

Radiation-Functional Photopolymers for Additive Manufacturing: Scintillation, Shielding and Dosimetric Constraints

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Statement of Significance

Radiation functionality covers fundamentally different engineering tasks: converting deposited energy into detectable light, attenuating photons, absorbing neutrons, reproducing radiological attenuation in a phantom, or surviving accumulated dose. These functions depend on different physics and cannot be collapsed into a single “radiation resin” property. This review separates the relevant mechanisms and defines the measurement chain required before a printed photopolymer can be described as a scintillator, shield, dosimetric material or radiation-hard component.

Keywords: radiation-functional photopolymer; plastic scintillator; radiation shielding; neutron absorber; dosimetry; radiopacity; vat photopolymerisation; DLP; SLA; optical transport

Abstract

Additive manufacturing enables radiation-functional polymer components with complex geometry, but performance depends on the interaction between active species, polymer optics, filler distribution, cure and geometry. Plastic scintillators require efficient energy transfer and photon collection; photon shields depend on composition, density, thickness and energy spectrum; neutron absorbers require isotope-specific interaction physics and secondary-radiation assessment; dosimetric and radiological phantoms require calibrated response or attenuation; and radiation-hard parts require retained properties after dose. This review organises these functions into separate qualification pathways. It emphasises optical attenuation and self-absorption in printed scintillators, energy-dependent shielding metrics, neutron-specific testing, dose-response calibration and radiation ageing. 3Dresyn PSci PPO and the 3Dresyns neutron-absorption additive family are presented only as commercial implementation examples, with no proprietary recipe or unsupported attenuation values disclosed.

1. Introduction

Radiation-related photopolymers are often grouped together because they are used in nuclear, medical, high-energy-physics or aerospace environments. The underlying functions are nevertheless different. A scintillator is a sensor material: it must convert deposited energy into optical photons and deliver those photons to a photosensor. A shield is an attenuator whose performance depends on interaction cross-sections, density and thickness. A dosimetric material must provide a calibrated response to absorbed dose. A radiation-hard structural material must retain function after irradiation. The experimental evidence required for each is therefore different. [6]

2. Four distinct radiation functions

Domain	What is measured	Primary dependency	What it does not establish
Scintillation	Light output, decay, spectrum, energy response.	Fluor system, optical transport, geometry, photosensor.	Shielding effectiveness or dose calibration.
Photon shielding	Transmission/attenuation versus photon energy and thickness.	Composition, density, atomic number, geometry.	Neutron shielding or scintillation.
Neutron absorption	Neutron transmission/capture response.	Absorber isotope, concentration, thickness, energy.	Gamma attenuation from density alone.
Dosimetry / phantom	Dose-dependent signal or radiological equivalence.	Calibration, beam quality, geometry, stability.	Intrinsic radiation hardness.
Radiation hardness	Retained optical/mechanical/function after dose.	Dose, dose rate, radiation type, environment.	Detector sensitivity or shielding coefficient.

Table 1. Engineering distinctions that must be preserved.

3. Printed plastic scintillators

Plastic scintillators combine an organic polymer matrix with primary and often secondary fluorescent species. In a printed part, the optical path is as important as the local scintillation chemistry. Layer interfaces, scattering, absorption, surface roughness and pigment/filler content can reduce collected light even if molecular energy transfer remains efficient. Additive manufacturing research has therefore moved from simply demonstrating luminescent printable materials toward segmented detector geometries and optical-performance control. [1,3,9]

Stage	Measurement	Why needed	Failure if omitted
Material optics	Absorption/transmission and emission spectrum.	Defines self-absorption and sensor matching.	Bright fluor may still give poor photon collection.
Scintillation	Light output / relative response and decay.	Confirms radiation-to-light conversion.	Photoluminescence alone is not scintillation evidence.
Geometry	Path length, segmentation, surface finish.	Controls photon escape and collection.	Coupon data may not transfer to detector geometry.
Detector coupling	Photosensor, coupling medium, readout.	Defines system-level signal.	Material cannot be ranked independently of readout.
Radiation stability	Response after accumulated dose.	Tests ageing of matrix/fluor.	Initial signal does not establish lifetime.

Table 2. Qualification chain for a printed scintillator.

Recent studies include DLP-printable scintillating composites and additively manufactured segmented plastic-scintillator detectors for tracking and calorimetry. The latter demonstrate why detector geometry and readout architecture belong to validation rather than being treated as decorative applications of a bulk material. [1–3,9]

4. Photon shielding

For X-rays and gamma rays, attenuation is energy-dependent and should be reported through transmission, linear or mass attenuation coefficient, or an equivalent quantity tied to photon energy and specimen thickness. High-density or high-atomic-number fillers can increase attenuation but can also increase viscosity and optical attenuation during VPP. A nominal filler fraction therefore does not by itself define shielding performance, and attenuation data from one energy cannot be transferred across a broad spectrum without a justified model. A recent SLA Bi2O3-photopolymer study provides a calculation-based attenuation example, not a broad experimental shielding certification [10].

5. Neutron-functional materials

Neutron interaction physics differs from photon attenuation. Effective absorbers are selected for neutron-capture cross-section and energy range, and capture can generate secondary radiation that may need assessment. For a printed neutron-functional composite, dispersion, absorber homogeneity, specimen thickness and neutron spectrum should be reported. Density or radiopacity cannot serve as a proxy. ISO 8529-1:2021 and ISO 8529-3:2023 define reference-field and dosimeter-calibration context [8]. Direct peer-reviewed evidence for neutron-absorbing vat-photopolymerised composites remains limited. Evidence from borated material-extrusion systems can inform absorber selection and geometry, but it must not be presented as validation of VPP dispersion, cure or final neutron performance [11].

