Plastic Footprint Network

Plastic Footprint Guidelines

Module on micro- and nanoplastics from packaging into food

April 2026

Convened by EA – Earth Action · www.plasticfootprint.earth

Introduction to the Plastic Footprint Network

Leading organizations have united within the Plastic Footprint Network to chart a new, more effective path toward plastic pollution mitigation.

The network's first priority was unifying the framework for measuring plastic leakage into a single, science-based methodology for organizations to accurately assess the environmental impact of their plastic use. Over 100 professionals from 40+ organizations collaborated to establish the methodology, consisting of 16 modules, all optimized for usability and delivery of actionable results.

Objectives

Unifying the methodologies and perspectives of leading scientists, experts, and global practitioners, PFN enables organizations to understand the full impact, or footprint, from the use of plastic in their companies, products, and services.

1. Update and unify plastic footprinting methodologies
2. Ensure the methodology is used consistently by practitioners
3. Disseminate and scale the use of plastic footprinting
4. Explore how mitigation actions can be effectively measured and prioritized

What will you find in this module?

The goal of this module is to provide a unified approach to estimate the amount of micro- and nanoplastics (MNP) migrating from food packaging into food in the context of a plastic footprint. Plastic additives (IAS and NIAS) are out of the scope.
To achieve this, we will address the following questions:

1. What are the essential components of the proposed methodology for estimating the contribution of plastic packaging migration into food in a plastic footprint?

2. How does this module integrate and build upon existing approaches and literature to ensure a thorough and up-to-date assessment of the plastic footprint?

3. What secondary data sources are essential for calculating MNP migration and how can these inputs be integrated into the overall assessment process?

At the end of this module, the users should know how to include packaging migration of MNP into food in the context of their plastic footprint assessment.

Where does this module fit in the PFN landscape?

Guidance

Strategic | Cross-cutting or specific issue

- Introduction to plastic footprinting
- Scopes and boundaries – Alignment with environmental reporting standards
- Data governance
- Plastic Pollution Mitigation Action Framework (PAF)

Technical

- Technical introduction to plastic leakage
- Glossary

Inventory: Macroplastics

- Packaging
- Textile
- Fishing gears
- Leakage from export
- Release rates
- Long Life Items
- Paint
- Construction
- Automotive

Inventory: Microplastics

- Micro tire dust
- Textile Microfibers
- Micro packaging (Current module)
- Micro paint
- Micro recycling
- Micro pellets

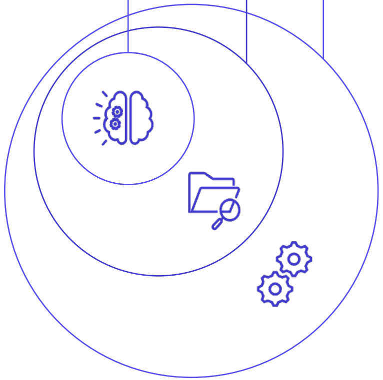
Impact

- Impact MariLCA (new)
- Impact Valuation (new)

Sectoral guidance

- Agriculture
- Medical
- Apparel

Structure of each technical module



1 Methodological choice

High level overview and different methodologies available at the moment, which one(s) to use and when.

Target audience: busy reader, scientific journalist

2 System map and calculation routes

- The different elements to take into account during MNP migration assessment.
- How these elements interact.
- The calculation routes to follow.

Target audience: scientist, experts

3 Key data & background assumptions

The secondary data needed to perform the assessment and the main assumptions for the modeling.

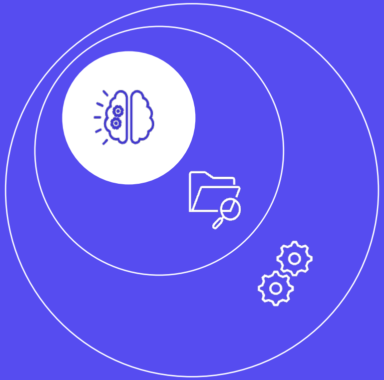
Target audience: scientist aiming at performing a plastic footprint.

