Oxford Instruments plc

Abingdon

Impact of a PFAS restriction on analytical, semiconductor and optical device manufacturing equipment

Technical and Socio-Economic Impact Report

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Note on report approval.

The persons identified above have signed off each stage of this report in accordance with RINA's BMS/QA procedure.

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Link: RINA Questionnaire

Thank you.

Issue and Revision Record

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EXECUTIVE SUMMARY

RINA Tech UK Limited (RINA) was requested by Oxford Instruments to prepare an impact assessment report in support of the stakeholder engagement currently being undertaken for Per- and Polyfluoroalkyl substances (PFAS) under the REACH restriction proposal (ECHA, 2023)[1] (hereafter the Restriction).

Oxford Instruments plc is a global provider of high technology products and services to the world's leading manufacturing and scientific research companies. Oxford Instruments operates in a number of end markets comprising semiconductors and communications, advanced materials, healthcare and life science, energy and environment, quantum technology, and research and fundamental science. Oxford Instruments' stated purpose is "to enable a greener, healthier, more connected advanced society". Sustainability is a key corporate policy for Oxford Instruments, with policies in place to achieve measurable sustainability targets such as net zero by 2045. In accordance with this stated policy, Oxford Instruments supports the objectives of the Restriction proposal to control human exposure and emissions of PFAS to the environment. Oxford Instruments is undertaking a review of its products and the materials and components they contain to ensure that it will comply with any restriction on PFAS that may be introduced and supports the phasing out of PFAS use as soon as possible. However, for some products sufficient time needs to be permitted to allow the transition to PFAS-free alternatives where this is technically possible.

Oxford Instruments manufactures two types of equipment which are described here as "analytical equipment", and "nanoscience and plasma technology". The analytical equipment comprises chemical analysis, microscopy, spectroscopy, and imaging technology. This equipment is used in research and development underpinning key EU policy such as the Green Deal and environmental policies such as REACH and RoHS as it provides chemical analysis to ensure compliance to the regulations, including PFAS testing. The nanoscience and plasma technology products are used to design, develop and manufacture semiconductors and optical devices such as those for human/machine interactions. Examples include those used in smartphones and other devices for facial recognition and other/human/machine interaction techniques and augmented reality devices where data is superimposed on a viewing image. The equipment is essential for the delivery of key EU policy such as the Chips for Europe Initiative (European Council, 2023) and the Green Deal. The Chips for Europe Initiative will not be achievable without nanoscience and plasma technology products being allowed to be placed on the market as they currently rely upon PFAS.

PFAS materials are used in a relatively small number of critical parts in each product as determined by the Oxford Instruments spreadsheet of parts information. These parts are contained within equipment which typically has a long service life. The equipment is relatively low volume production and represents a very high capital investment by purchasing companies. The equipment is maintained via service and repair contracts. It is disposed of in accordance with the Waste Electronic and Electrical Equipment (WEEE) Directive 2012/19/EU at the equipment's end of life. The waste equipment is recycled for its valuable metals and in this process, any PFAS present is incinerated. Disposal into landfill is very unlikely because operators of the equipment have well-established waste disposal procedures and also because of the value in the recycled metals. As a result, there is no significant exposure of PFAS to operators or the environment.

Oxford Instruments' products are manufactured using many purchased components, some of which are complex, and the detailed composition of which is unknown to Oxford Instruments as it is often proprietary confidential information. It is, therefore, difficult to establish in all cases which parts contain

[1] Annex XV reporting format 040615 (europa.eu)

PFAS. The products are high technology products, operating in harsh conditions of high vacuum, high voltages, extremes of temperatures, strong magnetic fields, and electromagnetic radiation. For some critical parts, there are currently no available alternative materials to PFAS. Oxford Instruments does not manufacture PFAS materials and therefore, cannot determine the date when PFAS-free alternative materials will become available. Time is required for industry to develop alternatives and for Oxford Instruments to undertake qualification of these parts to ensure that they are valid for their applications. For this reason, Oxford Instruments requests the derogations listed in Table 0.1 to enable redesign, testing and validation of PFAS-free equipment once alternative materials become available.

The continued use of PFAS in spare parts and repairs of products already placed on the market is also critically important. Oxford Instruments not only manufactures new products but also services and maintains existing products. Without the general consideration to permit the use of PFAS in these applications, this will cause the premature end-of-life and scrappage of products which otherwise could be maintained in service with PFAS-containing parts. It is therefore vital that the restriction does not impact products already placed on the market. It must be ensured that these products can continuously be made available on the market. With the current definition of “placing on the market” under REACH this would not be possible, as any supply or making available to a third party, and hence any resale or lease, for example, is considered “placing on the market” under REACH.

Table 0.1: Summary table of derogations on which Oxford Instruments will be relying.

Derogation reference	Derogation text
5.s.	Lubricants where the use takes place under harsh conditions or use is needed for safe functioning and safety of equipment until 13.5 years after EiF.
5.t.	Calibration of measurement instruments and as analytical reference materials.
5.v.	Hard chrome plating until 6.5 after EiF.
Potential derogation with requested text amendments	
5.ee.	Semiconductor manufacturing process, related equipment and supporting processes until 13.5 after EiF.
Additional derogations	
New	Analytical equipment for 20 years after EiF.
New	Refrigerants in semiconductor manufacturing process, related equipment and supporting processes until 13.5 years after EiF.
New	Spare parts repairs of products already placed on the market for an unlimited time.

Finally, a formal process for requesting new derogations as well as permitting existing derogations to be extended beyond the originally agreed time period is requested. This is important where PFAS-free alternatives are still either in the early stages of their development, or do not exist as yet and as such the estimations of the minimum steps and time to be considered to qualify alternatives has a significant degree of uncertainty.

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ABBREVIATIONS AND ACRONYMS

AFM	Atomic Force Microscope
BMS	Business Management System
CTI	Comparative Tracking Index
CVD	Chemical Vapour Deposition
DSiE	Deep Silicon Etching
EDS	Energy Dispersive Spectroscopy
EEA	European Economic Area
EiF	Entry into Force
EPDM	Ethylene propylene diene monomer
ePTFE	Expanded PTFE
eTFE	Poly(ethene-co-tetrafluoroethene)
EU	European Union
FFKM	Fluoroelastomer trade name
FKM	Fluoroelastomer trade name
FVMQ	Fluorovinylmethylsiloxane rubber
ICP	Inductively Coupled Plasma
ICPCVD	Inductively Coupled Plasma Chemical Vapour Deposition
JRC	Joint Research Centre (EU)
NBR	Nitrile Butadiene Rubber
NMR	Nuclear Magnetic Resonance
PCB	Printed Circuit Board
PCBA	Printed Circuit Board Assembly
PD	Plasma Deposition

PE	Plasma Etching
PECVP	Plasma Enhanced Chemical Vapour Deposition
PEEK	Polyether ether ketone
PEEKNMR	Polyether ether ketone
PFAS	Per and Perfluoroalkyl Substances
PFPE	Perfluoropolyether
PTFE	Polytetrafluoroethylene
PVC	Polyvinyl chloride
PVDF	Polyvinylidene fluoride
PVF	Polyvinyl fluoride
QA	Quality Assurance
QC	Quality Control
R&D	Research and Development
REACH	Registration, Evaluation, Authorisation of Chemicals
RIE	Reactive Ion Etching
SDS	Safety Datasheet
SEM	Scanning Electron Microscope
SVHC	Substances of Very High Concern
TD NMR	Time Domain Nuclear Magnetic Resonance
TPE	Thermoplastic elastomer
Tygon™	PVC polymer specialist grade
WDS	Wavelength Dispersive Spectroscopy
WEEE	Waste Electronic and Electrical Equipment

1 INTRODUCTION

RINA Tech UK Limited (RINA) was requested by Oxford Instruments plc to gather information to support the stakeholder engagement currently being undertaken for Per- and Polyfluoroalkyl substances (PFAS) under the REACH restriction proposal[2] (the Restriction) relating to analytical equipment, and nanoscience and plasma technology products. Oxford Instruments is conducting a review of all parts used in its products to establish whether PFAS is likely to be present and to identify PFAS-free alternatives if these are available. A number of parts have been identified as critical to the functioning of the equipment and are suspected or known to contain PFAS. Considering that as yet there is no legal obligation to communicate the use of the majority of PFAS within the supply chain, it has been challenging to confirm, in many cases, whether parts use PFAS. Adding to this challenge, is that material compositions are often trade secrets.

Owing to the unique combination of essential physical and chemical properties required in the equipment which currently only PFAS materials offer, derogations are proposed with supporting technical and socio-economic reasons as outlined in this report.

1.1 Profile of Oxford Instruments

Oxford Instruments employs more than 2,000 people at 30 sites across 17 countries and is a global provider of high-technology products and systems. Oxford Instruments' products enable manufacturing companies and scientific research organisations to image, analyse and manipulate materials down to the molecular and atomic scale. Its products are used in the development of key emerging technologies such as quantum technology, new generation environmentally sustainable low energy compound semiconductors, batteries and 5G communication equipment. Revenue and operating profit each grew by 21% during 2022, reflecting strong demand for the products (Oxford Instruments, 2023).[3]

Oxford Instruments is committed to environmental sustainability with a net zero emission target of 2045. It has company policy in place to ensure compliance with the EU environmental legislation including Waste Electronic and Electrical Equipment (WEEE Directive), Restriction on Hazardous Substances (RoHS), Registration, Evaluation, Authorisation of Chemicals (REACH) and the European Waste Framework Directive. Oxford Instruments supports the overall objectives of the Restriction on PFAS.

