

Post-Processing Control for VPP Printed Parts

Cleaning, drying, post-curing and application-specific verification without material-level regulatory release claims

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Highlights

- Post-processing is a controlled sequence comprising drainage, cleaning, drying, post-curing and verification.
- Each cleaning agent must be compatible with the named resin and controlled for concentration, contact time, agitation, temperature and renewal state.
- Drying acceptance should demonstrate removal of the cleaning medium to the limit established by the validated process before post-curing.
- Degree of conversion can support process monitoring only when method, specimen, sampling and acceptance criteria are validated for the named application.
- Biological evaluation and regulatory conformity apply to the finished device and remain the responsibility of the legal manufacturer.
- ISO 10993-10:2021 addresses skin sensitization and ISO 10993-23:2021 addresses irritation; neither defines a universal release panel.

Abstract

Post-processing strongly influences the dimensional, mechanical, surface and chemical condition of VPP printed parts. A controlled workflow should define drainage, cleaning, drying, post-curing and final verification for each formulation, printer, geometry and intended application.

This paper describes those operations as process-control stages rather than as a universal regulatory release pathway. Degree of conversion may be used as a formulation-specific process indicator, but a percentage value alone does not establish biological safety, dental suitability, medical-device conformity or compliance with an ISO standard. Acceptance criteria must be supported by validation showing that the selected measurements predict the relevant finished-part requirements.

For medical and dental devices, the legal manufacturer determines the biological-evaluation strategy within risk management, considering the final device, processing residues, chemical characterization, tissue contact and available evidence. The necessary endpoints cannot be prescribed solely from the resin family or a conversion threshold.

Keywords VPP · post-processing · cleaning · drying · post-curing · degree of conversion · process verification · production release

Source use. Controlled workflow and product documentation is mapped in [1–3]; conversion, cleaning and photopolymer evidence in [4–8]; biological, dental and risk-management boundaries in [9–14].

1. Controlled post-processing chain

The printed green part can retain surface resin, material in recessed features and an incompletely developed network. Post-processing converts that intermediate into a finished article through a connected sequence. Inadequate control can cause tack, swelling, cracking, dimensional change, residue retention, incomplete cure or other nonconforming product and rework [1–5].

Sequence alone is insufficient. Each stage requires a named procedure, measurable variables, acceptance criteria and change control. The exact route depends on formulation, geometry, printer, cleaning chemistry, equipment and intended use.

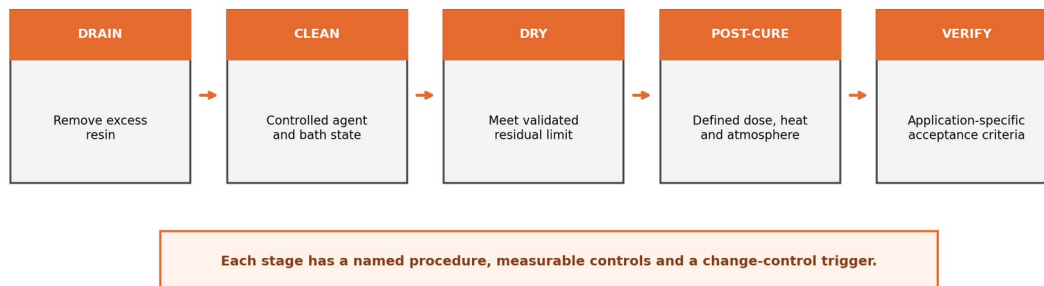


Figure 1. Controlled post-processing chain. The sequence is linked, but every stage also requires its own validated controls.

2. Drainage and cleaning

Drainage should reduce transfer of recoverable excess resin into the cleaning process without damaging the green part. Orientation, time and temperature are selected for the named viscosity, geometry and handling route. Fixed drain times or temperatures should not be transferred between formulations without confirmation.

Cleaning removes accessible uncured material from surfaces, cavities and channels. The cleaning agent must be documented as compatible with the exact resin. Concentration or composition, bath loading or renewal state, contact time, agitation, temperature, sequence and part geometry should be controlled. A two-stage bath can be useful, but it is not a universal requirement; the validated procedure and acceptance results decide suitability.