Reading keys: Main take away | Supporting information | Key warning

Part. 1

Methodological choice

The different methodological approaches that can be taken, which one(s) to use and when.



Context

The challenge of micro- and nanoplastics migration from food packaging into food

- Recent scientific evidence shows that the common use of food packaging can result in the migration of micro- and nanoplastics (MNP) into food.
- This implies that plastic packaging is not only a leakage-to-environment issue, but also a direct ingestion pathway.
- While numerous studies have assessed specific cases (e.g., opening/closing PET bottles, microwaving plastic containers), findings are fragmented and methods are heterogeneous.
- Therefore, this module fills a methodological gap in current plastic footprinting approaches.

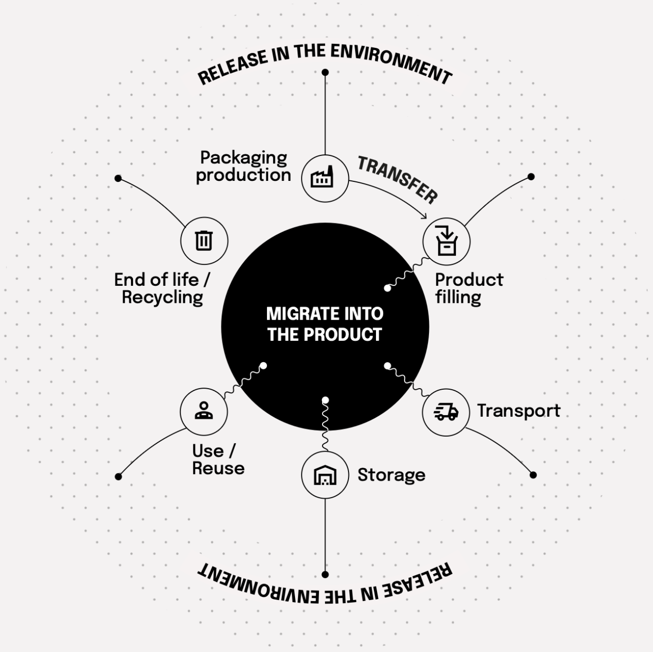


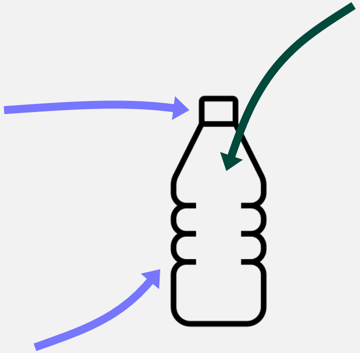
Fig 1. Packaging-related micro- and nanoplastic leakage pathways across the life cycle, distinguishing emissions in the environment from direct migration into food.

Context

Which factors influence the generation of micro- and nanoplastics from packaging?

Packaging design

The way components are shaped or joined affects friction and wear – e.g. a continuous cap ring generates less abrasion than a segmented one.



Product characteristics

The nature of the contained product (acidic, fatty, aqueous) drives polymer chain scission at the interface.

Material properties

The intrinsic structure of the polymer and the materials (brittleness, crystallinity, chemical resistance) determines its tendency to crack under stress or degrade chemically.

Other influencing factors across the packaging life cycle

Other factors include irradiation, temperature exposure, and mechanical stresses such as cutting, squeezing, friction, or repeated handling during use.

Outcome of this module

Outcome
MNP emissions from packaging into food

This module provides a scenario-based framework to estimate MNP emissions from plastic packaging into food and beverages.

It quantifies the migration of MNP into products across multiple packaging formats and use conditions, enabling comparison, identification of key drivers, and support for decision-making.

This module does not evaluate health effects of MNP ingestion.

Metric
Mass of MNP

This methodology expresses MNP emissions in terms of mass. However, mass-based metrics do not fully capture exposure, as particle number and size distribution are critical determinants of biological interaction. In particular, small particles may dominate particle counts while contributing little to total mass.

Results should be interpreted as indicative of material transfer and not as a complete representation of MNP exposure.

Useful definitions

MNP emissions into food and beverages result from a sequence of processes: mechanisms lead to particle formation (generation), followed by particle detachment (release) and transfer into the product (migration). Emissions correspond to the aggregation of this migration across system.

