Food Safety AUTHORITY OF IRELAND

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Polycyclic Aromatic Hydrocarbons (PAHs) in Food

This factsheet is intended for food business operators, enforcement officers and other interested persons. It:

- Summarises the dietary sources and health hazards of polycyclic aromatic hydrocarbons (PAHs)
- Suggests methods of sampling and analysis of foods for the presence of PAHs
- Explains the legal measures in place to minimise the levels of PAHs in food
- Outlines risk management measures required to control PAHs in food and
- Lists other sources of further information in a bibliography

Summary

PAHs are a class of complex chemicals that are formed and released during incomplete combustion or pyrolysis (burning) of organic matter such as waste or food, during industrial processes and other human activities. PAHs are also formed in natural processes such as carbonisation. Studies on individual PAHs in animals, mainly on the PAH benzo[*a*]pyrene, have shown various toxicological effects, such as haematotoxicity (effects on the blood), reproductive and developmental toxicity and immunotoxicity. A number of PAHs have shown carcinogenic effects in experimental animals and it has been concluded that benzo[*a*]pyrene is carcinogenic to humans (Group 1) (IARC, 2012).

There is concern therefore, about their formation and presence in food.

In food, PAHs may be formed during industrial processing and domestic food preparation, such as barbecuing, smoking, drying, roasting, baking, frying or grilling. Direct fire-drying and heating processes used during the production of some oils of plant origin and in particular olive pomace oil (oil extracted from olive pulp after the first press) can result in high levels of PAHs. This can be prevented by application of appropriate control measures coupled with awareness of the ways that PAHs are formed in food.

Maximum levels (MLs) have been set for PAHs in key foodstuffs, e.g. smoked meat and smoked meat products, smoked fish and smoked fish products, oils and fats, via Commission Regulation (EC) No 1881/2006, the framework EU legislation which sets maximum levels for chemical contaminants in foodstuffs. These MLs are set at a very low level (as low as reasonably achievable for the particular foodstuff in question), in order to reduce adverse effects on the health of consumers. To demonstrate that these MLs are not being exceeded, routine surveillance of food must be carried out; this involves taking samples of potentially contaminated produce, followed by laboratory analysis to determine the levels of PAHs in the food. The Food Safety Authority of Ireland (FSAI) and other bodies responsible for ensuring the safety of Irish food, including the Environmental Health Service Public Analysts' Laboratories within the Health Service Executive (HSE) and the Marine Institute, carry out regular checks on levels of PAHs in the food chain. The results of these checks show that the levels in food in Ireland are generally low and are considered to present little risk to the health of the Irish consumer, although occasional instances of elevated levels are observed.

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In addition to the overall responsibility placed on food business operators by the General Food Law (Regulation (EC) No 178/2002) to supply safe food, food business operators must also ensure that their products comply with the legislative limits for PAHs as laid down in Commission Regulation (EC) No 1881/2006.

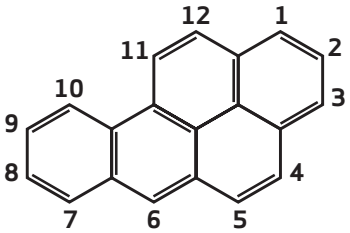
In developing a food safety management system based on HACCP principles, it is important to identify PAHs as a potential hazard and the risk of their occurrence needs to be controlled. Food business operators therefore, need to identify any critical control points (CCP) in their processes such as combustion products and drying processes that may be a source of PAH production. The identification of appropriate CCPs along the process chain enables food business operators to eliminate PAHs or reduce them to acceptable levels.

1. Introduction

The term 'polycyclic aromatic hydrocarbons' (PAHs) commonly refers to a large class of organic compounds containing two or more fused aromatic rings made up of carbon and hydrogen atoms. PAHs are formed and released during incomplete combustion or pyrolysis (burning) of organic matter such as waste or food, during industrial processes, fuel burning and other human activities. PAHs are also formed in natural processes, such as carbonisation. The general characteristics common to these chemicals are high melting and boiling points, low vapour pressure and very low water solubility which tend to decrease with increasing molecular mass. PAHs are soluble in many organic solvents and are therefore, lipophilic (soluble in fat).

