A Practical Guide for

Understanding and Testing Hazardous Substances in Electrical and Electronic Products

Agilent

Trusted Answers

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Overview of RoHS Regulations Across Global Markets

The rapid advancement of digitalization has driven exponential growth in the global production of electrical and electronic equipment, resulting in significant amounts of electronic waste. To mitigate the environmental impact of this waste, the European Union introduced two key directives:

- **RoHS (Restriction of Hazardous Substances)**, which limits the use of certain toxic substances in electrical and electronic equipment.

- **WEEE (Waste Electrical and Electronic Equipment)**, which governs the proper management and recycling of products at the end of their life cycle.

The original RoHS Directive (2002/95/EC) was adopted by the European Parliament and the Council in January 2003, restricting six hazardous substances in electronic equipment. It was subsequently revised in 2005 and 2011, leading to the implementation of RoHS 2 (Directive 2011/65/EU) on 3 January 2013. Further updates came on 4 June 2015, when Directive (EU) 2015/863 amended Annex II of RoHS 2 by adding four phthalate esters to the list of restricted substances.

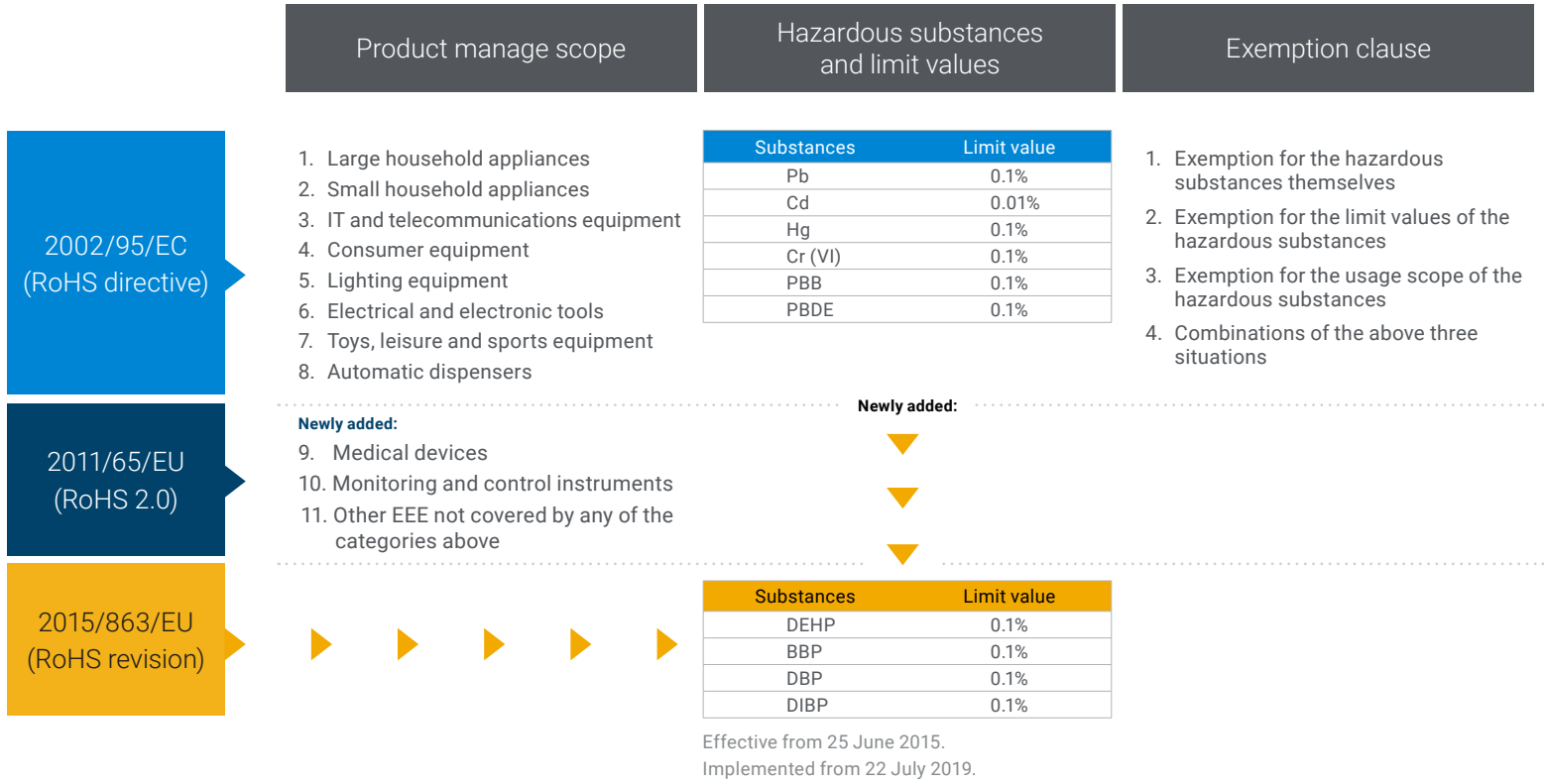


Figure 1. The development timeline for EU RoHS.

Pb: lead; Cd: cadmium; Hg: mercury; Cr (VI): hexavalent chromium; PBB: polybrominated biphenyls; PBDE: polybrominated diphenyl ethers; DEHP: bis (2-ethylhexyl) phthalate; BBP: butyl benzyl phthalate; DBP: dibutyl phthalate; DIBP: diisobutyl phthalate.