1.2 Methodology used to compile this report

A spreadsheet of questions against products was prepared for each Oxford Instruments business unit to answer for critical parts used in their products that met the following criteria:

- Parts required for the equipment to function or to achieve a stated level of performance.
- PFAS confirmed as either present by the supplier or suspected to be present from supply chain documentation and specific in-house technical knowledge.
- Identification if PFAS-free alternatives are available that are technically suitable.

The questions asked covered the following aspects:

[2] Annex XV reporting format 040615 (europa.eu)

[3] www.oxinst.com

- Description of the part.
- PFAS name, if known.
- The combination of properties required such as operating temperatures, pressures, voltages etc.
- Timeline estimates to validate the suitability of the PFAS-free alternative, redesign, test and revalidate the product.

In addition to the spreadsheet, meetings were held with engineers from the business units to understand technical details concerning the critical parts and the equipment operating parameters.

2 DESCRIPTION OF THE EQUIPMENT

Oxford Instruments products exploit scientific phenomena that are associated with the interaction of matter with the electromagnetic spectrum. They may be divided into two product categories, those for which the output is an analytical measurement and those for which it is not. These two categories comprise the following equipment:

- Analytical equipment used in either a laboratory or a production setting.
- Nanoscience and plasma technology products. Nanoscience is the study of matter at the nanoscale. The nanoscale is where the matter being manipulated has at least one dimension in the range 1 to 100 nanometres. Plasma technology products operate in both the nanometre and atomic scale range.

The two product types are described in more detail below.

2.1 Analytical equipment

These fall into the following products, each of which uses different scientific principles which are briefly described below.

Nuclear magnetic resonance spectroscopy (NMR) is an analytical chemistry tool for identifying the chemical structure or quantifying the concentration of a chemical. The equipment uses a combination of a magnetic field (1.5 to 2 Tesla) and an excitation radiofrequency (9 – 100 MHz) to monitor a resonant radiofrequency emitted by the target nuclei. The frequency is dependent upon the nuclei and its environment of electrons that is dictated by the chemical structure of the sample. Applications include:

- Industrial Quality Assurance/Quality Control (QA/QC) checks.
- Research in agriculture and food, batteries, education, and pharmaceuticals.
- Rapid and accurate measurements of oil, water, fluorine, and fat content in industrial products.
- Chemical structure identification.
- Permeability measurements in environmental studies relating to industrial activity such as oil and gas extraction and carbon capture.

NMR is an important analytical tool for the study of PFAS and its degradation products and starting monomers. The fluorine, carbon and hydrogen nuclei are ideal nuclei for NMR analysis. Whilst other analytical techniques such as mass spectrometry also allow chemical structural elucidation, a combination of analytical techniques is required to unequivocally establish a chemical structure, with NMR often the definitive structural identification tool.

Electron microscopy or Scanning Electron Microscopy (SEM) with wavelength dispersive detection allows both a microscope image and the identification and quantification of chemical elements. Applications include:

- Screening for chemical elements including fluorine.
- Failure analysis of materials.
- Research in many areas such as healthcare, semiconductors, batteries etc.

Total fluorine can be measured in polymers samples within the detection limits consistent with the concentrations listed on page 4 of the Restriction (50 ppm total fluorine) and as such can be an analytical technique which is utilised to ensure compliance to the Restriction.

Atomic force microscopy uses a sensitive probe attached to a cantilever which is moved over a sample surface. The cantilever moves according to the surface topography and a laser monitors the movement of the cantilever to generate the measurement signal. This allows for the testing of force measurements (mechanical properties such as stiffness and surface imaging) and surface properties while the surface is being manipulated. Applications include:

- Research and development in semiconductors and optical electronic devices. For example, with an electrochemical cell attachment, chemical reactions may be observed at the surface of samples.
- QA/QC of industrial products.
- Material failure analysis.

The ability to obtain measurements during chemical alteration of a surface and perform measurements of surface properties makes this an important tool in material science and for industrial development.

Raman spectroscopy equipment operates in the spectral range 250 nm through to 2,200 nm. The technique operates on the principle of light scattering from the sample surface. The surface is bombarded with photons, and these interact with the sample surface. The inelastic scattering of the photons results in the scattered photon having a lower energy and therefore frequency. This frequency shift effect is then detected to allow an excitation scan and detection scan across a wavelength range. The technique provides information on chemical functional groups in a molecule. Applications include:

- Mobile non-destructive sampling instruments for studies in archaeology, geology, and art (for example in identification of paints and coating materials).
- Research and development in applications such as semiconductors and pharmaceuticals.
- QA/QC of industrial products.

The technique is amenable to miniaturisation and incorporation into other equipment. This allows its use outside of traditional laboratory environments where rapid measurements of chemicals are required.

Optical microscopy includes scientific cameras, spectroscopy, and microscopy in the ultraviolet and visible region of the electromagnetic spectrum. The equipment is used for:

- Medical diagnostic applications.
- QA/QC of industrial products.
- Scientific research such as astronomy.
- Research and development of industrial products.

The equipment is increasingly used to control equipment and to combine spectroscopic analysis of chemicals with imaging obtained using very fast frame rates.

X-ray technology allows the generation of X-rays that are then used in other equipment to obtain measurements and images from samples. Examples of its use include:

- X-ray fluorescence spectroscopy where chemical elements may be identified and quantified.
- Medical diagnostic and monitoring imaging.
- Industrial X-ray inspections, for example metal welding integrity.
- Industrial X-ray production thickness monitoring equipment such as QA/QC on printed circuit boards.

The technology provides non-destructive testing for the control of defects in castings and composites, and the optimisation of critical thicknesses in coatings, plastics, textiles, wood, and steel sheets.

2.2 Nanoscience and plasma technology products

These products may be subdivided into two categories: the nanoscience products that operate at the nanometre scale and the plasma technology products that operate at both the nanometre and the atomic scale.

2.2.1 Nanoscience products

These products allow the manipulation of matter in controlled conditions of temperatures down to < 10 mK (Kelvin). This allows quantum level physics effects to be exploited. Magnetic fields of up to 16 Tesla may be applied with integrated cold electronics and optical fibre connections. Examples of applications include:

- Superconducting quantum computing.
- Large computer data handling centres.
- General research.
- Photonics and sensing applications.

The products use $^{3}He/^{4}He$ dilution refrigeration technology where the heat of mixing of the two helium isotopes is exploited to reach temperatures very close to absolute zero. The products are, therefore, highly specialised cooling equipment.

2.2.2 Plasma technology products

This technology allows the creation and manipulation of matter on surfaces down to atomic-scale accuracy. It includes techniques such as:

Atomic layer deposition (ALD) is an advanced deposition technique that allows for ultra-thin films of a few nanometres to be deposited in a precisely controlled manner.

Plasma etching is a way of creating features on a substrate; the features can be on the nanometre scale or 100s of microns. The etching process can be by inductively coupled plasma etching or reactive ion etching.

Plasma deposition: In this technique, a chemical vapour is created over the substrate which is held at temperatures up to 250°C and pressures down to 1 x 10^{-7} mbar. This allows the precise deposition of layers of materials.

2.3 Summary of Oxford Instruments products and applications

The equipment and their uses are summarised in Table 2.1 below.

Table 2.1: Oxford Instruments product types and end uses.

Product category	Products	End use
Analytical equipment	Electron Backscatter Diffraction Analysis, Energy Dispersive Spectroscopy (EDS), Wavelength Dispersive Spectroscopy (WDS) and Nanomanipulators.	Chemical analysis and R&D
Analytical equipment	X-Pulse Nuclear Magnetic Resonance (NMR) Spectrometer, Time Domain-NMR.	R&D, academia and production QA/QC
Analytical equipment	Scientific cameras, spectrographs and microscopy systems	R&D and production QA/QC
Analytical equipment	Atomic force microscopes	R&D, such as semiconductors and batteries.
Analytical equipment	X-ray source generation technology	Used in medical, diagnostic, chemical analysis and imaging equipment in production, laboratory, and other professional settings.
Analytical equipment	Raman spectroscopy and imaging equipment	R&D and production QA/QC
Nanoscience	Dilution refrigerators and super conducting magnets	Scientific research, quantum computing and large computer data centres.
Plasma technology	Plasma Etching, Reactive Ion Etching (RIE), Reactive Ion Etching, Inductively Coupled Plasma Etching (ICP), Deep Silicon Etching (DSiE), Plasma Deposition, Plasma Enhanced Chemical Vapour Deposition (PECVD), Inductively Coupled Plasma Chemical Vapour Deposition (ICPCVD) and Chemical Vapour Deposition (CVD).	Semiconductor R&D and manufacturing. Optical device R&D and manufacturing.

3 REQUESTED DEROGATIONS

Derogations are requested to allow the continued use of PFAS in critical applications. The requests are detailed below in support of proposed derogations, derogations that Oxford Instruments wish to be amended and new derogations requested by Oxford Instruments.

