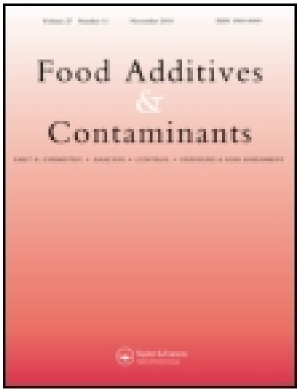

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Active and intelligent packaging: applications and regulatory aspects

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Changes in the way foods are produced, distributed, stored and retailed, reflecting the continuing increase in consumer demands for improved quality and extended shelf-life for packaged foods, are placing ever-greater demands on the performance of food packaging. Consumers want to be assured that the packaging is fulfilling its function of protecting the integrity, quality, freshness and safety of foods. To provide this assurance and help improve the performance of the packaging, innovative active and intelligent packaging concepts are being developed and applied in various countries. In Europe, however, the development and application of active and intelligent packaging systems have been limited thus far. The main reasons are legislative restrictions and a lack of knowledge about consumer acceptance, the efficacy of such systems, and the economic and environmental impact they may have. Therefore, in 1999, a European study was started within the framework of the EU FAIR R&D programme. It aims to initiate amendments to European legislation for food-contact materials to establish and implement active and intelligent systems within the current relevant regulations for packaged food in Europe. This paper presents an overview of existing active and intelligent systems and their current and future food-related applications. In addition, developments and trends in active and intelligent food packaging are discussed. The objectives and the work programme of the European project are reviewed and the results obtained so far are presented. The benefits for both the European consumer and the European food and food-packaging industries are highlighted.

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Introduction

In recent years, new food-packaging systems have been developed as a response to trends in consumer preferences towards mildly preserved, fresh, tasty and convenient food products with a prolonged shelf-life. In addition, changes in retail practices, such as centralization of activities (e.g. preparation of retail packs of fresh meat and sliced vegetables) and the globalization of markets resulting in longer distribution distances, present major challenges to the food-packaging industry to develop packaging concepts that extend shelf-life while maintaining the safety and quality of the packaged food.

Traditional systems are reaching their limits with regard to further extension of shelf-life of packaged food. To provide this shelf-life extension, and to improve the quality, safety and integrity of the packaged food, innovative active and intelligent packaging concepts are being developed.

Active and intelligent packaging may be defined as follows.

- Active packaging changes the condition of the packaged food to extend shelf-life or improve food safety or sensory properties, while maintaining the quality of the packaged food.
- Intelligent packaging systems monitor the condition of packaged foods to give information

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about the quality of the packaged food during transport and storage.

Food condition in the definition of active packaging encompasses various aspects that may play a role in determining the shelf-life of packaged foodstuffs, such as physiological processes (e.g. respiration of fresh fruits and vegetables), chemical processes (e.g. lipid oxidation), physical processes (e.g. staling of bread, dehydration), microbiological aspects (e.g. spoilage by microorganisms) and infestation (e.g. by insects). These conditions can be regulated in numerous manners through the application of appropriate active-packaging systems. Depending on the requirements of the packaged food, food quality deterioration can be significantly reduced. In this manner, the desired extension of the shelf-life of the packaged food can be achieved.

Examples of active-packaging systems are oxygen scavengers, ethylene absorbers, moisture regulators, taint removal systems, ethanol and carbon dioxide emitters, and antimicrobial-releasing systems.

Typical examples of intelligent packaging include indicators of gas leaks, time–temperature history and microbial spoilage.

In the USA, Japan and Australia, active and intelligent packagings are already being successfully applied to extend shelf-life or to monitor food quality and safety. In Europe, however, only a few of these systems have been developed and are being applied. This backlog is partly due to the strict European regulations for food-contact materials that cannot keep up entirely with technological innovations and currently prohibit the application of many of these systems. In addition, a lack of knowledge about consumer acceptance, economic aspects and the environmental impact of these novel concepts and, in particular, the lack of hard evidence of their effectiveness demonstrated by independent investigators has inhibited commercial usage.

No European regulation currently covers specifically the use of active and intelligent packaging.

The existing packaging regulations require compounds in contact with food to be included in approved lists of compounds. These 'positive lists' usually include only components used to prepare or improve the packaging material, not constituents used for other purposes such as extending or monitoring the shelf-life of the packaged food. Therefore, most active and intelligent agents are not yet listed. In addition, the overall migration from the packaging material into the food is set at a maximum of 60 mg kg^{-1} food. This may be said to be incompatible with the objective of active packagings, especially when the system is designed to release active ingredients into foods to extend their shelf-life or to improve their quality. Thus, a new approach for food-packaging regulations is required.

Therefore, in 1999, a European study was started within the framework of the EU FAIR R&D programme. The study aims at initiating amendments to European legislation for food-contact materials to establish and implement active and intelligent systems within the current relevant regulations for packaged food in Europe.

This paper presents an overview of existing active and intelligent systems and their current and future food-related applications. In addition, developments and trends in active and intelligent food packaging are discussed.

The objectives and the work programme of the European project are reviewed and the results obtained so far are presented.

The benefits for both the European consumer and the European food and food-packaging industries are highlighted.

Active systems

Active-packaging systems can be classified into active scavenging systems (absorbers) and active-releasing systems (emitters). Scavenging systems remove undesired compounds such as oxygen, excessive water, ethylene, carbon dioxide, taints and other specific food compounds. Releasing systems actively add compounds to the packaged food such as carbon dioxide, water, antioxidants or preservatives. Both absorbing and releasing systems aim at extending shelf-life and/or improving food quality. In a recent paper, the developments in the active packaging of foods are described in great detail (Vermeiren *et al.* 1999). Here only a compendious survey of the major active systems is presented.

Oxygen scavengers

Oxygen present in food packages accelerates spoilage and deterioration of many foods. The oxygen present may derive from oxygen permeability of the packaging material, air enclosed in the food and packaging material, small leakages due to poor sealing and inadequate evacuation and/or gas flushing (Smith *et al.* 1986).

Oxygen may cause off-flavours (e.g. rancidity as a result of lipid oxidation), colour changes (e.g. discoloration of plant pigments such as chlorophyll and carotenoids, meat oxidation) and nutrient losses (e.g. oxidation of vitamin E, ß-carotene (pro-vitamin A), ascorbic acid (vitamin C)). Oxygen may also facilitate microbial growth (e.g. aerobic bacteria) and the growth of insects, and it has a considerable effect on the respiration rate and ethylene production of respiring foodstuffs such as fruits and vegetables.

Removal of oxygen reduces the effects of the shelf-life-limiting processes described above. Consequently, the application of oxygen scavengers will have a shelf-life extending effect on various foods.

In general, existing oxygen-scavenging technologies utilize one or more of the following mechanisms: iron powder oxidation, ascorbic acid oxidation, photosensitive dye oxidation, enzymatic oxidation (e.g. glucose oxidase/catalase and alcohol oxidase), ferrous salts, unsaturated fatty acids (e.g. oleic and linoleic acids), and combinations of these (Floros *et al.* 1997, Day 2000).

Oxygen scavengers can be applied as sachets containing oxygen-absorbing components, which are inserted into the package or are adhesive-bonded to the inner wall of the package (usually called a label), or they can be incorporated in the closure or in the packaging material through dissolution or dispersion into the plastic material or immobilization of oxidizing enzymes in the packaging material.

Oxygen scavengers are the most investigated and most patented of all active-packaging technologies. Until 1989, more than 50 patents involving oxygen scavengers had been granted across the world. From 1990 to 1994, more than 20 new patents concerning this particular technology have been issued (Floros *et al.* 1997). The use of discrete sachets containing oxygen absorbents has already found commercial application. The active agent is usually iron powder. The main commercial iron-based oxygen scavengers in sachet form include: Ageless (Mitsubishi Gas Chemical Co., Japan), ATCO® (Standa Industries, France), the Freshilizers series (Toppan Printing, Japan) and Freshpax® (Multisorb Technologies, Inc., USA). The main advantages of these scavenging sachets are that they can reduce oxygen levels to $<0.01\%$, which is significantly lower than the residual oxygen levels achievable by modified atmosphere packaging (0.3–3%), and that they have a higher oxygen-absorbing capacity than other oxygen-scavenging systems. A commercially available oxygen-removing sachet based on reactions catalysed by food-grade enzymes is the Bioka oxygen absorber (Bioka, Finland).

