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Optical Properties of Polymers Under Gamma Irradiation: A Systematic Review 2020-2025

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Abstract

Gamma irradiation is widely applied in polymer processing, sterilization, and radiation resistance testing, yet its optical consequences are interpreted inconsistently across applications. This systematic literature review synthesizes Scopus indexed experimental studies published between 2020 and 2025 to clarify how gamma exposure modifies polymer optical properties and how interpretation depends on material architecture and analytical approach. Following PRISMA procedures, 657 records were identified, 76 full texts were assessed, and 24 studies met predefined eligibility criteria. The included corpus is dominated by PVA based composites and functional films, with fewer studies on neat engineering polymers and multilayer packaging systems. Across studies, UV–Vis spectral changes and visible color modification are the most frequently reported outcomes. In dosimetry oriented systems, absorbance and color intensity commonly increase with dose and support calibrated optical readout. In stability focused systems, especially EVA based materials, optical constants such as refractive index often remain largely unchanged within moderate dose windows. Optical band gap Eg, when reported, is frequently described as decreasing with increasing dose in composite and doped films, although its magnitude depends on transition assumptions and fitting procedures. Overall, optical response under gamma irradiation is material and context dependent, and changes may indicate either functional responsiveness or degradation, requiring endpoint aware interpretation and more standardized reporting practices.

Keywords: Gamma irradiation; Polymer optical properties; UV–Vis spectroscopy; Optical band gap; Polymer nanocomposites

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INTRODUCTION

Gamma radiation is a high-energy form of ionizing radiation widely used in industrial and materials-research settings, especially for sterilization, material modification, and radiation-resistance testing (Shim et al., 2022; Tayel et al., 2015). Unlike thermal or chemical treatments that typically depend on temperature gradients or reagent diffusion, gamma rays can penetrate materials relatively uniformly and trigger ionization and electronic excitations at the molecular scale (Shim et al., 2022). As a result, polymers exposed to gamma irradiation may undergo chemical-structural and morphological changes through pathways such as chain scission, crosslinking, oxidation, and the formation of defects or color centers (Yassien & El-Zahhar, 2019). These processes can modify polymer optical behavior across the ultraviolet (UV), visible, and near-infrared (NIR) regions, which becomes critical when polymers function as packaging films, radiation dosimeters, optoelectronic components, or other light-transmitting and light-absorbing functional materials (Edalatkhah & Rezaeian, 2023).

Interest in polymer optics under gamma irradiation is not driven solely by the need to understand degradation mechanisms. In many cases, optical change is intentionally exploited as a dose-calibrated signal. Certain polymer films can be engineered to show consistent dose-dependent changes in absorbance, color, or absorption-edge position, making them relevant for dosimetry and radiation sensing (Eid et al., 2014; Doyan et al., 2021). In this context, an increase in absorbance or a measurable color shift can be a desirable and functional response because it supports robust dose readout and calibration logic (Eid et al., 2014). Conversely, in applications that demand optical stability, even modest changes can indicate performance loss, for example increased haze, yellowing, or reduced transparency at functionally important wavelengths (Sabbaghizadeh et al., 2017; Bekhit et al., 2021). These two orientations, engineering optical responsiveness versus preserving optical stability, often coexist in the literature but are not always made explicit. Consequently, the same observation, such as irradiation-induced absorbance growth, may be interpreted as an advantage for dosimetry yet as degradation for transparent packaging (Doyan et al., 2021).

Experimentally, polymer optical properties are commonly assessed through UV–Vis spectroscopy, color analysis, and derived parameters such as the optical band gap (Eg), Urbach energy (Eu) as a disorder indicator, and optical constants including refractive index (n) and extinction coefficient (k) (Evingür et al., 2020; Zaki et al., 2023). Although these parameters provide a shared language for comparing different materials, cross-study comparison becomes difficult when methodological details are inconsistent. A major issue is that Eg estimation is strongly dependent on the analytical model, most notably the Tauc approach, and on assumptions about the transition type (direct vs indirect) and the chosen linear fitting region (Siddhartha et al., 2011). Therefore, reported Eg shifts can reflect both genuine physical changes in irradiated polymers and differences in analysis protocols, meaning that Eg is useful as a compact descriptor of absorption-edge behavior but requires careful interpretation in methodologically rigorous synthesis (Zaki et al., 2023).

Diversity in polymer identity and formulation adds another layer of complexity. Neat polymers such as EVA or ultrahigh molecular weight polyethylene (UHMWPE) are often described as showing relatively small optical responses within certain dose windows, whereas PVA- or PEO-based systems incorporating ionic dopants, colorimetric dyes, or nanoparticles tend to exhibit stronger and more traceable optical changes (Halder et al., 2015; Hejazy & Hammad, 2024). This contrast is not only a matter of polymer chemistry but also reflects interactions among the matrix, additives, and irradiation environment. Oxide, sulfide, or carbon-based nanoparticles can introduce additional energy states, promote absorbing-center formation, and alter electron relaxation pathways under irradiation (Ngono-Ravache et al., 2016; Laxmayyaguddi et al., 2018). In dosimeter films, indicator dyes are selected for their reactivity with radiation-induced radical species, which amplifies optical response and improves practical signal detectability (Fahim & El-Kelany, 2016). As a result, the literature spans a wide spectrum, ranging from fundamental degradation-focused studies to research explicitly aimed at engineering optically responsive functional materials (Rammah et al., 2019; Evingür et al., 2020).

At the level of irradiation conditions, total dose, dose rate, atmosphere (air vs inert gas), temperature, and post-irradiation time can shift the dominant mechanisms that govern optical change. In oxygen-rich environments, gamma irradiation can enhance oxidative pathways and introduce new functional groups that influence optical and mechanical properties, whereas inert conditions may suppress oxidative contributions (Mouaci et al., 2017; Adenan et al., 2015). At low-to-moderate doses, optical response may be dominated by radical formation and localized rearrangements that modify absorption tails and produce gradual UV–Vis spectral changes (Ferreto et al., 2014; Mouaci et al., 2017). At higher doses, accumulated defects and network-level modifications may become large enough to produce visible color changes and more pronounced shifts in derived parameters such as Eg (Maio et al., 1997; Beeson & Mayhan, 1972). However, treating optical response as a simple function of dose can be misleading because studies at nominally similar doses can report different outcomes when atmosphere or formulation differs. For synthesis, this implies that evidence should be structured around comparable experimental contexts rather than dose values alone (Zhu et al., 2023; Mironova, 2022).

Between 2020 and 2025, publications on gamma-irradiation effects on polymer optical properties have expanded but not necessarily in a linear pattern, and the evidence base reflects heterogeneous material choices and aims. Many studies focus on highly processable platforms such as PVA, producing multiple variations of composite films, hydrogels, and dosimeter systems designed to be optically responsive. Other studies examine engineering polymers where irradiation is treated as one lever in broader property-tuning strategies, often alongside specific nanofillers. Meanwhile, multilayer systems and application contexts that demand optical stability treat “small changes” as meaningful compatibility evidence rather than as weak results (Doyan et al., 2021; Bekhit et al., 2021).

Against this background, this study aims to synthesize experimental evidence (2020–2025) on how gamma irradiation affects the optical properties of diverse polymer systems, emphasizing how responses vary by polymer type, formulation (neat, blend, composite, hydrogel, and functional films), irradiation conditions, and characterization approaches. More specifically, the study addresses the following research questions:

1. How do UV–Vis behavior, color changes, and derived optical parameters in polymers change after gamma irradiation?
2. To what extent do polymer type and material architecture moderate the direction and magnitude of optical response across dose levels?
3. Under what conditions should optical changes be interpreted as undesirable degradation or stability loss, versus a functional response exploitable for dosimetry or film-performance engineering?
4. How do methodological differences, particularly in Eg estimation, influence cross-study comparability?

The novelty of this study is its explicit synthesis of gamma-irradiation-induced optical changes in polymers through an endpoint-aware and context-sensitive framework, rather than treating all optical variation as a uniform marker of degradation. Prior studies have commonly examined gamma-induced optical change through specific application pathways such as dosimetric films and radiation-sensing systems (Eid et al., 2014; Doyan et al., 2021; Fahim & El-Kelany, 2016), stability-sensitive packaging or compatibility contexts (Sabbaghizadeh et al., 2017; Bekhit et al., 2021), or particular polymer families with matrix-specific response profiles such as EVA- and UHMWPE-based systems (Halder et al., 2015; Hejazy & Hammad, 2024). In contrast to this fragmented pattern, the present review integrates diverse polymer architectures, including neat polymers, blends, composites, hydrogels, multilayer films, and functional dosimeter systems, within a single analytical structure. In addition, this study offers methodological novelty by critically positioning optical band gap (Eg) not as a universally comparable standalone parameter, but as a model-dependent descriptor whose interpretation must be linked to transition assumptions and fitting procedures (Siddhartha et al., 2011; Zaki et al., 2023). By combining material type, formulation, irradiation conditions, application intent, and analytical method into one systematic synthesis, this review provides a more differentiated understanding of when optical change should be interpreted as functional responsiveness, compatibility evidence, or genuine optical degradation.

METHODS

Study Design and Reporting Standard

This study was conducted as a systematic literature review and reported in accordance with the PRISMA framework (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). PRISMA was adopted to ensure that identification, screening, full-text eligibility assessment, and inclusion of studies were documented transparently and reproducibly. The review synthesizes experimental evidence on how gamma irradiation affects the optical properties of polymeric materials, emphasizing how responses vary across polymer types, material formulations, and irradiation conditions.

Data Source and Time Window

Scopus was used as the sole bibliographic database. This restriction was applied to maintain methodological consistency because Scopus provides standardized indexing and stable metadata fields that support reproducible query execution. This choice also bounds the evidence base to Scopus-indexed records, meaning relevant studies not captured by Scopus are outside the scope of the present synthesis. The search and eligibility window was limited to publications from 2020 through 2025 in order to focus on contemporary experimental practice and current conventions in optical-property reporting and analysis.

