



National Institute for Public Health
and the Environment
Ministry of Health, Welfare and Sport

Towards a definition of microplastics

Considerations for the specification of
physico-chemical properties

RIVM Letter report 2015-0116
A.J. Verschoor



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Colophon

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Naar een definitie voor microplastics

Dit rapport is bedoeld om te komen tot een definitie van microplastics. Het RIVM levert bouwstenen voor de discussie hierover, evenals overwegingen voor criteria en normen. Het streven is om de discussie Europees te agenderen. Om een snelle en kosteneffectieve screening van microplastics mogelijk te maken wordt in dit document ook een beslisschema voorgesteld, waarmee in maximaal vijf stappen kan worden bepaald of een materiaal een microplastic is.

Uitgangspunt voor de definitie is de globale overeenstemming die momenteel binnen de milieuwetenschappen bestaat over de belangrijkste eigenschappen van microplastics. Het startpunt voor een verdere specificatie is daarom de volgende beschrijving: microplastics zijn kunststoffen en bestaan uit vaste deeltjes die kleiner zijn dan 5 millimeter. Daarnaast zijn microplastics slecht oplosbaar in water en niet afbreekbaar.

Een definitie van microplastics is nodig om wettelijke of vrijwillige maatregelen te kunnen implementeren die emissies van microplastics verminderen. Een definitie geeft bedrijven wettelijke duidelijkheid en bevordert dat trends in verontreinigingen door microplastic consistent in kaart kunnen worden gebracht. Ook kan op basis van een definitie de effectiviteit van beleidsmaatregelen worden geëvalueerd.

Kernwoorden: plastic, microplastic, nanoplastic, rubber, particles, deeltjesgrootte, definitie.

Synopsis

Towards a definition of microplastics

This report aims to achieve a definition of microplastics. RIVM provides building blocks to support a discussion on this subject, as well as considerations for criteria and threshold values. The intention is to start a European-wide discussion about the microplastics discussion. To facilitate a quick and cost-effective screening of microplastics a decision scheme is proposed. Confirmation of microplastic identity is obtained in 5 steps.

Point of departure for the definition is the broad understanding in environmental science about the general properties of microplastics. The starting point for further refinement is therefore the following description: microplastics are synthetic materials, and consist of solid particles that are smaller than 5 mm. Additionally, microplastics are insoluble in water and not degradable.

A definition is needed when legal or voluntary measures to reduce the emission of microplastics. A definition provides legal certainty and enables the consistent monitoring of trends in microplastic pollution and the transparent evaluation of effects of policy measures.

Keywords: plastic, microplastic, nanoplastic, rubber, size, definition.

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Summary

This report opens the discussion towards setting a well-specified and workable microplastics definition. A definition is needed when legal or voluntary measures to reduce the emission and effects of microplastics on man and environment are to be implemented. A definition provides legal certainty and a level playing field amongst industries, and enables the consistent monitoring of trends in microplastic pollution and the transparent evaluation of effects of policy measures.

This report describes various criteria and considerations that may be included in the definition of microplastics. A proper definition is unambiguous and does not leave room for different interpretations. Therefore, the definition must contain criteria and threshold values that can be verified and enforced.

As part of a microplastic definition, the general characteristics of plastics need to be described. There is an almost endless list of physico-chemical properties available to describe plastics. "Micro" refers to the small size of the plastic particles; the size boundaries are therefore a crucial element of the microplastic definition.

For pragmatic reasons 5 major properties are recommended to be included in a microplastics definition:

1. Chemical composition
2. Physical state
3. Particle size
4. Solubility in water
5. Degradability

Suggestions for quantification of limit or threshold values are derived as much as possible from existing guidelines, for example from the Globally Harmonised System for Classification and Labelling of Substances and Mixtures (GHS), though alternative considerations are described as well.

To facilitate a quick and cost-effective screening of microplastics a decision scheme is proposed. Rejection of the microplastics identity may be obtained in at least one up to five steps. Confirmation of microplastic identity is obtained in 5 steps.

1 Introduction

Microplastics are identified as a global environmental problem [1], originating from many sources [2], and have shown to affect aquatic life [3-11]. The presence of plastics in the environment is of great concern because plastics are persistent [12], they often carry potentially toxic chemicals [13-15] and because they are consumed by aquatic organisms [16-22]. Under the Marine Framework Directive and OSPAR, plans are being developed to reduce the emission of plastics and microplastics [23].

Before measures to reduce the emission of microplastics can be taken, a clear definition of microplastics is of utmost importance. A univocal definition is a prerequisite for future socio-economic impact assessments, law enforcement, and monitoring trends in microplastic pollution.

The fact that a material is a microplastic does not necessarily mean that emission reducing measures improve environmental quality. The environment only benefits from measures that actually reduce the exposure of living organisms to microplastics. From the perspective of the marine environment microplastics that disappear quickly by natural processes (e.g. dissolving, biodegradation to harmless degradation products), or microplastics that never reach the aquatic environment are not of concern.

Therefore 3 questions need to be answered:

- 1) Is a material a microplastic?
- 2) Is it a microplastic that persists in the environment?
- 3) Is it likely that (aquatic) organisms are exposed?

