

RESEARCH ARTICLE

Event-Buffered Helium Circularity Assessment for Cryogenic Spectroscopy and Scanning Probe Microscopy

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Abstract

Low-temperature analytical instruments require helium management strategies that preserve both cryogen supply and measurement integrity. Recovery systems are commonly summarized by annual retention, yet an annual percentage cannot show whether a laboratory can absorb refill surges, maintain enough reliquefaction headroom, control impurity-driven maintenance, and keep vibration-sensitive spectra and images stable. This paper asks whether a compact helium recovery installation can be considered analytically ready when its performance is judged through an event-buffered continuity envelope rather than by recovery rate alone. The dataset is organized as five operating windows: annual liquid-helium circulation, daily cryogen demand, refill-event gas capture, impurity and maintenance behavior, and instrument-side stability. The evaluated record contains 1,825 L annual liquid-helium use, 98.5 L annual loss, a 5 L per day daily load, more than 10 L per day liquefaction capacity, 4,677 L gas storage at 125 psi, a typical refill input below 2,100 L gas, more than 99.5% helium purity, 0.4% hydrogen, pressure fluctuation near plus/minus 0.01 psi, and retained scanning probe spectra and images. The event-buffered assessment shows that the system is ready for the documented 5 L per day analytical load because annual retention is 94.60%, steady liquefaction capacity exceeds demand by more than a factor of two, storage capacity exceeds a typical refill input by about 2.23-fold, and measurement evidence remains compatible with low-vibration spectroscopy. The same analysis identifies three boundaries: operation at about 10 L per day becomes a steady-capacity limit, one-half storage leaves only a narrow refill reserve, and hydrogen-dominated impurities require maintenance planning beyond routine purifier recovery. The conclusion is therefore specific to the operating envelope: the system is analytically ready for the documented single-instrument operating envelope, but scale-up requires added liquefaction capacity, storage reserve, or a different refill schedule.

Keywords: helium circularity; event-buffered assessment; cryogenic spectroscopy; scanning probe microscopy; analytical instrumentation; helium recovery; low-vibration measurement

1. Introduction

Liquid helium occupies a distinctive position in analytical science because it is both a resource and part of the measurement environment. Its low boiling point and chemical inertness make it essential when an analytical signal depends on thermal stability, superconducting operation, or suppressed mechanical disturbance. Early helium technology established the practical basis for liquefaction, storage, purification, and low-temperature use, while modern analytical laboratories rely on helium for superconducting magnets, far-infrared spectroscopy, cryogenic detectors, low-temperature microscopy, and

vacuum diagnostics [1–4]. The analytical problem is therefore not limited to the amount of helium consumed. A cryogenic instrument produces reliable data only when the surrounding helium infrastructure supports a stable sample temperature, a quiet mechanical environment, and uninterrupted operating time.

The connection between helium infrastructure and analytical quality is especially clear in scanning tunneling microscopy and scanning probe spectroscopy. Atomic-scale tunneling measurements depend on stable tip-sample separation, low electronic noise, stable pressure, and reduced mechanical disturbance [5–7]. Inelastic electron tunneling spectroscopy extends this sensitivity by using tunneling electrons to

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probe vibrational signatures of adsorbed molecules, making spectral quality vulnerable to vibration, thermal drift, and unstable tunneling-current conditions [8,9]. A helium recovery loop may therefore conserve a valuable cryogen while still failing analytically if it transmits mechanical noise, produces pressure pulses, or imposes maintenance interruptions during spectroscopy.

Helium is also embedded in more conventional chemical analysis. Gas chromatography and helium-discharge detection use helium because of its transport behavior, inertness, and plasma properties, while helium leak detection supports vacuum integrity in cryogenic and analytical platforms [10–13]. These roles show why helium cannot be treated only as a facility utility. It functions as a carrier, a coolant, a diagnostic gas, and an enabling component of instrument performance. For laboratories that combine cryogenic surface analysis, spectroscopy, microscopy, magnetometry, or quantum-materials characterization, helium management is part of analytical quality assurance.

Resource vulnerability gives this instrumentation problem a broader urgency. Helium is a finite terrestrial resource; its economically recoverable supply is tied to geological accumulation, natural gas processing, geopolitical concentration, and specialized transportation infrastructure. Recent resource and supply-risk studies describe helium as a critical material with nontrivial geopolitical exposure, and official mineral summaries continue to track its production and reserve constraints [14–17]. A laboratory that depends on repeated liquid-helium deliveries is therefore exposed to cost volatility, shipment interruption, and prioritization of other helium users. Recovery and reliquefaction are not only sustainability measures; they are operational continuity strategies for analytical science.

