ILSI Europe
Report Series

Packaging Materials
2. Polystyrene for Food Packaging Applications

Report

Prepared under the responsibility of the ILSI Europe Packaging Material Task Force

ILSI
International
Life Sciences
Institute

© 2002 International Life Sciences Institute

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission of the copyright holder. The International Life Sciences Institute (ILSI) does not claim copyright on U.S. government information.

Authorization to photocopy items for internal or personal use is granted by ILSI for libraries and other users registered with the Copyright Clearance Center (CCC) Transactional Reporting Services, provided that $0.50 per page per copy is paid directly to CCC, 222 Rosewood Drive, Danvers, MA 01923. Tel: (+1) 978 750 8400, fax: (+1) 978 750 4744.

ILSI®, "A Global Partnership for a Safer, Healthier World.®", and the ILSI logo image of the microscope over the globe are registered trademarks of the International Life Sciences Institute. The use of trade names and commercial sources in this document is for purposes of identification only, and does not imply endorsement by the International Life Sciences Institute (ILSI). In addition, the views expressed herein are those of the individual authors and/or their organizations, and do not necessarily reflect those of ILSI.

ILSI Press
One Thomas Circle, NW
Ninth Floor
Washington DC 20005-5802
USA
Tel: (+1) 202 659 0074
Fax: (+1) 202 659 3859

ILSI Europe
Avenue E. Mounier 83, Box 6
B-1200 Brussels
Belgium
Tel: (+32) 2 771 00 14
Fax: (+32) 2 762 00 44

Printed in Belgium

ISBN 1-57881-127-9

Report on Packaging Materials: 2. Polystyrene for Food Packaging Applications.

ILSI Europe Packaging Material Task Force, 83 Avenue E. Mounier, Box 6, B-1200, Brussels, Belgium.

ILSI

International Life Sciences Institute

PACKAGING MATERIALS

2. POLYSTYRENE FOR FOOD PACKAGING APPLICATIONS

REPORT

PREPARED UNDER THE RESPONSIBILITY OF THE ILSI EUROPE PACKAGING MATERIAL TASK FORCE

May 2002

CONTENTS

INTRODUCTION	4
WHAT IS POLYSTYRENE?	5
BASIC CHEMISTRY OF POLYSTYRENE PLASTICS	6
POLYSTYRENE AND FOOD PACKAGING APPLICATIONS	9
FOOD CONTACT REGULATIONS	11
SAFETY/TOXICOLOGY	14
ENVIRONMENTAL ASPECTS	18
GENERAL CONCLUSIONS	19
REFERENCES	20

INTRODUCTION

Polystyrene and the styrene-butadiene co-polymer plastics have been used as packaging materials for many years.

The clarity of the crystal polystyrene homo-polymer, the high impact resistance of the styrene-butadiene co-polymers and the low density combined with good strength and insulation properties of foamed polystyrenes, have made the plastics manufactured from these polymers especially suitable to be transformed into a variety of packaging materials and articles, particularly containers and trays, for use with a wide range of foods and beverages.

Polystyrene plastics packaging which comes into direct contact with foods and beverages complies with the safety requirements in the relevant European Directives on "food contact plastics".

WHAT IS POLYSTYRENE?

Polystyrene is the parent polymer of a family of styrene-based plastics which are used for the manufacture of items ranging from furniture and electrical goods, to toys, housewares and a wide variety of packaging. The principal co-monomer which is coupled with styrene to form plastics with enhanced physical properties suitable for food packaging is 1,3-butadiene. The resultant plastics are known as the high impact polystyrenes (HIPS).

Polystyrene homo-polymer, also known commercially as crystal polystyrene, is an amorphous polymer and has the particular properties of high clarity, colourless, hard, but rather brittle with low impact strength. The amorphous nature and other properties, which arise from the aromatic chemical structure and glass transition temperature (Tg) of around 100°C, differ markedly from those of the polyolefin plastics, such as polyethylene, which are based on aliphatic hydrocarbons and have below ambient glass transition temperatures.

The styrene-based plastics are considered to be some of the most versatile, easily fabricated and cost-effective plastics (Brady and March, 1997). The amorphous nature makes polystyrene an ideal plastic for injection moulding.

Crystal polystyrene is, however, susceptible to stress cracking by organic liquids and oils, which precludes it use with foodstuffs containing high levels of fats and vegetable oils (Mark *et al*., 1985; Briston, 1992; Ashford, 1994).

A major use of polystyrene plastics is in expanded sheet form. Expanded polystyrene plastics are extensively employed as general protective packaging, sometimes called cushioning packaging, but they also find wide use as packaging for food formed into trays and containers, and as disposable beverage cups (Robertson, 1992). The expanded polystyrene plastics used for these applications are known as foamed polystyrenes, from the particular process used in their manufacture.

Polystyrene film can be biaxially oriented and in this form maintains clarity and overcomes some of the brittleness of un-stretched plastic. The stretching operation also improves the strength, even though crystals are not produced. It is manufactured in both thin gauges – less than 75 microns – and thick gauges which can be used to make thermoformed containers (Briston, 1992; Ashford, 1994; Robertson, 1992; Brown, 1992).

To overcome the brittleness of non-orientated crystal polystyrene, butadiene synthetic rubbers (between 5% and 14%) are reacted with styrene during polymerisation to manufacture HIPS. The superior impact strength of HIPS, compared to that of crystal polystyrene plastics, is off-set by inferior clarity which makes them either translucent or opaque. HIPS plastics also have reduced tensile strength, but there is a higher resistance to stress cracking and to crazing caused by organic liquids, oils and fats. Recent developments, however, now enable HIPS to be manufactured using special polymerisation technology which results in crystal clear plastics (anionic polymerisation) (Anonymous, 1999).