Figure 1 shows the structure of benzo[*a*]pyrene (BaP), one of the best characterised members of the PAH family.

Figure 1: structure of benzo[*a*]pyrene



benzo[*a*]pyrene

Hundreds of individual PAHs may be formed during roasting or burning processes such as barbecuing. Many of these have been characterised chemically. In relation to their presence in food however, the EU Scientific Committee on Food in its 2002 opinion on PAHs focused most attention on those listed in Table 1, the so-called "SCF-15".

2. Toxicity of PAHs

Although studies in experimental animals on individual PAHs, mainly on benzo[*a*]pyrene, have shown various toxicological effects, such as haematological effects, reproductive and developmental toxicity and immunotoxicity, it is the carcinogenic and genotoxic (DNA-damaging) potential of these compounds that has caused most concern. A number of PAHs have shown carcinogenicity in experimental animals and genotoxicity and mutagenicity *in vitro* and *in vivo*. The International Agency for Research into Cancer (IARC) in 2012 concluded that benzo[*a*]pyrene is a human carcinogen. Some other PAHs have also been identified as being carcinogens with possible genotoxic properties. Although like dioxins and PCBs, PAHs are lipophilic chemicals, they are metabolised or broken down faster, both in the human body and in the environment. Thus, persistence for long periods is not such a major problem.

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In 2002, the Scientific Committee on Food (SCF, 2002) carried out a risk assessment on 33 PAHs (http://ec.europa.eu/food/fs/sc/scf/out153_en.pdf) originally evaluated by the International Programme on Chemical Safety (IPCS) (http://www.inchem.org/documents/ehc/ehc/ehc202.htm) in 1998. The Committee considered on the basis of the available toxicological information, that benzo[*a*]pyrene could be used as a marker for the occurrence and effect of the carcinogenic PAHs in food and that 15 out of the 33 PAHs evaluated, as listed in Table 1, showed clear evidence of mutagenicity/genotoxicity in somatic cells in experimental animals *in vivo*.

With the exception of benzo[*ghi*]perylene, these PAHs have also shown clear carcinogenic effects in experimental animals. Although only benzo[*a*]pyrene has been adequately tested using dietary administration, in the opinion of the SCF all 15 of these compounds should be regarded as potentially genotoxic and carcinogenic to humans. The SCF recommended that, in view of the non-threshold effects of these genotoxic substances, the levels of PAHs in foods should be reduced to as low as reasonably achievable (the ALARA principle).

Table 1. Polycyclic aromatic hydrocarbons considered by SCF 2002 to be mutagenic/genotoxic *in vivo* (the SCF-15)

COMMON NAME	CAS NAME	CAS REGISTRY NO.	ABBREVIATION
Benz[*a*]anthracene	Benz[*a*]anthracene	56-55-3	BaA
Benzo[*b*]fluoranthene	Benz[*e*]acephenanthrylene	205-99-2	BbFA
Benzo[*j*]fluoranthene	Benzo[*j*]fluoranthene	205-82-3	BjFA
Benzo[*k*]fluoranthene	Benzo[k]fluoranthene	207-08-9	BkFA
Benzo[*ghi*]perylene	Benzo[*ghi*]perylene	191-24-2	BghiP
Benzo[*a*]pyrene	Benzo[*a*]pyrene	50-32-8	BaP
Chrysene	Chrysene	218-01-9	CHR
Cyclopenta[*cd*]pyrene	Cyclopenta[*cd*]pyrene	27208-37-3	CPP
Dibenz[*a,h*]anthracene	Dibenz[*a,h*]anthracene	53-70-3	DBahA
Dibenzo[*a,e*]pyrene	Naphtho[*1,2,3,4-def*]chrysene	192-65-4	DBaeP
Dibenzo[*a,h*]pyrene	Dibenzo[*b,def*]chrysene	189-64-0	DBahP
Dibenzo[*a,i*]pyrene	Benzo[*rst*]pentaphene	189-55-9	DBaiP
Dibenzo[*a,l*]pyrene	Dibenzo[*def,p*]chrysene	191-30-0	DBalP
Indeno[*1,2,3-cd*]pyrene	Indeno[*1,2,3-cd*]-pyrene	193-39-5	IP
5-Methylchrysene	Chrysene, 5-methyl-	3697-24-3	5-MCH

