual temperature sensors (one probe at the container wall and one in the headspace above it). Through this setup, each PowerLoop node is better equipped to detect signs of thermal runaway, and approximate origins. Four load cells are placed under the drawer to provide fill level and can detect a swelling battery through slow mass increases measured between consumer deposits. These slow mass increases can often be detected before any external sign of failure. A humidity sensor corrects errors in optical smoke

sensor readings, as high humidity is a well-documented negative factor, causing the smoke sensor to misfire. The humidity sensor also monitors electrolyte vapors, which are released in the stage between excess thermal runaway and battery fire. Lastly, a drawer position sensor logs open and close events.

All five channels of the sensor suite feed into a microcontroller, which classifies the entire collection system as one of four risk states. The most serious of the four risk states notifies emergency services. Therefore, at least two channels must corroborate such an event to reduce false alarm rate. When this threshold is reached, the collection drawer locks, alarms activate, and the external monitoring service is promptly notified of the situation.

II. FIELD OF THE INVENTION

This disclosure regards a battery collection module. This module is part of a dual-compartment enclosure called the Battery Node (FIG. 1), which also includes a battery vending section. The collection is operated through a sliding drawer and removable fire-resistant container. A five channel sensor suite continuously sends data to an external controller that processes it for real-time hazard detection. When a hazard is detected, The Lock for Drawer (FIG. 4) blocks consumer access to the collection section.

III. BACKGROUND OF THE INVENTION

Consumer battery waste does not consist of just a single stream. It includes alkaline cells, which come in AA, AAA, C, D, and 9V sizes; lithium primary coin cells such as the CR series; NiMH rechargeable packs; and a growing volume of lithium-ion and lithium-polymer cells from phones, earbuds, laptops, and similar electronic devices. The issue is that these chemistries do not all fail in the same way, and a combined collection of them increases chances for failure of each.

Alkaline cells at end of life typically leak potassium hydroxide electrolyte if the outer casing has been breached. This is caustic, but not a fire risk alone and under normal conditions. Lithium-ion and lithium-polymer cells differ in this aspect. Separator breakdown causes an internal short circuit in the cells, which generates heat and accelerates the separator breakdown in a compounding effect; this is known as thermal runaway. Once it is self-sustaining, gas temperatures can exceed 700 °C. The byproducts of the reaction include hydrogen fluoride and volatile organic compounds, some which are toxic at low concentrations. Furthermore, this is not a slow process; a cell can go from early-stage venting to full propagation in minutes.

The existing retail collection uses open-top bins inside stores or public buildings. They fill up between service visits and rarely offer information about their contents and condition. There is no fill-level limit, no way to detect early-stage venting, and no fire-mitigating mechanism in case of an incident. The bin and the smoke alarm in the ceiling detect the issue at roughly the same time.

Prior art exists in the form of hazmat drums, temperature alarms fixed to collection containers, and kiosks that give coupons in exchange for alkaline cell recycling. None of these, individually or in combination, are able to address the entire issue: a removable, fire-resistant collection vessel with integrated passive and active fire mitigation; a complete sensor suite to detect multiple phenomena and analyze of these signals for hazard classification; and retail vending housed in the same enclosure with thermal separation between the two compartments.

IV. SUMMARY OF THE INVENTION

The battery collection module is comprised of the following parts:

