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Anton Trostin

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- Anastasiya Anchugova (ORCID: https://orcid.org/0000-0001-6589-7574)

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Hidden Deadly Factors in Everyday Life: A review

Anton E. Trostin[1]*

[1]Independent Researcher, Chelyabinsk, Russia

*antontrostin@atomicmail.io

https://orcid.org/0009-0000-3553-318X

This paper provides an overview of everyday environmental factors with a non-zero probability of a delayed lethal effect, according to the author's systematization. Several groups are distinguished: harmful organic compounds, harmful external influences, and harmful additives. The review is aimed at the actual detection of these factors under domestic conditions: where, in what form, and in what quantity their presence has been recorded in the literature. For organic compounds, the pathways and numerical data on the formation of volatile organic compounds, aldehydes, acrylamide, and polycyclic aromatic hydrocarbons are considered during heating (Maillard reaction, thermal oxidation, pyrolysis), under the action of household oxidizing agents (sodium hypochlorite, ozone), and at room temperature. Data are presented on VOC emission from paints, adhesives, varnishes, metalworking fluids, 3D printing processes, and particleboard. Data are presented for external influences such as UV and ionizing radiation. Literature data are shown for structural additives such as nickel, vanadium, cobalt, fiberglass, and asbestos. For hexavalent chromium, the conditions of its formation at high temperatures are given. For the remaining additives, the recorded concentrations and detection frequencies are as follows: nitrosamines, polychlorinated biphenyls, bisphenol-A, phthalates, and brominated flame retardants.

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This work is a preprint version and will be supplemented further. An artificial intelligence language model (Claude, Anthropic) was used only to help find sources during the initial literature search. The author checked every reference manually and wrote the analysis and text.

Keywords: volatile organic compounds; aldehydes; acrylamide; polycyclic aromatic hydrocarbons; ozone; ultraviolet radiation; ionizing radiation; radon; hexavalent chromium; hazards; toxicity; domestic environment; 3d printing.

Introduction

The everyday human environment consists of natural factors and products of technological progress. However, among them there are also those capable of causing harm to health, including factors with a non-zero probability of a delayed lethal effect. The toxicity of many of them belongs to fundamental and widely known scientific knowledge, which emphasizes the critical importance of systematizing the pathways by which they enter human everyday life. Such factors can be conditionally divided into several groups: harmful organic compounds, harmful external influences, and harmful additives. This division is not an official classification; however, it is adopted by the authors for convenience of systematization.

The subject of this review is the actual detection of toxic factors under conditions of the human everyday environment. Sensitivity to them is individual, and permissible levels differ between jurisdictions and are revised as data accumulate. Therefore, the authors deliberately shift the emphasis from the question of what quantity is permissible to the question of where and in what form the presence of these factors has been

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recorded. Establishing threshold values permissible for humans is outside the scope of this review. Interpretation of the findings in terms of safety remains the domain of specialists in the relevant field.

Harmful Organic Compounds

Organic compounds are defined as compounds of carbon, typically in combination with hydrogen, oxygen, and nitrogen. Organic objects in everyday human life are so numerous that listing them would be impractical; it's more convenient to go the other way and name what isn't organic. Inorganic substances include simple substances (metals and nonmetals, including graphite, diamond, oxygen, and nitrogen in air), metal alloys, inorganic compounds (water, oxides, salts, minerals, and the simplest carbon compounds such as CO_2 and carbonates), and inorganic materials (glass, ceramics, concrete). The list is incomplete, but it covers what's relatively frequent in everyday life. Everything else that surrounds a person is, with high probability, organic. Including materials that may not outwardly look the part. Composite products that visually resemble metal, for instance, may actually be polymer-based [1]. Kardos et al. show this directly: commercial PLA-based composites filled with copper and bronze powders impart a metallic appearance and texture, while the matrix itself stays polymeric, and the metal particles (3–5 μm for the copper filler, 6–30 μm for the bronze filler) are simply distributed within it, with weak adhesion to the matrix in a number of these materials.

Harmful organic compounds formed under everyday conditions include primarily volatile organic compounds (VOCs), including aldehydes, as well as acrylamide and polycyclic aromatic hydrocarbons (PAHs). In domestic settings, many of these arise

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during the heating of organic materials and products, which facilitates several processes: the Maillard reaction[2], oxidation[3], and pyrolysis[4].

The Maillard reaction is a non-enzymatic interaction of the amino groups of amino acids, peptides, and proteins with the carbonyl groups of reducing sugars[2]. In food products simultaneously containing proteins or amino acids and reducing sugars (glucose, fructose, lactose, etc.), it proceeds most intensively during thermal processing, though it can also occur during prolonged storage. A typical visual manifestation of the reaction is the formation of a golden-brown crust[5]. Among the products of this reaction, toxic aldehydes have been identified [6]. Cha et al. found that heating (160 °C) systems of “reducing sugar – amino acid” produces glyoxal (5.92–39.1 μg/mL) and methylglyoxal (3.66–151.88 μg/mL), with higher content in monosaccharide systems than disaccharide ones; the maximum methylglyoxal (151.88 μg/mL) came from the fructose–threonine system. Acrylamide can also result from this reaction [7]. Here asparagine is the key player, per Mottram et al. [7] — heating asparagine alone, without sugar, produces no acrylamide. According to [8], acrylamide content in Spanish-market potato chips (80 samples, 18 manufacturers) ranged from 108 to 2180 μg/kg, averaging 630 μg/kg with a median of 556 μg/kg.