Timelines have been estimated for replacement steps required **once PFAS-free alternatives become available**. However, for many applications it is not known if alternatives are under development or when these may become available. In addition, it is difficult to establish whether parts contain PFAS. This is due to the complexity of the supply chain (some parts are bought in complex sub-assemblies) and the fact that many PFAS are not declared on supply chain documents such as technical data sheets or safety data sheets. This is because most PFAS have not been classified as hazardous under the Globally Harmonised System for classification and labelling or listed as substances of very high concern (SVHC) or included on the Candidate List of SVHC for Authorisation.

Potential alternative parts will have to undergo a checking procedure (this might include chemical analysis as well as supply chain documentation checks) to ensure that the part is PFAS free. This is not straightforward, as there are many parts used with different material grades and suppliers and information must be requested and checked for all of these. Oxford Instruments is a technical user of materials and components, rather than a specialist in materials development. This ranges from a raw material, such as a polymer sheet, through to simple parts such as O-rings, up to complex assemblies such as PCBA’s or entire sub-assemblies. Oxford Instruments is, therefore, reliant on suppliers to both communicate the presence or absence of PFAS in existing materials and to develop PFAS-free alternatives. Sufficient time will need to be permitted to allow Oxford Instruments to test, re-design and validate products with PFAS-free parts before placing them on the market. The timeline cannot be estimated with certainty due to the number of steps to be undertaken and the potential for unforeseen challenges. For Oxford Instruments known current uses, PFAS-free alternatives are either not known to exist or are at a very early stage in their development.

3.1 Proposed derogations relied upon by Oxford Instruments

The following derogations are required by Oxford Instruments without the need for any alteration of the text.

3.1.1 Derogation 5.s. Lubricants

Oxford Instruments supports the need for a derogation for lubricants where the use is undertaken in harsh conditions, or the uses are needed for the safe functioning and safety of the equipment. Oxford Instruments relies on the critical functionality such lubricants provide to its products.

Most Oxford Instruments products have surfaces that require lubrication where the use takes place under harsh conditions or is needed for safe functioning and safety of equipment. Indicative examples include:

- Laser systems for use in Raman spectroscopy where low outgassing and/or UV resistance are required.
- Scanning electron microscopes where low outgassing (due to impact on image quality and ability to use in vacuum), high radiation / UV stability, chemical inertness (preventing early corrosion of lubricated metal parts) and excellent tribological properties over a long period of time are required.

- Microscopes which have sliding and rolling bearings of rotational and translational guide units which require good lubricating properties over a wide temperature range and low hydroscopic water absorption.
- Turbo Molecular pumps or rotary vane pumps which create a vacuum environment down to levels from 5 x 10^{-3} to 10^{-10} mbar due to their low outgassing requirements and high operational temperatures.

There are two types of lubricants, applied greases and oils or solid self-lubricating surfaces.

Grease and oil-based lubricants

The types of PFAS-containing lubricants include polytetrafluoroethylene (PTFE) greases and sprays, and lubricants with PFAS additives such as perfluoropolyether (PFPE), PTFE or proprietary PFAS polymers and mixtures. The following specialist PFAS-based lubricants are used by Oxford Instruments in the analytical equipment products:

- Krytox™ low vapor pressure (LVP)

These are greases formulated to perform in temperatures ranging from -15 to +300°C, at vapor pressures as low as 1.0 x 10^{-13} torr at 20°C. Evaporation loss indicative value is 0.3 % w/w after 22 hours at 204°C. Other essential properties include:

  - Chemically inert to reactive chemicals such as uranium hexafluoride, ammonia gas at 250 °C, hydrogen peroxide, nitrogen tetroxide and fuming nitric acid.
  - Non-flammable when tested at 649°C.
  - Compatible with gaseous and liquid oxygen.

- Fomblin™ LVP

This is a grease formulated using PFPE. Properties include:

  - Chemical resistance.
  - Electromagnetic spectrum radiation resistant.
  - Wide operating temperature.
  - Low evaporation loss.
  - Required viscosity index range.

Alternatives based on silicone lubricants and silicone oils cannot be used as they do not have the required properties such as low outgassing at high temperatures. A further example is their poor stability in harsh radiation such as UV light. The UV light de-polymerises the silicone polymer to more volatile lower molecular weight oligomers that deposit on critical surfaces. This phenomenon has been outlined in multiple studies, including in the following domains: space science[4], laser fusion[5], photomasks for lithography[6] and lithography scanner optics.[7] It should also be considered that silicone alternatives may contain D4-, D5-, and D6-ring siloxanes which are classified as SVHC under the REACH Regulation due to their classification as persistent, bio accumulative and toxic-substances. A change from PFAS-based lubricants to silicone is therefore not viable.

Other potential substitute lubricants include hydrocarbon and chlorocarbon-based formulations. These are not suitable because they do not have all of the essential properties required such as low evaporative loss, chemical stability, or other properties.

As such, there are no alternatives to PFAS-containing oils and lubricants available which show the same low outgassing behaviour and the same stability against chemical decomposition and UV light as the PFAS-containing oils and lubricants do. In addition to this, in many of the applications, PFAS-free lubricants and oils have a shorter lifetime and thus would require shorter maintenance intervals and/or require more comprehensive maintenance activities or cause higher wear and scrap rates of the affected parts.

Solid self-lubricating surfaces

The nanoscience products use PTFE as a guide surface for introduction of the sample into the equipment. In this application, the PTFE is functioning as a rigid guide whilst also providing a low friction self-lubricating surface. The low coefficient of friction of PTFE allows the moving surfaces to be positioned in very close contact with each other so that a vacuum seal is maintained without loss of vacuum in the inner working environment of the equipment. In addition to all of the above property requirements, low outgassing, chemical stability, and inertness are also required.

Self-lubricating surfaces are used in the atomic force microscopes for sliding bearings on sample mounting and positioning stages. Polymers based on grades of PTFE such as Rulon™ and Fluoron™ are used. These provide the following required properties:

- Low coefficient of friction.
- High rigidity.
- Good movement and vibration damping.
- Chemically inert and stable.

[4] Boeder, Paul & Visentine, James & Shaw, Christopher & Carniglia, Chuck & Alred, John & Soares, Carlos. (2004). Effect of a silicone contaminant film on the transmittance properties of AR-coated fused silica. Proceedings of SPIE - The International Society for Optical Engineering. 10.1117/12.560859. Mossman, D. L., Bostic, H. D., & Carlos, J. R. (1987, January). Contamination induced degradation of optical solar reflectors in geosynchronous orbit. In Optical Systems Contamination: Effects, Measurement, Control (Vol. 777, pp. 12-19). SPIE. Luey, K. T., Olson, K. R., & Coleman, D. J. (2018). Optical system contamination: formation of films and droplets. Journal of Astronomical Telescopes, Instruments, and Systems, 4(3), 036001-036001.

[5] Mangote, B. & Tovena-Pecault, I. & Néauport, J. (2012). Study of the LIDT degradation of optical components by intentional organic contamination. Proceedings of SPIE - The International Society for Optical Engineering. 8530. 25-. 10.1117/12.968573.

[6] Grenon, Brian. "Impact of micro-contamination on advanced lithography."

[7] Meute, J., Rich, G. K., Hien, S., Dean, K. R., Gondran, C., Cashmore, J. S., ... & Dewa, P. G. (2002, July). Contamination and degradation of 157-nm stepper optical components: field experience at International SEMATECH. In Optical Microlithography XV (Vol. 4691, pp. 724-733). SPIE.

A PTFE coating is applied to the electrical wire windings on magnets used in nanoscience products. These generate high magnetic fields (up to 16 Tesla) with voltages up to 10,000 volts. Operating temperatures may be <10 mK. The PTFE functions as a solid lubricant to prevent a slip and stick effect. This occurs because the high voltage and magnetic field generated during use of the product can cause movement of the wire in the coil, resulting in vibration and electrical interference. The PTFE also acts as a dry lubricant during manufacture to allow correct winding onto the coil bobbin. The PTFE solid lubricant must withstand the harsh conditions of extreme low temperature and also provide electrical insulation at the very high voltages. The combination of properties required include:

- Low temperature (<10 mK) physical properties resistance to cracking.
- High electrical insulation performance at high voltage (10,000 Volts DC).
- Low coefficient of friction.

There are currently no available suitable alternatives to PFAS-based polymers that could be used in the manufacture of these magnets. Alternative PFAS-free solutions would require lubricating greases or oils which risk sample contamination (and will not function at very low temperature) or air bearings (not a substitute for wire insulation) which introduce complexity and engineering problems which would need sufficient time to develop and qualify. As outlined in

Table 3.1 it would take at least 13.5 years to re-design, test for reliability and go through necessary client and regulatory approvals. This process can only be initiated once PFAS-free components have been identified. There is a great degree of uncertainty with the timeline as currently there is no known PFAS-free alternative meeting the necessary technical requirements.

Table 3.1: Estimated lubricant development timeline after availability of PFAS-free alternatives.