- **(a)** A steel outer enclosure (Main Box, Item 1, FIG. 1), consisting of a battery collection section and a battery vending section, separated by a fire-separated barrier
- **(b)** Two consumer-facing Return Doors (Item 2, FIG. 1) mounted on the collection section, each providing access to a sliding Return Drawer behind it;
- **(c)** A Return Drawer (Item 3, FIG. 1, FIG. 2, FIG. 4) that slides horizontally within the collection section to receive mixed end-of-life consumer batteries deposited through the Return Doors, and which houses a removable Collection Container;
- **(d)** A removable Collection Container (FIG. 3), with walls formed with fire-resistant material, is located within the Return Drawer. A Tank for Fire Mitigating Medium is located inside of the Collection Container, and holds granular mineral material that settles around the deposited batteries. This both physically separates them and slows heat transfer between adjacent cells. A Container for Fire Resistance Liquid stores liquid that is dischargeable through the Nozzle for Fire Mitigation.
- **(e)** A 5 sensor suite made of the following: (i) two temperature sensors monitoring thermal rise within the collection space; (ii) one dust sensor detecting smoke and other thick fumes formed by thermal runaway; (iii) four Load Cells used for Weight Collection at the corners of the Return Drawer (FIG. 4). This provides fill estimation and swell detection. (iv) a humidity sensor eliminates false alarms by differentiating thermal events from normal environmental variation; (v) a sensor for drawer position regulates access to the Return Drawer
- **(f)** A Lock for Drawer (FIG. 4) physically locks the drawer upon hazard detection. This will remain locked until manually unlocked by authorized personnel
- **(g)** An embedded microcontroller that fuses outputs from all sensor channels to classify the system into one of four discrete risk states and actuates the Lock for Drawer and local and remote alerts proportional to the determined risk level.

The collection and sales sections are separated by a fire-resistant barrier (FIG. 2) to prevent thermal propagation from the collection section to the retail battery inventory in the Sales Compartment.

V. BRIEF DESCRIPTION OF THE DRAWINGS

Four drawings are submitted with this application.

FIG. 1 — (Scale 1:20 inches.) Isometric view of the Battery Node. Steel outer enclosure (Item 1), two blue laminate Return Doors (Item 2), Return Drawer (Item 3), Vending Assembly (Item 4), consumer keypad (Item 5).

FIG. 2 — (Scale 1:34 inches.) Section view A-A showing the internal layout: Dead Battery Return Drawer, Dead Battery Storage region, Sales Compartment, Order Keypad, Battery Collection Drawer region, Fire Mitigating Medium Nozzle, and fire-resistant barrier.

FIG. 3 — (Scale 1:10 inches.) Collection Container views showing Fire Resistant Barrier walls, Container for Fire Resistance Liquid, Tank for Fire Mitigating Medium, Nozzle for Fire Mitigation.

FIG. 4 — (Scale 1:10 inches.) Return Drawer assembly in four views. Load Cells for Weight Collection at each corner, Lock for Drawer mechanism labeled in front elevation.

VI. DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

What follows is a detailed description intended to enable a person skilled in mechatronics, thermal management, or battery safety to build and operate the disclosed system. Numerical thresholds and material specifications throughout are illustrative and non-limiting.

Overall Architecture (FIG. 1 and FIG. 2)

Looking at FIG. 1, the Battery Node is a steel box — the Main Box, Item 1 — with two consumer-facing zones on its front face. Above is the vending section, the Vending Assembly (Item 4) operated through the keypad (Item 5). Below that are two Return Doors (Item 2) in blue matte laminate. Those doors are the only way a consumer interacts with the collection section. The Return Drawer (Item 3) sits directly behind them.

The section view in FIG. 2 shows how the two compartments relate internally. The Dead Battery Return Drawer is in the upper portion of the collection side, with Dead Battery Storage below it. A steel bulkhead with intumescent insulation — targeting 30 minutes per ASTM E119 — separates the collection section from the Sales Compartment above. The Fire Mitigating Medium Nozzle visible in this view is the discharge interface of the Collection Container, described further under FIG. 3 below.

Return Drawer and Collection Container (FIG. 3 and FIG. 4)

The Return Drawer (FIG. 4) is pulled only by service personnel during a container swap. Consumers never access it. The drawer is rated for a fully loaded container — approximately 15 kilograms at capacity — and rests on four load cells at its corners.

The Collection Container (FIG. 3) is the core passive safety element of the system. It is replaced whole at each service visit, so technicians do not handle individual deposited batteries. The outer walls are the Fire Resistant Barrier, rated to hold integrity during a thermal incident inside. Inside, the Tank for Fire Mitigating Medium is pre-loaded with expanded vermiculite before deployment. The choice of vermiculite comes down to two properties: low thermal conductivity and reasonably high heat capacity. It settles around deposited cells, keeps them from making direct contact, and slows inter-cell heat transfer if one cell starts to heat up. The Container for Fire Resistance Liquid holds a liquid suppressant that discharges through the Nozzle for Fire Mitigation either passively via a fusible thermal element or on a direct command from the controller.

