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Environmentally
hazardous substances

Selected polybrominated flame retardants

PBDE and TBBPA

Substance flow analysis

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Mit Zusammenfassung auf Deutsch
Avec résumé en français
Con riassunto in italiano

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Translator’s note

Where no distinction is necessary, the abbreviations BFR, PDBE, MWIP, etc. refer both to the singular and the plural.

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Abbreviations

General

SFA	Substance flow analysis
PHH	Private households
IG	Trade and industry
VIC	Voluntary industry commitment
UBA	Federal Agency for the Environment, Berlin
UL	Underwriters Laboratory
APME	Association of plastics manufacturers in Europe
BSEF	Bromine Science and Environmental Forum
PCDD+PCDF	Polychlorinated dioxins and furans
PBDD+PBDF	Polybrominated dioxins and furans
PXDD+PXDF	Halogenated dioxins and furans

Flame retardants

FR	Flame retardant(s)
BFR	Brominated flame retardant(s)
DecaBDPE[1]	Decabromodiphenyl ether(s)
OctaBDPE[1]	Octabromodiphenyl ether(s)
PentaBDPE[1]	Pentabromodiphenyl ether(s)
PBDE	Polybrominated diphenyl ether(s) (overall designation for decaBDPE, octaBDPE and pentaBDPE)
TBBPA	Tetrabromobisphenol A
HBCD	Hexabromocyclododecane

Materials, appliances and components

EE	Electrical und electronic appliances
FR4	Fibreglass reinforced epoxy resin laminates of printed circuit boards
FR2	Paper reinforced phenolic laminates of printed circuit boards
PR	Prepegs

System processes

MWIP	Municipal waste incineration plant(s)

Plastics

ABS	Acrylonitrile butadiene styrene
PE	Polyethylene
LDPE	Low density polyethylene
HDPE	High density polyethylene
PP	Polypropylene
PVC	Polyvinylchloride
PS	Polystyrene

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[1] The alternative abbreviations DBDPE, OBDPE and PBDPE are also found in the literature. These have been avoided in the present study to improve understanding. The abbreviations DBDO, OBDO und PBDO are also used, where ‘O’ stands for oxide instead of ether. DecaBDPE is also referred to as bis(pentabromophenyl)ether.

PA	Polyamide
PC	Polycarbonate
HIPS	High-impact polystyrene
EP	Expanded polystyrene
XPS	Extruded polystyrene
PUR	Polyurethane (foam fillers and insulating foams)
PC/ABS	Blend of polycarbonate und acrylonitrile butadiene styrene polymers
PPE/HIPS	Blend of polyphenylene ether and high-impact polystyrene polymers
UP	Unsaturated polyester

Abstracts

Bromierte Flammschutzmittel (BFS) sind Kunststoffadditive, die vor allem in Elektro- und Elektronikgeräten und in Baustoffen eingesetzt werden. In den letzten Jahrzehnten hat sich der Verbrauch der vier untersuchten Flammschutzmittel (pentaBDPE, OctaBDPE, DecaBDPE, TBBPA) weltweit nahezu verdoppelt. Einige BFS haben typische Eigenschaften persistenter organischer Schadstoffe (POP; Persistent Organic Pollutants) und stehen im Verdacht kanzerogen und östrogen aktiv zu sein. Die vorliegende Studie über die Schweiz zeigt auf, über welche Güter die BFS importiert, exportiert, verbraucht und entsorgt werden. Weiter wird gezeigt, über welche Wege die BFS in die Umwelt gelangen. Grundlage sind vorhandene Literaturdaten und eigene Abschätzungen. Basierend auf den vier Stoffflussanalysen werden Datenlücken und ein zukünftiger Handlungs- und Forschungsbedarf dargestellt.

Les produits ignifuges bromés sont des additifs synthétiques employés surtout dans les appareils électriques et électroniques et dans les matériaux de construction. Durant les dernières décennies, la consommation mondiale des quatre produits ignifuges examinés (pentaBDPE, octaBDPE, décaBDPE et TBBPA) a quasiment doublé. Certains de ces produits présentent les caractéristiques typiques des polluants organiques persistants (POP) et sont suspectés de posséder des effets cancérogènes et œstrogènes. La présente étude sur la Suisse dresse un bilan des produits dans lesquels ces substances sont importées, exportées, consommées et éliminées. Elle montre en outre par quelles voies les produits ignifuges bromés atteignent l’environnement. Elle repose sur des données issues de la littérature et sur ses propres évaluations. En se basant sur les quatre analyses de flux des matières, elle présente les données qui devront être complétées à l’avenir, les mesures qui s’imposent et les recherches nécessaires.

I prodotti ignifughi bromati (PIB) sono additivi sintetici utilizzati essenzialmente in apparecchi elettrici e elettronici e in materiali da costruzione. Negli ultimi decenni il consumo dei quattro prodotti ignifughi bromati esaminati (penta-, octa-, decaBDPE, TBBPA) è quasi raddoppiato a livello mondiale. Alcuni PIB hanno le caratteristiche tipiche degli inquinanti organici persistenti (POP; Persistent Organic Pollutants) e si teme che siano cancerogeni ed estrogeni. Il presente studio condotto in Svizzera indica tramite quali merci i PIB sono importati, esportati, consumati e smaltiti. Inoltre mostra con quali canali i PIB giungono nell'ambiente. Lo studio poggia sui dati della letteratura scientifica e su proprie stime. Sulla base delle quattro analisi del flusso di sostanze vengono evidenziati le carenze di dati e i settori nei quali agire e proseguire con la ricerca in futuro.

Brominated flame retardants (BFRs) are synthetic additives, which are used above all in electrical and electronic appliances, and in construction materials. Over recent decades, global consumption of the four flame retardants that are examined here (penta-, octa- and decaBDPE, and TBBPA) has almost doubled. The properties of some BFRs are typical of persistent organic pollutants (POPs), and these substances are suspected of being carcinogenic and of having oestrogenic activity. The present study, carried out in Switzerland, shows via which goods BFRs are imported, exported, used and disposed of, and the ways in which BFRs get into the environment. The study is based on data drawn from the literature, and on our own estimates. Flow chart analyses for the four groups of substances show where there are gaps in the data and where there is a need for future action and research.

Foreword

Some brominated flame retardants (BFR) are persistent, practically non-degradable compounds that accumulate in the food chain (e.g. pentaBDPE and TBBPA). When these are incinerated in an uncontrolled fashion, brominated dioxins and furans may be formed, and these can have carcinogenic (e.g. decaBDPE) or estrogenic effects (e.g. pentaBDPE).

In 2001, SAEFL decided to study the situation in Switzerland in detail, and commissioned a substance flow analysis for four brominated flame retardants (pentaBDPE, octaBDPE, decaBDPE and TBBPA). These four compounds represent some two-thirds of world production of brominated flame retardants.

The SAEFL mandated the firms of GeoPartner (Zurich) and RMA (Vienna) to prepare the substance flow analysis. The study addresses the status in Switzerland as per the end of the 1990s and is based solely on data available in the literature. It shows how the use of the four compounds has changed in recent years.

In order to keep the risk as low as possible, the use of substances that are persistent or accumulate in the biosphere should be avoided whenever possible. Of course, in the present era of global material flows, it would not be sufficient if Switzerland alone were to introduce restrictions. Measures must be implemented internationally by several countries in concert, e.g. within the framework of the OECD. By illustrating the importance and magnitude of the problem in the Swiss context, the present substance flow analysis represents a contribution to achieving this aim.

I should like here to thank all those who have participated in the preparation of this report for their commitment.

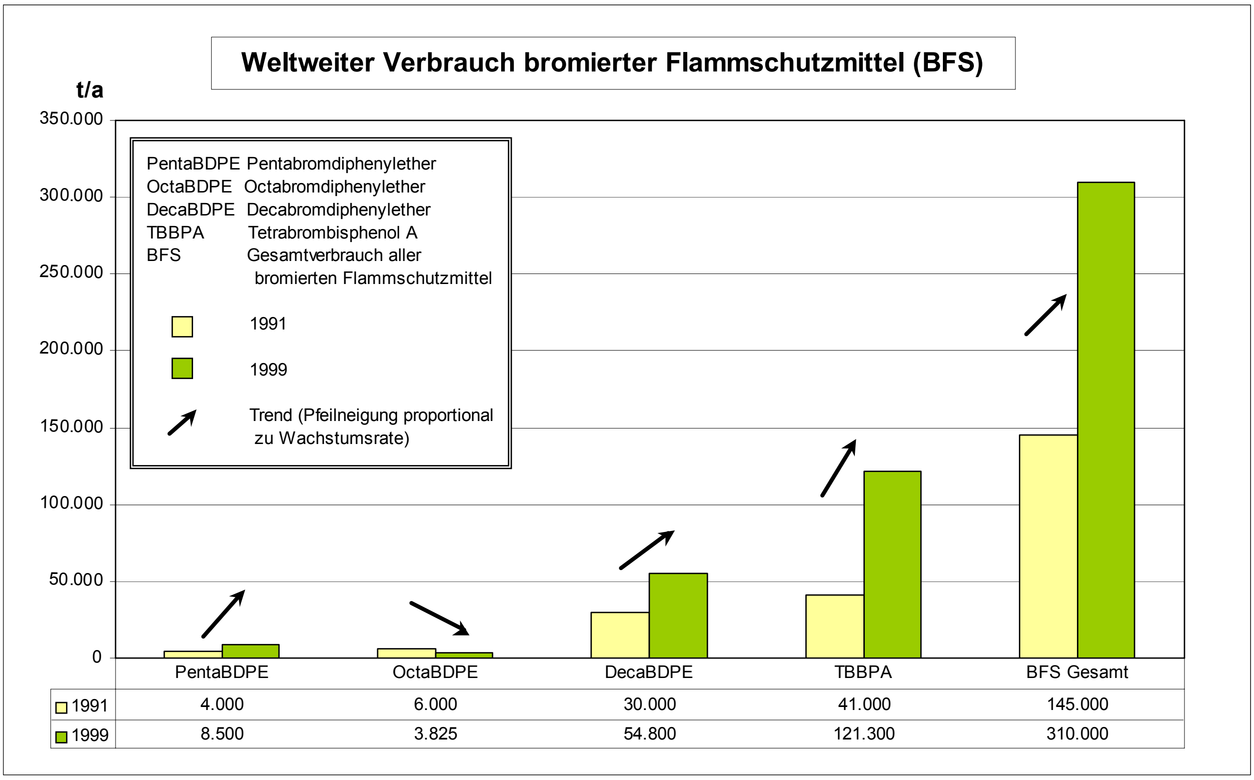
Georg Karlaganis
Head of the Materials, Soil and Biotechnology Department

Zusammenfassung

Bromierte Flammschutzmittel (BFS) werden seit mehr als 15 Jahren kontrovers diskutiert. Heute weiss man mehr über Verhalten und Bedrohungspotenzial der bromierten Flammschutzmittel für Mensch und Umwelt, als man beispielsweise seinerzeit über PCB beim Inkrafttreten von Anwendungs- und Produktionsverboten dieses Stoffes wusste. Das Bedrohungspotenzial einiger der untersuchten Flammschutzmittel besteht vor allem darin, dass sie persistent sind und sich in der Nahrungskette anreichern können (z.B. pentaBDPE, TBBPA), dass es bei unkontrollierter Verbrennung zur Bildung von bromierten Dioxinen und Furanen kommen kann (z.B. DecaBDPE), und dass es Hinweise auf ein kanzerogenes Potenzial (z.B. DecaBDPE) und östrogene Wirkung (z.B. pentaBDPE) gibt.

Ziel dieser Studie ist die Erstellung einer Stoffflussanalyse für vier ausgewählte Vertreter bromierter Flammschutzmittel: Pentabromdiphenylether [pentaBDPE], Octabromdiphenylether [OctaBDPE], Decabromdiphenylether [DecaBDPE] und Tetrabrombisphenol A [TBBPA].

Die Studie basiert ausschliesslich auf Literaturangaben und untersucht den Einsatz der BFS in der Schweiz Ende der 90er Jahre. Ausgehend vom Import von flammgeschützten Halb- und Fertigprodukten in die Schweiz, wurde deren anthropogenes Lager ermittelt. Zudem wurden die jährlichen Flüsse in den Export, in die Abfallwirtschaft und die Emissionen in die Umwelt bestimmt.



	PentaBDPE	OctaBDPE	DecaBDPE	TBBPA	BFS Gesamt
1991	4.000	6.000	30.000	41.000	145.000
1999	8.500	3.825	54.800	121.300	310.000

Abbildung 1: Vergleich weltweit verarbeiteter BFS-Mengen (Quellen: TBBPA 1991 [OECD, 1994], PBDEs 1991 [IPCS 1994b], TBBPA+PBDEs 1999 [Leisewitz & Schwarz, 2000], BFS Gesamt: Werte von 1990 und 2000 [Arias, 2001])

Rund zwei Drittel des Weltbedarfs an BFS wurde in den 90er Jahren durch die vier untersuchten Substanzen gedeckt. In den letzten Jahrzehnten ist der Bedarf durch den Anstieg des Kunststoffverbrauchs und durch strengere Brandschutzvorschriften stark gestiegen. Der weltweite Verbrauch der untersuchten BFS stieg in der Zeitspanne von 1991 bis 1999 von 100.000 t/a auf 190.000 t/a an, und es wird mit einem weiteren jährlichen Wachstum von 5 bis 7 % bis zum Jahr 2005 gerechnet. Im Detail betrachtet, nahm der Verbrauch von OctaBDPE in den 90er Jahren stark ab, jener von pentaBDPE, DecaBDPE und TBBPA stieg hingegen stark an (siehe Abbildung 1).

Resultate

In Halb- und Fertigprodukten gelangen jährlich etwa 1'700 t der vier untersuchten BFS in die Schweiz. Etwa 46 % davon werden in Fertigprodukten wieder exportiert, der Rest wird in der Schweiz konsumiert (Verkehr mit Produkten). Haupteinträge in den Konsum der Schweiz sind für pentaBDPE: Kraftfahrzeuge (Polsterungen, Textilien), für OctaBDPE: Elektro- und Elektronikgeräte (EE-Geräte) und Kraftfahrzeuge, für DecaBDPE: EE-Geräte (EDV- und Bürogeräte), Kraftfahrzeuge und Baumaterialien (PE-Folien) und für TBBPA: EE-Geräte (Computer).

Durch den Konsum von flammgeschützten Produkten in den letzten 20 Jahren wurde in der Schweiz ein Lager von etwa 12'000 t der untersuchten BFS akkumuliert. Gegenwärtig werden die Lager von pentaBDPE und OctaBDPE abgebaut, jenes von TBBPA wächst und jenes von DecaBDPE ist nahezu im Fliessgleichgewicht.

Etwa 900 t BFS verlassen jährlich das Lager im Konsum. Nahezu die gesamte Menge geht über die festen Abfälle in die Abfallwirtschaft. Dort werden die in den festen Abfällen befindlichen BFS schliesslich mit Ausnahme des PentaBDE (23 %) zum grössten Teil (65 – 85 %, je nach BFS) durch thermische Behandlung in kontrollierten Verbrennungsprozessen entsorgt und dabei praktisch vollständig zerstört. Neben dem Lager im Konsum wurde in den letzten Jahrzehnten ein zehnmal kleineres Lager von 1'500 t BFS in Schweizer Deponien aufgebaut. Dieses Lager wächst jährlich um etwa 130 t. Es stellt bei unsachgerechtem Management eine potentielle zukünftige Gefahr für Mensch und Umwelt dar. Die Schätzung der Flüsse sowohl aus dem Konsum als auch aus der Abfallwirtschaft in die Umwelt ist zur Zeit ohne aktuelle Messungen für die Schweiz nur sehr grob möglich.

PentaBDPE

Im Vergleich zu den anderen Flammschutzmitteln wurden Ende der 90er Jahre geringe Mengen von pentaBDPE flammgeschützten Produkten in der Schweiz eingesetzt. Jährlich werden etwa 1.9 t pentaBDPE in Fertigprodukten in die Schweiz importiert und davon etwa 1.5 t konsumiert. Der Grossteil der pentaBDPE-haltigen Konsumgüter sind Polsterungen, Textilien und Kunststoffe von Kraftfahrzeugen. Im Vergleich zu den anderen BFS sind Penta-BDPE-Frachten um das 10- bis 1'000-fache geringer.

Durch vielfältige Nutzung in den letzten beiden Jahrzehnten hat sich ein Lager von 500 t pentaBDPE im Konsum aufgebaut, welches zu 91 % aus pentaBDPE-haltigen Baumaterialien besteht. Gegenwärtig wird dieses Lager um rund 30 t/a abgebaut. Setzt sich dieser Trend in den nächsten Jahren fort, so wird in etwa 7 bis 10 Jahren das Lager in der Abfallwirtschaft mit rund 280 t das bedeutendste anthropogene Lager darstellen.

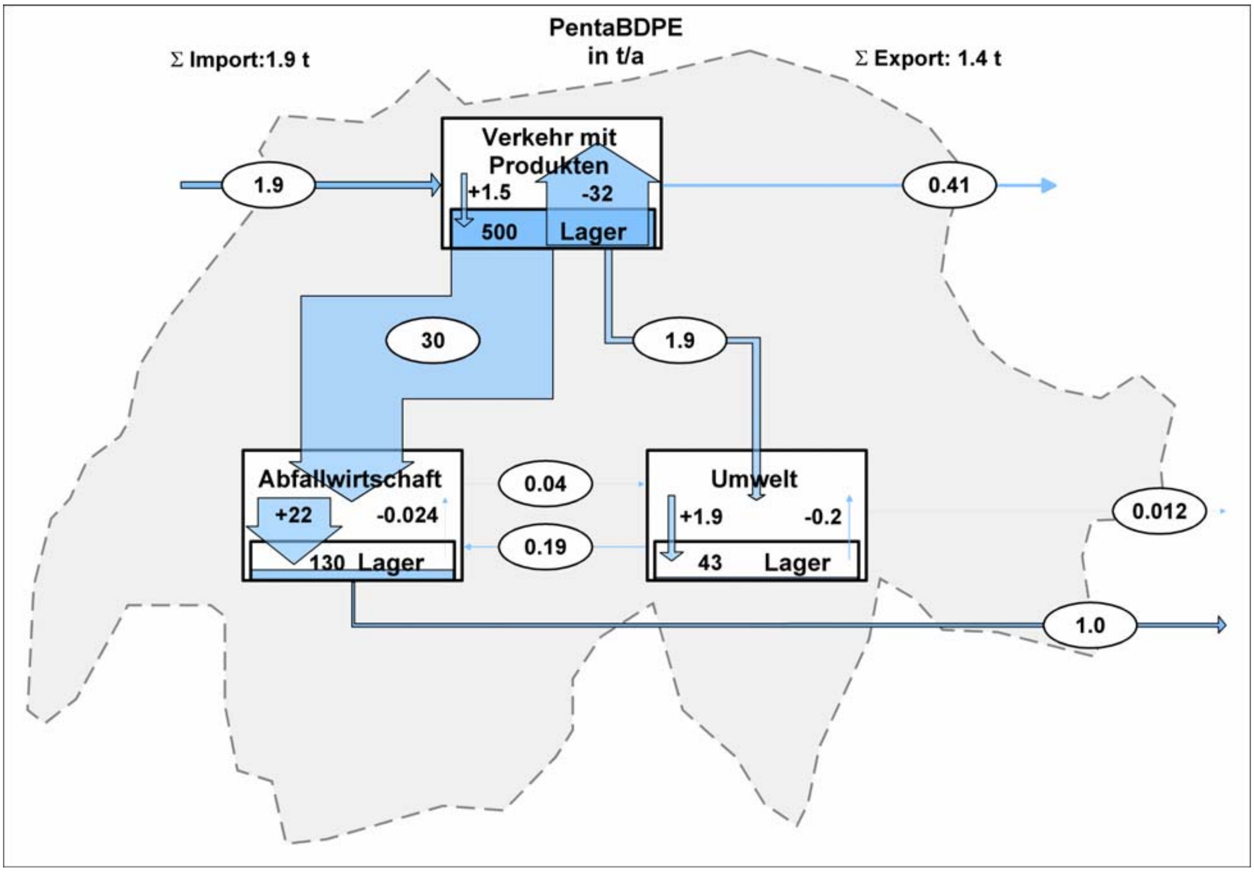


Abbildung 2: PentaBDPE-Flüsse in der Schweiz, Ende der 90er Jahre

In die Abfallwirtschaft gelangen derzeit jährlich rund 30 t/a pentaBDPE, wovon der überwiegende Teil (72 %) auf Deponien geht und rund 20 % in Verbrennungsanlagen zerstört wird. Ein kleiner Rest von 1 t/a (3 %) wird exportiert.

Aus dem Lager im Konsum diffundieren jährlich etwa 1.9 t/a, welche nahezu vollständig in die Pedo-/Lithosphäre gelangt. In Bezug auf die jährlich diffundierte Fracht liegt pentaBDPE deutlich über OctaBDPE und TBBPA.

OctaBDPE

Jährlich werden etwa 41 t OctaBDPE als Flammschutzmittel in Produkten in die Schweiz importiert und davon etwa 22 t/a konsumiert, der Rest wird exportiert. Die konsumierte OctaBDPE-Fracht befindet sich zu etwa 67 % in EE-Geräten und zu etwa 33 % in Kraftfahrzeugen.

In den letzten beiden Jahrzehnten wurde ein Lager von 680 t OctaBDPE im Konsum aufgebaut, welches zu 69 % aus EE-Geräten, zu 21 % aus Kraftfahrzeugen und zu 10 % aus Baumaterialien besteht. Gegenwärtig wird dieses Lager um rund 40 t/a abgebaut. Setzt sich dieser Trend in den nächsten Jahren fort, so wird in etwa 13 bis 18 Jahren das Lager in der Abfallwirtschaft mit rund 160 t das bedeutendste anthropogene Lager darstellen.

Die Abfälle aus dem Konsum enthalten jährlich rund 62 t OctaBDPE, wovon fast die gesamte Fracht (87 %) in Verbrennungsanlagen zerstört wird und etwa 10 % auf Deponien abgelagert werden. Der Rest (ca. 3 %) wird exportiert.