Polystyrene and HIPS plastics have poor barrier properties to water vapour and gases, such as oxygen and carbon dioxide.

BASIC CHEMISTRY OF POLYSTYRENE PLASTICS

Styrene and butadiene monomers are the starting chemical substances from which polystyrene polymer and styrene-butadiene copolymers are produced. To convert polystyrene polymer, and the copolymers, into plastics with the required physical properties for use as packaging for foodstuffs, "additives" are incorporated.

Monomers

Styrene monomer

Styrene, which is also commonly known as vinyl benzene, is a colourless liquid with a distinctive and penetrating odour (Ashford, 1994).

styrene (phenyl ethene) $C_6H_5\text{-}CH{=}CH_2$

The raw material used for the manufacture of styrene is ethyl benzene. Styrene is manufactured commercially from ethyl benzene by means of catalytic dehydrogenation.

$$\underset{\text{ethyl benzene}}{C_6H_5\text{-}CH_2\text{-}CH_3} \rightarrow \underset{\text{styrene}}{C_6H_5\text{-}CH{=}CH_2} + \underset{\text{hydrogen}}{H_2}$$

Styrene monomer is produced with high purity usually in the range of 99.7–99.9%.

Butadiene monomer

There are two isomers of butadiene: 1,2-butadiene and 1,3-butadiene. The 1,3-butadiene isomer is used in the manufacture of the styrene-butadiene co-polymers.

1,3-butadiene (buta-1,3-diene) $CH_2{=}CH\text{-}CH{=}CH_2$

A variety of processes can be used for the commercial manufacture of this plastics monomer. A principal method is the catalytic dehydrogenation of butane or butenes.

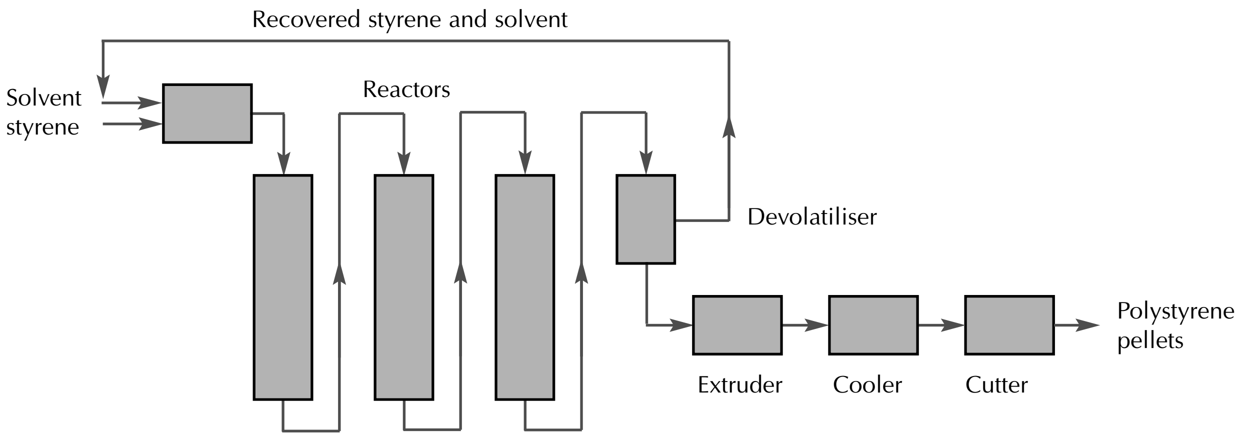
$$\underset{\text{1-butene}}{CH_2{=}CH\text{-}CH_2\text{-}CH_3} \rightarrow \underset{\text{1,3-butadiene}}{CH_2{=}CH\text{-}CH{=}CH_2} + \underset{\text{hydrogen}}{H_2}$$

Manufacture of polystyrene homo-polymer (crystal polystyrene)

There are two main commercial processes used for the manufacture of crystal polystyrene – the *solution process* and the *suspension process*.

Most general-purpose polystyrene is produced by solution polymerisation in a continuous process consisting of one or more vessels, with free radical catalysis by means of peroxides, such as benzoyl peroxide. Volatiles, including the diluent and un-reacted styrene, are removed by heat and vacuum stripping. The molten polymer is then cooled and pelletised. Figure 1 shows a diagram of the continuous solution process for polystyrene polymerisation.

Figure 1. Diagram of the continuous solution process for polystyrene polymerisation



In the suspension process, the styrene monomer is dispersed in water in the presence of a suspending agent and a peroxide polymerisation initiator. The mixture is heated in a closed vessel until polymerisation is substantially complete. The polymer is separated off, dried and un-reacted monomer together with other volatiles, removed by vacuum stripping before being pelletised (McGraw-Hill, 1997).

Foamed polystyrene is manufactured from polystyrene polymer into which an expanding agent – a volatile substance – has been incorporated. In the process used to produce foamed polystyrene for conversion into food packaging trays, containers and beverage cups, the expanding agent is directly injected into molten polymer (Brady and March, 1997). The volatile expanding agents used in the past were mainly chlorofluorohydrocarbons (CFCs). As use of these chemical substances is now prohibited under the Montreal Agreement and other national environmental agreements, they have generally been replaced with the hydrocarbons pentane or butane. Over the last five years, industry has developed a new technology using carbon dioxide (CO_2) as the foaming agent, which provides the benefit of reduced flammability. Carbon dioxide is also neutral with respect to volatile organic compounds (VOC) emissions and, in addition, the finished plastics benefit by having improved organoleptic properties opening up new food packaging applications without affecting the odour and taste of the food products.