Mechanism

Mechanical and physico-chemical processes by which MNP are generated from packaging materials. Mechanisms describe how particles are generated.

Parameter

Quantitative value defining the intensity, duration, or frequency of a mechanism (e.g. time, temperature, number of cycles). Parameters determine the conditions under which a mechanism operates.

Scenario

Combination of active mechanisms and their associated parameter levels, representing a coherent set of use conditions under which MNP generation and migration occur.

Generation

Formation of MNP within or at the surface of packaging materials as a result of mechanical and/or physico-chemical mechanisms.

Release

Detachment of MNP from the packaging material into the surrounding medium. Does not necessarily imply transfer into the product.

Migration

Transfer of MNP from packaging into the contained food or beverage. Represents the fraction of released particles that enters the product.

Emissions

Total quantity of MNP transferred into products over a defined system and period.

An overview of micro- and nanoparticles generation

Mechanisms by which plastic packaging can generate micro- and nanoplastics

Micro- and nanoplastics release from food packaging is driven by a number of identifiable mechanical and physico- chemical mechanisms that act cumulatively during normal use.

Mechanical mechanisms

Physical detachment of fragments from the packaging surface under stresses such as opening and closing, cutting or squeezing.

> These mechanisms tend to generate larger microplastic fragments (> 1 µm).

Physico-chemical mechanisms

Degradation of the polymer matrix through processes such as hydrolysis, oxidation, and photo-oxidation, under the influence of heat, moisture, UV, and contact with specific products.

> These mechanisms tend to generate smaller nano fragments (< 1 µm).

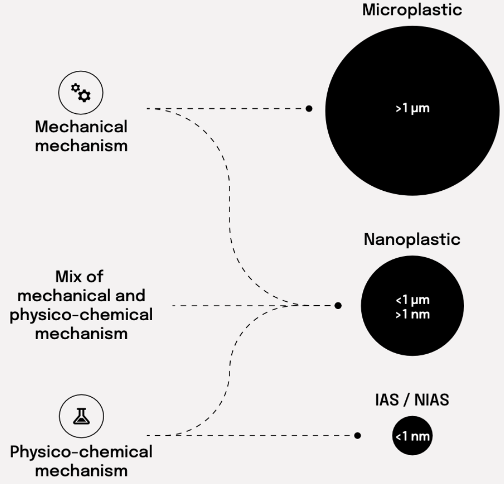


Fig 2. Mechanisms of MNP generation from packaging and associated size continuum. In practice, mechanical and physico-chemical mechanisms often act together, resulting in a continuum of particle sizes rather than discrete categories *(M. Singh et al. "Materials science underpinnings of micro and nanoplastics," 2025)*

An overview of micro- and nanoparticles generation

Life-cycle stages relevant for particle generation

Micro- and nanoplastic generation associated with food and beverages packaging may occur at different stages of the packaging life cycle

« Inherited » MNP

Particle generation may occur during packaging manufacturing, and industrial handling before the product is introduced into the packaging. MNP formed at these early stages may remain embedded within the packaging material and subsequently be released after filling. Such particles are referred to as inherited MNP, as they are generated before any contact between the packaging and the product and are therefore entirely outside consumer control.

Post-filling and use-related MNP

After filling, the packaging-product system can generate particles during transport, storage, and distribution due to mechanical stress, temperature changes, and light exposure.

Further emissions occur during consumer handling, such as opening and repeated interaction with the packaging.

Mechanisms covered in this module :

- Opening/Closing
- Stacking
- Product contact
- Irradiation
- Microwaving

Recommended methodological approach

General overview

MNP emissions from packaging arise from the interaction between material properties and mechanisms. This methodology is based on a scenario-based framework to estimate emissions under realistic conditions of use.

Step 1 – Define and collect activity data

Select the most appropriate activity metric depending on data availability:

- Option A : mass of packaging used (g), by packaging type and material
- Option B : volume of product placed on the market (L), by packaging type and material

Note: The choice determines how migration factors will be applied (per g of packaging or per L of product).