Search Strategy

A single comprehensive Boolean search string was used to capture three core concepts: (i) gamma irradiation exposure, (ii) polymeric materials (including representative polymer names), and (iii) optical outcomes and common optical descriptors. The exact Scopus search string was: (“gamma irradiation” OR “gamma radiation” OR “Co-60”) AND (polymer OR polymeric OR “polymer film” OR PMMA OR PVC OR PVA OR PET) AND (“optical properties” OR UV-Vis OR absorbance OR transmittance OR “band gap” OR “Urbach energy” OR “refractive index”).

To maximize recall, no Scopus filters were applied for subject area, document type, source type, or language. This strategy intentionally increases the number of non-relevant records at the identification stage; therefore, relevance was determined through explicit inclusion and exclusion criteria during screening and full-text assessment rather than through database-level restrictions.

PRISMA Flow and Study Selection Process

Study selection followed the four-stage PRISMA workflow, summarized in Figure 1.

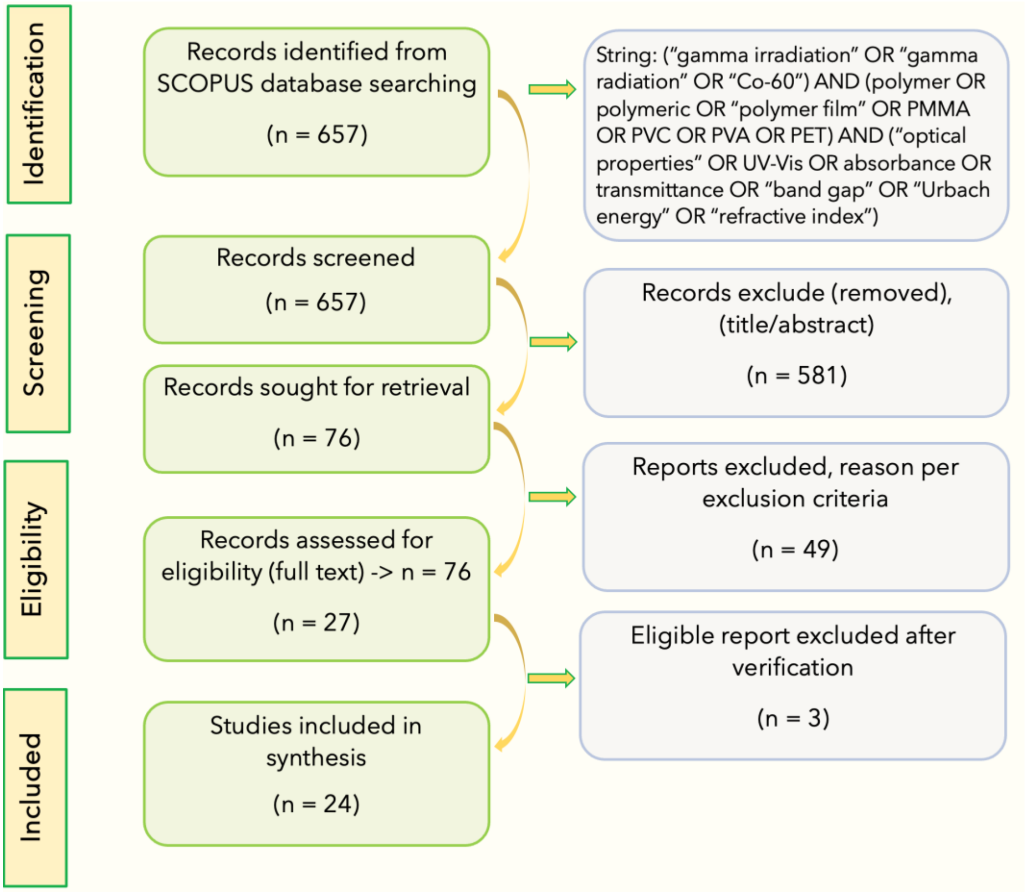

Figure 1. PRISMA flow diagram of study selection from Scopus (2020–2025): 657 records identified, 76 full texts assessed, and 24 studies included in the synthesis

Figure 1 presents the PRISMA flow diagram of study selection from Scopus (2020–2025): 657 records identified, 76 full texts assessed, and 24 studies included in the synthesis.

1. Identification. The Scopus search returned 657 records for the 2020–2025 publication window. Because records were retrieved from a single database using one query and the exported set contained no duplicates, duplicate removal was not required.
2. Screening. Titles and abstracts of all 657 records were screened against the predefined inclusion and exclusion criteria. Screening retained 76 records for full-text assessment and excluded 581 records because they did not match the review scope (e.g., not polymer-based, not gamma irradiation, not primary experimental research, or not reporting optical outcomes).

3. Eligibility (full-text assessment). Full texts were assessed for the 76 retained records. Forty-nine records were excluded at this stage due to failure to meet one or more eligibility criteria (e.g., gamma dose not reported, optical data not extractable, non-primary publication type, or irradiation modality not being gamma). Twenty-seven reports met the eligibility criteria after full-text assessment.
4. Inclusion. Final verification was applied to the 27 eligible reports to ensure strict alignment with the review scope (polymer systems exposed to gamma irradiation). Three reports were excluded at this step because they were determined not to be polymer–gamma irradiation studies. The final dataset therefore comprised 24 studies included in the qualitative synthesis.

Eligibility Criteria (Inclusion and Exclusion)

Eligibility criteria were defined prior to screening to reduce selection bias and to support comparability across studies. Inclusion criteria. Studies were included if they met all of the following conditions:

1. Primary, experimental research article published in a peer-reviewed journal with full text available.
2. Publication year within 2020–2025.
3. Investigated material was a polymer system (neat polymer, polymer blend, or polymer-based composite) with the polymer as the primary matrix; films, bulk specimens, and fibers were eligible.
4. Exposure used gamma irradiation (e.g., Co-60 or Cs-137), and absorbed dose was explicitly reported (kGy or MGy).
5. Reported at least one extractable optical outcome, such as UV–Vis absorbance/transmittance, absorption-edge shift, optical density or color indicators, optical band gap (including Tauc-based estimates), Urbach energy, refractive index, extinction coefficient, or photoluminescence outcomes.
6. Provided minimum methodological information for interpreting and comparing optical outcomes, such as UV–Vis wavelength range or the approach used to estimate optical band gap (including direct versus indirect transition assumptions where applicable).

Exclusion criteria. Studies were excluded if any of the following applied:

1. Radiation modality was not gamma (e.g., electron beam, UV, X-ray, ion irradiation) and gamma-specific outcomes were not separable.
2. Publication type was not primary experimental research (e.g., review, editorial, book, or conference proceedings lacking adequate experimental detail).
3. Optical outcomes were not reported, or optical claims were not supported by extractable data (e.g., narrative statements without readable spectra, scales, or numerical values).
4. Gamma dose was not reported or irradiation parameters were not identifiable.
5. Duplicate datasets were identified across multiple publications; in such cases, only the most complete and clearly reported study was retained.

A key methodological point is that optical band gap estimation depends on the analytical model (commonly Tauc formalism) and assumptions regarding transition type (direct vs indirect). Because these assumptions can influence reported Eg values, studies were not excluded solely for using different band-gap models. Instead, the model and assumptions were treated as analytical variables and were captured for interpretation during synthesis.

Data Extraction and Coding Procedure

A structured extraction form was used to collect comparable information from each included study. Extracted items included:

1. Bibliographic information: author(s), year, and journal.
2. Material characteristics: polymer type, whether neat/blend/composite, sample form (film/bulk/fiber where reported), and composition details such as filler type, additive content, or blend ratios.
3. Gamma irradiation parameters: radiation source when specified, total absorbed dose, and supporting parameters when reported (dose rate, irradiation atmosphere, irradiation temperature, and post-irradiation storage/aging time).
4. Optical measurement details: technique(s) used (e.g., UV–Vis, photoluminescence, refractometry), measurement wavelength range, sample thickness when provided, and analytical procedures used to derive optical parameters (including band-gap estimation approach and assumptions).
5. Optical outcomes: qualitative and/or quantitative changes in absorbance/transmittance, absorption-edge behavior, optical density or color indicators, band-gap-related results, optical constants (e.g., refractive index, extinction coefficient), and related dielectric descriptors where reported.

When results were presented only as figures, numerical values were recorded only when axis scales and relevant points were clearly readable. Otherwise, outcomes were coded qualitatively (e.g., "Eg decreases with dose" or "absorbance increases with dose") while maintaining traceability to the reported figures and text, minimizing artificial precision.

Study Quality and Risk-of-Bias Considerations

Although the review was designed as a qualitative synthesis rather than a meta-analysis, reporting quality influences interpretive confidence. Each included study was assessed using a transparency-oriented checklist covering: (i) clarity of irradiation reporting (dose and key conditions), (ii) transparency of optical methods (measurement range and analytical steps), (iii) clarity of band-gap estimation (Tauc approach and direct/indirect assumptions where stated), (iv) adequacy of optical data presentation (spectra/tables/extractable values), and (v) internal consistency of mechanistic interpretation when used to explain optical outcomes. Studies were not excluded based on quality scoring alone; instead, reporting quality was used to weight confidence when synthesizing and comparing findings.

Data Synthesis Approach

Given heterogeneity across polymer classes, formulations, irradiation conditions, and analytical approaches, synthesis was conducted as a structured narrative synthesis. Studies were grouped by polymer type and by optical outcome domains (UV–Vis absorbance/transmittance and related spectral behavior, absorption-edge and band-gap-related reporting, optical constants and dielectric-related outcomes, and application-oriented optical responses where relevant). Within each domain, the direction and, where available, the magnitude of changes were compared in relation to dose and contextual parameters (e.g., additives and reported irradiation conditions). Band-gap comparisons were treated cautiously:

empirical spectral trends were prioritized, and absolute Eg values were interpreted in light of the stated estimation approach and assumptions. A formal meta-analysis was not planned because the included studies were not expected to provide sufficiently homogeneous designs and outcome definitions for quantitative pooling.