Several technical routes have been developed to reduce helium vulnerability. Facility-scale recovery systems collect boil-off from multiple cryostats through gasbags, compressors, storage tanks, purification trains, and reliquefiers [18–20]. Process-level helium recovery has also been considered in relation to natural gas separation and membrane-based recovery technologies [21,22]. These approaches are important, but they are usually optimized for institutional throughput, not for a single low-vibration analytical instrument. A centralized recovery percentage can be impressive while leaving unanswered questions about refill-event buffering, local pressure stability, service-room footprint, and whether the recovery pathway is compatible with spectroscopic data quality.

Closed-cycle cryogenic technologies provide another route by reducing or eliminating repeated liquid-helium transfer. Pulse-tube coolers and cryogen-free low-temperature instruments have enabled new scanning probe and cryogenic measurement architectures [23–28]. These designs demonstrate that cryogen-free or remote-liquefaction concepts can support demanding low-temperature measurements, but the vibration problem remains central. Cryocooler measurements show that pulse-tube and Gifford–McMahon systems can introduce cold-head vibration, high-frequency mechanical noise, and temperature oscillation, requiring careful decoupling and instrument-specific validation [29–32]. In other words, eliminating helium transfer does not automatically eliminate the analytical-readiness problem; it relocates the problem into vibration and thermal management.

Compact helium recovery for a single instrument or a small cluster of instruments occupies the middle ground between centralized recovery and fully cryogen-free replacement. The practical appeal is clear: the laboratory can retain the bath-cryostat or low-vibration instrument architecture while reducing external helium demand. A compact system can also place the compressor, purifier, and liquefier away from the microscope, preserving vibration isolation more effectively than direct cryocooler integration. This approach has been demonstrated for vibration-sensitive recovery around a commercial low-temperature scanning probe microscope, with operation designed to capture normal boil-off and refill-related gas while avoiding gasbag contamination and oil-lubricated compression [33]. Similar logic appears in other

sensitive cryogenic fields, including low-vibration helium recycling for magnetoencephalography [34].

The remaining challenge is interpretive. Reporting annual recovery alone does not tell a laboratory whether a compact recovery system is ready for analytical use. Annual retention does not identify the demand at which liquefaction becomes limiting, the storage fraction at which refill capture fails, the impurity class that controls downtime, or the measurement evidence needed to show that spectra and images remain valid. The central research question of this paper is therefore specific: can a compact helium recovery installation be judged analytically ready by an event-buffered continuity envelope that requires annual retention, daily capacity, refill-buffer capacity, impurity-aware maintenance, pressure stability, and retained measurement quality to pass together?

This manuscript answers that question using a reorganized dataset derived from the documented operating record of a compact helium recovery system coupled to a commercial low-temperature scanning probe microscope [33]. The approach differs from a recovery-percentage report by treating the operating record as a set of time-windowed events: annual circulation, daily demand, refill surge, impurity accumulation, maintenance downtime, and measurement verification. The method is intentionally transparent and table-driven so that spectroscopy, microscopy, magnetometry, and cryogenic facility laboratories can adapt it without building a full dynamic process model.

2. Event-Window Dataset and Assessment Method

The dataset was constructed from the documented operating values of the compact recovery installation rather than from simulated hardware. Bounded values were preserved as bounded values: liquefaction capacity was interpreted as more than 10 L per day, average daily liquid-helium loss as less than 0.27 L per day, typical refill-induced gas input as less than 2,100 L, helium purity as more than 99.5%, and system footprint as less than 4 square meters. This prevents false precision and keeps the analysis close to the operating record. The numerical values are not treated as isolated measurements; they are assigned to operating windows that correspond to how an analytical laboratory experiences helium use.

Table 1: Event-window operating dataset.