The World Health Organization/Food and Agriculture Organization's Joint Expert Committee on Food Additives and Contaminants (JECFA) also concluded that PAHs are clearly genotoxic and carcinogenic (http://www.who.int/ipcs/food/jecfa/summaries/summary_report_64_final.pdf). Except for benzo[*ghi*]perylene and cyclopenta[*cd*]pyrene, the PAHs of concern were the same as those identified by the SCF. They applied a Margin of Exposure (MoE) approach to assessing the possible risk from PAHs in food and concluded that estimated intakes of PAHs, based on available exposure data, were of low concern for human health. A similar approach was applied in 2008 by the European Food Safety Authority's (EFSA) Panel on Contaminants in the Food Chain (CONTAM), to assess the possible risk from PAHs in food. Overall, EFSA reached a similar conclusion to JECFA, although they considered that high consumers of PAH-contaminated food could be at some risk.

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Toxic Equivalence Factors (TEFs) for PAHs

Some assessments have made use of the toxic equivalence factor (TEF) concept for PAHs, as has been used for the dioxins, furans and PCBs. The TEF approach is used to normalise exposures to chemicals with the same mechanism of action (common mechanism chemicals) but with different potencies to yield a total equivalent exposure (TEQ) to one of the chemicals, the "index compound", which in the case of the PAHs, is benzo[*a*]pyrene.

Although a number of PAHs bind to the Ah receptor (aryl hydrocarbon receptor, which is involved in the regulation of biological responses to substances such as PAHs) this is not the only effect that determines their carcinogenic potency. DNA binding and induction of mutations are other significant effects in the carcinogenesis of PAHs. There is no indication that different PAHs are activated via the same metabolic route, bind to DNA in the same positions or induce the same types of mutations in the same organs or tissue. Therefore, the SCF concluded that it was not appropriate to endorse the use of the TEF approach for the risk assessment of PAHs in food. JECFA (2005) and EFSA (2008) reconsidered the TEF approach and reached the same conclusion.

Use of indicator PAHs for PAH occurrence in food

Based on scientific knowledge at the time, benzo[*a*]pyrene was deemed a suitable marker of occurrence and effect of the carcinogenic PAHs in food, and as a consequence, legislative maximum limits were originally set for benzo[*a*]pyrene in foods (Commission Regulation (EC) No 208/2005[1]).

In 2005, the European Commission issued a Recommendation (2005/108/EC) that Member States should perform or continue to perform random monitoring for the presence of PAHs in foodstuffs. The aim of this measure was to:

- Provide information on environmental sources of PAH contamination in foods
- Generate data on the levels of PAHs other than benzo[*a*]pyrene in food in order to inform the review of the suitability of maintaining benzo[*a*]pyrene as a marker
- Investigate the production and processing methods used for smoking and drying foods
- Determine PAH levels in foodstuffs other than those originally covered by legislation

Based on a review of these data collected from the Member States, EFSA's CONTAM Panel, in 2008, concluded that benzo[*a*]pyrene was not a suitable indicator for the occurrence of PAHs in food. The Panel found that PAH4 (the sum of benzo[*a*]pyrene, benz[*a*]anthracene, benzo[*b*]fluoranthene and chrysene) and PAH8 (the sum of benzo[*a*]pyrene, benz[*a*]anthracene, benzo[*b*]fluoranthene, benzo[*k*]fluoranthene, benzo[*ghi*]perylene, chrysene, dibenz[*a,h*]anthracene and indeno[*1,2,3-cd*]pyrene) were the most suitable indicators for PAHs in food, with PAH8 not providing much added value compared to PAH4.

In accordance with these findings, the legislation was updated and separate maximum limits are now set for benzo[*a*]pyrene and PAH4 (Commission Regulation (EU) No 835/2011).