The presence of microplastics in environmental samples and biota is the sum of emissions from different sources. Effects are exerted regardless of the source. A microplastic definition should therefore preferably be a generic definition; useful and valid for the identification of microplastics in or originating from all sorts of products and media.

In environmental science there is a common understanding on the general characteristics of microplastics [24]. Microplastics:

- Are synthetic materials with a high polymer content
- are solid particles,
- smaller than 5 mm,
- insoluble in water, and
- not degradable.

We adopted this description as a starting point for further refinement. A definition of microplastics for legislative purposes and for the development of environmental management plans should be crystal clear and enforceable. The aim of this report is to provide background information and considerations to facilitate an international discussion about threshold values or more specified descriptions for each element

of the microplastics definition. A decision scheme is proposed to guide the evaluation.

In this report each element of microplastic description is elaborated in a separate chapter.

2 Chemical composition

2.1 Plastic and rubber

There are many definitions of plastics¹. There are definitions used by industry, medicine, science et cetera. The definitions are slightly different but they share the fact that it concerns solid materials that can be molded and that consist of polymers.

The International Organization for Standardization (ISO) defined terms used by the plastic industry. ISO defined plastic as "a material which contains as an essential ingredient a high polymer and which, at some stage in its processing into finished products, can be shaped by flow". Although rubber meets this description, rubbers (elastomers) are not considered as plastics in the ISO definition [25]. A definition of rubber or justification for the separate treatment of rubber was not found in this ISO-document.

Plastic and rubber can be differentiated based on the reaction of the material on a deformation force. The deformation of plastics is irreversible, while the deformation of rubbers is reversible, which make them elastic. The elasticity of rubber is susceptible to ageing; rubber loses its elasticity and becomes hard and brittle after prolonged exposure to UV and ozone. Examples of synthetic rubbers are listed in Appendix 1. The monitoring guidance documents for marine litter count some rubber items as plastic objects (for instance rubber gloves), but also distinguishes rubber as a separate category for some other rubber items such as balloons and tyres [26, 27].

The question is whether the microplastics definition must follow the ISO-definition of plastics, or that "plastic" in microplastic should rather be understood as a popular synonym for man-made macromolecular materials, which includes plastic and rubber. From an environmental point of view, plastic and rubber are both relevant, because they can both produce solid particles with a high polymer content, and therefore they are both potential sources of microplastics.

2.2 Different kinds of polymers

All plastics are made from polymers, but not all polymers are plastic, as will become clear in this chapter. A polymer molecule is a large molecule, composed of many (>3) repeated subunits (monomers). Polyethylene for example is a chain of many ethylene monomers, polypropylene consists of many propylene monomers et cetera (see Figure 1). Copolymers consist of a sequence of two or more different monomers, for example styrene-butadiene rubber, an elastomer which is used amongst others for car tyres.

¹ <http://dictionary.reference.com/browse/plastic>

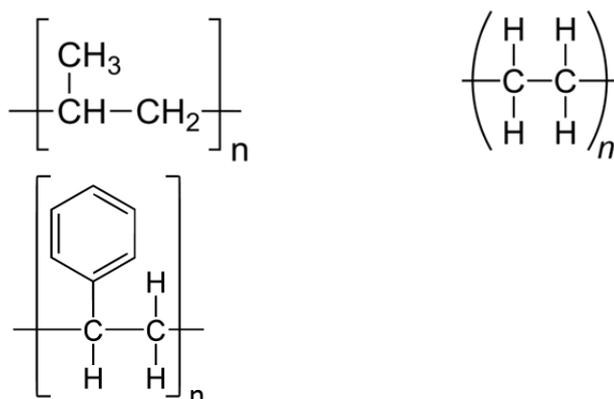


Figure 1 Examples of monomers used as building blocks for the production of polymers. Monomers of polypropylene (left), polyethylene (middle) and polystyrene (right).

Polymers are the base material for common synthetic plastics and rubbers, but also for natural biopolymers such as DNA and proteins that are fundamental to biological structure and function. The backbone of the polymer molecule is mostly a carbon (such as in polyethylene), but other elements may also be also possible (for instance silica and oxygen in silicone). The type, number and arrangement of monomers in the polymer have large influence on the appearance and characteristics of plastic. Some plastics are rigid, while other plastics are softer and more flexible. In chapter 3, more details are provided about the physical state of plastics.

2.2.1 *Petro-based and bio-based polymers*

Classical plastics are petroleum-based organic polymers and although petroleum was also formed by natural processes, the plastics derived from it are clearly of synthetic nature. Similarly bio-based plastics derived from renewable sources such as vegetable oil, corn starch or microbiota should be considered as synthetic polymers. A bio-based polymer that is similar to a petro-based one does not imply any superiority with respect to its impact on the environment, unless comparison of the respective life cycle assessments is favorable [28]. Bio-based plastics should therefore be considered as a potential source of microplastic.

2.2.2 *Natural and artificial biopolymers*

Natural polymers such as DNA and proteins are **not** considered as (micro)plastics, neither are natural polymeric materials as wool, silk, natural rubber, amber and cellulose. Non-natural analogues of biopolymers can be produced by genetic engineering. These biopolymers should be referred to as artificial biopolymers, e.g., artificial protein, artificial polynucleotide, etc.