Manufacture of styrene-butadiene copolymers and high-impact polystyrene (HIPS) plastics

The commercial process most commonly used to produce styrene-butadiene copolymers is the continuous solution process, which is similar to that used for the commercial manufacture of crystal polystyrene. At the start of the process polybutadiene (rubber) is dissolved in the styrene monomer. As the polymerisation process proceeds two phases are formed – a polybutadiene rich phase and a polystyrene rich phase with grafted polybutadiene. The grafting arises when some of the styrene free radicals react with the polybutadiene (McGraw-Hill, 1997).

The HIPS plastics used for food packaging are mostly a blend of crystal polystyrene and a styrene-butadiene co-polymer. The ratio of crystal polystyrene and the co-polymer used depends on the required functional performance of the plastic.

Additives used in polystyrene plastics for food contact use

Polystyrene plastics and HIPS are manufactured with various "additives" which include anti-oxidants, colourants, mould release agents and processing aids. Antioxidants, such as penta-erythritol tetrakis [3-(3,5-di-tert-butyl-4-hydroxphenyl)propionate], are usually present at concentrations well below 1% and are typically at around the 0.1% level. A common mould release agent is zinc stearate, added at the low level of about 0.05%. White mineral oils are used as processing aids and flow promoters with levels of between 0.5 and 6% by weight, with an average of about 2%. White mineral oils are not used in foamed polystyrene plastics.

POLYSTYRENE AND FOOD PACKAGING APPLICATIONS

Crystal polystyrene is used as a packaging material where the "crystal clear" properties can be utilised to advantage. These are containers for a variety of foods and as disposable "plastic glasses" for beverages.

Foamed polystyrene plastics are thermoformed into a variety of trays for meat, poultry, fish, fruit and vegetables; "clam" containers for eggs, and fast-foods, and disposable cups for beverages. Some foamed polystyrene trays, cups and containers have surface layers of crystal polystyrene which provide a "barrier" layer between the plastic and the foodstuff. The bulk density of foamed polystyrene plastics used for food packaging trays and containers is typically in the range 0.05 to 0.19 g/cm^3. The thickness range is typically 0.3 to 6.4 mm.

Biaxially oriented polystyrene films in thin gauges are used for food packaging carton windows. They have also been used as "breathable" films for over-wrapping fresh produce, such as lettuce. Thicker gauges are used to manufacture clear vending cups, and tubs for desserts and preserves, using the thermoforming process.

HIPS are used in the form of pots for dairy products, such as yoghurts, as vending cups for beverages such as coffee, tea, chocolate and also soup, and in the form of "clams" for eggs. As mentioned earlier, HIPS plastics are usually produced from blends of styrene-butadiene co-polymer and crystal polystyrene; the ratios being selected to achieve the required balance of physical properties for the different forms of packaging and the conversion process – injection moulding or thermoforming. Pots for dairy products are manufactured either by the injection moulding process or the thermoforming process. Vending cups are usually manufactured by the thermoforming process, as only thin walls are necessary because they do not have to withstand high-speed filling operations.

Some pots and containers have multilayer structures, which often consist of a layer of HIPS sandwiched between layers of crystal polystyrene. The crystal polystyrene layers provide "barrier" properties between the HIPS and the food or beverage, and an attractive "glossy" external appearance. Other multilayer composites contain layers with barrier resins such as ethylene vinyl alcohol (EVOH) and polyesters (PET/PETG).

In recent years, polypropylene (PP) plastics have replaced HIPS plastics in some of the above mentioned uses, but for some types of food packaging, the reverse has occurred due to advantages of ease of processing and low shrinkage provided by polystyrene plastics.

The physical properties and performance of polystyrene and HIPS plastics may set limitations on the use as food packaging. For example with the exception of polystyrene thermoset plastics (not covered in this report), crystal polystyrene and HIPS cannot physically withstand "high" temperatures and consequently cannot be used for oven cooking of foods. As mentioned earlier, polystyrene plastics are also normally not suitable for use with high-fat foods, due to the tendency for stress cracking when in contact with such foods. The full extent of the use limitations is well understood by the polystyrene plastics manufacturers from the extensive knowledge accumulated over the years and potential users are always suitably advised.

Migration of substances from polystyrene plastics under conditions of use

The conditions of use of the polystyrene family of food packaging plastics range from low temperatures for periods of days or weeks, for example packaged dairy and meat products, to high temperatures approaching the boiling point of water for short periods of time, for example vending cups.

The principal classes of substances, which can migrate from polystyrene plastics to foods and beverages, are: residual monomers, low molecular weight components (oligomers) and the various additives. Substances migrating to foodstuffs are of concern if they present a possible health hazard to the consumer, or cause unacceptable changes to the organoleptic properties of the food or beverage. High levels of "inert" substances migrating and contaminating the food or beverage are also unacceptable. All substances migrating from the plastics to the packaged foods and beverages must however, be in full compliance with the legislative controls which are discussed in the next section.

Numerous studies and investigations have been carried out to establish levels of migration of styrene monomer into foods and beverages from the various polystyrene plastics used for food packaging and for beverage containers.