Stage	Time (Years)
Identification of PFAS-free components	At least 0.5
Testing of PFAS-free components	2
Redesign of product	2
Testing of prototypes	2
Production trials and testing	2
Reliability testing	1
Final product validation	1
Customer notification and acceptance	1
Global approvals from notified bodies. Product-specific requirements such as technical documentation and conformity checking with standards.	2
Total time	**At least 13.5**

3.1.2 Derogation 5t. Calibration of measurement instruments and as analytical reference materials

Oxford Instruments supports the need for the derogation 5.t. calibration of measurement instruments and as analytical reference materials, as without such applications many of its products, such as scanning electron microscopes, would no longer be able to operate.

Calibration materials are used in equipment such as the Scanning Electron Microscope (SEM). PTFE is used to calibrate the instrument response for elemental nitrogen in the SEM. In this technique, the sample surface is bombarded with a beam of electrons with a known energy. These electrons interact with the surface electrons. These are ejected from an inner orbital of the atom or ion and an outer orbital electron then drops down to an inner orbital, releasing the energy difference as an X-ray photon. This X-ray emission is detected and is characteristic of the electron configuration of the chemical element. The X-ray emission is referred to as emission lines. To calibrate the instrument, the calibration material must be composed of chemical elements that provide X-ray emission lines that do not overlap.

The SEM is not a separation technique so that the presence of a combination of chemical elements may result in an overlap of emission lines. PTFE is an ideal calibrant because there is no such overlap. Alternatives such as lead fluoride or manganese fluoride cannot be used because of overlap of the metal emission lines. Fluorine cannot be used because the emission lines are characteristic of the electronic configuration of the atom, which is different when covalently bonded in a polymer structure compared to the elemental state. PTFE also has the advantage of not outgassing in the vacuum required for electron microscopy. Currently there is no known substitute to PTFE for this application.

3.1.3 Derogation 5.v. Hard chrome plating

Oxford Instruments supports the need for a derogation for hard chrome plating. Oxford Instruments relies on the critical functionality that the chrome confers on its products.

Due to its unique characteristics (non-magnetic, hard wearing and corrosion resistance) hard chrome plating may possibly be used in Oxford Instruments products or in systems where an Oxford Instruments product has been integrated as a component to enable critical functional or analytical features. Hard chrome plating is carried out by suppliers of components and assemblies and the formulation of plating baths is never divulged to Oxford Instruments. Examples of its possible use includes:

- Guide components in moving module assemblies which are subject to abrasive degradation.
- Components exposed to alternating loads (including mechanical, thermal, vibration, and combinations of these factors).
- Components with adhesive stress due to high surface pressure and without lubrication (e.g., in vacuum applications).

Hard chrome plating currently uses PFAS in its production process. Alternative surface hardening processes can only be used in combination with materials that are suitable for this purpose, but often they have different technical parameters such as corrosion resistance, residual magnetism and suitability for vacuum application which mean they are not suitable for particular applications.

One such example is scanning electron microscopes (SEM) where any residual magnetism (such as occurs with nickel or cobalt based coatings) would disturb the electrons which are generated in the microscope to scan the sample (as well as the backscattered and the secondary electrons produced in the scan, and which are recorded to allow the elemental analysis of the sample). Given that SEMs operate under vacuum, the heat dissipation is significantly reduced as there is no convection possible, which results in significantly higher temperature loads for the components when compared to their operation under atmospheric conditions. SEMs operate at the micrometre range, which causes short travel distances to be travelled at an extremely high frequency, resulting in a high wear load for many components. In many cases this wear cannot be mitigated using lubricants due to the operation of the equipment under vacuum. Due to all these factors, the hard chrome plating is essential to the operation of such equipment.

Oxford Instruments does not manufacture the chrome-plated metal. The plated components are purchased from suppliers. The PFAS use arises from plating processes in which PFAS is used to control emissions of toxic substances such as hexavalent chromium. Oxford Instruments will be reliant on the plating industry eliminating the use of PFAS. A possible alternative for Oxford Instruments to chrome plating is High Velocity Oxygen Fuel Thermal Spray Process. This allows the deposition of materials such as cermets (metal ceramic composite material), ceramics such as chromium, aluminium and zirconium oxides, metals (such as titanium) and metal alloys. However, the availability of components manufactured using this technique is not known. In addition, components would need to be evaluated and the design, production and validation steps described above worked through. As outlined in Table 3.2 it would take at least 6.5 years to re-design, test for reliability and go through necessary client and regulatory approvals.

Table 3.2: Estimated timeline for alternative to hard chrome plating after availability of PFAS-free components.

Stage	Time (Years)
Testing of PFAS-free components	1
Redesign and testing of prototypes	0.5
Production trials and testing	1
Reliability testing	1
Final product validation	1
Customer notification and acceptance	1
Global approvals from notified bodies. Product specific requirements such as technical documentation and conformity checking with standards.	1
Total time	**6.5**

3.2 Requested amendments to proposed derogations

The derogations discussed below are proposed derogations outlined in the Restriction, to which Oxford Instruments would like to suggest the following amendments to allow continued use of critical PFAS parts.

3.2.1 5.ee. Semiconductor manufacturing process, related equipment and supporting processes

Oxford Instruments produces equipment that supports the manufacture of semiconductors. The semiconductor industry shares technical requirements across the entirety of its equipment and processes, including the manufacturing equipment for semiconductors. As such Oxford Instruments requests that the derogation permits the use of PFAS in the ‘semiconductor manufacturing process, related equipment and supporting processes.’ It is expected that at least 13.5 years, or more would be required to qualify PFAS-free materials due to the highly complex technical requirements that they will have to meet.

The plasma technology products are used in semiconductor manufacturing and also in the manufacture of optical devices. The Restriction does not include optical device manufacturing equipment as end use applications of PFAS. However, semiconductor manufacturing is increasingly integrated with the development and production of optical devices. This means that these are not separate industrial activities. Therefore, an amendment to derogation 5.ee. is requested to include ‘related equipment and supporting processes’. If the amendment is not granted, the design of semiconductors for optical electronic devices will be impeded and applications such as human/machine interaction no longer able to be supported.

Without a derogation to allow the semiconductor process technology to also be used for optical device manufacture, a different cooling technology will have to be developed and implemented. This will result in divergent technologies requiring both types of equipment to be purchased without the present existing ability to use the same equipment. This will impede both the development and manufacture of optical semiconductor devices, as both are interrelated.

PFAS are used as they provide the following combination of technical functions, with the exact technical requirements depending on the end application:

- Temperature stability (-150 up to 200°C) without embrittlement or outgassing. The materials must not produce any particle emissions, which would otherwise disturb the function of the equipment.
- High chemical resistance against aggressive chemicals (such as HFO_3, H_2SO_4, $POCl_3$, and BBr_3), as well as against reactive radicals such as O*, OH*, OOH* H* and H-Plasma.
- Very low outgassing into vacuum and into ultrapure inert gases, and low water absorption. Hydrocarbon elastomers, even if marketed for vacuum use, outgas by a factor of 1000 more than fluorocarbon (FKM).
- Insulation (electrical and thermal) properties and dielectric strength at voltages up to 900 Volts DC.
- Good sliding properties which is important for the feedthrough of components that operate under vacuum.

Some examples of PFAS uses are given below.

Process gases are used in plasma etching and plasma deposition processes. PFAS are used because of their ability to form stable process reagent species. The end user of the equipment utilises the following process gasses:

- Hexafluoroethane,
- Hexafluoro-2-butyne, and
- Octafluorocyclobutane.

These PFAS gases are ionised in the plasma environment and generate aggressive etching ionic species that have unique technical performance allowing the etching of silicon oxide in certain semiconductor manufacturing processes. They allow the cleaning of the substrate being worked upon without leaving residues. They must have the required stability in the plasma and aggressive etching and cleaning properties.

There are currently no alternatives for PFAS process gasses with the unique properties required. Nitrogen trifluoride (NF_3) and sulphur hexafluoride (SF_6) are under consideration for some applications but require major redesign and redevelopment and may not be suitable for all applications.

Refrigerants and heat transfer fluids

Oxford Instruments plasma technology products use PFAS-containing refrigerants that are required to reach a guaranteed temperature of -30°C. Temperature control is critical and is achieved through relatively small chiller units that are integrated with the process equipment. A heat transfer fluid is pumped through the process chambers to control the temperature. The heat transfer fluid is then circulated through a heat exchanger where refrigeration gases are used to remove heat from the heat transfer fluid. The heat transfer fluids used are PFAS when current alternatives (such as ethylene glycol water mixtures) are not suitable. Examples of PFAS heat transfer fluids include perfluoroalkanes, perfluoroethers and tertiary perfluoroamines. Properties required of the heat transfer fluid include a combination of all of the following properties:

- Chemical stability.
- Chemical inertness.
- Physical properties (boiling point etc) to match the required operating range.
- Non-flammable.
- Non-toxic.
- No residues on evaporation.

The heat transfer fluid and refrigerants do not remain in the finished semiconductor or optical device but are recovered for reuse within the process. Therefore, there is negligible PFAS exposure risk to humans or the environment.

Gaskets and O-rings

The following fluoroelastomers are used in Oxford Instrument products.

Kalrez® is a perfluoroelastomer manufactured by Dupont. It is designed to “be one of the most inert polymer structures available standing up to more than 1,800 different chemicals while offering high-temperature stability” up to 327°C [8].