RESULTS AND DISCUSSION

Study Selection (PRISMA)

A total of 657 records were identified from Scopus for the 2020–2025 period, and no duplicates were reported in the retrieved set. The full selection pathway and record counts at each stage are summarized in Figure 1. The title and abstract screening step was then applied to all identified records using the predefined inclusion and exclusion criteria, with particular emphasis on ensuring that the study concerned polymer-based systems, used gamma irradiation as the exposure modality, and reported at least one extractable optical outcome. This screening process retained 76 records for full-text assessment and excluded 581 records because they did not fit the review scope or failed to satisfy key eligibility requirements at the title/abstract level, such as being unrelated to polymers, focusing on non-gamma irradiation modalities without separable gamma results, representing non-primary publication types, or lacking optical-property reporting.

The full-text eligibility assessment was conducted for the 76 reports, leading to the exclusion of 49 articles due to reasons aligned with the exclusion criteria, including insufficiently reported irradiation parameters (especially missing dose information), absence of extractable optical data (for example, claims not supported by readable spectra or numerical values), or publication formats that did not provide adequate experimental evidence. After this step, 27 reports met the eligibility criteria and were classified as eligible. A final verification step was subsequently applied to ensure strict compliance with the central scope of this review, namely polymer systems exposed to gamma irradiation; during this verification, 3 reports were excluded because they were determined not to be polymer–gamma irradiation studies. As a result, 24 studies were ultimately included in the qualitative synthesis and carried forward to data extraction and narrative comparison of optical outcomes across polymer types and irradiation conditions.

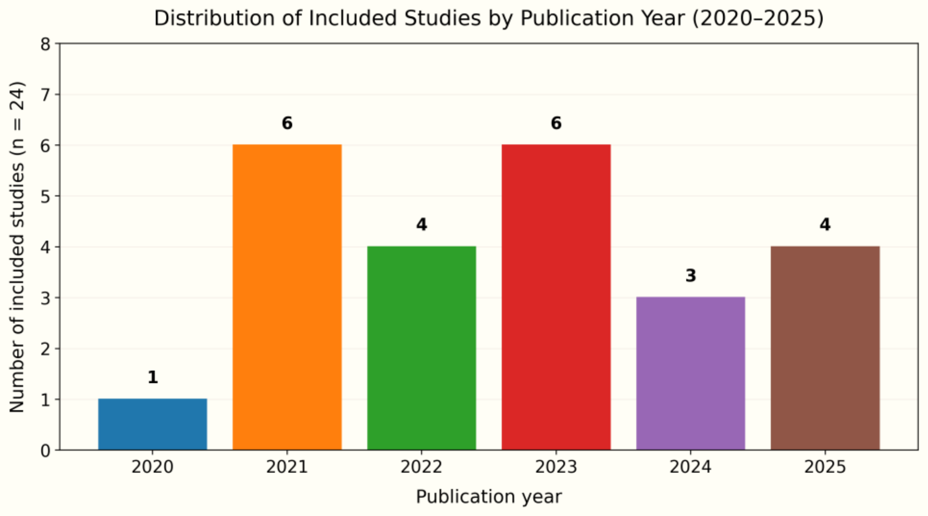

Figure 2. Distribution of included studies by publication year (2020–2025; n = 24).

Figure 2 shows the distribution of the included studies (n = 24) by publication year across 2020–2025, and the pattern does not indicate a steady year-to-year increase. Only 1 study was published in 2020, followed by a sharp rise to 6 studies in 2021. The number then dropped to 4 studies in 2022, before returning to the same peak level of 6 studies in 2023. Descriptively, this suggests that research outputs on gamma irradiation effects on polymer optical properties tend to fluctuate and cluster in certain years rather than grow linearly over the entire period.

In the final two years of the review window, the publication counts remained moderate, with 3 studies in 2024 and 4 studies in 2025. Consequently, the strongest concentration of included studies occurred in 2021 and 2023, while other years contributed fewer studies. This distribution should be interpreted cautiously: it reflects the temporal profile of the specific Scopus-derived corpus that met the predefined eligibility requirements, rather than serving as a definitive indicator of global research growth, particularly given the database restriction and the requirement that irradiation parameters and extractable optical outcomes be clearly reported.

Material Characteristics of Included Polymer Systems

The material characteristics of the reviewed studies show a clear dominance of PVA-derived polymer systems, spanning composite films, nanocomposites, hydrogels, and functional dosimetry materials, as summarized in Table 1. This dominance is meaningful because it indicates where the experimental emphasis sits within the 2020–2025 Scopus-derived corpus: many included studies rely on a matrix that is easy to process into thin films or gels and that can host optically active additives.

Table 1. Material characteristics of the included polymer studies (n = 24)

No	Author(s) & Year	Polymer matrix/ system	System type	Key additive/ dopant
1	Radojković et al., 2025	PVA-based hydrogel actuator (PNiPAAm/PVA bilayer)	Composite / hydrogel	Au nanoparticles (nanospheres/ nanorods)
2	Wechakorn et al., 2025	PVA composite film	Composite film	Carbon dots (water hyacinth-derived)
3	de Medeiros et al., 2025	EVA	Neat polymer	None reported
4	de Oliveira et al., 2025	PMMA	Composite / nanofilled	Mg-layered double hydroxide (LDH)
5	Alshahrani et al., 2024	PVC	Nanocomposite film	CeO_2 + TiO_2 nanoparticles
6	Kamoun et al., 2024	PEVA	Composite	Conductive copper fluoroborate glass powder
7	Lima et al., 2024	PVA	Nanocomposite film	Histidine-modified reduced

No	Author(s) & Year	Polymer matrix/ system	System type	Key additive/ dopant
				graphene oxide (H-RGO)
8	Baghirov et al., 2023	GO/PVA	Composite	Graphene oxide (GO)
9	Bambal et al., 2023	Chitosan; sodium alginate	Neat biopolymers	None reported
10	Guimarães et al., 2023	PVC	Nanocomposite	ZnS nanoparticles + compatibilizer
11	Ni et al., 2023	EVA/EVOH/EVA multilayer	Multilayer film	EVOH barrier layer
12	Qwasmeh et al., 2023	PEO	Doped polymer film	Potassium iodide (KI)
13	Rabaeh et al., 2023	PVA film dosimeter	Functional film (dosimeter)	MMT tetrazolium dye
14	Gharbi et al., 2022	PVA-based nanocomposite	Nanocomposite film	Lignosulfonate + Pd nanoparticles
15	Hariyanti et al., 2022	PVA–gelatin	Hydrogel (blend/network)	Gelatin
16	Mahrous et al., 2022	Polycarbonate (Makrofol/PC)	Nanocomposite film	CdS nanoparticles
17	Petisiwaveth et al., 2022	PVA/Ag hybrid	Functional nanomaterial (dosimeter)	Ag nanoparticles (from $AgNO_3$)
18	Abramowska et al., 2021	Starch: PVA	Blend film	Starch
19	Doyan et al., 2021	PVA-based film	Functional film (dosimeter)	Trichloroethylene (TCE) + cresol red dye
20	Ogiwara et al., 2021	Liquid crystal polymer composite (HPDLC-type)	Composite / polymer network	Liquid crystal phase
21	Rahaman et al., 2021	PM-355 polymer	Neat polymer (with post-treatment)	Chemical etching (process)
22	Rizwan et al., 2021	UHMWPE	Neat polymer (modeled)	Not specified in summary
23	Susilawati et al., 2021	PVA–H_3PO_4	Blend film	Phosphoric acid (H_3PO_4)
24	El-Kader et al., 2020	PEO/PVA	Nanocomposite	CuO nanoparticles

Within the PVA-centered subset, the matrix is frequently paired with carbon-based fillers that are commonly used to tune absorption behavior and irradiation sensitivity. Representative examples include a PVA–carbon dots composite film (Wechakorn et al., 2025), GO/PVA composites (Baghirov et al., 2023), and a PVA nanocomposite film incorporating histidine-modified reduced graphene oxide (Lima et al., 2024). This means a substantial part of the evidence base reflects engineered composite platforms rather than neat-polymer baselines.

A second recurring PVA pattern is functional dosimetry or optical sensing, where formulations are explicitly designed to convert dose into an optical signal. Examples include tetrazolium-dye dosimeter films (Rabaeh et al., 2023), Ag-nanoparticle-containing PVA hybrids used for dose response (Petisiwaveth et al., 2022), and a dye-containing PVA-based film system (Doyan et al., 2021). This concentration of dosimetric studies implies that "optical response" in the included literature is often operationalized as a measurable signal change, not only as a mechanistic proxy such as an absorption-edge shift.

PVA also appears as a hydrogel-network material where irradiation is linked to network formation and functional performance, rather than only film optics. This includes a PVA–gelatin hydrogel system (Hariyanti et al., 2022) and a PVA-based bilayer hydrogel actuator containing Au nanoparticles (Radojković et al., 2025). These hydrogel cases broaden the corpus, but they also make direct comparison with UV–Vis-centric film studies less straightforward because the architecture and intended function differ.

Beyond PVA, EVA/PEVA/EVOH systems form another material cluster that is closer to irradiation compatibility and stability contexts than to optical-sensing design. This group includes neat EVA (de Medeiros et al., 2025), a PEVA composite containing conductive copper fluoroborate glass powder (Kamoun et al., 2024), and multilayer EVA/EVOH/EVA films with an EVOH barrier layer (Ni et al., 2023). In these systems, modest or absent optical changes should be interpreted as potentially meaningful evidence of stability under dose windows relevant to application contexts, rather than as uninformative null results.