Oxidation is a reaction in which a substance donates electrons to an oxidizing agent — most often, in everyday life, atmospheric oxygen. Frying is one example: the thermal oxidation of fats and oils. According to [9], this produces hydroperoxides, which then break down into low-molecular-weight volatile compounds (aldehydes, ketones, carboxylic acids, short-chain alkanes and alkenes), as well as dimers and polymers of triacylglycerols formed via radical reactions and Diels–Alder reactions.

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During oven roasting of beef (250 °C, 3×3×2 cm pieces), hexanal rose from 122.67 μg/kg in raw meat to a peak of 811.42 μg/kg after 6 minutes, then fell to 196.56 μg/kg by minute 18 [10]. Nonanal rose from 44.84 to 179.55 μg/kg, octanal from 8.64 to 70.46 μg/kg, and heptanal from 0 to 69.69 μg/kg. Hexanal, heptanal, octanal, and nonanal were the dominant aldehydes. Toluene, meanwhile, kept climbing: 9.32 to 446.34 μg/kg by the 18th minute.

Pyrolysis — chemical reactions in organic substances at high temperature without oxygen, or with too little of it — leads to new and often more complex compounds. This is what happens when food is cooked over coals or open fire, and one result can be PAHs. According to [11], total PAH content (16 compounds) in grill-cooked steaks, across different charcoal types, ranged from 23.80 to 36.39 μg/kg.

Oxidation doesn’t require oxygen or heat, though. In everyday life the oxidizing agent might instead be something like sodium hypochlorite [12]. Household bleach based on NaOCl (pH around 12) releases hypochlorous acid (HOCl) and chlorine (Cl_2) into the gas phase during use — both strong oxidizers.

Ozone, too, can act as an oxidizer. It’s an allotropic form of oxygen (O_3), and its reactivity comes from the molecule’s thermodynamic instability — an oxygen atom detaches easily, forming stable O_2. Waring and Siegel [13] recorded rising formaldehyde and nonanal concentrations (in some cases within measurement error) in a 27 m³ residential room while an ozone-releasing ion generator was running.

In addition to heating, a cooling system can also serve as a source of VOCs. Organic components of cooling agents, when in contact with a heated object, may undergo oxidation, degradation, and other thermally initiated transformations; the resulting VOC composition depends on the composition of the agent itself. Levilly et al.

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identified 15 carbonyl compounds among the VOCs generated during the use of metalworking fluids (MWFs). These included formaldehyde, acetaldehyde, acetone, acrolein, propanal, crotonaldehyde, butyraldehyde, benzaldehyde, isovaleraldehyde, valeraldehyde, o-tolualdehyde, m+p-tolualdehyde, glutaraldehyde, hexanal, and 2,5-dimethylbenzaldehyde [14]. In petroleum-based MWFs the median total aldehyde concentration was 32.4 μg/m³ (IQR 28.7–65.5). Formaldehyde accounted for 5.4 μg/m³ of that figure (IQR 3.9–7.0). Water-based MWFs had a higher median of 43.5 μg/m³ overall (IQR 24.7–77.2), with formaldehyde at 6.1 μg/m³ (IQR 3.5–8.0). Room-temperature evaporation is another, independent release pathway for VOCs.

Chamber studies by Xiong et al. and others established that occupational-air concentrations for water-based paints (WBPs) stay within 3.5–18.2 mg/m³, far below the 3.5×10^{3}–14.8×10^{3} mg/m³ measured for solvent-based paints (SBPs)[15]. Emission-chamber data comparing low- and zero-VOC latex formulations against conventional ones showed TVOC near 10 mg/m³ at the 28-day mark, versus 120 mg/m³ for the conventional formulations, while certain zero-VOC products reached as little as 7.1–240 μg/m³ by day 60[16]. Process reformulation in industrial waterborne automotive painting brought ozone-formation-potential (OFP) emission factors down from 10.7 to 3 mg/m³, with the most advanced lines achieving 2.0 g VOC per m² of painted surface[17]; separately, auto-repair facilities recorded total VOC levels of 1.06–1.27 mg/m³ for water-based paints against 2.93–53.46 mg/m³ for solvent-based ones[17]. Comparing UK decorative paints before and after EU Paints Directive reformulation (1990 vs 2024 solvent speciation), atmospheric modelling pointed to secondary organic aerosol formation potential (SOA_P) falling from 10.1 to 1.7 mg/m³[18]. Micro-chamber (μ-CTE) testing of three water-based paint formulations recorded VOC release

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of 300.3–935.4 μg/m³ at 18–24 hours, attributed mainly to coalescing agents[19]. Direct GC-MS field measurements in auto-repair painting workshops gave total VOC concentrations ranging from 5069 to 8058 ppb, led mainly by butyl acetate, toluene, ethylbenzene and xylene[20]. For architectural paints, dynamic-chamber evaporation testing produced total emission factors of 56 g VOC kg^{-1} for water-based products, where oxygenated VOCs and alkenes predominated, against 228 g VOC kg^{-1} for solvent-based products, dominated instead by alkanes, oxygenated VOCs and aromatics[21]. Cumulative VOC release from solvent-based automotive paint sludge classified as hazardous waste was further characterized through a diffusion-controlled mass-transfer model validated against ventilated-chamber data[22]. Reported VOC concentrations and emission factors across different paint types are summarized in Figure 1.