Isolast® is a perfluoroelastomer manufactured by Trelleborg Sealing Solutions. It combines the elastic properties of FKM with the high chemical resistance and the high temperature stability of PTFE. Isolast® seals can be used for applications in high temperature service up to 325°C[9].

[8] https://www.dupont.co.uk/products/kalrez.html

[9] https://www.trelleborg.com/en/seals/products-and-solutions/o-rings/isolast-ffkm-perfluoroelastomer-o-ring

Viton is a fluoroelastomer manufactured by Dupont. It withstands temperatures up to 316°C and has high chemical resistance to oils, lubricants, and acids. It has low gas permeability, high resistance to compression, low flammability and electrical properties required for low voltage, low frequency applications. It is used for O-rings, gaskets and seals and ferrules on tubing connectors.

Dupra is a fluoropolymer manufactured by Daiken and is specially developed for plasma applications. Physical and chemical properties information and data are available on the internet[10] for this special polymer grade.

Fluorovinyl methylsiloxane rubber (FVMQ) is a fluorosilicone consisting of polysiloxane chains where methyl side groups are replaced by trifluoropropyl side groups. They have nearly the same mechanical and physical properties as silicone rubber but due to the fluorination they show better resistance against many fluids. FVMQ has a good heat resistance [-50°C up to 300°C], very good low temperature flexibility, and excellent resistance to ozone and UV rays.

These PFAS-containing polymers show the following enhanced properties over other polymers:

- Higher purity (lower residual metals by atomic absorption measurement).
- Lower organic volatiles as measured by Purge and Trap Gas Chromatography. This is a very sensitive analytical technique with detection limits in the sub parts per billion range. The quoted sampling conditions of 200°C for 15 minutes are particularly demanding exposure conditions.
- Longer service life.
- Improved heat resistance. Plasma applications require high temperature stability with low adhesion to the contact metal parts being sealed. Softening with subsequent bonding to the surfaces increases maintenance times. The O-rings are compressed during use between the surfaces that they are sealing. This results in a deformation of the O-ring, termed a “Compression Set”, and this is expressed as a percentage of the thickness. The time required to reach a Compression Set % is an indicator of performance and is dependent on a number of factors including temperature and the material properties. The PFAS materials exhibit a flatter curve of Compression Set % as a function of time at a required operating temperature compared to other PFAS-free polymers[11].

Research would need to be carried out to identify PFAS-free process gases. Assuming that alternatives become commercially available, the suitability of these would need to be tested across the product range and the range of end use applications. The equipment would then also have to go through the redesign, testing, validation, and approval stages. The estimated timeline to substitute all PFAS-containing components in plasma technology equipment is given in Table 3.3 below. This shows that at least 13.5 years is required after alternative PFAS-free materials become available.

[10] http://en.scmchem.com/product/88.html

Table 3.3 Estimated timeline after availability of PFAS-free components in plasma technology equipment.

Stage	Time (Years)
Specific research to identify alternative process gases	3 (or longer)
Redesign of product	2
Testing of prototypes	2
Production trials and testing	2
Reliability testing	1
Final product validation	1
Customer notification and acceptance	1
Global approvals from notified bodies. Product specific requirements such as technical documentation and conformity checking with standards.	1.5
Total time	**13.5**

3.3 Additional derogations requested by Oxford Instruments

The following additional derogations are requested to allow continued use of critical PFAS parts.

Analytical equipment

It is important that a derogation permits PFAS uses for analytical products and is not limited to laboratory use only, as not all applications of analytical equipment are in laboratories. The derogation for analytical equipment, if limited to the laboratory, will impede the important role this equipment provides in health and safety, culture, and society. It is expected that at least 13.5 years would be required to qualify PFAS-free materials and there will remain a small number of critical parts (such as NMR probes) for which it will not be possible to replace with PFAS-free materials. For this reason, a derogation for analytical equipment is requested for 20 years after EiF, with a process to extend the derogation, if required.

The term analytical equipment includes chemical analysis such as that carried out using spectrographs in laboratories. Spectrographs include NMR and Raman spectroscopy; these obtain measurements such as a chemical concentration and they also identify chemical structures for which measurements of wavelength and electromagnetic absorbance are required. Raman spectroscopy is an example of a technique that is portable and is used outside a laboratory setting. Examples include archaeological sites, stately homes and museums with paintings and other artworks. Analytical equipment also includes techniques such as X-ray imaging techniques that may be conducted either in a laboratory or a production environment. In addition, they may or may not obtain a measurement that can be related to a numerical quantity. The output might, for example, be an acceptance of a production stage in a production process.

Specific component requirements and their use in analytical equipment is described below.

Printed Circuit Board Assemblies

Printed Circuit Board Assemblies (PCBAs) are used in all Oxford Instruments products and are designed and manufactured by its supply chain. Their use is described here because of the particular requirements in analytical equipment. These are:

- Low outgassing.
- Chemical inertness.
- High chemical stability.
- Low contamination potential (which would result in poor sensitivity and inaccurate test results).

PFAS are known to be used in the manufacture of such components, including on the PCBA's conformal coatings which is a specially formulated polymeric material that protects the PCBA from harmful environments such as moisture, thermal shock, static electricity, vibration, and contamination. The formulation will vary depending upon the specific operating environment of the PCBA. It will be a complex proprietary formulation and will affect the compliance status of the PCBA against safety standards such as UL 796 where UL is the Underwriters Laboratories designation for a particular standard. UL-94 is the set of flammability standards. These include V0, V1, V2, HB, 5VB and 5VA. To achieve these flammability standards, flame retardants are added. These may include PFAS such as potassium nonafluorobutane sulphonate (CAS number 29420-49-3).

There is also a comparative tracking Index (CTI) requirement which is the applied voltage difference at which electrical insulation breaks down. There is a classification into categories for a set of CTI voltage ranges. Oxford Instruments buys in these PCBAs by selecting them according to their performance and compliance status against the relevant safety, technical and other standards. Whilst a PCBA supplier may be able to use PFAS-free alternatives, Oxford Instruments also has its own operating environment requirements for these PCBAs such as low outgassing. In addition, there are other environmental compliance requirements. For example, Oxford Instruments is committed to a net zero carbon target of 2045 so some suppliers of alternative PFAS-free parts may not be suitable as the corporate policy of the supplier will also need to comply with this requirement and not all may do so. Given these additional requirements, it may require up to 12 years to select, redesign, test and validate PFAS-free alternatives.

O-rings and gaskets

PFAS O-rings and gaskets are used across the entire Oxford Instruments product range. An example of their use is in Atomic Force Microscopy (AFM), where an accessory termed here a "Liquid Cup" allows a user to image a sample surface, immersed in a liquid electrolyte, at the sub-nanometre scale while at the same time carrying out electrochemical experiments to modify the surface. The AFM observes the atomic-scale effects of the electrochemical experiment on the surface. Applications range from fundamental surface science to green-energy research on battery technology. The O-rings are used to form a seal between the sample surface and the Liquid Cup. The Liquid Cup contains the liquid electrolyte, keeps it in the vicinity of the AFM probe and sample surface, and prevents it from spilling or leaking into other parts of the Electro Chemical Cell and AFM. A gasket in the form of a flexible membrane is also used to connect the outer, immobile frame of the AFM and the inner, moving part that includes the sample and the Liquid Cup. It seals the environment around the sample, protecting the sample and electrolyte from contamination. It also protects the AFM mechanical components and electronics from leakage and spillage. If contamination occurred, it would cause incorrect experimental results. If leakage or spillage occurred, it would cause damage—possibly catastrophic damage—to the AFM and would present a safety hazard to the user.

The O-rings and gasket are exposed to a wide range of aggressive chemicals. Electrochemical experiments often require strongly acidic conditions (sulfuric acid), strongly alkaline conditions, oxidisers (perchloric acid), ionic liquids (battery electrolytes), or various organic solvents. Only fluorinated elastomers are sufficiently chemically inert.

The O-rings and gaskets are used across the Oxford Instruments product range with operating conditions including temperatures up to 250°C, voltages of 1,000 Volts and pressures down to 1 x 10^{-7} mbar. Currently, FFKM perfluoroelastomer (similar to Kalrez™) is the only available material which meets all of these technical requirements. FFKM grades are specially formulated for analytical instruments for resistance to exposure to plasmas, high temperatures (up to 325°C) and oxidising gases. The combination of properties required are:

- Resistant to temperatures in the range -100 to 200°C.
- Chemically inert and stable.
- Free of migratable contaminants such as plasticisers and additives.
- Electrically and thermally insulating.
- Resistant to electromagnetic radiation.
- Low outgassing at pressures down to 10 x 10^{-10} Pa.
- Non-flammable.

There are currently no suitable PFAS-free alternatives. Materials such as nitrile, ethylene propylene diene terpolymer (EPDM) and silicone rubbers have been evaluated but have inadequate chemical resistance to all the chemicals in the wide range of corrosive reagents used for electrochemistry experiments. This would mean that equipment could not be supplied that would be suitable for the most aggressive chemical reagents. This would then leave three different versions of the equipment that would have to be purchased by the end user to cover the range of these remaining milder chemical reagents. This would prevent research and development requiring these most aggressive reagents and would triple the cost for the end users for the remaining applications, as all three versions would have to be purchased to achieve a reduced functionality compared to the single PFAS-containing equipment.

