22 Legislative and Safety Aspects of Food Packaging

22.1 INTRODUCTION

22.1.1 Package Selection Criteria

A number of criteria must be considered when selecting a packaging system for a food. These include the following:

1. The stability of the food with respect to the deteriorative chemical, biochemical and microbiological reactions that can occur. The rates of these reactions depend on both intrinsic (compositional) and extrinsic (environmental) factors.
2. The environmental conditions to which the food will be exposed during distribution and storage. The ambient temperature and humidity are the two most important environmental factors and they dictate the barrier properties required of the package.
3. The compatibility of the package with the method of preservation selected. For example, if the food is being thermally processed after packing, then the packaging must obviously be able to withstand the thermal process. Likewise, if the food is to be stored at freezer temperatures after packing, then the packaging must be able to perform at these temperatures.
4. The nature and composition of the specific packaging material and its potential effect on the intrinsic quality and safety of the packaged food as a consequence of the migration of components from the packaging material into the food.

The latter consideration—namely, the migration of potentially toxic moieties from the packaging material to the food—is of major concern in the selection and use of plastic packaging materials for food packaging. However, the migration of components from the packaging to the food occurs with other packaging materials as well and these will also be discussed in this chapter.

22.1.2 Migration

In food packaging terminology, *migration* is generally used to describe the transfer of substances from the package to the food. Substances that are transferred to the food as a result of contact or interaction between the food and the packaging material are often referred to as *migrants*. However, it is important to note that migration is a two-way process because constituents of the food can also migrate into the packaging material. An example is the "scalping" of flavor compounds from fruit juices by plastics and this was discussed in Chapter 21. In addition, compounds present in the environment that surrounds the packaged food can be sorbed by the packaging and migrate into the food. For example, perfumes from soaps can be picked up by fatty foods under certain circumstances, which depend, among other factors, on the nature of the packaging materials used for the soap and the food, as well as on the proximity of the two products and the time of exposure.

It is important to distinguish between *overall migration* (OM; originally referred to as *global migration*) and *specific migration* (SM). OM is the sum of all (usually unknown) mobile packaging components released per unit area of packaging material under defined test conditions, whereas SM relates to an individual and identifiable compound only. OM is, therefore, a measure of all

compounds transferred into the food whether they are of toxicological interest or not, and will include substances that are physiologically harmless. Mass transport by diffusion is one of the most important processes that occur during the shelf life of packaged foods, and legislation to limit the quantity of migrants in foods is discussed later in this chapter.

The migration of molecules from the packaging material into the food is a complex phenomenon, and most mathematical treatments of transport processes are derived initially from a consideration of gaseous diffusion as discussed in Chapter 4. It is worth recalling that diffusion in liquids is approximately one million times slower than in gases, and diffusion in solids about one million times slower than in liquids. In most cases, migration from a polymer package into a food can be described by Fick's second law, which was derived in Chapter 4:

$$\frac{\delta c}{\delta t} = D\frac{\delta^2 c}{\delta x^2} \tag{4.7}$$

This simplified form of Fick's second law of diffusion applies under circumstances where diffusion is limited to the x-direction and D is independent of concentration that is usually true in polymers above their T_g. A solution of Equation 4.7 describing the flux J of substance m_t migrating into the food in time t across a surface of area A is

$$J = \frac{m_t}{A} = 2c_{P_o}\left[\frac{\beta}{1+\beta}\right]\left[\frac{D_p t}{\pi}\right]^{1/2} \tag{22.1}$$

where

$$\beta = \frac{1}{K}\left[\frac{D_F}{D_p}\right] \tag{22.2}$$

and c_{Po} is the initial concentration of a migrant in the polymer. Equation 22.2 shows that the magnitudes of the diffusion coefficients (D_F and D_P) in both the food and the polymer phases, respectively, are important. The partition coefficient K gives the ratio of the concentration of the migrant in the polymer to that in the food at time t. In most cases, D_F is orders of magnitude greater than D_P so that $\beta >> 1$ (i.e., the concentration gradient of the migrant in the food is negligible), and migration is controlled by the slower diffusion of the migrant in the polymer phase. If, on the other hand, $\beta << 1$ (i.e., because of the poor solubility of the migrant in the food), migration will be dominated by migration in the food as indicated in the following equation:

$$\frac{m_t}{A} = \frac{2c_{Po}}{K}\left[\frac{D_p t}{\pi}\right]^{1/2} \tag{22.3}$$

Equation 22.1 shows that m_t is proportional to the square root of time. This is a common result in the initial stages when up to 60% of the migrant is lost from a polymer to a food. Mathematical solutions of Fick's second law for cases involving different volumes, types of food phases, fixed or agitated systems, or with boundary layers can be found in Crank (1975). Detailed aspects of migration have been discussed by other authors (e.g., Piringer, 2007; Mercea and Piringer, 2008; De Meulenaer, 2009) and should be consulted for further details.

There is a general consensus about the usefulness of mathematical modeling of migration to limit laboratory tests that are tedious and costly, and there is now the possibility to use mathematical modeling in order to prove compliance with legislation in both the EU and the United States.

Poças et al. (2012) analyzed mathematical models to describe migration from packaging into food using two approaches: Fick's second law and a kinetic model based on the Weibull distribution function. Results indicated that the Weibull model can be used to describe the migration from packaging to foods with the advantage of significant simplicity of calculation compared to Fick's second law. The model can also be applied to packaging systems with mass transfer processes more complex than those described by simple diffusional phenomena. In addition, this simple model can potentially be used in probabilistic approaches for exposure assessments of consumers to migrants originating from packaging materials.

22.2 REGULATORY CONSIDERATIONS

22.2.1 General Requirements

Concern about the wholesomeness and safety of foods has increased dramatically over the last century, particularly in those countries where food security is not a problem. An increasing understanding of, and interest in, technological matters on the part of consumers and organized consumer groups, coupled with a recognition that neither government nor industry can guarantee the safety of food, has lent support to this concern.

Safety is an emotive issue, and because everyone must consume food to live, the safety of food is especially emotive. Most concern usually focuses on food additives, both those added intentionally to the food and those ending up in the food from, for example, the packaging material or processing equipment. A detailed discussion of food safety is outside the scope of this book but the basic concepts will be presented to put the discussion that follows into perspective.

It is worth repeating the oft-quoted saying of the sixteenth-century Swiss alchemist and physician (and the patron saint of toxicology) Paracelsus (also known as Auroleus Phillipus Theophrastus Bombastus von Hohenheim) that "all substances are poisons; there is none that is not a poison; the dose differentiates a poison and a remedy." The last phrase is particularly important; only the dose makes the difference. Attempts to determine what a "safe" dose is lie at the heart of the problem faced by legislators and regulatory authorities.

Because food safety is a subject of intense study by a large group of highly sophisticated scientists, many consumers think that food safety determination can be solely a scientific process. That this is not so has been pointed out by several authors including one (Zeckhauser, 1979) who stated that

1. There is no known way to demonstrate absence of risk
2. Controlled experiments, the most reliable means for assessing risk levels, cannot ethically be applied to humans
3. Retrospective studies are unreliable
4. Reliance must, therefore, be placed principally on animal studies
5. Unfortunately, the mechanisms for extrapolating from risks to animals at high concentrations to risks to humans at low concentrations are unreliable

It follows from the preceding paragraph that absence of evidence of harm is not evidence of absence of harm. It is important to note that it is not the toxicity of the chemical at the concentrations at which it is present in the packaging material that is at issue here, but rather the toxicity of the chemical at the concentration at which it is present in the food after migrating from the packaging material.

The various terms used in toxicology need to be defined. The *toxicity* of a substance is its inherent capacity to produce injury when tested by itself. Almost any chemical substance can be shown to be toxic if tested at some sufficiently high level of consumption in experimental animals. Thus, a chemical may be toxic (i.e., inherently capable of producing injury when tested by itself) without being a *hazard* (i.e., likely to produce injury under the conditions of exposure as in a diet).

The concern, therefore, is not directly with the intrinsic toxicity of a particular chemical component of a food, but rather with the potential hazard of that material when the foods in which it is present are consumed.

Underlying the idea of food safety is the risk/benefit concept. *Benefit* can be defined as something that contributes to an improvement in condition or promotes well-being, while *risk* is the possibility of an adverse event occurring such as loss, injury, disadvantage or destruction and can be subdivided into two categories: vital and nonvital. A *vital risk* is one necessary or essential to life, while a *nonvital risk* does not usually involve a threat to life but may lead to injury, loss or damage. Although the difference between vital and nonvital risks is not always clear-cut, the categories of risks are different. The terms risk and benefit are not opposites, because risk always and explicitly includes the element of chance; benefit does not (IFT Expert Report, 2009).

Risks can also be subdivided into voluntary and involuntary risks. An example of a *voluntary risk* is cigarette smoking, where the risk of lung cancer is likely but no one is compelled to smoke (passive smoking is an *involuntary risk*). Another example of an involuntary risk would be a food additive in a staple item of the diet, if the additive had been shown from animal tests to be carcinogenic. In this situation, consumers would have difficulty avoiding the risk since the food was a staple item. An investigation of consumer attitudes toward technological risk concluded that the public's willingness to accept voluntary risks is approximately a thousand times greater than that for involuntary risks, and the risk of death from disease appears to be a psychological yardstick for establishing the acceptability of other risks. The consumption of a chemical that had migrated from a packaging material into a food would be classified as an involuntary risk, even if the chemical had regulatory approval.

The toxicity assessment of food additives usually follows a decision-tree approach. Acute, subchronic and chronic toxicity tests are normally required. The final phase of toxicologic evaluation involves an assessment of the potential risk to humans, and, in particular, the extrapolation of high-dose experiments with animals to low-dose risk assessments of humans. The maximum dose at which there are no observed effects is called the no observed effect level (NOEL). Sometimes the term no observed adverse effect level (NOAEL) is used instead of NOEL to distinguish between an observed effect that is adverse and an effect that is not.

Acceptable daily intake (ADI) is generally used for substances intentionally added to food. Tolerable daily intake (TDI) is generally used for substances appearing in food but not deliberately or intentionally added, for example, chemicals migrating from packaging material into the food. The ADI or TDI is defined as the amount of a chemical, expressed on a body weight basis (using standard body mass of 60 kg) that can be ingested daily over a lifetime without appreciable risk to health. A TDI for a chemical is generally calculated by dividing the lowest NOAEL revealed by toxicity tests by a factor, usually 100, known as a safety factor or uncertainty factor (UF). The incorporation of a safety factor or UF gives an additional margin of reassurance to take account of the possibility that humans may be more sensitive than animals, and that among humans, some may be more sensitive than others. Thus, a TDI errs on the safe side, producing a conservative estimate of the intake of a food chemical likely to be without risk for humans.

Various mathematical models have been proposed for the relationship between dose and response, and much debate has resulted, particularly over the appropriateness or otherwise of a linear extrapolation. In connection with carcinogens, debate has centered over whether or not it is possible to have a "no-effect" or threshold level of a carcinogen in a food. Different approaches to evaluating the nature of the low end of the dose–response curve and the possible existence of thresholds for toxic agents has been discussed by Boobis et al. (2009).

Returning to the risk/benefit concept, the evaluation of the benefit arising from the presence of a particular chemical in a food is also fraught with difficulties and is ultimately a subjective decision. Manufacturers package foods in a variety of packaging materials to achieve certain benefits such as extending the shelf life of the food, or making its storage and preparation for consumption more convenient, or reducing the cost of the food compared to its cost if another type of packaging

material were used. The fact that a component of the packaging material may migrate into the food and pose a risk to the consumer requires that the benefits arising from the use of the particular packaging material be balanced against the risk arising from consumption of the component. Attempting to quantify the risks and benefits and then arrive at a decision that a certain packaging material should be permitted for use because the benefits outweigh the risks is extraordinarily complex, and because it is ultimately subjective, there will always be some consumers (and manufacturers) who will disagree with the final decision.

The ways in which decisions are made about the migration of components from packaging materials into foods differ to varying degrees in various countries around the world and are detailed in a recent book (Rijk and Veraart, 2010). Rather than describe the situation in each country, the legislation adopted by the United States and the EU will be discussed because, between them, they account for a large proportion of packaging materials used with foods, and many other countries have modeled their own legislation on one or the other of these approaches (Heckman, 2005).

It is worth noting that there have not been any documented cases of deaths arising from the consumption of food containing food contact substances that have migrated from packaging. This is in contrast to the many deaths each year resulting from microbial contamination of food.

22.2.2 United States of America

The 1906 Food and Drugs Act was the first time that the U.S. Government exercised the principle that it has a duty to protect public health by controlling the adulteration of food. Although adulterated food became less common, the provisions of the legislation were clearly inadequate to insure that public health was protected.

In 1938, the federal Food, Drug and Cosmetic Act (FDCA) was introduced. Among other provisions, it prohibited foods dangerous to health; prohibited unsanitary packages; established the Food and Drug Administration (FDA); established fines for unauthorized practices; and gave the FDA the authority to close plants and to issue injunctions. However, it did not control food additives, except where such additives were already known to be poisonous substances. While this legislation provided an improvement over the previous legislation, the laws regarding toxic additives were handled in an ad hoc fashion and only those additives with a long toxic history were acted upon.

In 1958, congress passed the Food Additives Amendment to the 1938 Act. This amendment required the manufacturer to establish the safety of any product about to be marketed and the government had the responsibility to check the evidence of safety supplied. The shift in the burden of proof of safety from government to industry meant that manufacturers were required to demonstrate the safety of additives before they would be allowed to be used. The FDA generally defines "safe" as requiring "a reasonable certainty in the minds of competent scientists that the substance is not harmful under the intended conditions of use" (§ 170.3(i)). It is not altogether clear what a "reasonable certainty" is, which experts are qualified or even expert, and how the intended conditions of use are to be defined (Heckman, 1992).

§ 348(c)(3)(A) of the amendment (often referred to generally as the "Delaney clause" after New York congressman James J. Delaney who was Chairman of the House Rules Committee) states in part:

> ….no additive shall be deemed to be safe if it is found to induce cancer when ingested by man or animal, or if it is found, after tests which are appropriate for the evaluation of the safety of food additives, to induce cancer in man or animal.…

At the same time, congress provided for the approval of commonly used food ingredients by defining Generally Recognized As Safe (GRAS) substances as well as prior-sanctioned food

ingredients (i.e., those approved before September 6, 1958). The latter category contains certain substances employed in the manufacture of food packaging materials (§ 181.22). Such substances are excluded from the definition of a food additive, provided that they are of good commercial grade, are suitable for association with food, and are used in accordance with good manufacturing practice.

U.S. legal requirements are published in the Code of Federal Regulations (CFR). The Code is divided into 50 titles or broad areas subject to federal control and includes nearly 1900 sections and 1200 pages. Title 21 is made up of seven volumes and contains general regulations for enforcement of the Food, Drug and Cosmetic Act and the Fair Packaging and Labeling Act. However, these CFR provisions do not even begin to tell the whole picture, since thousands of substances are addressed through nonrule actions by FDA or are not reviewed by the FDA at all (Neltner et al., 2011).

The most important provisions relating to packaging materials can be found in Volume II, Parts 100–199, including lists of specific antioxidants, plasticizers, release agents, stabilizers, and so on, as well as copolymers and resins. Material composition is controlled by specifying the amount of additive that can be used, as well as the types of polymer to which it can be added. Other regulations contain specifications for the residual monomer content and minimum molecular mass, and many of them limit OM from the polymer or the final food contact article. The regulations contain time–temperature–solvent conditions for short-term migration simulations. Selection of extractability conditions depends on the type of food and the conditions of use and, in particular, the thermal treatment applied to the package after filling with food.

Subpart E § 110–80(h) states the following:

> Packaging processes and materials shall not transmit contaminants or objectionable substances to the products, shall conform to any applicable food additive regulation (Parts 170 to 189) and should provide adequate protection from contamination.