Particles consisting of natural or artificial biopolymers are not considered microplastics.

2.2.3 *Modified natural bio-polymers*

Many commercially important polymers are synthesized by chemical modification of naturally occurring polymers, for example 1) the processing of vulcanized rubber by heating natural rubber in the

presence of sulfur and 2) the reaction of nitric acid and cellulose to form nitrocellulose. These modified natural polymers should also be considered as synthetic polymers. Modified natural bio-polymers are therefor considered as a potential source of microplastics.

2.2.4 *Inorganic and hybrid polymers*

Unlike the classical petro-based polymers, an inorganic polymer does not consist of a carbon-backbone, but is built from inorganic monomers (see Figure 2). A hybrid polymer is a polymer or polymer network comprised of both inorganic and organic components [29]. Inorganic and hybrid polymers form materials with properties that are in many aspects very similar to materials made from organic polymers. Silicone is a well-known example of a hybrid polymer and is composed of a silicon-oxygen backbone with organic hydrocarbon side groups, which gives them plastic-like characteristics. The classical descriptions of plastics tend to exclude inorganic polymers. However, the limitation of plastics to organic polymers only seems obsolete.

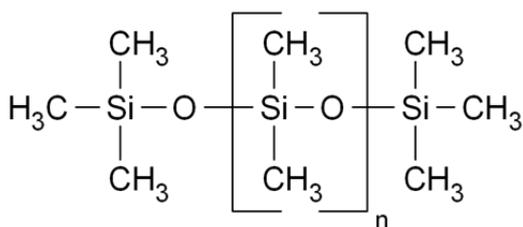


Figure 2 Structural formula of a silicone polymer. Between brackets the monomer building block of silicone.

Siloxanes comprise a very diverse group of chemicals, comprising solids, liquids and volatile compounds. Siloxanes are found in the aquatic environment, and there indications that some of them are persistent, bioaccumulating and/or toxic [30]. We recommend to start a debate about the environmental relevance of inorganic and hybrid polymers and whether or not to consider them as plastics.

2.3 **Additives and composite materials**

Plastics do not consist of polymers only. Other ingredients may be present to improve the processability, safety, durability, performance or look and feel.

In accordance with REACH, a polymer material is defined as a substance meeting the following criteria [31]:

- a) Over 50 percent of the weight for that substance consists of polymer molecules (see definition above); and,
- b) The amount of polymer molecules presenting the same molecular weight must be less than 50 weight percent of the substance.

Additives may be classified as follows: reinforcing fibers, fillers, and coupling agents, plasticizer,; colorants, stabilizers (halogen stabilizers, antioxidants, ultraviolet absorbers, and biological preservatives); processing aids (lubricants, others, and flow controls), flame retardants, peroxides, and antistats [32]. The most common functions of additives are listed in Appendix 2. The fraction of additives in plastic ranges from <1% to >50% of the product. The additives vary from harmless natural

components (amongst others limestone or cellulose) to more hazardous substances (amongst others polybrominated flame retardants or heavy metals). The most hazardous substances are gradually phased out, restricted or replaced based on the implementation of REACH and other legislative obligations. When reinforcing fibres or large amounts of fillers are used, the material is referred to as a composite material.

Composites are built up from at least two constituent materials: matrix and reinforcement. The resulting composite possesses properties that are superior to the individual constituent materials. Composites concern for example a combination of plastic and glass fibres, wood, carbon fibres or inorganic particles. Matrix and/or reinforcement may be polymeric. A well-known example is fibre-glass more precisely called fibre-reinforced polyester, which is used for boats, canoes, ponds etcetera. Polyester is also often mixed with cotton and wool and used for fabrics and clothing.

Composite materials are not designed to be used as microplastics. It is currently unknown to what extent mechanical wear or waste will lead to exposure of the aquatic environment with microplastics originating from composite materials.

It should be discussed if these composite materials are to be seen as plastics, and whether it is necessary to set threshold for the percentage of polymer present in a material in order to define the material as (micro)plastic. The difficulty is that the value of such a threshold will be quite arbitrary, because scientific data to underpin the threshold percentage of polymer value is lacking.

2.4 Overview

Table 1 summarizes the different base materials described in the previous paragraphs and a preliminary assignment as plastic or no plastic. Some examples and typical products are added to indicate some of the most common or known products. The number of plastic application is numerous, it was not the intention to provide a complete list of plastic applications.

Table 1 Proposed assignment of base materials as sources of microplastic.

Base material	Description/examples	Typical products	Plastic?
Petro-based polymers	Polystyrene Polyethylene	Insulation Packaging, abrasives	Yes
	Polyurethane	Swimwear, floors, matrasses	
Bio-based polymers	Analogues of petro-based polymers made from renewable resources	Same as petro-based	Yes
Mineral-based polymers	Silicones	Breast implants Cookware Hair conditioners	Yes or no?
Natural biopolymers	DNA, proteins, wool, silk, amber, cellulose, natural rubber		No
Artificial biopolymers	Non-natural analogues of biopolymers		No
Modified natural polymers	Nitrocellulose,	Printing ink, laquers	Yes
	vulcanized rubber	Car tyres	Yes or no
Composites	Fibre-reinforced plastics	Boats, automotive, aircraft, clothing and fabrics	Yes
Elastomers	Rubber, silicones	Car tyres, roofing, toys, kitchenwear, balloons	Yes or no ?