Probes for NMR instruments

PFAS materials are used in the construction of the sample probe. The probe is a complex part that contains the excitation and detection radiofrequency coils, the sample and hardware to control the sample temperature. The sample is contained within a tube that is inserted into the probe. The sample can be heated to 200°C, with the exact temperature depending upon the testing being carried out. There are different designs of probe depending upon the nuclei being measured. The radiofrequency coils are positioned and held in place on the probe using polymer components selected according to the nuclei being measured. For ^{1}H measurement PTFE is used and for ^{19}F measurement, rigid PVC is used. The property requirements are:

- Absence of the nuclei being monitored (i.e. PVC and hydrocarbon based polymers cannot be used to analyse hydrogen-containing substances, PTFE is suitable as it does not contain hydrogen atoms).
- Resistant to temperatures up to 200°C.

- Chemically inert and stable.
- Free of migratable contaminants such as plasticisers and additives.
- Electrically and thermally insulating.

There are currently no suitable PFAS-free alternatives.

Sample tubes for NMR

In order to carry out an analysis on a sample, it is typically dissolved in a suitable solvent such as deuterated dimethyl sulphoxide or deuterated chloroform. These solvents contain no interfering ^{1}H nuclei which would interfere with the NMR signal. The sample tube is typically borosilicate glass with different diameters available to give different volumes depending upon the sensitivity required. The sample tube is often spun using pressurised air within the probe, to even out small inhomogeneity of the applied magnetic field. Typical spin rates are 20 Hz for a 5 mm tube and 12Hz for a 10 mm tube. The tubes are capped to avoid loss of the sample into the instrument probe assembly. The choice of polymers for these caps are limited. They cannot contain plasticisers and other additives that might migrate into the sample. They must have the following properties:

- Resistant to the very aggressive sample solvents (such as chloroform and dimethyl sulphoxide) and cleaning reagents being used.
- Easily slide off the delicate very thin borosilicate glass tube but act as a seal to prevent evaporation losses.
- Resistant to temperatures up to 200°C.
- Not be a polymer containing the nuclei being measured, at a concentration giving rise to an interfering background NMR signal at or above the required sensitivity level for the analysis.

To meet this combination of required properties, PTFE or (if the required sensitivity allows the presence of some ^{1}H nuclei in the cap) ethylene-tetrafluoroethylene (ETFE) are often the only available choices. The sample tube must also be selected for the sample and analysis being performed. PTFE tubes are used where chemicals such as hydrofluoric acid, ammonium bifluoride or concentrated alkali hydroxide solutions are present. In studies where ^{29}Si NMR experiments are being conducted, the borosilicate glass tubes can’t be used because of interference from silicon in the glass with the NMR signal. For these experiments, PTFE tubes are the only available option.

Overburden pressure test fluid for NMR studies

The NMR products are used to obtain permeability measurements in environmental studies relating to industrial mining, power generation such as oil and gas extraction, and carbon capture. The analysis is performed on rock core samples. Time Domain NMR techniques are used to study porosity, permeability, and pore size distributions in rock samples. NMR measurements provide a convenient way to monitor the actual movement of fluids such as brine and carbon dioxide (CO_2) in a rock by carrying out real-time core flooding experiments. The rock sample is saturated with a fluid such as dodecane and then exposed to an overburden pressure (typically up to 10,000 psi) in a monitoring cell to simulate the pressure exerted on rock when underground. Fluorinert™ is used as an overpressure oil. Fluorinert™ is a PFAS and is available in a range of molecular weights and grades. Fluorinert™ FC-40 (CAS number 51142-49-5 as a mixture of perfluorotributylamine and perfluoro(dibutylmethylamine)) and Fluorinert™ FC-70 (CAS number 338-84-1) are two examples where the molecules are entirely fluorinated with no hydrogen atoms present. Fluorinert™ is used as it has a combination of the required physical properties of chemical stability and absence of hydrogen atoms which would interfere with the NMR signal.

The combination of property requirements is:

- Absence of ^{1}H nuclei.
- Chemically inert and stable.
- Non-flammable.
- Free of migratable contaminants such as plasticizers and additives.

There are currently no suitable PFAS-free alternatives because the only available fluids with suitable physical properties all contain hydrogen nuclei which would overwhelm the ^{1}H measurement signal.

Laser sources used in spectroscopy

Lasers are used in Oxford Instruments products such as Raman spectroscopy equipment. Oxford Instruments does not make lasers, but purchases these in as finished self-contained components. The function of the laser is to provide electromagnetic radiation of an accurately known wavelength. This radiation may be source radiation upon which the technique is dependant or in wavelength calibration in signal processing techniques using mathematical treatments such as Fourier transform. Fluoropolymers are used in laser components for electrical and thermal insulation, electromagnetic radiation resistance, high temperature (in some cases up to 300°C) and low outgassing. For example, FKM (a fluoroelastomer) O-rings are utilised in a number of laser systems which must have low outgassing. One equipment manufacturer measures[11] the outgassing load (organic compounds) which needs to be less than 6µg/m^3 otherwise this would result in an increased degeneration rate of the optical components (induced by interaction of outgassing components and UV light). If the outgassing loads were to increase the product would no longer function as required and as such that would not be a viable alternative to FKM. The required properties include:

- Resistant to temperatures up to 200°C.
- Chemically inert and stable.
- Free of migratable contaminants such as plasticizers and additives.
- Electrically and thermally insulating.
- Resistant to electromagnetic radiation.
- Low outgassing at pressures down to 10×10^{-10} Pa.
- Non-flammable.

The estimated timeline to substitute with PFAS-free alternatives is given in Table 3.6 below. The estimated time is from when PFAS materials become available. However, for some uses such as NMR probes, there is no known replacement likely to become available for the foreseeable future.

[11] Tested as 24g of material at elevated temperature for 24 hours.

.Table 3.4: Estimated time to implement PFAS-free components in analytical equipment.

Stage	Time (Years)
Identification of PFAS-free components	At least 0.5
Testing of PFAS-free components	2
Redesign of product	2
Testing of prototypes	2
Production trials and testing	2
Reliability testing	1
Final product validation	1
Customer notification and acceptance	1
Global approvals from notified bodies. Product specific requirements such as technical documentation and conformity checking with standards.	2
Total time	**At least 13.5**

3.3.1 Maintenance and repair of equipment

Oxford Instruments supports its products in the field with service and repair contracts. It is expected that some of these may remain in service for 20 years, or more. It is requested that the use of PFAS-containing spare parts be permitted in equipment for which no drop-in PFAS-free replacements can be fitted.

PFAS are required for servicing and maintaining existing products already placed on the market. The parts most commonly replaced are O-rings and gaskets, topping up of refrigerants and heat transfer fluids. It is likely that in many applications there will not be a drop-in replacement for the PFAS due to these having different and unsuitable technical properties as described above in this submission. Oxford Instruments products can contain numerous PFAS-containing parts and the disassembly of the product may be impossible as removal of some parts may cause irreparable damage. Without permission to use PFAS in these applications, this will cause the premature end-of-life and scrappage of products which otherwise could be serviced and maintained in service with PFAS-containing parts. The inability to upgrade such systems will increase waste. Also, end-users in the EU will be prevented from working if replacement new equipment is also not available due to the Restriction without derogations.

It is therefore vital that the Restriction does not impact spare parts for products already placed on the market. In addition, it must be ensured that these spare parts may continuously be made available on the market. With the current definition of “placing on the market” under REACH this would not be possible, as any supply or making available to a third party, and hence any resale or lease, for example, is considered “placing on the market” under REACH.

Service, maintenance, and repairs are crucial for the success of the European Green Deal in relation to better resource efficiency and therefore it is important that this is reflected in all of the derogations.

3.3.2 Derogation extension process

As is outlined in the respective sections of this report, PFAS substances in some critical parts do not have a known viable alternative or are at a very early stage in their development. It is important to keep in mind that although minimum steps and time to be considered have been estimated in this report, they have a significant degree of uncertainty due to the number of steps still left to be undertaken and the possibility of unforeseen challenges yet to be identified. Estimated timescales are from when a potential substitute is developed and available to Oxford Instruments for evaluation. For some uses, this could take many years or may even be impossible for some end uses. The possibility arises that, in some cases, the development or use of PFAS-free alternatives will not be possible for scientific and technical reasons, or additional time will be required. In these circumstances the only option will be to withdraw the product from sale in the EU unless an additional derogation is granted.

It is therefore necessary to include a simple mechanism and formal process for extending derogation timelines beyond the timelines indicated above in this submission.

4 SOCIO-ECONOMIC IMPACT ASSESSMENT

The importance and benefits to society derived from the availability of the equipment are described, together with negative effects that the proposed restriction of PFAS in the EU would have, without the derogations requested in this submission.

4.1 Importance to society

Oxford Instruments is a high technology company at the forefront of research and development of equipment that is improving our lives and protecting the environment.