In 1983, the UK Ministry of Agriculture, Fisheries and Food (MAFF), published the results of a comprehensive survey on styrene levels in food contact materials and migrations into foods in the *Eleventh Report of the Steering Group on Food Surveillance* (MAFF, 1983). The report highlighted the fact that although residue levels of styrene monomer in the various polystyrene plastics were found to be as high as 0.1% by weight (1,000 mg/kg), the quantities determined in the foods and beverages which came into contact with the plastics, due to migration, were relatively low. The mean styrene values found in various food types were in the region of 10 ppb (µg/kg), with maximum levels around 200 ppb (µg/kg). From the investigations reported in the survey it was concluded that the levels of styrene present in the foodstuffs could not be related to any one particular factor. It was stated that levels varied, for instance, with the nature of the food, the level of residual styrene in the container and the length and temperature of storage. Plastics with higher butadiene contents did however, show enhanced migration of styrene. This observation was substantiated by Linssen *et al.* (1992). The results from the survey were evaluated by the Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment (COT), and it was concluded that the levels present in food did not present a toxicological hazard to man.

As with many investigations into the migration of substances from plastics used for food packaging, migration of styrene monomer was higher with fatty foods than with aqueous foods.

Further surveys on styrene monomer in foods were undertaken by MAFF in 1992 and 1994. The findings from these surveys are discussed in the section "Safety and Toxicology".

FOOD CONTACT REGULATIONS

European regulations that apply to polystyrene: Specific European Commission Directives on plastics used for packaging of foodstuffs

As part of the process of harmonizing legislation of the European Union Member States, the European Commission (EC) has introduced "framework" directives concerned with the safety of all materials and articles intended to come into contact with foodstuffs. Article 2 in the current "framework" Directive 89/109/EEC is the most important, which states:

Materials and articles must be manufactured in compliance with good manufacturing practice so that, under their normal and foreseeable conditions of use, they do not transfer their constituents to foodstuffs in quantities which could:

- endanger human health;
- bring about an unacceptable change in the composition of the foodstuffs or a deterioration in the organoleptic characteristics thereof.

Under the European Commission "framework" Directive 89/109/EEC on food contact materials and articles, the Commission has added directives specifically concerning plastics materials and articles intended to come into contact with foodstuffs, which, of course, include plastics used for packaging of foodstuffs. The "plastics" directives consist of the principal Directive 90/128/EEC and a number of amendments introduced over the last 10 years. Other directives lay down testing procedures. The provisions of these European directives are brought into use by European Member States implementing them into their individual national laws and legislative systems. The laws of some European Member States may contain additional legislative specifications and/or restrictions for food contact plastics materials and articles, particularly on components not yet covered by directives, such as colourants, aids to polymerisation and certain additives. Some countries that are not European Union Member States, for example Switzerland, have adopted provisions of the European directives by incorporating them into their national laws.

All substances included in the authorized lists of substances in Directive 90/128/EEC and the amendments have been assessed by the European Scientific Committee on Food (SCF). The assessments are based on toxicological and safety data. Where considered necessary restrictions are assigned.

Styrene and butadiene monomers are included in the authorized list of plastics monomers in Directive 90/128/EEC.

Styrene monomer is listed without any restrictions. In practice, the tainting properties of styrene monomer in foodstuffs and the pungent odour act as a restriction on the level at which styrene is tolerated by the consumer in most foodstuffs.

The SCF is however, currently evaluating safety data on styrene monomer. The result of the evaluation will determine whether styrene will be assigned a restriction in the form of a specific migration limit (SML). The conclusions from the SCF should be available in 2002.

Butadiene is listed with the restrictions:

> QM = 1 mg/kg in FP or SML = not detectable (DL = 0.02 mg/kg analytical tolerance included). QM is the maximum permitted quantity of "residual" substance in the material or article; FP is the finished material or article; SML is the specific migration limit in food or food simulant; and DL is the detection limit of the method of analysis.

Commission Directive 90/128/EEC has been amended seven times. No change has been made to the restriction for butadiene and no restriction has been introduced for styrene in these amendments. The third amendment to Directive 90/128/EEC – Directive 95/3/EC – introduced an *Incomplete List of Plastics Additives*. The fifth, sixth and seventh amendments – Directives 1999/91/EC, 2001/62/EC and 2002/17/EC – contain additives with restrictions, which are mainly SMLs. Included in the "additives" list are additives which are commonly used in polystyrene and the polystyrene co-polymers, such as antioxidants and white mineral oils.

Additives which are not in the *Incomplete List of Plastics Additives* may be used in "food contact plastics" provided that they are currently accepted for use in national regulations of European Member Sates.

Table 1 lists typical "additives" used in polystyrene plastics with the "restriction" status.

Table 1

Additive	Restriction
Pentaerythritol tetrakis [3-(3,5-di-tert-butyl-4-hydroxphenyl)propionate] – antioxidant, commercial name Irganox 1010	None
octadecyl 3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionate – antioxidant, commercial name Irganox 1076	SML = 6 mg/kg (6th amendment, Dir. 90/128/EEC)
white mineral oils	specification

Full details on all the directives relating to "food contact materials and articles" can be found at the website http://cpf.jrc.it/webpack/ which is organised on behalf of the European Commission by the Food Products & Consumer Goods Group of the Institute of Health & Consumer Protection at the Joint Research Centre, Ispra, Italy.

Frequently, additives and also colourants are being incorporated into polystyrene plastics using master batches based on polystyrene as a carrier. Sometimes other carriers are used. To ensure that the final food contact material or article is in compliance with Commission Directive 90/128/EEC, and where applicable national legislation, the carrier as well as the additives must meet the requirements of the legislation.