In December 2025, the Official Journal of the European Union published Directive (EU) 2025/2456, amending RoHS 2 (2011/65/EU) and formally transferring the control of hazardous substances in electrical and electronic equipment to ECHA. It requires a mandatory review of the restricted substances list every four years to ensure that regulatory standards keep pace with the latest scientific findings and market developments.

In addition to the EU directives, many regions and countries have introduced their own local versions of RoHS. Any company that sells applicable electrical or electronic products, equipment, sub-components, cables, components, or spare parts directly to RoHS-regulated countries—or supplies products to resellers, distributors, or integrators who then sell into those markets—must ensure RoHS compliance.

China's RoHS requirements originated from the 2006 recommended standard, "Administrative Measures for Pollution Control of Electronic Information Products", which aligned with the EU Directive's substance restrictions. In 2016, this evolved into the "Administrative Measures for the Restriction of Hazardous Substances in Electrical and Electronic Products". Initially, the regulation controlled six substances. In August 2025, China released GB 26572-2025, its mandatory national RoHS standard, which will take effect in 2027. This update expands the list of restricted hazardous substances from six to ten, adding four phthalate esters.

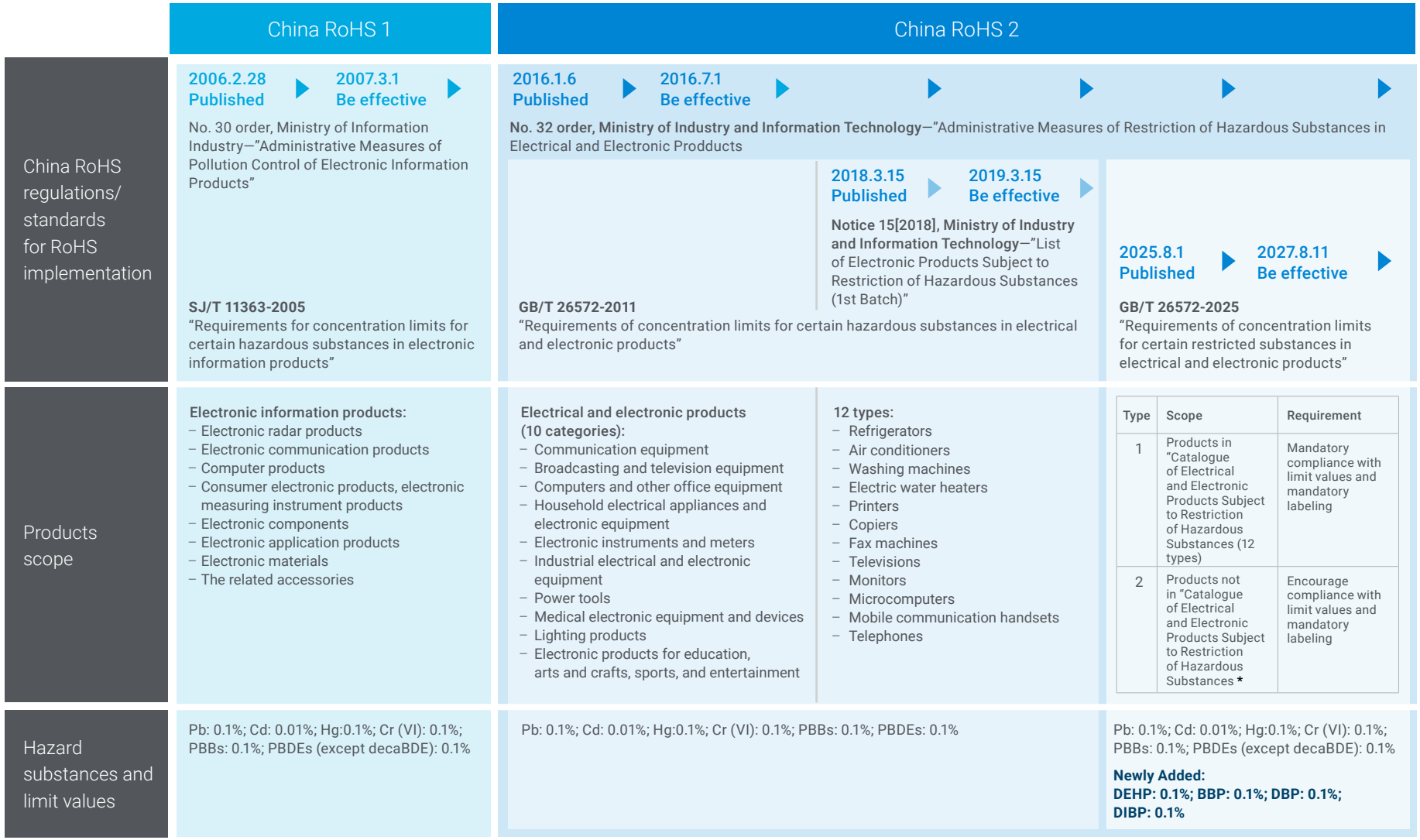
Although the United States does not have federal legislation governing hazardous substances in electrical and electronic equipment, numerous states have enacted their own regulations.