Operating window	Documented values	Analytical interpretation
Annual circulation	1,825 L liquid-helium use; 98.5 L liquid-helium loss	Year-scale helium circularity and external supply dependence
Daily operation	5 L per day demand; less than 0.27 L per day loss; more than 10 L per day liquefaction capacity	Baseline continuity of the scanning probe measurement day
Refill event	4,677 L gas storage at 125 psi, equivalent to 6.24 L liquid helium; less than 2,100 L typical refill-induced gas input; approximately 3 day refill interval	Short-duration surge capture before reliquefaction can return gas to liquid inventory
Purity and maintenance	More than 99.5% helium; 0.4% hydrogen; less than 0.1% combined water, nitrogen, oxygen, carbon dioxide, and trace organics; purifier blockage two to three times per week; cold-head recovery below 6 h to 80 K and nearly 1 day to room temperature	Impurity class and downtime consequences for experiment scheduling
Instrument-side stability	Approximately plus/minus 0.01 psi inline pressure fluctuation; comparable tunneling-current spectra; retained atomic-resolution imaging; retained CO vibrational spectroscopy	Measurement-integrity evidence for low-vibration analytical compatibility

The event-window dataset shows that the study is not based on a single conservation number. Annual, daily, refill, purity, maintenance, and measurement descriptors are all needed because each one can fail independently. A laboratory could retain most helium over a year but still vent gas during refilling; it could capture refill gas but lack enough

reliquefaction capacity for a higher daily load; it could satisfy both resource metrics while still degrading tunneling spectra. Treating the entries as operating windows therefore turns a static inventory into a continuity test.

The event-buffered continuity assessment was then applied in four stages. The first stage evaluated the annual and daily balance to determine whether the laboratory retains most of its liquid-helium throughput. The second stage compared steady liquefaction capacity with daily demand and tested demand increases from 5 to 12 L per day. The third stage compared available gas storage with a typical refill input and then reduced storage to one-quarter, one-half, three-quarters, and full capacity. The fourth stage interpreted impurity composition, maintenance time, pressure stability, and measurement evidence as analytical-quality gates rather than as secondary operating notes. The system is considered ready only when the resource gates and the measurement gate support the same decision.

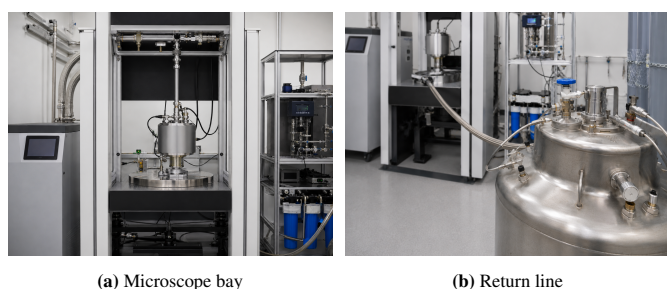


Figure 1: Instrument boundary.

The instrument-boundary view places the recovery problem at the cryostat interface rather than in the service room alone. The microscope-facing bay and the return line define the location where helium circularity must remain mechanically quiet and pressure stable. This is the reason the paper evaluates pressure fluctuation and scanning probe evidence together with helium recovery; the recovered gas is only useful if the instrument continues to behave as a high-stability analytical platform.

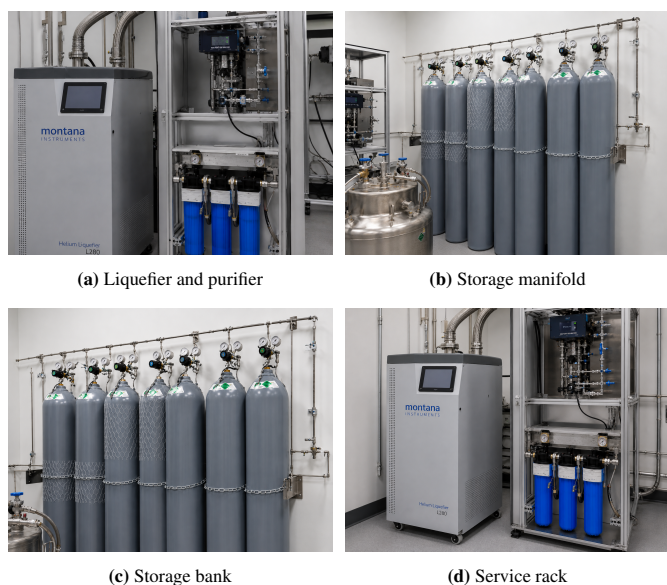


Figure 2: Service-side recovery path.