The definition of a *food additive* can be found in § 201(s):

> Any substance the intended use of which results or may reasonably be expected to result, directly or indirectly, in its becoming a component or otherwise affecting the characteristics of any food (including any substance intended for use in … packing, … packaging, … or holding food …).

A *food contact substance* (FCS) is specified in § 348(h)(6) as

> Any substance that is intended for use as a component of materials used in manufacturing, packing, packaging, transporting, or holding food if such use of the substance is not intended to have any technical effect in the food.

The FDA identifies any FCS that is reasonably expected to migrate to food under conditions of intended use to be a food additive in § 170.3, which includes the following statements:

> A material used in the production of containers and packages is subject to the definition [of a food additive] if it may reasonably be expected to become a component, or to affect the characteristics, directly or indirectly, of food packed in the container.

> If there is no migration of a packaging component from the package to the food, it does not become a component of the food and thus is not a food additive.

In addition to the inherent toxicity of the packaging material components, it is the extent of migration that comprises the parameters of risk assessment of packaging materials (Munro et al., 2002). While the FDA has not provided definitive criteria for determining at what point a substance may

reasonably be expected to become a component of food, guidance has been provided by a 1979 U.S. Court of Appeals opinion in *Monsanto v. Kennedy* (Monsanto, 1979), which was concerned with migration of acrylonitrile monomer into food. In this case, the court essentially said that the FDA was required to determine with a fair degree of confidence that a substance migrates to food in more than insignificant amounts for the substance to be classified as a food additive. This case has been cited as authority for the FDA's adoption of what has come to be called the de minimis policy (Middlekauf, 1985). The words de minimis refer to the legal maxim de minimis non curat lex, which is commonly interpreted as meaning that the law does not care for, or take notice of, very small or trifling matters. Under this policy, the FDA has permitted substances that contain low levels of carcinogenic impurities to remain on the market when the amounts expected to become a component of food have been found to be of no toxicological significance or de minimis (Heckman, 1992).

Since migration is the principal mechanism by which components of packaging materials enter food, the focus of the premarket safety evaluation by FDA is a prediction of the amount and nature of the migrants from the packaging material under the proposed conditions of use. These predicted levels of migration are then translated into an ADI derived by dividing the NOEL by an applicable safety factor, generally 1000 for 90-day studies and 100 for chronic data.

Unlike food additives, human exposure to components of packaging materials that have migrated into foods (FCSs) is typically very small. Because complete toxicological data sets are not always available for such migrants, the FDA developed a process in the 1990s to make the evaluation of packaging materials more efficient, instead of relying on the extensive review normally required for food additives. This process is used to determine "when the likelihood or extent of migration to food of a substance used in a food contact article is so trivial as not to require regulation of the substance as a food additive." This trivial level, also known as the *threshold of regulation* (TOR), was based on a large database of carcinogenic potencies. The basic concept is that, because the toxic hazard arising from a substance varies with dose, then for every substance, there must be a level below which the hazard is so low that there is no need for it to be controlled by specific legislation.

The TOR applies when the overall dietary concentration of a packaging material migrant is <0.5 ppb, which equates to an intake of 1.5 μg day^{-1} if it is assumed that the total daily intake of food and drink is 3 kg per person. Substances that are below the threshold value are considered by the FDA to be exempted from regulation as food additives (Munro et al., 2002). The exemption is applicable provided the substance does not contain any carcinogenic constituents or impurities with a TD_{50} (the dose that causes cancer in 50% of the test subjects) of less than 6.25 mg kg^{-1} body weight day^{-1}. Complete details concerning the criteria to be followed in seeking TOR exemption can be found in § 170.39 and in the Federal Register.

FDA's Center for Food Safety and Applied Nutrition (CFSAN) has accepted the concept of "functional barrier" as a subset of the "no migration" exclusion in the definition of food additive (§ 170.3(e)). An exception to the requirement for assessing the migration of materials used in food packaging is made when there is a determination that the material is not reasonably expected to migrate to the food above the TOR, or at least not above a safe limit based on the toxicity of the material in question. If the food contact materials are determined to form a layer that prevents the migration of materials from the outer layers, then a functional barrier is presumed to exist and materials outside the functional barrier are presumed to be unable to migrate into the food. Safety of the materials in the outer layers then requires less scrutiny.

No formal definition for functional barrier exists in the FDCA or in FDA regulations. The concept, however, is addressed in CFSAN guidances regarding recycled plastics and premarket submission for FCSs. An example of a functional barrier is metal foil or a polymeric material of sufficient thickness and impermeability. An example of an exterior layer material is printing ink or adhesive.

As a result of the FDA Modernization Act of 1997 (specifically § 309), the FDA implemented from January 2000 the *Food Contact Notification* (FCN) system as the primary means to regulate FCSs. The FCN system is applicable to all FCSs and represents a radically new approach to their regulation. Under the FCN system, manufacturers can file an FCN instead of a *Food Additive Petition* (FAP) with the FDA, and unless formal substantive objections are made by the FDA, the FCS may be marketed 120 days after filing of the FCN. This compares with an average time of 2–4 years for the FDA to publish a formal food additive regulation when an FAP is filed.

The requirements for an FCN are substantially similar to those for an FAP and will not be detailed here. Note that substances evaluated by the FDA under the FCN process are only allowed to be used in special applications and concentrations that are mentioned in their authorization processes (FCN). To use these substances in other applications, a new FCN has to be submitted to the FDA. In contrast, petition approval results in a "generic" listing in the CFR allowing widespread use. Also, a TOR exemption is effective for any manufacturer/supplier of the FCS. Under all three processes, the submitter bears the burden of demonstrating that the intended use of the FCS is safe.

Within CFSAN, the Office of Food Additive Safety (OFAS) is responsible for premarket evaluation of food and color additives submitted in petitions and notifications, and for the evaluation of GRAS notifications. If the FCS is a polymer, OFAS recommends toxicity testing on the low-molecular weight oligomers (LMWOs; typically 61,000 Da with exceptions for fluorinated compounds) but not on the polymer itself, as the oligomers are expected to be the primary migrants to food from the use of the FCS (Nelson et al., 2011).

The calculation methods used by the FDA to estimate probable exposure will not be described here except for two aspects. One is the "consumption factor" (CF), which describes the fraction of the daily diet expected to contact specific packaging materials. The CF represents the ratio of the weight of all food contacting a specific packaging material to the weight of all food packaged. CF values for packaging categories (e.g., metal, glass, polymer and paper) and specific food contact polymers are summarized in Table 22.1. These values were derived by the FDA using information on the types of food consumed, the types of food contacting each packaging surface, the number of food-packaging units in each food-packaging category, the distribution of container sizes and the ratio of the weight of food packaged to the weight of the package.

They were initially developed from market survey data collected around 1980 and have been periodically revised as newer market data became available.

When the FDA computes exposure to an FCS, it assumes that the FCS will capture the entire market for which it is intended for use. This approach reflects both uncertainties about likely market penetration as well as limitations in the data surveyed. Thus, if a company proposes the use of an antioxidant in PS, then it is assumed that the antioxidant will be used in all PS manufactured for food contact. In certain cases where an adjuvant is intended for use in only a part of a packaging or resin category, a lower CF representing the coverage that is sought may be used. For example, if a stabilizer is intended for use only in rigid and semirigid PVC, then a CF of 0.05 rather than 0.1 could be used in estimating exposure since only about 50% of all food contact PVC could contain the stabilizer.

When new products are introduced, they are initially treated as replacement items for existing technology. FDA generally makes estimates based on the assumption that the new product will capture the entire market. For example, the retortable pouch was initially treated as a replacement for metal cans and was assigned a CF of 0.17. As additional information on actual use of the retortable pouch became available, the CF was lowered to 0.05. In certain cases, the submission of resin or packaging market data may lead to the use of a lower CF.

Before migration levels can be combined with CF values to derive estimates of probable consumption, the nature of the food that will likely contact the food contact article containing the FCS must be known. To account for the variable nature of the food contacting each food contact article, the FDA has calculated "food-type distribution factors" (f_T) for each packaging material to reflect the fraction of all food contacting each material that is aqueous, acidic,

TABLE 22.1
Fraction of Daily Diet in the United States Expected to Contact Specific Packaging Materials, that is, CFs

Package Category	CF	Package Category	CF
A. General			
Glass	0.1	Adhesives	0.14
Metal–polymer coated	0.17	Retort pouch	0.0004
Metal uncoated	0.03	Microwave susceptor	0.001
Paper uncoated and clay coated	0.1	Polymer	0.4
		All polymers[a]	0.8
B. Polymer			
Polyolefins	0.35	PVC	0.1
LDPE	0.12	Rigid/semirigid	0.05
LLDPE	0.06	Plasticized	0.05
HDPE	0.13	PET[b]	0.16
PP	0.04	Other polyesters	0.05
Polystyrene	0.14	RCF	0.01
EVA	0.02	PA	0.02
Acrylics, phenolics, etc.	0.15	All others[c]	0.05

Source: From Guidance for Industry: Preparation of Premarket Submissions for Food Contact Substances: Chemistry Recom-mendations. 2007. U.S. Food and Drug Administration. Available at www.fda.gov/Food/GuidanceComplianceRegulatory Information/GuidanceDocuments/FoodIngredientsandPackaging/ucm081818.htm

[a] Originates from adding CFs for metal–polymer coated, paper–polymer coated and polymer (0.17 + 0.2 + 0.4 = 0.8).

[b] A CF of 0.05 is used for recycled PET applications.

[c] A minimum CF of 0.05 is used initially for all exposure estimates.

alcoholic and fatty. Appropriate f_T values for both packaging categories and polymer types are shown in Table 22.2.

For calculating the concentration of the FCS in the daily diet, the concentration of the FCS in the food contacting the food contact article, <M>, is derived by multiplying the appropriate f_T values by the migration values, M_i, for simulants representing the four food types. This effectively scales the migration value from each simulant according to the actual fraction of food of each type that will contact the food contact article. The estimated daily intake (EDI) is then determined by multiplying the dietary concentration by the total weight of food consumed by an individual per day. The FDA assumes that an individual consumes 3 kg of food (solid and liquid) per day:

$$\text{EDI} = 3\,\text{kg food person}^{-1}\text{day}^{-1} \times < \text{M} > \times \text{CF}$$

So a concentration in the daily diet of 1 ppm (1 mg kg^{-1}) corresponds to an EDI of 1 mg FCS kg^{-1} food × 3 kg food person^{-1} day^{-1} = 3 mg FCS person^{-1} day^{-1}. The cumulative estimated daily intake (CEDI) is estimated by considering all sources of exposure, and represents a conservative estimate of the dietary intake of the FCS because it is based on the assumption that the FCS will always migrate at the maximum level found in extraction studies, and that all food contact materials of

TABLE 22.2
Food-Type Distribution Factors (f_T) in the United States for Each Packaging Material to Reflect the Fraction of All Food Contacting Each Material That Is Aqueous, Acidic, Alcoholic and Fatty

	Food-Type Distribution Factors (f_T)			
Package Category	**Aqueous[a]**	**Acidic[a]**	**Alcoholic**	**Fatty**
A. General				
Glass	0.08	0.36	0.47	0.09
Metal–polymer coated	0.16	0.35	0.40	0.09
Metal uncoated	0.54	0.25	0.01[b]	0.20
Paper–polymer coated	0.55	0.04	0.01[b]	0.40
Paper uncoated and clay coated	0.57	0.01[b]	0.01[b]	0.41
Polymer	0.4	0.16	0.01[b]	0.34
B. Polymer				
Polyolefins	0.67	0.01[b]	0.01[b]	0.31
Polystyrene	0.67	0.01[b]	0.01[b]	0.31
Impact	0.85	0.01[b]	0.04	0.10
Nonimpact	0.51	0.01	0.01	0.47
Acrylics, phenolics, etc.	0.17	0.40	0.31	0.12
PVC	0.01[b]	0.23	0.27	0.49
Polyacrylonitrile, ionomers, PVdC	0.01[b]	0.01[b]	0.01[b]	0.97
Polycarbonates	0.97	0.01[b]	0.01[b]	0.01[b]
Polyesters	0.01[b]	0.97	0.01[b]	0.01[b]
Polyamides (nylons)	0.10	0.10	0.05	0.75
EVA	0.30	0.28	0.28	0.14
Wax	0.47	0.01[b]	0.01[b]	0.51
RCF	0.05	0.01[b]	0.01[b]	0.93

Source: From Guidance for Industry: Preparation of Premarket Submissions for Food Contact Substances: Chemistry Recom-mendations. 2007. U.S. Food and Drug Administration. Available at www.fda.gov/Food/GuidanceComplianceRegulatory Information/GuidanceDocuments/FoodIngredientsandPackaging/ucm081818.htm

[a] For 10% ethanol as the food simulant for aqueous and acidic foods, the food-type distribution factors should summed.

[b] 1% or less.

a given type will be made using the FCS (Baughan and Attwood, 2010). The simulants for use in migration studies with various types of foods are listed in Table 22.3.

The default FDA contact ratio is 10 g food in.$^{-2}$ FCM, which is equivalent to 10 g food 6.45 cm^{-2} (0.0645 dm^2) FCM or 1 kg food 6.45 dm^{-2} FCM. If 10 g of food are in contact with 1 in.^{2} of FCM, a migration of 0.01 mg in.$^{-2}$ corresponds to a concentration in the food of 1 mg kg^{-1} (1 ppm). For specialized food contact applications where an assumed ratio of 10 g food in^{-2} is not appropriate, such as in dual-ovenable trays and microwave susceptor applications, the lowest ratio from the actual food contact applications is used, provided that justification can be given for the ratio selected.

TABLE 22.3
Classification of Food Types and Recommended Food Simulants for Food Contact Articles in the United States

Type	Description	Classification
I	Nonacid, aqueous products; may contain salt, sugar or both (pH >5)	Aqueous
II	Acid, aqueous products; may contain salt, sugar or both, and including oil-in-water emulsions of low- or high-fat content	Acidic
III	Aqueous, acid or nonacid products containing free oil or fat; may contain salt, and including water-in-oil emulsions of low- or high-fat content	Fatty
IV	Dairy products and modifications	
	A. Water-in-oil emulsions, high- or low-fat	Fatty
	B. Oil-in-water emulsions, high- or low-fat	Aqueous
V	Low moisture fats and oils	Fatty
VI	Beverages	
	A. Containing up to 8% alcohol	Low alcohol
	B. Nonalcoholic	Aqueous
	C. Containing more than 8% alcohol	High alcohol
VII	Bakery products (other than those under types VIII or IX)	
	A. Moist bakery products with surface containing free fat or oil	Fatty
	B. Moist bakery products with surface containing no free fat or oil	Aqueous
VIII	Dry solids with the surface containing no free fat or oil	Dry
IX	Dry solids with the surface containing free fat or oil	Fatty

Food Types I, II, IVB, VIB and VIIB: 10% ethanol, for aqueous and acidic foods;
Food Types VIA, VIC: 10% or 50% ethanol (actual ethanol concentration may be substituted), for low- and high-alcoholic foods;
Food Types III, IVA, V, VIIA, IX: Food oil (e.g., corn oil), HB307, Miglyol 812, or others (HB307 is a mixture of synthetic triglycerides; Miglyol 812 is derived from coconut oil), for fatty foods.

More refined exposure estimates may be possible with additional information provided in an FCN or FAP. For instance, subdividing packaging or resin categories could reduce the calculated exposure by lowering the CF for the category. The division of PVC into rigid and plasticized categories is one example; another is the division of polymer coatings for paper into subcategories such as PVA coatings, styrene–butadiene coatings, and so on. If an FCS is to be used solely in styrene–butadiene coatings for paper, use of the CF for polymer-coated paper (0.2) would be a gross exaggeration.

Migration levels in food are typically estimated based on the results of migration testing under the anticipated conditions of use or, in certain cases, under the assumption of 100% migration of the FCS to food. A third alternative accepted by the FDA involves migration modeling. If this approach is taken, then the source of any material constants used in migration modeling should be appropriately referenced, whether the source is the FDA migration database or the open literature. Semiempirical methods have been developed to determine migration levels with limited or, in certain cases, no migration data. These diffusion models rely on estimation of diffusion coefficients based on the nature of the migrant and the physical properties of the polymer. The FDA considers that such models may be useful substitutes for, or additions to, experimental data under limited circumstances but has several caveats that should be considered in the application of such diffusion models.