Multi-Modal Sensor Suite

The redundancy argument for using five sensors rather than one or two is straightforward: a single sensor that misfires, drifts, or is placed in a suboptimal location can create either missed detections or false lockouts. Neither is acceptable in a deployed retail system. By requiring agreement between channels, both failure modes become less likely.

The smoke and gas sensors are the most sensitive early warning channel in the suite. An optical or photoelectric smoke sensor positioned in the collection section headspace detects aerosol particles from early-stage battery venting. In a developing lithium-ion thermal event, this signal typically appears before any temperature change registers on a probe. A separate gas sensor covers the molecular side: volatile organic compounds, hydrogen, and carbon monoxide. Battery off-gassing has both a particulate component and a chemical component, and the two sensors are needed to capture both. Both are calibrated against a rolling baseline $G0$ after each service event rather than against fixed absolute thresholds. The reason for this is that retail environments vary. A grocery store has a different ambient air chemistry than a hardware store, and a threshold set for one would be poorly matched to the other.

Temperature is monitored at two locations: one probe in contact with the outer wall of the Collection Container, and one in the airspace above it. A single temperature probe tells you that the temperature somewhere is elevated. Two probes at different heights, monitored together, tell you whether heat is moving upward by convection from a venting cell in the headspace or outward by conduction from inside the battery storage region. Those are different events and they can call for different responses, so the distinction matters. Both absolute temperature $T(t)$ and rate-of-rise dT/dt are tracked per probe on a rolling window.

The gravimetric assembly is four strain-gauge load cells at the corners of the drawer base (FIG. 4). Total mass $M(t) = w1 + w2 + w3 + w4$ gives fill level. Deposit events appear as step increases in $M(t)$. Between deposits, the controller watches dM/dt. A slow positive drift in total mass with no deposit event is the signature of a cell expanding internally from gas pressure buildup — which typically precedes any other detectable signal from that cell. The normalized imbalance ratio $R(t) = \max(wi) / \min(wi)$ adds a secondary indicator by catching asymmetric load shifts across the four corners, consistent with physical deformation of a specific cell inside the container.

Two of the five channels are largely about making the other three more reliable. A humidity sensor addresses a known weakness of optical smoke sensors: at high humidity, water vapor scatters light in a way that looks like combustion aerosol, producing false positives. The controller uses $H(t)$ to apply a correction to smoke sensor readings before they are used in risk classification. A humidity drop inside a sealed collection section can also itself indicate off-gassing, since dry electrolyte vapor displaces ambient moisture. The drawer position sensor prevents maintenance from generating false alarms — when a technician opens the drawer for a container swap, the resulting shifts in mass and airflow would otherwise look like anomalies to the controller. If the drawer opens without a logged service event, that access is flagged and transmitted to the remote service as an unauthorized entry.

Sensor Fusion and Risk State Machine

After each container swap, the controller runs a calibration pass: all five channels are sampled to compute a baseline mean and standard deviation for T0, G0, M0, W0, and H0. Detection thresholds are set as multiples of those standard deviations, with hard absolute lower limits applied so that an unusually calm calibration environment cannot result in thresholds that are too low to be safe.

The system occupies one of four states at all times:

> **S0 - NORMAL:** All channels within bounds. Return Doors accessible. Periodic telemetry sent.
>
> **S1 - SERVICE NEEDED:** M(t) has hit the fill threshold. Remote service request sent. A configurable buffer of additional deposits is permitted before a hard lockout is imposed via the Lock for Drawer.
>
> **S2 - CAUTION:** At least one sustained early-warning condition is present: smoke or gas above 3 standard deviations from baseline for 30+ seconds; temperature rate-of-rise above 0.5 degrees C/min for 2+ minutes; swelling score S(t) above threshold; or a humidity drop inconsistent with ambient conditions. Lock for Drawer engages immediately. Local alerts on. Remote CAUTION packet with full sensor snapshot sent.
>
> **S3 - CRITICAL:** Multiple channels simultaneously showing serious anomalies — temperature above T_critical (75 to 90 degrees C illustrative range) or rate-of-rise above 2 degrees C/min for 1+ minute; smoke or gas above 6 standard deviations for 15+ seconds; and corroboration from at least one additional channel. Maximum alarm. Full CRITICAL packet transmitted. Service access is restricted until temperatures normalize.