3 Solid state

One of the conditions for a substance to be identified as microplastic is that it concerns solid particles. This paragraph deals with three questions:

- 1) What is solid?
- 2) Are plastics solid?
- 3) Which parameter or method can be employed to distinguish solid materials from non-solid materials.

3.1 Definition of solid

The Globally Harmonized System for Classification and Labelling of substances and mixtures [33] defines a solid as *a substance or mixture which does not meet the definitions of liquid or gas.*² It employs the melting temperature and vapour pressure as threshold values. The complete GHS definition is shown in Textbox 1.

Textbox 1 Definitions of solid, liquid and gas according to the Globally Harmonized System for Classification and Labelling of substances and mixtures (GHS).

- A solid is a substance or mixture which does not meet the definitions of liquid or gas
- Liquid means a substance or mixture which at 50 °C has a vapor pressure of not more than 300 kPa (3 bar), which is not completely gaseous at 20 °C and at a standard pressure of 101.3 kPa, and which has a melting point or initial melting point of 20 °C or less at a standard pressure of 101.3 kPa.
- Gas means a substance which (i) at 50 °C has a vapour pressure greater than 300 kPa; or (ii) is completely gaseous at 20 °C at a standard pressure of 101.3 kPa.

Information about the physical appearance and characteristics of substances is basic information and can often be retrieved from Safety Data Sheets (SDS). The preparation of an SDS is a requirement for certain hazardous substances and mixtures following REACH (EC 1907/2006) and they contain information for the identification and hazards of substances and materials. The SDS usually contains information about the melting point.

² GHS is an internationally agreed-upon system, created by the United Nations. It is designed to replace the various classification and labeling standards used in different countries by using consistent criteria for classification and labeling on a global level.

http://ec.europa.eu/enterprise/sectors/chemicals/files/clp-ghs-glossary_en.pdf

3.2 Are microplastics solid?

A solid material is characterized by its structural rigidity and resistance to changes of shape or volume. Many plastics are flexible, malleable or rubbery, and the question is whether the GHS definition described in the paragraph above is applicable to microplastics. In order to understand the specific physical properties of plastic some background information is provided.

In a solid, the atoms are tightly bound to each other, either in a regular geometric lattice (crystalline solids) or irregularly (an amorphous solid), see Figure 3. The hardness of a material increases with the degree of crystallization. Crystallisation of polymers is hindered by the presence of large side groups, so branched polymer result in softer plastics. Crystallization of polymers is often not complete, and their arrangement is rather referred to as semi-crystalline. Examples of semi-crystalline plastics are linear polyethylene (PE), polyethylene terephthalate (PET), polytetrafluoroethylene (PTFE) or isotactic polypropylene (PP). Examples of amorphous plastics are rubber and silicone.

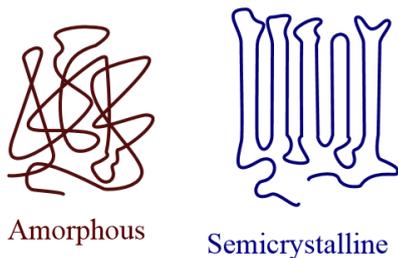


Figure 3 Arrangement of polymer chains in amorphous and crystalline structures (Polymerketten_-_amorph_und_kristallin.svg: Rainer Ziel).

On heating a solid usually changes into its liquid state. Plastics are divided into thermoplasts (melt at heating), thermosets (disintegrate at heating). Elastomers are a particular group of elastic synthetic materials, which are excluded from the plastic definition by ISO [25]. Crystalline and amorphous plastics behave differently when they are heated. Crystals become liquids at a specific temperature, T_m (the melting point). At this temperature physical properties of the crystalline solids change sharply. Amorphous solids soften gradually when they are heated. There tends to be a relatively wide temperature range for the melting point: a zone between the solid and the liquid state where physical properties of the substance change gradually.

In the intermediate zone between the glass transition temperature and the melting point, the materials are semi-solid, rubbery or flexible and the question is if these materials should be considered as solid in the microplastics definition. The phenomenon is visualized in Figure 2. The rubbery state has a lower temperature limit (the glass transition temperature [34]), below which the material is in a solid state, and an upper limit (melting point) above which it is a liquid. These limit values could be used as a simple thresholds to define whether a material is a microplastic.

The fundamental question remains if semi-solids should be included under the microplastic definition. It concerns for examples waxes, gels

and super absorbing polymers (SAP). Semi-solid particles are taken up by organisms like solid particles, but the softer rubbery particles may cause less abrasive injuries. Still, the differences in effect between solid and semi-solid plastic particles are unknown.