Colourants used in food contact plastics are currently not covered by any European Commission directive. There is, however, a Council of Europe Resolution AP (89) 1 on the use of colourants in plastics coming into contact with food. This resolution is currently under review. It requires that colourants do not pose a risk to health, or affect food quality, and are sufficiently integrated within the finished material so that there is no visible migration under normal conditions of use. There are also purity criteria and specifications covering contaminants such as toxic heavy metals, aromatic amines and PCBs.

U.S. Food and Drug Administration (FDA) Regulations

The U.S. Food and Drug Administration regulations are mandatory in the U.S. They are also often "used" by other countries, particularly small countries with high exports of packaged foodstuffs, such as New Zealand.

Regulations for polystyrene and rubber-modified polystyrene are contained in the Code of Federal Regulations (CFR) Title 21 Part 177.1640. Part 177.1810 deals with styrene block polymers used as "articles and components of articles that contact food".

The U.S. FDA regulations are updated annually. Full details of these regulations applicable to polystyrene, the copolymers and the additives that can be used with these plastics are available on the following websites: http://www.access.gpo.gov/nara/cfr/waisidx_01/21cfr177_01.html, and http://www.access.gpo.gov/nara/cfr/waisidx_01/21cfr178_01.html.

SAFETY/TOXICOLOGY

Styrene monomer – European overview

As a volatile substance used widely in industry for more than 50 years, a considerable body of toxicological and epidemiological data has been developed for styrene. Much of the focus has been on the potential effects of styrene inhalation because the most significant exposures have been to workers exposed through this route.

Styrene has low acute toxicity after inhalation or ingestion, although in the EU it is classified as harmful by inhalation and irritating to skin and eyes. Very high exposures induce dizziness, drowsiness, headache and potentially unconsciousness due to depression of the central nervous system.

Styrene is metabolised to mandelic and phenylglyoxylic acid (detoxication products which are safely excreted in urine) via a transient metabolite, styrene oxide. In addition, experimental work has shown that styrene oxide is also unstable in foods (Philo *et al.* 1997). Extensive epidemiological investigations of workers exposed to high concentrations of styrene vapour in the unsaturated polyester resin-processing industry have not shown excesses of cancer associated with styrene exposure. Although not ideal in design, several studies in experimental animals by both oral and inhalation routes had shown no convincing evidence of cancer induction. However, recent inhalation route cancer studies have been carried out in rats and mice in accordance to contemporary guidelines. Cancer induction was not associated with styrene inhalation in the rat. Lung cancer was found in the mouse, but this is not judged to be relevant to humans because of metabolic differences between humans and the mouse.

Mixed results have been reported for styrene in *in vitro* genotoxicity tests. However, there is no convincing evidence of cytogenic damage *in vivo* where animals have been exposed to styrene. Whilst some cytogenetic studies on peripheral blood lymphocytes of workers exposed to styrene have reported increases in chromosomal damage, there is no clear dose response relationship and the relevance of these data is unclear. No appreciable level of interaction with DNA has been shown in studies of DNA adduct formation.

The World Health Organisation's International Agency for Research on Cancer classified styrene as a Group 2B carcinogen (possible human carcinogen) in 1994 and regulatory reviews considering the latest experimental data are currently in progress both in the U.S. and the EU.

Styrene did not cause birth defects in studies in laboratory animals. Although lesser developmental effects have been reported, these only occurred at exposure levels that were maternally toxic. Studies in exposed workers do not show any significant risk of reproductive toxicity or birth defects from styrene exposure. No effects on fertility were observed in the rat in a three-generation fertility study with dosing via the drinking water, although the dose given was relatively low.

The large toxicological database for styrene provides an adequate basis for assurance of the safety of polystyrene, given the low exposures of styrene monomer that the public are exposed to as a consequence of the use of styrene-based polymers in food contact plastics.

Styrene is under review in the EU Risk Assessment programme. Conclusions are expected by mid 2002. These conclusions will be used by the SCF in their re-evaluation of styrene as a monomer for food contact plastics. The results of the SCF re-evaluation can be found on the DG SANCO website: http://www.europa.eu.int/comm/food/fs/sc/scf/index_en.html and will be included in the next amendment to Directive 90/128/EEC.

U.S. FDA risk assessment for styrene monomer

In the late 1990s, the U.S. FDA started reviewing the available toxicological data on styrene, which resulted in a recommendation for a decision to be made on whether styrene should be classified as a carcinogen. At the same time, action on petitions involving polystyrene plastics was suspended.

If the FDA Cancer Assessment Committee (CAC) decides that styrene should be classified as a carcinogen, a virtually safe dose value (VSD) will be assigned by the Quantitative Risk Assessment Committee (QRAC). It is expected, however, that the CAC will take some time before making a decision.

1,3-butadiene monomer

There is sufficient evidence of carcinogenicity of 1,3-butadene in experimental animals and limited evidence in humans resulting in the IARC classification group 2A: probably carcinogenic to humans.

As 1,3-butadiene is suspected of having carcinogenic potential, the European Scientific Committee on Food has placed it in List 4A *Substances for which an ADI or TDI could not be established, but could be used if the substance migrating into foods or in food simulants is not detectable by an agreed sensitive method*. This has resulted in a specific migration limit (SML) of *not detectable* in European Commission Directive 90/128/EEC, and in addition a QM limit of 1 mg/kg (see section on Food Contact Regulations).

Polystyrene plastics – safety in use

Polystyrene plastics which are intended for contact use with foods and beverages in European Member States are manufactured with components and by processes which ensure that there is full compliance with the safety requirements in the relevant European directives, as implemented into the laws of the Member States, and any other additional relevant national laws which are specific to individual Member States (see section on Food Contact Regulations).