Engineering polymers and related systems in the corpus are also predominantly studied as composites or doped films, reinforcing that formulation design is a central theme across polymer classes. PVC appears only as nanocomposites with oxide or sulfide fillers (Alshahrani et al., 2024; Guimarães et al., 2023), PMMA appears as an LDH-filled composite (de Oliveira et al., 2025), and polycarbonate is examined as a CdS-containing nanocomposite film (Mahrous et al., 2022). PEO likewise appears in doped or composite form (Qwasmeh et al., 2023; El-Kader et al., 2020), implying that many reported optical outcomes are mediated by additive–matrix interactions as well as irradiation.

Finally, the corpus includes materials and study framings where "optical properties" are not primarily reported through conventional UV–Vis film parameters, which increases heterogeneity. This includes holographic grating behavior in a liquid-crystal polymer network composite (Ogiwara et al., 2021), optical/light-transport modeling in UHMWPE (Rizwan et al., 2021), a PM-355 polymer study incorporating chemical etching as a processing factor (Rahaman et al., 2021), and biopolymer studies where degradation is central (Bambal et al., 2023). Taken together, the material characteristics support a cautious synthesis strategy: conclusions are most defensible when stratified by formulation type (neat, blend, composite, functional dosimeter) and by study intent (optical response engineering versus irradiation compatibility), rather than treating all polymer systems as directly comparable.

Gamma Irradiation Dose Ranges and Optical Characterization Approaches

Gamma irradiation conditions across the included corpus span conventional material-modification doses through to severe radiation-resistance testing, and the dose coverage is strongly patterned by polymer-matrix group, as summarized in Table 2. PVA-based systems dominate the low-to-moderate kGy space, with many studies reporting dose series that fall roughly in the 1–50 kGy range and, in several cases, extending into higher windows (50–150 kGy and up to about 250 kGy), reflecting both mechanistic studies on optical change and purpose-built dosimetry responses (Rabaeh et al., 2023; Petisiwaveth et al., 2022; Doyan et al., 2021; Baghirov et al., 2023). EVA/PEVA/EVOH systems cluster around sterilization-relevant or compatibility-oriented doses (approximately 5–60 kGy), consistent with packaging and performance-stability framings rather than aggressive property-tuning (Ni et al., 2023; de Medeiros et al., 2025; Kamoun et al., 2024). PVC-based nanocomposites and polycarbonate-based systems mostly sit within tens to about 100 kGy, consistent with studies where irradiation is treated as one lever among several in composite engineering and structure–property analysis (Alshahrani et al., 2024; Guimarães et al., 2023; Mahrous et al., 2022). UHMWPE appears in a higher-dose context around 200 kGy but in a modeling-oriented study rather than a conventional spectroscopy-only design (Rizwan et al., 2021). One clear outlier is the liquid-crystal polymer-network grating study reporting a total dose of 1000 Mrad, which represents a severe exposure scenario that is not directly comparable to the kGy-range material-modification literature (Ogiwara et al., 2021).

Table 2. Polymer matrices, gamma dose ranges, and optical methods/outcomes emphasized in the included studies (n = 24)

Polymer matrix (grouped)	Representative polymer systems in the included corpus	Gamma dose range(s) reported (kGy unless stated)	Optical methods/outcomes explicitly indicated
PVA-based systems	PVA–carbon dots composite film; PVA-based dosimeter films; PVA–H_3PO_4 blend; starch: PVA blend; GO/PVA composites; PVA nanocomposites (e.g., with rGO, Pd-based fillers); PVA-based hydrogels/actuators	Low–moderate: 1–50; Moderate–high: 50–150; High: up to 250	UV–Vis absorbance/transmittance (frequent); colorimetric response (dosimetry); band-gap-related reporting in several studies; occasional refractive-index-related reporting
EVA/PEVA/ EVOH systems	Neat EVA; PEVA composites; EVA/EVOH/EVA multilayer films	5–60	UV absorbance below 300 nm (multilayer packaging); refractive index (EVA); optical/electrical property reporting in PEVA composites
PVC-based systems	PVC/CeO_2/TiO_2 nanocomposites; PVC/ZnS nanocomposites	Around 25–100	UV–Vis-related optical behavior; band gap / Urbach energy reporting appears in this group; structure–property emphasis in nanocomposites

Polymer matrix (grouped)	Representative polymer systems in the included corpus	Gamma dose range(s) reported (kGy unless stated)	Optical methods/outcomes explicitly indicated
PEO-based systems	PEO:KI polymer electrolyte films; PEO/PVA composites with CuO nanoparticles	50–250	Optical-property reporting including absorbance-derived parameters; band-gap-related reporting in doped electrolyte films
Polycarbonate-based systems	Makrofol (PC)/CdS nanocomposite films; PM-355 polymer	Around 50–100	UV–Vis / color-difference-type reporting (Makrofol-based); optical-structure indicators in PM-355 work (as described)
UHMWPE	Gamma-irradiated UHMWPE (light-transport/optical modeling context)	Around 200	Optical/light-transport modeling outcomes (photon absorption/transport descriptors)
Biopolymers	Chitosan; sodium alginate	5–100	Degradation-linked reporting; optical outcomes are not the primary emphasis in these studies
Liquid-crystal polymer composites	Polymer-network liquid crystal gratings (HPDLC-type)	1000 Mrad (very high total dose; reported in radiation units)	Holographic/grating optical response and radiation resistance (application-specific optics)

This distribution matters because dose is not just an intensity variable: it changes the dominant balance of mechanisms that plausibly drive optical response, and those mechanisms are also conditioned by polymer chemistry and formulation. In low-to-moderate kGy studies on PVA composites and blends, optical outcomes are often framed as progressive signal development (useful for sensing/dosimetry) or as dose-dependent spectral change that supports derived-parameter reporting (Petisiwaveth et al., 2022; Rabaeh et al., 2023; Susilawati et al., 2021; Baghirov et al., 2023). In higher-dose windows used in some composite designs, the same polymer family can be discussed through stronger shifts in absorbance behavior, coloration, or band-gap-related proxies, which is consistent with an evidence base that includes both “materials engineering” and “measurement-device” motivations inside the PVA-heavy subset (Wechakorn et al., 2025; Gharbi et al., 2022; Lima et al., 2024). Meanwhile, in packaging-oriented EVA/EVOH multilayers, the relevant question is often whether UV-screening metrics or discoloration remain within acceptable bounds across a sterilization-like dose range, so a smaller optical shift is not a weak result but can be an application-relevant stability indicator (Ni et al., 2023).

Optical characterization approaches align tightly with these dose-and-application clusters. Across the included corpus, UV–Vis-type reporting anchors most optical evidence, either explicitly through absorbance/transmittance behavior or implicitly via parameters that typically require UV–Vis spectra for estimation. PVA-based studies frequently use UV–Vis to quantify dose response and to support functional readouts (e.g., linear or monotonic optical-signal changes) in dosimeter films or sensing materials (Petisiwaveth et al., 2022; Rabaeh et al., 2023; Doyan et al., 2021). UV–Vis also underpins composite-film performance framings such as photoselective or UV-protective behavior, where the optical goal is not simply detecting change but controlling spectral transmission for an end-use context (Wechakorn et al., 2025). In EVA/PEVA/EVOH studies, UV absorbance below 300 nm and refractive index appear as stability-relevant indicators rather than as pathways to extract many derived electronic proxies (Ni et al., 2023; de Medeiros et al., 2025).

Composite and doped-film systems more often motivate band-gap-related reporting, consistent with studies where irradiation is interpreted through changes near the absorption edge and derived descriptors. This is visible in GO/PVA and rGO-containing PVA composites, KI-doped PEO films, and nanocomposite systems where filler–matrix interactions and irradiation are both treated as contributors to absorption-edge behavior (Baghirov et al., 2023; Lima et al., 2024; Qwasmeh et al., 2023). PVC nanocomposites similarly sit in a structure–property framing where optical change is one component of a broader composite response to irradiation (Alshahrani et al., 2024; Guimarães et al., 2023). By contrast, a modeled UHMWPE study reports optical behavior as photon/light-transport descriptors rather than standard spectroscopic outputs, making it methodologically important but not directly comparable to UV–Vis-derived parameter trends (Rizwan et al., 2021).

The outlier exposure level in the holographic grating study illustrates a separate comparability boundary: extremely high total dose is paired with application-specific optical endpoints rather than conventional UV–Vis metrics. In that setting, "optical response" is defined through device-like performance (radiation resistance of holographic gratings) and not through absorption-edge shifts or colorimetric dose response, so it should be synthesized as a distinct evidence strand rather than merged into kGy-range film optics narratives (Ogiwara et al., 2021). A similar, though less extreme, comparability issue appears for biopolymer degradation-focused studies, where the central endpoint is degradation behavior and optical outcomes are not the primary reporting axis, even if irradiation is present and relevant (Bambal et al., 2023).

Taken together, the Results indicate that the evidence base is best interpreted through stratified synthesis: dose windows and optical-method choices co-vary with polymer class and application intent. PVA-heavy studies provide dense coverage across low-to-high kGy ranges using UV–Vis and optical signal readouts, making them the strongest basis for discussing dose-dependent optical response under broadly comparable measurement conventions (Petisiwaveth et al., 2022; Rabaeh et al., 2023; Gharbi et al., 2022). EVA/PEVA/EVOH studies support a complementary claim about optical stability under compatibility-relevant doses rather than large optical modulation (Ni et al., 2023; de Medeiros et al., 2025). Composite systems in PVC, PEO, polycarbonate, and PMMA more often represent "property-tuning" contexts where filler type, dopant content, and analysis model choices interact with irradiation, which supports mechanistic discussion but also increases heterogeneity in how optical outcomes are defined and compared (Guimarães et al., 2023; Qwasmeh et al., 2023; Mahrous et al., 2022; de Oliveira et al., 2025).