Step 2 – Identify relevant mechanisms

For each packaging format, define the mechanisms that the packaging-product system is exposed to during its lifecycle.

The following mechanisms shall be considered:

- Opening/Closing
- Stacking
- Squeezing
- Irradiation
- Product contact*
- Microwaving

*Product-contact reflects the combined influence of product type, temperature, and contact duration. Due to current data limitations, these effects cannot be reliably separated and are therefore treated as a composite mechanism.

Step 3 – Construct scenarios

Combine the identified mechanisms and their associated parameter levels to define coherent use scenarios.

One or several scenarios can be constructed:

- Low-emission scenario: limited cumulative stress
- Normal-use scenario: typical and foreseeable use conditions
- High-emission scenario: high cumulative stress

Scenarios are not intended to represent behavioural statistics. They define plausible ranges of use-conditions and consumer behaviours and provide a structured way to aggregate multiple mechanisms acting together.

Step 4 – Calculate MNP emissions

For each combination of packaging format and use scenario, apply the corresponding migration rates using one of the following approaches, depending on available data:

- Option A : Apply migration factors to the mass of packaging placed on the market
- Option B : Apply migration factors to the volume of product placed on the market

The mechanisms included in this module reflect the current state of available evidence. This list is not exhaustive; it will be expanded as scientific understanding evolves.

PFN

Recommended methodological approach
Data and formula

Primary data needed:
- Option A : Gram of packaging
- Option B : Volume of product

Secondary data needed (provided in the module):
- Migration rates (MR), inherited and for each mechanism-parameter combination, in µg/g (option A) or µg/L (option B) depending on the available primary data

Steps:

1. Define and collect activity data: For each packaging format considered, select packaging mass (option A) or product volume (option B) as the basis for calculation.
2. Identify key mechanisms and parameters: Determine the relevant use-related stressors (e.g. mechanical interaction, irradiation, thermal exposure) affecting each packaging format.
3. Construct scenarios: Combine mechanisms and parameter levels into coherent low-, normal-, and high-stress scenarios. Migration rates for a default scenario are provided in Part.3.
4. For each packaging and scenario, calculate emissions: Apply migration rates to estimate MNP emissions based on packaging mass (option A) or product volume (option B).

OPTION A

$$Emissions_{packaging,\,scenario} = \underbrace{Quantity_{packaging}}_{\text{in g of packaging}} \times \left(\underbrace{MR_{inherited}}_{\text{in µg/g packaging}} + \left(\sum_{mechanisms} \underbrace{MR_{mechanism}(parameter)}_{\text{in µg/g packaging}} \right)_{scenario} \right)$$

OPTION B

$$Emissions_{packaging,\,scenario} = \underbrace{Quantity_{packaging}}_{\text{in L of product}} \times \left(\underbrace{MR_{inherited}}_{\text{in µg/L product}} + \left(\sum_{mechanisms} \underbrace{MR_{mechanism}(parameter)}_{\text{in µg/L product}} \right)_{scenario} \right)$$

For more detailed explanations, refer to slide 18 of this module.