The service-side arrangement explains why the method separates steady and transient behavior. The liquefier and purifier represent the continuous return pathway, while the storage bank represents the buffer that absorbs refill gas before it can be reliquefied. The visual

separation between instrument-facing and service-facing equipment also supports the analytical rationale: compact recovery is valuable when service hardware can be kept outside the most vibration-sensitive measurement zone.

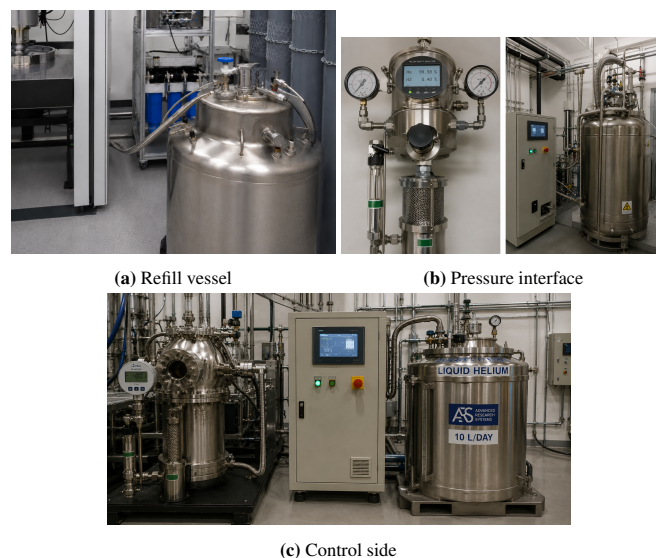


Figure 3: Refill-control interfaces.

The refill-control interfaces connect three different operating constraints. The refill vessel is the source of transient helium input, the gauge and vessel interface is the point where pressure behavior becomes visible, and the control-side hardware is the path through which gas is returned to liquid inventory. Interpreting the system through these linked interfaces prevents the analysis from treating refill capture, pressure stability, and liquefier operation as unrelated observations.

3. Results and Discussion

The annual material balance indicates high circularity but does not by itself prove analytical readiness. Out of 1,825 L of annual liquid-helium use, 98.5 L is reported as loss, leaving 1,726.5 L retained inside the laboratory recovery cycle. This corresponds to 94.60% annual retention and an external replacement fraction of 5.40%. The daily record is consistent with the annual value because the reported daily loss below 0.27 L against a 5 L daily load corresponds to a daily loss fraction below 5.4%. For a low-temperature analytical laboratory, this means that a microscope consuming 5 L per day can operate with much lower net helium purchase than its gross liquid-helium throughput would suggest.

The continuity outcomes clarify the paper's first major result: readiness comes from agreement among resource retention, buffer capacity, and measurement evidence. The annual number is favorable, but the refill-buffer multiple and the instrument-side measurement gate are what prevent the result from being merely an accounting statement. The table therefore converts a recovery percentage into an analytical decision: the documented configuration is ready for the 5 L per day instrument load because no individual continuity gate contradicts the recovery claim.

The next result concerns scale-up. A compact recovery system that is robust at 5 L per day may become constrained when a second instrument, a higher-load cryostat, or a more frequent experimental schedule increases daily demand. Because the reported liquefier capacity is greater than 10 L per day, the analysis uses 10 L per day as a conservative lower-bound capacity. The demand stress test therefore does not assume additional hidden capacity; it asks how far the documented system can be extended without changing the reliquefaction pathway.

Table 2: Continuity outcomes.

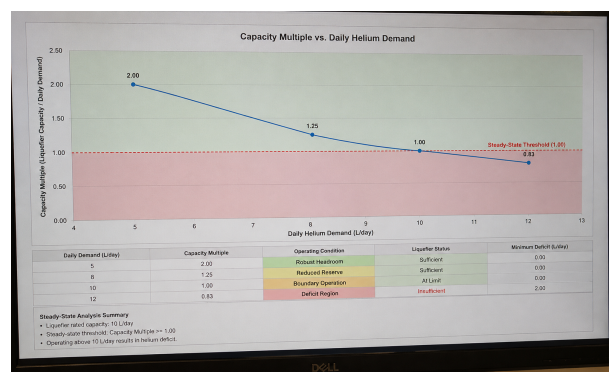
Outcome	Value	Meaning for analytical operation
Annual liquid helium retained	1,726.5 L	Most annual cryogen throughput stays inside the laboratory cycle
Annual retention	94.60%	External helium dependence is strongly reduced but not eliminated
Daily loss fraction	Less than 5.4%	The daily conservation result is consistent with the annual balance
Baseline liquefaction headroom	More than two-fold	Steady reliquefaction exceeds the 5 L per day analytical load
Refill-buffer multiple	About 2.23-fold	Full storage exceeds a typical refill input by more than a factor of two
Residual storage after typical refill	More than 2,577 L gas, approximately 3.44 L liquid-helium equivalent	Refill capture retains a usable reserve for variation in transfer conditions
Dominant impurity class	Hydrogen at 0.4%, at least 80% of the measured impurity budget	Maintenance planning must distinguish hydrogen from higher-condensation-temperature contaminants
Measurement gate	Passed for the documented configuration	Recovery connection is compatible with retained tunneling spectra, atomic-resolution imaging, and CO vibrational spectroscopy