Although sachets are still widely used in Japan and, to a lesser extent, in the USA, there is an increased interest in the development of integrated oxygen-scavenging systems for different types of packaging materials and food applications.

Recent developments of integrated systems include oxygen-scavenging labels such as Freshmax® (Multisorb Technologies, Inc., USA), Ageless and ATCO®, and incorporation of oxygen scavengers in closure seal liners for beer and soft drink bottles such as Smartcap (ZapatA Industries, USA) and Daraform (W. R. Grace & Co., USA).

Other examples of oxygen-scavenging systems that can be incorporated in the packaging are: Oxyguard (Toyo Seikan Kaisha, Japan) and Oxbar™ (Carnaud Metal Box, UK). Examples of light-activated scavengers integrated in the packaging are Zero$_2$™ developed by CSIRO and marketed by Southcorp Packaging (Australia) and Cryovac® OS 1000 (Cryovac Sealed Air Co., USA). In addition, Amoco Chemicals (USA) has developed a polymer-based oxygen absorber for incorporation in various packaging materials, i.e. Amosorb® (Day 2000).

Incorporation of oxygen scavengers in packaging material requires that the oxygen-scavenging system is not affected by oxygen before use. The system must thus be activated.

Several mechanisms have been described (Rooney 1995b) such as addition of a reagent on package filling, supply of water as solvent or swelling agent during package filling, continuous exposure to light as energy source and activation of a chain reaction (e.g. autoxidation) or photoreduction of the scavenger precursor upon short exposure to light.

In general, the speed and capacity of oxygen-scavenging systems incorporated in the packaging materials are considerably lower than those of (iron-based) oxygen scavenger sachets and labels.

The effectiveness of oxygen scavengers has been demonstrated for various foodstuffs including bakery products, fish and meat products (Nakamura and Hoshino 1983, Smith *et al.* 1986, Gill and McGinnes 1995, Schozen *et al.* 1997, Berenzon and Saguy 1998).

Ethylene scavengers

Ethylene acts as a hormone and triggers ripening, accelerates senescence, induces flowering, accelerates softening, increases chlorophyll degradation, and reduces shelf-life of fresh and minimally processed fruits and vegetables.

Several ethylene-scavenging systems are available. Some absorbers are based on potassium permanganate ($KMnO_4$), which is not integrated directly into food-contact materials because of its toxicity. It is usually applied in sachets inside produce packages. The sachet material itself is highly permeable to ethylene, and diffusion through it is not a limiting factor. Potassium permanganate oxidizes ethylene to acetate and ethanol. Potassium permanganate-based scavengers typically contain 4–6% $KMnO_4$ on substrates such as perlite, alumina, silica gel, vermiculate, activated carbon or celite (Zagory 1995). The scavenging capacity and efficiency of those ethylene scavengers strongly depends on the substrate surface area and the content of potassium permanganate reagent.

In addition, metal catalysts (e.g. palladium) on activated carbon can effectively remove ethylene.

Neupalon™ is an ethylene-scavenging sachet produced in Japan by Sekisui Jushi Ltd, and contains activated carbon and a water absorbent capable of absorbing up to 500–1000 times its weight of water. The supplier claims that the Neupalon™ sachets have an ethylene-absorbing capacity of 40 ml ethylene m^{-2}. Another ethylene scavenger, produced by Honshu Paper in Japan (Hatofresh System), is based on activated carbon impregnated with bromine-type inorganic chemicals. The carbon–bromine substance is embedded in a paper bag or corrugated box, which is used to hold the fresh produce. The producer claims an absorbing capacity of 20 ml ethylene g^{-1} absorbent. Application of these bags for packaging of foods is unlikely because of the reaction of bromine compounds with water, which can release toxic bromine gas (Zagory 1995, Labuza 1996).

Other ethylene-removing systems are based on the ability of certain finely dispersed minerals (e.g. pumice, zeolite, active carbon, cristobalite or clinoptilolite) to absorb ethylene. Those minerals are incorporated in, for example, polyethylene bags, which are used to package fresh fruits and vegetables. Although the incorporated minerals may absorb ethylene, they also could alter the permeability of the films so that ethylene and CO_2 will diffuse more rapidly and oxygen will enter more readily than through pure polyethylene. These effects can improve shelf-life and reduce headspace ethylene concentrations independently of any ethylene absorption. Commercially available examples of mineral-containing packaging materials are Evert-Fresh (Evert-Fresh Co., USA) and Peakfresh™ (Peakfresh Products, Australia).

Although there are a number of ethylene-scavenging sachets and films marketed to date, the evidence provided by the producers often fails to demonstrate the shelf-life-extending capacity of these systems. Based on the results of validation studies on ethylene scavengers, Zagory (1995) concluded that a profound understanding of the physiological effects of ethylene on shelf-life is required before application of such systems in food-packaging material.

Moisture-controlling systems

Several food products require control of liquid and gaseous water. For example, packed horticultural produce easily build up excessive water vapour through their respiration activity. High relative-humidity (RH) products are susceptible to temperature fluctuations during transport, resulting in the formation of condensate. The presence of too high levels of water in the packed food often favours growth of microorganisms as well as fogging of the plastic packaging. It also causes softening of dry crispy products, such as biscuits and crackers, caking of milk powder and instant coffee and wetting of hygroscopic products such as sweets and candies.

On the other hand, excessive water evaporation through the packaging material might result in desiccation of the packed foodstuff and/or favour lipid oxidation.

Obviously, food stability is closely related to the water activity (a_w) of the product, which is affected by the relative humidity in the headspace of the packed food.

According to Rooney (1995b), there are two distinct manners to regulate the moisture content of packed foodstuffs, namely by liquid water control or by humidity buffering.

The control of excessive water (liquid water control) can be carried out by application of drip-absorbent sheets such as Toppan sheet (Toppan Printing Co., Japan), Peaksorb® (Peakfresh Products, Australia) and Dri-Loc (Cryovac Sealed Air, USA). The cross-linking agent in the hydrogel used in Dri-Loc has been approved by the SCF (Scientific Committee for Food) for application in food-contact materials, which implies that all monomers used to manufacture the moisture-absorbing hydrogel are in compliance with the positive list of the EU. However, the application of the hydrogel is restricted to the use as moisture-absorbing agent.

Those drip-absorbent sheets are usually composed of two layers of microporous or non-woven polymer (e.g. polyethylene, polypropylene), which enclose a layer of superabsorbent polymer such as polyacrylate salts or cellulose fibres. The sheets can be used as pads under, for example, whole/sliced fresh poultry and meat to absorb drip, to improve the presentation of the product to consumers. Similar sheets are used for the absorption of melting ice water in the packaging of seafood for air transport.

Another manner to control excess moisture in packed food is to regulate the relative humidity of the packed food (humidity buffering) by means of humectants. These humectants can be placed between two plastic films. A suitable humectant is propylene glycol. This sandwich concept requires that the inner plastic layer is highly permeable to water vapour.

An example of such sandwich concept is Pichit™ (Showa Denko KK, Japan). The humectant consisting of propylene glycol and a carbohydrate is placed between two sheets of polyvinyl alcohol. Pichit™ is marketed for use in households for wrapping meat or fish to reduce the a_w proximate to the food.

In general, these water-regulating sheets can be used by food packers or in households for wrapping pieces of flesh food such as fish, meat and poultry.

In addition, for horticultural produce humidity-buffering systems are under development.

The humidity-controlling capacity of dry sorbitol, xylitol, NaCl, KCl and $CaCl_2$ enclosed in polyethylene pouches in modified atmosphere-packed tomatoes has been studied by Shirazi and Cameron (1992), who showed that the storage life of packaged red-ripe tomatoes at 20°C was extended from 5 days with no pouch to 15–17 days with a pouch containing sodium chloride, mainly by retarding surface mould development (Ahvenainen *et al.* 1999).

Taint scavengers

Until now, only few packaging materials have been commercially used selectively to remove undesirable flavour or aroma components of foods. There are, however, a number of opportunities.

For example, the inclusion of cellulose triacetate in the packaging material of orange juice might remove bitter tasting components such as limonin formed during standing and/or pasteurization of the juice. Another bitter-tasting component found in most fresh citrus fruit juices is naringin. Soares and Hotchkiss (1998a, b) reduced both the naringin and limonin contents of grapefruit juice by using cellulose acetate films that contained the immobilized enzyme naringinase.