The FDA Food Safety Modernization Act (FSMA), is the most sweeping reform of food safety laws in more than 70 years, and was signed into law in January 2011. It aims to ensure that the U.S. food supply is safe by shifting the focus from responding to contamination to preventing it. However, no changes have been made to the FDCA or FDA regulations related to FCSs.

22.2.3 European Union

22.2.3.1 Background

The Treaty of Rome was signed in 1956 and the European Economic Community (renamed the European Community [EC] in 1993) was born. After the entry into force of the Treaty of Lisbon in 2009, the EC was transferred to the newly consolidated European Union (EU). One of the original objectives in 1956 was to set up a common market so that goods could be moved as freely within the Community as within national borders. The European Commission (hereinafter referred to as the Commission) is the executive body of the EU and is responsible for proposing legislation, implementing decisions, upholding the Union's treaties and the general day-to-day running of the EU, while the Council of the European Communities (hereinafter referred to as the Council) is the decision-making body of the EU representing the executives of member states, the other legislative body being the European Parliament.

Because different regulations in member states in the EU could constitute a nontariff barrier to trade, it is valid under the Treaty of Rome and the Single European Act for directives to be promulgated that harmonize such legislation. Harmonization of food legislation is usually classified into *vertical directives* (concerned with a specific group of similar products, e.g., coffee extracts) and *horizontal directives* (concerned with subjects of general application to all foods, e.g., additives, materials intended to come into contact with foods, methods of control, and so on). To assist in the free movement of goods, the Commission has given priority to harmonization work in the horizontal sectors.

Directives do not immediately become Community law; rather, they are instructions to governments of member states to bring their own legislation into line within a certain period (typically, 12 months). There is a detailed process of consultation, study and preparation leading up to the promulgation of a directive, and although the resultant legislation is intended to represent a consensus, the views of the Commission carry considerable weight. In contrast, a regulation is automatically converted into the national law of all EU countries 20 days after publication.

The Scientific Committee for Food (SCF) was an advisory body set up by the Commission in 1974. It consisted of individuals nominated by member countries in the fields of toxicology, metabolism, mutagenicity and so on. The SCF constituted an ad hoc working committee in the area of packaging materials. The main task of the Scientific Committee was the preparation of scientific advice in the area of new and harmonized approaches for risk assessment of food and feed. It has now been superseded by the European Food Safety Authority (EFSA). The EFSA is the keystone of EU risk assessment regarding food and feed safety and works in close collaboration with national authorities to provide independent scientific advice and clear communication on existing and emerging risks; however, risk management decisions are made by the Commission.

22.2.3.2 Directives

The Commission initially drew up a framework directive in order to establish general principles for all materials and articles, and criteria and procedures to be followed in drafting specific directives; that is, directives concerning individual sectors to be regulated (e.g., plastics, ceramics, and so on) or individual substances (e.g., vinyl chloride). The framework Directive 76/893/EEC of 26 November 1976 (superseded by 89/109/EEC of 21 December 1988) established two general principles:

1. The principle of the "inertness" of the material and the "purity" of the food, whereby the materials and articles must not transfer to foods any of their constituents in quantities that could "endanger human health and bring about an unacceptable change in the composition of the foodstuffs or a deterioration in the organoleptic characteristics thereof." This regulation applied not only to packaging, but to all articles whose surface could come into contact with food at any stage of production, storage, transport or consumption. For practical reasons, covers and coatings, potable water distribution systems and antiques were excluded.

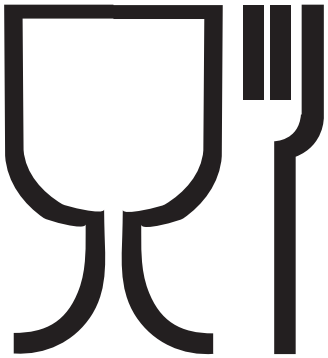

FIGURE 22.1 Symbol that may accompany materials and articles intended to come into contact with food in the EU.

2. The principle of "positive labeling" whereby materials and articles intended to come into contact with foods must be accompanied by the words "for food" or an appropriate symbol, described in Directive 80/590/EEC and shown in Figure 22.1. At the retail stage, Member States have the option not to insist on marking where articles are "by their nature clearly intended to come into contact with foodstuffs."

In 1989, the framework directive was replaced by Directive 89/109/EEC, which laid down the sectors in which the Commission is asked to establish Community rules and the criteria and procedures to be followed in the drafting of specific directives. Having defined the general framework, the Commission began to study three of the principal materials to be dealt with at Community level, these being regenerated cellulose film (RCF), ceramics and plastics. The most important of these is plastics and is discussed later.

In 1980, the Commission began to draw up rules for what is undoubtedly the most complex and economically important area of packaging, namely plastic materials and articles intended to come into contact with food. Directive 82/711/EEC (amended by Directive 2004/19/EC) laid down test methodology, in particular, simulants and test conditions for plastics, including laminates, where the plastic is in direct contact with the food. RCF, elastomers, rubbers, adhesives, paper and paperboard impregnated with plastic materials were all excluded. Directive 82/711/EEC listed conditions of time and temperature that simulate actual product use conditions. The migration of substances under these simulating conditions should not exceed the limits given in the positive list. Directive 85/572/EEC established the list of simulants to be used in migration tests and included a table of correlations between food groups and their food-simulating liquids.

The overall migration limit (OML) is a measure of the inertness of the material and prevents an unacceptable change in the composition of the food. Moreover, it reduces the need for a large number of specific migration limits (SMLs) or other restrictions, thus giving effective control.

The EU assumes an intake of 1 kg of food in contact with a particular packaging material per 60 kg person per day, which equates to 16.7 g kg^{-1} body weight. A food packaging surface area:volume ratio of 6 dm^2 kg^{-1} is assumed, equivalent to 0.1 dm^2 kg^{-1} of body weight. Directive 90/128/EEC set the OML at a level of 10 mg dm^{-2} of food contact surface area of material or article. The assumption is that 1 kg of food is exposed to 6 dm^2 surface area of packaging material, that is, it forms a 1 kg cube with a food contact surface area:volume ratio of 6 dm^2 L^{-1} or kg^{-1}, the same as a 1 dm (10 cm) cube as shown in Figure 22.2. If each face of the cube releases 10 mg into the food, then an OML of 10 mg dm^{-2} of contact area becomes 60 mg L^{-1} or kg^{-1}. Recall that the default FDA contact ratio is 10 g food $in.^{-2}$ FCM, which is equivalent to 10 g food 6.45 cm^{-2} (0.0645 dm^2) FCM, or 1 kg food 6.45 dm^{-2} FCM, which is close to the EU ratio of 1 kg food 6.0 dm^{-2} FCM except that the FDA assumes 3 kg rather than 1 kg food $person^{-1}$ day^{-1}. In reality, there are very few packages on the

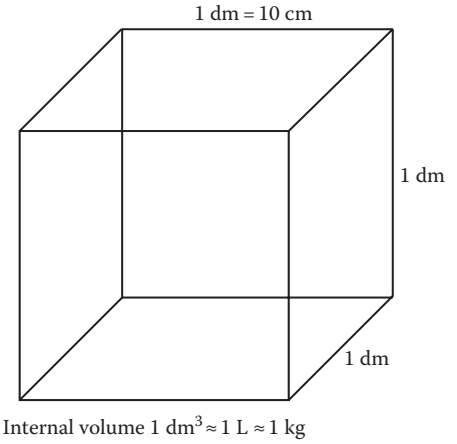

FIGURE 22.2 EU legislation assumes that for packages with a capacity of 0.5–10 L, 1 kg of food is exposed to 6 dm^2 surface area of packaging material, that is, it forms a 1 kg cube with a food contact surface area:volume ratio of 6 dm^2 L^{-1} or kg^{-1}, the same as a 1 dm (10 cm) cube.

market with these dimensions. In most foods, the contact surface area per unit weight of food is substantially larger. For example, in metal cans, the surface area to weight ranges from 8 to 17 dm^2 kg^{-1}. For metal closures, the ratio is 0.2–1.2 dm^2 kg^{-1}. Therefore, the tolerated migration in terms of concentration in the food is higher.

The OML of 60 mg kg^{-1} of food is for articles that are containers or are comparable to containers or that can be filled with a capacity of 0.5–10 L. For smaller containers, the limits apply as migration per surface area. For sheet, film or other materials that cannot be filled or for which it is impractical to estimate the surface area in contact with food, and for caps, gaskets, stoppers or similar devices for sealing, the limits always apply as migration per unit surface area in contact with the food, that is, as mg dm^{-2}. This means that for the majority of packs, the limits apply as amounts per contact surface area and, thus, the conversion factor of 6 dm^2 kg^{-1} is used, which is why this conversion factor is so important. It also means that SMLs are not really based on the consumption of 1 kg of food, but on the amount of food that is in contact with 6 dm^2, which is mostly far less than 1 kg in real life. Grob et al. (2007) suggested that the legal limits in terms of concentration in food should be converted to migration per contact surface area by a ratio that no longer focuses on the 1 L cube but on the current smaller packs. They proposed 20 dm^2 contact surface area L^{-1}, that is, the OML of 60 mg kg^{-1} should correspond to 3 mg dm^{-2}.

In contrast to the United States, no consumption or food-type distribution factors are used in the EU. Oldring (2008) quoted some "pseudo" food CFs that suggested that the food contact area for all packaging in the EU was 20.1 dm^2 $person^{-1}$ day^{-1} of which plastic accounted for 62% or 12.4 dm^2 $person^{-1}$ day^{-1}, which is significantly higher than the EU assumption of 6 dm^2 $person^{-1}$ day^{-1}. However, if the FDA assumption of 3 kg rather than 1 kg food $person^{-1}$ day^{-1} is used, there is much better agreement (18 dm^2 vs. 20.1 dm^2 $person^{-1}$ day^{-1}). Given the diversity of consumption within the EU (use of polyethylene in Benelux and Ireland is quoted as about 10 dm^2 $person^{-1}$ day^{-1} compared to just over 4 for Spain, Portugal and Greece), it would be difficult to derive any meaningful pan-European factors for exposure to migrants from FCMs.

Recently, Foster et al. (2010) suggested that children might be at increased risk to exposure from migrants as they have higher intakes of food per kg body weight compared with adults. In addition, much of the food marketed for/to children is in small portions and, therefore, the FCM surface area:volume ratio is relatively high. In a field study of 297 U.K. children aged 0–6 years, they found that these children, on average, consumed 1.6 times (ages 0–1), 2 times (ages 4–6) and 3 times (ages 1–4) as much food packaged in plastic as estimated by the current EU approach. The mean area of packaging in contact with the food consumed daily per kg body weight was 0.65 dm^2 kg^{-1} for the

infants under 1 year, 0.81 $dm^2\ kg^{-1}$ for the 1–4 year olds and 0.66 $dm^2\ kg^{-1}$ for the 4–6 year olds. All 297 children had intakes that exceeded 0.1 $dm^2\ kg^{-1}$ of body weight.

In addition, the directive contained two lists of substances (1340 in total of which 540 are monomers and 800 additives) used in the preparation of plastics for foods. The first, so-called Community list contains substances on which the SCF had delivered an opinion and which are, therefore, authorized and harmonized at Community level. The second, so-called optional national list contained substances on which the SCF had not yet been able to deliver a final opinion for lack of data and which, therefore, did not have Community recognition. Thus, the current list of additives was incomplete because it did not contain all the substances that were currently accepted in one or more member states. Accordingly, these substances continued to be regulated by national laws pending a decision on inclusion in the Community list. The European inventory list of chemicals used to make plastics intended for food contact contains more than 1500 listed substances, and inventory lists of a similar length exist for chemicals used to make paper, can enamels, inks and adhesives (Castle, 2001).

As migration experiments are time consuming, expensive and often complicated to carry out, the use of "generally recognized diffusion models" based on experimental data was approved in the sixth amendment of Directive 90/128/EEC (2001) for estimating the migration level of substances in certain types of plastics as an alternative test method.

The Framework Regulation (EC 1935/2004) is the basic Community legislation covering all FCMs and articles. It defines FCMs and articles and sets basic requirements for them:

1. Shall not endanger human health
2. Shall not change composition of the food in an unacceptable way
3. Shall not change taste, texture or odor of food
4. Shall be manufactured according to GMP

The authorization of substances is divided into a risk assessment performed by EFSA and a risk-management decision by the Commission. Until recently, this authorization procedure applied only to substances used in plastic FCMs or in RCF that were regulated by a specific measure. Since the promulgation of Regulation 10/2011 Plastics Implementing Measure in May 2011, plastics are now covered and the Plastics Directive 2002/72/EC has been repealed. Many of its specific provisions will be implemented over a 4-year period to allow industry additional time to comply with them, for example, use of additives others than plasticizers for plastic layers or plastic coatings in caps and closures. In addition to consolidating all of the EU's directives and regulations on plastic FCMs, this regulation introduced a number of significant changes including expansion of EU plastic legislation to include plastic layers in multimaterial articles (unless they are separated from the food by a functional barrier—see below) and changes in the simulants to be used for migration testing (see Table 22.4). As mentioned earlier, for very small and very large containers, the real surface area:volume ratio of packaged food varies a lot from the conventional assumption. Therefore, Regulation 10/2011 specifies that their surface area should be normalized before comparing testing results with migration limits.

TABLE 22.4
Simulants for Use With Plastic Food Contact Materials in the EU

Simulant A:	10% ethanol, mimicking aqueous foods pH >4.5
Simulant B:	3% acetic acid, mimicking acidic foods with pH <4.5
Simulant C:	20% ethanol, mimicking alcoholic foods
Simulant D1:	50% ethanol: for alcoholic foods with >20% alcohol and for oil in water emulsions including milk
Simulant D2:	Vegetable oil for foods that contain free fats at the surface
Simulant E:	Poly(2,6-diphenyl-*p*-phenylene oxide) also known as Tenax® for dry foods

A correction factor has been established to correct for overestimation in fatty foods: the fat reduction factor (FRF). The conventional assumption is that a 60 kg person consumes 1 kg of food daily. However, the consumption of fat is at most 200 g on a daily basis, and so for lipophilic substances that only migrate into fat, this should be taken into consideration.

No rules have yet been set out for the risk assessment of the use of colorants in plastics and, therefore, their use remains subject to national law. Although all plastics can be coated and printed, coatings, printing inks and adhesives are presently covered by national legislation but not yet by specific EU legislation; therefore, they not subject to the requirement of a declaration of compliance.

A functional barrier is defined as a barrier consisting of one or more layers of any type of material that ensures that the final material or article complies with Regulation 1935/2004 and 10/2011. Nonauthorized substances may be used behind a functional barrier, provided they fulfill certain criteria and their migration remains below a given detection limit (0.01 mg kg^{-1}). Substances that are mutagenic, carcinogenic or toxic to reproduction are not covered by the functional barrier concept. A functional barrier is not necessarily an absolute barrier but a function of the given food packaging application. In the specific case of PET bottles or sheets, an outer and inner layer of virgin PET acts as a functional barrier, while in the core layer some conventionally recycled PET is used. Another functional barrier technology is the application of a SiO_x coating on the inner surface of PET bottles (Welle and Franz, 2008). Cruz et al. (2006) showed the feasibility of employing a functional barrier made from amorphous carbon film deposited by the PECVD process on the inner surface of recycled PET bottles.