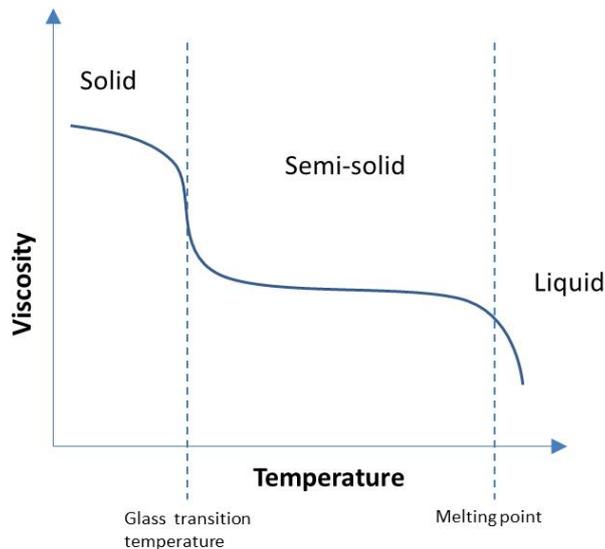


Figure 4 Relation between temperature and the physical state (expressed as viscosity) of materials.

3.3 Parameters to distinguish solids and semi-solids

As explained in paragraphs 3.1 and 3.2 the melting point and/or glass transition temperature mark distinct points in the physical state of plastics. Viscosity is another important parameter that indicates the flow properties of liquids (see also Figure 4). Viscoelastic parameters are widely used for characterizing polymers. These parameters could therefore serve as alternative criteria, instead of melting point or transition temperature.

Melting point is a standard parameter that is also shown on SDSs, and the GHS provides clear threshold values based on the melting point. Information on glass transition temperature and viscosity are normally not an integral part of the SDS, and will require additional testing. Moreover, there is currently no guidance on which threshold values can be based.

Based on the considerations mentioned above, a parameter that relates the physical state of a substance to its behavior at heating seems the most feasible, and practical option. Adopting the melting point implies that semi-solids will be considered as solid materials. A fundamental discussion should be held to determine if semi-solids should be considered as microplastics. The scientific discussion should focus on the adverse effects of semi-solids on aquatic life.

4 Size

4.1 Size boundaries

The litter descriptor of the Marine Strategy Framework Directive [23] makes a distinction between macro- and micro-particles of litter, defined as objects with largest measurement over or below a limit of 5 mm [26]. The shape involves beads, fragments, fibres and films.

The value of 5 mm was proposed by a group of marine environmentalists gathered at the National Oceanic and Atmospheric Administration (NOAA) during an international workshop in 2008 [35]. The maximum size of 5 mm was chosen "to focus the plastic litter discussion on possible ecological effects other than physical blockage of gastrointestinal tracts". With these "other effects", they referred to uptake of particles and associated contaminants into tissues. The definition is adopted by many, but not all scientists. Several toxicological or monitoring studies narrowed the size range to particles < 1 mm [36, 37].

Recently, the European MSFD Working Group on Good Environmental Status (WG-GES) provided a 'Monitoring Guidance for Marine Litter in European Seas', which represents an important step towards a standardized sampling and monitoring of marine microplastics. The WG-GES defines size classes for plastic litter as follows: macroplastics (>25 mm), mesoplastics (5 to 25 mm), large microplastics (1 to 5 mm), and small microplastics (20 µm to 1 mm). Larger items are often named fragments or debris, but a standardized definition of these terms is not available [26, 38]. In seabird (fulmar) studies it is standard to filter stomach contents over a 1 mm sieve, and these thus ignore the potential presence of microplastics below the 1 mm size [26]. The WG-GES suggested a lower limit of 20 µm because it is currently a limit of detection that can be reached with FT-IR equipment that is widely available in laboratories throughout Europe [26]. It should be kept in mind that analytical methods for microplastics improve as science advances and increasingly smaller particles can be detected and identified.

The International Union for Pure and Applied Chemistry has set the upper boundaries for microplastics to 100 µm [28, 39]. The proposed size range aimed at harmonization of terminology between polymer scientists, medical therapists, biologists, and ecologists. Different disciplines should preferably use the same terminology to reflect similar properties, phenomena, and mechanisms of microparticles. The International Union for Pure and Applied Chemistry³ has set a lower size boundary for microparticles to 0.1 µm [28, 39].

³ IUPAC has long been recognized as the world authority on chemical nomenclature, terminology, standardized methods for measurement, atomic weights and many other critically evaluated data.

A major discussion point is whether a distinction should be made between larger and smaller microplastics. There is a relationship between smaller microplastics and the nanomaterials, for which several legislations are in force (EU Biocides Regulation 528/2012, EU Cosmetic Products Regulation 1223/2009, EU Regulation on the provision of food information to consumers, No 1169/2011). To prevent overlap of legislative measures, the intended definition of microplastics should not interfere with the definition of nanomaterials. The size boundaries that are recommended by the EU for nanomaterials are 1-100 nm (see also Appendix 3) [40].

Many monitoring studies use a sequence of filters and nets net to sample small particles. Recently, the European Marine Strategy Framework Directive Working Group on Good Environmental Status (WG-GES) provided a 'Monitoring Guidance for Marine Litter in European Seas', which represents an important step towards a standardized sampling and monitoring of marine microplastics.

4.2 Particle size distributions

Particles in a material rather show a variety of sizes, the so –called particle size distribution. This phenomenon is reflected in the Biocidal Product Regulation, where a material is considered a nano-material when 50 % or more of the particles in the number size distribution, has one or more external dimensions in the size range 1-100 nm. This implies that nano-materials may contain a considerable number of particles smaller than 1 nm or larger than 100 nm. Further discussions are required to determine if lower micro-size boundary should seamlessly connect with the upper nano-size boundary.