Table 3: Demand stress test.

Daily demand	Capacity multiple	Minimum steady deficit	Continuity interpretation
5 L per day	2.00	0 L per day	Ready with strong steady headroom
8 L per day	1.25	0 L per day	Ready only with reduced reserve
10 L per day	1.00	0 L per day	Boundary operation with little tolerance for refill overlap or inefficiency
12 L per day	0.83	2 L per day	Not ready without larger or parallel liquefaction capacity

The demand stress test defines the most important scale-up boundary. At 5 L per day, the system is comfortably within the documented operating envelope. At 8 L per day, it remains feasible but loses much of the buffer that protects against maintenance variation, transient load, or imperfect scheduling. At 10 L per day, the system is no longer robust; it is at the conservative steady-capacity boundary. At 12 L per day, the daily load exceeds conservative liquefaction capacity before refill transients are considered. The practical conclusion is that high annual circularity at 5 L per day should not be generalized to indefinite instrument-cluster operation.

The demand-state panels provide a visual counterpart to the stress-test table. The same recovery architecture moves from a protected baseline condition to a boundary condition as the daily load approaches 10 L. This presentation is useful for laboratory planning because it shows that the risk is not a sudden annual failure; it is the gradual loss of daily operating reserve until refill timing, maintenance, or a second instrument can push the system beyond the conservative liquefier envelope.

**Figure 4:** Demand stress states.**Figure 5:** Capacity envelope.

The capacity envelope makes the same point in numerical form. The multiple of available liquefaction capacity decreases from 2.00 at 5 L per day to 1.25 at 8 L per day, 1.00 at 10 L per day, and 0.83 at 12 L per day. For spectroscopy and scanning probe microscopy, the 10 L per day case should be treated as a warning boundary rather than as a comfortable operating point, because any additional transient gas, purifier interruption, or partial downtime would consume the remaining margin.

The storage calculation addresses a different failure mode. Refill events generate short-duration gas input that may be larger than the amount the liquefier can immediately process. Storage therefore functions as an event buffer. Using the documented storage conversion, 4,677 L of gas corresponds to 6.24 L of liquid helium, and a typical refill input below 2,100 L gas corresponds to less than about 2.80 L liquid-helium equivalent. The full storage capacity consequently leaves more than 2,577 L gas after a typical refill, equal to about 3.44 L liquid-helium equivalent.

The storage buffer test changes the interpretation of the tanks. They are not passive accessories; they are the component that prevents refill events from becoming helium-loss events. At one-quarter capacity, a typical refill would overflow the available buffer. At one-half capacity, capture is possible but fragile because only about 239 L of gas capacity remains. At full capacity, the system can absorb the typical refill surge with a reserve that is larger than the surge margin available at half capacity. This result explains why single-number recovery claims should be accompanied by refill-event storage information.

Table 4: Storage buffer test.

Storage level	Available gas capacity	Reserve after 2,100 L refill input	Continuity interpretation
25%	1,169 L	About 931 L overflow	Not ready for typical refill capture
50%	2,339 L	About 239 L remaining	Marginal capture with little tolerance for variation
75%	3,508 L	About 1,408 L remaining	Ready with moderate refill reserve
100%	4,677 L	More than 2,577 L remaining	Ready with strong transient resilience

**Figure 6:** Refill buffer.

The refill-buffer image turns the storage calculation into an operating scenario. The 25% and 50% cases highlight two different risks: outright venting at low storage and fragile capture at half storage. The 75% and full-capacity cases show why reserve is operationally valuable. Refill volumes, temperature conditions, pressure settings, operator timing, and liquefier availability can vary from event to event, so storage capacity should be judged by remaining reserve, not merely by whether one idealized refill can fit.