Paint type	Key VOCs	Reported concentration / emission factor	Method
Water-based (WBP)	Mixed VOCs	3.5–18.2 mg/m³	Occupational air sampling
Solvent-based (SBP)	Mixed VOCs	3.5×10³–14.8×10³ mg/m³	Occupational air sampling
Low-VOC latex	TVOC	10 mg/m³ (vs 120 mg/m³ conventional)	Small test chamber
Zero/low-VOC	TVOC	7.1–240 μg/m³ (60 d)	Chamber emission testing
Waterborne automotive	Aromatics, aldehydes	OFP 3–10.7 mg/m³; 2.0 g/m²	Industrial process monitoring
Auto-repair (water/solvent)	Mixed VOCs	1.06–1.27 / 2.93–53.46 mg/m³	Field measurement
UK decorative (2024 vs 1990)	SOA precursors	SOA_P 1.7 vs 10.1 mg/m³	Atmospheric modelling
Water-based (3 formulations)	Coalescing agents	300.3–935.4 μg/m³ (18–24 h)	μ-CTE chamber (ISO 16000-6)
Auto-repair workshop (oil/water)	Butyl acetate, BTEX	TVOC 5069–8058 ppb	Field GC-MS sampling
Architectural (water/solvent)	OVOCs, alkanes, aromatics	56 vs 228 g VOC/kg paint	Dynamic chamber
Solvent-based paint sludge	Mixed VOCs	Diffusion-controlled cumulative flux	Ventilated test chamber model

Figure 1. Summary table of reported VOC concentrations and emission factors for different paint types.

Chamber-based studies on water-based adhesives reported total VOC (TVOC) concentrations of 172–320 mg/m³, with polyvinyl acetate (PVA) wood glue showing the lowest emission rate among the tested products at 4.6 mg/m²·hr[23]. Dispersion and cementitious waterproofing adhesives emitted n-butanol at up to 382 μg/m³ at 3 days,

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declining to 74 µg/m³ by 28 days[24]. A comparative chamber study of construction adhesives grouped by base material found solvent-based adhesives to have the highest average emissions (8451 µg/m³ at 3 days, declining to 2214 µg/m³ at 28 days), while water-based dispersion adhesives (methyl cellulose and cement-based) showed the lowest values, from 28–40 µg/m³ at 3 days to 9–13 µg/m³ at 28 days. Acrylic-based polymer adhesives (DA 1) showed emission decay from 2816 µg/m³ at 3 days to 504 µg/m³ at 28 days[25]. Chemical profiling of white emulsion and silicone adhesives identified xylene (maximum 125.99 mg/m³) as dominant in emulsion adhesives and butanone oxime (maximum 1036.71 mg/m³) as dominant in silicone adhesives[26]. In cross-laminated timber, soy-based adhesives produced formaldehyde emissions of just 2.5 µg/m³, far below the 54.4 µg/m³ recorded for melamine-formaldehyde adhesive[27]. VOC emission factors in chamber tests of consumer adhesive products ranged from 6.77 to 924 mg per gram of product, with 2-butoxyethanol, iso-propanol and ethanol standing out as principal released compounds[28]. Studies of hot-melt polyurethane adhesives used in furniture veneer bonding examined VOC and formaldehyde emission as a function of surface finish and retention period[29]. PVAc-based engineered-flooring adhesives emitted formaldehyde at 0.006–0.048 mg/m³, as measured by 20-L chamber and FLEC methods[30]. A numerical emission model, validated against chamber data for moisture-curing adhesives, produced emission factors spanning 33.49 g/L for tile adhesive up to 654.23 g/L for all-purpose adhesive, with 2-butanone oxime (MEKO) identified as the dominant compound released from silicone sealants[31]. Formaldehyde concentrations from laminate-flooring adhesive seams and cut edges were monitored over 1.5 years, contrasting low- and high-emitting composite wood cores in a chamber-testing setup[32]. Among the SVOCs emitted from adhesive-bonded PVC flooring and

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wallpaper materials were bis(2-ethylhexyl) adipate (1.76 mg/m³) and methyl hexadecanoate (13.0 mg/m³), together with VOCs like cyclohexanone and n-butyl acetate[33]. Field sampling in renovated residences in China found Σ15 VOC concentrations from adhesive application at 118.2–232.5 μg/m³ indoors, roughly three times higher than simultaneous outdoor levels[34]. Chamber mass-balance modelling of three water-based adhesives found double-exponential TVOC decay with cumulative release of 6.9–38 mg/m²[35]. An overview of key VOCs and their reported concentrations across adhesive types is provided in Figure 2.