Coverage of Optical Outcome Categories

Coverage of optical outcome categories in the included studies shows that the evidence base does not converge on a single standardized optical endpoint; instead, studies report a mix of empirical spectral responses, derived descriptors, and application-oriented optical readouts, as summarized in Table 3. UV–Vis absorbance/transmittance and UV-screening behavior appear frequently because polymer optical change under gamma exposure is often operationalized through spectrally observable attenuation, spectral-shape changes, or short-wavelength UV absorption relevant to protection and stability. This pattern is consistent with studies that frame irradiation effects via UV-region behavior in packaging-like multilayers (Ni et al., 2023) and in photoselective film contexts where UV-driven discoloration or preservation is central to the interpretation of performance (Wechakorn et al., 2025). In these cases, UV–Vis outcomes function as direct, instrument-based evidence of optical response, and they remain interpretable without relying on a single model-dependent parameter, provided that the wavelength range and reporting are adequately described.

Table 3. Coverage of optical outcomes across included studies

Number of studies (n)	Optical outcome category	Operational definition used in this review
4	UV–Vis absorbance/ transmittance or UV-screening behavior	Explicit reporting of UV–Vis absorbance/transmittance, UV absorbance (<300 nm), or photoselective/UV-filtering film performance
6	Optical band gap (Eg)	Explicit reporting of optical band gap/optical gap energy or direct–indirect transition band gap trends
1	Urbach energy (Eu)	Explicit reporting of Urbach energy
3	Refractive index (n)	Explicit reporting of refractive index
1	Extinction coefficient (k)	Explicit reporting of extinction coefficient
2	Dielectric/optical-constant–related outcomes	Explicit reporting of dielectric constant/loss in connection with optical-property interpretation
4	Color change/discoloration/ color difference	Explicit reporting of discoloration, color difference, or UV-related color preservation
2	Optical dosimetry response	Explicit dose–response behavior using an optical signal (absorbance/color) for sensing/dosimetry
2	Application-specific optics	Optical performance framed as device/application behavior (e.g., holographic grating resistance; actuator-related optical functionality)
1	Optical/light-transport modeling	Optical behavior assessed through photon/light-transport modeling rather than direct spectroscopy

A substantial subset of studies reports optical band gap (Eg) as a derived electronic/optical descriptor, and within the included corpus Eg is typically treated as dose-sensitive in composite and doped polymer films. This supports the view that gamma irradiation frequently modifies absorption-edge characteristics in ways that appear as reduced optical gap values under common extraction approaches. The trend is evident in nanocomposite and blend studies such as GO/PVA systems where Eg is reported to decrease under irradiation (Baghirov et al., 2023), doped polymer electrolyte films where Eg shifts with both dopant content and dose (Qwasmeh et al., 2023), and PMMA nanofilled systems where irradiation is discussed alongside reduced optical gap energy in a formulation-sensitive manner (de Oliveira et al., 2025). At the same time, Eg is inherently model-sensitive because it collapses spectral information into a single value and can vary with assumptions (for example, direct versus indirect transition choice), meaning that Eg trends are most defensible when paired with clearly reported UV–Vis spectra and explicit analytic assumptions, including when authors report both transition types (Doyan et al., 2021).

Optical constants and dielectric-related outcomes are reported less often but are methodologically important because they extend interpretation beyond absorption intensity and absorption-edge proxies to parameters tied to light–matter interaction and polarization response. Refractive index reporting illustrates that gamma exposure does not uniformly induce strong optical-constant shifts across all polymer chemistries and dose windows: an EVA-focused study reports refractive index as practically unchanged after irradiation within the tested range (de Medeiros et al., 2025). In contrast, optical-constant and dielectric descriptors are emphasized where irradiation effects are evaluated alongside electrical behavior, such as PVC-based nanocomposites and doped electrolyte films (Guimarães et al., 2023; Qwasmeh et al., 2023), and dielectric responses are also discussed in PEO/PVA composite systems containing nanoparticle additives (Abd El-Kader et al., 2020). Extinction coefficient is rarely treated as a named endpoint but appears explicitly in KI-doped PEO films where dose and dopant are discussed as concurrent drivers of optical-constant change (Qwasmeh et al., 2023). The selective reporting of these quantities implies that cross-polymer comparisons are often limited by inconsistent endpoint selection and reporting detail, not only by differences in dose coverage.

A notable portion of the corpus operationalizes optical response through visible color change, discoloration, or color-difference indicators, and a smaller but distinct subset focuses on optical dosimetry responses. This orientation is strongest where the polymer system is engineered to produce a monotonic optical signal as a function of dose, such as PVA-based dosimeter films incorporating dyes or nanoparticles (Rabaeh et al., 2023; Petisiwaveth et al., 2022; Doyan et al., 2021). Color-difference reporting also appears in nanocomposite contexts where irradiation-induced optical modification is visually apparent, supporting the idea that defect formation or new absorbing states can manifest strongly in the visible region even when mechanisms differ across materials (Gharbi et al., 2022; Mahrous et al., 2022). These outcomes can be highly comparable within dosimetry-focused formulations (signal versus dose) but are less directly comparable across heterogeneous materials unless measurement protocols (illumination, color space, and instrumentation) are stated clearly.

A smaller cluster of studies reports application-specific optics or modeling-based optical outcomes, which broadens the evidence base but complicates synthesis because the "optical endpoint" is embedded in device-level functionality rather than spectroscopy-derived parameters. Application-specific optics include optical performance framed as device behavior, such as radiation resistance of holographic gratings in polymer-network liquid crystal composites and actuator-related functionality in hydrogel actuator concepts (Ogiwara et al., 2021; Radojković et al., 2025). The single optical/light-transport modeling study provides a different kind of evidence by focusing on photon transport descriptors rather than direct optical spectra or constants (Rizwan et al., 2021). Taken together, the distribution of outcome categories supports a structured narrative synthesis: UV–Vis reporting and Eg provide the most common cross-study anchors, while optical constants, dielectric outcomes, colorimetric endpoints, and application-specific optics should be treated as complementary domains that require endpoint-aware interpretation rather than forced one-to-one comparison across all included polymer systems.

UV–Vis Spectral Response and Color-Related Changes

Table 4 summarizes the UV–Vis and color-related outcomes reported under gamma irradiation and shows that optical response is most often operationalized either as a dose-dependent spectral change (absorbance/transmittance, UV-screening behavior) or as a colorimetric signal that can be treated as a functional readout. Across the included corpus, two practical emphases emerge. One group of studies frames UV–Vis response as an application-relevant performance metric, such as UV-screening or photoselective function in polymer films. Another group treats irradiation-driven color or absorbance change as a quantifiable dose–response signal, which is especially visible in dosimetry-oriented formulations. This split matters for synthesis because the same empirical observation, such as increasing absorbance, can be interpreted either as improved UV attenuation or as an intentional sensor response, depending on the end-use context and material design (Wechakorn et al., 2025; Rabaeh et al., 2023; Petisiwaveth et al., 2022).

Table 4. Summary of UV–Vis and color-related outcomes under gamma irradiation

Polymer matrix group	Study	Gamma dose range	Optical endpoint(s)	Direction of change	Practical noted
PVA-based systems	Rabaeh et al., 2023	2–50 kGy	UV-Vis-based dosimetric response	Optical signal increases with dose	Suitable for high-dose dosimetry using an optical readout
PVA-based systems	Petisiwaveth et al., 2022	5–50 kGy	UV–Vis absorbance (colorimetric sensing)	Absorbance increases approximately linearly with dose	Sensitive dose–response for colorimetric gamma sensing
PVA-based systems	Wechakorn et al., 2025	50–150 kGy	Photoselective / UV-related	UV-related film	Enhanced photoselective

Polymer matrix group	Study	Gamma dose range	Optical endpoint(s)	Direction of change	Practical noted
			film performance	performance improved; UV-linked color change reduced	packaging film behavior
EVA/PEVA/ EVOH systems	Ni et al., 2023	Up to 60 kGy	UV absorbance (<300 nm); discoloration	UV absorbance is dose-dependent; discoloration reported stable up to 60 kGy	Irradiation compatibility window supported for multilayer films
Polycarbonate based systems	Mahrous et al., 2022	100 kGy	Color difference/ visible optical change	Color difference increases after irradiation	Clear irradiation-induced optical modification in nanocomposite film
PVA-based systems	Gharbi et al., 2022	Dose series (gamma-irradiated)	Color difference (permanent color change)	Strong color change after irradiation	Persistent optical response consistent with defect/color-center formation

In PVA-derived functional films, gamma exposure frequently produces monotonic optical signals that can be translated into sensing or monitoring logic. In PVA dosimeter films, the optical readout increases with dose, supporting calibration-type interpretations where larger doses map to stronger signals (Rabaeh et al., 2023). A similar pattern appears in PVA/Ag hybrid systems, where absorbance intensity correlates approximately linearly with dose, reinforcing that nanoparticle-enabled PVA matrices can convert irradiation into reproducible optical contrast (Petisiwaveth et al., 2022). Mechanistically, these patterns are consistent with progressive formation of radiation-induced absorbing centers or chemical transformations within the polymer–additive environment, but comparability still depends on reporting details such as wavelength window and how the optical signal is quantified (Rabaeh et al., 2023; Petisiwaveth et al., 2022).

In PVA composite films designed for photoprotection rather than sensing, gamma processing is reported in a different performance language. The carbon-dot composite film study emphasizes improved photoselective function and reduced UV-linked color change in a packaged-food context, which positions irradiation effects as enabling stability and protection rather than maximizing signal magnitude (Wechakorn et al., 2025). This is not directly comparable to dosimeter readouts because the success criterion is reduced discoloration (a suppressed failure mode), whereas in dosimetry formulations discoloration or absorbance growth is often the desired readout. This contrast implies that "color change" should not be treated as uniformly positive or negative across the corpus, because it depends on whether the material is engineered to resist visible alteration or to express it (Wechakorn et al., 2025; Ni et al., 2023).