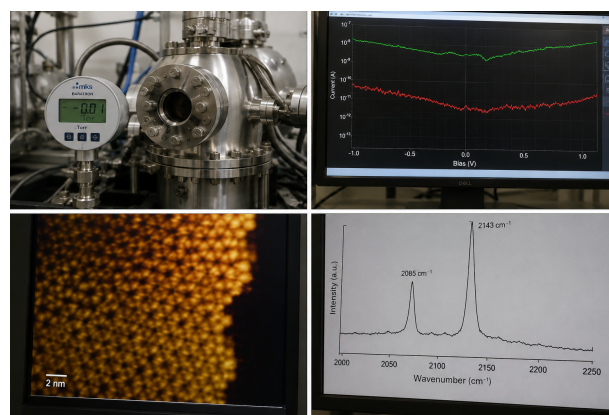
Impurity behavior introduces a third readiness boundary. The storage gas contains more than 99.5% helium, 0.4% hydrogen, and less than 0.1% combined water, nitrogen, oxygen, carbon dioxide, and trace organics. If the total impurity budget is conservatively treated as no more than 0.5%, hydrogen represents at least 80% of the measured impurity content. This matters because impurity class controls where maintenance occurs. Higher-condensation-temperature impurities can obstruct purifier pathways and require frequent purifier attention, whereas hydrogen may demand deeper cold-stage thermal management.

The maintenance table shows why purity cannot be reduced to a pass/fail gas specification. A gas stream that is more than 99.5% helium can still impose frequent service if the impurity class creates purifier blockage or cold-head accumulation. The two service times also differ qualitatively: recovery to 80 K is a shorter intervention, whereas warming to room temperature approaches a full-day interruption. For analytical experiments that require surface preparation, long acquisition windows, or repeated spectra from the same sample, this difference can determine whether a recovery system is convenient or disruptive.

The analytical signal panel is the decisive measurement gate. Pressure monitoring alone would not prove compatibility, and helium conservation alone would not prove data quality. The relevant observation is that the recovery-connected configuration remains compatible with comparable tunneling-current spectra, atomic-resolution surface imag-

Table 5: Maintenance consequences.

Maintenance driver	Documented behavior	Operational consequence
Higher-condensation-temperature impurities	Less than 0.1% combined water, nitrogen, oxygen, carbon dioxide, and trace organics	Routine purifier recovery remains necessary because small impurity fractions can still obstruct traps
Hydrogen	0.4%, at least 80% of the measured impurity budget	Cold-head management should be planned separately from ordinary purifier recovery
Purifier blockage	Two to three times per week	Frequent service must be included in experiment scheduling
Cold-head decontamination	Less than 6 h to 80 K and nearly 1 day to room temperature	Deeper maintenance can interrupt long sample series and must be treated as a downtime event

**Figure 7:** Analytical signal retention.

ing, and CO vibrational spectroscopy. This is a stringent test because STM-IETS is sensitive to mechanical and electronic instability. The retained signal quality therefore supports the central claim that the evaluated recovery system functions as analytical infrastructure rather than as a stand-alone cryogen-saving device.

The integration of resource and measurement evidence also explains why compact recovery differs from both centralized facility recovery and direct cryogen-free conversion. Facility recovery emphasizes institutional helium balance and large shared storage. Cryogen-free conversion emphasizes cooling without liquid transfer but requires major vibration-control engineering. The compact configuration analyzed here retains the bath-cryostat analytical environment while shifting helium losses into a local recovery, storage, purification, and reliquefaction pathway. Its strength is not maximum throughput; its strength is the alignment of a 5 L per day instrument load with sufficient storage, sufficient steady capacity, manageable impurity behavior, and retained measurement performance.

The decision dashboard summarizes the paper's main result in a compact form. The documented system passes the baseline event-buffered envelope because annual retention, daily loss, liquefier headroom, refill storage, gas purity, pressure stability, and measurement integrity all point in the same direction. The dashboard also prevents overstatement: the same envelope shows that the result is conditional on daily demand, storage volume, and maintenance behavior. A laboratory planning a second instrument or a higher-load cryostat should therefore use the dashboard as a boundary tool, not as proof that the same installation can scale without modification.