To provide the necessary confirmation that individual types of polystyrene plastics comply with the legislative specifications and relevant restrictions which apply for the intended conditions of use, manufacturers and/or users of the plastics carry out prior use tests on representative samples. In most cases, any necessary migration testing is carried out with food simulants rather than foodstuffs. The rules for such testing and the labelling requirements are given in the Annex of European Commission Directive 97/48/EC – the second amendment to Council Directive 82/711/EEC *that delineates the basic rules necessary for testing migration of the constituents of plastic materials and articles intended to come into contact with foodstuffs.*

When considered necessary, national government departments with responsibilities for food safety and national regulatory authorities may carry out tests and surveys on foodstuffs which have been packaged in, or which have come into contact with, plastics, to establish that the safety of the foodstuffs is being maintained. UK MAFF survey findings from 1992 and 1994 on styrene levels in packaging and migrations into packaged foods (see section on Polystyrene and Food Packaging Applications) revealed that the levels of styrene monomer in foodstuffs which had come into contact with various polystyrene plastics were similar to those reported in the 1983 survey. In the 1994 survey, 248 samples of foods were examined and, with the exception of two samples commonly referred to as "low-fat" table spread and 18 samples of milk and cream products sold as individual portions, the levels of styrene ranged from not detectable to 60 ppb (µg/kg). The limit of detection varied with the type of foodstuff but in most cases was 1 µg/kg. The comment was made that although levels of styrene in individual milk and cream portions were above those found in other foods, such portions are considered to make a very minor contribution to the daily diet and hence to styrene intake. It was further commented that the higher level of styrene found in two samples of "low-fat" table spread product was confined to a single batch and was not consistent with low levels found in other "low-fat" table spreads.

This survey report did, however, point out that styrene is known to occur naturally in some foods. For example, it can be formed from cinnamon in the presence of certain yeasts (MAFF, 1995).

In 1999, MAFF published the results from a survey which examined five sets of UK Total Diet Study samples for the presence of styrene monomer (MAFF, 1999). The levels found were quite low, with the highest being only 14 µg/kg. The 14-µg/kg value was with a sample from the oils and fats group and again confirms previous findings demonstrating that styrene migrates most readily into fatty foods. Dietary exposure to styrene was estimated at 0.03 to 0.05 µg/kg body weight per day. These levels were stated to be in the region of three orders of magnitude less than the provisional maximum tolerable daily intake of 40 µg/kg body weight per day set by the Joint FAO/WHO Expert Committee on Food Additives (World Health Organization, 1984).

Research work over the last few years suggests that some chemical substances can act similar to the female hormone, oestrogen. Such chemical substances are known as xenoestrogens. When xenoestrogen chemicals are taken into the human body, particularly by male persons, there is the possibility of adverse health effects. For example, it has been postulated that xenoestogen chemicals may be responsible for the well-publicised reductions in sperm counts which have been claimed to have occurred in some male populations in a number of countries.

During the manufacture of polymers, it is possible that not all of the monomer will be converted into long-chain/high molecular weight polymer. With a small proportion of the monomer, reaction may stop after only a few molecules have become linked together, resulting in very low molecular weight polymer units, known as oligomers. Where only two monomer units are linked together, the oligomer is called a dimer. A three-monomer oligomer is called a trimer.

As an oligostyrene-like chemical has been reported to have oestrogen-like activity, the Styrene Steering Committee of the European Chemical Industry Council (CEFIC) sponsored a series of comprehensive and closely controlled animal studies to evaluate oligomer migrates from 23 representative polystyrenes (9 general purpose polystyrenes, 8 high-impact polystyrenes, and 6 foamed polystyrenes) for any oestrogenicity. An independent organisation was appointed to be responsible for management, protocol development, monitoring, auditing and review of results, and interpretation of the study. Two concentrations of migrates of each of the 23 polystyrene samples were selected for testing to simulate human consumption of foods dosed with high and low levels. The report on the studies concluded that both low and high doses of the 23 polystyrene oligomer migrates tested did not induce an oestrogenic response (Anonymous, 1998). The oligomer migrates for the study were prepared using an aggressive food simulant (50% aqueous ethanol) with exaggerated exposure conditions. The highest levels of both dimers and trimers were from HIPS samples, but these were very low with a maximum dimer level of 0.65 mg/l (ppm) and a maximum trimer level of 1.55 mg/l (ppm) (Klärner *et al.*, 1998).

Based on extensive investigations over the last three years, Japanese health authorities have removed styrene oligomers from the SPEED list (list of possible endocrine substances).

ENVIRONMENTAL ASPECTS

EC Directives on packaging and packaging waste

The EU Packaging and Packaging Waste Directive 94/62/EC places legislative obligations on all Member States to reduce packaging waste and specifies targets for recovery and recycling. Revisions to this directive are underway with the possibility of increases in the targets for recovery and recycling (Reeves, 1999).

Recyclability and reuse

For much of the food packaging made from polystyrene plastics which ends up as consumer waste, it is not practical to attempt to either re-use or recycle the materials. Even if waste polystyrene plastics food packaging could be separated from other plastics by the consumer, a viable recovery system is unlikely to be achieved, with the various types of polystyrene plastics in use (e.g. crystal polystyrene, foamed polystyrene and HIPS, and the small individual quantities per household).