From an environmental point of view, aiming at reduction of plastic in the marine environment, it should be discussed whether it is wise to keep a number based criterion in case of the microplastics. Because the mass of particles increases with the radius raised to the third power, i.e a particle with a radius of 10 μm has a weight 1000 times smaller than a particle with a radius of 100 μm . From the mass perspective, larger particles are more relevant, though there are indications that smaller particles are more toxic [41].

From a monitoring point of view measuring mass of plastic particles is easier, quicker, cheaper and more robust than determination of a particle size distribution.

5 Solubility

A low solubility is a general characteristic that most plastic types have in common. A low solubility implies that the material will not “disappear” by dissolving and dilution in the aquatic environment, and could therefore serve as one of the elements in the definition of microplastics.

The solubility of polymers depends on their polarity, molecular weight, branching, crosslinking degree, and crystallinity. Polar macromolecules like polyethyleneglycol (PEG), polyacrylic acid, polyacrylamide and polyvinyl alcohol (PVA) among others, are soluble in water. Conversely, nonpolar polymers or polymers showing a low polarity such as polystyrene, polymethyl methacrylate, polyvinyl chloride, and polyisobutylene are poorly soluble in water.

In the implementation of REACH a substance is considered poorly water soluble when it has a water solubility **below 1mg/L** at 20 °C or below the detection limit of the analytical method of the tested substance [42]. We propose to adopt the interpretation as presented in the REACH guidance document on information requirements and chemical safety assessment [43].

There are many factors that affect the water solubility of a substance. Therefore it is essential to determine the solubility under standardised conditions. The composition of the aqueous solution, the temperature, pH and ionic strength, as well as the solid state and polymorph type of the microplastics need to be described. There is not one standard method to determine solubility. Specific recommendations are provided by REACH [43]. Information on the solubility of a substances or materials is a basic property that is routinely determined by manufactures, the information can often be found on a integral part of the SDS, so no additional laboratory tests are necessary.

6 Degradability

Plastics are considered as persistent materials. Persistence is the resistance against degradation. Despite their persistent nature, some degree of degradation, though slowly takes place [44].

REACH distinguished 5 threshold values for several environmental compartments (see Table 2). A substance is considered persistent if the threshold value in at least one of the compartments is exceeded.

Table 2 Criteria for persistency according to REACH Annex XIII [45].

Compartment	Half-life (days)
Marine water	>60 days
Fresh- or estuarine water	>40 days
Marine sediment	>180 days
Fresh- or estuarine sediment	>120 days
Soil	>120 days

Degradability is a term that refers to a transformation of the chemical structure due to physical, (photo-)chemical or biological interactions. Biodegradation is degradation caused by living organisms, for instance microbes; photo-degradation is degradation caused by light, and oxidation and hydrolysis are chemical forms of degradation involving a reaction with respectively oxygen and water. Degradation ranges from a single change of the molecular structure to a sequence of transformations leading to generation of energy and carbon for cell growth and mineralization to CO₂ and H₂O. The potential for degradation is generally expressed as a half-lifetime; i.e. the time required for degradation of 50% of the compound. In order to determine the persistence of microplastics not only the polymer, but also the degradation of its relevant transformation products need to be assessed. Degradation products of microplastics can be seen as microplastics as long as they comply with the criteria of microplastics.

The half-lifetime of a chemical not only depends on the properties and concentrations of the substance, but also on environmental characteristics such as temperature, pH and salinity. Half-life data should therefore be collected under relevant conditions. It is recognized that polymers are difficult substances for aquatic toxicity and biodegradation testing because of their low solubility. Recommendations and guidance for such substances are provided by ISO [46] and ECHA [43].

We propose to adopt the REACH criteria for persistency and consider that microplastics with half-life times smaller than the values mentioned in Table 2 are degradable and do not pose a threat to the environment. Information about degradability can be retrieved from experimental trials in the respective compartments, but also from screening tests or methods as recommended in the guidance document on information requirements and Chemical Safety Assessment for REACH [42].

7 Discussion and conclusion

7.1 Proposed decision scheme for microplastics

The fact that a material is a microplastic does not necessarily mean that emission reducing measures improve environmental quality. The environment only benefits from measures that actually reduce the exposure of living organisms to microplastics. To facilitate a quick and cost-effective screening of microplastics a decision scheme is proposed, which structures the elements of the microplastics definition (see Figure 5). Rejection of the microplastics identity may be obtained in at least one up to five steps. Confirmation of microplastic identity is obtained in 5 steps.