Using Oxford Instruments' products and services, Oxford Instruments' customers are developing new materials and approaches to enable the critical energy transition. This transition will directly impact everyone on the planet, as the world's governments and businesses pursue the goal of reaching net zero carbon emissions. In healthcare, its products are enabling medical researchers to understand the fundamental mechanisms of disease, accelerating their progress on new medicines and treatments. The company's products are also instrumental in the drive towards a more connected future, where everyone, everywhere can access information whenever they need – with a particularly meaningful impact in the emerging economies where connectivity has been proven to improve lives and increase prosperity.

While it supports all 17 of the United Nations Sustainable Development Goals, Oxford Instruments has identified that it makes a positive contribution towards the delivery of the following:

- Goal 2: Zero hunger
- Goal 3: Good health and well-being
- Goal 6: Clean water and sanitation
- Goal 7: Affordable and clean energy
- Goal 9: Industry, innovation, and infrastructure.

Specific applications of Oxford Instruments' products and services are considered in more detail below.

4.1.1 Analytical equipment

The analytical equipment is used across most industrial sectors for research and development and QA/QC. It is used in vital industries such as pharmaceuticals and supports EU policies on health and the environment. For example, analytical equipment is required to measure hexavalent chromium, lead and other substances to ensure compliance of components against the RoHS restrictions. It will be essential in the research into PFAS exposure and health risks and the support of the Restriction objectives and the implementation of regulations under REACH and RoHS. NMR analytical instruments will be required to identify the chemical structure of PFAS. Scanning Electron Microscopy with elemental analysis or X-ray fluorescence spectrometry can be used to screen parts for total fluorine to confirm the absence of PFAS. Research into the toxicity and prevalence in the environment of PFAS will require chemical structure identification, for which NMR studies are essential.

The equipment is used in the research and development and production of semiconductors and related devices, the importance of which is outlined below.

The equipment is also used to ensure food quality and safety, to identify and diagnose sources of air-borne and water-borne pollution, and in cultural and societal activities such as investigations of art works and understanding global history and evolution.

4.1.2 Nanoscience and plasma technology products

These Oxford Instruments products are being used as tools for the development and production of optical and semiconductor devices. Developments in these areas are critical for green technologies such as electric cars and renewable energy generation. There is an increasing demand for environmentally sustainable low energy consuming semiconductors (compound semiconductors) and increasing deployment of human/machine interfaces such as facial recognition requiring optical electronic devices used in mobile phones. The equipment is used in the roll out of 5G communications equipment that will bring a wider range of internet-based services to consumers as well as aid the deployment of driverless vehicles.

Oxford Instruments products are also being used to further academic and commercial advances in the rapidly growing quantum technology sector. Quantum has the potential to transform our ability to solve incredibly complex problems which are beyond today's capabilities, disrupting existing markets such as drug discovery, chemistry, finance, and logistics.

4.2 Economic impacts

The economic impact of the Restriction is considered below for the two types of products. If the requested derogations are not granted, the equipment will not be available for use in the EU. The equipment is used for research and development and industrial production across most industries. Therefore, in addition to the loss of sales of the equipment, there will be a significant economic impact resulting from a reduction in industrial output. Industrial activities that are dependent on the use of the equipment are likely to develop outside of the EU and some EU factories may be forced to close. An accurate estimate of the economic cost is not possible because of the complex factors involved. For example, research and development may result in new disruptive technologies from which the economics benefits can be disproportionately large compared to the investment made in the equipment.

4.2.1 Analytical equipment

The sales of analytical equipment were estimated at $51.7 billion in 2022 (Global Market Insights, 2023)[12] with sales estimated to grow by 4.8% to $81.6 billion by 2023. These sales values are at risk if PFAS-containing equipment cannot be placed upon the EU market or made in the EU. In addition, the economic value generated through the activities around the operation, servicing, and repair of the equipment (for which there is no data available) must also be considered. Analytical equipment is used for research, development, and production so that any restriction on the availability of this equipment will adversely affect industrial output across most industries in the EU. The total EU industrial production output was estimated at €5,209 billion in 2022 (Eurostat, 2023)[13].This industrial output is at risk if analytical equipment is not available.

4.2.2 Nanoscience and plasma technology products

Demand for these products is growing due to recent significant investments by the EU and countries including China, Japan, and the United States (tens of billions of Euros over a 5–10-year period) as they prioritise the development of the semiconductor industry, invest in low energy and develop their own quantum computing technology programmes. The size of the global plasma technology market has been estimated at $653 million[13]. Products to support the new generation of compound semiconductors have seen strong growth and now account for 65% of Oxford Instruments' semiconductor-related sales (Oxford Instruments, 2023)[14]. The factors behind these drivers are, increasing digital data flow, connectivity demand and large-scale data processing and storage centres. The Oxford Instruments products are targeted at reducing the production costs of more power efficient compound semiconductors such as gallium nitride. As an example, the Oxford Instruments products enable surface etching control to a uniformity of half a nanometre. This results in a four-fold improvement in manufacturing volumes and enhanced product performance.[14]

The Council of the EU and the European Parliament reached a provisional agreement on 18 April 2023 (European Council, 2023)[15] on the EU regulation proposal to strengthen Europe's semiconductor industry, the "Chips Act" (European Commission, 2022).[16] The Chips Survey and its subsequent report (European Commission Survey Report, 2022)[17] carried out for the European Commission found that demand for chips is expected to double by 2030 and that the EU's current global market share is only 10%. This demand is being driven by growth in new technologies, some of which are responses to green initiatives. For example, the energy renewable ecosystem has had significant growth since 2022 and is forecast to grow six-fold by 2030. A key finding was that the ongoing semiconductor supply chain shortage crisis is expected to continue until years 2024/2025 (European Commission Survey Report, 2022). Most of the Chips Survey respondents reported an adverse effect on production requiring mitigating measures. All respondents reported being either directly affected (83%) or indirectly affected (23%). Recent geopolitical tensions have highlighted the fact that current chip output is concentrated outside Europe in a small number of companies operating in Southeast Asia. The Council of Europe press statement makes the following statement:

[12] Analytical Instrumentation Market Share & Size Report – 2032 (gminsights.com)

[13] Industrial production statistics - Statistics Explained (europa.eu).

[14] https://www.oxinst.com/investors-content/annual-report-2023

[15] https://ec.europa.eu/newsroom/dae/redirection/document/89124

[16] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/european-chips-act_en

[17] https://ec.europa.eu/newsroom/dae/redirection/document/89124

Currently, Europe is too dependent on chips produced abroad, which became even more evident during the COVID crisis. The industry and other strategic sectors such as health, defence or energy have faced supply disruptions and shortages. The Chips Act aims to reduce the EU's vulnerabilities and dependencies on foreign actors while reinforcing the EU's industrial base for chips, exploit future business opportunities and create good quality jobs. This will improve the EU's security of supply, resilience, and technological sovereignty in the field of chips.

The Chips Act has three pillars:

- The chips for Europe Initiative to support technology capacity building.
- A framework to ensure security of supply and resilience by attracting investment.
- A monitoring and crisis Response system to anticipate shortages and respond.

A budget of €43 billion is expected to be raised, with €3.3 billion coming from EU funding. Under Pillar two, the agreement of 18 April widens the scope of the "First of a kind" facilities to include those producing equipment used in semiconductor manufacturing. The Council of the EU press statement recognises that 'First-of-a-kind' facilities contribute to the security of supply for the internal market. The Chip Act supports other EU policies such as the Green Deal, Horizon Europe[18] and the Digital Europe Programme[19]. The Chip Act recognises that:

The application of semiconductor technologies, and digital technologies in general, are powerful enablers for the sustainability transition and can lead to new products and more efficient and effective ways of working that contribute to the Green Deal objectives.

Oxford Instruments products, particularly the Plasma Technology products, are crucial to delivery of the Chips for Europe Initiative. Oxford Instruments is well connected to a cutting-edge chip design ecosystem involving high technology chip users in the UK, EU, and other world-leading technology centres. If the requested derogations are not granted, its products and similar products from other manufacturers cannot be marketed in the EU after entry into force of the Restriction requirements. This will render all three pillars of the Chips Act undeliverable. Design and research and development require both the analytical equipment and nanoscience and plasma technology products. Investment in chip production will go where research and development is supported. This will then be outside of the EU and the objective of the Chips for Europe Initiative to increase EU semiconductor market share to 20% will not be achievable.

5 ENVIRONMENTAL IMPACT AT END OF LIFE AND WASTE CONSIDERATIONS

At the end of the service life, due to the high capital investment, analytical equipment often goes into storage at the end user as a backup piece of equipment. The equipment usually reaches its end of life through being superseded by equipment with a smaller footprint and greater performance capabilities so that it is worthwhile storing the equipment. It can be many years before equipment is scrapped. The

[18] https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe_en

[19] https://digital-strategy.ec.europa.eu/en/activities/digital-programme

service life of a product may be up to 20 years. However, due to evolutions in technology, and changes in customers' requirements, upgrades often take place in a shorter timeframe.

If the derogations are not granted, the equipment will become waste at an early time point if it cannot be repaired. This will result in additional waste as new PFAS-free parts and equipment will need to be manufactured. Any emissions from the PFAS parts in currently existing equipment will be the same, the only difference is the time point when they become waste.