Commercially viable recycling systems have, however, been established for some types of polystyrene plastics with what are termed closed-loop systems, in which close control can be maintained over the use, disposal, and collection of the materials. Such a system is the *Save-A-Cup* scheme in operation in the UK, where vending machine polystyrene cups are collected after use. As HIPS is the standard plastic type used for these cups, a reliable process is possible to recycle the plastic after subjecting the cups to a rigorous cleaning operation to remove beverage residues and other contaminants. The cleaned cups are then processed into polymer pellets for re-use mainly in non-food contact applications. The recycled polystyrene plastics are not used to make new vending cups or other food packaging, due to concerns about the possibility of the waste having been exposed to toxic contaminants during the disposal and collection stages. Recycled polystyrene plastics have, however, been used for selected secondary food packaging, which includes “clam” type egg packs.

To assist in the identification of waste polystyrene plastics for recycling, the following symbol is used. This is often found printed or embossed on the base of the polystyrene containers and trays.

In the mid 1990s, research was carried out by a group of European laboratories in a European Commission-sponsored project to investigate the safety implications of plastic food packaging made from recycled waste plastic food packaging (European Commission, 1997). A particular part of the project looked at polystyrene food packaging plastics made from recycled vending cups and the possibility of safety being influenced if any of the vending cups contained toxic contaminants. Study findings suggest the possibility of using HIPS plastics recycled from vending cups as a centre core layer in a three-layer structure, with the two outer layers made with virgin polymer of HIPS or crystal polystyrene. The outer virgin polymer layers would be expected to provide an adequate barrier to any unacceptable contaminants migrating from the centre core layer of recycled plastic, to the foodstuff.

Non-food contact polystyrene plastics are considered to be a relatively easy plastics type to recycle with a higher secondary value than other commodity plastics and with a wide range of secondary markets.

Presently, there are no EC regulations which specifically address food contact materials and articles made from recycled plastics. The regulatory situation in individual European countries varies, with some forbidding the use of recycled materials, and others leaving it up to the user to ensure that there is compliance with the European directives and national regulations on food contact plastics and overall safety.

Incineration

Incineration is one of the processes used to dispose of consumer waste. As polystyrene plastics burn easily when ignited, modern incineration units with efficient combustion provide an effective process with energy recovery for the disposal of waste polystyrene plastics packaging materials.

GENERAL CONCLUSIONS

The family of polystyrene plastics is one of the major plastics types used for packaging of a wide range of foodstuffs as well as beverage containers. Polystyrene plastics are particularly suitable for formation into food trays, pots and containers by thermoforming or injection moulding processes, and they offer an attractive overall cost/performance balance. The properties of the basic polystyrene polymer have been modified and enhanced for particular applications, such as the incorporation of butadiene rubbers to produce HIPS and the use of blowing agents to form foamed polystyrene plastics.

Polystyrene plastics are easy to recycle. Closed-loop recycling systems are in operation, which provide recycled polymers of good quality suitable for a wide range of non-food contact applications.

Polystyrene plastics have been used for more than 50 years as food packaging materials and the safe continued use is fully supported by today's scientific knowledge on the polymer, the monomers and any possible exposure to low molecular weight residuals.

REFERENCES

Anonymous (1999). Modern Plastics International, 29, No.1, p. 89.

Ashford, R.D. (1994). Ashford's Dictionary of Industrial Chemicals, Wavelength Publications Ltd, London, UK, pp. 747 and 842.

Brady, A.L., and Marsh, K.S. eds. (1997). Wiley Encyclopaedia of Packaging Technology, 2nd Edition, John Wiley & Sons, New York, USA, pp. 1-12, pp. 449-450, and pp. 768-771.

Briston, J. (1992). Advances in Plastics Packaging Technology, Pira International, Leatherhead, UK, Chap. 6, pp. 45-47.

Brown, W.E. (1992). Plastics in Food Packaging: Properties, Design & Fabrication, Marcel Dekker Inc, New York, USA, p.117.

Christian, M.S., and Moore, D.H. (1998). Uterotrophic assays of polystyrenes, *Drug and Chemical Toxicology*, Vol. 21, Suppl. 1, pp. vii-ix and 1-122.

European Commission (1997). DG XII Science, Research & Development Project. AIR2-CT93-1014: Programme to establish criteria to ensure the quality and safety in use of recycled plastics for food packaging. Final Report.

Klärner, P., Klenz, R., Eder, R., Volz, W.E., Schnell, H.W., Leyendecker, D., Günter, A., Nießner, N., Morris, C.R., and Christian, M.S. (1998). Preparation and analysis of styrene oligomers containing migrates from various polystyrene used in food packaging, *Drug and Chemical Toxicology*, Vol. 21, Suppl. 1, pp. 31-49.

Linssen, J.P.H., *et al*. (1992). Polystyrene sheet composition and temperature as parameters for migration of styrene monomer into corn oil, *Packaging Science and Technology*, Vol. 5, pp. 217-222.

MAFF (1983). The Eleventh Report of the Steering Group on Food Surveillance, Survey of styrene levels in food contact materials and in foods, HMSO, London.

MAFF (1995). Food Safety Directorate Food Surveillance Information Sheet No.38.

MAFF (1999). Food Safety Directorate Food Surveillance Information Sheet No.189.

Mark, H.F., Bikales, N. M., Overberger, C. G., Menges, G., and Kroschwitz, J. (1985). Encyclopaedia of Polymer Science & Engineering, 2nd Edition, Wiley Interscience, Vol. 16, pp 64-66.

McGraw-Hill (1997). McGraw-Hill Encyclopaedia of Science & Technology, 8th Edition, Vol. 16, pp. 42-50 and pp. 207-208.

Philo, M.R., Fordham, P.J., Damant, A.P., and Castle, L. (1997). Measurement of styrene oxide in polystyrenes, estimation of migration to foods, and reaction kinetics and products in food simulants, *Food and Chemical Toxicology*, No. 35, pp. 821-826.