22.3 PLASTICS PACKAGING

22.3.1 Vinyl Chloride Monomer

PVC is used for food contact applications, not only for bottle and film applications but also for other uses including liners and sealing gaskets. Vinyl chloride (boiling point −13.9°C) is a colorless gas at ordinary temperatures and pressures but, in industry, it is usually handled as a liquid under pressure in steel cylinders. The acute toxic effects of vinyl chloride have been known since the 1930s when it was rejected as an anesthetic because it was found to be a cardiac irritant. An investigation in the United Kingdom in 1970/1971 into the tainting of spirits packaged in miniature PVC bottles for use in aircraft traced the cause to vinyl chloride monomer (VCM). However, the chronic effects were not made public until January 1974 when the B.F. Goodrich Co. voluntarily revealed to federal and state regulatory officials that, since 1971, three workers at its PVC polymerization plant in Louisville, Kentucky had died of angiosarcoma of the liver. This form of cancer is extremely rare, and workers who were in contact with PVC only and not VCM were apparently unaffected, suggesting that VCM was the culprit. By May 1974, a cause-and-effect relationship between VCM and human angiosarcoma was generally accepted, and confirmed cases of cancer in workers at PVC plants had risen to 19, 17 of whom were already dead.

In 1973, it was discovered that VCM in PVC packaging material could migrate into foods. Reported levels of VCM found in bottles, rigid film and some foods in the period 1974–1977 showed a marked reduction, and this change was also reflected in the levels found in foods such as fruit drink, cooking oil, butter and margarine. EU directive 78/142/EEC laid down the maximum permitted quantity of VCM in plastic materials and articles as 1 mg kg^{-1}, and stated that the quantity of VCM released to the food should not be detectable by a method of analysis with a detection limit of 0.01 mg kg^{-1} (10 ppb). Directives 80/766/EEC and 81/432/EEC established the methods of analysis for VCM in the finished article and in foods, respectively, and were repealed in Regulation 10/2011.

In the United States, the prior sanctions and the food additive regulations for PVC were all promulgated prior to the discovery that VCM caused liver tumors in humans, and, thus, there were no limitations on the residual VCM level in PVC. In response to the findings regarding the toxicology of VCM, the FDA published a series of proposals designed to control the potential exposure

to VCM from food contact materials. FDA did not propose to ban or otherwise limit use of PVC per se, however, because there was no evidence that PVC itself is a carcinogen.

In general, the FDA proposed to limit residual VCM levels to 10 ppb in rigid PVC food contact articles and 5 ppb in plasticized, flexible PVC. The FDA also proposed to issue new regulations that would have codified some of the prior sanctions for PVC polymers, as well as to establish a new regulation for rigid and semirigid PVC articles, and establish limits on the residual level of VCM permitted in these articles. This new regulation would have established a 10 ppb limit on the residual level of VCM in these articles. However, the FDA proposals were never finalized because of difficulties encountered in preparing an environmental impact statement for the proposed actions. PVC continues to be used in food contact applications in the United States subject to the limitations provided in the 1986 proposal. A practical result of the proposal was the removal of PVC liquor bottles from commercial use. Today, most rigid PVC applications have been replaced by PET, largely because of cost.

22.3.2 Styrene Monomer

Styrene monomer (boiling point 145°C) is metabolized to styrene oxide, which is a potent mutagen in a number of test systems; further metabolism produces hippuric acid. The most frequently observed changes from the toxic effects of styrene in humans are of a neurological and psychological nature: styrene acts as a depressant on the central nervous system, has a toxic effect on the liver and causes neurological impairment.

Vitrac and Leblanc (2007) estimated that median household exposure to styrene from yogurt pots in France ranged between 1 and 35 μg person^{-1} day^{-1} (5th and 95th percentiles) with a likely value of 12 μg person^{-1} day^{-1} (50th percentile). They found that exposure did not vary independently with the average consumption rate and contact times. Thus, falsely assuming a uniform contact time equal to the sell-by-date for all yogurts overestimated significantly the daily exposure (5th and 95th percentiles of 2 and 110 μg person^{-1} day^{-1}, respectively) because consumers with a high consumption showed quicker turnover of stock.

Between 1991 and 1999, the FDA's Total Diet Study analyzed 320 different foods and found styrene residues in 49 of them. In 258 samples containing styrene, the mean concentrations for individual food items varied between 10 μg kg^{-1} for eggs and 274 μg kg^{-1} for strawberries. The median concentration for the 49 foods was 21 μg kg^{-1}.

A TDI of 7.7 μg kg^{-1} body weight day^{-1} was set by the Joint FAO/WHO Expert Committee on Food Additives. A cigarette contains 20–48 μg of styrene.

Styrene contamination of foods is generally apparent as a characteristic, unpleasant, plastic-like chemical odor or taste and is discussed further in Section 22.7.2.

22.3.3 Acrylonitrile Monomer

Acrylonitrile (AN) (boiling point 77.5°C) is a component of several polymers used as food packaging materials, the basic terpolymer material containing as much as 70% AN in conjunction with styrene and/or butadiene.

The FDA began to examine PAN containers in 1974 when a polymer manufacturer submitted test results that indicated that there was the potential for significant migration from PAN containers. In 1975, the commissioner published a regulation that limited residual AN monomer levels to 80 ppm in the wall of the container and stipulated that monomer migration into the food could not be greater than 0.3 ppm.

In 1976, the FDA established an interim regulation limiting AN extraction in food-simulating solvents to 0.3 ppm and making the continued use of AN copolymers in food applications conditional on additional toxicological testing. The following year, the FDA stayed the interim regulations permitting the use of AN copolymers in beverage containers and proposed a reduction of the

extraction limit in other food applications from 0.3 to 0.05 ppm. The 1977 action was based in part on proliferative brain lesions observed in rats at 300 and 100 ppm of AN in drinking water after 13 months of a 2 year study. The 1977 ban on the use of AN copolymers for beverage bottles was removed in 1984 on the proviso that the level of residual AN in the container was less than 0.1 ppm. By this time, PET had become firmly established for the packaging of carbonated beverages, and even though AN has a significantly higher melting point and, thus, can be hot filled, it has never gained significant market share for beverage packaging. AN copolymers were not approved for alcoholic drinks.

Acrylonitrile–butadiene–styrene (ABS) resins are used in many food contact applications, where the levels of the three monomers in the polymer are varied to obtain the different properties desired. The correlation of residual AN monomer concentration in AN-containing polymers with AN migration into food simulants is of interest because the FDA regulates the use of these polymers on the basis of the amount of AN that may migrate into food simulants.

22.3.4 Plasticizers

A *plasticizer* is a substance that is incorporated into a material (usually a plastic or elastomer) to increase its flexibility and processability. The vast majority of plasticizers are esters of phthalic acid (phthalates) with a wide variety of long-chain alcohols containing up to 13 carbon atoms; next in importance are those based on adipic acid. About 90% of all plasticizers were used to convert PVC into a soft, elastic material. However, copolymers of PVC and PVdC are plasticized with up to 5% of acetyltributyl citrate (ATBC), and such films used to find widespread use in microwave cooking. They have now largely been replaced by LLDPE films that do not contain any plasticizers.

22.3.4.1 Phthalate and Adipate Esters

Surveys carried out in a number of countries have indicated that, over the last few decades, there has been a fall in the quantity and quality of male sperm, although the effects appear to be variable. There is also evidence that, in some countries, there has been an increase in testicular cancer. Much of the concern focuses on synthetic—and mainly organic—chemicals as highlighted in the book *Our Stolen Future* (Colborn et al., 1997). *Endocrine disrupting chemicals* (EDCs) enter the body from the external environment and mimic or interfere with the human endocrine system. Chemicals that mimic the female hormone estrogen or act as antiestrogens are suggested as being responsible for some observed effects on wildlife such as the feminization of fish. It has been further suggested that these same chemicals may be responsible for the aforementioned male human health problems. A recent book gives details of endocrine-disrupting compounds in foods (Nollet, 2011), and a recent review focuses on phthalate esters in foods (Cao, 2010). An updated review of exposure, effect and risk assessment of EDCs was presented by Muncke (2011).

Phthalates are among the chemicals that have been labeled as xenoestrogens. Of the phthalic acid esters, di-2-ethylhexyl phthalate (DEHP) was the most widely used. DEHP is also known as dioctyl phthalate (DOP), the terms dioctyl and di-2-ethyl being synonymous. Other phthalates include di-isononyl phthalate (DiNP), dibutyl phthalate (DBP) and di-isodecyl phthalate (DiDP). Adipates, such as di-2-ethylhexyl adipate (DEHA), dioctyl adipate (DOA) and di-isononyl adipate (DiNA), are also used frequently as plasticizers in PVC products as replacements for phthalates. Because they are not chemically bound to plastics, phthalates, and to a lesser extent adipates, have become ubiquitous environmental contaminants due to volatilization and leaching from their widespread applications, and are now commonly detected in the environment where they persist. The determination of phthalates is not an easy task, and often they cause "blank" problems when analyzed at low concentrations. Because of their widespread presence in the laboratory environment, including air, vinyl floor coverings, electrical cables, glassware and reagents, false-positive readings can result.

DEHP, together with diethyl phthalate (DEP) and di-isooctyl phthalate (DIOP) have been granted prior sanction by the FDA as plasticizers in the manufacture of food packaging materials for food

of high water content only, and are listed in § 181.27 of the CFR. Other phthalate esters have been cleared as plasticizers under § 178.3740 of the CFR for various food contact uses. Today, the majority of PVC used for food packaging does not contain phthalate plasticizers, and many PVC packaging materials are rigid and unplasticized. Minor uses of phthalates in food packaging include use as plasticizers in cap liners made from PVC plastisols.

The EU SML values for DBP, DEHP and DEHA are 0.3, 1.5 and 18 mg kg^{-1}, respectively. A useful review of recent EFSA toxicological evaluations of phthalates used in FCMs has been presented by Lhuguenot (2009).

Zhang et al. (2008) determined DBP in 110 domestic and imported paper packages and foods sold in U.S. marketplaces. The concentration of DBP ranged from 0.14 to 55 mg kg^{-1}, with most lower than 20 mg kg^{-1}, suggesting that migration into food would be very low or undetectable. DBP was only detected in two domestic and four imported food samples with concentrations ranging from 50.01 to 0.81 mg kg^{-1}. In many paper packages, DBP is associated with printing inks and may become a component of food via "set-off," which refers to the process whereby the nonprinted (inner) surface of packages contacts with the printed (outer) surface such as occurs when printed packaging material is stored as rolls or printed containers are stacked or "nested" within each other.

Recently, Cirillo et al. (2011) reported that 92% of foods employed in school meal preparation in Naples contained DEHP, and 76% of them DBP, at detectable levels. The meals were packed in plastic-coated alufoil, and the DEHP median values ranged from 127.0 to 253.3 ng g^{-1}, and DBP median values varied from 44.1 to 80.5 ng g^{-1}. The mean increases of median concentrations of DEHP and DBP in cooked foods before and after packaging were 113% and 125%, respectively. For nursery and primary schoolchildren, DEHP intake via school meals can raise on average the respective EFSA TDI by 18% and 12% and that of DBP by 50% and 30%.

Although plasticizers are not used in PET bottles, a number of studies have reported various phthalates in mineral water bottled in PET. Phthalates may come from bottling lines, cap-sealing resins or water treatment facilities. Background pollution in the laboratory analyzing phthalates may also be a source. A recent literature review showed that contradictory results for PET-bottled water can be explained by the wide variety of analytical methods, bioassays and exposure conditions employed (Bach et al., 2012). It was concluded that more investigations are needed to improve the accuracy of the analytical methods and to clarify the entry pathways of plasticizers in the bottling line.

Glass jars with metal twist closures are widely used for a broad range of foods such as infant foods, pickled herrings, vegetables in oil or water, sauces, peanut butter, milk products, soft cheese products, pesto and so on. Many of these products are intended for storage up to 2 years, and in order to ensure a long shelf life, a plasticized PVC gasket is placed inside the closures to form an airtight seal against the rim of the jar. A lid typically contains 1 g of gasket material of which 250–350 mg is in direct food contact. As PVC gaskets contain 35–45% plasticizer, more than 100 mg plasticizer is exposed to the food. Phthalates are the main plasticizers in some 25% of these gaskets, and in oily foods, phthalate concentrations up to 1000 mg kg^{-1} have been reported.

Plasticizers (predominantly phthalates) are also used in printing inks where they assist adhesion of the ink to the packaging material and improve the ink's flexibility. They can migrate into food either as a result of set-off or by migration through the packaging material.

22.3.4.2 Acetyltributyl Citrate

ATBC (tri-*n*-butyl acetyl citrate) is a plasticizer formed by the esterification of citric acid. It is considered a "prior sanctioned food ingredient" and is not classified as a food additive by the U.S. FDA. It is the most widely used plasticizer in PVdC copolymer films at levels of up to 4.8% w/w. The EFSA has given ATBC a TDI of 1.0 mg kg^{-1} body weight.

ATBC migrates into a variety of foods when plasticized film is used for normal domestic applications including cooking or reheating of meals in a microwave oven. The highest levels of migration would be expected where the film was used in direct contact with a fatty food surface. Zygoura et al.

(2011) reported ATBC migration into cod fillets of 11.1–12.8 mg kg^{-1} (0.11–0.13 mg dm^{-2}) and herring fillets of 32.4–33.4 mg kg^{-1} (0.32–0.33 mg dm^{-2}). The film surface area:weight of fish was ca. 89:1, in contrast to the generally agreed relationship of 6 dm^2 kg^{-1} food (6:1). Fish samples were stored at 4°C and analyzed for ATBC content at time intervals between 12 h and 240 h of contact. Electron beam (EB) radiation at pasteurizing doses did not significantly affect the SM characteristics of the films.

22.3.4.3 Epoxidized Soy Bean Oil

Epoxidized seed and vegetable oils such as epoxidized soy bean oil (ESBO) are widely used in a range of FCMs to serve as multifunctional additives exhibiting plasticizer, lubricant and heat stabilizer properties. ESBO is produced by the controlled epoxidation of soy bean oil in which the C=C double bonds are largely converted to epoxy groups. PVC gaskets used in the lids of glass jars can contain ESBO levels up to 30%, while other materials such as PVdC copolymer and PS used to contain epoxidized oils but at lower levels. ESBO was also employed as a component of enamels and, therefore, was present in the food contact surface of certain metal cans but its use for this purpose appears to have ceased. The use of ESBO, as well as some low molar mass plasticizers such as ATBC and DOA, has increased in recent years as an alternative to phthalates.

ESBO has an SML of 60 mg kg^{-1} food simulant, which corresponds to the OML. In 2007, the SML was lowered to 30 mg kg^{-1} for infant food because the TDI of 1 mg kg^{-1} body weight was often exceeded. Bueno-Ferrer et al. (2010) reported the migration of several plasticizers from commercial lids into the fat simulants 95% ethanol and iso-octane, neither of which are approved simulants in the EU. The results (Table 22.5) revealed that the highest amounts of plasticizers were found when 95% ethanol was used as a simulant. All plasticizers migrated in amounts higher than the current EU legal migration limits. Two of them showed high levels of ESBO and, in the case of the pâté lid, even above the transitional limit of 300 mg kg^{-1}. The pesto sauce showed high levels of ATBC.

22.3.5 Antioxidants

Antioxidants are used to prevent the degradation of the polymer as a result of its reaction with atmospheric O_2 during molding operations at high temperature, or when used in contact with hot foods. They are also used to prevent embrittlement during storage. A simple primary antioxidant is butylhydroxytoluene (BHT: 3,5-di-*tert*-butyl-4-hydroxytoluene), a lipophilic compound that is primarily used as an antioxidant food additive (E number E321). However, its use in FCMs has recently declined

TABLE 22.5
Migration of Plasticizers from Commercial Lids to Food Simulants

		Mean Value (mg kg^{-1} Food Simulant)		
Plasticizer	**Simulant**	**Pâté**	**Pesto Sauce**	**Mayonnaise**
ESBO	95% Ethanol[a]	676 ± 282	18 ± 18	71 ± 24
	Iso-Octane[b]	94 ± 49	<LOQ	<LOQ
ATBC	95% Ethanol[a]	22 ± 19	285 ± 12	ND
	Iso-Octane[b]	8 ± 2	19 ± 3	ND
DOA	95% Ethanol[a]	ND	ND	0.23 ± 0.01
	Iso-Octane[b]	0.23 ± 0.05	0.23 ± 0.01	0.53 ± 0.04

Source: Bueno-Ferrer, C. et al., *Food Addit. Contam.,* 27, 1469, 2010.
LOQ, Limit of Quantification; ND, Nondetectable.
[a] After 10 days at 40°C.
[b] After 2 days at 20°C.