The equipment falls under the EU WEEE Directive 2012/19/EU which ensures that it is disposed of in accordance with EU legislation. It is very unlikely that any is sent to landfill due to its retained relatively high value at end of life arising from component materials such as metals. Equipment will also be taken back as part exchange agreements and then disposed of in accordance with correct procedure. End users of the equipment have well-developed waste disposal procedures in place. Due to the heavy nature and relative raw material retained value in the equipment, almost all is believed to be recycled within the EU and the recycling processes used are regulated by EU waste legislation including the Industrial Emissions Directive (2010/75/EU). Electrical waste is usually smelted for metal recovery, either to recover steel or copper. Secondary steel smelting is carried out at over 1600°C and copper smelters operate at least at 1200°C. Fluoropolymer insulated copper wire is recycled in the EU to recover the copper metal for reuse. Copper has a melting temperature of 1085°C and so at least 1100°C is needed to melt the wire and at this temperature, any fluoropolymer insulation residues will be destroyed. The removed fluoropolymer is incinerated to destroy the PFAS. Electrical equipment recycling is efficiently carried out in the EU and strongly regulated by EU legislation. EU metal smelters which recover metals from electrical waste and operators of incinerators are already obliged to ensure that there are no emissions of polychlorinated biphenyls, dioxins, furans and other toxic by-products, and the high temperature process conditions that are required to achieve this should also completely destroy all types of PFAS.

The environmental impacts from incineration of the PFAS materials have been considered in Annex A of the Restriction under A.3.18.2.7. Incineration. This recognises that "*incineration of PFAS-containing waste is currently seen as the most effective treatment option for destroying PFASs. The fluorine in the PFASs will end up in either the bottom/fly ash or the flue gas".*

This conclusion is supported by various studies (OECD, 2015)[20] and (K, 2019).[21]

5.1 PFAS emissions from use of the equipment

The majority of PFAS used in products is mostly non-volatile, high molecular weight polymers. There are a few notable exceptions to this, which are discussed in turn:

- A small proportion of non-polymeric PFAS is suspected to be present as flame retardants. However, these are non-volatile substances that are dispersed and bound within the polymer matrix of the parts.
- Refrigerants and heat transfer fluids. There are small losses of the PFAS refrigerant gases and heat transfer fluids to the environment during use due to leaks and change out tasks during maintenance. The equipment is maintained in service contracts with specialist technicians. The refrigerant gases have been specifically designed to minimise ozone depletion and global warming impact. At end of

[20] Chemical safety and biosafety - OECD

[21] http://www.elsevier.com/locate/chemosphere

life, the gases and heat transfer fluids are recovered as part of the recycling process where they are either reused or incinerated.

For all of the PFAS parts utilised in Oxford Instruments products, the substances are fully contained within the equipment so that there is no exposure to operators via dermal contact. Service of the equipment is carried out via support contracts with qualified providers including by Oxford Instruments.

At and below ambient temperature there will be no vapour emissions of PFAS, and fluoropolymers will not decompose to form more volatile low molecular weight degradation products. The number of PFAS materials used in high temperature environments is small and emissions of PFAS has to be at trace levels to allow the correct functioning of the equipment. PTFE is extremely inert and stable up to 250ºC. Above this temperature, it decomposes very slowly, with a reported weight loss of 0.004%/h at 371ºC (Huber, Emissions from incineration of fluoropolymer materials a literature survey, 2009).[22] The other PFAS used have similar or superior heat stability to PTFE.

Micro particles of PFAS polymers may be generated during operation of the equipment as a result of abrasion of surfaces. This will occur on moving parts such as high vacuum pumps, bearings and sliding surfaces. However, the contact force applied is low and movement distances are low on equipment such as microscopes. Fluoropolymers are used because of their low coefficient of friction which minimises wear. Vacuum pump oil may contain PFAS particles. Operators have no contact with this as it is disposed of as hazardous waste by service engineers. Apart from microscope guide rails most moving PFAS-containing parts are fully enclosed within the equipment so that dust exposure is negligible.

Most of the equipment represents a high capital investment by the end user. The number of equipment items sold per year is relatively small as these are not consumer items. The equipment has a long service life (in some cases up to 20 years).

6 SUMMARY OF REQUESTED DEROGATIONS

Oxford Instruments requests the derogations listed below.

6.1 Proposed derogations as given in the Restriction

5.s. Lubricants where the use takes place under harsh conditions or use is needed for safe functioning and safety of equipment until 13.5 years after EiF

Oxford Instruments relies on this derogation across its product range. State of the art lubricant technology includes the use of solid-state compounds as lubricants without incorporation in a base fluid such as an oil or grease. This is recognised by the EU Joint Research Centre (JRC, 2018)[23] where the following definition was proposed. *“A lubricant means a product that is capable of reducing friction, adhesion, heat, wear or corrosion when applied to a surface or introduced between two surfaces in relative motion or is capable of transmitting mechanical power”.* The rationale given by JRC for this proposed definition is that a definition of a lubricant as being a preparation consisting of base fluids and additives *“is quite broad, nevertheless there exist more complex lubricant compositions, which do not consist of base fluids and additives only but can be emulsions (e.g., metalworking fluids, and demoulding agents) or solid-state compounds (e.g., fine powders to reduce friction)*”. The definition was implemented

[22] Page 20 https://www.nilu.com/publication/24739/

[23] https://ec.europa.eu/environment/ecolabel/documents/Final%20Report%20EU%20Ecolabel%20Lubricants.pdf

in COMMISSION DECISION (EU) 2018/1702 of 8 November 2018 establishing the EU Ecolabel criteria for lubricants.

Examples of use in Oxford Instrument products include guide surfaces for introduction of the sample into the equipment where close contact between moving surfaces is required to prevent loss of vacuum and low coefficient of friction on moving surfaces of wires. In these applications, harsh conditions include low and high temperature, high voltage, oxidising chemicals, and electromagnetic radiation. As yet no known alternatives exist, and Oxford Instruments expects that a derogation of at least 13.5 years (from the date when an alternative becomes available) will be required to design and implement alternatives in new equipment.

5.t. Calibration of measurement instruments and as analytical reference materials

Oxford Instruments relies on this derogation across its product range. Examples of use include calibration for Scanning Electron Microscope and X-ray fluorescence equipment. As yet, there are no known alternatives and Oxford Instruments supports an unlimited time derogation.

5v Hard chrome plating until 6.5 years after EiF

Hard chrome plating may be used by Oxford Instruments in its products or in systems where an Oxford Instruments product has been integrated as a component. The demanding technical requirements of products such as scanning electron microscopes introduce more limiting factors as to why alternative PFAS-free plating is not currently possible. An implementation period of at least 6.5 years after a suitable PFAS-free plating process alternative becomes available, is required.

6.2 Proposed derogations with amendments

5.ee. Semiconductor manufacturing process, related equipment and supporting processes until 13.5 years after EiF.

Oxford Instruments Plasma Technology equipment is used in both the optical electronics and semiconductor industries which have similar technical requirements to each other. Indeed, these sectors are so closely related that they merge into each other. The Chips for Europe and the Chips Act recognise that semiconductor design and development is increasingly integrated with a particular device design. As such Oxford Instruments requests that the derogation permits the use of PFAS in the ‘semiconductor manufacturing process and related equipment.’ A derogation of at least 13.5 years is required. The following derogation text is proposed.

<u>5.ee. the semiconductor manufacturing, related equipment and supporting processes.</u>

6.3 Additional derogations

Oxford Instruments would like to request that the following derogations are also included in the Restriction.

Analytical equipment for 20 years after EiF

There is a need for a broader derogation covering analytical equipment which the use of the equipment may or may not be operated in a laboratory. A time period of at least 13.5 years is estimated to be required to implement PFAS-free alternatives. However, it is not known at this stage when PFAS-free materials will become available or indeed if their replacement is possible in some equipment. The following derogation is requested for 13.5 years after EiF, with a process for extending the derogation if required.

Analytical equipment for at least 20 years after EiF

Spare parts to support in service equipment. Oxford Instruments products require servicing and repair and may have a service life of up to 20 years. In addition to the above derogations, Oxford Instruments would like to highlight the necessity for the continued use of PFAS in spare parts and repairs of products already placed on the market. Oxford Instruments not only manufactures new products but also services and maintains existing products. Without the general consideration to permit the use of PFAS in these applications, this will cause the premature end-of-life and scrappage of products which otherwise could be serviced and maintained in service with PFAS-containing parts. It is therefore vital that the restriction does not impact products already placed on the market. It must be ensured that these products can continuously be made available on the market. With the current definition of “placing on the market” under REACH this would not be possible, as any supply or making available to a third party, and hence any resale or lease, for example, is considered “placing on the market” under REACH.

Derogation Extension Process and new derogation process. Every effort has been made to accurately estimate the PFAS uses. However, data gathering for PFAS uses is still ongoing. Due to the broad scope of the derogation, the complexity of the supply chain and no reporting obligations for all PFAS in the supply chain, data at the end of the consultation phase will be incomplete. It is therefore necessary to include a simple mechanism and formal process for adding derogations once the Restriction is published. Also, additional time for the derogations may be required due to unforeseen challenges or where substitutes will not exist for the technical reasons explained in this submission. Substitution efforts might be delayed due to many different factors including additional testing or development requirements, lack of suitable alternatives and technical difficulties. Therefore, it is also necessary to include a formal process for extending derogation timelines beyond the timelines outlined in this report.

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