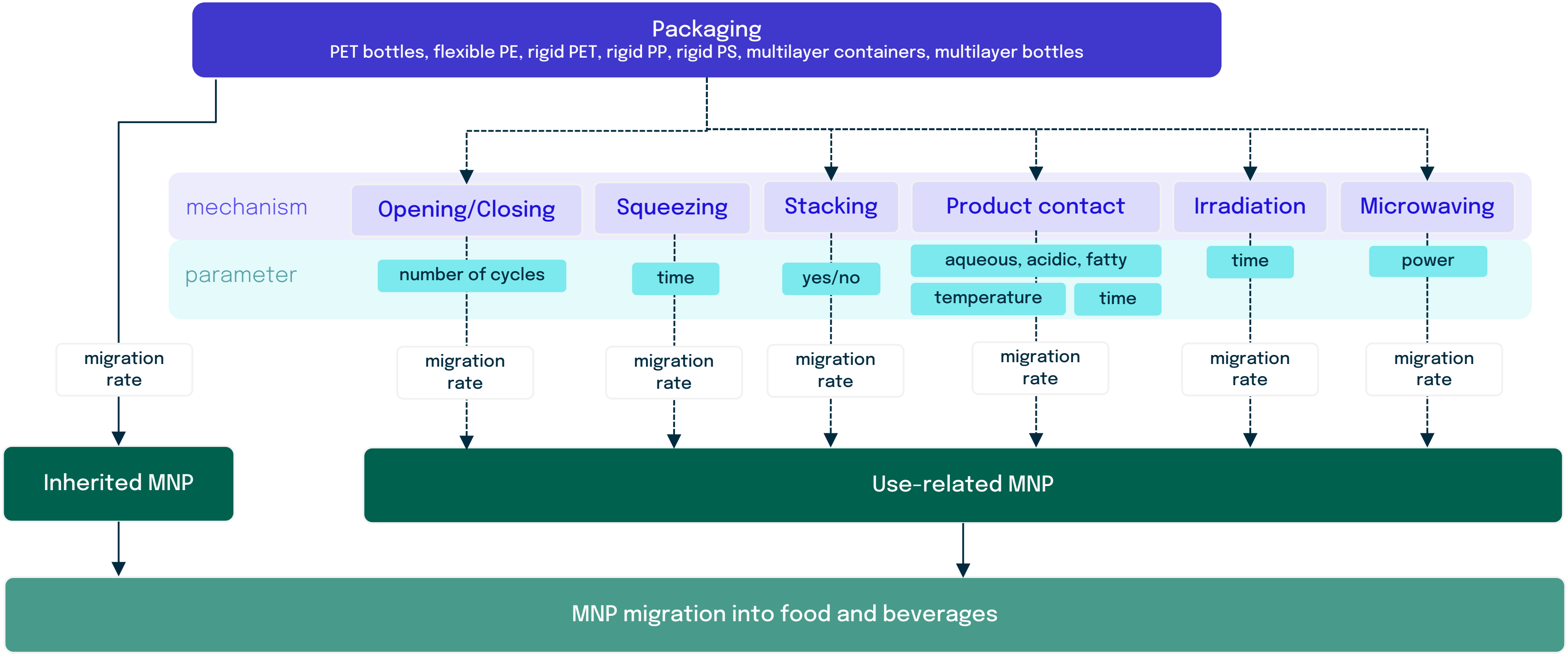
Generally speaking, always prefer primary data if available but be sure they are reliable. In case of doubt, use secondary data.

Part. 2

System map & calculation routes

The different elements to take into account during a plastic footprint. How these elements interact? Which calculation routes to follow?

System map


Packaging
PET bottles, flexible PE, rigid PET, rigid PP, rigid PS, multilayer containers, multilayer bottles
mechanism
Opening/Closing
Squeezing
Stacking
Product contact
Irradiation
Microwaving
parameter
number of cycles
time
yes/no
aqueous, acidic, fatty
temperature
time
time
power
migration rate
migration rate
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migration rate
Inherited MNP
Use-related MNP
MNP migration into food and beverages

Calculation route

Total MNP emissions for a given packaging and scenario are calculated as the quantity (option A: mass of packaging or option B: volume of product) multiplied by the migration rate of inherited MNP and the sum of the migration rates across all mechanisms included in that scenario, evaluated at their corresponding parameter levels.

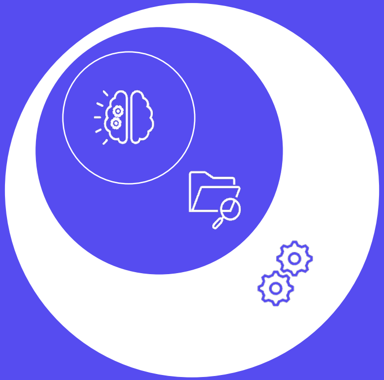
$$Emissions_{\,packaging,\,scenario} = Quantity_{packaging} \times \left(MR_{\,inherited} + \left(\sum_{mechanisms} MR_{\,mechanism}(parameter) \right)_{scenario} \right)$$

