

Long-Duration Storage of Photocurable Materials for Space Missions: Radiation, Thermal Excursions, Latency and Recovery

Qualification of uncured resin state after mission storage rather than assuming terrestrial shelf life survives launch and cruise

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Abstract

Long-duration space missions can store photocurable feedstocks far longer and under more variable environments than a terrestrial printer workflow. Resin chemistry can evolve through thermal ageing, inhibitor consumption, dark reactions, volatile loss, phase separation and radiation exposure before the material is ever printed. A valid shelf-life claim must therefore connect storage history to recovered processability and final-part performance. This review defines qualification for mission storage, including thermal excursions, radiation, vacuum or pressure state, latency, mixing or reconditioning, requalification and recovery after off-nominal exposure.

Keywords: photocurable resin; long-duration storage; shelf life; thermal ageing; radiation; latency; reconditioning; recovery; space mission

1. Significance and scope

Mission storage moves photopolymer qualification upstream from the printed part to the uncured formulation. A resin can remain liquid while its optical attenuation, viscosity, inhibition balance or reactive composition changes enough to move the print process out of calibration [1-3].

ER-445 owns short-term handling during a manufacturing event under vacuum or reduced gravity. This review owns latency: the period from formulation and launch through long storage, thermal excursions and eventual recovery for printing.

2. Shelf life is a defined storage history

A shelf-life statement is meaningful only with temperature, light exposure, atmosphere, container and acceptance tests. Terrestrial vat-photopolymer weathering studies show why environmental durability must be tied to an exposure history rather than a nominal material label [3]; warehouse expiry alone does not automatically transfer to a spacecraft bay or surface cache.

The storage clock should start from a defined material state, including inhibitor concentration, mixing history and packaging atmosphere. Multiple transfers or partial use can create a different ageing path from an unopened container.

Accelerated thermal ageing of a VAM resin has shown that storage history can change optical, dimensional and mechanical outcomes even when gross chemistry and viscosity remain comparatively stable [1]. This is precisely why print calibration belongs in shelf-life qualification.

3. Thermal ageing can shift process thresholds

Temperature excursions can also drive phase separation, crystallisation, additive migration or inhibitor loss. Qualification should include the expected hot/cold profile and not merely a constant elevated-temperature acceleration.

Radiation accumulated before use can initiate chemistry in a nominally dark resin or degrade photoinitiators, inhibitors and stabilisers. The relevant endpoint is recovered photosensitivity and final-part performance, not simply whether the liquid remains pourable.

4. Radiation and vacuum add non-terrestrial ageing routes

Vacuum or low-pressure storage can change composition through outgassing. High-vacuum screening of liquid photopolymers shows that uncured formulations can lose mass and change viscosity, making container permeability and headspace control part of the storage design [2].

Thermal, radiation and vacuum histories can interact. A formulation depleted in a volatile component may respond differently to later radiation or heat than a sealed terrestrial control.

Reconditioning by warming, rolling, stirring or remixing may restore uniform appearance without restoring chemistry. Any recovery procedure should have a bounded method and acceptance gate.

Resins containing fillers require additional checks for sedimentation, agglomeration and irreversible packing during long latency. Reduced gravity may alter sedimentation during some mission phases but launch and manoeuvre accelerations still create transient settling forces.

5. Reconditioning and device-level recovery

A recovered resin should be requalified for rheology, optical response and cure before critical manufacturing. Recalibration of exposure is an allowed recovery action only if the material remains within chemical and mechanical acceptance limits.

Off-nominal storage should be tested deliberately: thermal excursion, unplanned radiation event, partial vacuum loss or extended mission duration. The disposition should be use, recondition, down-rate to a noncritical application or reject.

Device-level recovery should print representative qualification geometry and measure final properties, because a resin can pass a liquid-state test and still produce parts with shifted dimensions or mechanics.

Axis	Measurement	Failure mode
Storage history	time, temperature, light, atmosphere	calendar age used without conditions
Radiation/vacuum	dose history, pressure, mass loss	terrestrial shelf life over-transferred
Material state	phase, viscosity, optical response	liquid appearance treated as fitness
Recovery	mixing/reconditioning and recalibration	ad hoc remixing accepted without gate
Final performance	print fidelity and part properties	liquid-state pass used as final qualification

Table 1. Domain-specific qualification matrix for long-duration storage of photocurable materials.

6. Transfer limits and minimum reporting dataset

Inventory strategy matters: smaller sealed cartridges can reduce repeated opening and contamination but increase packaging mass; bulk reservoirs improve mass efficiency but concentrate mission risk. Storage architecture is therefore part of material qualification.

Report formulation lot, manufacture date, initial acceptance, container, atmosphere, temperature-time history, radiation history, pressure state, agitation/reconditioning and any opening or transfer event.

At recovery, measure appearance/phase state, viscosity, optical or cure response, print calibration and final-part properties against a fresh or retained control.

7. Minimum qualification framework

A minimum storage programme should define the initial qualified state and then reproduce or bound the mission history: duration, temperature-time profile, radiation, pressure/atmosphere, light exposure, vibration/acceleration events and every opening or transfer. Retained controls should allow chemical ageing to be distinguished from handling-induced contamination or mixing changes.

Recovery criteria should be pre-defined rather than invented after an excursion. Reconditioning may include controlled warming, agitation or recalibration, but the recovered resin should still pass liquid-state checks and produce representative parts within dimensional and mechanical acceptance limits before critical use.

8. Engineering conclusions

Long-duration photoresin storage should therefore be qualified by recoverable manufacturing performance after a known history.

Calendar shelf life alone cannot represent a mission in which radiation, thermal excursions, reduced pressure and intermittent handling alter both the liquid formulation and the final cured network.

References

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Competing interest

Juan Segurola is founder, CEO and CTO of 3Dresyns by Resynr Technologies S.L., which develops and commercialises photopolymer materials and related additive-manufacturing technologies. This review is an engineering analysis and does not constitute a product-performance claim or a device qualification.