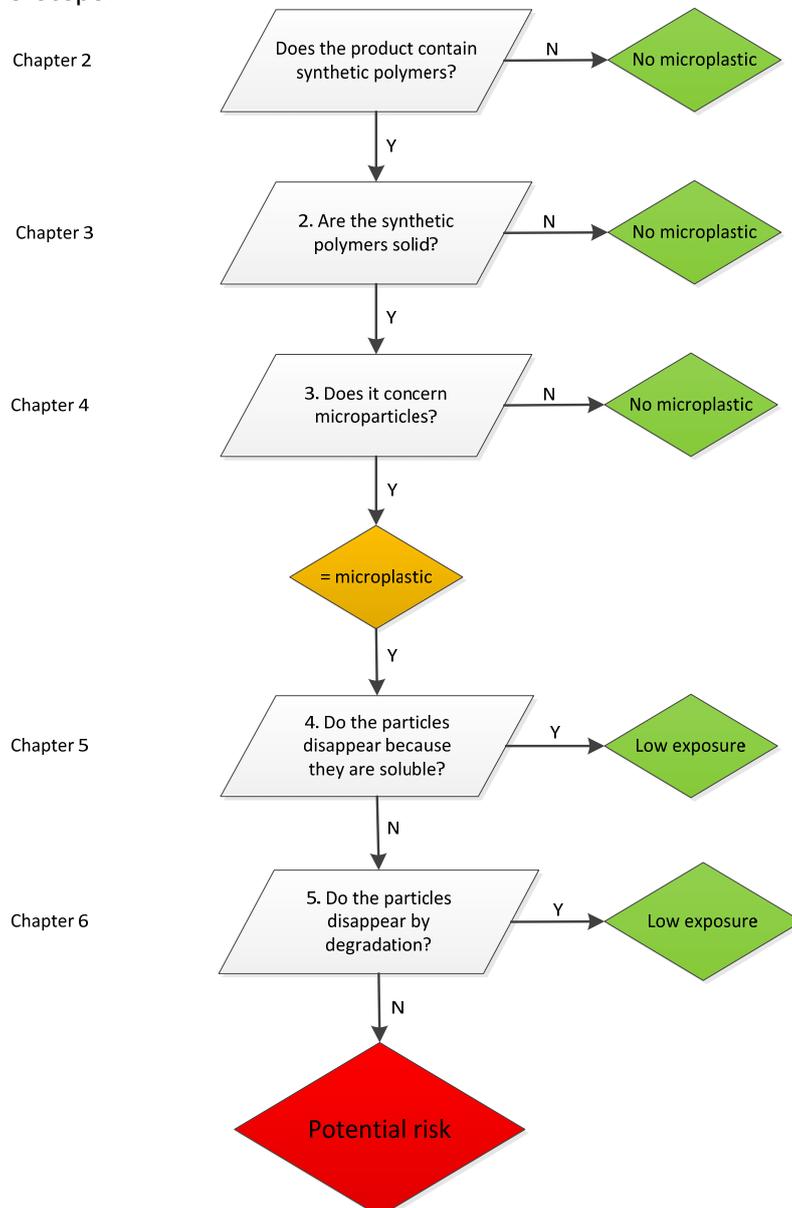


Figure 5 Proposed decision scheme for microplastics. Considerations for threshold values are discussed in Chapter 2 to 6.

The five elements of the definition, each described in a separate chapter (Chapter 2 to 6) are included in the decision scheme. The threshold values are not specified in the decision scheme because these need further discussion. This report provides input for further discussion on setting criteria and threshold values for a microplastic definition.

7.2 **Compilation of discussion points**

For each element in the decision scheme several options are mentioned in Chapter 2 to 6. Several points of discussion are raised throughout the report. The main discussion points are:

1. Concerning the chemical composition:
 - a. Should elastomers (rubber) be considered as potential source of microplastics?
 - b. Should organic-inorganic hybrid polymers (for example silicone) be considered as a potential source of microplastic?
 - c. Is it necessary to set a minimum polymer fraction for composite materials, in order to define them as microplastic?
2. Concerning the solid state:
 - a. Should semi-solids be considered as microplastics?
 - b. Is it feasible to follow the GHS classification for solid compounds, that is: are melting point and vapor pressure suitable parameters to define the solid state of plastics, or should other visco-elastic properties be considered?
3. Concerning the size:
 - a. Is there a need for a lower size boundary?
 - b. Is there a need for a seamless connection with nano-materials definition?
 - c. Is it opportune to harmonise the size limits with analytical equipment and detection limits?
 - d. How should the presence of microplastic particles be expressed: in number or mass?
4. Concerning the persistence:
 - a. Is adoption of REACH criteria for persistence feasible?
 - b. Which tests can be done to study the degradability of microplastics?
5. General issues:
 - a. What are the costs and benefits of the suggested options?
 - b. Is the proposed definition/decision scheme workable?

Further discussion and agreement on these elements is necessary, as a step towards a definition of microplastics.

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Appendix 1. Examples of common synthetic rubbers

- Synthetic polyisoprene (IR for Isoprene Rubber)
- Polybutadiene (BR for Butadiene Rubber)
- Chloroprene rubber (CR), polychloroprene,
- Butyl rubber (copolymer of isobutylene and isoprene, IIR)
- Halogenated butyl rubbers (chloro butyl rubber: CIIR; bromo butyl rubber: BIIR)
- Styrene-butadiene Rubber (SBR)
- Nitrile rubber (copolymer of butadiene and acrylonitrile, NBR)
- Hydrogenated Nitrile Rubbers (HNBR)
- EPM (ethylene propylene rubber)
- EPDM rubber (ethylene propylene diene rubber)
- Epichlorohydrin rubber (ECO)
- Polyacrylic rubber (ACM, ABR)
- Silicone rubber (SI, Q, VMQ)
- Fluorosilicone Rubber (FVMQ)
- Fluoroelastomers (FKM, and FEPM)
- Perfluoroelastomers (FFKM)
- Polyether block amides (PEBA)
- Chlorosulfonated polyethylene (CSM),
- Ethylene-vinyl acetate (EVA)
- Thermoplastic elastomers (TPE)
- Polyurethane elastomer

Appendix 2. Plastic additives and their function.