Restricted Substances by Region/Country

	Restricted substance									
Region/country	Pb	Cd	Hg	Cr (VI)	PBB	PBDE	DEHP	BBP	DBP	DIBP
EU	●	●	●	●	●	●	●	●	●	●
UK	●	●	●	●	●	●	●	●	●	●
US (New Jersey, Wisconsin)	●	●	●	●	●	●	●	●	●	●
US (California, Indiana, New York)	●	●	●	●	●	●				
China, Mainland	●	●	●	●	●	●	●	●	●	●
China, Taiwan	●	●	●	●	●	●				
South Korea	●	●	●	●	●	●	●	●	●	
Japan	●	●	●	●	●	●				
Singapore	●	●	●	●	●	●				
Thailand	●	●	●	●	●	●				
India	●	●	●	●	●	●				
Bangladesh	●	●	●	●	●	●	●	●	●	●
Brazil	●	●	●	●	●	●		●[1]	●[1]	●[1]
GCC[2]	●	●	●	●	●	●	●	●	●	●
EAEU[3]	●	●	●	●	●	●				

(1) Draft ongoing; (2) GCC: Gulf Cooperation Council; (3) EAEU: Eurasian Economic Union.

Table 1. Hazardous substances restricted under regional RoHS or RoHS-like legislations.



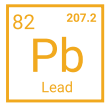
* In November 2025, the Ministry of Industry and Information Technology (MIIT) is soliciting public opinion on the "Catalogue of Restricted Use of Hazardous Substances in Electrical and Electronic Products (2025)" and the "List of Exceptions for the Application of Restricted Substances in the Catalogue of Restricted Use (2025)". The 12 product types will be consolidated into 10 types, and 23 new types will be added.

Figure 2.
The development timeline for China RoHS.

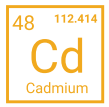
Restricted Substances Under RoHS

Heavy metals

All RoHS legislations define four key elemental substances: lead (Pb), cadmium (Cd), mercury (Hg), and hexavalent chromium (Cr(VI)).



Lead (Pb): Its toxic effects are well documented. Although once widely used in industrial processes, lead is being phased out as safer alternatives emerge. Currently, it is still found in solders, electronic components, printed wiring boards (PWBs), oil additives, packaging, plastic stabilizers, curing agents, dyes, pigments, and battery materials.



Cadmium (Cd): Commonly used in Ni-Cd batteries, photo materials, surface treatments, solder, paints, dyes, electronic ceramics, glass parts, and plastic stabilizers. Cadmium oxide (CdO) is a known carcinogen, strongly linked to prostate and kidney cancers.