[1] This regulation was repealed by Regulation (EC) No 1881/2006

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3. Exposure to PAHs

For the general population, the major routes of exposure to PAHs for non-smokers are from food and inhaled air. PAHs enter the environment during incomplete combustion or pyrolysis of organic matter, during industrial processes and other human activities. PAHs are also formed in natural processes, such as carbonisation. PAHs are emitted from a number of environmental sources, such as processing of coal, crude oil, petroleum, and natural gas, production of aluminium, iron and steel, heating in power plants and residences (oil, gas, charcoal-fired stoves, wood stoves), combustion of refuse, fires (including wood fires), motor vehicle exhaust and used motor lubricating oil. Soils, surface waters, precipitations and sediments may be contaminated by PAHs due to atmospheric fallout, urban run-off, deposition from sewage, and certain wastes such as oil or gasoline spills, and there is potential for food crops and animals to become contaminated as a result.

In food, PAHs may be formed during processing and domestic food preparation such as barbecuing, smoking, drying, roasting, baking, frying or grilling. Direct fire-drying and heating processes used during the production of some oils of plant origin and in particular olive pomace oil (oil extracted from olive pulp after the first press) can result in high levels of PAHs. Effective refining of olive pomace oil can remove PAHs but alternative methods that avoid the initial formation of PAHs should be used wherever possible. Vegetables may be contaminated by the deposition of airborne particles and through being grown in contaminated soil. Uncooked meat, milk, poultry and eggs will normally not contain high levels of PAHs due to rapid metabolism of these compounds in the animals from which these foods are produced. However, some marine organisms, such as bivalve molluscs, e.g. mussels, oysters, are known to absorb and accumulate PAHs from contaminated water.

In 2008, EFSA calculated human dietary exposure to PAHs based on data supplied by 17 European countries including Ireland. Exposure varied between 235 ng/day and 389 ng/day for average and high consumers, respectively, for benzo[*a*]pyrene alone, rising to 1,729 ng/day and 3,078 ng/day, respectively, for the sum of eight of the most critical PAHs. The two biggest contributors to the dietary exposure were found to be cereals and cereal products and seafood and seafood products; it should be noted however, that little data were available on foods with potentially high PAH content such as barbecued, smoked and roast meat products. In seafood, PAHs do not accumulate in finfish muscle due to rapid metabolism, but are primarily associated with shellfish (molluscs) and processed products, such as smoked fish.

The FSAI and other bodies responsible for ensuring the safety of Irish food, including the HSE and the Public Analysts' Laboratories, carry out regular checks on levels of PAHs in food. The results of these checks show that the levels in Irish food and animal feed are generally low, and are considered to present little risk to the health of the Irish consumer. The results of a specific surveillance study carried out in 2006 by the FSAI on levels of the SCF-15 PAHs in a range of foodstuffs available on the Irish market can be downloaded from the FSAI website: https://www.fsai.ie/uploadedFiles/PAH_levels.pdf

4. Sampling and analysis of PAHs

Commission Regulation 333/2007 sets out the sampling methods and the methods of analysis for PAHs in foodstuffs that meet the requirements of Regulation (EC) No 1881/2006 (see Section 6). The Regulation also stipulates requirements for laboratories carrying out analyses. Core requirements for analytical laboratories are accreditation for PAH analysis to the recognised international standard, competence in the specific analyses and on-going participation in inter-laboratory studies. The Regulation also includes the sampling procedures to be followed by regulatory authorities. Sampling has to be carried out by an authorised person, e.g. environmental health officer, sea-fisheries protection officer, veterinary inspector, and incremental samples must be taken as specified to give an aggregate sample which is representative of the lots or sub lots. Laboratory samples for analysis are then taken from this aggregate sample.

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5. Legislative limits for PAHs

Maximum limits have been set by Commission Regulation (EC) No 1881/2006 (as amended) for PAHs in key foodstuffs, e.g. smoked meat and smoked meat products, smoked fish and smoked fishery products, oils and fats, infant formulae and follow-on formulae and processed cereal-based foods and baby foods for infants and young children.

The limits laid down in the Regulation are shown in Table 2. Other food groups for which levels are currently under discussion include food supplements, cocoa fibre, banana chips, dried herbs and spices. Maximum limits for these foodstuffs may be added to the list at a later stage.

A maximum allowed content of 10 ppb for benzo[*a*]pyrene and 20 ppb for benz[*a*]anthracene in smoke flavouring has been set for the EU by Regulation 2065/2003 on smoke flavourings used or intended for use in or on foods.