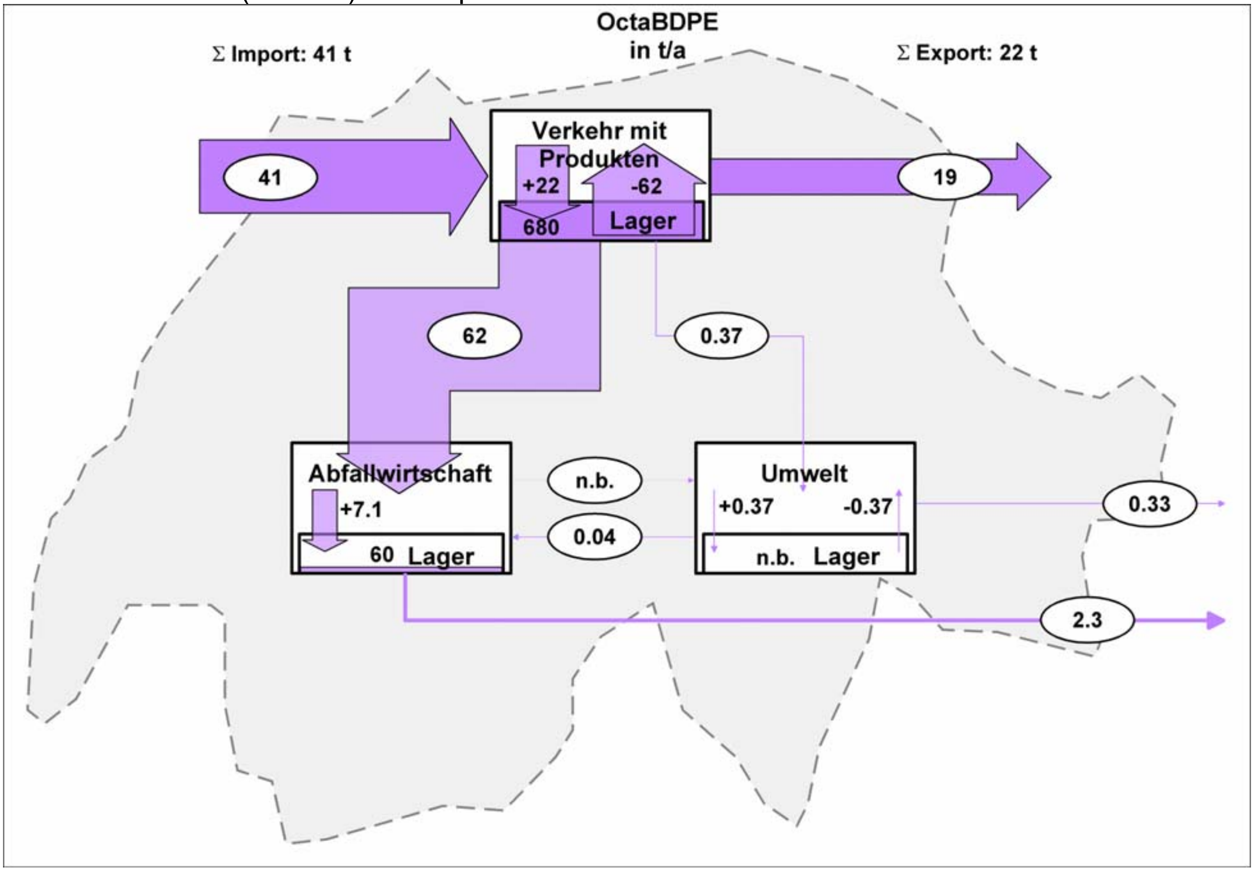


Abbildung 3: OctaBDPE-Flüsse in der Schweiz, Ende der 90er Jahre

Jährlich diffundiert rund 0.4 t Octa-BDPE aus dem Lager im Konsum und lagert sich nahezu vollumfänglich in der Pedo-/Lithosphäre ab.

DecaBDPE

Ende der 90er Jahre wurden jährlich 550 t DecaBDPE-Flammschutz in Halb- und Fertigprodukten in die Schweiz importiert. Davon wurden etwa 320 t/a konsumiert und der Rest wieder exportiert. Etwa 45 % des in der Schweiz konsumierten Deca-BDPEs befindet sich in EE-Geräten (EDV- und Bürogeräte), rund 30 % steckt in den importierten Kraftfahrzeugen und etwa 25 % in Baumaterialien (PE-Folien).

Das Lager an DecaBDPE in konsumierten Produkten beträgt etwa 5'600 t und befindet sich ungefähr im Fliessgleichgewicht. Das bedeutet, dass etwa dieselbe Deca-BDPE-Fracht, welche konsumiert wird, wieder durch Abfälle entsorgt wird. Die rund 370 t/a DecaBDPE in Abfällen werden zum überwiegenden Teil (rund 80 %) in Verbrennungsanlagen zerstört. Ca. 9 % werden exportiert und ein Anteil von rund 13 % auf Deponien abgelagert. Hält dieser Zustand an, so bleibt das Lager im Konsum, im Vergleich zum Deponielager und dem Lager in der Umwelt, in den nächsten 20 Jahren das bedeutendste Lager.

Das DecaBDPE-Lager im Konsum besteht zu 40 % aus EE-Geräten und zu jeweils 30 % aus Baumaterialien und Kraftfahrzeugen. Aus diesem Lager diffundiert jährlich etwa 2.1 t/a DecaBDPE und lagert sich nahezu vollständig in der Pedo-/Lithosphäre ab.

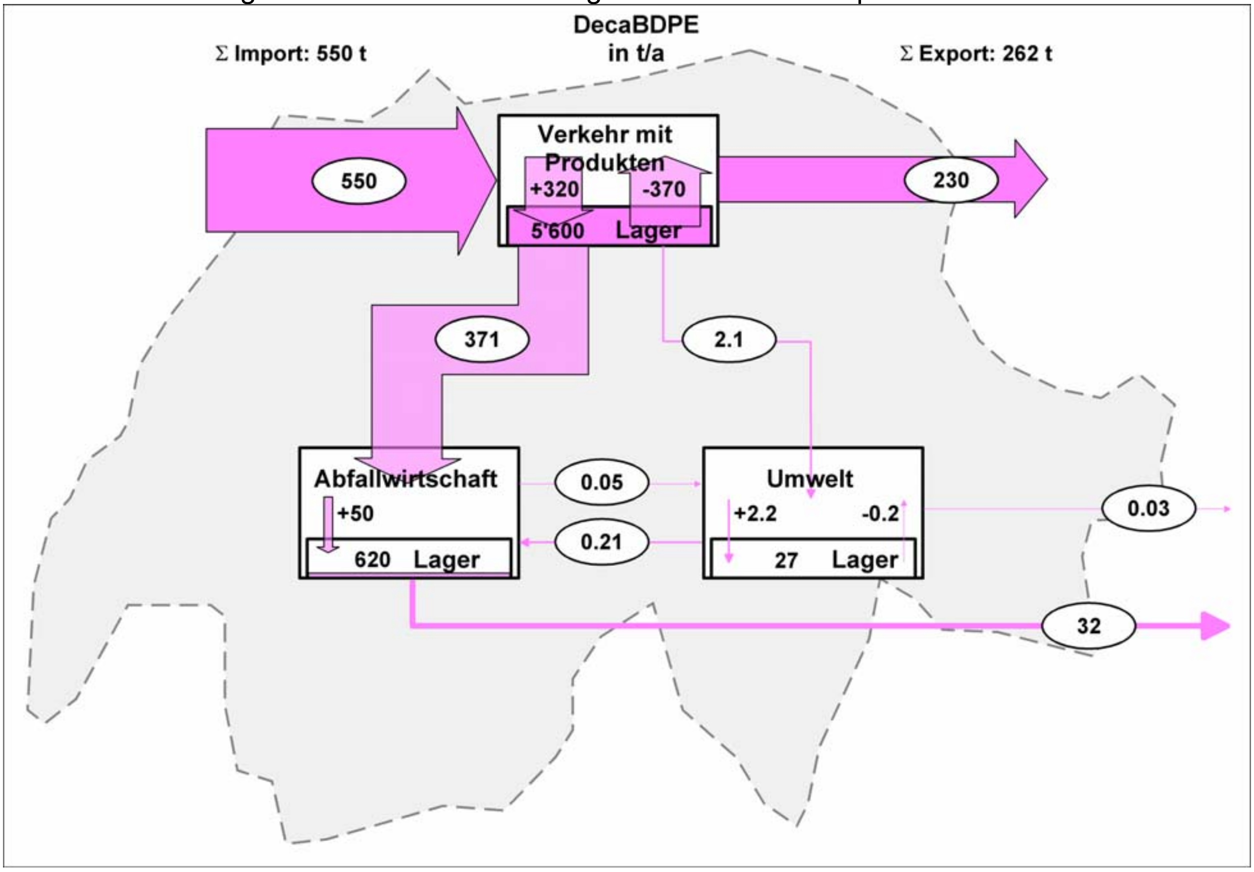


Abbildung 4: DecaBDPE-Flüsse in der Schweiz, Ende der 90er Jahre

Beachtenswert ist, dass im Vergleich zu pentaBDPE trotz des relativ hohen Lagerbestands etwa die selbe Fracht in die Umwelt diffundiert.

TBBPA

Ende der 90er Jahre wurden jährlich 1'130 t TBBPA-Flammschutz in Halb- und Fertigprodukten in die Schweiz importiert. Hiervon wurden etwa 570 t/a konsumiert und der Rest wieder exportiert. Nahezu die gesamte konsumierte TBBPA-Fracht (etwa 83 %) befindet sich in EE-Geräten: Etwa 83 % in Computern und rund 11 % in Unterhaltungselektronikgeräten. Im Vergleich zu den anderen BFS sind die gehandelten und konsumierten TBBPA-Frachten die höchsten.

Das Lager an TBBPA in konsumierten Produkten beträgt etwa 5'600 t und besteht zum überwiegenden Teil (59 %) aus EE-Geräten und zu kleineren Teilen (je 20 %) aus Baumaterialien und Kraftfahrzeugen. Obwohl im Vergleich zu Deca-BDPE etwa die doppelte Menge TBBPA jährlich konsumiert wird, ist der Lagerbestand etwa gleich gross. Dies resultiert daraus, dass die meisten TBBPA-haltigen Produkte kurzlebiger sind als decaBDPE-haltige.

Gegenwärtig wächst das Lager im Konsum um rund 180 t/a. Setzt sich dieser Trend in den nächsten Jahren fort, so bleibt das Lager im Konsum, im Vergleich zum Deponielager und dem Lager in der Umwelt, in den nächsten 20 Jahren das bedeutendste.

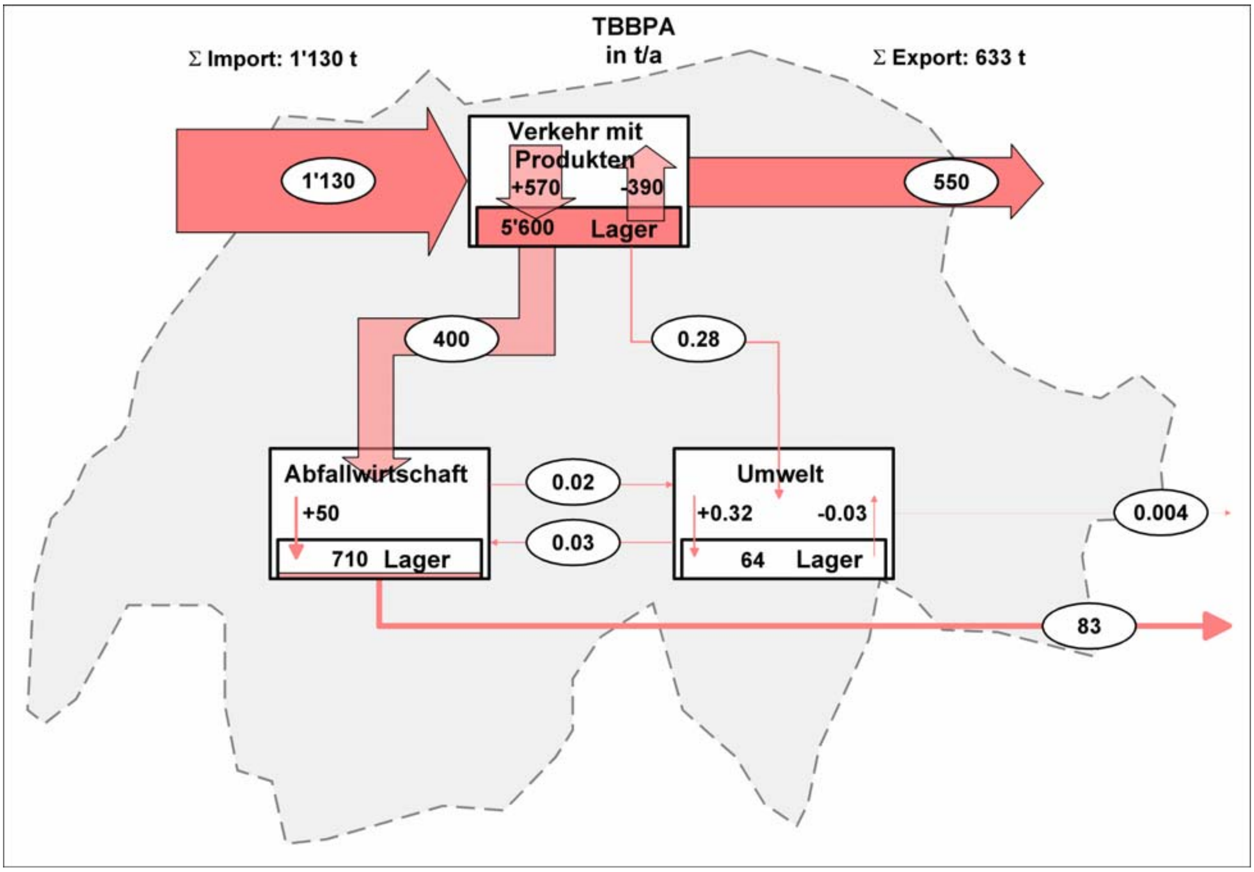


Abbildung 5: TBBPA-Flüsse in der Schweiz, Ende der 90er Jahre

Pro Jahr diffundiert etwa 0.3 t TBBPA aus dem Lager im Konsum in die Umwelt und lagert sich nahezu vollumfänglich in der Pedo-/Lithosphäre ab. Im Vergleich mit den anderen untersuchten BFS ist dies, trotz des grössten Lagerbestandes die geringste diffuse Emission.

Schlussfolgerungen

- Die Mehrzahl der Unternehmen haben ungenügende Informationen über die stoffliche Zusammensetzung der von ihnen in Verkehr gesetzten Produkte. Aus der Sicht eines vorsorgenden Umweltschutzes müssen die Unternehmen über das Umwelt- und Gesundheitspotential der von ihnen in Verkehr gebrachten Produkte Bescheid wissen. Dies ist zur Zeit nicht in genügendem Ausmass der Fall. Eine Möglichkeit der Optimierung der betrieblichen Strukturen ist der Einsatz einer betrieblichen Stoffbuchhaltung.
- Zur Zeit stehen nur wenig Informationen über die globale Verteilung der BFS zur Verfügung. Auf globaler Ebene sollen die Wege der Produkte und damit auch der Stoffflüsse zusammen mit Produzenten der Grundstoffe, der Halb- und Fertigprodukte verfolgt werden. Fernziel ist es, Informationen über Massenflüsse von kritischen Substanzen entweder dem Produkt direkt beizufügen oder zumindest verfügbar zu machen.

- Die Grösse und Zusammensetzung des anthropogenen Lagers ist nicht ausreichend genau bestimmt. Dieses Lager ist in seiner Dynamik zu erfassen und zu modellieren. Erst dann wird es möglich sein, es aktiv zu bewirtschaften, diffuse Emissionen abzuschätzen und zukünftige Abfallflüsse vorherzusagen. Erst so kann der Fluss in die Deponien und damit die diffusen Emissionen aus den Deponien gesteuert und minimiert werden sowie können auch entsprechende Rückbaukonzepte entwickelt werden.
- Aus dem Konsum gelangen grosse Flüsse in die Prozesse der Abfallwirtschaft. Welche Mengen an Emissionen aus den abfallwirtschaftlichen Prozessen resultieren, ist bis heute wenig (Verbrennung) bis gar nicht (Verwertung, Deponie, unkontrollierte Entsorgung) bekannt. Dieses Wissen ist aber eine Grundvoraussetzung, um ein optimales Management auch in der Entsorgungs- und Wiederverwertungsphase zu gewährleisten. Daher sind Messungen in den wichtigsten abfallwirtschaftlichen Prozessen (KVA, Deponie, Wiederverwertung, ARA) notwendig.

Résumé

Les produits ignifuges bromés font l'objet de vives controverses depuis plus de quinze ans. On dispose aujourd'hui de plus de connaissances sur le comportement de ces produits et sur les dangers qu'ils représentent pour l'être humain et l'environnement que l'on en disposait sur les PCB, par exemple, à l'époque où leur utilisation et leur production ont été interdites. Les principaux dangers associés à certains des produits ignifuges étudiés sont dus au fait qu'ils sont persistants et qu'ils peuvent s'accumuler dans la chaîne alimentaire (p. ex. pentaBDPE, TBBPA), que leur combustion incontrôlée peut provoquer la formation de dioxines et de furans bromés (p. ex. décaBDPE) et qu'il existe des indices suggérant l'existence d'un potentiel cancérigène (p. ex. décaBDPE) et œstrogène (p. ex. pentaBDPE).

L'objectif de cette étude est d'établir une analyse du flux de matières pour quatre représentants des produits ignifuges bromés : le pentabromodiphényléther [pentaBDPE], l'octabromodiphényléther [octaBDPE], le décabromodiphényléther [décaBDPE] et le tétrabromobisphénol A [TBBPA].

Cette étude repose exclusivement sur des données issues de la littérature disponible et examine l'emploi des produits ignifuges bromés en Suisse à la fin des années 90. Le stock anthropique des produits ignifuges bromés a été établi sur la base de l'importation en Suisse de produits finis et semi-finis ignifugés. Les flux annuels sous forme d'exportation, de rejet dans les déchets et d'émission dans l'environnement ont également été calculés.

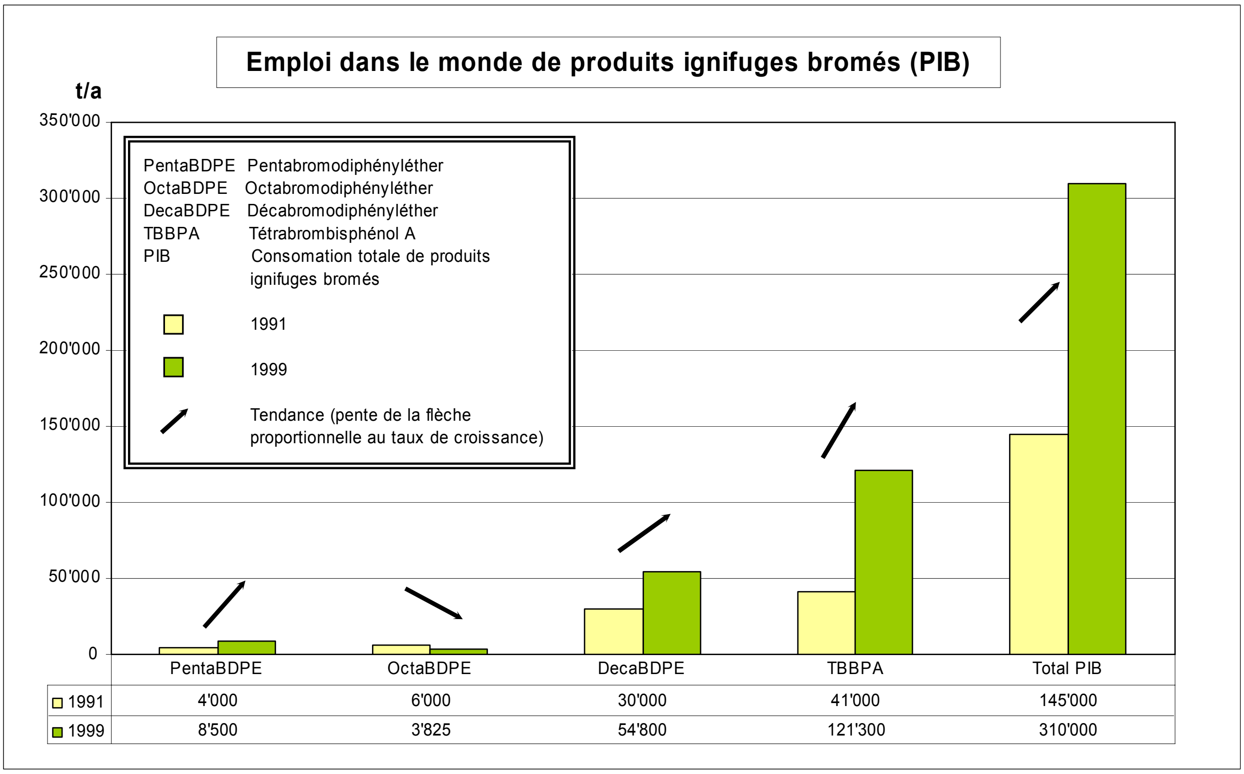


Figure 1: Comparaison de quantités de produits ignifuges bromés utilisés dans le monde (sources: TBBPA 1991 [OECD, 1994], PBDEs 1991 [IPCS 1994b], TBBPA + PBDEs 1999 [Leisewitz & Schwarz, 2000], Total PIB: valeurs de 1990 et 2000 [Arias, 2001])

Dans les années 90, près des deux tiers des besoins mondiaux de produits ignifuges bromés étaient couverts par les quatre substances examinées. Durant ces dernières décennies, les besoins ont fortement augmenté en raison de la hausse de la consommation de matières plastiques et de l'entrée en vigueur de prescriptions de protection contre le feu plus sévères. La consommation mondiale des produits ignifuges bromés étudiés est passée de 100'000 tonnes par an en 1991 à 190'000 tonnes par an en 1999. Une croissance annuelle supplémentaire de 5 à 7 % est attendue jusqu'en 2005. La tendance n'est toutefois pas la même pour tous les produits ignifuges bromés : la consommation d'octaBDPE a fortement reculé dans les années 90, alors que celle de pentaBDPE, de décaBDPE et de TBBPA a connu une hausse très importante (voir figure 1).

Résultats

Chaque année, près de 1'700 tonnes des quatre produits ignifuges bromés examinés parviennent en Suisse dans des produits semi-finis et finis. De cette quantité, quelque 46 % sont de nouveau exportées dans des produits finis; le reste est consommé en Suisse (commerce de produits). Les principales contributions à la consommation en Suisse sont, pour le pentaBDPE, les véhicules à moteur (rembourrages, textiles), pour l'octaBDPE, les appareils électriques et électroniques et les véhicules à moteur, pour le décaBDPE, les appareils électriques et électroniques (appareils informatiques et de bureau), les véhicules à moteur et les matériaux de construction (films en PE), et pour le TBBPA, les appareils électriques et électroniques (ordinateurs).

Un stock de près de 12'000 tonnes des produits ignifuges bromés examinés s'est constitué en Suisse suite à la consommation de produits ignifugés durant ces dernières vingt années. Actuellement, les stocks de pentaBDPE et d'octaBDPE diminuent, le stock de TBBPA augmente et celui de décaBDPE est proche de la stabilité.

Près de 900 tonnes de produits ignifuges bromés quittent chaque année le stock des produits de consommation. Quasiment la totalité de cette quantité passe avec les déchets solides dans la gestion des déchets. La plus grande partie des produits ignifuges bromés présents dans les déchets solides (de 65 à 85 % selon le produit), exception faite du pentaBDPE (23 %), y est finalement éliminée et pratiquement complètement détruite par traitement thermique dans des processus de combustion contrôlés. A côté du stock des produits de consommation, un stock dix fois plus petit, de 1'500 tonnes, s'est constitué durant ces dernières décennies dans les décharges contrôlées suisses. Ce stock augmente de près 130 tonnes par an. Traité de manière inappropriée, il représente un danger potentiel futur pour l'être humain et l'environnement. Comme on ne dispose pas de mesures récentes pour la Suisse, les flux allant des produits de consommation et des déchets vers l'environnement ne peuvent actuellement être évalués que très grossièrement.