Mercury (Hg): Like lead, mercury compounds are highly toxic. Mercury remains in use in certain electrical components, small batteries, lamps, preservatives, catalysts, electrodes, plastics, and pigments. Exposure can cause severe gastrointestinal irritation, renal failure, and death. Organic mercury, particularly methyl mercury, penetrates the central nervous system, leading to behavioral and neuromotor disorders.

Hexavalent chromium (Cr(VI)): Used in plating solutions, alloys, rust inhibitors, dyes, pigments, catalysts, and tanning processes. Cr(VI) is significantly more toxic, stable, and environmentally mobile than Cr(III). It is a respiratory irritant and a recognized human carcinogen.

PBBs/PBDEs

Brominated flame retardants (BFRs) are widely used in consumer product casings, circuit boards, building materials, furniture foams, insulation, and textiles. Because BFRs are not covalently bonded to materials, they can easily leach into the environment. There are four main groups of BFRs: tetrabromobisphenol A (TBBPA), hexabromocyclododecane (HBCD), polybrominated biphenyls (PBBs), and polybrominated diphenyl ethers (PBDEs). Among these, PBBs and PBDEs are the compounds that are regulated in almost all RoHS legislations.

Polybrominated biphenyls (PBBs), similar to PCBs, are highly stable, persist in the environment, and bioaccumulate in food chains. PBDEs have also been linked to significant health and environmental risks. The most popular PBDE types in production industry include penta-BDEs (used in foam products for mattresses and furniture), octa-BDEs (used in housings and keyboards for computers and business machines), and deca-BDEs (used in electrical/electronic equipment, automotive parts, construction materials, and textiles). Like PCBs, PBBs and PBDEs each have 209 congeners, with varying levels of mobility, bioavailability, toxicity, and stability. Their high molecular weights and boiling points make detection and measurement particularly challenging.

Phthalates

Plasticizers are widely used polymer additives in industrial production to improve flexibility, ductility, transparency, and processability. Among all types, phthalates dominate the market, accounting for about 80% of total plasticizer production due to their performance and well-established processing technology.

When used as a plasticizer, phthalates are typically esters formed from phthalic acid and alcohols with 1 to 15 carbon atoms. The most common is dioctyl phthalate, such as bis(2-ethylhexyl) phthalate (DEHP), primarily used in PVC for cable and wire insulation in electrical and electronic applications. Small amounts of DEHP may also appear in non-polymer uses, such as ceramics for electronics or electrolytes in capacitors. Butyl benzyl phthalate (BBP) is often combined with other plasticizers in PVC components like cables, sockets, pipes, and shock absorbers, and is also found in paints and adhesives. Dibutyl phthalate (DBP) can occur in synthetic leather, textile coatings, PVC materials, printing inks, sealants, and adhesives used in electronics. Diisobutyl phthalate (DIBP) serves as a PVC plasticizer, a DBP substitute, and is used in cellulose resin, vinyl resin, nitrile rubber, and chloroprene rubber.

Because phthalates do not form covalent bonds with plastics, they can easily migrate into the environment. While they exhibit low acute toxicity, high doses may cause teratogenic, mutagenic, and carcinogenic effects, as well as significant endocrine disruption.

Additional Substances of Concern

Electronic products may contain other substances of concern that are regulated under EU REACH (Registration, Evaluation, Authorization and Restriction of Chemicals) and POPs (Persistent Organic Pollutants) regulations. These substances are used as additives or generated during the production of raw materials. They pose significant risks to health and the environment, particularly during the recycling or disposal of associated products.

In May 2022, the European Commission initiated a proposal to add medium-chain chlorinated paraffins (MCCPs) and tetrabromobisphenol A (TBBPA) to the RoHS restricted substances list. However, the proposal was rejected by the EU RoHS committee in December 2024.

MCCPs are chlorinated hydrocarbons with carbon chain lengths of C14–C17. They function as plasticizers with flame retardant properties and are commonly used in PVC, flexible plastics, rubber, coatings, adhesives, sealants, and particularly in wires and cables. MCCPs pose reproductive and aquatic toxicity risks; alternatives are now available. are now available.

TBBPA is a reactive flame retardant used in printed wiring boards (PWBs) and epoxy resin-based sealants, adhesives, and encapsulations. The European Union is assessing its endocrine-disrupting potential and PBT (persistence, bioaccumulation, toxicity) characteristics.