TABLE 22.6
BHT Migration into Semisolid and Solid Foods

Food	Temperature (°C)	Duration (days)	Food Mass/ HDPE Surface Area (g dm^{-2})	Migration	
				μg dm^{-2}	%
Margarine	4	4	70	0.5	0.2
		45	130	1.6	0.5
		99	130	2.4	0.8
Whipped topping	4	7	130	0.9	0.4
		14	130	0.9	0.4
		21	130	0.9	0.4
Mayonnaise	21	2	70	4.7	1.8
		8	130	7.4	2.3
		45	130	26.4	8.5
		89	130	36.2	11.3
Vegetable shortening	21	2	70	6.3	2.5
		91	130	58.6	18.4
		206	130	59.2	18.6
Dry milk	21	100	130	17	5.1
Chicken soup mix	21	99	130	50	16.3

Source: Till, D.E. et al., *Ind. Eng. Chem. Prod Res. Dev*., 21, 106, 1982.

somewhat as it has a low SML of 3 mg kg^{-1} and a relatively high migration into fatty food compared to its higher MW alternatives (Cooper, 2008). Secondary antioxidants such as tris(2,4-di-*tert*-butylphenyl)phosphite (known as Irgafos 168) decompose hydroperoxides and remove peroxide radicals as they are formed. Use of both primary and secondary antioxidants usually provides a synergistic effect.

A study (Till et al., 1982) of the migration of BHT from HDPE to foods (skim and whole milk, margarine and mayonnaise) and food simulants found no accumulation of BHT in the aqueous phase. However, when corn oil was the simulant, all the BHT migrated during the 50 day test period. Migration at 4°C to skim and whole milk was less than for corn oil but greater than for migration to water. It was felt that some ingredients from milk could penetrate the HDPE even at such a low temperature, and modify the migration propensity of the BHT. A summary of the results is given in Table 22.6. The mechanism for BHT transfer would appear to be evaporation from the film surface with vapor phase diffusion from the HDPE and adsorption onto the powder.

Cereals packaged in HDPE impregnated with BHT have an extended shelf life, due to adsorption by the cereal of BHT from the package. Lee et al. (2004) evaluated the rate of loss of BHT from a co-extruded HDPE pouch with a heat seal layer of ionomer-EVA impregnated with BHT (0.1137% w/w). The BHT-impregnated pouch showed a notable effectiveness in retarding lipid oxidation of a freeze-dried model food at 45°C and 50% RH as a function of storage time. After 6 days, no BHT was detected in the pouch material.

22.4 METAL PACKAGING

22.4.1 Tin

When tinplate was first used to make containers for food over 200 years ago, many cases of food poisoning, apparently due to ingestion of excessive amounts of metal, occurred. A congress of physicians held in Heidelberg in Germany even went so far as to recommend that "tinplate should be forbidden for the making of vessels in which articles of food are to be preserved" (Reilly, 2007). The quality of tinplate

has been greatly improved since those days, and foods that are likely to attack tin are packaged in tinplate containers with an appropriate enamel coating (see Chapter 7). Despite considerable research, it has not yet been demonstrated that tin is an essential element in the diet of humans, although a WHO report suggested that tin deficiency can be produced in rats (Murphy and Amberg-Müller, 1996).

The provisional tolerable weekly intake for tin is 14 mg kg^{-1} body weight and the recommended maximum permissible levels of tin in food are typically 250 mg kg^{-1} for solid foods and 150 mg kg^{-1} for beverages. Although no long-term health effects are associated with consuming tin, a review of published data concluded that there appears to be a small amount of evidence suggesting that the consumption of food or beverages containing tin at concentrations at or below 200 mg kg^{-1} has caused adverse gastrointestinal effects in an unknown but possibly small proportion of those exposed (Blunden and Wallace, 2003). At its 55th meeting, the FAO/WHO Joint Expert Committee on Food Additives (JECFA) assessed the available evidence on the acute toxicity of tin, and concluded that it was insufficient to establish an acute reference dose or to derive maximum permissible levels in canned foods and beverages. However, they reiterated their previously stated opinion that the limited human data available indicate that concentrations of 150 mg kg^{-1} in canned beverages or 250 mg kg^{-1} in other canned foods may produce acute manifestations of gastric irritation in certain individuals.

22.4.2 Lead

The toxicity of lead, especially to the neonate, is a matter of great concern to regulatory authorities. Abundant evidence supports the fact that during early life, human infants are particularly susceptible to lead exposure, with a greater portion of the retained lead being distributed to bone and brain in infants than in adults. Subacute ingestion of lead by children results in encephalopathy, convulsions and mental retardation. The JECFA has recommended that for adults, the weekly dietary intake of lead should not exceed 50 µg kg^{-1} body weight, and for infants and young children, it should not exceed 25 µg kg^{-1} body weight.

For many years, the side seams of three-piece tinplate cans were soldered with a lead/tin (98:2) solder, resulting in some lead being taken up by the food depending on the amount of solder exposed to the food, the acidity of the food and the time the food had been in the can. Some lead contamination may also originate from the tin coating, which contains a small but finite proportion of lead at levels around 500 mg kg^{-1} (Murphy and Amberg-Müller, 1996). Regulatory limits for lead in most countries are now 2 mg kg^{-1} in canned foods generally, but only 0.5 mg kg^{-1} for baby foods and 0.2 mg kg^{-1} for soft drinks. EC Regulation 466/2001 limits lead in cows' milk and infant formulae to 0.02 mg kg^{-1} and 0.05 mg kg^{-1} in fruit juices. In Europe, EC Regulation 242/2004 limited lead in canned solid foods to 200 mg kg^{-1} and 100 mg kg^{-1} in canned beverages, with levels in canned foods for infants and young children being limited to 50 mg kg^{-1}.

U.S. canners voluntarily stopped using lead solder in 1991. Despite this and a 1995 FDA ban on lead-soldered cans, requiring their removal from shelves by June 1996, this source of lead in the diet has not been fully eliminated. A few countries still use lead-soldered cans for food, and these food items may still occasionally be imported, albeit illegally, into the United States.

To obtain the lower lead levels in baby foods, it was common to use a pure tin solder, which was considerably more expensive than the conventional solder. The newer welded cans have eliminated solder altogether, which has done much to reduce the lead intake from canned foods, typically to about one-tenth.

22.4.3 Aluminum

Although aluminum is a nonessential metal to which humans are frequently exposed, it has a long history of safe usage in connection with food and food packaging, and is deemed to be GRAS by the U.S. FDA. Aluminum-containing food ingredients are used mainly as preservatives, coloring agents, leavening agents, anticaking agents and so on.

Although aluminum forms an oxide layer very quickly on exposure to air after manufacture, it can still be attacked by certain foods, especially those containing acids and/or salts. As was discussed in Chapter 7, pure aluminum is not used as a food packaging material. Instead, to provide strength, improve formability and increase corrosion resistance, various alloying elements are added, including iron, copper, zinc, manganese and chromium. These metals, as well as aluminum itself, may migrate into the food if corrosion takes place. Published data on aluminum migration from food contact materials are sparse.

In one study, carbonated, nonalcoholic beverages had aluminum contents of 107–2084 ppb with an average of 830 ppb; carbonated, alcoholic beverages had aluminum contents of 67–1727 ppb. Beer in aluminum cans averaged 300 ppb, which is not much more aluminum than that in beverages in the same class; carbonated wines and wine coolers averaged 970 ppb of aluminum (Schenk et al., 1989).

Aluminum soft drink cans enameled on the inner surface were fairly resistant to acidic cola drinks for storage periods of 30–120 days, with the aluminum content of various batches ranging from 15 to 250 ppb; there was considerable variability between batches. High aluminum concentrations of 400–800 ppb were detected in these beverages after storage periods >400 days, while low aluminum levels of 15–20 ppb were found in colas stored in bottles made of glass or PET. Inconsistent quality of the protective stove lacquering in aluminum cans was suggested as being responsible for the observed effects (Murphy and Amberg-Müller, 1996).

22.4.4 Chromium

Chromium is an essential element for humans and is present in the diet mainly as Cr(III). It has a role in carbohydrate, lipid and protein metabolism related to improving the action of insulin. Cr(III) is much less toxic than the hexavalent form; some Cr (VI) compounds can be carcinogenic. As discussed in Chapter 7, the tin layer in tinplate cans undergoes a chromium treatment known as *passivation* in order to make it more resistant to oxidation and to improve enamel adherence. The chromium deposition on the tinplate after passivation can amount to 0.5 μg cm^{-2}, and if all this chromium were to dissolve in the food, this would result in the contamination of the contents of a 454 g can with about 0.4 mg kg^{-1} (Jorhem and Slorach, 1987). In their study of canned fruit and vegetables, the mean level of chromium in enamel cans was 0.018 mg kg^{-1}, and in plain cans 0.090 mg kg^{-1}. This compares with levels in fresh foods of the same type of 0.009 mg kg^{-1}. No cases of intoxication have emerged, and it appears that the level of chromium present in tinplate is probably not enough to cause either toxic or adverse organoleptic effects (Murphy and Amberg-Müller, 1996).

The whole surface of ECCS cans consist of chromium oxide, but since it is only about 1/30 of the thickness of the tin layer on tinplate, it is always enameled prior to use. Although some Italian studies indicated that the absence of a thin layer renders ECCS less suitable for acid fruit packs, this is only likely to be a problem if a major loss of enamel occurred, which is unlikely since ECCS displays excellent enamel adhesion properties (Murphy and Amberg-Müller, 1996).

22.4.5 Silver

Silver nanoparticles (Ag NPs) are widely used for their antibacterial, antimicrobial, antibiotic, antifungal and partial antiviral activity, and nanocomposite packaging containing Ag NPs is being used to extend the shelf life of fresh foods. The increasing use of antimicrobial Ag NPs has been the subject of concern regarding environmental and health issues. Several reports have indicated that Ag NPs are toxic to cells and can alter the normal function of mitochondria, increase membrane permeability and generate reactive O_2 species. The main risk of consumer exposure to NPs from food packaging is likely to be through the potential migration of NPs into food and drink, as found for other heavy metals. Song et al. (2011) determined the migration of Ag from nanosilver–polyethylene food packaging film into food simulants at different temperatures and migration times.

Results indicated that the maximum migration ratios were 1.70%, 3.00% and 5.60% for 3% (w/v) aqueous acetic acid at 20°C, 40°C and 70°C, respectively, while for 95% (v/v) aqueous ethanol, the maximum migration ratios were 0.24%, 0.23% and 0.22% at 20°C, 40°C and 70°C. A more general discussion on the toxicology of nanomaterials in food can be found in Magnuson and Bouwmeester (2011).

22.4.6 Epoxy Resin Coatings

Epoxy resins are thermosetting resins that contain two or more epoxide (oxirane) groups per molecule and are obtained by the condensation of epichlorohydrin and bisphenol A (BPA), which yields bisphenol A diglycidyl ethers (BADGEs) of varying degrees of condensation (n), depending on the reaction conditions and the mole ratio of the reactants (Biles et al., 1999). While high MW ($n = 9–11$) epoxy resins are used as can enamels, many commercial epoxy resins are BADGE ($n = 0$) free (Simal-Gándara et al., 1998).

It is well established that because a residual amount of monomer remains after the polymerization process, BPA and other components migrate, at very low concentrations (ppb), from the epoxy coatings into the can contents during processing and storage. Powder formulations of high MW epoxies are used mainly to coat the internal surfaces of two-piece DRD food cans, while UV-curable coatings based on low viscosity aromatic, aliphatic and cyclo-aliphatic epoxy resins are used to coat the exterior and ends of cans. The success of epoxies as coatings for food cans is a result of their desirable flavor-retaining characteristics, their excellent chemical resistance and their outstanding mechanical properties. BPA is also used in the manufacture of polycarbonates and as an antioxidant and an inhibitor of end polymerization in PVC.

Noonan et al. (2011) quantified BPA concentrations in 78 canned and two frozen food products representing 16 different food types from the U.S. market. BPA was detected in 71 of the 78 canned food samples but was not detected in either of the two frozen food samples. Detectable BPA concentrations across all foods ranged from 2.6 to 730 ng g^{-1}. Large variations in BPA concentrations were found between different products of the same food type, and between different lots of the same product. Given the large concentration ranges, the only distinguishable trend was that fruits and tuna showed the lowest BPA concentrations.

A report into the mechanisms involved in the migration of BPA from can enamels into drinks found that it was necessary to heat the can to a temperature above the T_g of the epoxy resin (105°C) in order for the compound to be mobilized (Kawamura et al., 2001).

In the mid-1990s, the U.S. FDA and the SCF in Europe began investigating human exposure to BPA and BADGE in order to ascertain whether the use of certain epoxy resins might be exposing consumers to estrogenic xenobiotics. The FDA concluded that there was no public health concern regarding these chemicals. Several risk assessment reports have been prepared in recent years by authorities in Europe, Canada and the United States to assess the risk to consumers emerging from regular exposure to BPA. These assessments draw different conclusions regarding the potential risk of BPA, based mainly on the interpretation of the toxicity data. For example, Beronius et al. (2010) scrutinized 10 risk assessments and found that differences in conclusions were mainly influenced by the evaluation of low-dose effects and the uncertainties surrounding the significance of these data for health risk assessment. The results illustrate the impact of differences in risk assessment policy and expert judgment on the risk assessment process and highlight the importance of transparency in this process. A useful opinion piece by Sharpe (2010) commented on many of the controversies surrounding scientific studies on BPA that have entered the wider media.

Current BPA food contact uses in the United States were approved in 1963 when BPA was classified as an indirect food additive and GRAS. Today, there exist hundreds of different formulations for BPA-containing epoxy linings, which have varying characteristics. As currently regulated, manufacturers are not required to disclose to FDA the existence or nature of these formulations.

In 2006, EFSA set the TDI for BPA at 0.05 mg BPA kg^{-1} body weight day^{-1} based on the NOAEL of 5 mg kg^{-1} body weight day^{-1} that had been identified in two multigeneration reproductive toxicity studies in rodents, where the critical effects were changes in body and organ weights in adult and offspring rats and liver effects in adult mice, respectively. In 2008, EFSA reaffirmed this TDI, concluding that age-dependent toxicokinetic differences of BPA in animals and humans would have no implication for the default uncertainty factor (UF) of 100 and in turn for the TDI. In 2010, after reviewing hundreds of recent studies, EFSA concluded that the current TDI should remain unchanged.

EU Regulation 1895/2005 established a TDI of 0.15 mg kg^{-1} body weight for BADGE and its hydrolysis products, and a corresponding SML of 9 mg kg^{-1} in food and food simulants or 9 mg 6 dm^{-2}. The use of BFDGE and NOGE was prohibited from 2005 and 2003 respectively.

BPA is also used in the manufacture of polycarbonate. Recently, the release of BPA from polycarbonate baby bottles into food and food simulants was reviewed from the perspective of the current intensive discussions on possible risks arising from such migration (Hoekstra and Simoneau, in press).

22.5 PAPER PACKAGING

Paper and board are natural products made up of a large number of organic molecules (>700) and the toxicity of all of these substances, individually and in combination, is not known. Paper and board for food contact use are inhomogeneous materials, and can be composed of virgin or recycled pulp, additives like fillers, sizes, starch, starch derivatives, wet strength sizing agents and pigment or polymer coatings. Although paper and board food packaging materials are not currently subject to any specific legislation at EU level, like all FCMs, they should meet the general requirements laid down in Framework Regulation (EC) No. 1935/2004. Article 3 states that materials and articles shall not, under normal or foreseeable conditions of use, transfer their constituents to food in quantities that could endanger human health. Some examples of contaminants that have migrated from paper and board into food are now discussed.