The two-channel corroboration requirement for CRITICAL exists because retail environments produce noise that a single-sensor threshold cannot reliably distinguish from a genuine event. Temperature spikes near HVAC vents. Cooking odors migrate from adjacent store tenants. A system that fires a full lockout on any one elevated reading would be removed from service quickly. Corroboration is what makes deployment practical.

Remote Monitoring and Fleet Operations

Each node transmits periodic status packets over Wi-Fi or LTE-M: current risk state, fill percentage, all sensor values, timestamp. State transitions trigger immediate event packets. The fleet dashboard lets operators sort by fill level or hazard state, review sensor history per node, and pull compliance records. Calibration logs, container swap records, and lockout history are stored in non-volatile memory and uploaded each connection cycle.

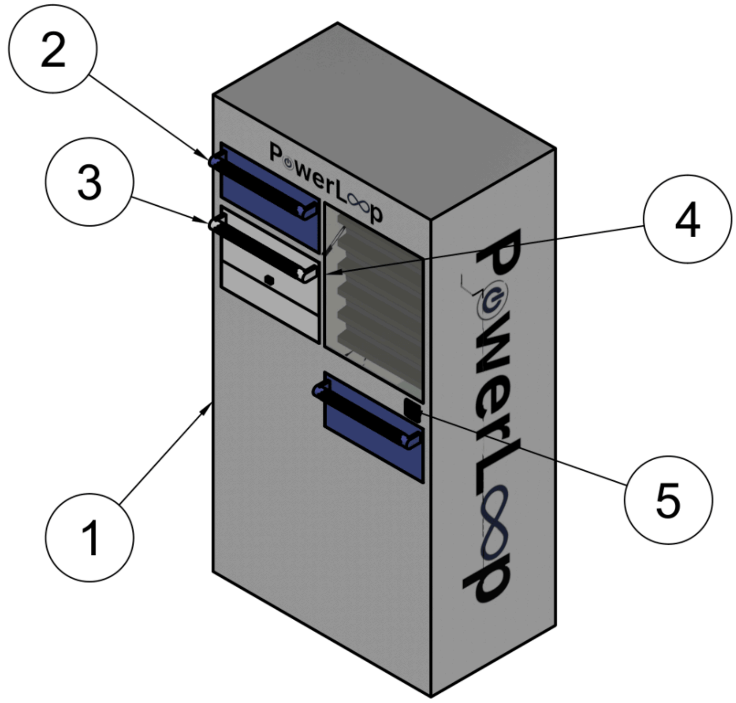

FIG 1:
(SCALE 1:20 INCHES.) ISOMETRIC VIEW OF THE BATTERY NODE. STEEL OUTER ENCLOSURE (ITEM 1), TWO BLUE LAMINATE RETURN DOORS (ITEM 2), RETURN DRAWER (ITEM 3), VENDING ASSEMBLY (ITEM 4), CONSUMER KEYPAD (ITEM 5).

PARTS LIST			
ITEM	QTY	PART NAME	MATERIAL
1	1	MAIN BOX V12	STEEL
2	2	RETURN DOOR V12	LAMINATE, BLUE, MATTE
3	1	RETURN DRAWER V16	----
4	1	VENDING ASSEMBLY V6	----
5	1	KEYPAD V1	STEEL