MCCPs and TBBPA have been designated as substances of very high concern (SVHCs) under EU REACH (MCCPs in 2021; TBBPA in 2023), triggering notification and compliance obligations when their concentration exceeds 0.1%. MCCPs were recently banned under the Stockholm Convention, and the European Commission has proposed adding MCCPs to the EU POPs regulation, with a ban expected in 2026.

Standard Methods for Hazardous Substances Testing

The IEC 62321 series serve as the harmonized standard for RoHS testing in the EU, developed by the International Electrotechnical Commission (IEC) TC111. Testing laboratories in most regions and countries have adopted IEC 62321 standards or equivalent methods for RoHS compliance testing.

In addition to the ten substances currently restricted under RoHS, IEC has been actively developing standards for testing a broader range of chemicals that pose potential risks to human health and the environment. These include polycyclic aromatic hydrocarbons (PAHs), HBCD, tris(2-chloroethyl) phosphate (TCEP), bisphenol A (BPA), short-chain and medium-chain chlorinated paraffins (SCCPs/MCCPs), and TBBPA.

Analytes	Matrix	IEC standard No.	GB standard No. which equivalent adopted IEC 62321	Testing methods
Pb, Cd, Cr	Polymers, metals, electronics	IEC 62321-5:2013	GB/T 39560.5-2021	AAS, AFS, ICP-OES, ICP-MS
Hg	Polymers, metals, electronics	IEC 62321-4:2013 +AMD1:2017 CSV	GB/T 39560.5-2021	AAS, AFS, ICP-OES, ICP-MS
Cr (VI)	Metals	IEC 62321-7-1:2015	GB/T 39560.701-2020	Colorimetric method
	Polymers, electronics	IEC 62321-7-2:2017	GB/T 39560.702-2021	Colorimetric method
Pb, Hg, Cd, total Cr, total Br	Electrotechnical products	IEC 62321-3-1:2013	GB/T 39560.301-2020	For screening: XRF
F, Br, Cl	Polymers, electronics	IEC 62321-3-2:2020	GB/T 39560.302-2024	For screening:C-IC
PBBs/PBDEs	Polymers	IEC 62321-6:2015	GB/T 39560.6-2020	GC/MS
PBBs, PBDEs, DEHP, BBP, DBP, DIBP	Polymers	IEC 62321-12:2023	GB/T 39560.12-2024	GC/MS
PBBs, PBDEs, DEHP, BBP, DBP, DIBP, DNOP, DINP, DIDP	Polymers	IEC 62321-3-3:2021	GB/T 39560.303-2024	Py/TD-GC/MS
DEHP, BBP, DBP, DIBP, DNOP, DINP, DIDP	Polymers	IEC 62321-8:2017	GB/T 39560.8-2021	GC/MS, Py/TD-GC/MS
DEHP, BBP, DBP, DIBP	Polymers	IEC 62321-3-4:2023	In development	For screening: FTIR, HPLC-UV, TLC, TD-MS

Table 2. IEC and GB standards for restricted substances testing under RoHS.

The inclusion of these substances in IEC standards reflects growing global concern over their persistence, bioaccumulation, and toxicity. Many of these chemicals exist in the polymer as additives or byproducts, making them relevant for compliance testing and environmental safety assessments. By addressing these substances, IEC aims to provide harmonized testing methodologies that support regulatory frameworks and industry best practices worldwide.

Analytes	Matrix	IEC Standard No.	Testing Methods
PAHs	Polymers, electronics	IEC 62321-10:2020	GC/MS
HBCD	Polymers	IEC 62321-9:2021	GC/MS
TCEP	Plastics	IEC 62321-11:2023	GC/MS, LC/MS
BPA	Plastics	IEC 62321-13 ED1*	LC/DAD, LC/MS, LC/MS/MS
SCCPs, MCCPs	Plastics	IEC 62321-14 ED1*	GC/NCI-MS
TBBPA	Plastics	IEC 62321-15 ED1*	GC/MS, LC/MS

Table 3. IEC and GB standards for testing the substances of concern in electrical and electronic products.

* In development

PAH: polycyclic aromatic hydrocarbon; HBCD: hexabromocyclododecane; TCEP: tris (2-carboxyethyl) phosphine hydrochloride; BPA: bisphenol A; SCCPs: short-chain chlorinated paraffins; MCCPs: medium-chain chlorinated paraffins; TBBPA: tetrabromobisphenol A.