22.5.1 Dioxins

Dioxin is the generic name for members of the family of polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs). The different amounts and locations of the chlorine substituents in these molecules give rise to 75 possible isomers of PCDDs and 135 of PCDFs; these related compounds are known as congeners. There is an enormous body of toxicological information available, although it relates almost entirely to the 2,3,7,8-tetrachlorodibenzo-*p*-dioxin isomer (2,3,7,8-TCDD), the most toxic isomer. In the case of the other isomers, their toxicity is related back to that of 2,3,7,8-TCDD to give the *toxic equivalent* (TEQ) to aid risk assessment. Toxicological and biological data are used to generate a series of weighting factors called *toxic equivalency factors* (TEFs), each of which expresses the toxicity of a "dioxin-like" compound in terms of the equivalent amount of TCCD. Multiplication of the concentration of a compound by its TEF gives a TEQ (Harrison, 2001).

Concern about trace amounts of dioxins in bleached paperboard packaging and the possible migration of the dioxins into milk packaged in paperboard cartons surfaced in North America in 1987. The dioxins arise during the bleaching process to delignify the pulp when chlorine is used. Although reported levels of dioxin in paperboard were extremely low and in the order of 4–5 pg kg^{-1} (ppt), concentrations in whole milk packaged in chlorine-bleached paperboard cartons were typically 0.1 ppt, with the concentration in the fat phase being around 3 ppt; the corresponding figures for milk packaged in glass containers were 0.005 and 0.15 ppt. In 1990, an expert group convened by the WHO recommended a TDI of 10 pg TCDD equivalents kg^{-1} bodyweight; in 1999 this was reduced to 1–4 pg kg^{-1} bodyweight, the lower end of the range being seen as a target (Harrison,

2001). EU Regulation 1881/2006 set maximum levels for dioxins and PCBs in food; for example, the sum of dioxins in milk and dairy products should not exceed 3.0 pg g^{-1} fat.

Despite the extremely low risk presented by dioxins in milk, suppliers of bleached paperboard adopted bleaching processes which reduced or avoided the production of dioxins in paper and paperboard. These processes included improving the washing of unbleached pulp to reduce dioxin precursors prior to the bleaching process; avoiding the use of elemental chlorine in the bleaching process by replacing chlorine with chlorine dioxide and/or oxygen compounds; and implementing an O_2 and/or extended delignification process prior to the bleaching process.

Dioxin continues to contaminate foods but the source is dioxin-contaminated animal feed rather than packaging. Recent incidents include Irish pork products and eggs in the Netherlands where animals had been exposed to feed contaminated with dioxin.

22.5.2 Benzophenone

Over the past 30 years, there has been a move away from solvent-based inks toward those that are cured by UV radiation or (less commonly) EBs. This move has been driven, in part, by the increasing legislative focus in developed countries on VOCs (volatile organic compounds) of which the solvents used in printing are a major source. Another reason for the widespread use of UV-cured inks for printing cardboard and labels is because the fast cure permits online cutting and folding, enabling rapid production of finished packaging.

Benzophenone (BP) is widely used as a photoinitiator for inks and varnishes/lacquers that are cured with UV light. In addition to being a drying catalyst, BP is an excellent wetting agent for pigments and acts as a reactive solvent, increasing the flow of inks. Such inks typically contain 5%–10% photoinitiator. Because only a small portion of the initiator is used up during the curing process, BP can remain in the printed material and migrate through the open structure of carton board into the packaged food as it is not irreversibly bound into the print film layer. It may also be present if the carton board is made from recycled fibers recovered from printed material (Anderson and Castle, 2003).

In an extensive analysis of 350 retail samples in carton board food packaging, 41% had significant (>0.05 mg dm^{-2}) BP with 22% in the range 0.8–3.3 mg dm^{-2}. The highest level was 7.3 mg dm^{-2} found in a high-fat chocolate confectionery product packaged in direct contact with carton board. When the mass fraction of BP migration was calculated for different contact and storage regimes, there was a 6-fold reduction in migration for indirect contact compared with direct contact, a 6-fold reduction for chilled/frozen storage compared with ambient storage, and a 40-fold reduction for the two contact conditions combined (Anderson and Castle, 2003).

Studies of the migration of BP from printed carton board have been carried out at freezer temperature and during microwave heating (Johns et al., 2000). BP was found to migrate to the packaged food, even from LDPE-coated board. After 1 week at −20°C, migration was readily apparent, with BP being detected in the carton board of four out of seven samples at levels of 0.4–3.0 mg dm^{-2}. BP was also detected in three foods at levels of 0.6–2.9 mg kg^{-1}, which corresponded to a 1%–2% transfer from the printed board.

In 2009, German authorities reported a high migration of 4-methylbenzophenone (4-MBP) from carton board packaging into cereals. Although an SML exists for BP of 0.6 mg kg^{-1} for its use as an additive in plastics, there is no specific European legislation covering cardboard boxes and printing inks for food contact use. However, due to the high levels detected, EFSA recommended a limit of 0.6 mg kg^{-1} for the sum of BP and 4-MBP. BP and 4-MBP are not usually present in the same packaging, but rather seem to replace one another (Koivikko et al., 2010).

The aforementioned studies emphasize that the potential for migration to dry and frozen foods cannot be ignored. Although the inks were applied to the outside of the carton board, the board itself presented little if any barrier to migration. UHT milk packaged in HDPE bottles in Australia was recalled due to the presence of BP (10 ppb) and benzaldehyde (25 ppb) that had migrated into

the milk from the UV-cured ink used to print the labels, giving rise to a metallic taint and many consumer complaints. The strong odor and taste of the offending chemicals prevented their ingestion by consumers.

22.5.3 Isopropylthioxanthone

Isopropylthioxanthone (ITX) is another photoinitiator used in UV-cured offset printing inks and is always mixed with a co-photoinitiator (mainly 2-ethylhexyl-4-dimethylamino benzoate (EHDAB)). In September 2005, Nestlé undertook a recall of over 30 million cartons in four European countries of UHT milk for babies packaged in Tetra Brik Aseptic cartons, following the discovery by Italian food safety authorities of the presence of the ITX and EHDAB. The level of ITX ranged from 120 to 305 ppb for baby milk and from 74 to 445 ppb in milk for babies aged 12 months and over; ITX was found at 600 ppb in a single sample of flavored milk tested. ITX was also found in chocolate and cocoa milk products sourced from Austria; in grapefruit juice and pineapple juice produced within Italy, and in milk and cocoa beverages from Germany.

Since then, German researchers detected ITX in 36 of 137 packages (26%) not limited to multilayer laminate cartons (e.g., it was found in sausage skins and plastic cups), and significant migration occurred in 75% of the packaging materials that tested positive (Rothenbacher et al., 2007). The levels of ITX ranged up to 357 ppb in orange juice. The authors concluded that industry should utilize other, less-migrating photoinitiators, and that the implementation of legislative standards for GMP with a positive list for printing inks and maximum migration limits, especially for substances with incomplete toxicological assessment, is essential.

ITX is not prohibited for use in food packaging by the EU; it is also not listed on the WHO's prohibited list. According to EFSA, the scientific evidence indicates that the presence of the chemical in packaged foods does not pose a health risk. Tetra Pak has stated publicly that it is no longer using ITX in its printing inks. ITX differs from BP in that there is no obvious off-taste or odor to alert consumers to its presence in food.

In response to the ITX recall, the printing ink industry has developed new low-migration printing inks based on a novel fatty acid ester (FAE) consisting of a quaternary alcohol esterified with short fatty acids as the solvent. Richter et al. (2009) reported migration of the FAE from printed cardboard packaging into simulants and meat, chocolate and sweets. Levels of contamination of these foods were between 5 and 80 μg FAE kg^{-1}, with higher levels in the simulants.

22.5.4 Mineral Oil Saturated Hydrocarbons

Since 1997, there has been an increasing number of reports of contamination of powdered baby milk and other dry foods packed in cardboard cartons with mineral oil saturated hydrocarbons (MOSH). The migration into dry foods proceeds by evaporation from the box and recondensation in the food, possibly with an intermediate passage through the wall of an internal bag. Internal paper bags with a plastic layer did not stop the migration.

There are two potential sources of mineral oil: offset printing inks applied to the package and recycled fibers (primarily from newspapers) contaminated by inks containing mineral oils. Conventional offset printing inks usually contain 20%–30% mineral oil as solvents. These oils range from about the *n*-alkane C_{13} to about *n*-C_{20}, and consist of MOSH as well as typically 5%–20% mineral oil aromatic hydrocarbons (MOAH). These inks "dry" by the solvent being sucked into the paperboard, where it largely remains.

At present, no regulatory authority has established legal limits for MOSH and MOAH. However, in 2002, JECFA specified a "temporary" ADI of 0–0.01 mg kg^{-1} body weight. Assuming 60 kg body weight and 1 kg of food contaminated with the given substance being consumed daily, the SML for these oils can be calculated as 0.6 mg kg^{-1} food. The JECFA evaluation was based on white mineral

oils, refined to eliminate MOAH, whereas the mineral oils in recycled board and most printing inks are of technical grade and, thus, also contain MOAH.

Biedermann et al. (2011) investigated the migration of MOSH into taglioline (fine noodles with a large surface area, 4.1% fat and a shelf life of 2 years) packaged in a printed paperboard box overwrapped with LDPE; the box was glued together with an adhesive containing less than 1000 mg kg^{-1} MOSH. After 65 days, bottom packs in contact with the corrugated fiberboard transport package (estimated MOSH of 158 mg kg^{-1} at time of packing) contained 6.1 mg kg^{-1} MOSH and had the potential to contaminate all the packs on average at about 10 mg kg^{-1} after 2 years. Second, the migration from an improved recycled paperboard with five times less mineral oil than average amounted to 4.9 mg kg^{-1}. Third, a printing ink containing 3 g kg^{-1} MOSH (about 100 times less than conventional offset inks) contaminated the taglioline with 0.6 mg kg^{-1} MOSH. Finally, the taglioline were already contaminated with 2.5 mg kg^{-1} MOSH and <0.2 mg kg^{-1} MOAH before packing, illustrating that there are other as yet unidentified sources of mineral oil.

One way to minimize the migration of contaminants from packaging materials into food is to use a functional barrier. Fiselier and Grob (in press) determined the breakthrough periods of MOSH through various potential functional barriers. Polyethylene films showed breakthrough periods of only a few hours, whereas those of PP were roughly a month. Even thin layers of PA and PET were characterized by breakthrough periods of more than 6.9 years at 25°C, well beyond that needed to protect foods stored at room temperatures.

Recently, Biedermann-Brem et al. (2012) reported the confusion that exists between MOSH and POSH (polyolefin oligomeric saturated hydrocarbons). POSH consist largely of branched hydrocarbons such as the oligomers released by polyolefins and, thus, are comparable to MOSH; both could accumulate in the human body. Difficulties can arise in the analysis of MOSH as a result of interference from POSH because both POSH and MOSH consists largely of highly isomerized, branched and possibly cyclic hydrocarbons. No adequate data set is available to draw conclusions about the significance of POSH concentrations in foods currently on the market. Table 22.7 details levels of POSH and MOSH detected in powdered infant formula.

22.5.5 Miscellaneous

The manufacturing process of paperboard food packaging can produce small quantities of 3-monochloropropane-1,2-diol (3-MCPD) when wet-strength resins containing epichlorohydrin are used. 3-MCPD is from the same family as 1,3-dichloro-2-propanol (1,3-DCP), which is known to cause cancer in animals. 3-MCPD has been found in paperboard for food contact.

TABLE 22.7
POSH and MOSH in Powdered Infant Formula by Molecular Mass Ranges of the *n*-Alkanes (POSH + MOSH Extracts from the Internal Surface of the Packaging Material)

	Food POSH + MOSH (mg kg^{-1})			Packaging (Internal Side) POSH + MOSH (μg dm^{-2})		
Packaging Type	**<C16**	**C16–C24**	**C24–C35**	**<C16**	**C16–C24**	**C24–C35**
Paperboard box with internal heat sealable alufoil bag	0.6	1.5	3.4	12	92	383
Same as above	1.4	3.5	5.1	5	24	309
Paperboard box with internal metallized and heat sealable bag	0.3	1.2	1.9	2	20	66
Paperboard box lined with alufoil/polyolefin	0.7	1.5	1.4	26	79	240

Source: Biedermann-Brem, S. et al., *Food Addit. Contam.*, 29(3), 449, 2012.

Pace and Hartman (2010) demonstrated that although 3-MCPD was present at concentrations up to 9.9 mg kg^{-1} within the paperboard matrix, it does not migrate through polyethylene extrusion-coated paperboard beverage cartons into food simulants. Also, no significant amount of 3-MCPD migrates through the unskived edges on the inside seam of the paperboard structure.

With the increasing use of microwave-interactive packaging, there is the possibility of degradation products that might adulterate the foods they contact. The high temperatures attained by packaging using susceptor technology may result in (1) the formation of significant numbers of volatile chemicals from the susceptor components and (2) the loss of barrier properties of FCMs, leading to rapid transfer of nonvolatile adjuvants to foods. Studies by the FDA with hot vegetable oil in contact with a susceptor, have shown that the susceptor materials liberate volatile chemicals that may be retained in the oil at ppb levels. The FDA recommends the use of the protocol outlined by McNeal and Hollifield (1993) for the identification and quantification of volatiles from susceptors.

The possible migration of diisopropylnaphthalenes (DIPNs) from recycled paper and paperboard used for food contact applications has raised health concerns since it was first detected in FCMs in 1994. DIPNs are widely used for ink-jet printers and as solvents in the preparation of specialty papers such as carbonless and thermal copy paper. As not all DIPNs are removed during the recycling process, some may be present in the finished board and, under certain circumstances, migrate into food via direct contact or gas phase transport. The concentration of DIPN in food and paper packaging materials from the U.S. marketplace ranged from 0.09 to 20 mg kg^{-1} (Zhang et al., 2008). DIPNs have been detected in U.K. takeaway food packaging materials (paperboard rings around hamburgers) at levels ranging from 0.06 to 0.17 ppm in the food after a contact time of less than 10 min.

Trimethyldiphenylmethanes (TMDPMs), used as solvents in carbonless copy paper, have also been found in solid foods such as egg pasta and rice packed in paperboard containing recycled fibers. Maximum levels of TMDPM in the paperboard were 998 ppb and in egg pasta 34 ppb; DIPN was present at 72.9 ppb in the paperboard and 0.9 ppb in rice.

Perfluorochemicals are biopersistent and widely used in the manufacturing and processing of a vast array of consumer goods, including electrical wiring, clothing, household and automotive products. Furthermore, relatively small quantities are also used to coat paper and make it oil and moisture resistant. In 2005, there were reports that fluoropolymers used in the manufacture of grease-resistant packaging for candy, pizza, microwave popcorn and hundreds of other foods are absorbed by fatty foods and then broken down by the body into perfluorooctanoic acid (PFOA). PFOA was labeled a "likely" human carcinogen by the EPA in January 2006.

Begley et al. (2008) reported that fluorochemical paper additives migrated to food during actual package use. For example, microwave popcorn contained 3.2 mg fluorochemical kg^{-1} popcorn after popping, and butter contained 0.1 mg kg^{-1} after 40 days at 4°C. Tests also indicated that common food-simulating liquids for migration testing might not provide an accurate indication of the amount of fluorochemical that actually migrates; oil containing small amounts of an emulsifier significantly enhanced migration of a fluorochemical from paper. The average and high U.K. adult dietary intakes of PFOA from the diet in 2007 were estimated at 0.01 and 0.02 μg kg^{-1} body weight day^{-1} respectively, well below the TDI recently set by the EFSA of 1.5 μg kg^{-1} body weight day^{-1}.