Removal of aldehydes such as hexanal and heptanal from the package headspace is claimed by Dupont Polymers (USA) for a Bynel IXP 101 master batch blended with unmodified HDPE or other linear polyethylenes to form an intermediate layer in co-extrusion (Rooney 1995b).

Another potential application might be the removal of amines resulting from protein breakdown in fish muscle. The amines formed include strongly basic compounds that are potentially susceptible to interaction with acidic components such as citric acid and ascorbic acid. Anico Co. Ltd in Japan has made bags from film containing ferrous salt and an organic acid which are claimed to oxidize the amine as the polymer absorbs it. However, the effectiveness of the concept and the safety of the reaction products were not supported by any data (Rooney 1995b).

Commercial odour-absorbing sachets include MINIPAX® and STRIPPAX® (Multisorb Technologies, USA). These systems absorb the odours developed during storage and distribution of certain packaged foods due to the formation of mercaptanes and hydrogen sulphide.

Antimicrobial-releasing systems

Besides affecting bacterial growth through removal of oxygen, the release of specific antimicrobial agents is a potential application of active packaging. In the literature a number of antimicrobial agents are evaluated on their capacity to inhibit bacterial growth when incorporated in packaging materials, including the bacteriocins nisin and pediosin (Ming *et al.* 1997), potassium sorbate and sodium benzoate (Chen *et al.* 1996), benzoic anhydride (Weng and Hotchkiss 1993), sorbic acid (Ghosh *et al.* 1977) and the fungicides imazalil (Miller *et al.* 1984), benomyl (Halek and Garg 1989) and permethrin (Highland and Cline 1986).

In addition, the application of a film containing a synthetic zeolite, which has had a portion of its sodium ions replaced with silver ions, is described by Hotchkiss (1995).

Antimicrobial systems can be divided into two types: those containing an antimicrobial agent that intentionally migrates to the surface of the food, and those that are effective against surface growth without intentional migration of the active agent to the food. Examples of the latter system are the Microban® kitchen products such as chopping boards and dish cloths (Microban Products Co., USA), which recently have become commercially available in the UK. These Microban® products contain triclosan, an antimicrobial compound allowed for use in cosmetics such as soap, shampoo and toothpaste. The use of triclosan (2,4,4-trichloro-2-hydroxydiphenylether) in food-contact applications, however, is not yet regulated at EU level.

The two major applications of anti-microbial packaging, however, are ethanol- and carbon dioxide-releasing systems. The use of alcohol to prolong shelf-life is a well-known method in food preservation. Ethanol is commonly used as surface disinfectant. The effect of ethanol depends on its concentration. At higher concentrations (60–70% v/v), ethanol denatures the proteins of the protoplasts of vegetative cells of microorganisms. However, also at relatively low concentrations (4–12%), ethanol has proved effective in controlling growth of several moulds and bacteria in model systems.

In Japan, several ethanol vapour-generating sachets have been developed. Commercially successful systems include Ethicap® and Negamold® (Freund Industrial Co. Ltd, Japan) and Ageless® type SE. Ethicap is widely being used in Japan to extend the mould-free shelf-life of high-moisture bakery products. Moreover, the technical information supplied by Freund suggests that Ethicap sachets exert an anti-staling effect. However, this anti-staling effect was not found for pita bread by Black *et al.* (1993). Other applications of Ethicap include shelf-life extension of semi-moist and dry fish.

Carbon dioxide has a bacteriostatic effect on certain microorganisms, extending the lag phase and decreasing the growth rate during the logarithmic growth phase. This bacteriostatic effect is influenced by age and range of the initial bacterial population, storage temperature and oxygen concentration. The inhibition is not equal for all types of bacteria.

Ageless Type C is a commercial carbon dioxide-releasing system produced in Japan by Mitsubishi Gas Chemical Co.

Other active-packaging systems

The systems discussed here are just some of the commercial and non-commercial applications of active packaging. Consumers become increasingly critical towards food quality, which puts demands on the creativity of the food-packaging industry. As a result, active packaging is the subject of intense research in many countries, and rapid developments are foreseen (Rooney 1995a, Floros *et al.* 1997). Other active-packaging systems that are either already available or could soon become available are anti-oxidant releasing films, flavour-releasing systems, CO_2 scavengers (for roasted coffee, for example), microwave susceptors, packaging systems that cool or generate heat or foam, anti-sticking and anti-fogging films, and temperature-compensating films.

Temperature-compensating films exhibit dramatic changes in permeability as temperature is increased above a switch temperature. These films can tolerate temperature fluctuation during storage and distribution of produce. By changing the permeability as a function of temperature, these films can compensate the increased respiration of produce at higher temperatures.

Applications

There are many current and future applications of active packaging. Oxygen scavengers will inhibit the growth of moulds (cheese, bakery products, processed meat or seafood, pasta), or yeast and aerobic bacteria (high a_w foods such as meat and prepared dishes). These systems also limit lipid oxidation (nuts, fried food, processed meat, whole milk powder, beer, fruit juices), loss of nutrients such as vitamin C (a wide range of fresh and processed foods) and the discoloration of plant and muscle pigments (processed meat, green noodles, herbs, tea, dried vegetables). Oxygen scavengers can also affect the respiration of horticultural and agricultural produce and the growth of insects (beans, grains, herbs, spices, flour).

Ethylene scavengers can extend the shelf-life of climacteric fruits such as apples, kiwi fruit, apricot, bananas, mango, cucumber, tomato and avocados, and vegetables such as carrots, potatoes and asparagus.

Moisture regulators can prevent the growth of moulds (bakery products such as cakes and bread rolls) or yeast and bacteria (high a_w foods like meat, fish, poultry, prepared dishes, sandwiches, sliced fruits and vegetables). These systems can remove melt water or condensate from frozen products (fish, meat, poultry) or dripping fluid of tissue or blood (cured meat, poultry) or limit water diffusion (bread, multilayer cakes).

Taint scavengers can remove amines (oxygen-sensitive protein-rich foods such as fish), aldehydes (biscuits, fried snack foods, cereals) and bitter-tasting components (fruit juices).

Ethanol emitters can extend the shelf-life of bakery products and dry fish. Carbon dioxide releasers have a bacteriostatic effect (meat, fish, poultry, prepared dishes) and an effect on the respiration of fresh fruit and vegetables. Other antimicrobial-releasing systems can be applied in a wide range of fresh and processed foods, bakery products, dried fruits, vegetables, wine, flour, rice, grain and beans.

Intelligent systems

In this paper, intelligent packaging is defined as packaging systems that monitor the condition of the food to provide information on the quality of the packaged food during transport and storage. A variety of indicators that belong to the group of intelligent systems are of interest to the food-packaging chain, such as indicators of temperature, time–temperature, pack integrity, microbial growth, product authenticity and physical shock. Many indicator systems have been patented, especially temperature and time–temperature indicators. Only a limited number of these patents have been commercialized because of strict requirements: an indicator must be easily activated, exhibit an easily measurable, reproducible time/temperature-dependent change, be irreversible, and ideally correspond or easily be correlated to food quality. Commercially available indicators of interest for monitoring the food quality include indicators of time–temperature, leakage and freshness.

Time–temperature indicators

A time–temperature indicator can be defined as a small measuring device that shows a time- and temperature-dependent, easily, accurately and precisely measurable irreversible change that mimics the changes of a target attribute undergoing the same variable time and temperature exposure (Hendrickx *et al.* 1995). The basic idea behind temperature-related food-quality indicators is that the quality of food deteriorates more rapidly at higher temperature due to reinforced (bio)chemical reactions and microbial growth. It is important that the activation energy of the indicator reaction is similar to that of the food deterioration and that the 'run-out' time of the indicator correlates well with the shelf-life of the food. The major mechanisms on which time–temperature indicator systems are based include enzymatic reaction, corrosion, polymerization, melting point or chemical diffusion. Only few methods are available to measure the indication, i.e. colour change, movement (diffusion) or both.

An example of a time–temperature indicator is the Fresh-Check® indicator (LifeLines Technology, USA) that has been developed for consumer use. It consists of a small circle of polymer surrounded by a printed reference ring. The inside polymer circle darkens upon accumulated temperature exposure. If the polymer centre is darker than the outer ring, then the consumer is advised not to consume the product, regardless of the use-by date. The indicators are activated by temperature and are stored deep-frozen before use. The system has been validated for a number of food products such as fruit cake, lettuce, milk, chilled fresh produce and orange juice.