Agilent Solutions for Hazardous Substances Testing

With decades of expertise in delivering reliable, cutting-edge measurement solutions, Agilent empowers labs to confidently meet RoHS compliance requirements. From identifying hazardous substances to ensuring accurate testing, our technology helps you achieve compliance and stay ahead of evolving regulations.

Heavy metals testing

ICP-OES

Inductively coupled plasma optical emission spectroscopy (ICP-OES) is the most widely used technique for meeting the requirements of IEC 62321 and most other standards for heavy metals testing in electrical and electronic products. ICP-OES offers fast and robust multi-element testing capability; the Agilent 5800 ICP-OES delivers precise and consistent results, supporting the industry's need for rigorous and reliable compliance testing on heavy metals:

5800 ICP-OES

IntelliQuant smart software
Provides expert-level knowledge to identify spectral interferences that can affect accuracy, with recommendations that allow you to quickly select the best wavelength to prevent time-consuming remeasurement.

Early maintenance feedback (EMF)
Utilizes over 100 sensors that monitor and track instrument health, alerting the analyst when maintenance is needed, to help overcome common reasons for service calls and reduce expense and wasted time.

Smart tools
Fitted background correction (FBC), fast automated curve-fitting technique (FACT), inter element correction (IEC), and other tools simplify method development for the analysis of both routine and complex samples.

Neb alert
Continuously monitors the nebulizer and alerts you when it is leaking or needs cleaning, which helps prevent wasted time and the cost of troubleshooting.

Vertical dual view (VDV)
Offers flexibility between viewing modes to avoid interferences, enhancing both the sensitivity and the linear dynamic measurement range.

Vertically oriented torch design
Reduces cleaning downtime and ensures fewer replacement torches are needed.

Advanced freeform optical design:
Results in a small footprint, which saves valuable bench space, reduces warm up and purge times, and lowers the cost of ownership.

Intelligent rinse feature
Enables laboratories to enhance both the efficiency and accuracy of sample measurements.

Atomic absorption spectroscopy

Atomic absorption spectroscopy (AAS) is another important instrument for determining heavy metal content. It is characterized by high accuracy and speed and low cost. The Agilent 240FS AA is a fast sequential atomic absorption spectrometer that can double sample throughout and dramatically reduce running costs, and is able to handle multi-element suites with ease:

240FS AA

- Reduce your analysis time by determining the concentration of all elements from a single aspiration
- Reduce sample consumption with less delay throughout analysis and less sample waste
- Get accurate results by determining 10 elements per sample in less than 2 minutes without sacrificing data quality
- Improve precision and accuracy with online internal standard corrections for physical differences, sample preparation errors, or drift
- Simplify your analysis by taking the guess work out of the method development with the SpectrAA comprehensive cookbook
- Tune your flame AA performance and achieve high sensitivity with the Mark 7 atomization system

ICP-MS

Under some situations, monitoring trace elements or more hazardous elements present at lower levels may be required. Inductively coupled plasma mass spectrometry (ICP-MS) has excellent detection limits, extremely wide linear range, high speed, and strong interference removal capability, which meets the requirements of RoHS and other regulations. The Agilent 7850 ICP-MS is an ICP mass spectrometer that can handle samples with up to 25% solids, reducing the dilution time trap.

7850 ICP-MS

- Standard operating procedures and fully developed methods for regulated and routine methods save you weeks of method development and documentation time.
- Ultra-high matrix introduction (UHMI) reduces sample preparation time by allowing you to directly analyze samples containing up to 25% total dissolved solids without dilution.
- Helium collision cell and half-mass correction remove troublesome polyatomic and doubly charged interferences that can reduce data quality and increase the need for costly sample remeasurements.
- Robust hardware allows you to measure high matrix samples without having to matrix-match calibration standards.
- IntelliQuant gives you a complete elemental profile of each sample, helping you to easily identify unusual sample matrices.
- Outlier conditional formatting (OCF) reduces data review times for busy or inexperienced ICP-MS operators by highlighting results that are outside a selected range or have failed a test requirement.
- Early maintenance feedback (EMF) uses sensors and counters to determine when maintenance is needed. Traffic light, color-coded alerts mean maintenance tasks are never missed but are also not performed more frequently than necessary.
- ICP Go is an optional, browser-based user-interface for mobile devices, offering simplified set up and control of routine sample batches—great for ICP-MS operators on the move.
- Method-specific analyzer packages containing ICP-MS hardware, software, consumables, professional services, and documentation ensure you'll be running samples in weeks instead of the months it can take to develop, optimize, verify, and document a regulated method.