Packaging-oriented multilayer systems further show that spectroscopic change does not automatically imply unacceptable optical degradation. In EVA/EVOH/EVA multilayer films, UV absorbance below 300 nm is dose-dependent, but discoloration was reported as stable up to the stated dose ceiling, supporting an interpretation where measurable UV–Vis shifts can coexist with application-level compatibility under sterilization-relevant exposures (Ni et al., 2023). This evidence challenges a blanket claim that gamma irradiation necessarily degrades optical performance across polymers. Instead, it supports a conditional view: response magnitude and practical significance are shaped by polymer chemistry, architecture (e.g., multilayers), and whether the target is stability under moderate doses or property-tuning in functional composites (Ni et al., 2023; de Medeiros et al., 2025).

Visible color-difference outcomes are also reported in nanocomposites where irradiation is framed as producing clear optical modification. In a polycarbonate (Makrofol/CdS) nanocomposite film, irradiation leads to significant color difference, indicating strong optical alteration that is likely tied to new absorbing states extending into the visible region (Mahrous et al., 2022). A related pattern is reported in a PVA-based nanocomposite formulation that exhibits strong, permanent color change after irradiation, consistent with persistent irradiation-induced absorbing centers (Gharbi et al., 2022). These studies broaden the UV–Vis narrative beyond UV-screening and dosimetry by showing that gamma exposure can also function as a route to durable optical alteration, which may be advantageous for some sensing concepts but problematic for transparency-critical applications (Mahrous et al., 2022; Gharbi et al., 2022).

Optical Band Gap (Eg)

Table 5 summarizes the optical band gap (Eg) evidence reported across the included studies that explicitly quantified Eg under gamma irradiation. As a group-level pattern, the direction of change is notably consistent: in the studies that reported dose-dependence, Eg most often decreased with increasing gamma dose, either reported directly as an Eg reduction or described as a lowering of optical gap energy inferred from UV–Vis-derived analyses. This pattern appears in PVA-derived systems such as GO/PVA composites and functional PVA films, in doped PEO films, and in composite engineering contexts such as PMMA with LDH nanofiller. Across these diverse matrices, Eg therefore functions as a shared derived proxy for irradiation-induced changes near the absorption edge, even though the underlying chemistries and material architectures differ (Baghirov et al., 2023; Doyan et al., 2021; Qwasmeh et al., 2023; de Oliveira et al., 2025).

Table 5. Reported trends in optical band gap (Eg) under gamma irradiation

Polymer matrix	Study	Gamma dose range (as reported)	Reported Eg trend with increasing dose	Notes on band-gap reporting stated in the study
PVA-based systems	Baghirov et al., 2023	25 kGy	Eg decreases with dose	Band-gap reduction reported with increasing

Polymer matrix	**Study**	**Gamma dose range (as reported)**	**Reported Eg trend with increasing dose**	**Notes on band-gap reporting stated in the study**
				gamma dose in GO/PVA composites
PVA-based systems	Lima et al., 2024	Dose series (gamma-irradiated)	Eg reduced (composite shows lower Eg)	H-RGO addition strongly lowers Eg; irradiation contributes to modification
PEO-based systems	Qwasmeh et al., 2023	50–150 kGy	Eg decreases with KI content and with dose	Dose and dopant jointly influence absorption-edge behavior
PVA-based systems	Doyan et al., 2021	1–20 kGy	Direct and indirect Eg decrease with dose	Both transition types explicitly reported as decreasing
PMMA-based systems	de Oliveira et al., 2025	Dose series (gamma-irradiated)	Optical gap energy decreases (with LDH + gamma)	LDH nanofiller plus gamma associated with reduced optical gap energy
PVC-based systems	Guimarães et al., 2023	25 kGy	Eg reported as modified under irradiation	Band-gap change discussed in nanocomposite context

Within PVA-derived systems, Eg reduction is reported in contexts where the polymer matrix is coupled to electronically active or defect-forming components, which plausibly amplifies edge-tail absorption after irradiation. In GO/PVA composites, the reported decrease in Eg with increasing dose is consistent with the idea that gamma exposure modifies the electronic/optical behavior of the composite, likely by increasing defect-related states or altering conjugation pathways at polymer–filler interfaces (Baghirov et al., 2023). A related logic appears in the PVA nanocomposite study incorporating histidine-modified reduced graphene oxide, where Eg is described as substantially reduced in the composite, and irradiation is treated as contributing to the overall modification profile rather than acting alone (Lima et al., 2024). In PVA-based functional films, Eg decreases were also reported under both direct and indirect transition assumptions, which matters methodologically: it implies that the directionality of Eg change (decrease with dose) can persist even when the transition model is varied within the same study, reducing the likelihood that the trend is only an artifact of a single modeling choice (Doyan et al., 2021).

Outside PVA, the Eg findings still converge on dose-associated reduction, but the interpretation should be more conditional because additives and dopants act as co-drivers. In doped PEO:KI thin films, Eg reportedly decreases with both KI content and irradiation dose, suggesting that the absorption edge is shaped by a combined “composition + dose” effect rather than a pure irradiation response (Qwasmeh et al., 2023). This is important for synthesis: if dopant concentration shifts Eg strongly, then cross-study comparison of absolute Eg values becomes fragile unless composition is aligned. Similarly, the PMMA system with LDH nanofiller reports lowered optical gap energy after irradiation in the presence of the filler, which positions Eg change as part of a composite-engineering outcome rather than a baseline PMMA irradiation effect (de Oliveira et al., 2025). The PVC/ZnS nanocomposite study is reported as having Eg "modified" under irradiation, but the summary-level phrasing is less specific about directionality than the other cases; as a result, it provides weaker directional evidence unless the full-text reports a clear monotonic dose response (Guimarães et al., 2023).

Taken together, the Eg results support a synthesis claim that is narrow but defensible: in the subset of polymer studies that explicitly report optical band gap under gamma exposure, the most commonly stated trend is a reduction of Eg with increasing dose, especially in composite and doped systems where irradiation likely interacts with filler-related or dopant-related electronic states (Baghirov et al., 2023; Qwasmeh et al., 2023; de Oliveira et al., 2025). At the same time, this pattern should not be overstated as universal across all polymers, because the evidence base is skewed toward formulations that are designed to be optically responsive (e.g., nanocomposites, doped films, and functional PVA systems) rather than toward neat polymers tested under harmonized optical analysis protocols (Lima et al., 2024; Doyan et al., 2021). This is precisely where the method decisions matter: Eg is model-dependent, and the strongest comparisons are those that interpret Eg trends alongside clearly reported analysis assumptions (as in the study reporting both direct and indirect transitions) rather than treating Eg as a single standardized endpoint across the entire corpus (Doyan et al., 2021).

Optical Constants and Dielectric-Related Outcomes

Table 6 compiles the subset of included studies that reported optical constants and/or dielectric-response metrics under gamma irradiation, showing that this evidence base is smaller than the UV–Vis and band-gap reporting corpus but is methodologically important because it targets parameters that directly describe light–matter interaction (refractive index, n, and extinction coefficient, κ) and polarization behavior (dielectric response, ε). Across the four studies captured here, refractive index was explicitly reported in three polymer-matrix groups (EVA, PVC-based nanocomposites, and doped PEO), while extinction coefficient was reported only in the doped PEO system. Dielectric outcomes were reported in three studies, spanning PVC nanocomposites, doped PEO films, and PEO/PVA composite systems, indicating that optical-constant reporting often appears in papers that treat gamma irradiation as part of a broader optical–electrical structure–property analysis (de Medeiros et al., 2025; Guimarães et al., 2023; Qwasmeh et al., 2023; El-Kader et al., 2020).

Table 6. Optical constants and dielectric-related outcomes reported under gamma irradiation

Polymer matrix group	Study	Gamma dose range	Reported			Key direction of change stated
			n	κ	ε	
EVA/PEVA/EVOH systems	de Medeiros et al., 2025	5–30 kGy	Yes	No	No	Refractive index stable within tested doses
PVC-based systems	Guimarães et al., 2023	25 kGy	Yes	No	Yes	Optical constants and dielectric behavior reported as modified under irradiation

Polymer matrix group	**Study**	**Gamma dose range**	**Reported**			**Key direction of change stated**
			n	κ	ε	
PEO-based systems	Qwasmeh et al., 2023	50–150 kGy	Yes	Yes	Yes	Absorption-related parameters and optical constants increase with dose/dopant
PEO/PVA composite systems	El-Kader et al., 2020	50–250 kGy	No	No	Yes	Dielectric constant and loss decrease with frequency under higher doses

A key result from this subset is that refractive index does not behave as a uniformly sensitive indicator of gamma exposure across polymer classes. In EVA, refractive index was described as practically unchanged over 5–30 kGy, supporting an interpretation of optical-constant stability within a sterilization-adjacent dose window for that material context (de Medeiros et al., 2025). By contrast, refractive-index change was discussed in a PVC/ZnS-type nanocomposite context alongside broader optical-property modification, which is consistent with the idea that composite architectures and filler–matrix interfaces can amplify measurable optical-constant shifts under irradiation even when neat polymers show smaller changes (Guimarães et al., 2023). The PEO:KI system further illustrates that refractive index can increase when irradiation is coupled with ionic doping, aligning with a scenario where increased absorption-related parameters and modified electronic structure proxies coincide with a higher effective optical density (Qwasmeh et al., 2023).

Extinction coefficient reporting was rare but informative in the doped PEO film study, where k increased with KI content and dose alongside increases in absorption-related metrics. Interpreted cautiously, this pattern is internally consistent with stronger light attenuation in the measured spectral region and with irradiation-plus-dopant conditions that promote defect-related absorption or broadened absorption tails, which would be expected to elevate k when derived from UV–Vis-type optical analysis (Qwasmeh et al., 2023). The absence of extinction-coefficient reporting in the other studies in Table 6 is also a practical result: it suggests that many polymer–gamma investigations still prioritize spectra, color metrics, or band-gap proxies over full optical-constant extraction, which limits cross-study comparability for n and k as shared endpoints.