Source: <http://www.bpf.co.uk/plastipedia/additives/>

Additive group	Function
Anti counterfeiting	There are a number of ways manufacturers and brand owners can combat counterfeiting by employing one of several or indeed multilayer anti-counterfeiting technologies. Optical brighteners absorb ultraviolet and violet light then re-emit this energy at a higher wavelength, normally as a blue glow.
Antimicrobials/Biostabilisers	Help prevent deterioration of plastic materials where part of the material might be susceptible to microbiological attack. Such attacks can cause staining, discoloration, odor and loss of aesthetics but more importantly, loss of electrical insulating properties, hygiene and overall loss of mechanical properties in the material.
Anti-oxidants	Help prevent "oxidation", the polymer reacting with oxygen. Oxidation can cause loss of impact strength, elongation, surface cracks and discoloration. Antioxidants help prevent thermal oxidation reactions when plastics are processed at high temperatures and light-assisted oxidation when plastics are exposed to UV light.
Anti-static agents	Help to prevent the buildup of static electric charge. Plastics are generally insulating and so have the capacity to build up static charges on the surface which greatly disturb processing procedures and can be an issue for hygiene and aesthetics.
Biodegradable plasticisers	Used to make plastics softer and more flexible and to enhance the degradability of the product.
Blowing agents	Form gases in the plastic to produce a foam material. The blowing agents form gases by breaking down on heating at a pre-determined temperature and form a foam structure within the plastic's polymer matrix.
External lubricants	To prevent damage to plastics or the mould during processing. Applied to the material or directly to the machine to allow processing without damage.

Additive group	Function
Fillers/extenders	Natural substances used to improve strength and lower the cost of the material. Usually mineral-based, fillers/extenders literally increase the overall "bulk" of the plastic.
Flame retardants	To prevent ignition or spread of flame in plastic material. Plastics see substantial use in critical construction, electrical and transport applications which have to meet fire safety standards either by mandatory regulations or voluntary standards. Flame retardants are added to plastics to meet these requirements.
Fragrances	Fragrances and deodorants for plastics are used in a variety of applications and are products for the home.
Heat stabilizers	To prevent decomposition of the polymer during processing. Processing usually results in temperatures well above 180 deg Celsius, which without the addition of heat stabilizers would result in the plastic material literally falling apart.
Impact modifiers	Enables plastic products to absorb shocks and resist impact without cracking. Particularly relevant for polyvinyl chloride (PVC), polystyrene (PS) and polypropylene (PP) materials.
Internal lubricants	Used to improve processability of plastics by increasing the flowability. Internal lubricants improve the melt flow of material by lowering the viscosity and heat dissipation (also see Processing Aids)
Light stabilizers	Used to inhibit the reactions in plastics which cause undesirable chemical degradation from exposure to UV light.
Pigments	Tiny particles used to create a particular color.
Plasticisers	Used to make plastics softer and more flexible.
Process aids	Used to improve processability of plastics by increasing the flowability. Internal lubricants improve the melt flow of material by lowering the viscosity and heat dissipation (Also see Internal Lubricants) High-polymeric processing aids also improve flowability of PVC compounds.
Reinforcements	Used to reinforce or improve tensile strength, flexural strength and stiffness of the material. Often fibre-based.

Appendix 3. Definitions of nano-materials in EU regulations concerning biocidal products, cosmetics and food.

Under the **EU Biocides Product Regulation 528/2012**, nanomaterials are defined as:

- 'nanomaterial' means a natural or manufactured active substance or non-active substance containing particles, in an unbound state or as an aggregate or as an agglomerate and where, for 50 % or more of the particles in the number size distribution, one or more external dimensions is in the size range 1-100 nm. Fullerenes, graphene flakes and single-wall carbon nanotubes with one or more external dimensions below 1 nm shall be considered as nanomaterials. For the purposes of the definition of nanomaterial, 'particle', 'agglomerate' and 'aggregate' are defined as follows:
 - 'particle' means a minute piece of matter with defined physical boundaries,
 - 'agglomerate' means a collection of weakly bound particles or aggregates where the resulting external surface area is similar to the sum of the surface areas of the individual components,
 - 'aggregate' means a particle comprising strongly bound or fused particles'

Under the **EU Cosmetic Products Regulation 1223/2009**:

'nanomaterial' means an insoluble or biopersistent and intentionally manufactured material with one or more external dimensions, or an internal structure, on the scale from 1 to 100 nm

Under the **EU Regulation on the provision of food information to consumers, No 1169/2011**:

'engineered nanomaterial' means any intentionally produced material that has one or more dimensions of the order of 100 nm or less or that is composed of discrete functional parts, either internally or at the surface, many of which have one or more dimensions of the order of 100 nm or less, including structures, agglomerates or aggregates, which may have a size above the order of 100 nm but retain properties that are characteristic of the nanoscale.