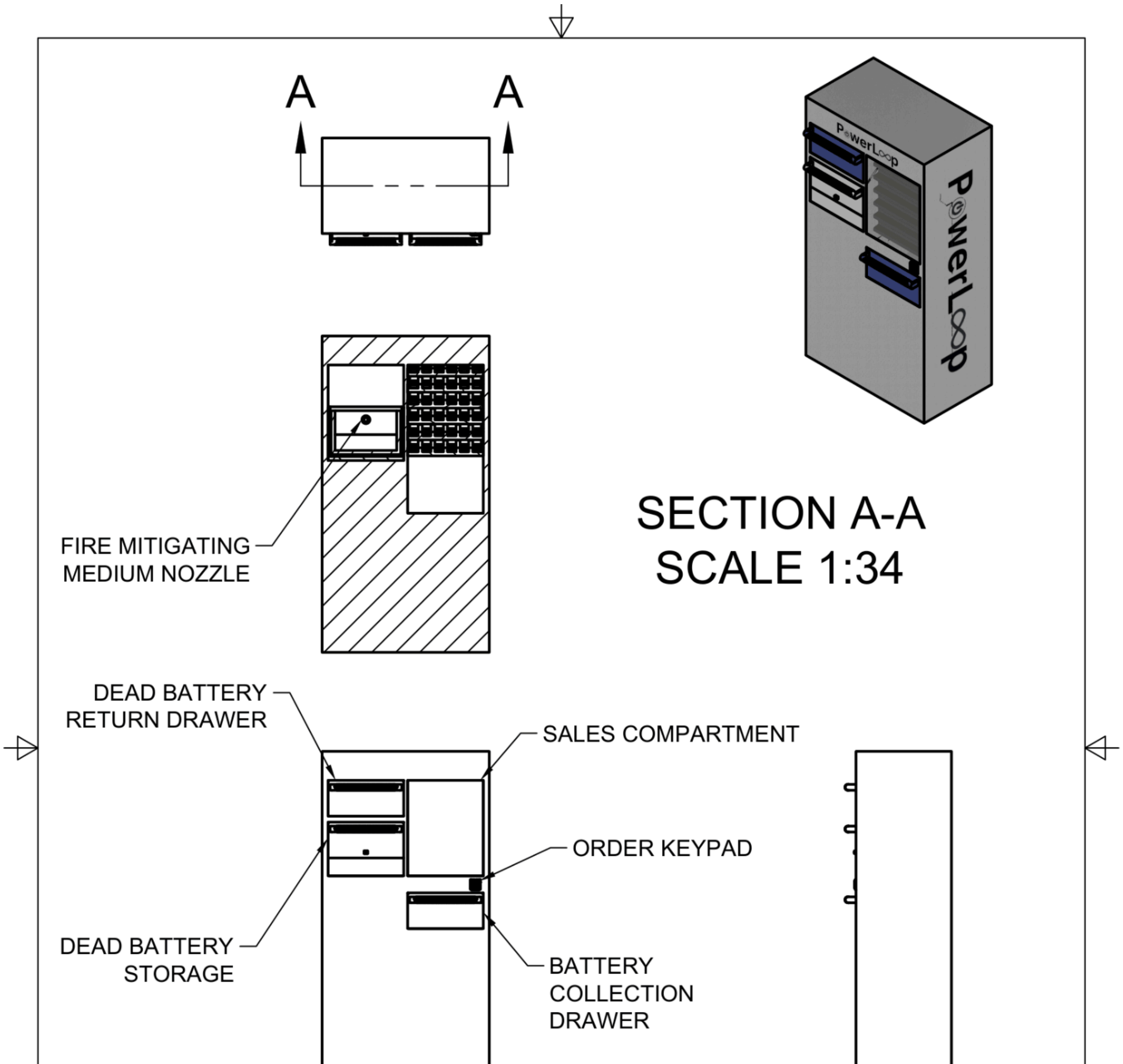

FIG 2:
(SCALE 1:34 INCHES.) SECTION VIEW A-A SHOWING THE INTERNAL LAYOUT: DEAD BATTERY RETURN DRAWER, DEAD BATTERY STORAGE REGION, SALES COMPARTMENT, ORDER KEYPAD, BATTERY COLLECTION DRAWER REGION, FIRE MITIGATING MEDIUM NOZZLE, AND FIRE-RESISTANT BARRIER.