6. Dosimetry and radiological phantoms

Dosimetric use requires calibration. A printed polymer may be geometrically useful as a phantom without being a dose sensor, while a scintillator may provide a signal without being tissue-equivalent. Radiological equivalence should therefore specify imaging modality, energy range and comparator. Radiopacity is valuable as a boundary property but should not be used to claim shielding or dosimetric performance without the corresponding experiment. ISO 4037 provides reference X/gamma-field context [7]. SLA-printed holders for OSL extremity dosimetry and SLA-resin maxillofacial phantoms show that fixtures, sensors and radiological equivalence must remain separate evidence claims [12,13].

7. Radiation ageing

Observable	Potential radiation effect	Measurement approach	Interpretation
Optical transmission	Yellowing, absorption-band growth, scattering.	Spectrophotometry before/after dose.	Relevant to scintillator and optical readout.
Scintillation response	Fluor damage or matrix quenching.	Same radiation/readout protocol before/after ageing.	Direct detector-retention metric.
Mechanical properties	Chain scission or additional crosslinking.	Tensile/flexural after defined dose.	Needed for structural function.
Dimensions	Warping, stress release or degradation.	Metrology before/after irradiation.	Important for precision detectors/phantoms.
Electrical response	Charge-trapping or conductivity change where relevant.	Application-specific electrical test.	Not inferred from optical stability.

Table 3. Radiation-ageing observables.

8. VPP-specific formulation constraints

Radiation-active additives can strongly affect cure. Aromatic fluors, heavy fillers and neutron absorbers may absorb or scatter the same wavelengths used for photopolymerisation. Sedimentation can create z-dependent composition in long builds. A radiation-functional formulation should therefore be characterised for rheology, optical working behaviour, dispersion and conversion in addition to the radiation endpoint. Otherwise a high-performing coupon may not represent the printed geometry. [4,5,9,10]

9. Minimum reporting framework

Function	Minimum material/process data	Radiation test data	Claim limit
Scintillator	Matrix/fluor class, process, dimensions, optical transmission.	Radiation type/energy, light output, spectrum/decay, readout.	Photoluminescence alone is insufficient.
Photon shield	Composition, density, thickness, filler dispersion.	Photon energy/spectrum and transmission/attenuation.	No universal shielding percentage.
Neutron absorber	Absorber identity, homogeneity, thickness.	Neutron energy/spectrum and capture/transmission method.	No inference from X-ray radiopacity.
Dosimetric material	Composition, geometry, conditioning.	Dose calibration, beam quality, repeatability.	No dose claim without calibration.
Radiation-hard part	Cure state and baseline properties.	Radiation type, total dose, dose rate, retained properties.	No lifetime claim beyond tested exposure.

Table 4. Minimum reporting set for radiation-functional VPP.

3Dresyns implementation examples

Two 3Dresyns products provide direct examples of how distinct radiation functions should remain separated in a commercial portfolio.

- 3Dresyn PSci PPO is positioned for SLA/DLP/LCD printing of plastic scintillators using a PPO/POPOP fluor system. In this review it is cited only as an implementation example; proprietary concentrations and detector-performance values are not used as scientific evidence. [M1]

- The current 3Dresyns neutron-absorption additive family provides commercial absorber-route context distinct from scintillation. No universal loading, attenuation or shielding percentage is inferred from the collection positioning [M2].
- 3Dresyns radiopaque grades can serve as comparison examples for imaging visibility, but radiopacity is explicitly not equated with photon shielding, neutron absorption or dosimetry.

Commercial product descriptions identify intended function and implementation route. Actual radiation response must be established on the printed geometry with the relevant radiation field and measurement system.

10. Conclusions

- Scintillation, photon shielding, neutron absorption, dosimetry and radiation hardness are distinct functions with different evidence requirements.
- Printed scintillator performance depends on both molecular scintillation and optical transport through the manufactured geometry.
- Shielding must be reported against radiation energy, thickness and composition; a single percentage is not universal.
- Neutron functionality cannot be inferred from radiopacity or material density.
- Dosimetric use requires calibration, while radiation hardness requires retained-property measurement after defined dose.
- Radiation-active additives must also be qualified for VPP rheology, cure attenuation, dispersion and conversion. [3,9,10]
- Commercial radiation-functional materials should be presented as implementation examples rather than as substitutes for application-specific radiation testing.

Limitations

The review does not pool attenuation, light-yield or dose-response values because radiation fields, detector systems and specimen geometries differ substantially. Product recipes are not disclosed and commercial claims are not independently verified here.

Author contributions

Juan Seguro: conceptualisation, literature synthesis, engineering framework, writing and critical review.

Competing interests

The author is affiliated with 3Dresyns by Resyner Technologies S.L. Commercial 3Dresyns materials are identified only as implementation examples supported by controlled product documentation. They are not treated as independent peer-reviewed evidence and no proprietary formulation composition is disclosed.

Data availability

No new experimental dataset was generated for this review. Scientific statements are attributed to the cited literature and standards; commercial examples are separated from the independent evidence base.

Company information

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