PentaBDPE

A la fin des années 90, les quantités de produits ignifugés au pentaBDPE utilisées en Suisse étaient faibles par rapport aux quantités d'autres produits ignifuges bromés. Chaque année, près de 1,9 tonnes de pentaBDPE sont importées en Suisse dans des produits finis, dont près de 1,5 tonnes sont consommées. La plupart des biens de consommation contenant du pentaBDPE sont des rembourrages, des textiles et des matières plastiques de véhicules à moteur. Les charges de pentaBDPE sont de 10 à 1'000 plus faibles que celles des autres produits ignifuges bromés.

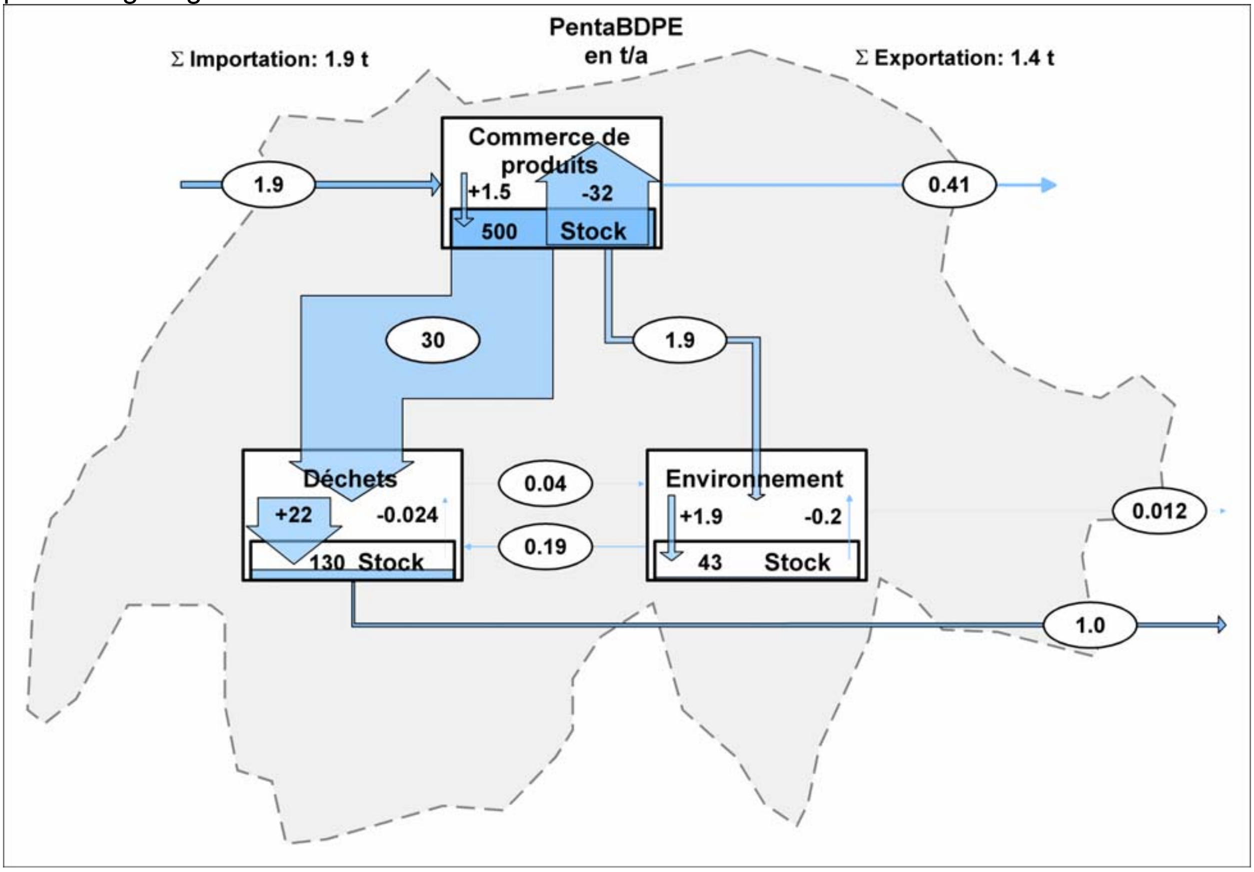


Figure 2: Flux de pentaBDPE en Suisse, à la fin des années 90

Les multiples utilisations de ces deux dernières décennies ont entraîné la création d'un stock de 500 tonnes de pentaBDPE dans les produits de con-sommation, qui consiste pour 91 % en matériaux de construction contenant du pentaBDPE. Ce stock diminue actuellement de 30 tonnes par an. Si cette tendance se maintient ces prochaines années, le stock contenu dans les déchets (280 tonnes environ) sera dans 7 à 10 ans le stock anthropique le plus important.

Actuellement, près de 30 tonnes par an de pentaBDPE parviennent dans les déchets, dont la majeure partie (72 %) passe dans les décharges contrôlées et quelque 20 % sont détruites dans des usines d'incinération. Un petit reste de 1 tonne (3 %) est exporté.

Près de 1,9 tonnes sont émises chaque année à partir du stock des produits de consommation, dont quasiment la totalité se dépose dans la pédosphère ou la lithosphère. En ce qui concerne la charge diffusée annuellement, les quantités de pentaBDPE sont nettement supérieures à celles d'octaBDPE et de TBBPA.

OctaBDPE

Chaque année, près de 41 tonnes d'octaBDPE sont importées en Suisse sous forme d'agents ignifuges dans des produits, dont près de 22 tonnes sont consommées annuellement, le reste étant exporté. La charge d'octaBDPE des produits de consommation se trouve pour 67 %

environ dans des appareils électriques et élec-troniques et pour quelque 33 % dans des véhicules à moteur.

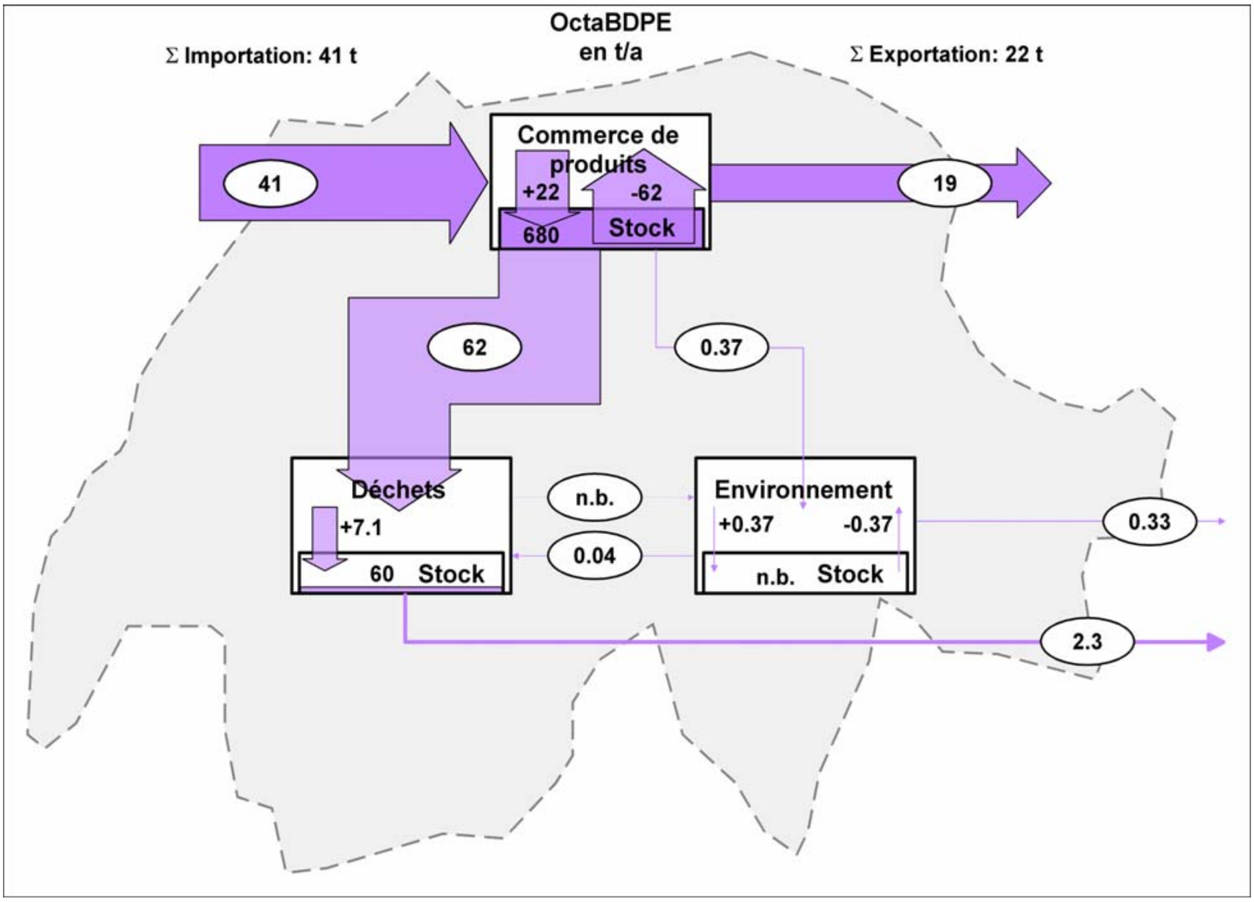


Figure 3: Flux d'octaBDPE en Suisse, à la fin des années 90

Un stock de 680 tonnes d'octaBDPE s'est constitué ces vingt dernières années dans les produits de consommation. Ce stock consiste pour 69 % en appareils électriques et électroniques, pour 21 % en véhicules à moteur et pour 10 % en matériaux de construction. Il recule actuellement de près de 40 tonnes par an. Si cette tendance se maintient ces prochaines années, le stock contenu dans les déchets, avec près de 160 tonnes, sera le stock anthropique le plus important dans 13 à 18 ans.

Les déchets de produits de consommation éliminés annuellement contiennent près de 62 tonnes d'octaBDPE, dont quasiment la totalité (87 %) est détruite dans des usines d'incinération et près de 10 % sont déposés dans des décharges contrôlées. Le reste (environ 3 %) est exporté. Chaque année, près de 0,4 tonne d'octaBDPE quitte le stock des produits de consommation et quasiment la totalité de cette quantité se dépose dans la pédosphère ou la lithosphère.

DécaBDPE

A la fin des années 90, 550 tonnes de l'agent ignifuge décaBDPE ont été importées en Suisse chaque année dans des produits semifinis et finis, dont près de 320 tonnes ont été consommées et le reste a été réexporté. Les appareils électriques et électroniques (appareils informatiques et de bu-reau) abritent près du 45 % du décaBDPE con-sommé en Suisse, environ 30 % se trouvent dans les véhicules à moteur importés et quelque 25 % se trouvent dans des maté-riaux de construction (films PE).

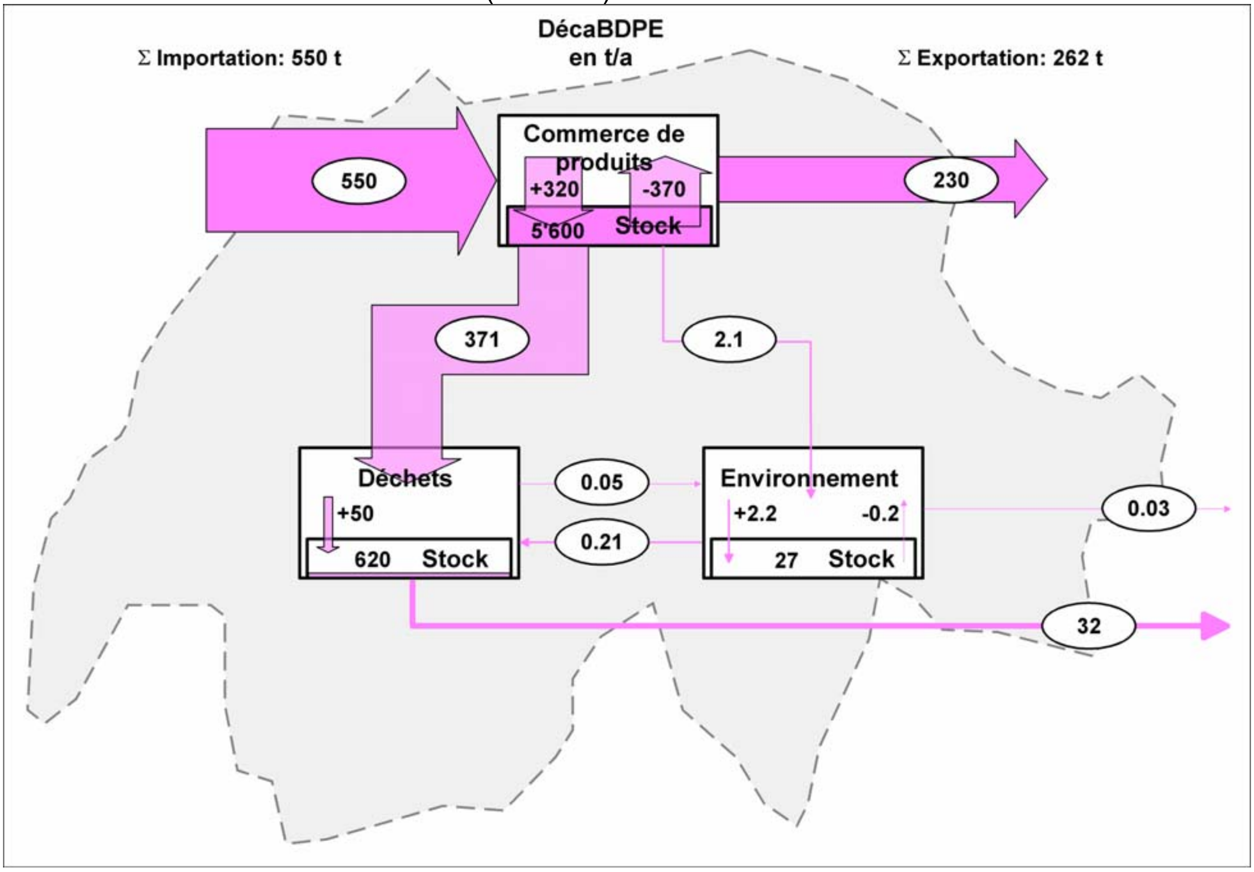


Figure 4: Flux de décaBDPE en Suisse, à la fin des années 90

Le stock de décaBDPE dans les produits de consommation se monte à 5'600 tonnes environ et est pratiquement stable. Cela signifie que l'on élimine avec les déchets environ autant de décaBDPE que l'on en consomme. La majeure partie (environ 80 %) des quelque 370 tonnes annuelles de décaBDPE contenus dans les déchets est détruite dans des usines d'incinération. Près de 9 % sont exportés et une fraction de 13 % environ est stockée dans des décharges contrôlées. Si cette situation se maintient, le stock des produits de consommation restera, au cours de ces vingt prochaines années, plus important que le stock des décharges contrôlées et que le stock dans l'environnement.

Le stock de décaBDPE dans les produits de consommation consiste pour 40 % environ en appareils électriques et électroniques, pour 30 % en matériaux de construction et pour 30 % en véhicules à moteur. Près de 2.1 tonnes de décaBDPE sont émises chaque année à partir de ce stock et quasiment la totalité de cette quantité se dépose dans la pédosphère ou la lithosphère. Il est intéressant de noter que la charge de décaBDPE émise dans l'environnement est similaire à celle de pentaBDPE, malgré l'importance du stock de décaBDPE.

TBBPA

A la fin des années 90, 1'130 tonnes par an du produit ignifuge TBBPA ont été importées en Suisse dans des produits semi-finis et finis, dont près de 570 tonnes ont été consommées et le reste a été réexporté. Les appareils électriques et électroniques abritent quasiment la totalité de la charge de TBBPA consommée: près de 83 % de cette quantité se trouve dans des ordinateurs et environ 11 % dans des appareils électroniques de loisir. Par rapport aux autres produits ignifuges bromés, les quantités de TBBPA commercialisées et consommées sont les plus élevées.

Le stock de TBBPA dans les produits de consommation se monte à 5'600 tonnes environ, dont la majeure partie (59 %) consiste en appareils électriques et électroniques et de plus petites fractions en matériaux de construction (20 %) et en véhicules à moteur (20 %). Bien que la quantité de TBBPA consommée annuellement soit proche du double de celle de décaBDPE, les quantités en stock sont comparables. Cela est dû au fait que la plupart des produits contenant du TBBPA présentent une durée de vie plus courte que les produits contenant du décaBDPE.

Actuellement, le stock de TBBPA dans les produits de consommation croît de près de 180 tonnes par an. Si cette tendance se maintient ces prochaines années, le stock des produits de consommation restera plus important ces vingt prochaines années que le stock des décharges contrôlées et que le stock dans l’environnement.

Les déchets issus des produits de consommation contiennent une charge annuelle de TBBPA de près de 400 tonnes, dont environ 68 % sont détruites dans des usines d’incinération, près de 11 % sont déposées dans des décharges et environ 21 % sont exportées.

Chaque année, le stock des produits de consommation émet près de 0,3 tonne de TBBPA dans l’environnement et quasiment la totalité de cette quantité se dépose dans la pédosphère ou la lithosphère. Par rapport aux autres produits ignifuges bromés étudiés, et bien que le stock de TBBPA soit le plus important, cela représente l’émission diffuse la plus faible.

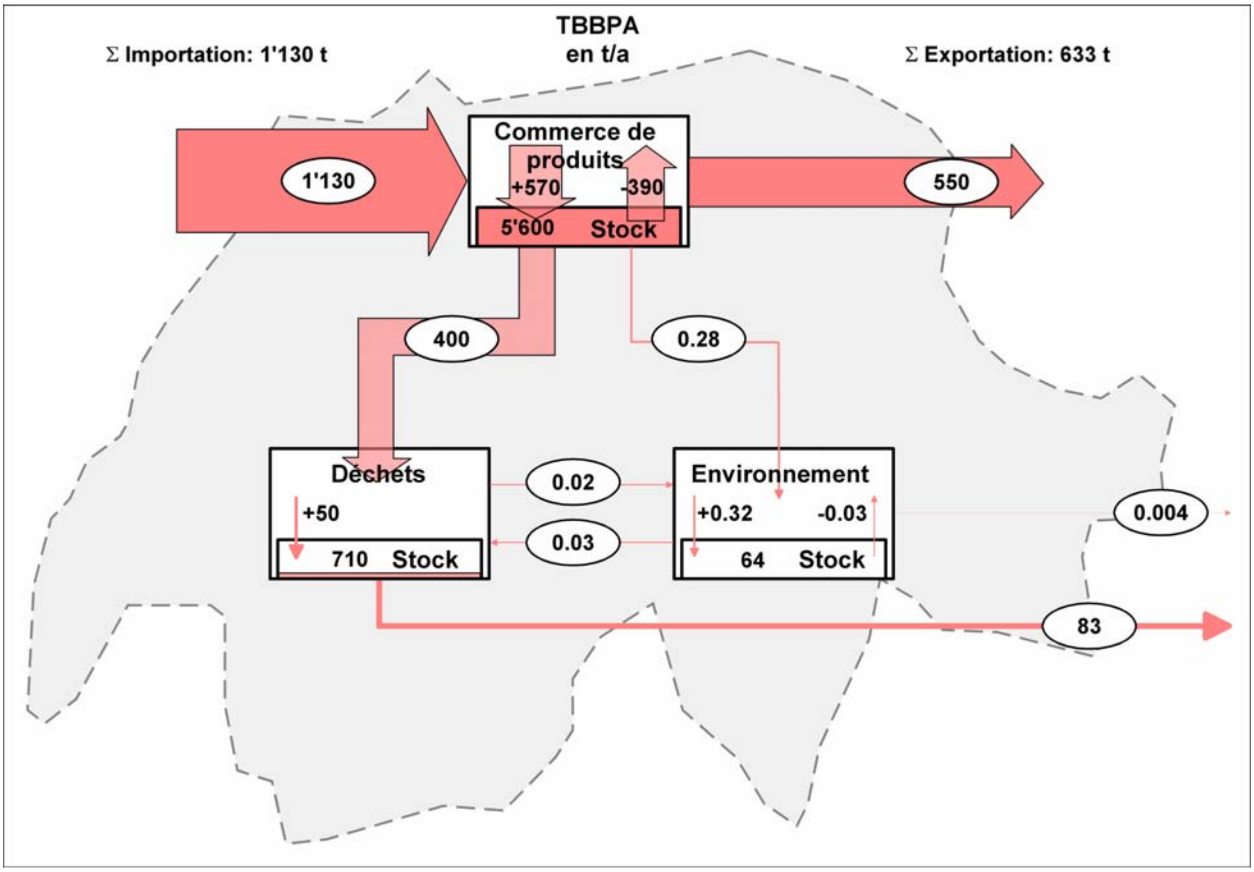


Figure 5: Flux de TBBPA en Suisse, à la fin des années 90

Conclusions

- La plupart des entreprises ne disposent pas d'informations suffisantes sur la composition chimique des produits qu'elles mettent en circulation. Dans la perspective d'une politique préventive de protection de l'environnement, les entreprises doivent être informées de l'impact possible, pour l'environnement et la santé, des produits qu'elles mettent en circulation. Cette information n'est actuellement pas suffisante. La tenue d'une comptabilité des substances par les entreprises pourrait être une façon d'optimiser leur fonctionnement.
- On ne dispose actuellement que de peu d'informations relatives à la répartition globale des produits ignifuges bromés. De manière générale, les chemins pris par les produits et donc également les flux de matières devraient être connus, de même que les producteurs des substances de base, des produits semi-finis et des produits finis. Le but visé à long terme est de joindre directement au produit les informations relatives aux flux de matières des substances critiques ou au moins de rendre disponibles ces informations.
- La taille et la composition du stock anthropique n'ont pas été déterminées avec suffisamment de précision. Il ne sera possible de gérer activement ce stock, d'évaluer les émissions diffuses et de prévoir les futurs flux de déchets qu'une fois que la dynamique du stock aura été caractérisée et modélisée. Ce n'est qu'ainsi que le flux vers les décharges et par conséquent également les émissions diffuses qui proviennent des déchets pourront être contrôlés et réduits autant que possible, et que les stratégies de démolition adéquates pourront être mises au point.

- D’importantes quantités de produits ignifuges bromés passent des produits de consommation aux déchets. Les quantités d’émissions qui résultent des processus du traitement des déchets ne sont pour le moment que peu connues (combustion), voire pas du tout étudiées (recyclage, décharges contrôlées, élimination non-contrôlée). Ces connaissances sont toutefois une condition fondamentale pour garantir également une gestion optimale dans les phases d’élimination et de recyclage. C’est pourquoi il est indispensable de procéder à des mesures dans les principaux processus de gestion des déchets (UIOM, décharges contrôlées, recyclage, STEP).

Riassunto

Da oltre 15 anni si dibatte sui prodotti ignifughi bromati (PIB). Oggi si hanno maggiori informazioni sul comportamento e sul potenziale di minaccia dei prodotti ignifughi bromati per l'umanità e l'ambiente di quanto si sapesse per esempio sui PCB all'epoca dell'entrata in vigore del divieto di utilizzare e produrre tali sostanze. Il potenziale di minaccia di alcuni prodotti ignifughi esaminati consiste essenzialmente nel fatto che sono persistenti e possono accumularsi nella catena alimentare (per. es. il pentaBDPE, il TBBPA), e che nel caso di incenerimento incontrollato possono provocare la formazione di diossine bromate e furani (per es. il decaBDPE). Inoltre si teme che tali sostanze siano cancerogene (per es. il decaBDPE) e abbiano un effetto estrogeno (per es. il pentaBDPE).