Dielectric outcomes add a complementary dimension because they link irradiation effects to polarization response and, in some systems, to coupled optical–electrical behavior rather than optics alone. In the CuO-doped PEO/PVA composite system, dielectric constant and dielectric loss were reported to decrease with frequency under higher doses, a pattern that points to irradiation-modulated dielectric behavior within a composite that is also framed by functional nanoparticle inclusion (El-Kader et al., 2020). In the PVC nanocomposite study, dielectric behavior was reported as modified under irradiation in parallel with optical-constant changes, reinforcing that the studies reporting dielectric metrics often aim to interpret gamma effects through an integrated structure–property lens (Guimarães et al., 2023). Taken together, this subset indicates that optical constants and dielectric response are not routinely reported across the corpus, but when they are reported, they provide higher-level descriptors that help distinguish "spectral change" from more general modifications to optical density, absorption strength, and polarization behavior under gamma irradiation (Qwasmeh et al., 2023; El-Kader et al., 2020).

CONCLUSION

This review synthesizes Scopus-indexed experimental studies published between 2020 and 2025 to clarify how gamma irradiation alters the optical properties of polymer systems and how interpretation depends on material architecture, formulation, irradiation context, and analysis choices. Across the included evidence base, the most recurrent empirical pattern is a dose-associated modification of UV–Vis spectra and/or visible appearance in systems that are intentionally engineered to be optically responsive. Many studies operationalize response as increased absorbance, an absorption-edge shift, and measurable color change, especially in PVA-centered films and composites designed for sensing or functional optical output. When derived parameters are reported, optical band gap (Eg) is frequently described as decreasing with dose in composite and doped films, consistent with strengthened absorption tails and the emergence of additional absorbing states. By contrast, optical constants and dielectric-linked descriptors are less consistently reported across studies; where refractive index is measured, it can remain essentially stable within application-relevant dose windows for some neat polymers, while doped or nanofilled systems more often report meaningful shifts in optical-constant-related behavior.

Regarding moderation by polymer type and material architecture, the direction and magnitude of optical response do not appear uniform across polymer classes or specimen designs. Neat or packaging-oriented architectures (notably EVA-based and multilayer EVA/EVOH/EVA systems) more often treat the central question as optical compatibility under sterilization-adjacent doses, meaning that small spectral changes or stable discoloration can represent practically meaningful stability evidence rather than weak effects. In contrast, PVA- and PEO-based platforms that incorporate dyes, ionic dopants, or nanoparticles typically show stronger, more traceable dose dependence in UV–Vis and color metrics, which supports their frequent use in dosimetry and radiation-sensing designs. Composite engineering systems in PVC, PMMA, and polycarbonate similarly emphasize additive–matrix interactions, where filler chemistry and interfaces plausibly amplify irradiation-induced optical changes, but these studies also increase heterogeneity because the same "polymer class" is rarely examined in a neat baseline form under matched conditions. Consequently, the most defensible cross-study statements are stratified: optical responses are more consistently strong and monotonic in engineered/doped composites, while stability claims are more credible within neat or multilayer systems evaluated under comparable application dose windows.

A key interpretive result is that optical change is not intrinsically "good" or "bad"; it becomes degradation or functional performance depending on the intended application and on the design logic of the material. In dosimetry-oriented films, irradiation-induced increases in absorbance or systematic color development are advantageous because they enable calibrated dose readout and practical signal detectability. In transparent packaging and optoelectronic contexts, the same trends may represent optical degradation, because haze, yellowing, or reduced transparency at relevant wavelengths can directly undermine performance. The literature often reports both orientations within the same broader topic area without making the distinction explicit, which helps explain why similar observations can be framed as either improved functionality (for sensing) or impaired quality (for stability-critical uses). Therefore, synthesis should treat "response" and "stability" as separate evaluative frames rather than forcing a single evaluative label onto irradiation-induced optical change.

Finally, cross-study comparability is constrained not only by differences in polymer systems and irradiation conditions but also by methodological variation in optical analysis, especially Eg estimation. Eg is frequently derived using Tauc-type approaches that depend on assumptions about transition type (direct versus indirect) and on the chosen fitting region; as a result, reported Eg shifts may reflect a combination of genuine material modification and analysis protocol choice. The most interpretable evidence is produced when Eg trends are contextualized by clearly presented UV–Vis spectra and when analytic assumptions are stated explicitly (including cases where both direct and indirect transitions are examined within the same study). Accordingly, future evidence synthesis and primary studies would benefit from more standardized reporting of optical measurement ranges, sample thickness where relevant, irradiation atmosphere and dose rate, post-irradiation timing, and explicit band-gap extraction choices. With these reporting improvements, the field would be better positioned to distinguish robust, material-driven optical trends from model-dependent variability and to translate irradiation–optics relationships into either reliable dosimetry designs or credible stability windows for polymer applications.

LIMITATION

This review is reproducible but constrained because it relies on Scopus as the only database and on one Boolean query, so relevant studies outside Scopus coverage or using different terminology may have been missed. The included corpus is highly heterogeneous in polymer type, formulation, additives, dose window, atmosphere, dose rate, post irradiation time, and optical endpoints, which limits strict cross study comparability and makes quantitative pooling inappropriate. In addition, optical band gap Eg is analysis dependent because it varies with the transition assumption and the fitting choices used to extract Eg from UV–Vis data, so reported Eg shifts can partly reflect analytical decisions rather than only radiation induced physical changes.

RECOMMENDATION

Future reviews should broaden retrieval beyond a single database and predefine a protocol that stratifies synthesis by polymer class and application intent, separating optical stability studies from dosimetric response engineering studies. Primary studies should report irradiation and optical methods using a consistent minimum set, including source, total dose, dose rate, atmosphere, temperature, and post irradiation timing, as well as UV–Vis wavelength range, sample thickness or optical path length, and how scattering or baseline corrections are handled. For Eg reporting, authors should state the transition assumption, provide a transparent fitting rule, and when defensible report results under more than one transition assumption so readers can judge robustness. Finally, optical trends should be paired with corroborating characterization such as FTIR for oxidation, XRD or DSC for crystallinity changes, and ESR or XPS when relevant, so mechanistic interpretations are supported by direct evidence.

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REFERENCES

Abramowska, A., Wawro, D., Niekraszewicz, B., & Sztajnowski, S. (2021). Influence of electron beam and gamma irradiation on properties of starch/PVA films. *Radiation Physics and Chemistry, 183*, 109440. https://doi.org/10.1016/j.radphyschem.2021.109440

Adenan, M., Ahmad, M., Noor, N., & Saion, E. (2015). A study of N-isopropyl acrylamide (NIPAM)-based polymer gel dosimeter by using Raman spectroscopy. *Advanced Materials Research, 1107*, 103–107. https://doi.org/10.4028/www.scientific.net/amr.1107.103

Alshahrani, H. A., Ahmed, M. A., & Abdelrazek, E. M. (2024). Gamma irradiation impact on the structural and optical properties of PVC/CeO_2/TiO_2 nanocomposite films. *Journal of Inorganic and Organometallic Polymers and Materials, 34*(1), 152–166. https://doi.org/10.1007/s10904-023-02746-4

Baghirov, N. M., Ismailov, A. A., Rasulova, F. S., & Sadigova, S. I. (2023). Optical properties and band gap of GO/PVA nanocomposites under gamma irradiation. *Radiation Physics and Chemistry, 205*, 110709. https://doi.org/10.1016/j.radphyschem.2023.110709

Bambal, D., Bhat, P., Sharma, S., & Kumar, A. (2023). Gamma irradiation-induced degradation of chitosan and sodium alginate: Effect of dose on molecular weight. *Radiation Physics and Chemistry, 204*, 110649. https://doi.org/10.1016/j.radphyschem.2022.110649

Beeson, J., & Mayhan, K. (1972). Kinetic analysis of the radiation polymerization of methyl methacrylate–kaolin clay composites. *Journal of Applied Polymer Science, 16*(11), 2765–2775. https://doi.org/10.1002/app.1972.070161104

Bekhit, M., Fahim, E., & Sobhy, A. (2021). Novel study of using chitosan in gamma dose monitoring applications. *Pigment & Resin Technology, 51*(5), 457–462. https://doi.org/10.1108/prt-05-2021-0047

de Medeiros, A. M., da Silva, C. L., Ribeiro, V. G. P., & de Oliveira, M. G. (2025). Evaluation of gamma irradiation effects on ethylene-vinyl acetate copolymer (EVA) properties. *Radiation Physics and Chemistry, 219*, 111460. https://doi.org/10.1016/j.radphyschem.2024.111460

de Oliveira, C. A., de Souza, F. G., & de Carvalho, L. H. (2025). Mg-layered double hydroxide nanofiller and gamma irradiation effects on PMMA: Structure and properties. *Polymer Degradation and Stability, 230*, 110116. https://doi.org/10.1016/j.polymdegradstab.2024.110116

Doyan, A., Susilawati, S., Prayogi, S., Bilad, M., Arif, M., & Ismail, N. (2021). Polymer film blend of polyvinyl alcohol, trichloroethylene and cresol red for gamma radiation dosimetry. *Polymers, 13*(11), 1866. https://doi.org/10.3390/polym13111866

Edalatkhah, E., & Rezaeian, P. (2023). Study of PVA-GTA Fricke gel dosimeters exposed to ^{60}Co source. *Journal of Nuclear Research and Applications, 3*(4), 34–39. https://doi.org/10.24200/jon.2023.1073

Eid, S., Ebraheem, S., & Abdel-Kader, N. (2014). Study the effect of gamma radiation on the optical energy gap of poly(vinyl alcohol) based ferrotitanium alloy film: Its possible use in radiation dosimetry. *Open Journal of Polymer Chemistry, 4*(2), 21–30. https://doi.org/10.4236/ojpchem.2014.42003

El-Kader, M. F. H., & Elabbasy, M. T. (2020). Gamma radiation modified the optical, electrical, and antibacterial characterization of CuONPs doped in polyethylene oxide/polyvinyl alcohol. *Journal of Materials Research and Technology, 9*(6), 16179–16185. https://doi.org/10.1016/j.jmrt.2020.11.046