The Vitsab TTI indicator (Vitsab Sweden AB, Sweden) is based on an enzymatic reaction causing a pH change in the reaction mixture. The indicator is produced in two versions. The version for consumer packages contains one indicator window, which indicates the difference between acceptable and inedible. Another version intended for retailers and to be attached to the transport package contains three indicator windows and indicates the different phases of ageing.

3M Packaging Systems Division (USA) has recently launched a new time–temperature indicator in a label form, which is activated upon application. In the activation, two tapes are brought together and, as the visco-elastic material from one tape moves into the receptor of the other tape, the light transmission increases, revealing the colour underneath. A previous time–temperature indicator manufactured by 3M (MonitorMark™) is based on melting of a coloured fatty acid ester at a predetermined temperature and its migration from a reservoir along a carrier. This diffusion can be observed through transparent windows.

Time–temperature indicators have been used in the USA in a variety of chilled ready-made meat and dairy foods. In Europe, both the French supermarket chain Monoprix (Labuza 1996) and, recently, the Dutch supermarket chain Albert Heijn applied these indicators to a niche product range with a very high quality, presented as a special market concept with a high price.

Leakage indicators

Oxygen and carbon dioxide indicators can also be used to monitor food quality. They can be used as a leak indicator or to verify the efficiency of, for example, an oxygen scavenger. Most of these indicators assume a colour change as a result of a chemical or enzymatic reaction. The most common redox dye used for leak indicators is methylene blue. Other redox dyes can also be applied.

At present, the main application of commercially available oxygen indicators is to ensure the proper functioning of oxygen absorbers, and most indicators have been developed indeed by producers of oxygen scavengers. For example, Mitsubishi Gas Chemical Co. has strongly contributed to the development of oxygen scavengers. This company was the first to commercialize oxygen-absorbing sachets under the trade name 'Ageless'. Ageless-eye sachets containing an oxygen indicator tablet have been designed to confirm the proper functioning of the Ageless absorbers.

A two-component system for a leakage indicator has been developed and patented, which both indicates leakage and absorbs residual oxygen (Ahvenainen and Hurme 1997). This oxygen indicator was designed specifically for leak detection of modified-atmosphere packages.

Carbon dioxide indicators are used to monitor the modified carbon dioxide level in modified-atmosphere packaging (MAP) systems. Carbon dioxide is generally used in MAP, together with inert nitrogen, because of its bacteriostatic effect. For non-respiring products, the modified atmosphere is typically a low O_2 level (0–2%) and a high CO_2 level (20–80%). For respiring produce, the MAP conditions must be optimized for each fresh vegetable or fruit type. In high CO_2 packages, a leak will result in a lowered CO_2 level and an increased O_2 level. These changes can be monitored by leakage indicators (Smolander *et al.* 1997).

Cryovac Sealed Air Ltd (USA) has produced Reflex indicator labels containing a visible CO_2 indicator. According to the manufacturer's information, the Reflex indicator can be used in MAP to identify machine faults and gas supply problems, to check that the desired gas mixture is present and to detect the non-integrity of the package.

Ahvenainen *et al.* (1995) warned for the deficiencies of leakage indicators. Microbial spoilage bacteria may consume oxygen entrapped through leakage, or microorganisms may produce carbon dioxide which will maintain the CO_2 level in the headspace while there is a leak.

Oxygen indicators have mainly been used in Japan with a variety of chilled or shelf-stable ready-made foods packed with an oxygen absorber in transparent plastic or glass packages. Carbon dioxide indicators have only recently become commercially available.

Freshness indicators

An ideal indicator for the quality control of packaged foodstuffs would indicate the spoilage or lack of freshness of the product, in addition to temperature abuse or package leaks. In patent literature, a number of freshness indicator or detector concepts are described that are based on the detection of volatile metabolites produced during ageing of foods, such as CO_2, diacetyl, amines, ammonia and hydrogen sulphide. At present, the only almost commercial system is the FreshTag® indicator label (Cox Recorders, USA), which reacts with volatile amines from fish with a colour change and is claimed to indicate the freshness of fish.

It is expected that in the future other freshness indicators will become commercially available.

Other likely future trends include the development of intelligent electronic tags that supply information on product identification, date of manufacture, price, etc., and, in addition, function as time–temperature, leak and/or freshness indicators.

Regulatory aspects

Active and intelligent packaging systems are emerging and promising technologies that will increasingly be applied in the years to come to extend shelf-life and improve the quality, safety and integrity of packaged foods. In recent years, many active and intelligent systems have been developed and it is expected that new concepts will become commercially available in the near future. However, for innovative food-packaging technologies to be successful, they must comply with regulations.

In Europe, no specific regulations for active and intelligent food packaging exist to date. With the exception of releasing agents, most of the active and intelligent agents are not considered as food additives but rather as food-contact material constituents, and, therefore, these food-packaging systems should comply with the existing regulations for food-contact materials. These regulations are very strict. Moreover, when those regulations were drafted, the development of active and intelligent food packaging could not be foreseen. As a consequence, many innovative packaging systems do not comply with current European regulations for food-contact materials. Because of these legislative restrictions, the application of active and intelligent packaging throughout Europe is still very limited.

The EU framework directive applicable to all food-contact materials (Directive 89/109/EEC) prescribes that a food-contact material shall not be hazardous to human health and shall not affect the composition or sensory character of the packed foodstuff in an unacceptable way. In the EU, so far, only a few food-contact materials have been specifically regulated and most attention has been paid to plastic food-packaging materials.

However, many active and intelligent systems are not exclusively made of plastics. For example, most oxygen-scavenging or moisture-absorbing sachets are made of multiple materials. Besides plastics, they may contain paper, adhesive, ink and active ingredients. These systems are not completely covered by existing EU Directives for food-contact materials such as the EU Directive for plastic food-contact materials (Directive 90/128/EEC) and its amendments. For these systems, the national regulations of EU member states should also be taken into account.

The EU Directive for plastic food-contact materials and its amendments are based on two principles.

- The so-called positive list: only the monomers and additives listed are allowed in the production of plastics intended for food contact.
- Limits for overall (total) migration and for migration of specific components; specific migration limits are generally based on the results of extensive toxicological studies.

To include new or unlisted components in the EU regulations a full dossier with toxicological data, and non-toxicological (e.g. migration) data should be submitted to the Scientific Committee for Food (SCF). The SCF advises the EU as to acceptance of new components, with or without a specific migration limit. In the EU, active and intelligent agents should now be subjected to the same procedures as new monomers and additives. This implies that the active and intelligent systems should comply with the positive list, i.e. all components used for manufacturing the systems should be mentioned in the EU positive list.

In addition, the active or intelligent system should comply with overall and relevant specific migration limits.

Most active and intelligent agents are not yet listed, which implies that for most agents petitions should be drafted including full toxicological data and non-toxicological data. Adding agents to the EU positive list is an expensive and time-consuming procedure. However, a more important hurdle in the application of active packaging in Europe is the overall migration limit of 60 mg kg^{-1} food, especially when the system is designed to release active agents to foods. In practice, the release of active ingredients is restricted to 60 mg kg^{-1}, which implies that the agent should be very active at a low concentration. Many active systems and, in particular, the releasing systems do not fulfil this requirement. Moreover, current migration tests are not always suitable for these new packaging systems because the conventional ratio of 6 dm^2 to 1 kg food is generally much smaller and, in addition, the contact mode of an active packaging differs from a conventional packaging. Thus, new migration test methods should be developed and validated for some of these systems.

The food-contact application of active and intelligent systems may have an effect on various European regulations for packaged food, such as regulations for food-contact materials, food additives, biocides, modified-atmosphere packaging, hygiene of foodstuffs, labelling and packaging waste. As all active and intelligent systems can be considered to be food-contact materials, the EU framework directive (Directive 89/109/EEC) appears to be of primary importance. It is, therefore, worthwhile to first investigate the possibilities to adapt this directive to regulate active and intelligent packaging in Europe.

European project

In 1999, a European study was started within the framework of the EU FAIR R&D programme, which aims at initiating amendments to European legislation for food-contact materials to establish and implement active and intelligent packagings in current relevant regulations for packaged food in Europe, thus enabling the safe application of these systems throughout Europe.