Figure 8: Decision dashboard.

4. Analytical Scope, Transferability, and Limitations

The analysis belongs within analytical chemistry, spectroscopy, microscopy, and instrumentation because it addresses the support conditions required for valid cryogenic measurement. The analytical object is not only the surface, molecule, or material being measured; it is also the instrument environment that allows that object to be measured reproducibly. In STM and STM-IETS, helium management affects temperature stability, tunneling-current noise, refill scheduling, and long-duration spectral acquisition. In broader cryogenic spectroscopy and superconducting-magnet instrumentation, helium management affects field stability, detector operation, and experiment continuity. These are analytical-readiness concerns rather than peripheral facility details.

The assessment approach is transferable because its inputs are common to many cryogenic laboratories. A superconducting magnet laboratory, a dilution-refrigerator facility, a cryogenic optical spectroscopy room, or a scanning probe laboratory can populate the same event windows with its own values: annual use, annual loss, daily demand, liquefier capacity, gas storage, refill input, impurity composition, pressure fluctuation, maintenance downtime, and measurement-quality evidence. Thresholds will differ by instrument. A scanning probe microscope may have a stricter vibration tolerance than a less mechanically sensitive cryostat, whereas a magnet facility may have a larger inventory and a different refill rhythm. The method remains useful because it separates annual conservation from event buffering and then forces both to be checked against measurement integrity.

The principal limitation is the form of the available operating record. The values are sufficient for an event-buffered manuscript-level assessment, but they do not include raw time-series logs for pressure, mass flow, temperature oscillation, compressor state, vibration spectra, purifier loading, or long-term hydrogen accumulation. The demand and storage analyses are therefore stress tests based on documented operating values, not predictive dynamic simulations. Future studies could improve the method by combining flow-meter logs, pressure traces, residual-gas analysis, cold-head temperature records, compressor activity, and tunneling-current noise spectra. Such data would allow the same event-buffered logic to become a continuous monitoring tool rather than a table-based readiness assessment.

5. Conclusions

This study asked whether a compact helium recovery installation can be judged analytically ready only when annual retention, daily capacity, refill buffering, impurity-aware maintenance, pressure stability, and retained measurement quality are evaluated together. The answer is affirmative for the documented single-instrument operating envelope, but not unlimited. The system is ready for the 5 L per day low-

temperature scanning probe load because it retains 1,726.5 L from 1,825 L annual liquid-helium use, giving 94.60% annual retention; it loses less than 0.27 L per day against a 5 L daily demand; its more than 10 L per day liquefaction capacity provides more than two-fold baseline headroom; and its 4,677 L gas-storage capacity is about 2.23 times a typical refill input below 2,100 L. These results answer the resource part of the research question by showing that circularity is not only high annually but also supported at the daily and refill-event time scales.

The analytical part of the research question is answered by the stability and measurement evidence. Inline pressure fluctuation near plus/minus 0.01 psi, comparable tunneling-current spectra, retained atomic-resolution imaging, and retained CO vibrational spectroscopy indicate that helium conservation does not compromise the low-vibration data stream in the documented configuration. The conclusion would be different if recovery degraded spectra or images, even with the same annual retention percentage. For this reason, the paper's main contribution is the event-buffered continuity envelope: it treats helium recovery as a measurement-support problem rather than a stand-alone conservation claim.

The boundary conditions are equally important. Operation near 10 L per day becomes the conservative steady-capacity limit, and 12 L per day is not ready without larger or parallel reliquefaction capacity. Storage below one-half of the 4,677 L capacity is also risky: one-quarter storage would fail to capture a typical refill, while one-half storage would leave only about 239 L gas reserve. The impurity result adds a maintenance boundary because hydrogen accounts for at least 80% of the measured impurity budget, requiring cold-head decontamination planning in addition to frequent purifier recovery. The system should therefore be described as ready for a specific compact analytical-use envelope, not as a universally scalable helium solution. Laboratories adapting this approach should preserve the same decision logic: pass annual circularity, pass daily capacity, pass refill buffering, pass impurity-maintenance planning, and pass measurement integrity before claiming analytical readiness.

Data Availability

All numerical values used in this analysis are listed in the tables and are traceable to the published operating record of the compact recovery system [33]. No additional raw instrument logs accompany this manuscript.

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