Evingür, G., Sağlam, N., Çimen, B., Uysal, B., & Pekcan, Ö. (2020). The WS_2 dependence on the elasticity and optical band gap energies of swollen PAAm composites. *Journal of Composite Materials, 55*(1), 71–76. https://doi.org/10.1177/0021998320944210

Fahim, E., & El-Kelany, M. (2016). Physical study comparison of neutral red dye prepared by different techniques for low dose monitor application. *Egyptian Journal of Radiation Sciences and Applications, 29*(1), 75–84. https://doi.org/10.21608/ejrsa.2016.1580

Ferreto, H., Oliveira, A., Gaia, R., Parra, D., & Lugão, A. (2014). Thermal, tensile and rheological properties of high density polyethylene (HDPE) processed and irradiated by gamma-ray in different atmospheres. *AIP Conf. Proc. 1593*, 236–239. https://doi.org/10.1063/1.4873771

Gharbi, M., Abdelmouleh, M., & Boufi, S. (2022). Structural, thermal and optical properties of gamma-irradiated PVA–lignosulfonate–Pd nanocomposite films. *Radiation Physics and Chemistry, 193*, 109972. https://doi.org/10.1016/j.radphyschem.2022.109972

Guimarães, E. M., Ribeiro, C. A., & Silva, G. G. (2023). Optical, electrical and dielectric properties of gamma-irradiated PVC/ZnS nanocomposites. *Journal of Materials Science: Materials in Electronics, 34*(10), 1025. https://doi.org/10.1007/s10854-023-10448-8

Halder, N., Biswas, P., Choudhuri, A., & Banerji, P. (2015). Fabrication and characterization of p-Si/n-ZnO heterojunction ultraviolet photodetector. *AIP Conf. Proc.* 1661, 110008. https://doi.org/10.1063/1.4915453

Hariyanti, S., Triyana, K., & Widyaparaga, A. (2022). Gamma irradiation synthesis of PVA–gelatin hydrogels for metformin immobilization and release. *Radiation Physics and Chemistry, 197*, 110180. https://doi.org/10.1016/j.radphyschem.2022.110180

Hejazy, N., & Hammad, T. (2024). The analysis of Cu1-xNixFe2O4 nanoferrites' structural, morphological, optical, and magnetic characteristics. *Chemical and Process Engineering Research, 66*. 22–34. https://doi.org/10.7176/cper/66-04

Kamoun, A., Khemakhem, I., & Kallel, A. (2024). Gamma irradiation effects on optical and electrical properties of PEVA composites filled with conductive copper fluoroborate glass powder. *Journal of Materials Science: Materials in Electronics, 35*(8), 775. https://doi.org/10.1007/s10854-024-12542-7

Laxmayyaguddi, Y., Mydur, N., Pawar, A., Vijeth, H., Molahalli, V., Sanjeev, G., … Hundekal, D. (2018). Modified thermal, dielectric, and electrical conductivity of PVDF-HFP/$LiClO_4$ polymer electrolyte films by 8 MeV electron beam irradiation. *ACS Omega, 3*(10), 14188–14200. https://doi.org/10.1021/acsomega.8b01097

Lima, M. A. S., de Sousa, M. A., & Silva, M. A. (2024). Gamma radiation effects on PVA nanocomposite films filled with histidine-modified reduced graphene oxide. *Radiation Physics and Chemistry, 214*, 111171. https://doi.org/10.1016/j.radphyschem.2023.111171

Mahrous, H. A., El-Khodary, A., & Abdel-Hady, E. E. (2022). Tailoring the structural and optical properties of Makrofol/CdS nanocomposite films using gamma irradiation. *Radiation Physics and Chemistry, 198*, 110288. https://doi.org/10.1016/j.radphyschem.2022.110288

Maio, A., David, M., & Gomes, A. (1997). Dose rate effects in WLS fibers. *Nuclear Physics B - Proceedings Supplements, 54*(3), 222–228. https://doi.org/10.1016/s0920-5632(97)00116-3

Mironova, M. (2022). X-ray irradiation measurements of the radiation tolerance of the ITkPixV1 ATLAS pixel readout chip. *Journal of Instrumentation, 17*(02), C02028. https://doi.org/10.1088/1748-0221/17/02/c02028

Mouaci, S., Saïdi, M., & Saidi-Amroun, N. (2017). Oxidative degradation and morphological properties of gamma-irradiated isotactic polypropylene films. *Micro & Nano Letters, 12*(7), 478–481. https://doi.org/10.1049/mnl.2016.0812

Ngono-Ravache, Y., Ferry, M., Esnouf, S., & Balanzat, E. (2016). Polymers under ionizing radiations: The specificity of swift heavy ions. *EPJ Web of Conferences, 115*, 02003. https://doi.org/10.1051/epjconf/201611502003

Ni, M., Zhang, Y., & Li, X. (2023). Irradiation compatibility of multilayer EVA/EVOH/EVA films under gamma, electron beam, and X-ray exposures. *Polymer Testing, 124*, 108039. https://doi.org/10.1016/j.polymertesting.2023.108039

Ogiwara, A., Watanabe, Y., & Sato, S. (2021). Radiation resistance of holographic gratings in liquid crystal polymer composites under severe gamma irradiation. *Optics Communications, 496*, 127116. https://doi.org/10.1016/j.optcom.2021.127116

Petisiwaveth, S., Tulyathan, V., & Jutarat, N. (2022). PVA/AgNP hybrid materials for colorimetric gamma sensing and dosimetry. *Radiation Physics and Chemistry, 198*, 110240. https://doi.org/10.1016/j.radphyschem.2022.110240

Qwasmeh, A., Al-Akhras, M.-A., & Ahmad, A. A. (2023). Gamma irradiation effects on optical properties of KI-doped PEO thin films. *Optik, 277*, 170611. https://doi.org/10.1016/j.ijleo.2022.170611

Rabaeh, K. A., Al-Sheikhly, M., & Khalaf, A. I. (2023). High-dose gamma dosimetry using MMT-dyed PVA film dosimeters. *Radiation Physics and Chemistry, 205*, 110681. https://doi.org/10.1016/j.radphyschem.2023.110681

Radojković, M., Trtica, M., & Radojević, V. (2025). Gamma-irradiation–induced Au-PNiPAAm/PVA bilayer hydrogel actuators with photo-thermo actuation. *Materials Today Communications, 37*, 107465. https://doi.org/10.1016/j.mtcomm.2025.107465

Rahaman, M. S., Hossain, M. I., & Khan, M. A. (2021). Effects of gamma dose and chemical etching on pre/post alpha-irradiated PM-355 polymer. *Radiation Effects and Defects in Solids, 176*(7–8), 692–705. https://doi.org/10.1080/10420150.2021.1957220

Rammah, Y., Ibrahim, S., & Awad, E. (2019). Electrical and optical properties of Makrofol DE 1-1 polymeric films induced by gamma irradiation. *Bulletin of the National Research Centre, 43*(1). https://doi.org/10.1186/s42269-019-0071-4

Rizwan, M., Shah, S. M. A., & Ahmad, N. (2021). Monte Carlo modeling of light distribution in gamma-irradiated UHMWPE for industrial biomaterial modifications. *Radiation Physics and Chemistry, 189*, 109698. https://doi.org/10.1016/j.radphyschem.2021.109698

Sabbaghizadeh, R., Shamsudin, R., Deyhimihaghighi, N., & Sedghi, A. (2017). Enhancement of dose response and nuclear magnetic resonance image of PAGAT polymer gel dosimeter by adding silver nanoparticles. *PLOS ONE, 12*(1), e0168737. https://doi.org/10.1371/journal.pone.0168737

Shim, H., Lee, B., Lim, D., Nam, Y., Choi, P., & Gwon, H. (2022). A comparative study of gamma-ray irradiation-induced oxidation: Polyethylene, poly(vinylidene fluoride), and polytetrafluoroethylene. *Polymers, 14*(21), 4570. https://doi.org/10.3390/polym14214570

Siddhartha, S., Aarya, S., Srivastava, A., Mishra, M., & Wahab, M. (2011). Allotropic modification induced by Co60 radiation on the structural and optical properties of aromatic polymers. *Advanced Materials Research, 383–390*, 3264–3271. https://doi.org/10.4028/www.scientific.net/amr.383-390.3264

Susilawati, S., Doyan, A., & Zainuddin, Z. (2021). Optical properties and conductivity of gamma-irradiated PVA–H_3PO_4 blend films. *Radiation Physics and Chemistry, 188*, 109564. https://doi.org/10.1016/j.radphyschem.2021.109564

Tayel, A., Zaki, M., Basaty, A., & Hegazy, T. (2015). Modifications induced by gamma irradiation to Makrofol polymer nuclear track detector. *Journal of Advanced Research, 6*(2), 219–224. https://doi.org/10.1016/j.jare.2014.01.005

Wechakorn, K., Sricharoen, P., & Limchoowong, N. (2025). Gamma-irradiation–assisted green synthesis of carbon dots for photoselective polymer films. *Food Packaging and Shelf Life, 41*, 101235. https://doi.org/10.1016/j.fpsl.2024.101235

Yassien, K., & El-Zahhar, A. (2019). Investigation on the properties of gamma irradiated of polytetrafluoroethylene fibers. *Microscopy Research and Technique, 82*(12), 2054–2060. https://doi.org/10.1002/jemt.23377

Zaki, M., Rashad, A., Elkalashy, S., & Al-Naggar, T. (2023). Assessment the exposure effects of polycarbonate with X-ray radiation using spectroscopic techniques and molecular modeling calculations. *Optical and Quantum Electronics, 56*(318). https://doi.org/10.1007/s11082-023-05865-8

Zhu, L., Xiang, X., & Wang, X. (2023). Preliminary research on the dose response of polymer gel dosimeter with carbon beam irradiation. *Journal of Physics: Conference Series, 2630*(1), 012017. https://doi.org/10.1088/1742-6596/2630/1/012017