Reeves, T. (1999). EU Packaging waste legislation: tough new targets are on the way, *Paper and Packaging Analyst*, No. 37, pp. 78-88.

Robertson, G.L. (1992). Food Packaging, Principles and Practices, Marcel Dekker Inc. New York, USA, pp. 34-36.

World Health Organization (1984). Toxicological Evaluation of Certain Food Additives and Food Contaminants. 28th Report of the Joint FAO/WHO Expert Committee on Food Additives, *WHO Food Additives Series* no. 19. World Health Organisation, Geneva, Switzerland.

Acknowledgment

ILSI Europe and the Packaging Material Task Force would like to thank Mr. Philip A. Tice for writing this report. This review was coordinated and supported by an unconditional grant from the Packaging Material Task Force of the International Life Sciences Institute (ILSI Europe).
Industry members of this task force are:

Groupe Danone	Dow Europe	Nestlé
Frito Lay	BP Chemicals	Cognis
Coca-Cola	Heineken	

Non-industry members are:
Prof. J. Gilbert MAFF, UK, Dr. L. Rossi, EC-DG SANCO, B, and Prof. J.-C. Lhuguenot, ENSBANA-University of Burgundy, F.

ILSI Europe Report Series

The following titles are available in the series:

Safety Considerations of DNA in Foods, 2002
36pp, ISBN 1-57881-126-0

Approach to the Control of Entero-haemorrhagic *Escherichia coli* (EHEC), 2001
36pp, ISBN 1-57881-119-8

Assessing and Controlling Industrial Impacts on the Aquatic Environment with Reference to Food Processing, 2001
36pp, ISBN 1-57881-121-X

Method Development in Relation to Regulatory Requirements for the Dectection of GMOs in the Food Chain, 2001
26 pp. ISBN 1-57881-122-8

Markers of Oxidative Damage and Antioxidant Protection: Current status and relevance to disease, 2000
24 pp. ISBN 1-57881-102-3

Overweight and Obesity in European Children and Adolescents: Causes and consequences – prevention and treatment, 2000
24 pp. ISBN 1-57881-103-1

Packaging Materials: 1. Polyethylene Terephthalate (PET) for Food Packaging Applications, 2000
16 pp. ISBN 1-57881-092-2

Salmonella Typhimurium definitive type (DT) 104: A multi-resistant *Salmonella,* 2000
24 pp. ISBN 1-57881-094-9

Threshold of Toxicological Concern for Chemical Substances Present in the Diet, 2000
24 pp. ISBN 1-57881-101-5

Detection Methods for Novel Foods Derived from Genetically Modified Organisms, 1999
24 pp. ISBN 1-57881-047-1

Overview of Health Issues Related to Alcohol Consumption, 1999
16 pp. ISBN 1-57887-068-X
(Translations available in Chinese, French, German, Portuguese and Spanish)

Safety Assessment of Viable Genetically Modified Micro-organisms Used in Food, 1999
20 pp. ISBN 1-57881-059-0 (Translation available in Japanese)

Significance of Excursions of Intake above the Acceptable Daily Intake (ADI), 1999
24 pp. ISBN 1-57881-053-1

Validation and Verification of HACCP, 1999
20 pp. ISBN 1-57881-060-4

Addition of Nutrients to Food: Nutritional and Safety Considerations, 1998
24 pp. ISBN 1-57881-036-1

Food Safety Management Tools, 1998
20 pp. ISBN 1-57881-034-5

Recycling of Plastics for Food Contact Use, 1998
20 pp. ISBN 1-57881-035-3

Applicability of the ADI to Infants and Children, 1997
20 pp. ISBN 1-57881-018-3

Antioxidants: Scientific Basis, Regulatory Aspects and Industry Perspectives, 1997
28 pp. ISBN 1-57881-016-7

An Evaluation of the Budget Method for Screening Food Additive Intake, 1997
12 pp. ISBN 1-57881-019-1

Food Consumption and Packaging Usage Factors, 1997
12 pp. ISBN 1-57881-017-5

Food Additive Intake – Scientific Assessment of the Regulatory Requirements in Europe, 1995
13 pp. ISBN 1-57881-032-9

The Safety Assessment of Novel Foods, 1995, *reprinted 2001*
16 pp. ISBN 1-57881-033-7

ß-Carotene, Vitamin E, Vitamin C and Quercetin in the Prevention of Generative Diseases – The role of foods, 1995

Report Series Editor: Dr. Kevin Yates

ILSI

International Life Sciences INSTITUTE

The International Life Sciences Institute (ILSI) is a nonprofit, worldwide foundation established in 1978 to advance the understanding of scientific issues relating to nutrition, food safety, toxicology, and the environment. By bringing together scientists from academia, government, industry and the public sector, ILSI seeks a balanced approach to solving problems of common concern for the well-being of the general public.

The branches are supported primarily by their industry members. A list of industry members worldwide can be found on the website (http://www.ilsi.org/about/). ILSI Europe was established in 1986 to identify and evaluate scientific issues related to these topics through symposia, workshops, expert groups, and resulting publications. Further information about ILSI Europe can be found in this brochure and on the website: http://europe.ilsi.org

ILSI Europe
Avenue E. Mounier, 83, Box 6
B-1200 Brussels
BELGIUM
Telephone: (+32) 2 771 0014
Telefax: (+32) 2 762 0044
E-mail: publications@ilsieurope.be

ISBN 1-57881-127-9

9 781578 811274