In fact, this project aims at creating opportunities for the European food and food-packaging industry to adapt to continuous changes and thus to enhance the competitive position of the European industry, especially vis-à-vis the USA, Australia and Japan. A second objective is to assure the safety of packaged foodstuffs for consumers in view of the European regulations for food-contact materials.

The European study is entitled ‘Evaluating safety, effectiveness, economic-environmental impact and consumer acceptance of active and intelligent packagings’ (‘Actipak’) (CT 98-4170). Nine research organizations and three industrial companies are carrying it out. The project is coordinated by TNO Nutrition and Food Research in The Netherlands. Other participants are: VTT Biotechnology, Finland; University of Santiago de Compostela, Spain; ADRIAC, France; Ghent University, Belgium; DISTAM, Italy; PIRA International, UK; TMI Europe, France; Inspectorate for Health Protection, Commodities and Veterinary Public Health, Netherlands; Eastman Chemical BV, Netherlands; Nestec Ltd, Switzerland; and Danone Biscuit Branch, France.

Objective and tasks

The objective of this project is to establish and implement active and intelligent packagings within the current relevant regulations for packaged food in Europe. This will enable these systems to be developed and introduced throughout Europe, enhancing the competitiveness of the food and food-packaging industries, especially vis-à-vis the USA, Australia and Japan. The specific objectives include:

- to investigate the suitability of existing active and intelligent packaging systems in view of current European food-packaging regulations;
- to establish their safety, shelf-life-extending capacity, economic aspects and environmental impact;
- to study the attitude of European consumers towards these packaging systems;
- to develop test methods for food-contact approval evaluation of active and intelligent packagings; and
- to draft a proposal for legislative amendments aimed at admitting these innovative systems in the near future.

The project consists of five key tasks.

(1) An in-depth review of technologies, legislation, market and consumer demands, and trends in active and intelligent packaging in relation to current European food-packaging regulations.
(2) An analytical study of the composition and migration behaviour of selected active and intelligent systems to be used for classification in view of restrictions of current legislation. Combinations of food and packaging will be selected and prepared for further testing.
(3) An investigation of:
   - the safety of selected systems through microbial safety analysis and assessment of the risk for false indications;
   - the effectiveness of systems' sensory, microbial and chemical shelf-life-extending capacity; and
   - the efficiency of the systems as scavengers of, for example, oxygen or ethylene.
(4) Examination of the toxicological properties of selected active and intelligent packaging systems, their economic and environmental effects and the attitude of European consumers towards these innovative concepts.
(5) Discussion with the EU and national authorities about legislative aspects of active and intelligent packaging and drafting of amendments pertinent to these systems. Modification of current migration testing methods and development of procedures for systematic evaluation of the fitness for food contact of active and intelligent systems.

Work programme

Based on the five key tasks, a detailed work programme has been drafted for the three-year project. In this work programme the key tasks have been further elaborated. In summary, the work programme consists of the following tasks.

(1) *Inventory*
(a) An in-depth review of technology, legislation, market and consumer needs and trends.
(b) Collection of available active and intelligent systems, which are representative of different technologies in active and intelligent food packaging, such as absorbing and releasing systems and indicators. Both commercial and experimental systems can be included. The systems will be collected for compositional analysis and migration studies.
(c) A project information sheet introducing the aims and benefits of the research project will be prepared. The project information sheet will be distributed to promote the project and to attract sponsors from the European industry, including SMEs.

(2) *Classification of active and intelligent systems*
(a) Investigation of the analytical composition of the active and intelligent systems collected in view of the positive lists for packaging components of the EU (90/128/EEC and amendments) and positive lists of national regulations. The composition of the active and relevant intelligent systems will be evaluated administratively followed by experimental verification by various analytical techniques. In addition, by-products that might be formed after action will be investigated.
(b) Investigation of the overall migration behaviour of active and intelligent packaging systems following the CEN EN 1186 methods.
(c) Classification of the active and intelligent systems into categories A–E (figure 1), based on results of the evaluation of composition and migration behaviour (tasks 2a, b):
   - Category A: systems that comply with current legislation (i.e. composition and migration).
   - Category B: a system belongs to this category if it contains components not listed in the positive lists of the EC (90/128/EEC and amendments) but which are food additives and/or natural components and/or other components on which toxicological data are available. The migration behaviour of the category B systems complies with the migration limits as set by the EC.
   - Category C: these systems contain components included in the positive lists of the EC whose migration exceeds the migration limit(s) set in current legislation (e.g. active release of organic acids). For these systems, dedicated migration test methods should be developed (task 5b).
   - Category D: these systems contain components which are not included in the positive lists of the EC but are food additives or natural components or other components for which toxicological data are available. In addition, the migration from these systems exceeds the migration limit(s) set by the EC.

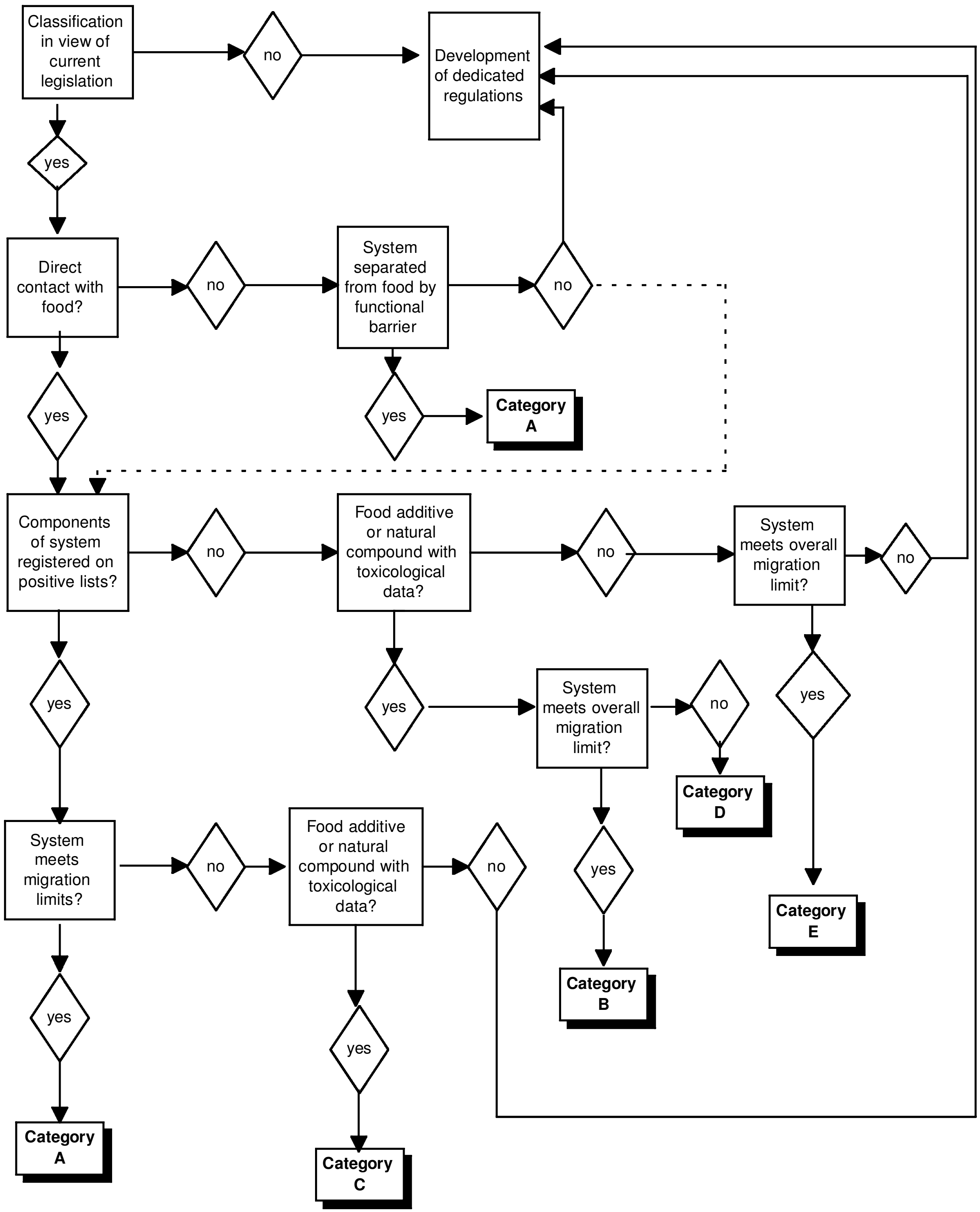

Figure 1. Classification of active and intelligent food-packaging systems in view of current legislation. For a description of categories A–E, see the text.