Scopo del presente studio è effettuare un'analisi del flusso di sostanze per i quattro campioni selezionati di prodotti ignifughi bromati: il derivato pentabromato [pentaBDPE], il derivato octabromato [OctaBDPE], il derivato decabromato [DecaBDPE] e il tetrabrombisfenolo A [TBBPA].

Lo studio si basa esclusivamente sui dati della letteratura scientifica e analizza l'uso dei PIB in Svizzera alla fine degli anni '90. A partire dall'importazione in Svizzera di prodotti ignifughi semifiniti e finiti è stato possibile risalire ai loro depositi antropogeni. Inoltre sono stati stabiliti i flussi annuali nell'esportazione e nella gestione dei rifiuti, come pure le emissioni nell'ambiente.

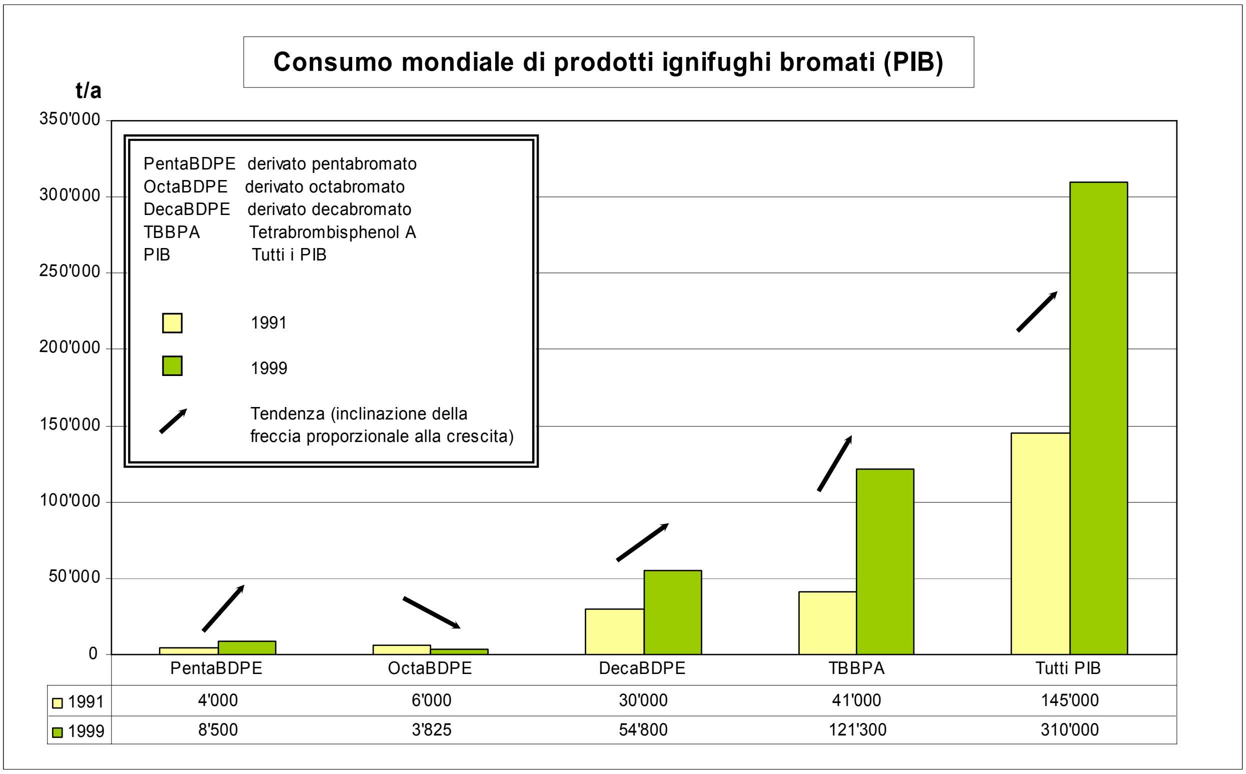


Grafico 1: Quantità dei PIB diffusi in tutto il mondo a confronto (Fonte: TBBPA 1991 [OCSE, 1994], PBDE 1991 [IPCS 1994b], TBBPA+PBDE 1999 [Leisewitz & Schwarz, 2000], Tutti PIB:1990 e 2000 [Arias, 2001])

Circa due terzi del fabbisogno mondiale di PIB sono stati coperti negli anni '90 dalle quattro sostanze prese in esame. Negli ultimi decenni tale fabbisogno è cresciuto notevolmente da un canto a causa dell'aumento del consumo di materia plastica e, dall'altro, a causa di prescrizioni anti incendio sempre più rigide. Il consumo mondiale dei PIB esaminati è aumentato dal 1991 al 1999 da 100.000 t/a a 190.000 t/a, e sino al 2005 si prevede un'ulteriore crescita annua del 5-7 %. Se si osserva la situazione più da vicino, si nota che, negli anni '90, il consumo di octaBDPE è diminuito notevolmente, mentre quello di pentaBDPE, decaBDPE e TBBPA è aumentato vertiginosamente (cfr. grafico 1).

Risultati

Ogni anno, in Svizzera, circa 1'700 t dei quattro PIB esaminati finiscono in prodotti semifiniti o finiti. Il 46 % circa delle quali è nuovamente esportato sotto forma di prodotti finiti, mentre ciò che resta viene consumato in Svizzera (commercio dei prodotti). I valori più alti nel consumo della Svizzera si registrano nei veicoli a motore (imbottitura, tessuti) per il pentaBDPE, negli apparecchi elettrici e elettronici (EE) e nei veicoli a motore per l'octaBDPE, negli apparecchi EE (strumenti EDP e per l’ufficio), nei veicoli a motore e nei materiali di costruzione (fogli di PE) per il decaBDPE, e negli apparecchi EE (computer) per il TBBPA.

Il consumo di prodotti ignifughi negli ultimi 20 anni in Svizzera ha determinato l'esistenza di un deposito nel quale sono accumulate circa 12'000 t dei PIB esaminati. Attualmente i depositi di pentaBDPE e di octaBDPE vengono smantellati, quello di TBBPA aumenta, mentre quello di decaBDPE resta più o meno costante.

Ogni anno circa 900 t delle sostanze esaminate che si accumulano nei depositi vengono consumate. Di cui quasi la totalità finisce tramite i rifiuti solidi nella gestione dei rifiuti dove i PIB contenuti nei rifiuti solidi vengono smaltiti e in pratica completamente distrutti (dal 65 % all 85 %, secondo la sostanza, salvo il pentaBDPE al 23 %), attraverso il trattamento termico nel processo di incenerimento controllato. Oltre al deposito nel consumo, negli ultimi anni è stato costruito un deposito dieci volte più piccolo di 1'500 t di PIB nelle discariche svizzere. Questo deposito cresce ogni anno di circa 130 t e se mal gestito costituisce un potenziale pericolo per le future generazioni e l'ambiente. Poiché attualmente mancano dati aggiornati, le stime sui flussi sia provenienti dal consumo, sia provenienti dalla gestione dei rifiuti verso l'ambiente sono solo approssimative.

PentaBDPE

Rispetto agli altri prodotti ignifughi, alla fine degli anni '90 sono stati utilizzate in Svizzera quantità inferiori di prodotti ingnifughi contenenti pentaBDPE. Ogni anno vengono importate in Svizzera circa 1.9 t/a di pentaBDPE sotto forma di prodotti finiti, di cui ne vengono consumate circa 1.5 t/a. La maggior parte dei beni di consumo che contengono pentaBDPE sono le imbottiture, i prodotti tessili e i materiali sintetici dei veicoli a motore. Rispetto agli altri PIB, le merci contenenti penta-BDPE sono da 10- a 1'000 volte inferiori.

Attraverso le diverse applicazioni, negli ultimi vent'anni è venuto a crearsi nel consumo un deposito di 500 t di pentaBDPE composto per il 91 % da materiali di costruzione contenenti pentaBDPE. Attualmente si sta procedendo all'eliminazione di circa 30 t/a del deposito. Qualora la tendenza dovesse persistere nei prossimi anni, fra 7 - 10 anni il deposito nella gestione dei rifiuti con circa 280 t sarà il principale deposito antropogeno.

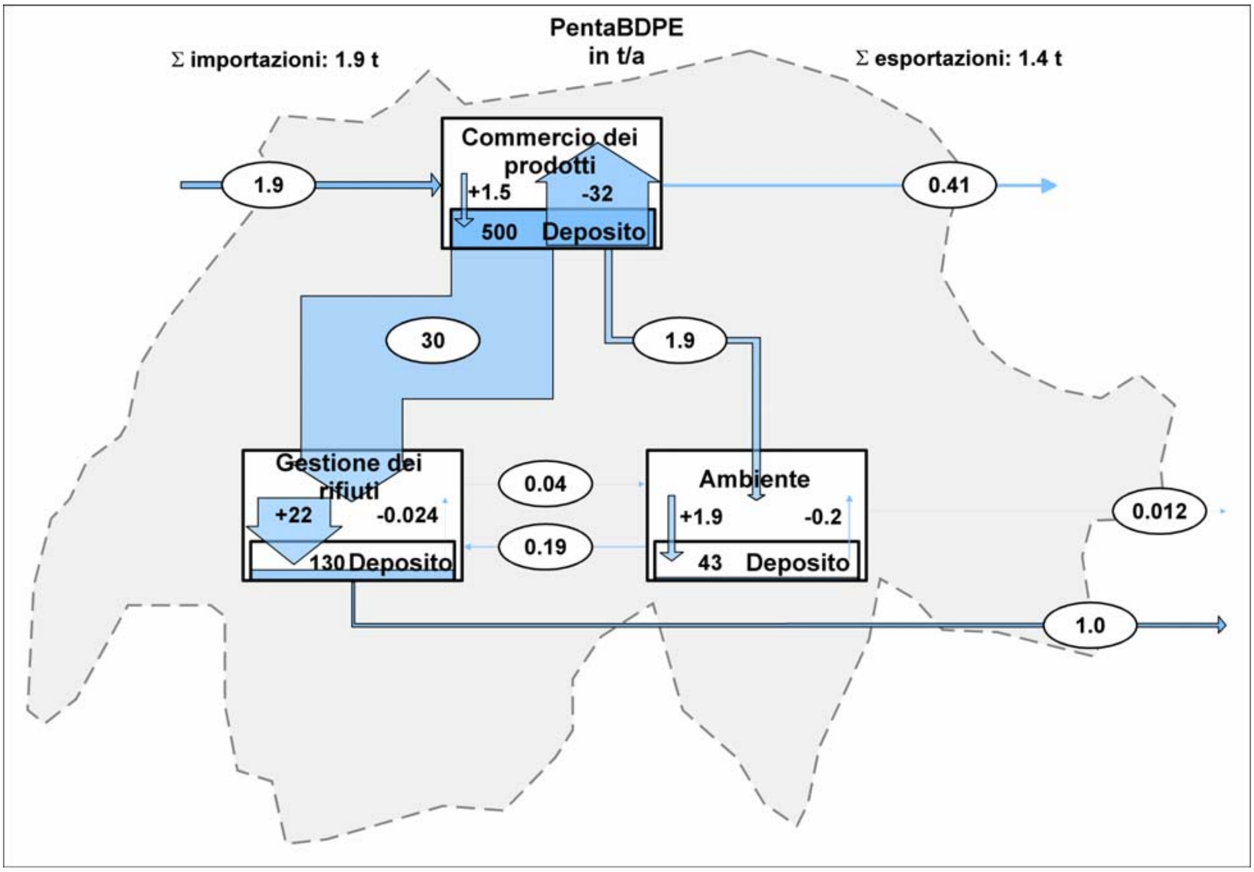


Grafico 2: flussi di pentaBDPE in Svizzera, fine anni '90

Ogni anno finiscono nella gestione dei rifiuti circa 30 t/a di pentaBDPE, di cui la maggior parte (72 %) viene distrutta in discariche e circa il 20 % in impianti di incenerimento. Una minima parte di 1 t/a (3 %) viene esportata.

Dal deposito nel consumo si diffondono ogni anno circa 1.9 t/a, che finiscono quasi interamente nella pedosfera e nella litosfera. Quanto al carico diffuso ogni anno, per il pentaBDPE vengono registrati valori superiori a quelli per l'octaBDPE e per il TBBPA.

OctaBDPE

Ogni anno vengono importate in Svizzera cira 41 t di octaBDPE sotto forma di materiale ignifugo nei prodotti, 22 t/a circa delle quali vengono consumate. Ciò che resta viene esportato. Il carico di octaBDPE consumato è pari al 67 % circa negli apparecchi EE e al 33 % circa nei veicoli a motore.

Negli ultimi due decenni è stato allestito un deposito nel consumo di 680 t di octaBDPE composto per il 69 % da apparecchi EE, per il 21 % da veicoli a motore e per il 10 % da materiali da costruzione. Attualmente si procede all'eliminazione di circa 40 t/a del deposito. Qualora la tendenza dovesse persistere nei prossimi anni, fra 13 - 18 anni il deposito nel settore della gestione dei rifiuti con circa 160 t sarà il principale deposito antropogeno.

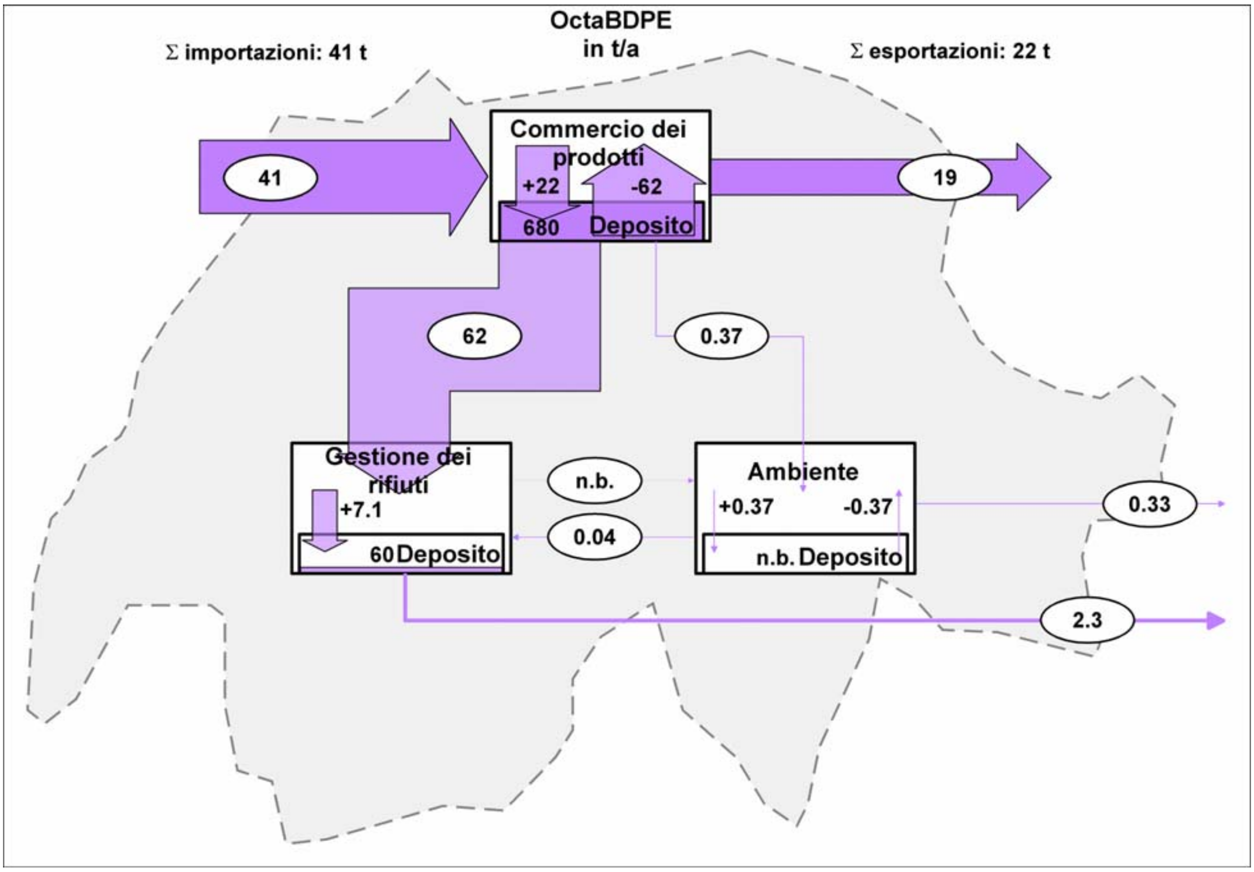


Grafico 3: flussi di octaBDPE in Svizzera, fine anni '90

I rifiuti provenienti dal consumo contengono ogni anno circa 62 t/a di octaBDPE. La maggior parte delle merci (l'87 %) viene distrutta in impianti d'incenerimento e il 10 % circa viene depositato in discariche. Ciò che resta (circa il 3 %) viene esportato.

Ogni anno circa 0.4 t/a di octa-BDPE si diffondono dai depositi nel consumo e giungono quasi nella loro totalità nella pedosfera e nella litosfera.

DecaBDPE

Alla fine degli anni '90 sono stati importati in Svizzera ogni anno 550 t di sostanze ignifughe con decaBDPE sotto forma di prodotti semifiniti o finiti. 320 t/a circa delle quali sono state consumate e il resto nuovamente espor-tato. Il 45 % circa delle deca-BDPE consumato in Svizzera si trova negli apparecchi EE (strumenti EDP e per l'ufficio), il 30 % circa nei veicoli a motore importati e il 25 % circa nei materiali da costruzione (fogli di PE).

Il deposito di decaBDPE nei prodotti consumati ammonta a 5'600 t ed è più o meno costante. Il che significa che lo stesso carico di deca-BDPE che viene consumato, viene poi smaltito tramite i rifiuti. Le 370 t/a circa di decaBDPE presenti nei rifiuti vengono in gran parte (80 %) distrutte in impianti d'incenerimento. Il 9 % circa viene esportato, mentre il 13 % circa viene depositato in discariche. Se questa situazione persiste, nei prossimi 20 anni il deposito nel consumo sarà più importante del deposito di discarica e di quello nell'ambiente.

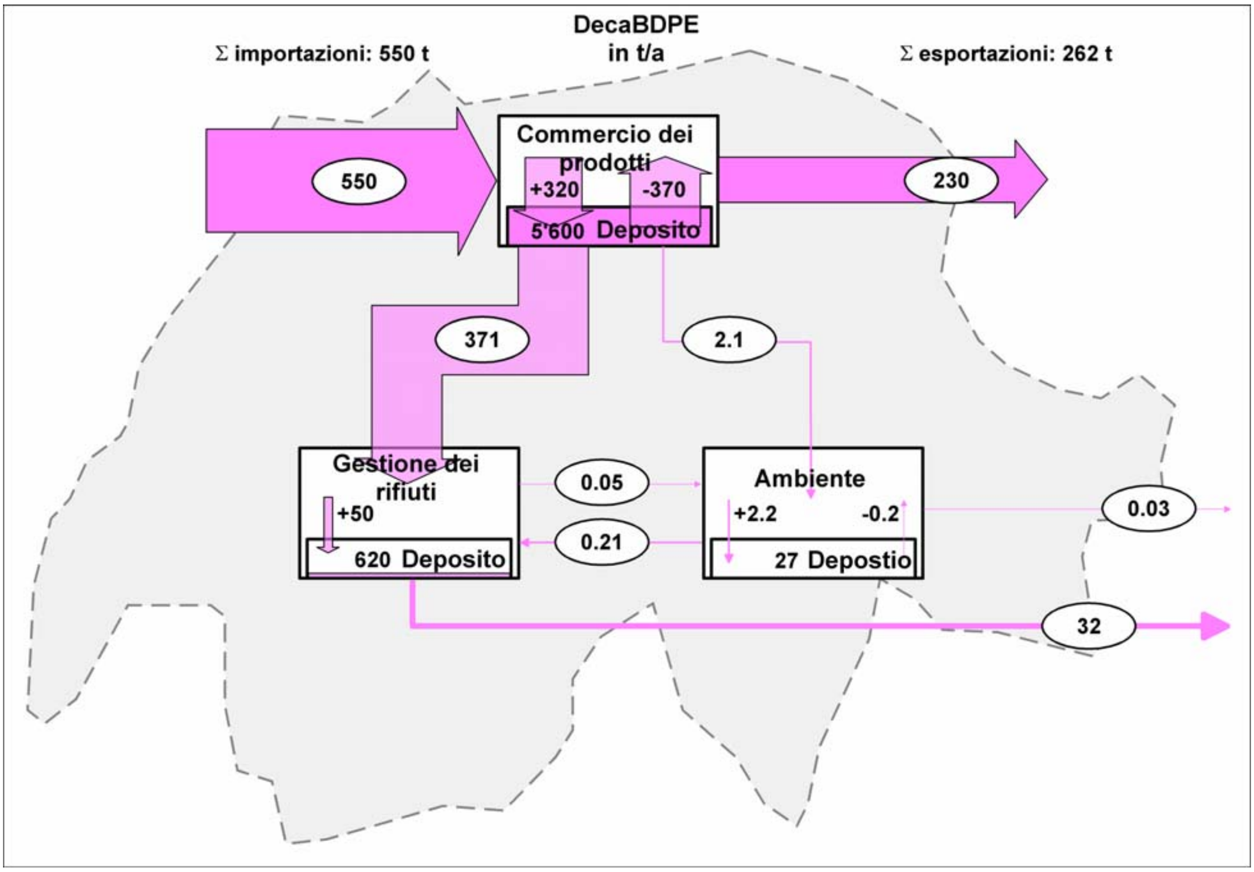


Grafico 4: flussi di decaBDPE in Svizzera, fine degli anni '90

Il deposito di decaBDPE nel consumo è costituito per il 0 % da apparecchi EE, per un 30 % da materiali da costruzione e da un altro 30 % da veicoli a motore. Ogni anno dal deposito nel consumo si diffondono circa 2.1 t/a di decaBDPE che giungono quasi nella loro totalità nella pedosfera e nella litosfera. Va notato che nonostante le importanti scorte, rispetto al pentaBDPE, viene diffuso nell'ambiente quasi lo stesso carico.

TBBPA

Alla fine degli anni '90 sono state importate in Svizzera ogni anno 1’130 t di sostanze ignifughe con decaBDPE in prodotti semifiniti o finiti. 570 t/a circa delle quali sono state consumate e il resto nuovamente esportato. Quasi la totalità del carico di TBBPA consumato si trova negli apparecchi EE: l'83 % circa nei computer e l'11 % circa in apparecchi elettronici d'intrattenimento. Rispetto agli altri PIB i carichi di TBBPA commercializzati e consumati sono i più elevati.

Il deposito di TBBPA nei prodotti consumati am-monta a circa 5'600 t ed è costituito in gran parte (59 %) da apparecchi EE e in minor parte (20 %) da materiali da costruzione e da veicoli a motore (20%). Nonostante rispetto al deca-BDPE venga consu-mata ogni anno una quan-tità doppia di TBBPA, le scorte sono più o meno le stesse. Il che dipende dal fatto che la maggior parte dei prodotti che conten-gono TBBPA sono meno durevoli di quelli che contengono decaBDPE.