In a study on the capability of a PP film barrier to prevent the migration of residual contaminants from recycled paperboard into food simulants, benzophenone, anthracene, methyl stearate and pentachlorophenol were chosen as chemical surrogates (Song et al., 2003). Although the concentrations of the surrogates in the food simulants decreased with an increase in PP film thickness, they were still high and generally resulted in dietary concentrations >0.5 μg kg^{-1}, the level that the FDA would equate with negligible risk for a contaminant migrating from food packaging. It was concluded that, for an extended time at 100°C, PP would not be an acceptable barrier to migration of contaminants that are expected to be in post consumer paper and paperboard.

22.6 GLASS PACKAGING

Chemically, glass is highly resistant to attack from water, aqueous solutions and organic compounds. Water and acids have very little effect on silica, although they attack some other constituents of the glass. Standard tests have been developed in which glass containers are autoclaved with various test liquids under defined conditions and the liquid analyzed for components present in the glass. Silica and alkali are the main components leached from the glass, and as the initial rate of solution varies approximately with the square root of time, a diffusion mechanism of leaching is suggested. The main chemicals extracted into aqueous solutions (i.e., silica and sodium oxide) are unlikely to have any significant effect on the organoleptic properties of foods. The danger of contamination by leaching of lead and cadmium from glass into food is remote since these two metals seldom occur in glasses used in food contact applications.

22.7 TAINTS AND OFF-FLAVORS

A *taint* is a taste or odor foreign to the product (i.e., derived from an external source such as packaging); an off-flavor is defined as an atypical flavor or odor usually associated with deterioration (e.g., microbial spoilage or lipid oxidation). Both are generally unpleasant. Although the compounds responsible for taints and off-flavors in food are frequently only present at trace levels (ppt) and thus rarely present a health risk to the consumer, they are perceived by the human senses, and consumers seldom distinguish between the two, particularly when making complaints (Ridgway et al., 2010).

The odor or taste threshold of a taint is defined as the lowest concentration of a compound detectable by a certain proportion (usually 50%) of a given group of people.

The threshold is not an inherent property of the compound, because the threshold for any substance will vary with the medium in which it is present (i.e., the food or drink) and between different people. The wide range of human thresholds to chemical stimuli is a major reason for the difficulties in preventing food taints and in positively identifying the causes of taints. The threshold concentration difference between the most sensitive 5% and the least sensitive 5% is typically 2000-fold. This is why most complaints about taint arise from only a small proportion of those purchasing a particular batch of tainted product, because in most cases only the more sensitive detect it as a taint.

Because of the complex structure and chemical composition of packaging materials, a variety of chemical reactions can occur during package manufacture and use. These reactions occur between some packaging components, with other components acting as catalysts, resulting in the formation of compounds with low odor thresholds. These compounds then migrate through the material during storage and slowly diffuse into the product or package headspace. Identification and analysis of these compounds is very difficult, and usually many isolation and concentration steps are required because the odor thresholds are lower than analytically detectable. Resolving sensory issues related to food packaging involves knowledge provided by sensory scientists, materials scientists, packaging manufacturers, food processors and consumers (Duncan and Webster, 2009).

22.7.1 Solvents

During the printing of plastic and paper packaging materials, many inks were applied dissolved or dispersed in organic solvents, which were subsequently removed by evaporation, usually in specially designed ovens. Today, water-based or UV-cured inks have replaced organic solvents to a large extent. However, if organic solvents are used, then a certain amount of residual solvent can remain. The solvents may be low MW organic compounds consisting of hydrocarbons, alcohols, glycol ethers, ketones and esters, which can then migrate into the foods by direct contact or via the free space inside the package. Fortunately, the human senses of smell and taste often show very high sensitivity to the presence of such volatiles, and, in most cases, the threshold for sensory detection of the solvents used in ink and adhesive formulations is considerably below the

toxicologically significant level. The sensory thresholds for toluene, ethyl acetate, various aldehydes and ketones range from the ppm to ppb level. Toluene and xylene, which are aromatic compounds, should be avoided in the printing of food packages. The regulatory problem is mitigated by the potential for economic damage from off-taste and odor in packaged foods. The migration of alkylbenzenes (used as solvents in offset inks) into food at a level of 2 ppm have been reported (Aurela and Söderhjelm, 2007).

22.7.2 Residual Monomers

Residual styrene monomer in PS packaging has been associated with tainting problems in different foods. The taste recognition threshold of styrene monomer in water is 22 ppb, while thresholds in foods range from 0.2 to 0.3 ppm for orange fruit juice drink, a 3% oil-in-water emulsion, and skim milk (0% fat), 1–3 ppm for whole milk and greater than 3 ppm for condensed milk (10% fat), butter, and cream (33% fat) (Baner, 2000). The taste recognition threshold in yogurt ranges from 36 ppb in 0.1% fat yogurt to 171 ppb in 3% fat yogurt.

Coffee creamers and condensed milk packaged in thermoformed PS single serve (5–10 g product) portion packs have demonstrated styrene taint problems (Baner, 2000). These products are typically packaged aseptically and stored at ambient temperature, which increases the potential for styrene taint and substantially decreases shelf life because of tainting issues. The estimated styrene concentration migrating into creamers was 23–31 ppm, far exceeding the sensory threshold of 0.1–3 ppm in cream and potentially creating a sensory impact when the cream is diluted into tea or coffee. The large surface area:volume ratio of single serve portion packs contributes to this high concentration, as does the high fat content of cream.

Monomers used in PET packaging, although not particularly odorous, can form degradation products during the manufacturing process, which can cause taints in beverages. The major significant volatile compound in PET is acetaldehyde (AA), and it was discussed in Section 20.2.3.

Although residual monomers present in polyolefins are not generally responsible for odors, oxidation compounds such as 1-heptene-3-one and 1-nonenal have been identified and these can lead to taints (Piringer and Rüter, 2000).

22.7.3 Organohalogens

The major organohalogens (organic compounds containing chlorine, bromine or iodine) of interest to the food industry are the halophenols and haloanisoles, and the structure of two of the most common are shown in Figure 22.3. Numerous cases of tainting and off-flavors in foods from contamination by organohalogens originating from packaging materials have been reported and documented in the literature. These substances have very low sensory thresholds, with the taste threshold in water for 2,4,6-trichlorophenol (TCP; described as disinfectant) being 2 ppt and the odor threshold for 2,4,6-trichloroanisole (TCA; described as musty) being 3×10^{-8} ppm. Chlorophenols have been

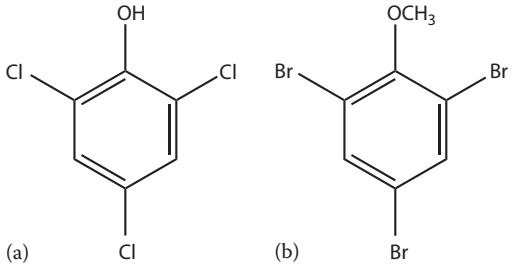

FIGURE 22.3 Structure of two of the most common organohalogen compounds: (a) 2,4,6-trichlorophenol and (b) 2,4,6-tribromoanisole.

used industrially as fungicides, biocides and herbicide intermediates, and tribromophenols (TBP) and their derivatives have been used as fire retardants as well as wood preservatives and general fungicides in leather, textiles, paint, plastics, paper and pulp. Chloro- and bromoanisoles are produced by fungal methylation of the parent halophenols under humid and warm conditions (xerophilic fungi require a moisture content between 12% and 16% and a temperature between 25°C and 35°C for germination and growth). They impart "musty" and "moldy" taints to foods at extremely low (often ppt) concentrations.

Chloroanisole-induced mustiness in dried fruit exported from Australia was found to be due to methylation of chlorophenols from virgin and recycled fiberboard cartons by fungi, with the concentration increasing with increasing RH. The total chlorophenol content in virgin kraft fiberboard was 66 ppb, and in fiberboard prepared from recycled waste paper 1375 ppb; local newsprint made up the bulk of the recovered waste used in the recycling process. The chloroanisole readily migrated through the LDPE liner into the dried fruit, producing the musty taint. Similar experiences have been recorded with multiwall paper sacks implicated in the tainting of cocoa powder, and jute sacks used to package cereal grains and flour.

Shipping containers have been responsible for many food tainting incidents with some shipping container wooden floors having concentrations of chlorophenols >15 ppb. The chlorophenols could originate from previous cargoes such as leather hides, or pretreatment of the timber floor with a chlorophenol-based preservative. Alternatively, it has been shown that when wood is treated with 5% sodium hypochlorite solution, trichlorophenols at the ppm level are formed.

Organohalogens are responsible for taints in wine, and a musty or corked character in wines (referred to as cork taint) has long been associated with 2,4,6-TCA. Around 5%–10% of corked wines are affected, and TCA is capable of producing an off-flavor in wines at levels as low as 10 ppt. The source of the TCA and other chlorinated compounds was presumed to be from chlorination of lignin-related compounds during chlorine bleaching of the corks.

Chatonnet et al. (2004) first identified 2,4,6-TBA in wines, resulting in pungent, musty odors in the absence of chloroanisoles. The TBA came from the precursor TBP, and both derived mainly from environmental pollution in wineries where the atmosphere was contaminated with TBA coming from TBP used recently to treat wood, or originating from much older structural elements of the winery or from used wooden containers. In certain cases, although the initial source had been eliminated, residual pollution adsorbed on walls or found in old barrels could be sufficient to make a building unsuitable for storing wines or sensitive materials (including corks and glass bottles) intended for direct contact with wine. Bromoanisoles have also been identified as the cause of musty odor and chemical taste in packaging where, previously, it resulted from the presence of chloroanisoles. The source of these compounds was traced to phenol-based wood preservatives used on wooden pallets and freight container floors, and, in particular, 2,4,6-TBP, which is converted to 2,4,6-TBA.

Case Study I

HDPE resin was imported into Australia in a shipping container with an LDPE liner supported by fiberboard walls and floor. The resin spent approximately 6 weeks inside the container until it was unloaded and blow molded into bottles, which were then filled with pasteurized milk. Consumer complaints resulted in a product recall and subsequent analysis of the resin and the affected milk revealed the presence of a range of organohalogens as shown in Table 22.8.

With the exception of 4-bromophenol and 2,4-dibromophenol, all the halophenols detected in the contaminated HDPE resin exceeded their taste thresholds in water; six also exceeded their odor thresholds. In the milk, five compounds (2-chlorophenol; 2,4-dichlorophenol; 2,6-dichlorophenol; 2-bromophenol and 2,4,6-tribromophenol) all exceeded their odor and taste thresholds in water. No anisoles were detected, indicating that the container floor was probably quite dry. To avoid repeat incidents, rigorous container inspection procedures prior to loading have been introduced by the resin supplier, and a plastic–alufoil laminate sheet is used to cover the container floor. In addition, sensory testing methods of incoming resin prior to unloading into silos at the blow molding site have been upgraded.

TABLE 22.8
Concentrations of Organohalogens Detected in HDPE Resin and Milk[a]

Organohalogen	Odor Taste Thresholds µg/L (ppb)		Resin	Milk
2-Chlorophenol	0.4	0.1	0.4	0.9–3.36
4-Chlorophenol	20	39		n/d–1.88[b]
2,4-Dichlorophenol	0.4	0.3	2.1	1.14–12.59
2,6-Dichlorophenol	3.5	0.0062	9.6	n/d–29.16
2,4,6-Trichlorophenol	300	2	3.0	n/d–0.42[b]
2-Bromophenol	0.1	0.03	0.7	0.28–1.07
4-Bromophenol	4	23	3.0	n/d–0.01[b]
2,4-Dibromophenol	0.5	4	1.3	n/d
2,6-Dibromophenol	0.1	0.0005	0.7	n/d
2,4,6-Tribromophenol	0.1	0.6	33.9	1.09–272

[a] Twelve different samples that gave rise to consumer complaints.
[b] Below odor and taste threshold concentrations in water.

Case Study II
Consumer feedback cited a musty aroma in freshly canned beer and subsequent analysis identified TBA as the primary entity at levels of 10–40 ppt. Further investigations in the brewery identified the same musty taint in an unbroached pallet of empty can bodies. The can bodies were transported to the brewery by sea freight—a journey lasting 10 days. Climatic conditions during transport and production periods were warm and humid (>30°C and often >60% RH over 14 consecutive days).

An audit of the production facilities found no evidence of atmospheric TBA contamination within the packaging operations of the brewery. However, the floor of the shipping container used to transport the can bodies was found to contain TBA at very high levels (15 g kg^{-1}) and this was the most likely origin of the TBA taint.

Conclusions and Recommendations
Although the mechanism of organohalogen tainting has been studied since the 1960s and the scientific literature is considerable, they continue to be a major source of concern to the food industry and of annoyance to consumers. While there are seldom health concerns arising from taints, the tainting is very objectionable and the threshold levels are extraordinarily low. The food industry has experienced (and continues to experience) many cases of organohalogen tainting resulting in serious losses. Tainting of any component within the ingredient and packaging supply chain may lead to a taint in the packaged food. Most of these incidents are avoidable if the following recommendations are implemented:

1. TBP used either as a preservative, fungicide or fire retardant poses ongoing risks to food contamination and should not be used where it may transfer to food packaging materials.
2. Recycled timber, paperboard products and polymer plastics provide a source of potential taint compounds.
3. Timber pallets and the floors in shipping containers should be closely assessed for taints and, where necessary, covered with a plastic–alufoil laminate barrier as a precaution.
4. Environmental taint potential should be assessed adopting Hazop protocols within a production facility.
5. TCP and TBP levels within the material supply chain should be managed to defined levels within a QA program.

22.7.4 Miscellaneous

The development of a "catty" odor (described elsewhere as *ribes* [blackcurrant leaves from the botanical name *Ribes nigrum* for blackcurrant] or tomcat urine) has been identified in many foods as a result of interactions between food and migrants from packaging. Such odors have been attributed to a sulfur-containing compound 4-methyl-4-mercaptopentan-2-one, which is a hydrogen sulfide adduct of mesityl oxide and has an odor threshold of 10 ppt. Investigations into catty odor in two different "cook-in-the-bag" ham products demonstrated that the mesityl oxide originated from diacetone alcohol (DAA), which was present as a residual printing ink solvent (Franz et al., 1990). Formation of the mesityl oxide was thought to have arisen from dehydration of the DAA, promoted by some property of the ethylene ionomer sealing layer in the multilayer packaging film. Mesityl oxide can also be formed from acetone, which is sometimes used as a solvent in coatings and adhesives. Avoiding the use of mesityl oxide precursors such as DAA in packaging materials can prevent the occurrence of catty odor in sulfur-rich foods. Mesityl oxide is not a true oxide and was assigned this name at an early date because of an erroneous conception of its chemical nature. It is, in fact, an α,β-unsaturated ketone with the formula $(CH_3)_2C{=}CHCOCH_3$ and has a peppermint-like odor (Tice, 1996).

Off-flavor in two-piece cans was shown to be caused by the lubricant used in their production. Fatty acids and esters (normal constituents of the lubricants) are easily oxidized and can contaminate the packaged beer, causing stale, rancid, woody or cardboard-like flavors. A potent flavor constituent of mineral oil (used to aid forming of the cans), which appeared to be naphthenic in nature, has also been found. To eliminate this problem, additional washings were included employing cleaning materials specifically effective at removing fatty acids, esters and mineral oil.

Beer is particularly sensitive to the pickup of off-flavors from metal packaging. If the enamel coating is disrupted in a steel can, a metallic flavor will develop as iron migrates into the beer. With aluminum cans, the off-flavor that develops is sulfury rather than metallic because of galvanic reactions.

22.8 TRACEABILITY

One of the consequences of globalization is that it has become more difficult to trace the origin of our foods and the packaging that surrounds them. Regulatory authorities simply cannot analyze every package on the market for the thousands of possible contaminants that may be present in the packaging material, the adhesives, the ink or the food itself.

Traceability has become an integral requirement of modern quality management systems. In the EU, Article 17 of Regulation 1935/2004/EC requires FCMs or articles to be unequivocally identified when they are shipped to the next operator in the value chain. For materials or articles sourced from outside the EU, traceability extends back to the importer responsible for putting them on the EU market for the intended food contact application. Just how successfully the importer could trace back the origin of the material is unknown.