- Category E: these systems contain components that neither are listed nor are food additives or natural components, or other components for which no toxicological data are available. Systems belonging to this category will not be evaluated within the framework of the project.

(d) Based on the results of the classification of the packaging systems collected, representative combinations of food products and active and intelligent packaging systems will be selected for further validation studies. The combinations should be relevant to the European food industry and cover a broad range of foods. The selected systems will comprise active release, active scavenging and intelligent packaging systems. The selection of the foods is based on the main spoilage factor, such as bacterial growth, lipid oxidation and colour loss. The storage conditions will be selected from the categories frozen, chilled and ambient temperature storage.

(e) After selection of the food/packaging test combinations, detailed experimental protocols for the validation studies will be drafted.

(3) *Evaluation of microbial safety, shelf-life-extending capacity and efficacy of active and intelligent systems*

(a) Determination of microbial safety by analysing the microbial condition of the foods packed and stored in active-packaging systems and examination of the risk of misindication of intelligent systems.

(b) Investigation of the capacity of active-packaging systems to improve the microbial stability of food, as compared to traditional packaging systems, as well as the extension of the sensory and chemical shelf-life of different active packaging/food product combinations.

(c) Determination of efficacy of the active and intelligent systems. The study can be divided into three subtasks, i.e. absorbing capacity, releasing capacity and indication accuracy.

(d) To select successful systems for further study in task 4, task 3 will be completed by an overall evaluation of the capability (including efficacy, safety, and shelf-life-extending capacity) of the active and intelligent packaging systems investigated.

(4) *Toxicological, economic and environmental evaluation of successful active and intelligent systems as selected in task 3*

(a) Toxicological evaluation of active and intelligent systems for which, based on the classification of active and intelligent packaging systems, a toxicological evaluation is required (figure 1). Only those active or intelligent systems which:
- contain components not included in the positive lists (task 2a);
- and/or exceed the overall migration limit of $60\,\mathrm{mg\,kg^{-1}}$ (task 2b); and
- and appear to be fit for use (task 3d)

will be subjected to toxicological evaluation studies. Evaluations will be based on the results of the migration behaviour studies and on available toxicological documents on the active or intelligent agents.

(b) To establish the acceptance by European consumers of active and intelligent packaging, systems that have proved to be suitable and safe (tasks 3d and 4a) will be subjected to an international study into consumer attitudes towards application of these systems. This study will also provide insight into national differences and general attitudes.

(c) Evaluation of the economic consequences and environmental implications for systems that have been classified as safe and effective. To ensure that these evaluations are complete, the assessments will be made on a life-cycle basis.

(5) *Recommendations for legislative amendments*

(a) Communication of results to European authorities and discussion of proposals for legislative amendments. At a European level, the subject will be discussed in bilateral discussion groups and at meetings of the Council of Europe. At a national level, the individual partners will discuss the project progress related to legislative aspects with national authorities. Moreover, the project will be supported by a steering group in which various European umbrella organizations and EU regulatory authorities are represented. The steering group will be informed on the progress of the project and will discuss the relevant subjects, pending the project.

(b) In close collaboration with regulatory EC authorities, current migration methods will be modified for testing the safety of active and intelligent packagings as food-contact material.

(c) Relevant data obtained in de evaluation studies described under tasks 3 and 4 will be reviewed and discussed. These data will be used as a basis for drafting the recommendations for legislative amendments.

(d) The final recommendations will include suggestions for amendments to relevant regulations for food packaging such as the Directives for food-contact materials, food additives and labelling. Also suggestions for modified food-contact approval testing of active and intelligent packaging will be presented and discussed.
(e) Drafting of the final report. The final report will include a compilation of all experiments, results, discussions, conclusions, publications as well as recommendations for legislative amendments.

Results and discussion

The Actipak project started in January 1999 and will be completed by the end of 2001. Most of the work undertaken so far concerns the first, second and third tasks of the project.

Task 1: Inventory

As part of the study, an in-depth review has been conducted of technologies, legislation, market and consumer demands and trends in active and intelligent packaging in relation to European food-packaging regulations. This review describes the state-of-the-art with regard to active and intelligent packaging as well as the legislative aspects of these systems. An overview is given of all existing technologies and new promising technologies concerning active and intelligent packaging. The report also covers market trends, consumer acceptance and future trends of these systems. In addition, an overview is presented of the existing legislation on food packaging in European as well as relevant non-European countries (USA, Japan and Australia) and the restrictions these regulations impose on the application of active and intelligent packaging. The review is based on relevant literature of the past five years and available patents of active and intelligent packaging applications. Part of the review has been described in detail in a separate publication (Vermeiren *et al.* 1999).

Also, a product information sheet has been prepared introducing the objective and tasks as well as the benefits of the research project. The product information sheet has been used and will be used to promote the project, and to attract potential sponsors from the European industry, including small and medium-sized enterprises.

A selection of available active and intelligent systems has been made for compositional analysis and overall migration study. The following criteria were used for the selection of the active and intelligent systems.

- European systems, whenever possible.
- As many different types as possible (e.g. sachets, films, closures).
- Different mechanisms of action.
- Systems of sponsors have priority.
- Include promising (not yet) commercial systems.

Based on these criteria some 25 packaging systems have been selected for task 2. The selection includes oxygen scavengers (films, closures and a sachet) with mechanisms based on iron powder, sulphite and photosensitive dye oxidation, moisture absorbers (sachets, a film and a pad) with mechanisms based on silica gel, molecular sieve and sugars, ethylene scavengers (a film and a sachet) with mechanisms based on minerals and $KMnO_4$, antimicrobial packaging (films and a sachet) based on release of ethanol, bacteriocin, zinc and acids, an odour and flavour absorber (aldehyde remover), a CO_2-emitting system, a flavour/odour releaser, a susceptor film and indicators for time–temperature, oxygen and carbon dioxide. In table 1, an overview of these systems is presented.

The collection of active and intelligent systems appeared to be significantly more time-consuming than anticipated. To safeguard the confidentiality of the results of the investigation on the composition and migration behaviour of the active and intelligent systems supplied for study, confidentiality agreements had to be signed by all participants and the providers of systems. This appeared to be no easy task, and the procedure delayed the progress of the project significantly.

Task 2: Classification of active and intelligent systems

The composition of the supplied active and intelligent systems has been investigated in view of the EU positive list and positive lists of national regulations. First, an administrative evaluation was carried out based upon the compositional details supplied by the providers of the systems. Subsequently, the composi-

Table 1. Active and intelligent packaging systems collected for study of the composition and overall migration.

No.	Packaging system	Type
1	oxygen scavenger	sachet
2	oxygen scavenger	cap
3	oxygen scavenger	crown cork
4	oxygen scavenger	film
5	oxygen scavenger	film
6	ethylene scavenger	film
7	ethylene scavenger	sachet
8	moisture absorber	sachet
9	moisture absorber	sachet
10	moisture absorber	pad
11	moisture absorber	film
12	anti-microbial releaser	sachet
13	anti-microbial releaser	film
14	anti-microbial releaser	film
15	anti-microbial releaser	film
16	anti-microbial releaser	film
17	anti-microbial releaser	film
18	colour/aroma releaser	film
19	aldehyde absorber	film
20	susceptor	film
21	time–temperature indicator	sticker (on outside of package)
22	time–temperature indicator	sticker (on outside of package)
23	time–temperature indicator	sticker (on outside of package)
24	oxygen indicator	tablet in sachet (inside package)
25	oxygen indicator	label (inside package)
26	carbon dioxide indicator	label (inside package)

tion was experimentally verified by means of analytical techniques such as GC-MS, MS, atomic absorption spectrometry, IR spectrometry, X-ray fluorescence spectrometry and scanning electronic microscopy.

The determination of the composition was focused on the active ingredients and relevant reaction products. Some typical results obtained so far are shown in table 2.

In addition, determination of the overall migration from the provided systems into the food simulants distilled water, 3% acetic acid, 10 or 15% ethanol, 95% ethanol, iso-octane and olive oil under appropriate test conditions has been started. For the determination of the overall migration from the various systems in the food simulants, the relevant CEN methods were followed as closely as possible (CEN EN 1186). Some relevant results of the overall migration study obtained for oxygen scavengers and moisture absorbers are presented in table 3.