Symbol	Description	Unit	Value	Note
$Emissions$	Quantity of MNP transferred from the packaging into products	µg	result of the calculation	
$packaging$	selection between: PET bottles, flexible PE, rigid PET, rigid PP, rigid PS, multilayer containers, multilayer bottles	–	-	
$scenario$	selection between: high, low, normal, global a scenario represents a combination of mechanisms and associated parameter a global scenario reflects a combination of low, normal and high use conditions	-	-	see Excel annex
$Quantity$	option A) mass of packaging, in g option B) volume of product, in L	g or L	primary data collected	
$mechanism$	selection between: Opening/Closing, Squeezing, Stacking, Product contact, Irradiation, Microwaving	–	-	
$MR_{\,inherited}$	Migration rate of production-related MNP originating from polymer processing and packaging manufacturing. Available for every packaging.	µg/g or µg/L	see migration rates in Part. 3	see Excel annex
$MR_{\,mechanism}(parameter)$	MNP migration rate from each packaging, mechanism (e.g. irradiation, squeezing) and associated parameter (e.g. irradiation time, squeezing time).	µg/g or µg/L	see migration rates in Part. 3	see Excel annex

Part. 3

Data

The secondary data needed to perform the assessment.



Coverage of packaging formats and mechanisms

Packaging	Polymer	Inherited	Opening/ Closing	Squeezing	Stacking	Contact, aqueous content	Contact, acidic content	Contact, fatty content	Irradiation	Micro-waving
PET bottles	PET	covered	covered	covered	n/a	covered	no data	covered	covered	n/a
Rigid food packaging	PET	covered	n/a	no data	no data	covered	covered	no data	no data	n/a
Rigid food packaging	PP	covered	n/a	no data	covered	covered	covered	covered	no data	covered
Rigid food packaging	PS	covered	n/a	no data	no data	covered	covered	covered	no data	n/a
Flexible packaging	PE	covered	covered	n/a	n/a	covered	covered	no data	covered	n/a
Multi-layer containers	PE-lining	covered	n/a	no data	no data	covered	covered	no data	no data	n/a
Multi-layer bottles	PE	covered	no data	no data	n/a	no data	no data	no data	no data	n/a
Flexible packaging	other polymers	no data	no data	no data	no data	no data	no data	no data	no data	n/a
Bottles	other polymers	no data	no data	no data	n/a	no data	no data	no data	no data	no data

Limitations and outlook

Several limitations should be considered when interpreting the results.

- The underlying literature exhibits substantial variability in experimental methods, analytical techniques, detection limits, and reported particle size ranges. Absolute concentration values therefore remain subject to data-related uncertainty.

- Available data cover only a subset of packaging designs and conditions. Pre-retail stages – including transport, storage, and retail display – remain under-characterised. Product-related effects, such as the influence of acidity, fat content, or carbonation, remain incompletely quantified. This data imbalance means that apparent differences in reported migration levels may reflect gaps in the literature rather than true differences in emission. Cross-material comparisons should therefore be interpreted with caution.

- Scenarios are designed to capture plausible exposure ranges. Constructing a scenario for a specific use condition that was not yet studied – for example, food contact at a given temperature for a given time – is not yet possible, as the relationship between migration and parameters such as time and temperature is not well established and may not be linear.

- The migration rates compiled here are intended as a stepping stone toward broader risk characterisation. A next step would be to translate these exposure estimates into health effect assessments – by combining migration rates with toxicological data to evaluate health impacts.

Migration rates for use | Default scenario

The following migration rates are based on a combined scenario integrating normal, low-use, and high-use conditions.
Detailed results per scenario and per packaging are provided in the Excel annex.