Temporary derogation from current maximum levels

According to Regulation (EC) No 1881/2006, maximum levels for PAHs must be safe and as low as reasonably achievable (ALARA) based upon good manufacturing and agricultural and fishery practices. In 2011, data for smoked fish and smoked meat supported the lowering of existing maximum limits. Nevertheless, adaptations of smoking technology were necessary in some cases to achieve these limits. Therefore, for smoked meat and meat products and smoked fish and fishery products, a transition period of three years had been granted before the lower maximum levels became applicable on 1 September 2014.

Evidence, however, presented prior to the lower maximum levels coming into force in September 2014, demonstrated that despite the application of good smoking practices, the lower levels for PAHs are not achievable in several EU Member States where the traditional smoking practices used for smoked meat and meat products and fish and fishery products, cannot be changed without significantly changing the organoleptic characteristics of the foods.

Consequently, if the lower maximum levels for PAHs were applied, such traditionally smoked products would disappear from the market, resulting in the closure of many small and medium sized enterprises. This was considered disproportionate to the low risk presented by the trace presence of PAHs in these foods.

Therefore, the Commission granted a derogation on 12 Dec 2014 (Regulation 1327/2014) from the application of the lower maximum levels for PAHs (which came into force on 1 September 2014) for certain Member States, including Ireland, for three years (until 12 Dec 2017) for local production and consumption of traditionally smoked meat and meat products and/or fish and fishery products. During this period of the derogation, the previous higher maximum levels (which were applicable until 1st Sep 2014) continue to apply to these smoked products.

In 2017, the Commission will re-assess the situation based on information available as the end of the derogation period approaches. This could result in a more limited and detailed list of smoked meat and meat products and fish and fishery products for which a derogation for local production and consumption could be granted without a time limit.

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Table 2*. Maximum levels in Regulation 1881/2006 (as amended) for polycyclic aromatic hydrocarbons (PAHs) in certain foodstuffs*

ENTRY NO	FOODSTUFFS (1)	PAH	MAXIMUM LEVELS (µg/kg)
6.1	**Polycyclic Aromatic Hydrocarbons**		
6.1.10	Dietary foods for special medical purposes (9) (29) intended specifically for infants	Benzo(a)pyrene	1.0
		Sum of PAH4 (45)	1.0
6.1.1	Oils and fats (excluding cocoa butter and coconut oil) intended for direct human consumption or use as an ingredient in food	Benzo(a)pyrene	2.0
		Sum of PAH4 (45)	10.0
6.1.2	Cocoa beans and derived products	Benzo(a)pyrene	5.0 µg/kg fat
		Sum of PAH4 (45)	30.0 µg/kg fat
6.1.3	Coconut oil intended for direct human consumption or use as an ingredient in food	Benzo(a)pyrene	2.0
		Sum of PAH4 (45)	20.0
6.1.4	Smoked meat and smoked meat products	Benzo(a)pyrene	5.0 until 31.8.2014** 2.0 as from 1.9.2014
		Sum of PAH4 (45)	30.0 as from 1.9.2012 until 31.8.2014** 12.0 as from 1.9.2014
6.1.5	Muscle meat of smoked fish and smoked fishery products (25) (36), excluding fishery products listed in points 6.1.6 and 6.1.7. The maximum level for smoked crustaceans applies to muscle meat from appendages and abdomen (44). In case of smoked crabs and crab-like crustaceans *(Brachyura and Anomura)*, it applies to muscle meat from appendages.	Benzo(a)pyrene	5.0 until 31.8.2014** 2.0 as from 1.9.2014
		Sum of PAH4 (45)	30.0 as from 1.9.2012 until 31.8.2014** 12.0 as from 1.9.2014
6.1.6	Smoked sprats and canned smoked sprats (25) (47) *(sprattus sprattus)*; bivalve molluscs (fresh, chilled or frozen) (26); heat treated meat and heat treated meat products (46) sold to the final consumer	Benzo(a)pyrene	5.0
		Sum of PAH4 (45)	30.0
6.1.7	Bivalve molluscs (36) (smoked)	Benzo(a)pyrene	6.0
		Sum of PAH4 (45)	35.0
6.1.8	Processed cereal-based foods and baby foods for infants and young children (3) (29)	Benzo(a)pyrene	1.0
		Sum of PAH4 (45)	1.0
6.1.9	Infant formulae and follow-on formulae, including infant milk and follow-on milk (8) (29)	Benzo(a)pyrene	1.0
		Sum of PAH4 (45)	1.0
PAH4 = benzo(a)pyrene, benz(a)anthracene, benzo(b)fluoranthene and chrysene			