Table 2. Some typical results of the evaluation of the composition of active and intelligent packaging systems.

Packaging system	Ingredients identified
Oxygen scavengers	iron powder
	silicates
	sulphite
	chloride
	polymeric scavenger
	elements: Fe, Si, Ca, Al, Na, Cl, K, Mg, S, Mn, Ti, Co, V, Cr, P
Ethylene scavengers	plasticizer
	permanganate
	zeolite
	elements: Mg, Al, Si, K, Ca, Ti, Fe, Mn
Moisture absorbers	silicates
	plasticizer
	cellulose fibre
	sugars
	acids
	ethanol
	glycerol
	surfactant
	elements: Mg, Fe, Ca, K, S, Ti, P, V, Mn, Cr, Zn, Sr, Si, Al, Na
Anti-microbial releasers	acids
	silicates
	ethanol
	zinc
	elements: Si, Na, Al, S, Cl, Ca, Mg, Fe, Pd, Ti
Indicators	methylene blue and other colour indicators
	acids
	anti-oxidants
	mineral oils
	sugars
	elements: Na, Ca, K, Si, Al, Mg

As shown in this table, varying overall migration values were obtained for both active systems, depending on the type of system. For example, for both oxygen-scavenging closures very different overall migration values were obtained with water, 3% acetic acid and 10% ethanol. In addition, the choice of the simulant has a significant effect on overall migration from some samples. For example, for the oxygen-scavenging sachet, the oxygen-scavenging cap and

Table 3. Overall migration from oxygen scavengers and moisture absorbers.

Sample	Type	Test condition	Overall migration (mg/sample) into: Water	3% Acetic acid	10% Ethanol	15% Ethanol	95% Ethanol	Iso-octane	Olive oil
Oxygen scavenger	sachet	10 days at 40°C	620[b]	1700[c]	–	800[a]	210[c]		–
		2 days at 20°C						1.9[c]	
Oxygen scavenger	cap	10 days at 40°C	74[c]	98[c]	80[c]	–	43[c]		–
		2 days at 20°C						0.9[c]	
Oxygen scavenger	crown	30 min. at 70°C + 10 days at 40°C	1.0[c]	1.7[c]	1.5[a]	–	–	–	27.8[a]
Oxygen scavenger[d]	film	10 days at 40°C	0.2[a]	0.7[a]	0.4[c]	–	–	–	2.0[c]
Moisture absorber	sachet	10 days at 40°C	< 0.1[a]	970[c]	–	0.6[c]	2.3[c]		–
		2 days at 20°C						< 0.1[a]	
Moisture absorber	sachet	10 days at 40°C	< 0.1[a]	11[c]	–	1.1[c]	1.3[c]		–
		2 days at 20°C						1.1[c]	
Moisture absorber	pad	10 days at 40°C	9.3[b]	46[c]	–	7.2[b]	21[c]		–
		2 days at 20°C						18[c]	
Moisture absorber[d]	film	10 days at 40°C	260[a]	300[a]	–	300[b]	8.2[b]		–
		2 days at 20°C						0.1[c]	
Moisture absorber[d]	film	10 days at 40°C	300[a]	320[b]	–	320[a]	5.1[c]		–
		2 days at 20°C						< 0.1[a]	

[a] Standard deviation < 5% ($n = 3$ or 4).
[b] Standard deviation > 5% and < 10% ($n = 3$ or 4).
[c] Standard deviation > 10% ($n = 3$ or 4).
[d] Overall migration in mg dm^{-2} instead of mg/sample.
–, Not measured.

both moisture-absorbing films significant differences were found between the overall migration values obtained with iso-octane and 95% ethanol.

The three time–temperature indicators were not included in the overall migration study. As the current systems are generally applied on the outside of the packaging and for relatively short periods, the packaging material can be considered to be a functional barrier, and, therefore, migration testing of time–temperature indicators is not relevant.

Based on the results of the evaluation of the composition and migration behaviour, the active and intelligent systems investigated were classified in view of restrictions of current regulations into five categories (A–E) according to the scheme shown in figure 1. So far, some 20 systems have been provisionally classified. Most of these classified systems fall into categories A–C.

The results of the classification have been used to select representative combinations of food and active and intelligent packaging systems for further validation studies. An overview of the food-packaging combinations selected for evaluation of microbial safety, shelf-life-extending capacity and efficacy of the active and intelligent systems is presented in table 4. Detailed experimental protocols for most of the validation studies have been drafted.

Task 3: Evaluation of microbial safety, shelf-life-extending capacity and efficacy of active and intelligent systems

The food-packaging combinations that will be further studied in task 3 (table 4) were selected on the following criteria.

- Relevant to the European food industry.
- Covering a broad range of foods with different spoilage factors (bacterial growth, lipid oxidation, colour loss).
- Different types of systems (active release, active scavenging, intelligent systems).
- Different storage conditions (time, temperature).

As appears from table 4, a broad range of foods and active and intelligent packaging systems were selected indeed. The storage conditions vary from a few days at 3°C to 1 year at 30°C. This part of the study is ongoing. Most of the storage experiments will be completed by the end of 2000. The results of task 3 will be used to select successful (i.e. safe and effective) systems for a toxicological, economic and environmental evaluation and for the study of consumer acceptance in task 4 of the project. This task will be carried out in 2001.

Task 5: Recommendations for legislative amendments

The execution of this task has also been started. The results obtained so far have been communicated with the European authorities. Ideas for legislative amendments have been exchanged and an inventory of foreseeable conflicts with present legislation has been discussed with the authorities. A presentation of the project has been given at meetings of the Rossi group and the Council of Europe. At a national level, the individual partners have discussed the project progress related to legislative aspects with the national authorities. Also, ideas for modified food-contact approval testing of active and intelligent systems have been discussed. This part of the study will be continued. The recommendations for legislative amendments will be included in the final report which will be drafted by the end of 2001.

In 2000, the Nordic countries started a project group under the auspices of the Nordic Council of Ministers. This project group has prepared an overview of all European regulations relevant to active and intelligent packaging. This overview is presented in the report 'Active and Intelligent Food Packaging: A Nordic Report on the Legislative Aspects' (Fabech *et al.* 2000). It describes all relevant European regulations and some types of active and intelligent food-contact materials. In addition, it contains proposals for administrators for future work and recommendations on legislative aspects. The report will be used in the Actipak project as a starting document for discussions with national and European authorities and for drafting proposals for amendments.

Benefits of the project

The Actipak project will provide a number of benefits to the European consumer and the European agro-food and food-packaging industries.

Based on profound European research this project will provide a scientific basis with a broad European

Table 4. Food-packaging combinations selected for validation studies.

Packaging system	Food	Storage conditions	Evaluation
Oxygen-scavenging film	fresh pasta	3 months at 4°C	sensorial, microbial and chemical quality
Moisture-absorbing film	fish	6 days at 3°C	sensorial, microbial and chemical quality
Moisture-absorbing pad	fresh meat	10 days at 7°C	sensorial and microbial quality
Ethylene-absorbing film	bananas	14 days at 15°C	sensorial quality and ethylene concentration in headspace
Anti-microbial film	cheese	3 months at 8°C	sensorial, microbial and chemical quality
Anti-microbial film	meat	Depends on meat type	sensorial and microbial quality
Anti-microbial film	fruit	Few days at 3°C	sensorial and microbial quality
Aldehyde-absorbing film	cereal	1 year at 20 and 30°C	sensorial and chemical quality
Oxygen-scavenging sachet	milk powder	1 year at 20 and 30°C	sensorial and chemical quality
Oxygen-scavenging sachet	biscuits	9 months at room temperature	sensorial and chemical quality
Moisture-absorbing sachet	milk powder	1 year at 20 and 30°C	sensorial and chemical quality
Anti-microbial sachet	sandwich bread	6 months at 23°C	sensorial, microbial and chemical quality
Oxygen-scavenging crown	beer	4 months at 25°C	sensorial and chemical quality
Time–temperature indicators	fish	various	lifetime, accuracy, Arrhenius response, effect of tampering, effect of light
Oxygen indicators	sliced meat	5 and 8°C	optical changes of indicators, sensorial and microbial quality of food, oxygen concentration in headspace
Carbon dioxide indicator	sliced meat	5 and 8°C	optical changes of indicators, sensorial and microbial quality of food, CO_2 concentration in headspace.

acceptance among food and packaging industries, consumers, retail and regulatory authorities for a well-balanced development of amendments to current European regulations for food-contact materials, to implement active and intelligent packagings in these regulations and to enable the safe application of these systems throughout Europe.