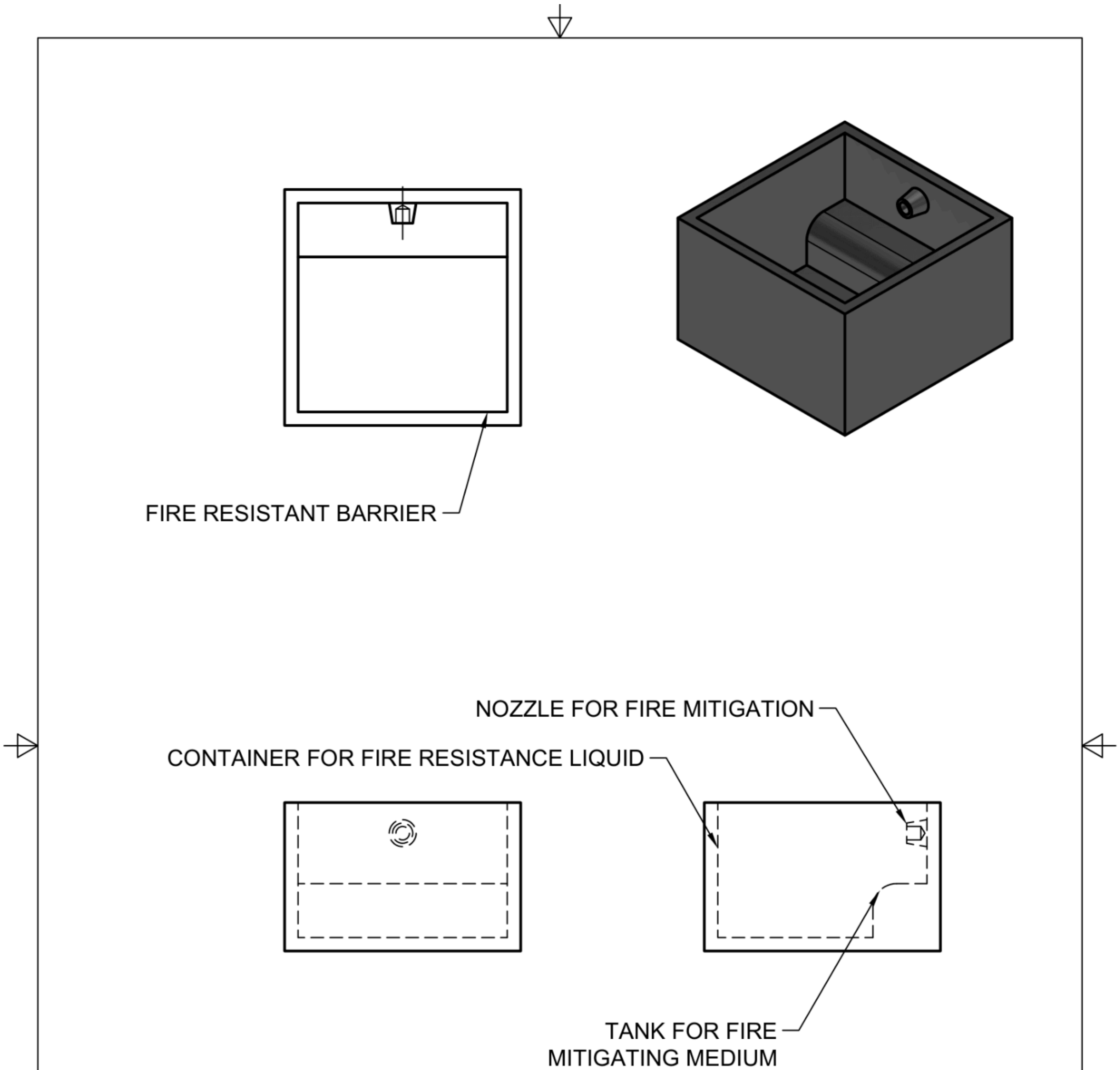

FIG 3:
(SCALE 1:10 INCHES.) COLLECTION CONTAINER VIEWS SHOWING FIRE RESISTANT BARRIER WALLS, CONTAINER FOR FIRE RESISTANCE LIQUID, TANK FOR FIRE MITIGATING MEDIUM, NOZZLE FOR FIRE MITIGATION.

