# Polymer Crosslinking Process Comparison

*Electron Beam and Co 60 Gamma Irradiation*

Products: Wire insulation, cable jackets, heat-shrink tubing and other polymer products
Audience: ParagonLED management, research, engineering and market development teams

## 1 Main conclusions

Both electron beam and Co-60 irradiation can promote polymer crosslinking. Electron beams generally suit rapid, continuous processing. Co-60 gamma radiation penetrates more deeply and can process thicker or complex products, but irradiation usually takes longer. Selection depends on formulation, product thickness and density, target dose, dose uniformity and throughput. [1][2]

Both methods can induce crosslinking and chain scission simultaneously. Formulation, oxygen, temperature, total dose and dose rate influence the outcome. Equipment names alone are insufficient for comparison, and process settings cannot be transferred directly between the methods. [2][3]

## 2 Mechanism of polymer crosslinking

Radiation deposits energy in the material, ionizing and exciting the polymer and generating free radicals. Reactions between radicals on different molecular chains form a crosslinked network that restricts chain movement and improves heat resistance and other properties. If chain scission or oxidation dominates, material performance may deteriorate. [2][3]

Electron beam processing uses accelerator-generated energetic electrons directly; conversion to gamma radiation is unnecessary. Co-60 emits gamma photons, which deposit energy through secondary electrons generated by interactions with the material.

## 3 Common preparation steps

Select a polymer and additives suitable for radiation crosslinking, then form the product by extrusion or injection molding. For wire, insulation is extruded around the conductor, cooled and prepared for irradiation. Heat-shrink tubing is first formed as tubing. Antioxidants and any crosslinking coagents must be validated for the formulation; there is no universal recipe.

Before production, establish the dose window and dose distribution using representative products. The minimum dose must achieve crosslinking requirements, while the maximum must avoid excessive degradation. Validate product thickness, metal conductors, arrangement and handling configuration. [4]

## 4 Typical processing sequence

| Stage | Electron beam | Co-60 gamma |
|---|---|---|
| 1 Formulation | Select polymer, antioxidants and any crosslinking coagents | Select and validate formulation, including gamma dose-rate and exposure-time effects |
| 2 Forming | Extrude wire insulation, tubing or film; injection molding is also possible | Likewise, extrude or form before irradiation |
| 3 Cooling and preparation | Cool, then feed using pay-off equipment, guide rollers or a conveyor | Cool, load carriers and arrange products, or feed a continuous irradiation system |
| 4 Irradiation | Pass through the scanned beam at controlled speed for direct electron exposure | Expose products to gamma radiation around the Co-60 source |
| 5 Dose uniformity | Use multiple passes, two-sided or multidirectional exposure to improve rear and internal dose | Adjust orientation, carrier position and routing to control surface and internal doses |
| 6 Quality testing | Verify dose, gel content, hot-set, mechanical and electrical performance | Verify similar metrics; validate process settings independently |
| 7 Postprocessing | Take up, cut or perform further processing | Unload, cut or perform further processing |

These are typical steps; the sequence and equipment depend on the product. Electron beam systems establish an irradiation zone using a scanned beam, and products pass through at controlled speed. Two-sided or multidirectional irradiation can improve circumferential dose uniformity in wires and cables. [4][5]

Co-60 processing is not limited to batches. In addition to carrier-based processing, continuous cable irradiation designs exist: cables pass through a region surrounded by Co-60 sources, with dose controlled by residence time and routing. [6]

## 5 Postprocessing of heat shrink tubing

Typically, tubing is formed and crosslinked, heated and expanded, then cooled in the expanded state. It shrinks when reheated during use. Crosslinking establishes the network needed to retain shape memory; it does not itself shrink the tubing. Temperature and expansion ratio depend on the material and product specification.

## 6 Process and equipment comparison

| Parameter | Electron beam | Co-60 |
|---|---|---|
| Radiation | Energetic electrons from an accelerator | Gamma photons from a radioactive source |
| Processing speed | High dose rate; generally suits rapid continuous processing | Generally lower dose rate and longer irradiation time |
| Penetration | Limited; match thickness, density and beam energy | Generally deeper; can process thicker products |
| Dose control | Beam current, conveyor speed, scan width and passes; energy affects depth distribution | Source activity, distance, residence time and routing |
| Geometry and density | Metal conductors and complex sections affect electron dose distribution | Also affected by density and arrangement; generally favorable for deeper penetration |
| Switching | Electron beam generation can be stopped | Source decays continuously; move it into shielding to stop product exposure |
| Material response | High dose rate and brief exposure; assess oxidation and temperature rise | Longer exposure; assess oxygen diffusion and dose-rate effects |
| Quality confirmation | Acceptance based on product dose and post-crosslinking performance | Likewise based on dose and properties, not irradiation time alone |

These are general comparisons, not fixed throughput ratings or thickness limits. Local electron beam exposure may be brief, but total processing includes loading, unloading, repeated passes and cooling. Gamma throughput depends on source activity, target dose and carrier configuration. [1][4][5]

## 7 Quality testing and production control

Dose validation should establish minimum and maximum product absorbed doses, with routine dosimetry and equipment parameter records. Gel content can assess the degree of crosslinking. Hot-set, tensile strength, elongation, heat resistance and electrical tests should be selected according to product requirements; not every test applies to every polymer.

Equal doses in kGy do not guarantee equal performance with the two methods. Compare dose rate, oxygen conditions, temperature, product geometry and postirradiation properties as well as total dose. The extent and distribution of oxidation can depend jointly on oxygen diffusion and reaction rate. [3][7]

## 8 Implications for TTL RH

Electron beam irradiation chambers: For TTL-RH outside the primary beam, assess scattered electrons and secondary X-rays. Exposure can change substantially near scanned beams, metal fixtures or beam stops. Do not assume that the luminaire receives the full electron beam. [8]

Co-60 irradiation chambers: Gamma radiation is the main external radiation. Luminaire location, distance from the source rack, shielding and irradiation operating time determine cumulative exposure.

Product crosslinking dose must not be treated as luminaire dose. Obtain the dose rate and expected cumulative dose at the installation location before selecting a TTL-RH model and validation requirements. Co-60 testing can support assessment of photon-induced ionization damage, but does not alone cover electron displacement damage or all electron beam operating conditions.

## 9 References

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