UV-Vis

The Cary 60 UV/Vis spectrophotometer is widely used for chromium (VI) analysis, combining innovation and convenience to deliver accurate, reliable results.

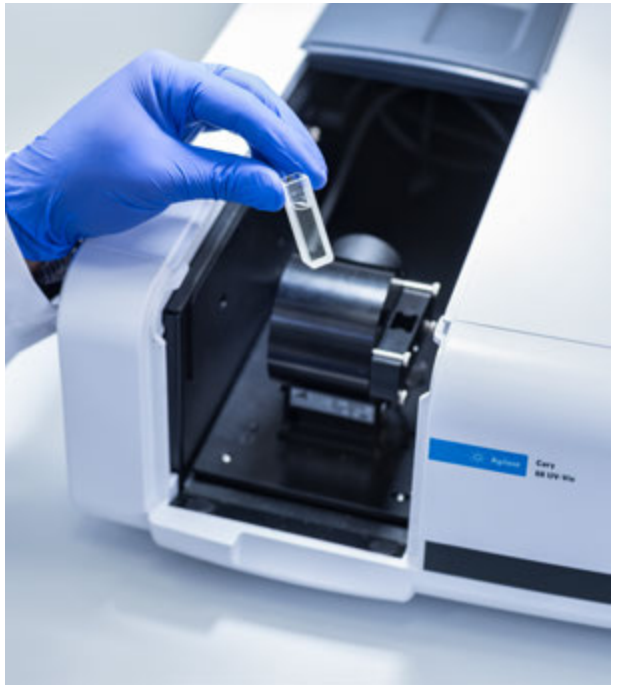
Cary 60 UV/Vis

Advanced light source
A unique pulsed xenon flashlamp with an exceptionally long lifetime covers the full UV-Vis range, replacing two conventional lamps (deuterium and tungsten) for simplified maintenance.

Instant high-energy output
Ensures stable, precise measurements every time.

Open-access design
Measurements are unaffected by ambient light, so you can keep the sample chamber open—making reagent addition and accessory changes easier.

Fiber optic flexibility
One-of-a-kind fiber optics eliminate frequent sample changes, boosting productivity and efficiency.



Organic compounds testing

Agilent provides a complete solution for organic substances analysis. For volatile or semi-volatile compounds, GC and GC/MS are used; for non-volatile compounds, LC and LC/MS are used. In some cases, a mass spectrometer is needed for either confirmation or screening. Some instruments (e.g., GC, LC, MS/MS) are designed for routine analysis; other instruments (e.g., TOF, Q-TOF) are designed for identifying non-targets (unknowns).

GC/MS

The Agilent GC/MS family is widely used for detecting volatile and semi volatile organic compounds, including PBBs, PBDEs, phthalates, PAHs, HBCD, TCEP, SCCPs/ MCCPs, TBBPA, and other high risk substances. These systems deliver low detection limits for precise quantitative analysis, along with strong qualitative performance. Among them, Agilent GC/MS is the most widely adopted technique for RoHS testing.

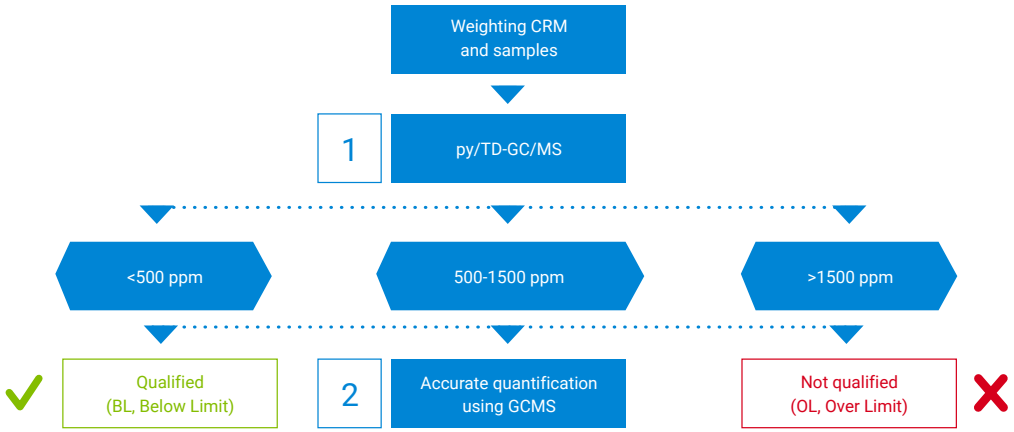
- Detection limits as low as 1 fg IDL assert reliability and sensitivity for your analysis.
- The new HydroInert source improves chromatographic efficiency for hydrogen carrier gas applications and minimizes loss in sensitivity and spectral anomalies associated with H_2 gas.
- JetClean self-cleaning ion source greatly reduces or even eliminates the need for manual source cleaning.
- Inert Flow Path products like columns, liners, inlets, gold seals, and ferrules improve mass spectrometry workflows and ensure the inertness of every surface that touches your sample.
- Cerno Bioscience MassWorks MS calibration technology enables high mass accuracy on the 5977C GC/MSD.