Water-based, organic and other cleaning routes differ in hazards, waste classification and material compatibility. A water-based route does not make residues harmless or eliminate waste obligations. SDS, local rules and controlled disposal procedures still apply. Product-specific cleaner names or portfolio claims must be checked against current TDS or IFU documentation before use.

3. Drying before post-curing

Drying separates cleaning from post-curing. The process should demonstrate that the cleaning medium has been reduced below a validated residual limit before irradiation. Visual dryness or a fixed elapsed time may be inadequate for complex channels, porous supports, thick sections or low-volatility media.

The validation may use mass stability, a formulation-specific analytical method or another justified indicator. Airflow, temperature, orientation, part spacing, geometry and maximum hold time should be recorded. Claims that residual solvent becomes permanently photo-trapped or raises an extractables result require formulation-specific analytical evidence and should not be inferred from ISO 10993-12.

4. Post-curing and process indicators

Post-curing conditions should be defined by wavelength distribution, irradiance, exposure time, chamber temperature, atmosphere, part orientation, geometry and validated equipment condition. The applicable recipe is the one documented for the named formulation and use case.

Degree of conversion may be measured by a validated spectroscopic or calorimetric method and used to monitor process consistency. The report should identify specimen preparation, spectral or thermal method, calculation, measurement uncertainty, sampling position and acceptance criterion. A DC value should not be described as a universal release threshold unless a controlled validation demonstrates its relationship to every relevant final-part property.

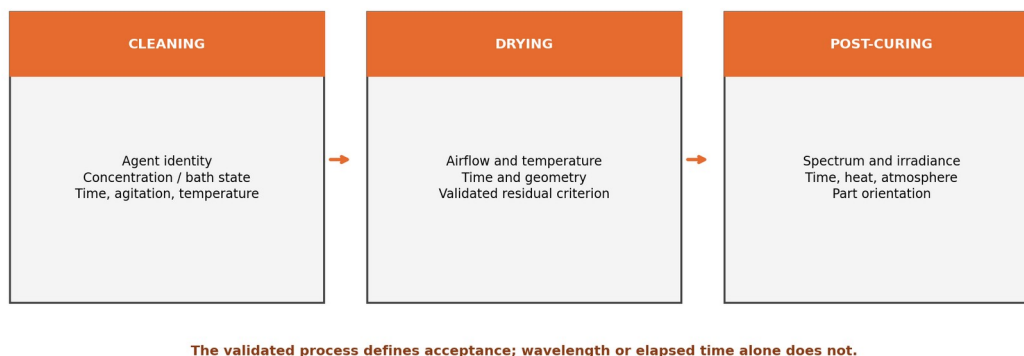


Figure 2. Minimum controls for cleaning, drying and post-curing. A wavelength or time value alone cannot define the process.

5. Verification and production release

Stage	Controlled variables	Evidence / acceptance	Change trigger
Drain	Orientation, time, temperature	No uncontrolled transfer of excess resin	Viscosity, geometry or temperature
Clean	Agent, concentration, bath condition, time, agitation, temperature	Surface and channel cleanliness against validated criterion	Resin, cleaner, bath or equipment
Dry	Airflow, temperature, time, geometry	Cleaning medium below validated residual limit	Cleaner, part geometry or drying equipment
Post-cure	Spectrum, irradiance, time, heat, atmosphere, orientation	Named formulation and application criteria	Recipe, lamp, chamber or formulation
Verify	Sampling, method, limits and disposition	Documented production release	Specification, method or intended use

Verification progresses from visual and dimensional inspection to application-specific mechanical, chemical and, where required, biological evaluation. Production release means approval against the legal manufacturer's documented and validated specifications. It is not an ISO release.

Traceability may include resin and additive batches, cleaning-fluid identity and condition, equipment identification and calibration status, post-curing record, inspection results and nonconformance disposition. A process indicator is retained only when its relationship to the relevant finished-part requirement has been demonstrated.