Adhesive type	Key VOCs	Reported concentration / emission factor	Method
Water-based (3 types)	TVOC	172–320 mg/m³; PVA 4.6 mg/m²·hr	Dynamic test chamber
Dispersion / cementitious waterproofing	n-Butanol, ethylene glycol	382 μg/m³ (3 d) → 74 μg/m³ (28 d)	100-L ventilated chamber, Tenax TA
Solvent-based / hybrid / PU / water-based (construction)	Mixed VOCs	28–8451 μg/m³ (3 d); 9–2214 μg/m³ (28 d)	TD-GC/MS test chambers
White emulsion / silicone (sealant)	Xylene, butanone oxime	Xylene max 125.99; butanone oxime max 1036.71 mg/m³	Chamber + odor threshold analysis
Soy-based (CLT wood)	Formaldehyde, toluene	Formaldehyde 2.5 μg/m³ (soy) vs 54.4 μg/m³ (MF)	CDPH chamber method
Consumer adhesives (PG, SG, IG)	2-Butoxyethanol, iso-propanol, ethanol	Emission factors 6.77–924 mg/g	Chamber testing
Hot melt (PU, furniture veneer)	VOCs, HCHO	Emission vs retention period (variable by finish)	Small-chamber testing
Polymer-based acrylic (DA 1)	Mixed VOCs	2816 → 504 μg/m³ (3 → 28 d)	Test chamber, time series
Engineered flooring adhesive (PVAc)	Formaldehyde, TVOC	FE 0.006–0.048 mg/m³	20-L chamber + FLEC
Neutral silicone sealant / tile / wall adhesives	MEKO (2-butanone oxime)	Emission factors 33.49–654.23 g/L (by type)	Environmental chamber + model
Flooring adhesive (standard reference)	Formaldehyde, generic VOC	0.1–1.0 mg/m³ (30 m³ chamber, 1 ACH)	LIFE reference chamber (ISO 16000-9)
Laminate flooring adhesive (seams/edges)	Formaldehyde	Chamber concentration, LE vs HE core (time series)	ASTM D6007 small-scale chamber
PVC flooring / wallpaper adhesive-bound materials	Cyclohexanone, n-butyl acetate, SVOCs	DOA 1.76 mg/m³; methyl hexadecanoate 13.0 mg/m³	Emission chamber + micro-chamber
Indoor decoration adhesives (China, field)	Σ15 VOCs	118.2–232.5 μg/m³ (indoor homes)	TD-GC-MS field sampling
Water-based adhesives (3 types, TVOC dynamics)	TVOC	6.9–38 mg/m² (total release range)	Chamber mass-balance model

Figure 2. Comparative table of key VOCs and their reported concentrations across adhesive types.

Volatile organic compound (VOC) emissions from wood lacquer coatings have been systematically assessed across a range of chamber-based and field studies. Lu et al. reported that substrate type (aluminium, plasterboard, gypsum board, plywood) significantly altered the VOC emission profile of an interior finishing varnish applied under dynamic environmental chamber conditions[36]. Chao and Wong found that

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increasing wet film thickness of a finishing varnish raised peak total VOC (TVOC) concentrations, with emission decay well described by a first-order model[37]. Ieda et al. measured a TVOC peak of 5.7 mg/m³ for a solvent-based wood stain, higher and more persistent than corresponding water-based formulations, in which limonene was a dominant species[38]. Headspace analysis via PTR-ToF-MS and GC pre-separation showed that solvent-borne polyurethane coatings reached a maximum VOC emission rate of 6.7 mg/h, more than twice that of the highest-emitting water-borne coating product, with Texanol and PCBTF (parachlorobenzotrifluoride) identified as compositional markers distinguishing water-borne from solvent-borne systems respectively[39]. Field exhaust-gas measurements at Chinese wooden furniture manufacturers found VOC concentrations of 2.82–155.37 mg/m³ for solvent-based coatings, 1.13–104.45 mg/m³ for water-based coatings and only 0.57–1.15 mg/m³ for UV-cured coatings[40]. A review of 427 chamber tests concluded that lacquer products are suitable for indoor application only when TVOC chamber concentrations remain below 2 mg/m³[41]. Very volatile organic compounds (VVOCs, C3–C6) were found to show a broadly similar spectrum across most lacquered wooden construction materials tested in chamber studies[42]. Nano-modification of a natural raw lacquer coating with Al_2O_3 nanoparticles and cellulose nanofibrils (CNF) increased surface glossiness by 102.94% and 50%, respectively, relative to unmodified raw lacquer, alongside improved adhesion grade and UV-aging resistance[43]. GC-MS/olfactometry analysis of PU, waterborne and UV-curable lacquers applied to solid wood showed a TVOC increase of about 227.9% relative to uncoated wood for the PU lacquer, while the UV-curable lacquer produced the smallest VOC increase but elevated toluene release[44]. Lacquer and other surface coatings were found to produce a significant reduction in

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formaldehyde, acetaldehyde, formic acid and acetic acid release from particleboard relative to uncoated board, with the notable exception of acid-curing lacquer systems[45]. UV-curable coating systems based on acrylic resins modified with low concentrations of fluorinated monomers were applied as 100% solid formulations to wood panels, avoiding solvent-related VOC emission entirely during the curing process while enhancing surface hydrophobicity and chemical resistance[46]. Finally, Zhu et al. showed that nanoparticle (TiO_2/montmorillonite) modification of waterborne polyurethane varnish reduced equilibrium TVOC emission from coated wood-based panels by 21.05–41.57% relative to unmodified control panels after UV irradiation over a 28-day test period[47]. The range of VOC emissions reported for various lacquer and coating types is shown in Figure 3.