* Table 2 is reproduced from Commission Regulation (EC) No 1881/2006. The references () in the table refer to footnotes in the Regulation, and persons intending to use the MLs should refer to the Regulation for further details.

** A special derogation applies to certain countries, including Ireland

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6. Hazard Analysis Critical Control Points (HACCP) and other control measures for PAHs

In addition to the overall responsibility placed on food business operators by the General Food Law (Regulation 178/2002) to supply safe food, they must also ensure that their products comply with the legislative limits for PAHs as laid down in Commission Regulation (EC) No 1881/2006.

In developing a food safety management system based on HACCP principles, it is important to identify PAHs as a potential hazard and the risk of their occurrence needs to be controlled. Food business operators therefore, need to identify any CCPs in their processes, such as combustion products and drying processes, that may be a source of PAH formation. The identification of appropriate CCPs along the process chain enables food business operators to eliminate PAHs or reduce their presence to acceptable levels. The Codex Alimentarius Commission's Code of Practice for the Reduction of Contamination of Food with Polycyclic Aromatic Hydrocarbons (PAH) from Smoking and Direct Drying Processes CAC/RCP 68-2009, (see http://www.codexalimentarius.org/download/standards/11257/CXP_068e.pdf), is a useful reference point.

The amount of PAHs formed during cooking or processing of food depends markedly on a number of factors such as food type and heating and cooking methods. The following are some preventative measures that may be applied:

- Avoid direct contact of oil seeds or cereals with combustion products during drying processes
- Select lean meat and fish
- Avoid contact of foods with flames when barbecuing
- Use less fat for grilling
- Cook at lower temperatures for a longer time

These measures result in a significant reduction in the PAH contamination of foods. Broiling, i.e. with the heat source above the food, can significantly reduce PAH levels. Fat should not drip down onto an open flame, sending up a column of smoke that coats the food with PAHs. The use of medium to low heat and placement of the meat further from the heat source can greatly reduce formation of PAHs. The intensity of flavour is not necessarily associated with the depth of the brown colour of grilled foods. It is therefore, not necessary to overcook the food to get the flavour. Cooking however, must always remain effective as regards inactivation of any possible contaminating bacteria.

The PAH contamination of smoked foods can be significantly reduced by replacing direct smoking (smoke developed in the smoking chamber used traditionally in smokehouses) with indirect smoking. The latter is obtained by an external smoke generator, which in modern industrialised kilns, is operated automatically under controlled conditions. Also the use of smoke flavourings is generally considered to be less of a health concern than the traditional smoking process as it may minimise PAH contamination. A smoke flavouring (also known as 'liquid smoke') is produced from condensed smoke, which is then fractionated and purified to remove most PAHs.

The waxy surface of vegetables and fruits can concentrate low molecular mass PAHs, mainly through surface adsorption. The concentrations of PAHs are generally greater on the plant surface such as the peel or outer leaves than on internal tissue. Consequently, washing or peeling may remove a significant proportion of the total PAHs. Particle-bound high molecular mass PAHs which remain on the surface are easily washed off, whereas low molecular mass compounds which are in the vapour phase, can penetrate the waxy layer of fruits and vegetables and are less efficiently removed by washing.

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Commission Regulation (EU) No 1327/2014 of 12 December 2014 amending Regulation (EC) No 1881/2006 as regards maximum levels of polycyclic aromatic hydrocarbons (PAHs) in traditionally smoked meat and meat products and traditionally smoked fish and fishery products

Regulation (EC) No 2065/2003 of the European Parliament and of the Council of 10 November 2003 on smoke flavourings used or intended for use in or on foods

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Sampling and Analysis for PAHs

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