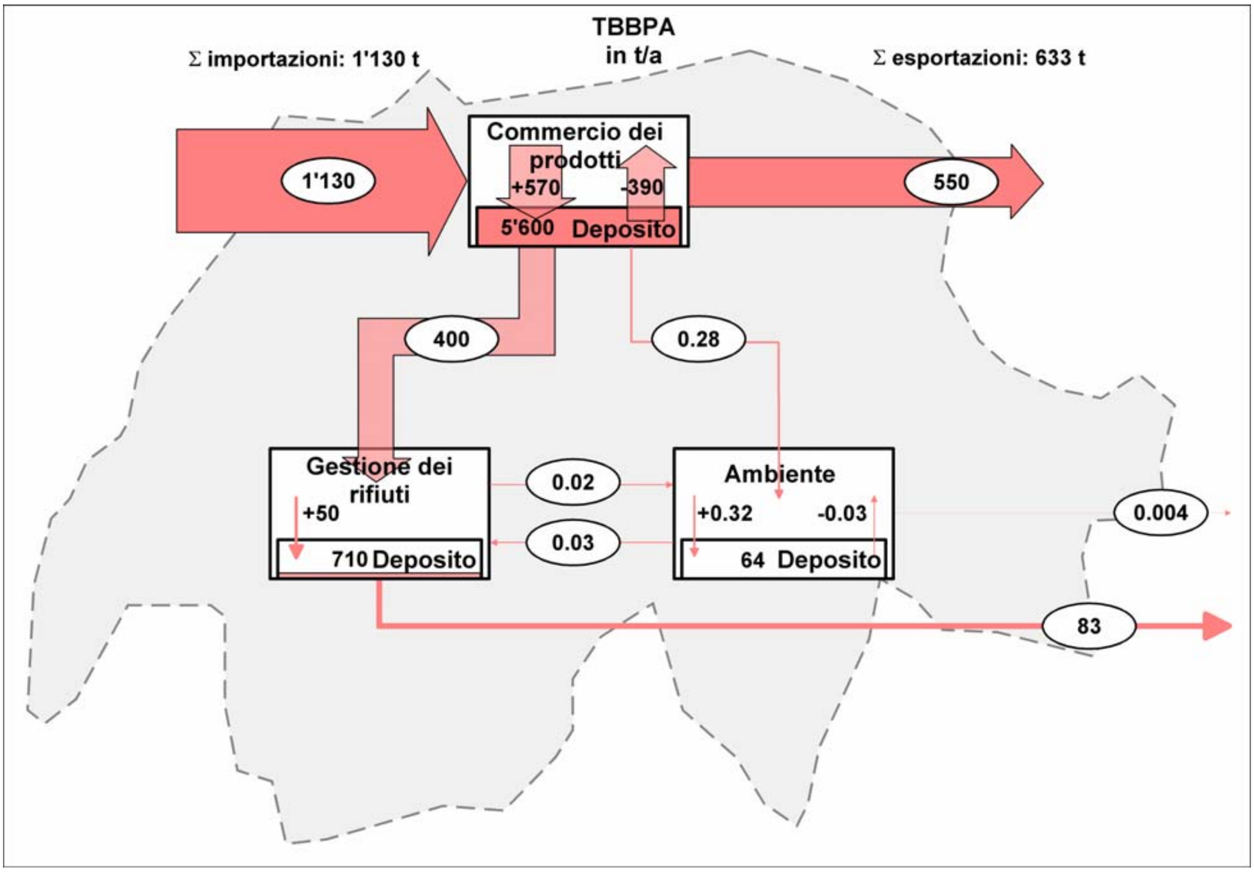


Grafico 5: flussi di TBBPA in Svizzera, fine anni '90

Attualmente il deposito nel consumo aumenta di circa 180 t/a. Se tale tendenza dovesse persistere nei prossimi anni, il deposito nel consumo rimarrà nei prossimi 20 anni più importante rispetto a quello delle discariche e quello nell'ambiente.

I rifiuti provenienti dal consumo contengono ogni anno circa 400 t/a di TBBPA, di cui il 68 % viene distrutto in impianti d'incenerimento, l'11 % depositato e il 21 % esportato.

Ogni anno circa 0.3 t/a di TBBPA provenienti dal deposito nel consumo si diffondono nell'ambiente e si depositano nella loro quasi totalità nella pedosfera e nella litosfera. Rispetto agli altri PIB presi in esame, e nonostante si tratti delle scorte più importanti, questa è l'emissione meno diffusa.

Conclusioni

- La maggior parte delle imprese non dispone di informazioni sufficienti sulla composizione delle sostanze dei prodotti da loro messi sul mercato. Da un punto di vista della protezione previdenziale dell'ambiente le imprese dovrebbero conoscere il potenziale di danno alla salute dei prodotti da loro commercializzati. Per il momento tuttavia ciò non avviene in misura sufficiente. Un modo per ottimizzare le strutture aziendali sarebbe quello di introdurre un sistema di contabilità delle sostanze.
- Attualmente sono poche le informazioni di cui si dispone sulla distribuzione totale dei PIB. A livello globale occorre seguire, insieme ai produttori delle materie di base, dei prodotti semifiniti e dei prodotti finti, i percorsi dei prodotti e pertanto anche dei flussi di sostanze.

L'obiettivo di lungo periodo è quello di scrivere sul prodotto, o per lo meno rendere accessibili, le informazioni sui flussi di massa delle sostanze critiche.

- Le dimensioni e la composizione del deposito antropogeno non sono sufficientemente definiti. Occorre rilevare e modellare l'andamento del deposito. Solo così sarà possibile gestirlo in modo attivo, stimare le emissioni diffuse e prevedere futuri flussi di rifiuti. Sarà inoltre possibile incanalare il flusso nelle discariche che consentirà di controllare e ridurre le emissioni diffuse dalle discariche e elaborare i relativi progetti di trasformazione.
- Dal consumo finiscono nei processi della gestione dei rifiuti grandi flussi. Quali siano tuttavia le emissioni che provengono dai processi di gestione dei rifiuti non è tuttavia attualmente ancora noto (incenerimento) o lo è solo parzialmente (recupero, discarica, smaltimento incontrollato). Tali informazioni sono nondimeno il presupposto fondamentale per garantire una gestione ottimale anche nelle fasi di smaltimento e di riciclaggio. Ecco perché risulta indispensabile effettuare rilevamenti nei processi principali della gestione dei rifiuti (IIRU, discarica, riciclaggio, IDA).

Summary

Brominated flame retardants (BFR) have been a controversial topic for over 15 years. Today, more is known about the behaviour of BFR and about the potential threat that they present to human beings and to the environment than was known at the time about PCB, when their use and production were prohibited. Among the BFR examined here, some present a potential threat in that they are persistent and can accumulate in the food-chain (e.g. pentaBDPE and TBBPA). Also, dioxins and furans may be formed during uncontrolled incineration (e.g. decaBDPE), and there are indications of carcinogenic potential (e.g. decaBDPE) and estrogenic effects (e.g. pentaBDPE).

The present study presents substance flow analyses for four representative groups of brominated flame retardants: pentabromodiphenyl ethers [pentaBDPE], octabromodiphenyl ethers [octaBDPE], decabromodiphenyl ethers [decaBDPE] and tetrabromobisphenol A [TBBPA].

The study is based solely on data available in the literature, and examines the use of BFR in Switzerland in the late 1990s. The accumulated anthropogenic stock was determined from the figures for semi-finished and finished products treated with flame retardants that were imported into Switzerland. The annual flows arising from export, waste management and emission to the environment, were also estimated.

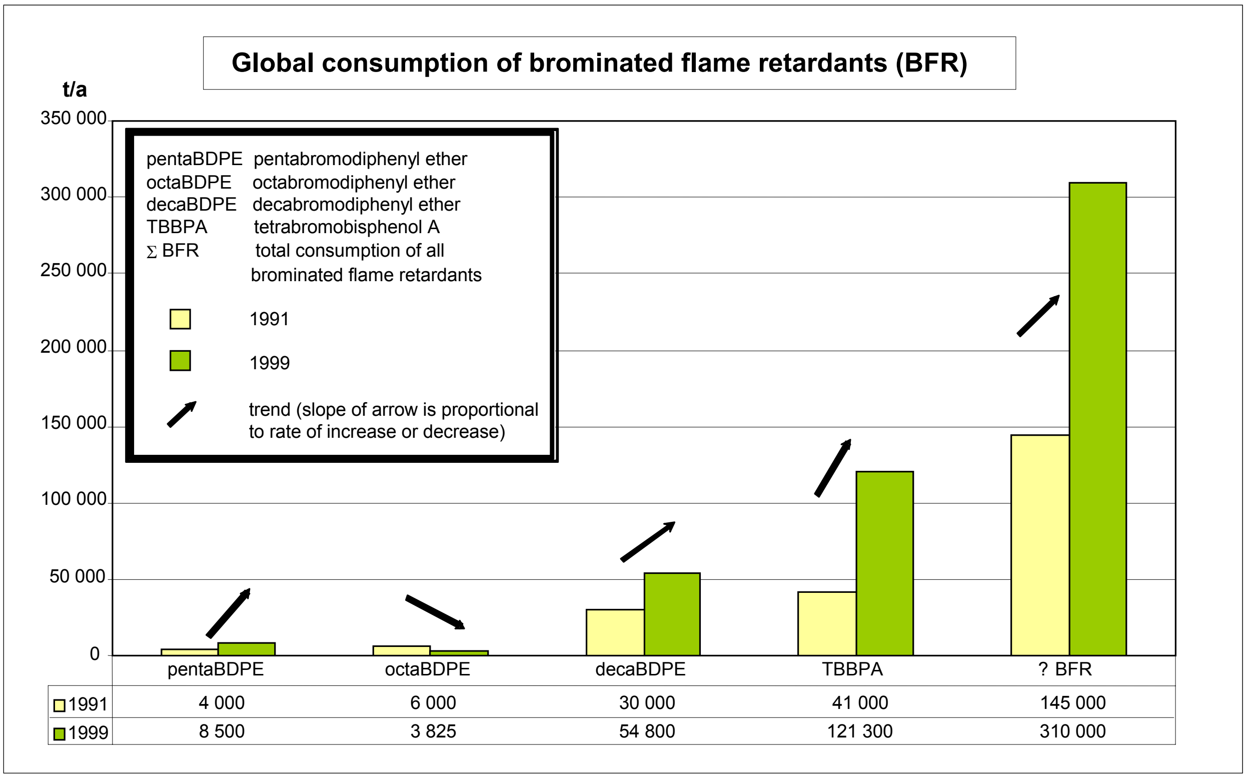


Figure 1: Comparison of world consumption for selected BFR (sources: TBBPA 1991 [OECD, 1994], PBDE 1991 [IPCS 1994b], TBBPA + PBDE 1999 [Leisewitz & Schwarz, 2000], total BFR: values for 1990 and 2000 [Arias, 2001]).

In the 1990s, the four groups of substances under study accounted for about two thirds of world demand for BFR. In recent decades, the demand has risen sharply as a result of the increasing use of plastics, and stricter fire regulations. The world consumption of the BFR under study rose between 1991 and 1999 from 100 000 t/a to 190 000 t/a, and further increases of 5 to 7 percent per annum are expected up to 2005. From a detailed breakdown of the data, it may be seen that the consumption of octaBDPE decreased strongly during the 1990s, while that of pentaBDPE, decaBDPE and TBBPA rose sharply (see Figure 1).

Results

About 1700 tonnes of the BFR under study are imported annually into Switzerland via semi-finished and finished products. About 46 percent of these are re-exported via finished products, and the remainder is consumed in Switzerland (‘trade in products’). The consumption of pentaBDPE within Switzerland is mainly accounted for by motor vehicles (upholstery, textiles), of octaBDPE by electrical and electronic appliances (EE appliances) and motor vehicles, of decaBDPE by EE appliances (EDP and office equipment), motor vehicles and building materials (PE sheeting), and of TBBPA by EE appliances (computers).

Over the past twenty years, the consumption of products treated with flame retardants in Switzerland has resulted in the accumulation of about 12 000 t of the BFR under study. While the stocks of pentaBDPE and octaBDPE are at present declining, that of TBBPA is increasing, and that of decaBDPE is approximately in dynamic equilibrium.

Approximately 900 tonnes of BFR leave the stock in consumption annually, almost all of which is disposed of via solid waste. A total of 65 to 85 percent of the BFR (except for pentaBDPE with only 23 percent) are treated in controlled incineration processes, in which they are almost completely destroyed. Over and above the stock in consumption, a further stock of 1500 t of BFR (i.e. about a factor of 10 lower) has accumulated in Swiss landfills in recent decades. This is increasing by about 130 t per year. If inappropriately managed, this, too, could represent a potential future hazard to humans and the environment. In the absence of up-to-date measurements for Switzerland, only very rough estimates of the flows to the environment from consumption and from waste management could be made.

PentaBDPE

In comparison to the other flame retardants, only very small quantities of products containing pentaBDPE were employed in Switzerland at the end of the 1990s. About 1.9 t of pentaBDPE are imported into Switzerland annually in finished products, of which about 1.5 t are consumed. The majority of the consumer goods treated with pentaBDPE consist of upholstery, textiles and plastics in motor vehicles. In comparison to the other BFR, the quantities of pentaBDPE are a factor of ten to a thousand lower.

Over the last two decades, pentaBDPE was employed in a variety of ways, resulting in a stock of 500 t being built up in consumption, about 91 percent of which is present in building materials. This stock is now diminishing at the rate of about 30 t per year. Should this trend continue, the stock in waste management will increase to some 280 t within the next 7 to 10 years to become the key anthropogenic stock of pentaBDPE.

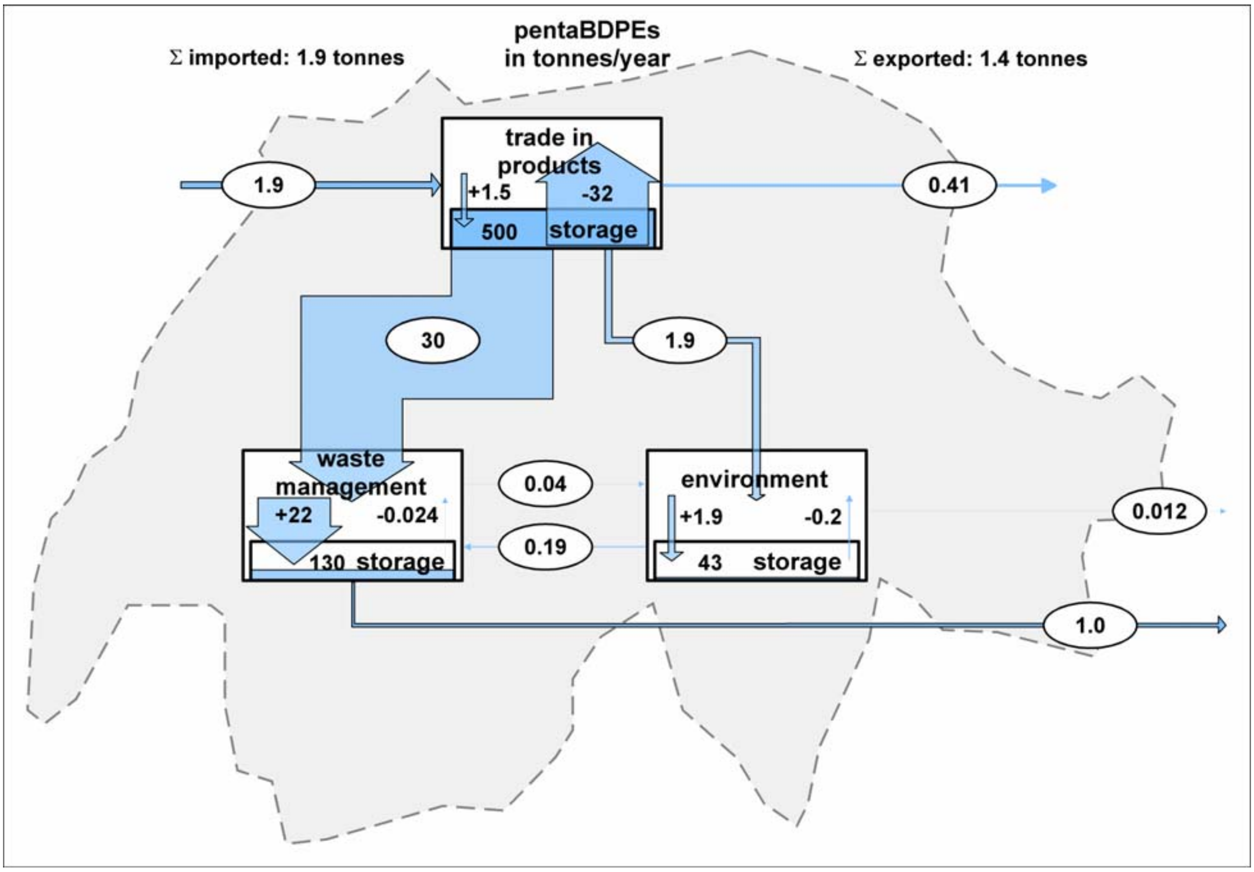


Figure 2: Flows of pentaBDPE in Switzerland in the late 1990s

Of the 30 t of pentaBDPE that are now being input annually to waste management, about 72 percent is disposed of in landfills, and 20 percent destroyed by incineration. A small remainder of 1 t per year (= 3 percent) is exported.

A flow of 1.9 t diffuses annually from the stock in consumption, and almost all of this is carried over into the pedosphere and the lithosphere. The annual diffusion of pentaBDPE is considerably greater than that of octaBDPE or TBBPA.

OctaBDPE

Some 41 t of octaBDPE flame retardants are imported annually into Switzerland in products. About 22 t of this are consumed and the remainder re-exported. About 67 percent of the octaBDPE consumed is present in EE appliances, and about 33 percent in motor vehicles.

A stock of 680 t of octaBDPE has built up in consumption over the last two decades. Of this, 69 percent is attributable to EE appliances, 21 percent to motor vehicles and 10 percent to building materials. This stock is presently diminishing at the rate of 40 t per annum. If this trend continues over the next 13-18 years, the stock in waste management will grow to about 160 t, and thereby become the key anthropogenic stock of octaBDPE.

Almost all of the 62 t of octaBDPE that arise annually from consumption (87 percent) is destroyed in incineration plant, and about 10 percent is deposited in landfills. The remainder (about 3 percent) is exported.

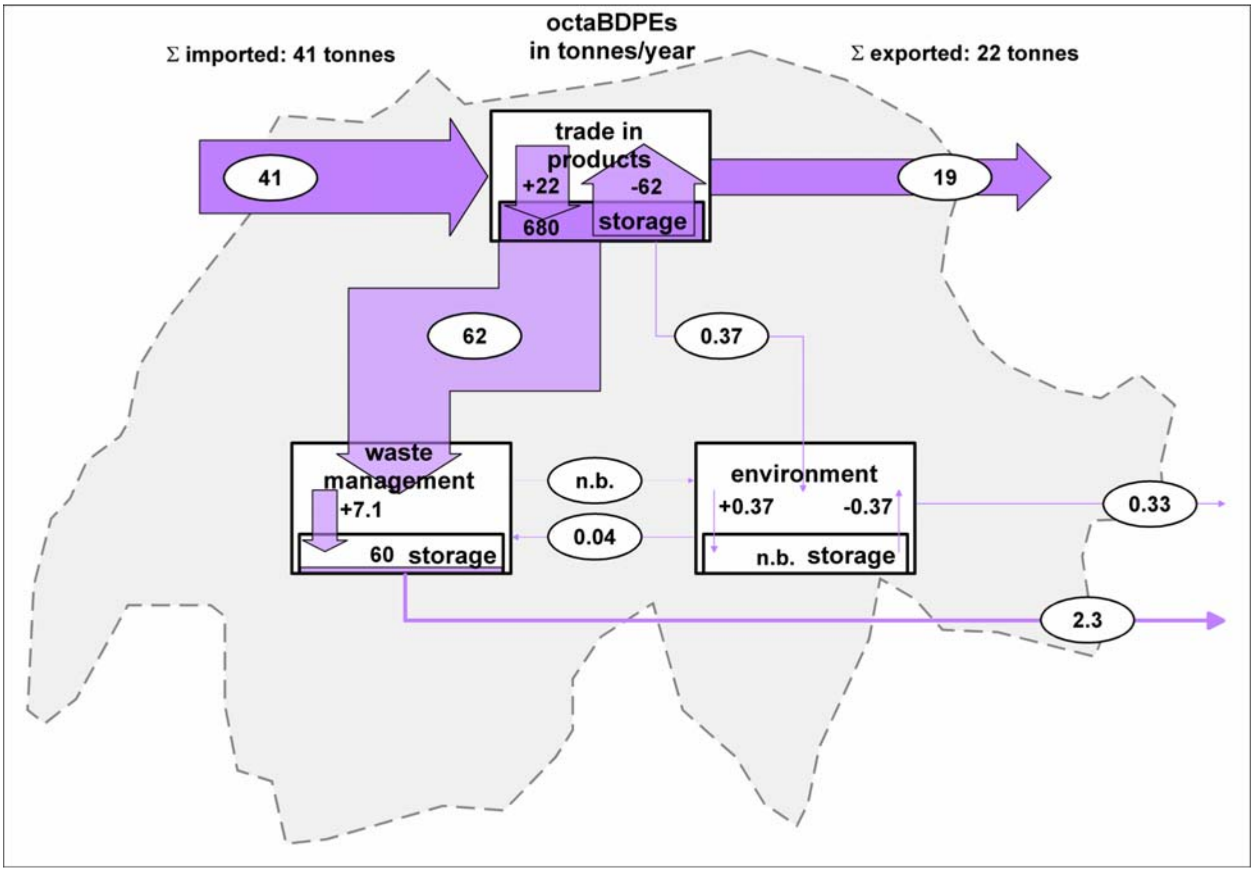


Figure 3: Flows of octaBDPE in Switzerland in the late 1990s

An annual 0.4 t of octaBDPE diffuses from the stock in consumption, and this largely accumulates in the pedosphere and the lithosphere.

DecaBDPE

At the end of the 1990s, 550 t of decaBDPE flame retardants were imported annually into Switzerland in semi-finished and finished products. Of this, about 320 t per year were consumed and the remainder re-exported. About 45 percent of the decaBDPE consumed in Switzerland are present in EE appliances (EDP and office equipment), about 30 percent in imported motor vehicles and about 25 percent in building materials (PE sheeting).

The stock of decaBDPE in consumed products amounts to approximately 5600 t, and is approximately in dynamic equilibrium, i.e. the amount of decaBDPE consumed is almost equal to that disposed of with waste. Of the approximately 370 t of the decaBDPE that arise annually in waste, the greater part (about 80 percent) is destroyed in incineration plant. About 9 percent is exported and about 13 percent deposited in landfills. If this trend continues, the stock in consumption – in comparison to the stocks in landfills and the environment – will remain the key stock of decaBDPE over the next 20 years.

Of the stock of decaBDPE in consumption, 40 percent is present in EE appliances and 30 percent each in building materials and motor vehicles. About 2.1 t of decaBDPE diffuse annually from the stock, and almost all of this accumulates in the pedosphere and the lithosphere.