Lacquer type	Key VOCs	Reported concentration / emission factor	Method
Interior finishing varnish (solvent-based)	Mixed VOCs (aromatic/aliphatic)	Significant substrate-dependent variation; SVOC content assessed by solvent extraction	Dynamic environmental chamber
Finishing varnish (oil-based)	Mixed VOCs	Peak TVOC increased with wet film thickness; first-order decay	Dynamic environmental chamber
Solvent- and water-based wood stain	TVOC, Limonene	TVOC 5.7 mg/m³ (solvent-based, peak)	Small-scale test chamber
Solvent-borne vs. water-borne polyurethane coating	Toluene, C8 aromatics, acetone, methyl ethyl ketone, Texanol, PCBTF	Solvent-borne PU max emission rate 6.7 mg/h (>2× highest water-borne product)	PTR-ToF-MS + GC headspace analysis
Solvent-, water-based and UV coatings (furniture)	Aromatics, esters (mixed VOCs)	Solvent-based 2.82–155.37; water-based 1.13–104.45; UV 0.57–1.15 mg/m³	Field exhaust-gas sampling, GC/MS
Lacquers (general, AgBB/TVOC review)	TVOC	Recommended indoor use threshold <2 mg/m³ (chamber, 28 d)	Chamber database review (427 tests)
Wooden construction materials / lacquered elements	VVOC (C3–C6)	Similar VVOC spectrum across most wooden materials tested	Chamber + sorbent VVOC sampling
Nano-modified raw (natural) lacquer coating on wood	Urushiol-derived volatiles; coating VOCs	Glossiness increase of 102.94% (Al_2O_3-NP) and 50% (CNF) vs. unmodified raw lacquer; adhesion grade improved from 5 to 3	Chamber/performance evaluation, FTIR + GC
PU, waterborne, UV-curable lacquer (solid wood)	Esters, aromatics, alcohols, aldehydes, ketones	TVOC increase vs. uncoated: PU +227.9%; UV lowest VOC increase	GC-MS/Olfactometry chamber
Lacquer-coated particleboard (surface covering)	Formaldehyde, acetaldehyde, formic acid, acetic acid	Significant reduction in formaldehyde release after lacquer coating vs. uncoated board; acid-curing lacquer an exception	Small-scale environmental chamber (EN 717-1)
UV-cured acrylic/fluorinated-monomer wood coating	Reactive monomers, photoinitiator residues	100% solid formulation; no solvent emission required during curing (solvent-based VOC release avoided)	Film property + composition analysis
Nanoparticle-modified waterborne PU varnish (wood panel)	TVOC, aldehydes, ketones, benzene, ethylbenzene	TVOC 21.05–41.57% lower vs. control after UV irradiation (28 d)	Small-scale chamber method

Figure 3. Overview table of VOC emission ranges reported for various lacquer and coating types.

A study characterizing particle emissions from the 3D FDM printing process consolidated data from 447 particle emission and 58 VOC emission evaluations using a

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standardized chamber method, finding that ABS-W filament had the highest particle emission rate (4.3×10^{10} #/g), approximately one order of magnitude higher than ABS-F, ABS-G, and PLA-Fe filaments, and three orders of magnitude higher than PLA-O and PLA-C filaments [48]. Yi et al. found that the average emission rate of lactide from PLA was 111 μg/h — less than half the average emission rate of styrene from ABS — with total VOC yields of 77 μg/g filament for ABS compared to 13 μg/g for PLA [49]. A study on parameters influencing ultrafine particle emission during 3D printing conducted an extensive experimental evaluation across four common filament materials — ABS, PLA, PETG, and TPU — using thermogravimetric analysis to predict particle emission from thermal stability and decomposition behavior of each thermoplastic [50]. A review summarizing 50 FFF emission studies found that higher printing temperature consistently resulted in higher VOC emissions, with styrene identified as the most frequently reported dominant VOC emitted during ABS 3D printing [51]. A study employing solid-phase microextraction coupled to gas chromatography/mass spectrometry found that among three tested filaments, ABS liberated the greatest number of individual VOCs (34 detected compounds), compared to only 6 VOCs detected for a copolyester-based (CPE+) filament [52]. A study on thermal decomposition mechanisms found that TVOC mass yield was 0.03%, 0.21%, and 2.14% for PLA, ABS, and PVA respectively, with emissions beginning at the onset of glass transition and peaking during liquefaction, and noted that a low heating rate has the potential to restrain the formation of styrene from ABS [53]. Zisook et al. measured particle and VOC emissions from a 3D printer filament extruder and identified styrene and ethylbenzene as the primary VOCs from ABS pellets, with ABS producing the highest particle emission rate compared to PLA pellets and pulverized PLA [54]. A meta-analysis of particle emissions

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from FDM 3D printers found that ABS consistently produced higher ultrafine particle number emission rates than PLA across the reviewed literature, with a mean particle count diameter difference of 8.1 nm between the two materials [55]. Potluri et al. measured VOC concentrations across PLA, ABS, PETG, ASA, and flex-resin filaments and found styrene concentrations of 86 μg/m³ in flex resin and 27.96 μg/m³ in ASA filament, while identifying toluene and m-xylene — rather than styrene — as the dominant VOCs in their ABS samples [56]. Kristiawan et al. evaluated PETG and NGEN filaments and reported total VOC concentrations of approximately 550 ppb for PETG and 600 ppb for NGEN after one hour of printing, with styrene identified in PETG emissions in four of six tested conditions [57]. A study on 3D pen versus desktop 3D printer VOC emissions found that ABS extrusion via 3D pen released 1.4 to 62.6 times more VOCs than via desktop printer, with ABS emitting styrene and benzene while PLA emitted lactide [58]. Stefaniak et al. found that ABS filaments consistently produced the greatest particle number concentrations among seventeen tested filament types, followed by metal-containing PLA, standard PLA, and polycarbonate filaments [59]. A study on VOC emissions from 4D printing noted that nozzle temperature and filament material type are the major factors affecting VOC emission rate in FDM processes using ABS and PLA filaments [60]. A study on 3D-printed thermoplastics in sensor housings found that among ABS, PETG, PLA, PC, and PVDF, ABS exhibited the highest VOC off-gassing while PVDF showed negligible off-gassing [61]. A study evaluating particle and volatile organic compound emissions during the use of 3D pens found that particle emission rates were highest for ABS, followed by PLA and polycaprolactone (PCL), with the VOC emission trend following the same pattern, though the specific compounds varied depending on the filament material [62]. A