5977 GC/MSD

Streamlined phthalate testing

Traditional quantitative testing for phthalates, PBBs, and PBDEs often requires complex sample preparation (e.g., Soxhlet or microwave extraction), which is time consuming. IEC 62321 has offered semi-quantitative screening methods using py/TD-GC/MS—eliminating the need for sample prep and accelerating compliance testing.

Agilent GC/MSD coupled with a pyrolyzer/thermal desorption system (Py/TD) enables the polymer samples to be directly introduced into the Py/TD to thermally extract phthalates, PBBs, PBDEs or other target substances. The extracted analytes are then transferred into the GC to be separated by the column and detected by a mass spectrometer.



RoHS 2 GC/MS phthalate screening solution (available in China only)

Fast, simple, and accurate
Saves time, reduces labor, and minimizes maintenance.

Compliant and flexible
Includes pyrolysis-GC/MS per IEC 62321 and an optional JetClean mode for stable, accurate results.

User-friendly interface
Dedicated phthalate screening workflow for quick onboarding.

One-click reporting
Pre-built RoHS 2.0 phthalate report templates simplify documentation.

Complete guidance
Operation videos and manuals cover every step—from preprocessing to reporting.

Turnkey service
Everything you need for seamless implementation.

LC, LC/MS, LC/MS/MS

High-performance liquid chromatography (HPLC) system could do rapid qualitative or semi-quantitative analysis for industrial flame retardant mixtures of decabromodiphenyl ether, octabromodiphenyl ether, decabromobiphenyl, octabromobiphenyl according to IEC 62321-6:2015, and for phthalates IEC 62321-3-4:2023 as well. Besides that, HPLC could be used for quantitative analysis of BPA according to IEC 62321-13 ED1. The Agilent 1260 Infinity III LC System delivers reliable performance and robustness, offering the widest choice of modules for both analytical HPLC and entry-level UHPLC analysis.

Liquid chromatography/mass spectrometry (LC/MS) instruments take the performance of HPLC separation to another level with the sensitivity and specificity of mass spectrometry. According to IEC 62321 series, LC/MSD (single quadrupole mass spectrometry) or LC/MS/MS (triple quadrupole mass spectrometry) could be used for quantitative analysis of BPA, and LC/MS/MS for TCEP and TBBPA. The reliable family of Agilent LC/MS instruments provides a range of capability and performance to solve any LC/MS analysis challenge.

1260 Infinity III LC

1260 Infinity III Prime LC system with InfinityLab Pro iQ

FTIR

According to IEC 62321-3-4:2023, FTIR is used as one of the fast-screening methods for phthalates quantitative analysis. The method is rapid, with low running costs and no need for chemical sample pretreatment. The Agilent 4300 Handheld FTIR brings lab-grade performance to the outside world, enabling non-destructive portable FTIR testing in the field and nonlaboratory environments. Lightweight, ergonomic, and easy to use, this rugged handheld FTIR solution has the sensitivity and flexibility of a more traditional benchtop FTIR instrument.

4300 Handheld FTIR

Related peripherals, supplies, and support for Agilent instruments

With analysis solutions tailored to your unique needs, you can now enjoy peace of mind with Agilent's extensive suite of equipment. In addition, Agilent Technologies offers the world-class applications and service support required to rapidly implement these measurement tools into your process, including:

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- HPLC consumables, labware, and accessories
- Spectroscopy consumables
- Online ordering solutions

Software and Standards

- Software & informatics

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- Support for evolving labs
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