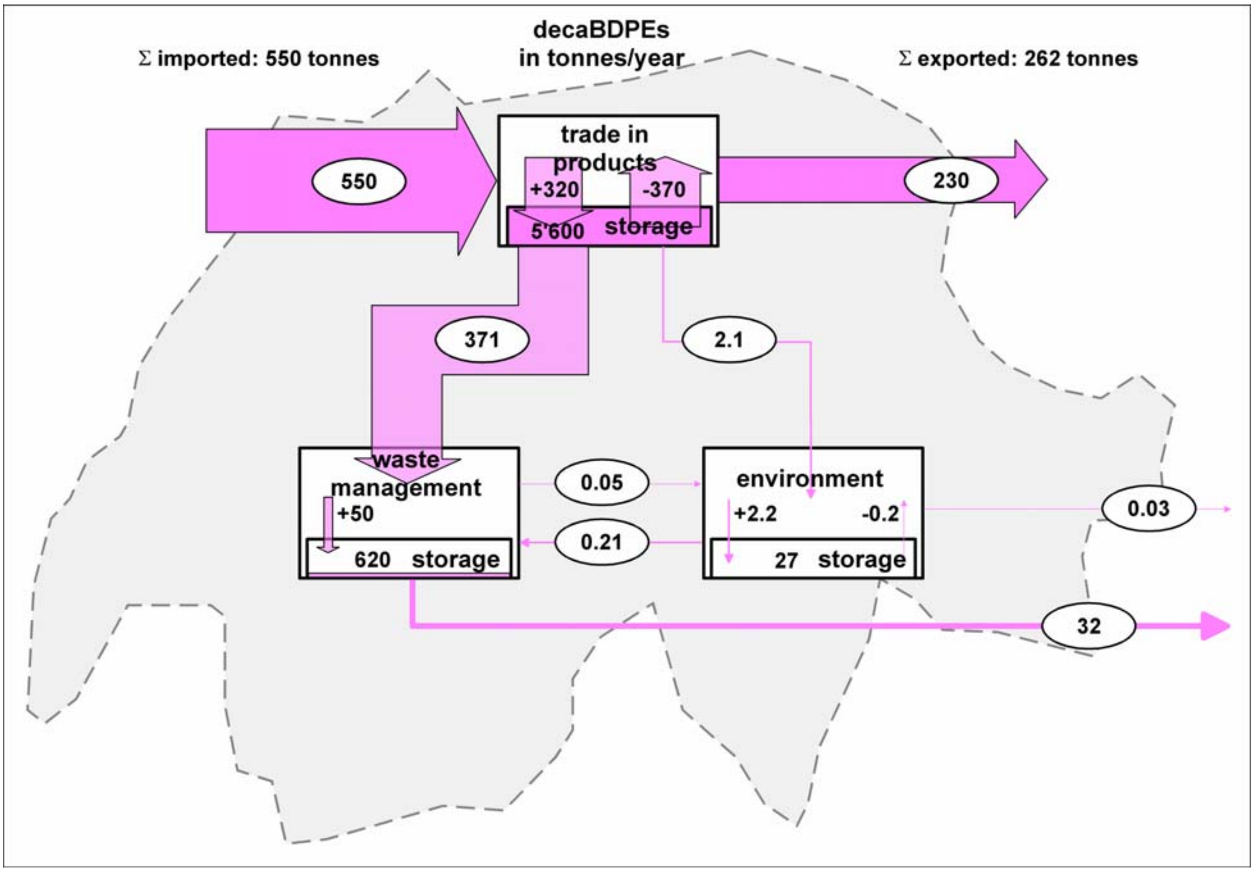


Figure 4: Flows of decaBDPE in Switzerland, late 1990s

It is noteworthy that despite the relatively large stock of decaBDPE, the annual diffuse emission to the environment is about the same as that for pentaBDPE.

TBBPA

At the end of the 1990s, 1130 t of TBBPA flame retardants were imported annually into Switzerland in semi-finished and finished products. About 570 t of this were consumed, and the remainder re-exported. Almost all (about 83 %) of the TBBPA consumed is attributable to EE appliances, and of these, about 83 percent are present in computers and 11 percent in household electronic appliances. Greater quantities of TBBPA are traded and consumed than of other BFR.

The stock of TBBPA in consumer products amounts to about 5600 t, of which the greater part (59 percent) is attributable to EE appliances, and the remainder in approximately equal quantities (about 20 percent each) to building materials and motor vehicles. Although the annual consumption of TBBPA is about twice that of decaBDPE, the quantities in the stocks are about equal. This results from the fact that most of the products that use TBBPA have a shorter service life than those containing decaBDPE.

The stock in consumption is currently increasing by about 180 t per year. If this trend continues, the stock in consumption of TBBPA – in comparison to the stocks in landfills and the environment – will remain the key stock over the next 20 years.

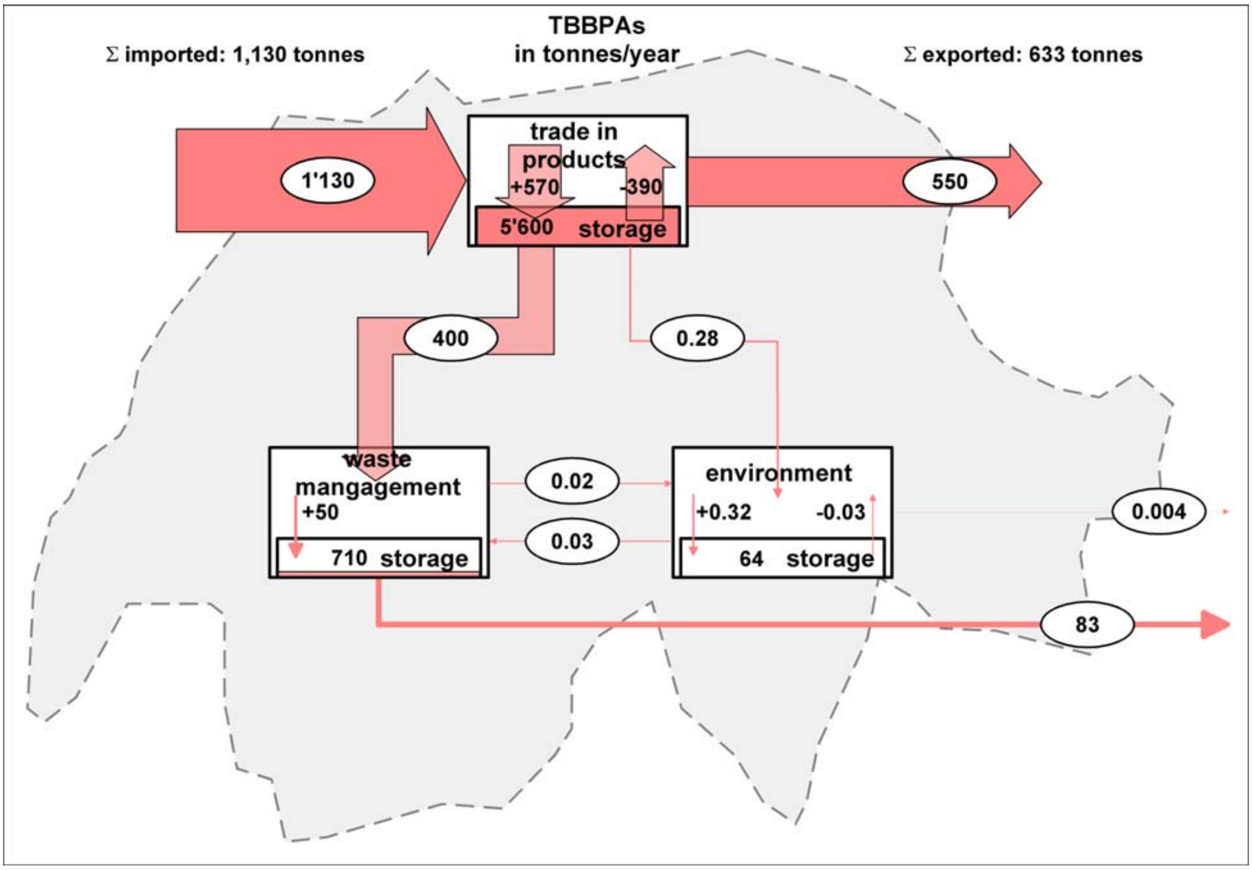


Figure 5: Flows of TBBPA in Switzerland in the late 1990s

About 0.3 t of TBBPA diffuse annually from the stock in consumption to the environment, and almost all of this accumulates in the pedosphere and the lithosphere. This represents the least significant diffuse emission, despite the fact that the stock of TBBPA is greater than that of any of the other BFR under study.

Conclusions

- The majority of companies dispose of insufficient information on the material constitution of the products they market. It is essential for purposes of precautionary environmental protection that companies are aware of the potential risks to health and the environment that their products present. At the moment, this is all too frequently not the case. A possible approach to the optimisation of manufacturing processes would be the introduction of substance flow balance sheets.
- Only scant information is available at present on the global distribution of BFR. An analysis is required at global level in cooperation with the manufacturers of basic materials and semi-finished and finished products, to trace the product paths, and – following from this – the substance flows. The long-term objective is to include information on the flow of critical substances with the product, or at least to make this data available.
- The magnitude and constitution of the anthropogenic stocks is not known in sufficient detail. To permit active management of these stocks, and enable their diffuse emission to be assessed and the flows of waste to be forecast, the stock dynamics need to be documented

and analysed. Only in this way will it be possible to control the flow to landfills, enabling diffuse emission to be minimised, and suitable landfill rehabilitation programs to be developed.

- There exists a very large flow from consumption to waste management. At present, our knowledge of the quantities emitted from waste management processes is either non-existent (i.e. for recycling, landfills and unsupervised disposal), or wanting (in the case of incineration). A knowledge of these flows is, of course, fundamental to effective management, particularly in the disposal and reuse phases. It is therefore essential to perform measurements on the principal waste management processes, i.e. in municipal waste incineration plants, landfills, reuse and waste water treatment.

1 Initial situation in the OECD

In 1990, the OECD Council adopted a recommendation on the Cooperative Investigation and Risk Reduction of Commercially Traded Chemicals. From among the five specific chemicals (or groups of chemicals), the OECD member countries selected brominated flame retardants as the subject of a pilot project.

In cooperation with the Netherlands, Sweden and the UK, Switzerland is managing the coordination centre for studies on this group of substances. In 1993, the four countries mentioned above commenced gathering data as a basis for the 'Risk Reduction Monograph No. 3: Selected Brominated Flame Retardants, Background and national Experience with Reducing Risk' published by the OECD in 1994.

In 1995, industry agreed to take various voluntary measures concerning the substances pentaBDPE, octaBDPE, decaBDPE and TBBPA contained in the OECD risk reduction programme (voluntary industry commitment, VIC). The data supplied by industry under this commitment are collated by the four coordinating countries and discussed at regular intervals at international conferences.

Industry prepared its first report in 1998, and this was evaluated by the coordinating countries. A meeting took place between the working group and representatives of the coordinating countries, at which the demand for improvements was voiced. It was decided that a second report should be presented by the year 2000.

The latter report dated 13.12.1999 was discussed at the meeting from 8 to 11 February 2000 in Paris between the working group and representatives of the coordinating countries. At the Paris meeting, it was agreed that under Swiss leadership the coordination centre should submit recommendations by the next meeting in February 2002 as to whether (1) measures concerning handling of the selected brominated flame retardants are necessary, and (2), if so, whether concrete measures should be proposed. These were to be based on data available from industry and any additional information available at national level.

In order to fulfil this task by the beginning of 2002, SAEFL decided to commission a material flow analysis for selected brominated flame retardants in Switzerland.

2 Aims and questions

The objective of this study is to prepare a substance flow analysis for four selected brominated flame retardants (pentabromodiphenyl ether [pentaBDPE], octabromodiphenyl ether [octaBDPE], decabromodiphenyl ether [decaBDPE] and tetrabromobisphenol A [TBBPA]), as a basis for preparing recommendations on the necessary action to take.

The following questions must be answered:

- What are the most important carriers, processes and forms of storage of the brominated flame retardants, and how great are the corresponding flows of materials and the substances under study? What total quantities ('stocks') of the latter have accumulated?
- Are gaps evident in the material balances of the above substances? Which of these need to be filled?
- How large are the uncertainties in the most critical data affecting the system as a whole?

3 Fundamentals

3.1 Bromine

Bromine (from the Greek *bromos* = stench) is a non-metallic element belonging to group VII (halogens) of the periodic table of the elements. Its main properties are: atomic number 35, relative atomic mass 79.916, dark red-brown liquid at room temperature; melting point -7.2°C, boiling point 58.78°C, and density 3.12 g/cm^3 [at STP???]. In nature it only occurs in the form of monovalent compounds (bromides). Bromine forms the basis of a large number of synthetic organic compounds (pigments, pharmaceuticals, solvents, etc.). Silver bromide is an important substance in the photographic industry. Ethylene bromide is used in motor fuels as an additive to anti-knocking substances. Both with respect to uses and chemical behaviour, bromine is akin to chlorine.

About a third to one-half of the annual production of 0.5 million t of bromine (70 % of this in the USA and Israel) is used in the production of flame retardants. The greater part of the brominated flame retardants is produced in the USA and Israel [Danish EPA, 1999]. Where Europe is concerned, BFR are manufactured in Belgium, France, Germany and the UK [UN, 2000].

3.2 Flame retardants (FR)

3.2.1 Function of flame retardants

Flame retardants are used to reduce the flammability of plastic products, enabling them to fulfil the testing requirements of electrotechnology, vehicle construction and building technology. FR are incorporated into plastics (polymers) or applied as coatings to textile fibres.

In general, FR have three different modes of action:

Production of radicals:

> At high temperatures, FR generate highly volatile, low activity, radicals. These – e.g. bromine and chlorine radicals – are able to interrupt the radical chain reaction.

Formation of a carbon coating:

> When heated, FR form a carbon layer on the surface of the polymer. The carbon coating hinders further heat and mass transfer, thereby preventing atmospheric oxygen from reacting with the polymer.

Dilution and cooling of the combustion gases:

> At high temperature, FR evaporate, while retaining their high thermal capacity. In this way, the gases are diluted and cooled.

3.2.2 Applications of flame retardants

FR are used mainly in the following sectors:

- Electrical and electronic appliances (EE appliances):
  Electrical and electronic products such as computers, home electronics, office equipment, household appliances and others, containing printed circuit laminates, plastic outer casings and internal plastic parts which may possibly have been treated with flame retardants.
- Traffic and transport:
  Cars, trains, aircraft and ships, containing textile and plastic interiors and electrical components (printed circuit boards, small plastic components), which may have been treated with flame retardants.
- Building materials:
  foam fillers, insulation boards, foam insulation, pipes, wall and floor panels, plastic sheeting, resins, etc.
- Furniture and textiles:
  Upholstered furniture, furniture covers, mattresses, curtains, carpets, flexible foam components and protective clothing.

The plastics industry is by far the largest consumer of FR. Smaller quantities of FR are also used in the textile and paper industries [Davenport et al., 1999].

3.2.3 Content of flame retardants

The content of FR in products varies depending on the use to which the plastics are put, the type of flame retardant, and the required standard of fire protection. The percentage of FR in plastics can be as high as 30% for organic FR, and up to 80% in the case of inorganic FR. A breakdown of common commercial formulae may be found in the ‘Handbook of Plastic Additives’ [Troitzsch, 1993]. Detailed information on the FR used in the various products may be found, for example, in a Danish [Danish EPA, 1999] and a German study [Leisewitz & Schwarz, 2000]. Detailed information on the amounts of FR in products is given in Chapter 5.1.

3.2.4 Substances used as flame retardants

Commercially, over 200 different substances are used as flame retardants. These are classified according to their chemical composition in Tab. 3-1 [IPCS, 1997]. The choice of FR depends on economic considerations, the polymer matrix involved (compatibility required between the FR and the polymer), the temperature at which it is to be used, and the level of fire protection.

Tab. 3-1: Flame retardant groups and the percentages produced [Danish EPA, 1999]

Percentage of world production	Flame retardant group (FR)
50 %	Inorganic FR
25 %	Halogenated (brominated and chlorinated) FR
20 %	Organophosphus FR (may contain chlorine or bromine)
5 %	FR based on nitrogen

The halogenated FR comprise [Danish EPA, 1999]:

- chlorinated paraffins
- aromatic, brominated, FR:
    - TBBPA (tetrabromobisphenol A)
    - TBBPA derivates
    - PBDE polybrominated diphenyl ether (pentaBDPE, octaBDPE, decaBDPE)
    - PBB polybrominated biphenyl
    - others
- aliphatic, brominated FR (relatively small proportion of total production)
- cycloaliphatic, brominated FR (e.g. HBCD hexabromocyclododecane)
- other brominated FR

3.3 Brominated flame retardants (BFR)

3.3.1 Function of brominated flame retardants

Under combustion conditions, organic compounds containing chlorine or bromine release substances that hinder oxygen access and chemically retard the combustion reaction (by the production of radicals). BFR (like the FR containing phosphorus) can either be combined chemically with monomers or used as additives to polymers. A distinction is therefore made between **reactive** and **additive** BFR [Saechtling, 1986].

This distinction is significant, since additive FR are released more readily from the plastic than reactive FR. Reactive FR do not have a plastifying effect and do not influence the thermal stability of the polymer. Reactive FR are usually more expensive than additive FR, and their use is restricted to particular polymers. They are mainly used in duroplastics (polyester resins, epoxy resins, polyurethane and polycarbonate), for which, however, additive FR may also be used.

Owing to the fact that reactive FR are chemically combined, they do not occur as separate substances in more than trace quantities in the final product. For reasons of simplification and clarity, the total quantity of FR used in production is used in the substance flow analysis of final products.

3.3.2 Properties of brominated flame retardants

A summary of the principal properties of the BFR under study will be found in Appendix 3: Properties of the FR under study.

3.3.3 Consumption of brominated flame retardants

In recent decades, the consumption of BFR has increased heavily, both as a result of the increasing use of plastics, and of stricter fire regulations. In the period 1992 to 1995, world consumption rose from 150 000 t/a to 200 000 t/a. The forecast for 2000 is 250 000 t/a [Danish EPA, 1999]. Over the next 5 years, an annual growth rate of 3.5% to 4% is expected for the FR market as a whole [Davenport et al., 1999]. In another study (Roskill, cited in [Danish EPA, 1999]), an annual growth rate of 8% is given for BFR. However, the growth rate forecast at the BFR 2001 Conference was 4% [Arias, 2001].

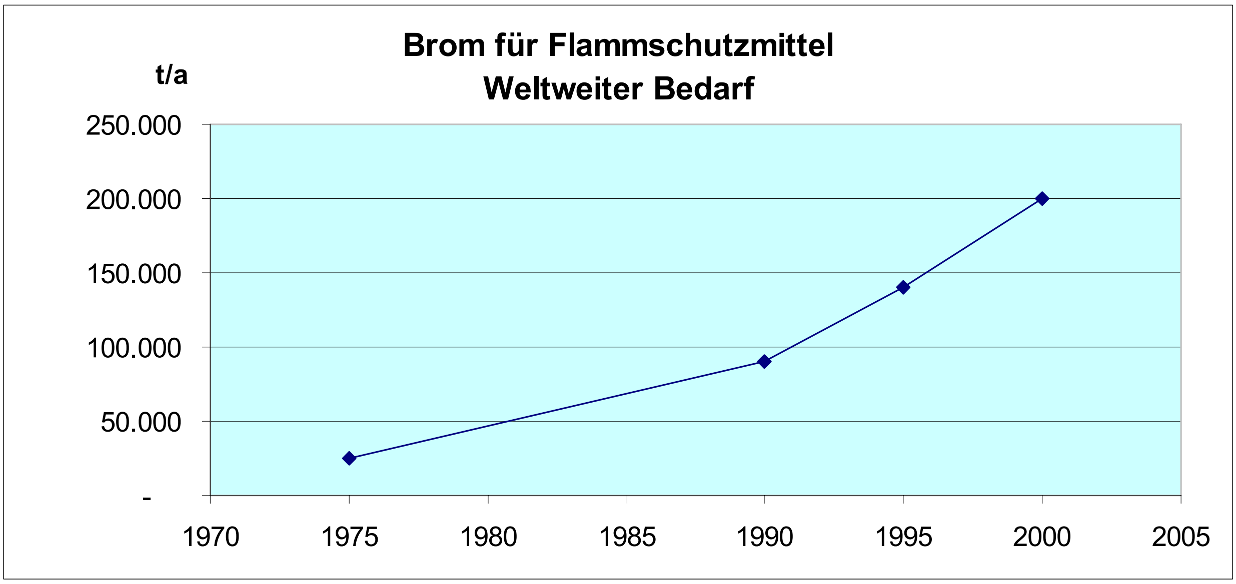


Fig. 3-1: Annual consumption of bromine in the production of flame retardants [Arias, 2001]

Commercially, some 40 different substances are employed. According to a substance flow analysis done for Denmark in 1997, PBDE and TBBPA account for some 60% of brominated flame retardants (BFR) in consumer goods, and some 70% to 80% in household waste [Danish EPA, 1999]. In Japan, where about a third of all BFR are processed, the percentage of PBDE and TBBPA contained in total BFR was about 77% in 1994 [IPCS, 1997]. Worldwide, PBDE and TBBA account for some $^2/_3$ of BFR consumption. This percentage remained approximately constant during the 1990s [Arias, 2001].

In the present study, only PBDE (restricted to penta, octa, and decaBDPE) and TBBPA belonging to the group of aromatic, brominated, FR are considered.

In other studies, polybrominated diphenyl ethers (PBDE) are referred to not only as polybrominated diphenyl ethers (PBDE), but also as polybrominated biphenyl ethers (PBBE). Commercial products are always a mixture of several polybrominated diphenyl ethers [Danish EPA, 1999] (see Tab. 4-5).

The following table shows a breakdown of the quantities of FR produced and processed.

Tab. 3-2: Breakdown of quantities of FR produced and processed

Consumption	Source	PentaBDPE	OctaBDPE	DecaBDPE	TBBPA
World, 1991	TBBPA [OECD, 1994] (p. 125) PBDE [IPCS, 1994b] (p. 34)	4 000 t/a	6 000 t/a	30 000 t/a	60 000 t/a
World, 1998	Estimate of world production of Great Lakes Chemical [Kuhn, 1999]	10 000 t/a constant	<20 000 t/a heavy reduction	50 000 t/a increasing trend	>50 000 t/a increasing trend
World, 1999	Sales acc. to BSEF [Leisewitz & Schwarz, 2000]1)	8.500 t/a	3.825 t/a	54.800 t/a	121.300t/a
Asia, 1999	Sales acc. to BSEF [Leisewitz & Schwarz, 2000]	0 t/a	2 000 t/a	23 000 t/a	85.900 t/a
America, 1999	Sales acc. to BSEF [Leisewitz & Schwarz, 2000]	8.290 t/a	1.375 t/a	24.300 t/a	21.600 t/a
Europe, 1999	Sales acc. to BSEF [Leisewitz & Schwarz, 2000]	210 t/a	450 t/a	7.500 t/a	13.800 t/a
Germany	Estimates [Leisewitz & Schwarz, 2000]	0 t/a	0 t/a	1 000 t/a	3.800 t/a

1) also see [Renner, 2000]

Owing to the different production systems and environmental standards, sales of flame retardants display different proportions of the four BFR (pentaBDPE, octaBDPE, decaBDPE, TBBPA) under study. Thus in Asia, the percentage of TBBPA used in production is far higher (77% of the total of the 4 BFR) than in America (39%) owing to the heavy production of electronic components and printed circuit boards there.