Broad European research on active and intelligent packaging undertaken by independent research organizations will provide insight in consumer acceptance, economic aspects, environmental impact and effectiveness of these novel systems. In addition, testing methods for a proper evaluation of the fitness for food contact of active and intelligent packagings will become available.

The possibility to develop and apply active and intelligent food-packaging systems in Europe will improve the competitiveness of the European food and food-packaging industries, especially vis-à-vis the USA, Australia and Japan.

Active packaging enables the shelf-life and quality of packed foods to be enhanced and the volumes of packaging materials to be reduced. The shelf-life-extending capacity of active packaging is expected to reduce food wastage due to spoilage. Consequently, energy and packaging material will be saved. Multilayer barrier materials might be replaced by more simple active-packaging systems containing fewer layers, thus reducing packaging waste.

Intelligent packaging indicators may control packaging integrity and the freshness of the product. Application of non-destructive indicators will significantly reduce costs compared to destructive random testing of samples. Consumers will be able to use indicators to help them choose products of the best quality and shelf-life.

The industry's need to effectively and safely package foods for transport and storage while maintaining the quality, along with increasing demands from consumers for fresher, minimally processed, more convenient and safer foods provide a bright future for active and intelligent packaging. The interest in active and intelligent packaging is expected to increase significantly in the years to come. Provided that the safety aspects of these systems will be adequately dealt with, active and intelligent packaging will no doubt increasingly be applied in Europe to extend shelf-life or to monitor food quality and safety.

This project will provide a major contribution to the safe introduction and application of active and intelligent food-packaging systems throughout Europe. When the project is successfully completed by the end of 2001, the expectations of Floros *et al.* (1997) might come true for Europe as well. In a publication that appeared by the end of the past millennium, they state that 'active packaging holds the promise of revolutionising the packaging industry and moving it forward into the new millennium'.

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References

Ahvenainen, R., and Hurme, E., 1997, Active and smart packaging for meeting consumer demands for quality and safety. *Food Additives and Contaminants*, **14,** 753–763.

Ahvenainen, R., Hurme, E., Randell, K., and Eilamo, M., 1995, *The Effect of Leakage on the Quality of Gas-packed Foodstuffs and the Leak Detection*. Research Notes 1683 (Espoo: Technical Research Centre of Finland, VTT).

Ahvenainen, R., Hurme, E., and Smolander, M., 1999, Active and smart packaging of food products. *Verpackungs-Rundschau*, **1**, 36–40.

Berenzon, S., and Saguy, I. S., 1998, Oxygen absorbers for extension of crackers shelf-life. *Food Science and Technology*, **31,** 1–5.

Black, R. G., Quail, K. J., Reyes, V., Kuzyk, M., and Ruddick, L., 1993, Shelf-life extension of pita bread by modified atmosphere packaging. *Food Australia*, **45,** 387–391.

Chen, M. C., Yeh, G. H. C., and Chiang, B. H., 1996, Antimicrobial and physicochemical properties of methylcellulose and chitosan films containing a preservative. *Journal of Food Processing and Preservation*, **20,** 379–390.

Day, B. P. F., 2000, Underlying principles of active packaging technology. *Food, Cosmetics and Drug Packaging*, **23,** 134–139.

Fabech, B., Hellstrøm, T., Henrysdotter, G., Hjulmand-Lassen, M., Nilsson, J., Rüdinger, L., Sipiläinen-Malm, T., Solli, E., Svensson, K., Thorkelsson, Á. E., and Tuomaala, V., 2000, *Active and Intelligent Food Packaging – A Nordic Report on the Legislative Aspects*. TemaNord 2000:584 (Copenhagen: Nordic Council of Ministers).

Floros, J. D., Dock, L. L., and Han, J. H., 1997, Active packaging technologies and applications. *Food Cosmetics and Drug Packaging*, **20,** 10–17.

Ghosh, K. G., Srivatsa, A. N., Nirmala, N., and Sharma, T. R., 1977, Development and application of fungi static wrappers in food preservation, Part 2: Wrappers made by coating process. *Journal of Food Science and Technology*, **14,** 261–264.

Gill, C. O., and McGinnes, J. C., 1995, The use of oxygen scavengers to prevent the transient discoloration of ground beef packaged under controlled oxygen-depleted atmospheres. *Meat Science*, **41,** 19–27.

Halek, W., and Garg, A., 1989, Fungal inhibition by a fungicide coupled to an ionomeric film. *Journal of Food Safety*, **9**, 215–222.

Hendrickx, M., Maesmans, G., de Cordt, S., Noronha, J., de Loey, J., and Tobback, P., 1995, Evaluation of the integrated time-dependent effect in thermal processing of foods. *CRC Critical Reviews in Food Science and Nutrition*, **35,** 231–262.

Highland, H. A., and Cline, L. D., 1986, Resistance to insect penetration of food pouches made of untreated polyester or permethrin-treated polypropylene film. *Journal of Economic Entomology*, **79,** 527–529.

Hotchkiss, J. H., 1995, Safety considerations in active packaging. *Active Food Packaging*, edited by M. L. Rooney (London: Blackie), pp. 238–255.

Labuza, T. P., 1996, An introduction to active packaging for foods. *Food Technology*, **50,** 68–71.

Miller, W. R., Spalding, D. H., Risse, L. A., and Chew, V., 1984, The effects of an imazalil-impregnated film with chlorine and imazalil to control decay of bell peppers. *Proceedings of the Florida State Horticultural Society*, **97,** 108–111.

Ming, X., Weber, G. H., Ayres, J. W., and Sandine, W. E., 1997, Bacteriocins applied to food packaging materials to inhibit *Listeria monocytogenes* on meats. *Journal of Food Science*, **62,** 413–415.

Nakamura, H., and Hoshino, J., 1983, *Techniques for the Preservation of Food by Employment of an Oxygen Absorber*. Technical Information (Tokyo: Mitsubishi Gas Chemical Co., Ageless Division), pp. 1–45.

Rooney, M. L. (editor), 1995a, Overview of active food packaging. *Active Food Packaging* (London: Blackie), pp. 1–37.

Rooney, M. L. (editor), 1995b, Active packaging in polymer films. *Active Food Packaging* (London: Blackie), pp. 74–110.

Schozen, K., Ohshima, T., Ushio, H., Takiguchi, A., and Koizumi, C., 1997, Effects of antioxidants and packing on cholesterol oxidation in processed anchovy during storage. *Food Science and Technology*, **30,** 2–8.

Shirazi, A., and Cameron, A. C., 1992, Controlling relative humidity in modified atmosphere packages of tomato fruit. *Horticultural Science*, **27,** 336–339.

Smith, J. P., Ooraikul, B., Koersen, W. J., Jackson, E. D., and Lawrence, R. A., 1986, Novel approach to oxygen control in modified atmosphere packaging of bakery products. *Food Microbiology*, **3**, 315–320.

Smolander, M., Hurme, E., and Ahvenainen, R., 1997, Leak indicators for modified-atmosphere packages. *Trends in Food Science and Technology*, **4**, 101–106.

Soares, N. F. F., and Hotchkiss, J. H., 1998a, Bitterness reduction in grapefruit juice through active packaging. *Packaging Technology and Science*, **11,** 9–18.

Soares, N. F. F., and Hotchkiss, J. H., 1998b, Naringinase immobilisation in packaging films for reducing naringin concentration in grapefruit juice. *Journal of Food Science*, **63,** 61–65.

Vermeiren, L., Devlieghere, F., van Beest, M., de Kruijf, N., and Debevere, J., 1999, Developments in the active packaging of foods. *Trends in Food Science and Technology*, **10,** 77–86.

Weng, Y. M., and Hotchkiss, J. H., 1993, Anhydrides as antimycotic agents added to polyethylene films for food packaging. *Packaging Technology and Science*, **6,** 123–128.

Zagory, D., 1995, Ethylene-removing packaging. *Active Food Packaging*, edited by M. L. Rooney (London: Blackie), pp. 38–54.