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comparative summary of VOC emission concentrations and rates by compound category and polymer type during FDM 3D printing is presented in Figure 4.

VOC Category	PLA	ABS	PETG	ASA	Nylon (PA)
Aromatic hydrocarbons	Trace levels, not dominant	Styrene dominant, up to 276 µg/h (25 µg/g); ethylbenzene, acrylonitrile also present	Styrene detected, generally not dominant	Styrene ~27.96 µg/m³ (< ¼ of ABS level)	Limited data, not a primary marker
Aldehydes	Trace concentrations	Acetaldehyde, benzaldehyde identified	Acetaldehyde, toluene, d-limonene among main VOCs	N/A	Formaldehyde, trace component
Esters / lactides	Lactide ~111 µg/h, dominant VOC	N/A	N/A	N/A	N/A
Amides / lactams	N/A	N/A	N/A	N/A	Caprolactam, largest average ER (~1749 µg/h)
Total VOC (TVOC)	13 µg/g filament, lower than ABS	Highest among thermoplastics; 77 µg/g; 0.2–40.5 µg/min	Lowest TVOC among tested materials	Higher than PETG, comparable to ABS	High, less quantitatively characterized
Particles (UFP)	Lower than ABS	Highest UFP concentrations and emission rates	An order of magnitude lower than ABS	N/A	N/A

Figure 4. Table summarizing VOC emission concentration and rate ranges by compound category and polymer type during FDM 3D printing.

SLA printing, by contrast, generates emissions tied to the components used in photopolymer resins. Zhang, Davis, and Black measured SLA's total VOC emission rate at three to six times that of FFF. It exceeded 4 mg/h. The mixture itself was complex, made up of acrylates, aldehydes, alcohols, ketones, and hydrocarbons[63]. Zhang, Davis, and Black (U.S. National Institute for Occupational Safety and Health instrumentation studies, published in ACS Chemical Health & Safety) measured total VOC emission rates of 5014 ± 915 µg/h during the stereolithography (SLA) printing phase, with emitted chemical classes including esters, alcohols, aldehydes, ketones, aromatics, and hydrocarbons; esters accounted for the largest fraction of identified compounds during printing (38%), while hydrocarbons and siloxanes dominated the curing phase (33% and 14%, respectively)[64]. Comparing standard and "eco"

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photopolymer resin formulations, Miller-Schulze and Williams identified six volatile organic chemicals — 2-hydroxyethyl acrylate, 4-acrylomorpholine, mesitaldehyde, tolylene-2,4-diisocyanate, 2,6-di-*tert*-butyl-*p*-cresol, and dipropylene glycol diacrylate — and found that standard-resin concentrations of 2-hydroxyethyl acrylate reached approximately 1.6×10^2 μg/m³ during the “during-print” phase, compared with 97 μg/m³ for the eco formulation, with dipropylene glycol diacrylate measured at 37 μg/m³ (standard) versus 31 μg/m³ (eco) over the same interval[65].

Also, formaldehyde in particleboard comes from the urea-formaldehyde (UF) resins used to make it. Que et al. studied these resins and found a molar ratio of formaldehyde to urea between 0.97 and 1.27 [66]. Using the perforator method, Kelleci et al. measured formaldehyde emission at 2.5–5.1 mg/100 g for particleboard based on foamed UF resins, rising to 3.95–7.31 mg/100 g for non-foamed resins [67].

Harmful External Influences

Such influences are ultraviolet and ionizing radiation. Short-wavelength UV radiation photolyzes molecular oxygen to form ozone, which makes it a double factor: through its own action and through the ozone formed. Stinson, Zhang, and Xia [68] showed that the photodissociation of O_2 at 185 nm yields two O (^3P) atoms, which produce ozone; for this, a 6 W low-pressure mercury lamp was used with an intensity at a distance of 20 cm of 42 μW/cm² at 185 nm and 73 μW/cm² at 254 nm. Szeto et al. [69] state that ozone-generating lamps of this type emit mainly at 254 nm, and the power of the 185 nm line is about 10% of that. At the same time, Martínez de Alba et al. [70] found that the peak ozone concentration on a surface at a distance of 20 cm from a robot with a 450 W quartz lamp (185–254 nm) was 0.37 ppm. And finally, Claus [71] notes

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that wavelengths shorter than 240 nm generate ozone more easily, while the 185 nm line produces ozone if it is not absorbed by the lamp envelope.