In America, the percentage of PBDE contained in the four BFR amounts to 61%. In Europe, the value is 37%, and in Germany only 21%. The differences are associated with regional practices, different levels of environmental awareness and different standardisation systems.

In Europe (particularly in Germany, the Netherlands and Scandinavia), there is been a strong trend away from PBDE in TV and computer monitors over the past 10 years. This change may be attributed in part to the German ordinance on dioxins, various eco-labels, pressure from consumers and to the environmental policies of producers in the countries concerned [Danish EPA, 1999].

3.3.4 Use of brominated flame retardants

PBDE are always used additively in conjunction with antimony trioxide (Sb_2O_3). In the main, TBBPA is used reactively (80 – 90 %). Antimony trioxide is only added to it (if at all) where the TBBPA is used additively.

3.3.4.1 PentaBDPE

PentaBDPE is the only commercial PBDE in liquid form. According to an OECD risk reduction study [OECD, 1994], the most frequent uses are in rubber goods (conveyor belts, e.g. in India and the UK; coatings and floor panels, e.g. in French trains) and flexible PUR foams (for furniture and as foam filler). An EU study [European Commission, 1996] quotes the percentage of pentaBDPE used in textile treatment at the beginning of the 1990s in relation to the total quantity of pentaBDPE produced annually as 60%.

The OECD and WHO publications do not mention the use of pentaBDPE for printed circuit boards, which was usual for FR2 laminates (phenolic resin) in Asia up to the early 1990s [Danish EPA, 1999]. However, the analysis of printed circuit boards in older equipment confirms the use of pentaBDPE in these [Leisewitz & Schwarz, 2000] [1].

The Risk Assessment Report [RA, 2000a] states that the main use of pentaBDPE is as an additive flame retardant for flexible PUR foam for furniture and upholstery, but also mentions that not all sectors of use could be quantified. In the Environmental Health Criteria EHC 192 [WHO, 1997], the main uses are given as in textiles and PUR foam.

The bromine industry [BSEF, 1999] fears that high concentrations of pentaBDPE could still be present in the environment owing to the highly emissive use of a mixture containing pentaBDPE deployed as hydraulic fluid in petroleum boreholes and mining up to a decade or two ago.

3.3.4.2 OctaBDPE

Typical uses are for ABS, HIPS, polyolefin and polyamide plastics. The main uses of the annual production of octaBDPE are in ABS plastics for TV casings and similar appliances (approx. 70%) [European Commission, 1996].

3.3.4.3 DecaBDPE

The uses of decaBDPE are very varied, since it may be used in almost all plastics (PUR, unsaturated polyesters, epoxy resins, PE, PP, PS, PA, latex, textile HIPS, PBT/PET, polycarbonate, styrene butadiene rubber). Potential uses in consumer products are in plastic casings, plastic electrical components, cables, latex-impregnated textile back panels, plastic sheeting in the building industry, etc. (see Tab. 3-3).

Other sources [IPCS, 1994b, p.71], [European Commission, 1996] quote the percentage of decaBDPE used for HIPS casings at 40%. According to an estimate of the BFR manufacturer Albemarle [Leisewitz et al., 2000], current use of decaBDPE for HIPS amounts to approx. 85%.

Substitutes for decaBDPE are mainly TBBPA and other halogenated and non-halogenated FR. In Europe, certain countries avoid the use of FR altogether. Some producers (Siemens, HP) are currently replacing brominated FR, particularly TBBPA, by phosphorus based FR [Renner, 2000].

Tab 3-3: Uses of decaBDPE [OECD, 1994]

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[1] p. 174: study carried out at the University of Hannover in 1997

Percentage of world market	Plastic	Products
30%	Polystyrene (HIPS)	Plastic parts, panels, keyboards, casings, TV
20%	Terephthalate (PBT, PET)	Plastic parts, plugs, switches, electrical appliances
15%	Polyamide (PA)	Injection moulded parts, protective contacts, coils, electrical components
10%	Styrene plastic (SBR)	Latex, carpet reinforcements, interior decoration
5%	Polycarbonate (PC)	Plastic parts, panels, keyboards, casings, computers, aircraft
5%	PP	Injection moulded parts, TV, condensers, electrical components
15%	Others: acetate copolymer (EVA), unsaturated polyester resin (UPE)	EVA: extrusion, coatings, cables, electricity distribution UPE: plastic parts, panels, keyboards, electrical appliances

3.3.4.4 TBBPA

From a global perspective, TBBPA is the most important BFR in terms of production and consumption on a weight basis. This flame retardant may be used reactively or as an additive to plastics. According to [Danish EPA, 1999], it is used reactively in 90% of applications, and according to [Leisewitz & Schwarz, 2000] in 80 to 85% of applications. Typical additive uses are in ABS and HIPS plastics, to which antimony trioxide is usually added. Typical reactive uses are for epoxy resin, unsaturated polyester and polycarbonate.

Tab. 3-4: Uses of TBBPA [Leisewitz et al., 2000]

Percentage of world market	Plastic	Products
70%	Epoxy resin	Printed circuit boards (FR2 and FR4 laminates)
15%	Polystyrene (HIPS)	Casings
10%	-	Further processing to TBBPA derivates
5%	ABS, terephthalate (PBT, PET), etc.	Various

3.4 Environmental relevance of flame retardants

Brominated flame retardants (BFR) are synthetic substances that do not occur naturally except in a few cases in sea sponges and sea grass [BSEF, 2000]. They pollute the environment in several ways:

- **Environmental and human toxicity**: the acute toxicity of PBDE and TBBPA is very low (see below). According to the EU research project ‘RENCO’ NL, UK, S [Kuhn, 2000], derivates of PBDE and TBBPA affect the balance of the thyroid hormone thyroxin and that of the sexual hormones (also see [SEPA, 1998], [de Wit, 2000] and [Meerts et al., 2000]).

- **Persistency and bioaccumulation**: PBDE are found in a wide range of organisms and sediments [Allchin et al., 1999], and this may be attributed to the highly lipophilic nature and persistence of certain PBDEs. These properties explain the accumulation of PBDE in environmental compartments (e.g. in river sediments and in fatty tissues of aquatic fauna) and this may be a hazard particularly at higher levels of the food chain,. According to a study carried out by the Swedish Karolinska Institute, the concentration of tetra, penta, and hexaBDPE in breast milk doubled every five years between 1972 and 1997. Nordic peoples are particularly affected owing to their higher fish consumption. Between 1998 and 2000, a diminution of approx. 30% was found for tetra and pentaBDPE. This reduction is possibly attributable to the withdrawal of PBDE from the market in Sweden and to reduced production and processing of PBDE in Europe [Guvenius & Norén, 2001]. Barely degradable organic substances are found in 10 to 20 fold higher concentrations among Polar peoples than in industrial countries [Grote, 1999]. However, owing to their persistence, even BFR that are no longer commercially produced may continue to pollute the environment for a very long time.

- **Degradation products**: in environmental compartments exposed, for instance, to UV radiation, higher brominated diphenyl ethers (e.g. decaBDPE) may break down to less highly brominated diphenyl ethers (nona to hexaBDPE) and brominated dibenzofuran [Tysklind et al., 2001], [IPCS, 1994b], [Renner, 2000] and [Kierkegaard, Balk et al., 1999]. Among the various PBDEs, although the most commonly used congener is decaBDPE, it is particularly the tetra and penta congeners[1] that are found in the environment. TBBPA may be partly broken down in the soil and in the hydrosphere under aerobic and anaerobic conditions [IPCS, 1995], although the available literature does not state which substances may arise as a result. In general, chemical degradation processes (debromination) have not yet been treated in sufficient detail in the literature to permit quantitative conclusions to be drawn.

- **Formation of dioxins and furans**: when BFR are heated, brominated dioxins and furans (PBDD+PBDF) may be formed (e.g. when decaBDPE is heated to 300° - 800°). If substances containing chlorine are also present, chlorinated dioxins and furans (PCDD+PCDF) may also be formed. However, with carefully controlled incineration (e.g. in MWIP meeting West European standards), no significant emission of brominated dioxins and furans occurs [OECD, 1994]. Studies [IPCS, 1997] have shown that PBDD+PBDF may be formed in the production of BFR and during processing of plastics treated with flame retardants. No studies are available concerning the formation of furans during the use of plastics.

- **Hazardous additives (synergists):** antimony trioxide (Sb_2O_3) is frequently used in combination with BFR to increase their flame retarding effect. The proportion of Sb_2O_3 to BFR typically lies between 1:2 to 1:4. In contrast, alternative FR do not require the addition of antimony trioxide. Antimony has a catalytic effect, promoting the formation of dioxins and furans during incineration. In Germany, antimony trioxide has been designated as being a "clearly carcinogenic product" [Borms, 1993, cited in Frey, 1999] (for the Sb_2O_3 content of plastics, see [OECD, 1994] p.35).

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[1] Congeners are similar chemical substances.

Studies were performed under the International Programme on Chemical Safety (IPCS) of the WHO on Environmental Health Criteria [IPCS, 1994a; IPCS, 1994b; IPCS, 1995; IPCS, 1997; IPCS, 1998]. Failing information on the long-term effects, persistence and bioaccumulation of BFR, the studies recommend that whenever suitable alternative FR are available, certain substances should no longer be used commercially. Further, the development of new, alternative, FR should be promoted in future.

The environmental relevance of the substances investigated in the present study may be summarised as follows:

PentaBDPE [IPCS, 1994b]
Pentabromodiphenyl ether is persistent, and accumulates in biota (bioaccumulation). As a result of its very high BCF (bioconcentration factor) and persistence, the substance is highly hazardous to humans and the environment. It has a suspected estrogenic effect, but its acute toxicity is very low. No information is available on the long-term effects and the risk of cancer.

OctaBDPE [IPCS, 1994b]
Octabromodiphenyl ether is persistent and accumulates in the soil and in sediments. Owing to its high molecular weight, bioaccumulation is unlikely, except for low brominated components (approx. 10 % fraction of the octaBDPE). Its acute toxicity is very low. No information is available on the long-term effects and the risk of cancer. OctaBDPE is always used in conjunction with antimony trioxide (Sb_2O_3). There is an indication that octaBDPE decomposes to low brominated, problematical, congeners such as pentaBDPE.

DecaBDPE [IPCS, 1994b], [Leisewitz et al., 2001] and [Kruse et al., 2001]
DecaBDPE is not acutely toxic. Very little published data[1] is available on its long-term toxicity. Tests on animals have shown a neurotoxic effect on newborn babies [Viberg et al., 2001]. Decabromodiphenyl ether is persistent and accumulates in the soil and in sediments. Owing to the high molecular weight of decaBDPE, bioaccumulation is unlikely. The absorption of decaBDPE in the digestive tract is minimal. Owing to its low acute toxicity, the risk to the population from present-day concentrations of decaBDPE may be regarded as minimal. From occupational health and animal tests, there are indications of a possible carcinogenic potential. In thermal processes and with recycling, substantial quantities of brominated furans are formed. There are indications that decaBDPE decomposes to low brominated – problematical – PBDEs such as pentaBDPE.

TBBPA [IPCS, 1995], [Leisewitz et al., 2001] and [Kruse et al., 2001]
When TBBPA is used as a reactive flame retardant, there is little danger of this substance being released. When employed as an additive flame retardant, however, TBBPA finds its way into the environment and the food chain. TBBPA is persistent. There are indications that tetrabromobisphenol A is bioaccumulative and highly toxic to fish, algae and daphnia. It accumulates in the soil and in sediments. Bioaccumulation is probable. Despite the high bioaccumulation factor, TBBPA is not normally found in biota, since it is very rapidly released. Absorption of TBBPA in the digestive tract is minimal. Owing to its low acute human toxicity (no indications of teratogenic or mutagenic effects in animal experiments), the risk of present-day TBBPA concentrations to the population may be regarded as minimal. TBBPA is highly toxic to

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[1] Data are available from a long-term (2-year) feeding study on mice (published in 1986 by the U.S. National Toxicology Program - NTP and described in detail in a WHO study [IPCS, 1994b]). Apart from contested effects on the liver, no significant effects were demonstrated.

aquatic organisms. No test results for carcinogenicity are available. Due to its relatively high vapour pressure, potentially significant evaporation can arise from additively applied TBBPA.

Recommendations, voluntary commitments and regulations:
In toxicity studies performed by the WHO through the IPCS (International Program on Chemical Safety), it is recommended that the use of commercial pentaBDPE flame retardants [IPCS, 1994b], [OECD, 1994] be discontinued.

In connection with the OECD Risk Reduction Programme, industry announced the following voluntary commitment (voluntary industry commitment, VIC) [OECD, 1995a]:

- no production or sale of PBB (exception: Elf Atochem (F) to produce PBB till the end of 2000)
- no production and sale of new PBDE
- minimisation of emission in the production of pentaBDPE
- purity of decaBDPE > 97 %
- minimisation of low brominated substances in octaBDPE
- minimisation of release to the environment from the production process
- minimisation of employee exposure in the production process
- ensuring data availability

Japanese manufacturers arrived at a voluntary agreement on discontinuation of production and import of pentaBDPE [OECD, 1995b].

The following substances are currently being studied under the EU Risk Assessment Programme: decaBDPE, octaBDPE, pentaBDPE, tetraBDPE, HBCD and chlorinated paraffins. The report on pentaBDPE has been completed [RA, 2000a]. At the time of going to print (November 2001), draft reports only were available for decaBDPE and octaBDPE.

In January 2001, the European Commission issued a draft directive [Draft Directive 2001/0018(COD), 2001] with the object of preventing pentaBDPE from being marketed.

The Swedish National Chemicals Inspectorate (KEMI) recommends discontinuing production of PBB, pentaBDPE, octaBDPE and decaBDPE [KEMI, 1999].

In Europe, voluntary commitments have resulted in PBB being almost completely, and PBDE largely, substituted by TBBPA and other FR. However, alternative FR for plastic casings (such as those based on phosphorus) are more expensive than BFR [Kuhn, 2000].

In Germany, the VKE (Verband der kunststofferzeugenden Industrie) and TEGEWA (Verband der Textilhilfsmittel-, Lederhilfsmittel-, Gerbstoff- und Waschrohstoff-Industrie) declared their voluntary commitment to discontinue use of PBDE, leading to a pronounced reduction in their consumption.

4 Methodical procedure

4.1 Method adopted

In the present report, the SAEFL guideline on ‘Material Flow Analysis for Switzerland’ (1996) was adopted as a basis. As in that report, the flows of substances are first determined in subordinate systems and then aggregated to form the whole system.

The following individual steps were performed:

- determination of the areas of application and occurrence in the various processes
- identification of products and product groups
- structuring of the system
- balancing of subsystems
- aggregation of the separate balances
- establishment and balancing of complete system

4.2 System analysis

The method of system analysis was used to establish a simulated system of reality. This is done by simplifying the complex real situation involving a multitude of processes and interconnections (material flows) to produce a cohesive and manageable model. This was reduced to its principal components, and tailored to suit the objectives and stated boundaries of the study.

System analysis involves three steps:

- limitation of the system in space and time
- establishment of the internal structure of the system: choice and definition of processes and their input and output material, and determination of interconnections
- definition of the substances to be studied

4.2.1 System boundaries

The system comprises the transport processes of four brominated flame retardants in Switzerland at the end of the 1990s.

The physical boundary of the system is identical to the political border of Switzerland. The boundary of the system in time was fixed at one year. Owing to the structure of the available data, it was not possible to analyse a particular year. Instead, a rough picture is sketched of the situation in Switzerland at the end of the 1990s. The data used is stated in the text in each particular case.

4.2.2 Definition of processes and materials

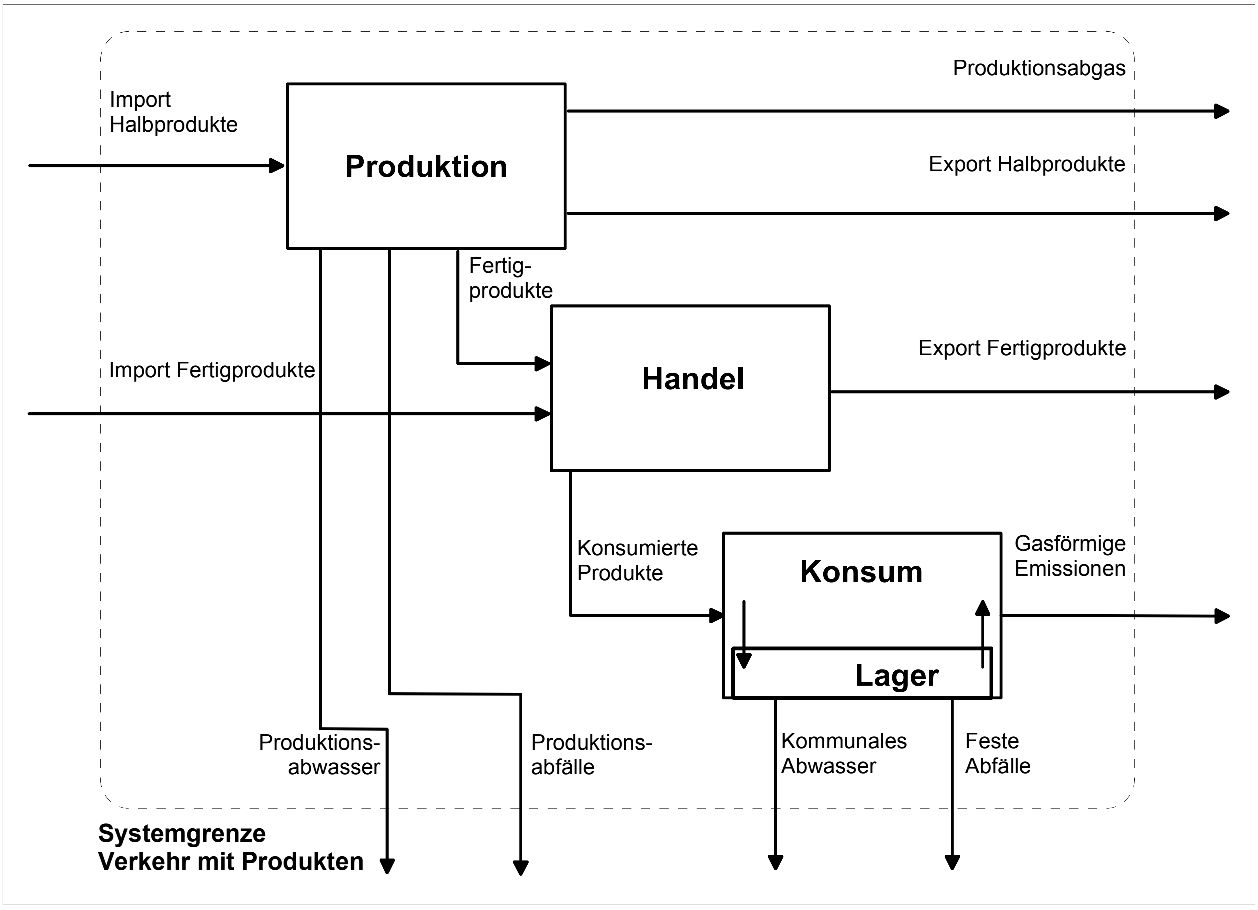
The system is divided into three separate subsystems comprising the following processes:

- **Trade in products** (Fig. 4-1 and Tab. 4-1):
  production, trade, consumption
- **Waste management** (Fig. 4-2 and Tab. 4-2):
  reuse, waste water treatment, incineration, dumping in landfill
- **Environment** (Fig. 4-3 and Tab. 4-3):
  atmosphere, hydrosphere, pedosphere or lithosphere, biota

In the following, the processes and materials are first defined and described separately in each of the three systems, then for the total system.

Subsystem: 'trade in products'

Fig. 4-1: System analysis of the subsystem: 'trade in products'



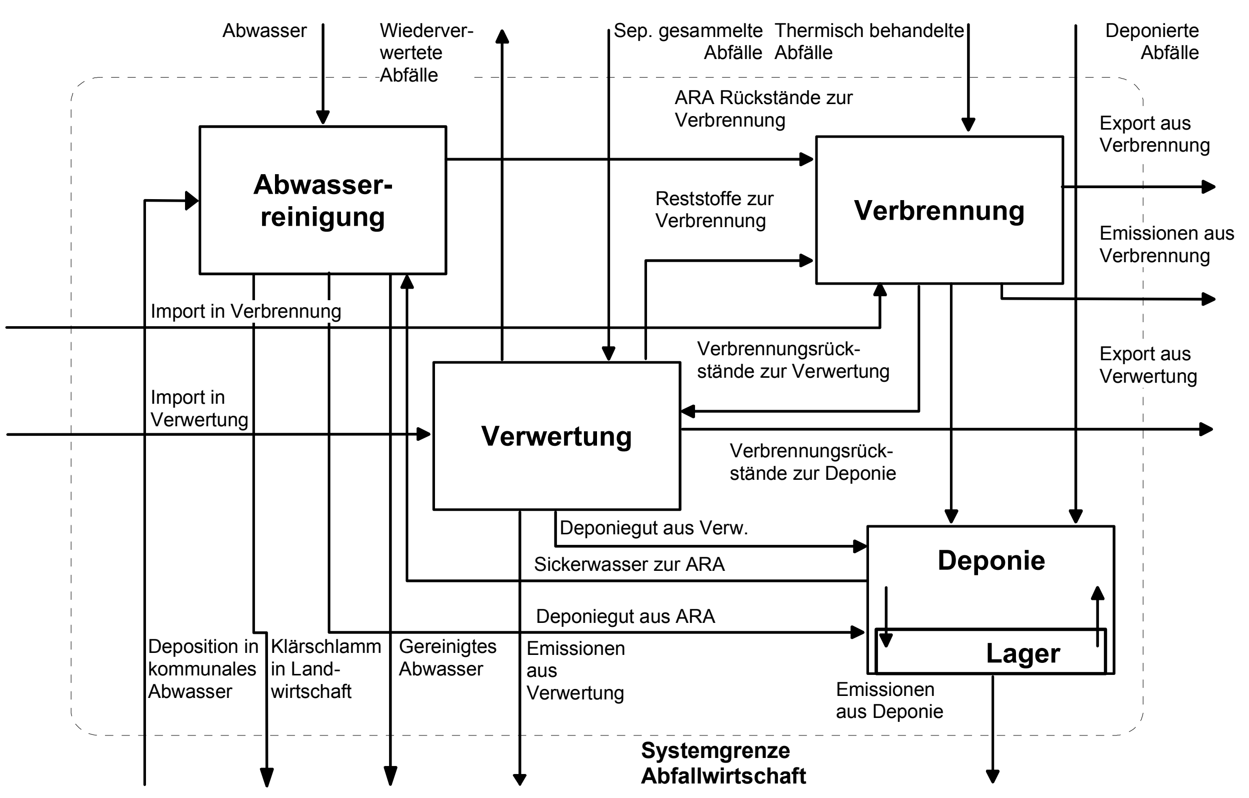
Tab. 4-1: Processes and materials in the subsystem: 'trade in products'