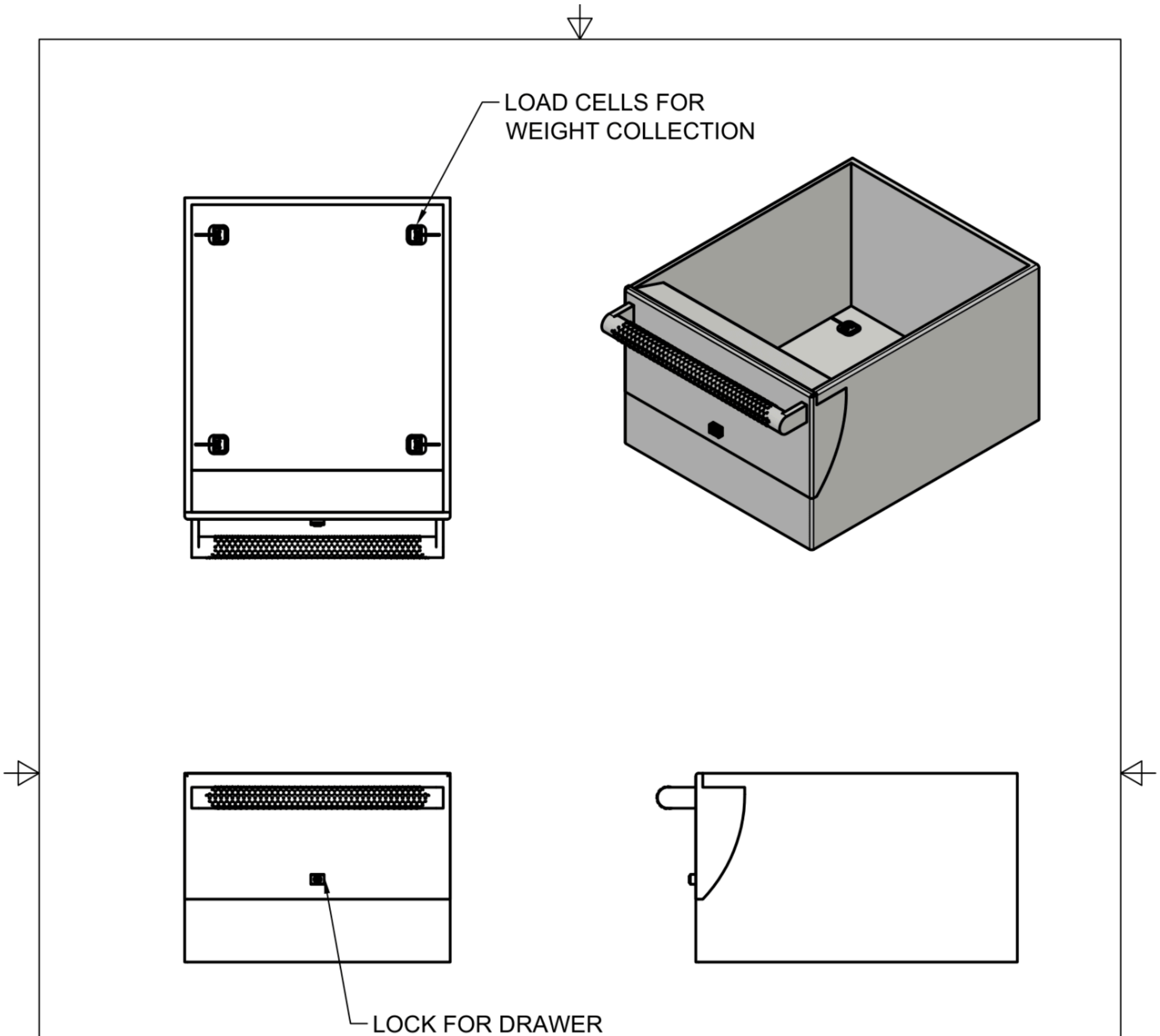

FIG 4:
(SCALE 1:10 INCHES.) RETURN DRAWER ASSEMBLY IN FOUR VIEWS. LOAD CELLS FOR WEIGHT COLLECTION AT EACH CORNER, LOCK FOR DRAWER MECHANISM LABELED IN FRONT ELEVATION.

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P.O. Box 1450
Alexandria, VA 22313-1450
www.uspto.gov

ELECTRONIC PAYMENT RECEIPT

APPLICATION #	RECEIPT DATE / TIME	ATTORNEY DOCKET #
63/988,274	02/22/2026 7:54:05 PM ET	-

Title of Invention

Consumer Battery Collection Module With Passive Thermal Containment, Multi-Modal Sensor Suite, and Automated Lockout for a Dual-Compartment Retail Battery Node