As regards UV sources, according to Yagura et al. [72], in the UV part of the solar spectrum at the Earth's surface, the share of UVA is ~95%, UVB ~5% (by radiation energy; UVC is completely absorbed by the atmosphere). Alhamdan, Spicer, and Cates [73] show that low-pressure mercury lamps emit mainly at the 254 nm line, the secondary 185 nm line provides about 10% of the photon output, and the ratio of these two lines depends on the lamp design (mercury vapor pressure, buffer gas, amalgam, quartz envelope transmission) and on the operating temperature. According to Ford et al. [74], manicure lamps emit ≈100% UVA. For solariums, according to Gerber et al. [75], these shares are ≈96–99.5% UVA, 0.5–4% UVB, and ≈0% UVC, respectively. Thus, according to the data, in modern tanning installations the share of UVB in the total UV radiation varies from 0.5 to 4%, while the rest is accounted for by UVA. For comparison, in old tanning lamps with a single mercury lamp (before the 1960s), the spectrum contained about 20% UVC and 30–50% UVB. Tanning products, meanwhile, may contain photoactive components that, under the action of UV radiation, generate strong oxidizers — reactive oxygen species and free radicals. For example, inorganic UV filters (TiO_2 and ZnO) are known to generate reactive oxygen species under the action of light, including short-lived free radicals, superoxide (O_2•–), and the hydroxyl radical (OH•) [76]. Vejerano et al. [76] found that the sunscreen formulation that produced the strongest radical signal contained 18.6 wt.% ZnO and 6.6 wt.% TiO.

Ionizing radiation is also present in the domestic environment. With increasing altitude above sea level, the attenuation of cosmic radiation by the atmosphere decreases, and the dose rate increases. Safitri, Miska, and Yusibani [77] report that the

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cosmic radiation dose rate at sea level is 0.03 μSv, while at an altitude of 10 km it reaches 2.38 μSv, that is, approximately 80 times higher.

By contrast, in basements, a significant source of exposure is the natural radioactive gas radon (^{222}Rn) and its decay products [78]. Ptiček Siročić et al. [78] found that in basements in Northern Croatia (15 measurement points), the arithmetic mean of the radon activity concentration was 70.9 ± 38.8 Bq/m³ (geometric mean 61.2 Bq/m³), whereas on the first and second floors it was 42.5 ± 30.8 Bq/m³ (geometric mean 32.8 Bq/m³).

Harmful Additives

Among them, structural additives should first be highlighted: nickel, vanadium, cobalt, fiberglass, asbestos, and also hexavalent chromium. Their content is relevant to take into account before beginning machining, welding, and other production operations that generate aerosols. Wu et al., studying friction-stir-processed 34CrNiMo6 (a high-strength quenched and tempered medium-carbon low-alloy steel), report the following composition: 1.5% Ni (wt.%), 1.5% Cr, 0.25% Mo, 0.34% C, 0.50% Mn, and 0.40% Si [79].

Ferrous metallurgy consumes around 85% of vanadium-containing products. The element goes into high-strength low-alloy, tool, and rail steels, as well as steels for construction and automobiles, while the remainder is directed into non-ferrous alloys with titanium, nickel, aluminum, and chromium (in particular, Al-V alloys for titanium alloys in the aerospace industry), into catalysts, and into flow vanadium batteries. These figures come from Moskalyk and Alfantazi’s review of vanadium processing [80], supplemented by Santos et al.’s assessment of vanadium’s role in decarbonization [81].

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Lithium-ion batteries are the primary consumer of cobalt. In 2024, batteries made up close to 76% of global cobalt consumption, with electric vehicles alone responsible for an estimated 43% of that share. Cobalt also appears in high-speed steels for cutting tools, such as M42 (8% Co), with this class of steels generally containing between 5% and 12% Co, and in WC-Co hard-alloy tools, where it functions as the binder phase — for instance, WC-7 wt.% Co. This picture draws on Picazo-Rodríguez et al.'s review of cobalt metallurgy and recycling [82], Wang et al.'s work on Co's influence on M42 microstructure [83], and Silva et al.'s study of multilayer diamond coatings for cemented-carbide milling [84].

Fiberglass, used mainly as a reinforcing filler for polymer composites (GFRP), accounts for the largest share by market volume among fiber-reinforced polymers, owing to the low cost of the fiber — a point made across the reviews by Silva et al. [84], Scaffaro, Di Bartolo, and Dintcheva on recycling of glass- and carbon-fiber composites [85], Mohammadi et al. on GFRP in automotive bumpers [86], and Sathishkumar, Satheeshkumar, and Naveen's broader review of glass-fiber-reinforced polymers [87]. In everyday life and closely related fields, such composites appear in electronics (printed circuit boards), the automotive industry (for example, bumpers made of polypropylene reinforced with 40% long glass fiber), construction, containers and tanks for chemical liquids, and sports equipment. In the form of glass wool it serves as thermal and acoustic insulation, including in buildings, as Ren et al. demonstrate in their work on glass-fiber-wool/MTMS aerogel composites with improved thermal insulation [88]. Kemari et al., reviewing high-temperature polymers for cable insulation, note that fiberglass can further raise the heat resistance of cable insulation [89]; and Levinson et al., studying airflow infiltration in ducts, report that a fiberglass lining for air ducts provides thermal

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and acoustic insulation, with an impermeable barrier over its air-facing surface helping to preserve that effectiveness [90].