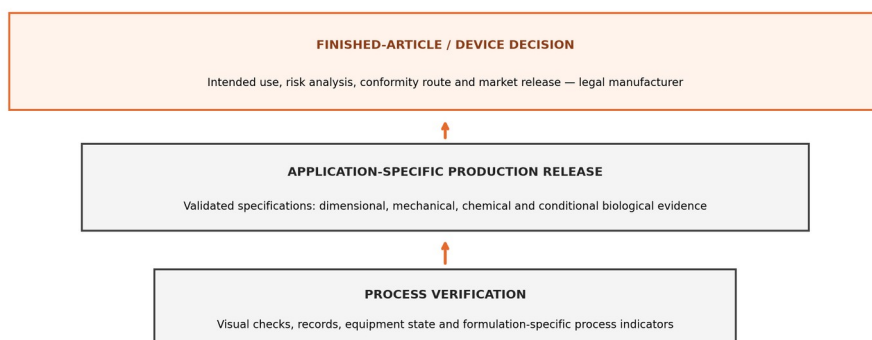


Figure 3. Corrected release hierarchy. Process verification supports, but does not replace, application-specific production release or the finished-device decision.

6. Medical and dental boundary

For a finished medical device, biological evaluation is conducted within risk management under ISO 10993-1:2025. ISO 10993-5 concerns in vitro cytotoxicity, ISO 10993-10:2021 concerns skin sensitization and ISO 10993-23:2021 concerns irritation. Their inclusion is determined by device-specific contact, duration, chemical characterization, existing information and risk analysis, not by a fixed resin-family panel [6–9].

ISO 10993-12 addresses sample preparation and reference materials; it does not define an extractables acceptance limit. ISO 4049:2019 applies within its dental restorative and luting scope. ISO 13485:2016 concerns quality-management systems and does not certify a resin or printed part as biologically safe [9–11].

KEY INSIGHT

A validated post-process is necessary evidence for a finished device, but no conversion percentage or ISO citation releases the device automatically.

7. Minimum process record

- Exact resin, additive and cleaner identities, batches and controlled-document revisions.
- Part geometry, orientation, channel features and support condition relevant to drainage and cleaning.
- Cleaning-agent concentration or condition, bath loading/renewal rule, temperature, time and agitation.
- Drying equipment, airflow, temperature, time and acceptance method for residual cleaning medium.
- Post-cure spectrum, irradiance, exposure, chamber temperature, atmosphere, orientation and equipment status.
- Sampling plan, measurement methods, acceptance criteria, deviations and disposition.

8. Limitations

- No universal DC threshold establishes release across engineering, dental and medical applications.
- Wavelength without irradiance, dose, thermal and geometry information is insufficient to define post-curing.
- ISO 10993-12 does not define an extractables acceptance limit.
- ISO 4049 applies only within its stated dental restorative and luting scope.
- Biological evaluation applies to the final device and processing state; resin or auxiliary substitution may require re-evaluation.
- ISO 13485 is a quality-management-system standard and does not certify a resin or printed part as biologically safe.
- Cleaner compatibility and process settings must be confirmed for specialty, pigmented, filled, water-soluble and complex-geometry parts.

9. Conclusions

- Drainage, cleaning, drying, post-curing and verification form a linked but individually controlled workflow.
- Cleaner selection and bath control are formulation-specific; water-based and organic routes retain their own safety and waste obligations.
- Drying requires a validated residual criterion, and post-curing requires spectrum, irradiance, time, heat, atmosphere and geometry information.
- Degree of conversion is a possible process indicator, not a universal engineering or medical release threshold.
- Finished-device biological evaluation, conformity and market release remain with the legal manufacturer.

Revision note

Version 5.5 removes universal DC release thresholds, fixed ISO 10993 panels, ISO release wording, unsupported extractables mechanisms and universal cleaning claims; adds controlled cleaning, drying and post-curing variables; updates sensitization and irritation standards; and separates process verification from finished-device release.

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