REFERENCES

Anderson W.A.C., Castle L. 2003. Benzophenone in cartonboard packaging materials and the factors that influence its migration into food. *Food Additives and Contaminants* 20: 607–618.

Aurela B., Söderhjelm L. 2007. Food packaging inks and varnishes and chemical migration into food. In: *Chemical Migration and Food Contact Materials*, Barnes K.A., Sinclair C.R., Watson D.H. (Eds). Cambridge, England: Woodhead Publishing, pp. 302–319.

Bach C., Dauchy X., Chagnon M.-C., Etienne S. 2012. Chemical compounds and toxicological assessments of drinking water stored in polyethylene terephthalate (PET) bottles: A source of controversy reviewed. *Water Research* 46: 571–583.

Baner A.L. 2000. Case study: Styrene monomer migration into dairy products in single serve portion packs. In: *Plastic Packaging Materials for Food: Barrier Function, Mass Transport, Quality Assurance, and Legislation*, Piringer O.-G., Baner A.L. (Eds). New York: Wiley-VCH, pp. 427–443.

Baughan J.S., Attwood D. 2010. Food packaging law in the United States. In: *Global Legislation for Food Packaging Materials*, Rijk R., Veraart R. (Eds). Weinheim, Germany: Wiley-VCH, pp. 223–242.

Begley T.H., Hsu W., Noonan G., Diachenko G. 2008. Migration of fluorochemical paper additives from food-contact paper into foods and food simulants. *Food Additives and Contaminants* 25: 384–390.

Beronius A., Rudén C., Håkansson H, Hanberg A. 2010. Risk to all or none? A comparative analysis of controversies in the health risk assessment of Bisphenol A. *Reproductive Toxicology* 29: 132–146.

Biedermann M., Ingenhoff J.-E., Barbanera M., Garbini D., Grob K. 2011. Migration of mineral oil into noodles from recycled fibres in the paperboard box and the corrugated board transport box as well as from printing inks: a case study. *Packaging Technology and Science* 24: 281–290.

Biedermann-Brem S., Kasprick N., Simat T., Grob K. 2012. Migration of polyolefin oligomeric saturated hydrocarbons (POSH) into food. *Food Additives and Contaminants* 29: 449–460.

Biles J. E., White K. D., McNeal T. P., Begley T. H. 1999. Determination of the diglycidyl ether of bisphenol A and its derivatives in canned foods. *Journal of Agricultural and Food Chemistry* 47: 1965–1969.

Blunden S., Wallace T. 2003. Tin in canned food: A review and understanding of occurrence and effect. *Food and Chemical Toxicology* 41: 1651–1662.

Boobis A.R., Daston G.P., Preston R.J., Olin S.S. 2009. Application of key events analysis to chemical carcinogens and noncarcinogens. *Critical Reviews in Food Science and Nutrition* 49: 690–707.

Bueno-Ferrer C., Jiménez A., Garrigós M.C. 2010. Migration analysis of epoxidized soybean oil and other plasticizers in commercial lids for food packaging by gas chromatography-mass spectrometry. *Food Additives and Contaminants* 27: 1469–1477.

Cao X.-L. 2010. Phthalate esters in foods: Sources, occurrence, and analytical methods. *Comprehensive Reviews in Food Science and Food Safety* 9: 21–43.

Castle L. 2001. Chemical migration from food packaging. In: *Food Chemical Safety*, Vol. 1. Watson D.H. (Ed.). Boca Raton, FL: CRC Press, pp. 193–217.

Chatonnet P., Bonnet S., Boutou S., Labadie M.D. 2004. Identification and responsibility of 2,4,6-tribromoanisole in musty, corked odors in wine. *Journal of Agricultural and Food Chemistry* 52: 1255–1262.

Cirillo T., Fasano E., Castaldi E., Montuori P., Cocchieri R.A. 2011. Children's exposure to di(2-ethylhexyl) phthalate and dibutylphthalate plasticizers from school meals. *Journal of Agricultural and Food Chemistry* 59: 10532–10538.

Colborn T., Dumanoski D., Myers J.P. 1997. *Our Stolen Future: Are We Threatening our Fertility, Intelligence and Survival?—A Scientific Detective Story with a New Epilogue by the Authors*. New York: Penguin.

Cooper I. 2008. Plastics and chemical migration into food. In: *Chemical Migration and Food Contact Materials*, Barnes K.A., Sinclair C.R., Watson D.H. (Eds). Cambridge, England: Woodhead Publishing, pp. 228–250.

Crank J. 1975. *The Mathematics of Diffusion*, 2nd edn. Oxford, England: Clarendon Press.

Cruz S.A., Zanin M., Nerin C., De Moraes M.A.B. 2006. Study of barrier properties and chemical resistance of recycled PET coated with amorphous carbon through a plasma enhanced chemical vapour deposition (PECVD) process. *Food Additives and Contaminants* 23: 100–106.

De Meulenaer B. 2009. Migration from packaging materials. In: *Predictive Modeling and Risk Assessment*, Costa R., Kristbergsson K. (Eds). New York: Springer Science + Business Media, pp. 139–151.

Duncan S.E., Webster J.B. 2009. Sensory impacts of food-packaging interactions. *Advances in Food and Nutrition Research* 56: 17–64.

Fiselier K., Grob K. Barriers against the migration of mineral oil from paperboard food packaging: Experimental determination of breakthrough periods. *Packaging Technology and Science* (in press) DOI: 10.1002/pts.982.

Foster E., Mathers J.C., Adamson A.J. 2010. Packaged food intake by British children aged 0–6 years. *Food Additives and Contaminants* 27: 380–388.

Franz R., Kluge S., Lindner A., Piringer O. 1990. Cause of catty odor formation in packaged food. *Packaging Technology and Science* 3: 89–95.

Grob K., Pfenninger S., Pohl W., Laso M., Imhof D., Rieger K. 2007. European legal limits for migration from food packaging materials: 1. Food should prevail over simulants; 2. More realistic conversion from concentrations to limits per surface area. PVC cling films in contact with cheese as an example. *Food Control* 18: 201–210.

Guidance for Industry: Preparation of Premarket Submissions for Food Contact Substances: Chemistry Recommendations. U.S. Food and Drug Administration, 2007. Available at www.fda.gov/Food/GuidanceComplianceRegulatoryInformation/GuidanceDocuments/FoodIngredientsandPackaging/ucm081818.htm

Harrison N. 2001. Environmental organic contaminants in food. In: *Food Chemical Safety*, Vol. 1. Watson D.H. (Ed.). Boca Raton, FL: CRC Press, pp. 169–192.
Heckman J.H. 1992. Safety and regulation. In: *Plastics in Food Packaging*, Brown W.E. (Ed.). New York: Marcel Dekker, pp. 397–420.
Heckman J.H. 2005. Food packaging regulation in the United States and the European Union. *Regulatory Toxicology and Pharmacology* 42: 96–122.
Hoekstra E.J., Simoneau C. Release of bisphenol A from polycarbonate—A review. *Critical Reviews in Food Science and Nutrition* (in press). DOI: 10.1080/10408398.2010.536919.
IFT Expert Report. 2009. Making decisions about the risks of chemicals in foods with limited scientific information. *Comprehensive Reviews in Food Science and Food Safety* 8: 269–303.
Johns S.M., Jickells S.M., Read W.A., Castle L. 2000. Studies on functional barriers to migration. 3. Migration of benzophenone and model ink components from cartonboard to food during frozen storage and microwave heating. *Packaging Technology and Science* 13: 99–104.
Jorhem L. Slorach S. 1987. Lead, chromium, tin, iron and cadmium in foods in welded cans. *Food Additives and Contaminants* 4: 309–316.
Kawamura Y., Inoue K., Nakazawa H., Yamada T., Maitani T. 2001. Cause of bisphenol A migration from cans for drinks and assessment of improved cans. *Journal of the Food Hygienic Society of Japan* 42: 13–17.
Koivikko R., Pastorelli S., Rodríguez-Bernaldo de Quirós A., Paseiro-Cerrato R., Paseiro-Losada P., Simoneau C. 2010. Rapid multi-analyte quantification of benzophenone, 4-methylbenzophenone and related derivatives from paperboard food packaging. *Food Additives and Contaminants* 27: 1478–1486.
Lee Y.S., Shin H.-S., Han J.-K., Lee M., Giacin J.R. 2004. Effectiveness of antioxidant-impregnated film in retarding lipid oxidation. *Journal of the Science of Food and Agriculture* 84: 993–1000.
Lhuguenot J.-C. 2009. Recent European Food Safety Authority toxicological evaluations of major phthalates used in food contact materials. *Molecular Nutrition and Food Research* 53: 1063–1070.
Magnuson B.A., Bouwmeester H. 2011. Toxicity of nanomaterials in food. In: *Nanotechnology in the Agri-Food Sector: Implications for the Future*, Frewer L.J., Norde W., Fischer A., Kampers F. (Eds). Weinheim, Germany: Wiley-VCH, pp. 173–190.
McNeal T.P., Hollifield H.C. 1993. Determination of volatile chemicals released from microwave-heat-susceptor food packaging. *Journal of AOAC International* 76: 1268–1275.
Mercea P., Piringer O.G. 2008. Possibilities and limitations of migration modeling. In: *Plastic Packaging: Interactions with Food and Pharmaceuticals*, 2nd edn., Piringer O.G., Baner A.L. (Eds). New York: Wiley-VCH, pp. 499–522.
Middlekauf R.D. 1985. Delaney meets de minimus. *Food Technology* 39(11): 62–69.
Monsanto v. Kennedy, 613 F.2d 947, 955 (DC Circuit 1979). United States Court of Appeals.
Muncke J. 2011. Endocrine disrupting chemicals and other substances of concern in food contact materials: An updated review of exposure, effect and risk assessment. *Journal of Steroid Biochemistry and Molecular Biology* 127: 118–127.
Munro I.C., Hlywka J.J., Kennepohl E.M. 2002. Risk assessment of packaging materials. *Food Additives and Contaminants* 19: 3–12.
Murphy T.P., Amberg-Müller J.P. 1996. Metals. In: *Migration from Food Contact Materials*, Katan L.L. (Ed.). London, U.K.: Blackie Academic & Professional, pp. 111–144.
Nelson C.P., Patton G.W., Arvidson K., Lee H., Twaroski M.L. 2011. Assessing the toxicity of polymeric food-contact substances. *Food and Chemical Toxicology* 49: 1877–1897.
Neltner T.G., Kulkarni N.R., Alger H.M., Maffini M.V., Bongard E.D., Fortin N.D., Olson E.D. 2011. Navigating the U.S. food additive regulatory program. *Comprehensive Reviews in Food Science and Food Safety* 10: 342–368.
Nollet L.M.L. 2011. *Analysis of Endocrine Disrupting Compounds in Food*. New York: Wiley-Blackwell.
Noonan G.O., Ackerman L.K., Begley T.H. 2011. Concentration of bisphenol A in highly consumed canned foods on the U.S. market. *Journal of Agricultural and Food Chemistry* 59: 7178–7185.
Oldring P.K.T. 2008. Exposure estimation—The missing element for assessing the safety of migrants from food. In: *Chemical Migration and Food Contact Materials*, Barnes K.A., Sinclair C.R., Watson D.H. (Eds). Cambridge, England: Woodhead Publishing, pp. 122–157.
Pace G.V., Hartman T.G. 2010. Migration studies of 3-chloro-1,2-propanediol (3-MCPD) in polyethylene extrusion-coated paperboard food packaging. *Food Additives and Contaminants* 27: 884–891.
Piringer O. 2007. Mathematical modelling of chemical migration from food contact materials. In: *Chemical Migration and Food Contact Materials*, Barnes K.A., Sinclair C.R., Watson D.H. (Eds). Cambridge, England: Woodhead Publishing, pp. 180–202.

Piringer O.-G., Rüter M. 2000. Sensory problems caused by food and packaging interactions. In: *Plastic Packaging Materials for Food. Barrier Function, Mass Transport, Quality Assurance and Legislation*, Piringer O.-G., Baner A.L. (Eds). New York: Wiley-VCH, pp. 407–426.

Poças M.F., Oliveira J.C., Brandsch R., Hogg T. 2012. Analysis of mathematical models to describe the migration of additives from packaging plastics to foods. *Journal of Food Process Engineering* 35: 657–676.

Reilly C. (Ed.). 2007. *Metal Contamination of Food: Its Significance for Food Quality and Human Health*, 3rd edn. Oxford, England: Blackwell Science.

Richter T., Gude T., Simat T. 2009. Migration of novel offset printing inks from cardboard packaging into food. *Food Additives and Contaminants* 26: 1574–1580.

Ridgway K., Lalljie S.P.D., Smith R.M. 2010. Analysis of food taints and off-flavours: A review. *Food Additives and Contaminants* 27: 146–168.

Rijk R., Veraart R. (Eds). 2010. *Global Legislation for Food Packaging Materials*. Weinheim, Germany: Wiley-VCH.

Rothenbacher T., Baumann M., Fügel D. 2007. 2-Isopropylthioxanthone (2-ITX) in food and food packaging materials on the German market. *Food Additives and Contaminants* 24: 438–444.

Schenk, R.U., Bjorksten J., Yeager L. 1989. Composition and consequences of aluminum in water, beverages and other ingestibles. In: *Environmental Chemistry and Toxicology of Aluminum*, T.E. Lewis (Ed.). Chelsea, MI: Lewis Publishers, Inc., pp. 247–270.

Sharpe R.M. 2010. Is it time to end concerns over the estrogenic effects of bisphenol A? *Toxicological Sciences* 114: 1–4.

Simal-Gándara J., Paz-Abuín S, Ahrné L. 1998. A critical review of the quality and safety of BADGE-based epoxy coatings for cans: Implications for legislation on epoxy coatings for food contact. *Critical Reviews in Food Science and Nutrition* 38: 675–688.

Song Y.S., Begley T., Paquette K., Komolprasert V. 2003. Effectiveness of polypropylene film as a barrier to migration from recycled paperboard packaging to fatty and high-moisture food. *Food Additives and Contaminants* 20: 875–883.

Song H., Li B., Lin Q.-B., Wu H.-J., Chen Y. 2011. Migration of silver from nanosilver–polyethylene composite packaging into food simulants. *Food Additives and Contaminants* 28: 1758–1762.

Tice P. 1996. Packaging material as a source of taints. In: *Food Taints and Off-Flavours*, 2nd edn., Saxby M.J. (Ed.). Glasgow, U.K.: Blackie Academic & Professional, pp. 226–263.

Till D.E., Ehntholt D.J., Reid R.C., Schwartz P.S., Sidman K.R., Schwope A.D., Whelan R.H. 1982. Migration of BHT antioxidant from high density polyethylene to foods and food simulants. *Industrial and Engineering Chemistry Product Research and Development* 21:106–113.

Vitrac O., Leblanc J.-C. 2007. Consumer exposure to substances in plastic packaging. I. Assessment of the contribution of styrene from yogurt pots. *Food Additives and Contaminants* 24: 194–215.

Welle F., Franz R. 2008. SiO_x layer as functional barrier in polyethylene terephthalate (PET) bottles against potential contaminants from post-consumer recycled PET. *Food Additives and Contaminants* 25: 788–794.

Zeckhauser R. 1979. Social and economic factors in food safety decision-making. *Food Technology* 33(11): 47–52, see also p. 60.

Zhang K., Noonan G.O., Begley T.H. 2008. Determination of 2,6-diisopropylnaphthalene (DIPN) and n-dibutylphthalate (DBP) in food and paper packaging materials from US marketplaces. *Food Additives and Contaminants* 25: 1416–1423.

Zygoura P.D., Riganakos K.A., Kontominas M.G. 2011. Study of the migration behavior of acetyl tributyl citrate from PVDC/PVC film into fish fillets as affected by intermediate doses of electron beam radiation. *European Food Research and Technology* 232: 1017–1025.