Asbestos was historically widespread in construction as an effective insulator, and was also worked into fabrics, paper, cement, and plastics to impart structural strength, as detailed in Bolan et al.'s review of hazardous asbestos-containing materials [91]. About 80% of the asbestos imported by Japan in 2006 went into building materials (asbestos boards and cement products), about 7% into friction materials, and less than 3% into asbestos textile products; among the specific materials cited are asbestos-cement sheets and pipes, external roofing products made of asbestos-cement, and thermal insulation materials for buildings.

Chromium behaves differently depending on its oxidation state: stable in its trivalent form, it becomes a health hazard upon transition to the unstable hexavalent form. The transition Cr(III) → Cr(VI) is an oxidation involving the loss of three electrons, a condition that can arise from machining metal without sufficient cooling. Van Leeuwen et al., reviewing the reactive evaporation and condensation of chromium, report that reactive evaporation of Cr from the surface oxide of stainless steels — forming volatile $CrO_2(OH)_2$ and CrO_3, i.e., Cr(VI) compounds — occurs above 500 °C in both humid and dry oxidizing environments [92]. Industrially, chromium is used predominantly as an alloying element: about 90% of primary chromium goes into metallurgy, mostly into stainless and heat-resistant steels (roughly 86% of chromium directed to steel), while the rest is split between chemicals (about 6.5%) and refractories (about 3.5%), per Johnson, Schewel, and Graedel's account of the anthropogenic chromium cycle [93]. Mehtani et al. show that in iron-chromium alloys, oxidation slows sharply once Cr content reaches 12 wt.%, owing to the protective oxide film Cr_2O_3,

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while high-temperature iron alloys typically cap chromium at around 30% [94]. Guo et al. report 4.5–6.0% Cr in high-speed steels with boron used for hot-rolling rolls [95], and Chen et al. find 0–0.6% Cr in automotive dual-phase steel DP980, where it suppresses bainitic transformation [96]. Among household items, Johnson et al. point to stainless steel kitchenware (about 18% Cr) [93].

A further group of additives worth noting includes nitrosamines, polychlorinated biphenyls (PCBs), bisphenol A, phthalates, brominated flame retardants, and heavy metals. Wang et al., analyzing commercial sausages on the Chinese market, found total N-nitrosamine content of 1.35–15.88 μg/kg (with one exception) and NDMA levels of 4.25–10.52 μg/kg in fermented sausages; in one sample (Shuanghui Corn Sausage), NPYR reached 71.73 μg/kg [97]. Hu and Hornbuckle, examining 33 commercial paint pigments, detected PCBs in 15 samples — predominantly organic pigments — in the range of 2–200 ng/g wet weight, identifying more than 50 congeners, with PCB11 present in 13 of the 15 PCB-containing samples [98]. Noonan, Ackerman, and Begley found bisphenol A in 71 of 78 canned food samples from U.S. retail, at concentrations of 2.6–730 ng/g [99]. Edwards et al., surveying 64 ready-to-eat meals from U.S. fast-food chains, detected di-n-butyl phthalate (DnBP) in 81% of samples and DEHP in 70%, with a median DEHP concentration of 36.0 μg/kg in hamburgers (method detection limit 14 μg/kg) [100]. Li et al., screening 120 consumer products with a portable X-ray fluorescence spectrometer, found that about 37% contained at least one bromine-positive spot — most often in electrical appliances and toys — and went on to quantify PBDEs, HBCDD, and TBBPA in 15 of the bromine-positive samples [101]. Kajiwara, Noma, and Takigami report a similar pattern for new items on the Japanese market (electronics,

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curtains, wallpaper, building materials), which contained traditional brominated flame retardants [102].

Conclusion

Thus, using the systematization proposed by the authors, the above-described factors encountered in everyday life can be divided into the following groups: harmful organic compounds, which will include predominantly VOCs, aldehydes, acrylamides, and PAHs; harmful external influences, such as ultraviolet and ionizing radiation; and harmful additives. The factors that form harmful organic compounds include predominantly the processes of heating organic objects involving such reactions as the Maillard reaction, oxidation, and pyrolysis. The oxidizing agents are atmospheric oxygen, specialized chemical agents, and ozone. The sources of UV under domestic conditions are sunlight, germicidal lamps, manicure lamps, and solariums. The factor of ionizing radiation is the change in the altitude of the location, manifesting as an increase in cosmic radiation, or radon and its decay products. And harmful additives, in turn, are structural additives such as nickel, vanadium, cobalt, fiberglass, asbestos, and chromium in its hexavalent form, as well as other additives: nitrosamines, heavy metals, polychlorinated biphenyls, bisphenol A, phthalates, and brominated flame retardants.

Conflicts of interest

The author declares no competing financial or non-financial interests that could have influenced the work reported in this paper.

Data availability statement

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No new data were generated or analyzed in this study. Data sharing is not applicable to this article. All sources used are listed in the reference list.

Declaration of the use of Artificial Intelligence

During the initial literature review for this manuscript, the author used Claude (Anthropic, Claude), an artificial intelligence language model, to help locate and compile relevant sources regarding mercury in consumer products. Every reference suggested by the artificial intelligence was verified manually through academic databases to confirm that it exists and supports the statements it is cited for. The final analysis, writing, and synthesis of ideas were done by the author, who takes full responsibility for the content of the manuscript.

Author contributions

Anton E. Trostin — conceptualization, writing (original draft), writing (review & editing).

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