OPTION A Migration rates (MR) per mass of packaging – in [µg/g]

Packaging	Polymer	MR Inherited	MR Opening/ Closing	MR Squeezing	MR Stacking	MR Contact - aqueous	MR Contact - acidic	MR Contact - fat	MR Irradiation	MR Micro-waving	Total migration rate (µg/g)
PET bottles	PET	0,1	0,7	0,006		0,6			14		15
Flexible packaging	PE	0,02	0,3			1			14		16
Rigid food packaging	PET	0,08				0,7	0,0005		25		25
Rigid food packaging	PP	0,07			16	1	0,1	0,06		0,9	18
Rigid food packaging	PS	0,002				1	0,006	3			5
Multi-layer containers	PE lining	0,2				0,2	0,1				0,6
Multi-layer bottles	PE	0,05									0,05

OPTION B Migration rates (MR) per volume of content – in [µg/L]

Packaging	Polymer	MR Inherited	MR Opening/ Closing	MR Squeezing	MR Stacking	MR Contact - aqueous	MR Contact - acidic	MR Contact - fat	MR Irradiation	MR Micro-waving	Total migration rate (µg/L)
PET bottles	PET	3	15	0,1		12			274		305
Flexible packaging	PE	0,08	1			5			72		78
Rigid food packaging	PET	2				20	0,01		738		760
Rigid food packaging	PP	3			630	42	5	2		36	718
Rigid food packaging	PS	0,04				19	0,09	50			68
Multi-layer containers	PE lining	1				1	0,6				3
Multi-layer bottles	PE	2									2

Migration rates – Detail for PET Bottles

This slide details each step of the calculation for PET bottles. Detailed results for the other packaging are provided in the Excel annex.

1 Detailed migration rates

Mechanism	Parameter	Migration rate [µg/L]	Migration rate [µg/g]
Inherited	-	2,9 (0 - 20,3)	0,15 (0 - 1,02)
Opening/ Closing	1 x	4,1 (0,2 - 26)	0,2 (0,01 - 1,3)
Opening/ Closing	11 x	9,3 (0,3 - 59,7)	0,46 (0,02 - 2,98)
Opening/ Closing	100 x	48,3 (0,3 - 423,4)	2,42 (0,01 - 21,17)
Squeezing	1 min	0 (0 - 0,7)	0 (0 - 0,04)
Squeezing	10 min	0,1 (0 - 1,7)	0,01 (0 - 0,08)
Squeezing	30 min	0,3 (0 - 2,6)	0,01 (0 - 0,13)
Contact - aqueous content	6 months	23,2 (0,3 - 205)	1,16 (0,02 - 10,25)
Irradiation	1 h	31,1 (30,8 - 31,4)	1,56 (1,54 - 1,57)
Irradiation	2 h	76,9 (76,8 - 77)	3,85 (3,84 - 3,85)
Irradiation	3 h	236 (235,7 - 236,3)	11,8 (11,78 - 11,82)
Irradiation	4 h	1 522 (1 521,8 - 1 522,2)	76,1 (76,09 - 76,11)

2 Default scenario

Scenario	Inherited	Opening/ Closing	Squeezing	Contact - aqueous*	Irradiation
Low-emission	✓	1 x	1 min	17% in contact 6 months	-
Normal-use	✓	11 x	10 min	50% in contact 6 months	1h
High-emission	✓	100 x	30 min	100% in contact 6 months	4h

**No data is available for the temperature parameter - only time is modeled here.*

3 Migration rates by scenario

Calculation example – Normal-use – µg/L : 2,9 + 9,3 + 0,1 + 0,5*23,2 + 31,1 = 55,0

Scenario	Migration rate [µg/L]	Migration rate [µg/g]
Low-emission	10,9	0,5
Normal-use	55,0	2,8
High-emission	1596,8	79,8

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Our mission is to continuously advance Plastic Footprint Methodology, ensuring it remains at the forefront of sustainable practices and promoting its widespread adoption. By empowering companies to rigorously assess, enhance, and transparently report their plastic footprints, we aim to make significant strides in mitigating the plastic pollution crisis.

PFN

Plastic Footprint Network

This working group was established to develop a scientifically robust and practical methodology for including packaging migration of MNP into food in the context of a plastic footprint assessment. It follows PFN's structured process for scientific integrity and alignment with global standards.

Working group lead

(Responsible for developing the methodology, ensuring scientific rigor, and managing the working group)

earth action

Contributing organisations

(Experts, stakeholders, and industry representatives, who provided insights, data, or case studies to inform the methodology)

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