PROCESS: ‘PRODUCTION’	
The process comprises the production of semi-finished (moulded) parts and finished products (building materials, EE appliances), that contain the BFR under study. The trade in chemicals and semi-finished products used for this is also included.	
Input material	
Import of semi-finished products	Semi-finished products imported into Switzerland (chemicals, moulded and unmoulded plastics, computer components, etc.) for conversion into finished products
Output material	
Finished products	Finished products produced in Switzerland (EE products, building materials, vehicles)
Export of semi-finished products	Semi-finished products exported from Switzerland (chemicals, moulded and unmoulded plastics, computer components, etc.)
Production waste	Solid waste from production (e.g. printed circuit board scrap)
Production waste water	Waste water from production
Production waste gases	Waste gases from production
PROCESS: ‘TRADE’	
The process comprises the trade in finished products (EE products, building materials, vehicles) that contain the BFR under study.	
Input material	
Import finished products	Finished products imported into Switzerland (EE products, building materials, vehicles)
Finished products	Finished products produced in Switzerland (EE products, building materials, vehicles
Output material	
Export finished products	Finished products exported from Switzerland (EE products, building materials, vehicles)
Consumed products	Finished products consumed in Switzerland (EE products, building materials, vehicles)
PROCESS: ‘CONSUMPTION’	
The process comprises the consumption of finished products (EE products, building materials, vehicles) that contain the BFR under study.	
Input material	
Consumed products	Finished products consumed in Switzerland (EE products, building materials, vehicles)
Output material	
Solid waste	Mixed household waste, separately collected household waste, electronics scrap, used cars, waste from building sites, remaining building waste
Municipal waste water	Waste water from urban areas. Release of FR under study via cleaning processes (e.g. textiles) and infrastructure (e.g. PE roof sheeting)
Gaseous emission	Diffuse emission of additive BFR from consumer goods in use (EE products, furnishings, vehicles) and buildings
Stock	
Stock in consumption	Stock from consumer goods in use (EE products, furnishings, vehicles)

	and buildings

Subsystem: 'waste management':

Fig. 4-2: System analysis of the subsystem: 'waste management'



Tab. 4-2: Processes and materials in the subsystem: 'waste management'

PROCESS: 'REUSE'	
The process comprises the collection and treatment in recycling installations of all separately collected waste from the subsystem: 'trade in products'.	
Input material	
Import to reuse	Waste imported into Switzerland that is treated in the reuse process
Separately collected waste	Percentage of waste introduced from the process: 'reuse' from the subsystem: 'trade in products'. In the present context this concerns waste from: electrical and electronics waste, vehicle waste, textile and furniture waste, biogenic waste. The relevant building waste is assigned directly to the two processes 'incineration' and 'landfill'
Output material	
Reused waste	Percentage of waste treated in the process: 'reuse' that is returned to the process: 'trade in products' within Switzerland
Materials from reuse to be deposited in landfills	Waste exported from Switzerland from the process: 'reuse'
Export from reuse	Percentage of waste treated in the process: 'reuse' that is exported from Switzerland
Output material	**(cont.)**

Remaining waste to be incinerated	Percentage of waste treated in the process: ‘reuse’ that is passed on for thermal treatment in Switzerland
Emission from reuse	Emission to the environment resulting from the process: ‘reuse’. This consists in the main of emission to the atmosphere (via spent air). Waste water is neglected

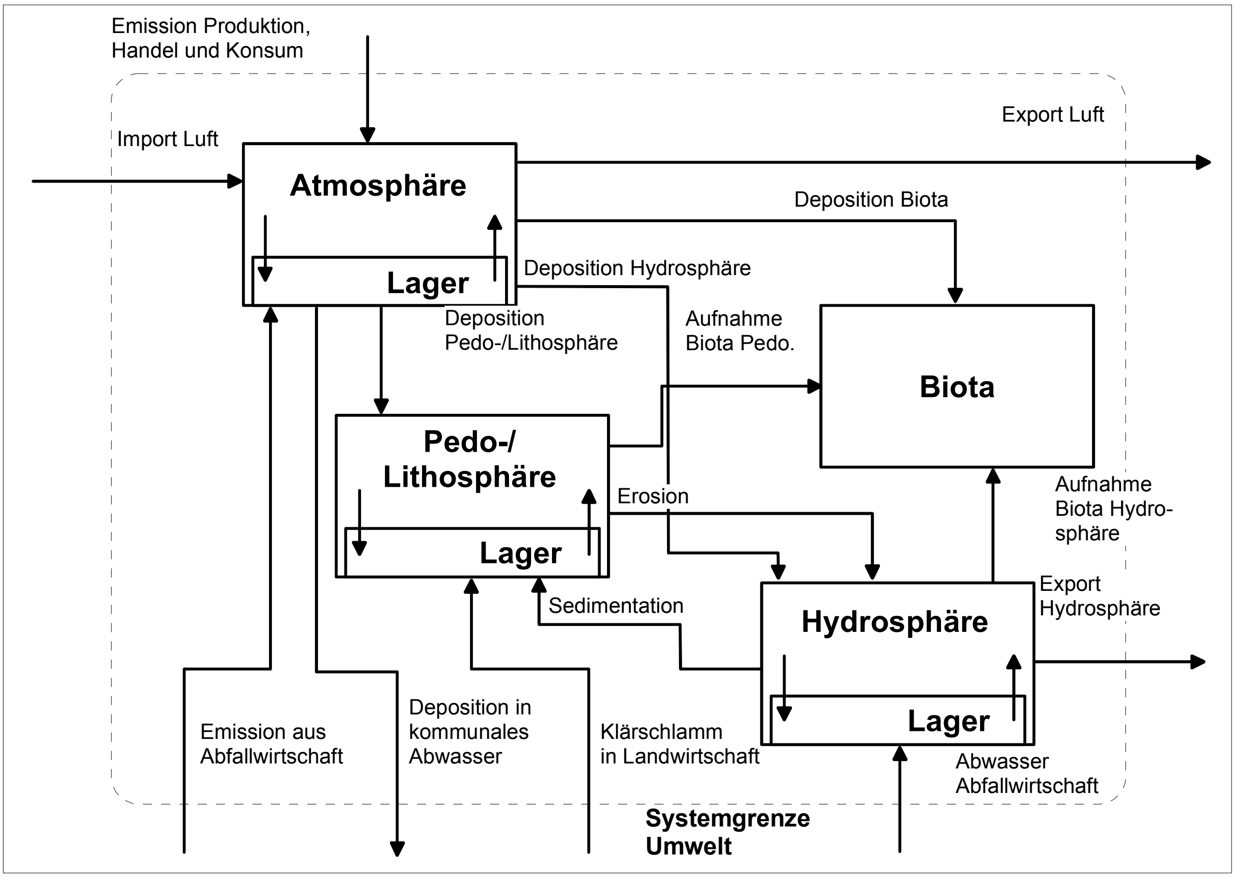
PROCESS: ‘WASTE WATER TREATMENT’	
The process comprises treatment of municipal waste water in waste water treatment plants in Switzerland. It also contains waste water from production, which is assumed to be disposed of via the municipal waste water system.	
Input material	
Waste water	Municipal waste water from the process: ‘consumption’ and waste water from the process: ‘production’
Deposition to municipal waste water	Percentage of particles from atmospheric deposition that descend on urban areas and are disposed of via municipal waste water treatment plants
Seepage water from waste water treatment	Seepage water as given for the process: ‘landfill’
Output material	
Landfill material from waste water treatment	Percentage of sewage sludge produced in the process: ‘waste water treatment’ that is deposited in landfills in Switzerland
Remaining waste from waste water treatment to incineration	Percentage of sewage sludge produced in the process: ‘waste water treatment’ that is passed on for thermal treatment in Switzerland
Sewage sludge to agriculture	Percentage of sewage sludge from the process: ‘waste water treatment’ that is reused in agriculture in Switzerland (i.e. input to the process: ‘pedosphere/lithosphere')
Purified waste water	Purified waste water from the process: ‘waste water treatment’ that is released to the main outfall

PROCESS: ‘INCINERATION’	
The process is composed of treatment processes in which waste is treated thermally (incineration). For the purposes of the present study, this mainly concerns the total of MWIPs, together with other thermal processes such as fluid bed incineration and cement works) in Switzerland.	
Input material	
Thermally treated waste	Percentage of waste passed on from the subsystem: 'trade in products' to the process: ‘incineration’, where it is thermally treated
Remaining waste to incineration	Percentage of products treated in the process: ‘reuse’ that is passed on for thermal treatment in Switzerland
Remaining waste from waste water treatment to incineration	Percentage of products treated in the process: ‘waste water treatment' that is passed on for thermal treatment in Switzerland
Output material	
Export from incineration	Percentage of incineration products from the process: ‘incineration’ that is exported abroad (flue gas filter residues, filter ash)
Incineration residues to landfill	Percentage of incineration products from the process: ‘incineration’ that is deposited in landfills in Switzerland (particularly slag)
Emission from incineration	Emission to the environment resulting from the process: ‘incineration’. This mainly consists of emission to the atmosphere (via flue gas). Waste water is neglected

PROCESS: ‘LANDFILL’	
The process comprises all landfills within Switzerland where waste is deposited.	
Input material	
Waste material to landfill	Percentage of waste passed from the subsystem: 'trade in products' to the process: ‘landfill’
Material from reuse to landfill	Percentage of waste treated in the process: ‘reuse’ that is deposited in landfills in Switzerland
Material from waste water treatment to landfill	Percentage of sewage sludge produced in the process: ‘waste water treatment’ that is deposited in landfills in Switzerland
Incineration residues to landfill	Percentage of incineration products from the process: ‘incineration’ that is deposited in landfills in Switzerland (particularly slag)
Output material	
Seepage water passed on to waste water treatment	Seepage water as given in the process: ‘landfill’
Emission from landfills	Emission to the environment resulting from the process: ‘landfill’. This mainly consists of emission to the hydrosphere (via seepage water). Landfill gas is neglected
Stock	
Landfill stock	Accumulation of waste passed on from the process: ‘landfill’

Subsystem: ‘environment’

Fig. 4-3: System analysis of the subsystem: ‘environment’



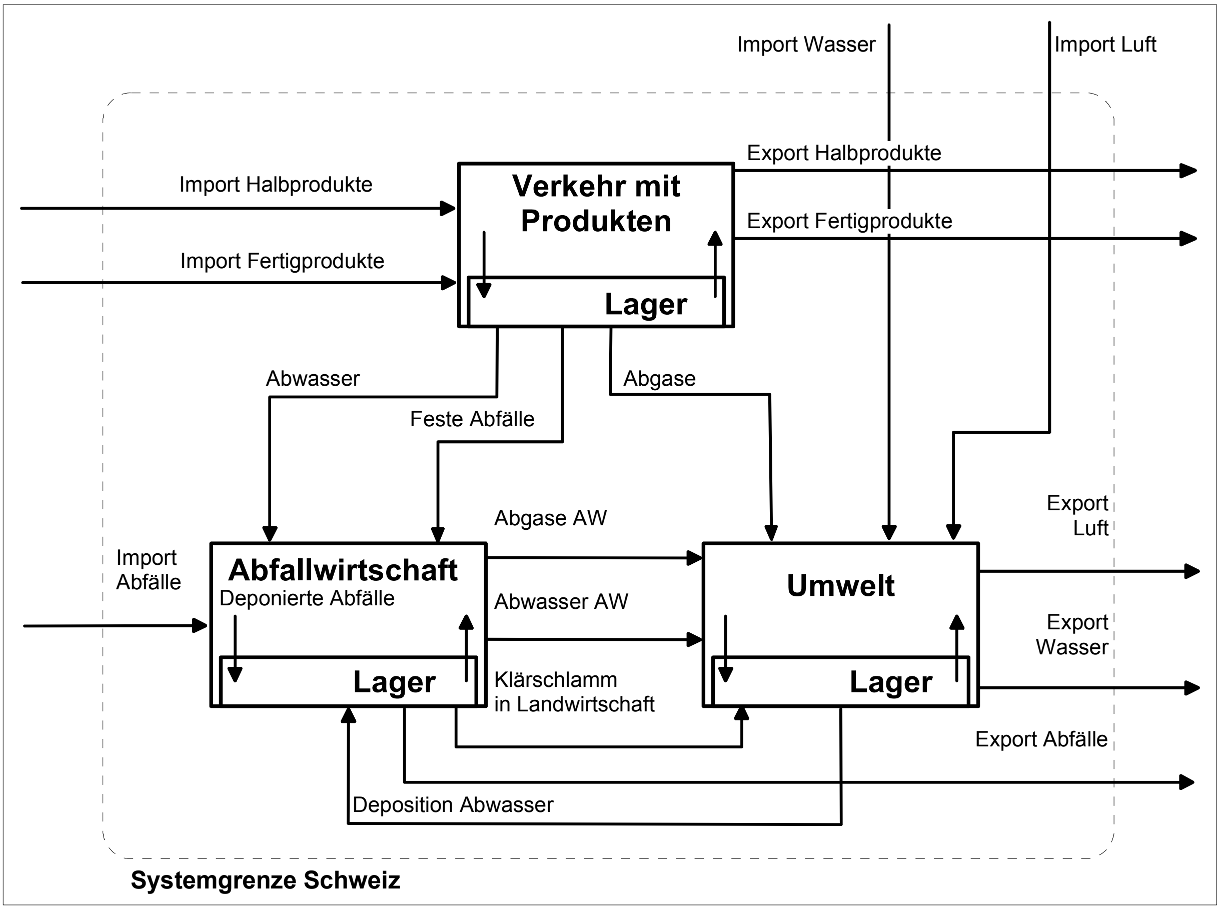
Tab. 4-3: Processes and materials in the subsystem: 'environment'

PROCESS: 'ATMOSPHERE'	
The process comprises the air layer lying above the land mass of Switzerland (first 500 m altitude).	
Input material	
Imported air	Import to Switzerland from abroad (via the air)
Emission from production, trade and consumption	Emission from flue gases from the process: 'production' and diffuse emission from additively used BFR from products in use (EE products, furnishings, vehicles), and from buildings
Emission from waste management	Flue gases from reuse and incineration. Gases given off from landfills are neglected
Output material	
Exported air	Export from Switzerland to abroad (via the air)
Deposition to pedosphere/lithosphere	Percentage of deposition from the atmosphere to the soil excl. urban areas
Deposition to hydrosphere	Percentage of deposition from the atmosphere to surface waters
Deposition to biota	Percentage of deposition from the atmosphere to plants
Deposition to municipal waste water	Percentage of deposition from the atmosphere on urban areas that are disposed of in municipal waste water treatment plants
Stock	
Stock atmosphere	Accumulated substances in the air layer lying above the land mass of Switzerland (first 500 m altitude)
PROCESS: 'HYDROSPHERE'	
The process comprises ground and surface waters (lakes, rivers) in Switzerland.	
Input material	
Waste water from waste management	Comprises the sum of purified waste water from the process: 'waste water treatment', landfill seepage water from the process: 'landfill' that was not passed on to the process: 'waste water treatment', and leakage from the waste water canalisation system
Deposition to hydrosphere	Deposition from the atmosphere to surface waters
Erosion	Input from the soil to ground and surface waters from erosion processes
Output material	
Export from hydrosphere	Export of substances via surface waters over the system boundary of Switzerland (in the main via Rhine and Rhone)
Sedimentation	Input from ground and surface waters to sediments (pedosphere/lithosphere)
Input to biota from hydrosphere	Assimilation by plants and living organisms from ground and surface waters
Stock	
Stock hydrosphere	Comprises the quantity of accumulated substances in ground and surface waters

PROCESS: 'PEDOSPHERE/LITHOSPHERE'	
The process covers the soil in Switzerland, and comprises the compact, natural, subsoil and the geological substratum.	
Input material	
Deposition to pedosphere/ lithosphere	Percentage of deposition from the atmosphere to the soil (excl. urban areas)
Sewage sludge to agriculture	Percentage of sewage sludge from the process: 'waste water treatment' reused in agriculture in Switzerland
Sedimentation	Input from ground and surface waters to sediments
Output material	
Erosion	Input from the soil to ground and surface waters from erosion processes
Output to biota from pedosphere	Absorption of substances from the soil by plants and living organisms
Stock	
Stock soil	Comprises the quantity of accumulated substances in the soil
PROCESS: 'BIOTA'	
The process comprises the total of all living organisms and plants	
Input material	
Input to biota from pedosphere	Assimilation of substances from the soil by plants and living organisms
Deposition to biota	Deposition from the atmosphere to plants
Input to biota from hydrosphere	Absorption of substances from ground and surface waters by plants and living organisms
Output material	
	No output considered
Stock	
Stock biota	Comprises the quantity of substances accumulated in biota

Total system 'Switzerland'

Fig. 4-4: System analysis of the total system 'Switzerland'



Tab. 4-4: Processes and materials in the total system

PROCESS: 'TRADE IN PRODUCTS'	
This comprises all processes of the subsystem: 'trade in products'	
Input material	
Import semi-finished products	Semi-finished products imported into Switzerland (chemicals, moulded and unmoulded plastics, computer components, etc.) for the production of finished products
Import finished products	Finished products imported into Switzerland (EE products, building materials, vehicles)
Output material	
Export semi-finished products	Semi-finished products exported from Switzerland (chemicals, moulded and unmoulded plastics, computer components, etc.)
Export finished products	Finished products exported from Switzerland (EE products, building materials, vehicles)
Waste water	Waste water from production and waste water from urban areas (municipal waste water)
Solid waste	Waste from the process: 'consumption' (mixed municipal waste, separately collected municipal waste, electronics scrap, used cars, building site waste, remaining building waste) and production waste (solid waste from production, e.g. printed circuit board scrap)
Output material	**(contd.)**

Flue gases	Flue gases from production and diffuse emission of additively processed BFR from consumer goods in use (EE products, furnishings, vehicles) and buildings
Stock	
Stock process: 'trade in products'	Stock from consumer goods in use (EE products, furnishings, vehicles) and buildings
PROCESS: 'WASTE MANAGEMENT'	
This comprises all processes in the subsystem: 'waste management'.	
Input material	
Imported waste	Waste imported into Switzerland
Waste water	See above (process: 'trade in products'
Solid waste	See above (process: 'trade in products'
Deposition municipal waste water	Particles deposited from the atmosphere that descend on urban areas, and are disposed of in municipal waste water treatment plants
Output material	
Exported waste	Waste exported from Switzerland
Waste water from waste management	Comprises the sum of purified waste water from the process: 'waste water treatment', landfill seepage water from the process: 'landfill' that is not passed on to waste water treatment, and leakage from the waste water canalisation system
Flue gases from waste management	Comprises gaseous emission from the process: 'waste management' (consisting in the main of the processes 'incineration' and 'reuse')
Sewage sludge to agriculture	Percentage of sewage sludge from the process: 'waste water treatment' that is reused in agriculture in Switzerland
Stock	
Stock process: 'waste management'	Mainly comprises accumulated waste passed on from the process: 'landfill'
PROCESS: 'ENVIRONMENT'	
The process comprises all processes in the subsystem: 'environment'.	
Input material	
Imported water	Input of substances to Switzerland via surface waters
Imported air	Input of substances to Switzerland via the air
Flue gases	See above (process: 'trade in products')
Flue gases from waste management	See above (process: 'waste management')
Waste water from waste management	See above (process: 'waste management')
Sewage sludge fertiliser	See above (process: 'waste management')
Output material	
Exported water	Export of substances from Switzerland via surface waters (in the main via the Rhine and the Rhone)
Exported air	Export of substances from Switzerland via the air
Deposition to municipal waste water	See above (process: 'waste management')
Stock	
Stock process: 'environment'	Mainly comprises accumulated substances in the processes 'pedosphere/lithosphere', 'hydrosphere' and 'atmosphere'

4.2.3 Substances under study

The flame retardants under study, being commercial products, are not pure chemical compounds (or substances) but mixtures of chemically similar substances. Tab. 4-5 shows a breakdown of the composition of the commercial BFR under study as given in the literature.

Tab. 4-5: Composition of commercial BFR products under study

	Tri-BDPE	Tetra-BDPE	Penta-BDPE	Hexa-BDPE	Hepta-BDPE	Octa-BDPE	Nona-BDPE	Deca-BDPE	Bromine
PentaBDPE²⁾	0-1%	24-38%	50-62%	4-8%					
PentaBDPE³⁾									71%
OctaBDPE¹⁾				4%	62%	34%			
OctaBDPE¹⁾				6.9%	46.8%	35.9%	10.4%		
OctaBDPE²⁾				10-12%	43-44%	31-35%	9-11%	0-1%	
OctaBDPE⁴⁾				1.4-12%	43-58%	26-35%	8-14%	0-3%	
OctaBDPE³⁾									79%
DecaBDPE¹⁾								97-98%	
DecaBDPE⁵⁾						0.8%	21.8%	77.4%	
DecaBDPE¹⁾						?%	0.3-4.5%	94-99%	
DecaBDPE¹⁾						0.5%	11.0%	88.1%	
DecaBDPE¹⁾							0.3-3%	97-99%	
DecaBDPE¹⁾						?	?	93-98.5%	
DecaBDPE⁴⁾							3%	97%	
DecaBDPE¹⁾						1%	2%	97%	
DecaBDPE³⁾									83%
TBBPA⁶⁾									59%

Sources:

1) [OECD, 1994] p.127-129
2) IPCS, 1994b
3) [Danish EPA, 1999]
4) [OECD, 2000]
5) produced in the early 19770s [OECD, 1994] p.127
6) commercial TBBPA has an average purity of approx. 98.5 % [Danish EPA, 1999]

In order to balance the quantities, the values for commercial FR must be expressed in terms of chemical substances. For commercial pentaBDPE, the concentration was set at 59% and for commercial octaBDPE at 34%. As a first approximation, it was assumed that commercial decaBDPE and TBBPA are present as pure substances.

4.3 Data

Subsystem: 'trade in products'
It was not possible within the present study to carry out market analyses or detailed company surveys. The study is therefore based on data from the literature. The substance flows were calculated from the flow of materials and the concentrations (percentage of plastics, FR applied

and FR concentrations) of the four BFR under study. The flow of materials was determined using market analyses for Switzerland and other European countries. The percentage of components potentially treated with flame retardants (casings, printed circuit boards, small EE components) in products was taken from the literature. The concentration of flame retardants in plastics was determined from information obtained from FR manufacturers and the plastics industry, and was also based on analyses of used and new EE appliances. The estimation of stocks in the process: ‘trade in products’ was based on the average life cycle of consumer products.

Subsystem: ‘waste management’

To determine the input flows from the process: ‘trade in products’, data from Switzerland were used. In this, substance flows were assigned to the treatment processes in waste management based on their product-related uses, taking into account the disposal situation in Switzerland. Data were also available from other studies (e.g. [Danish EPA, 1999]) and these were used for comparison purposes. The flows between the various processes of waste management – and among the products of disposal processes – were calculated using transfer coefficients. Wherever possible, the results were compared with data from the literature. The estimate of accumulated stocks in landfills was based on the input from the process: ‘trade in products’.

Subsystem: ‘environment’

For the subsystem: ‘environment’, inputs from the subsystems: ‘trade in products’ and ‘waste management’ were used. The attempt was also made to roughly estimate the flows and stocks based on concentration measurements made outside Switzerland as given in the literature. In Switzerland, no measurements of the four substances under study are at present available in environmental compartments.

5 Scope of application and occurrence of BFR

This chapter concerns the flame retardants under study that are used in semi-finished and finished products, treatment of waste containing flame retardants, and the presence of flame retardants in the environmental constituents air, water, soil and biomass (biota).

The data basis prepared for this serves both to calculate the flows of materials and substances, and to determine the most significant materials. Measured data are presented and assumptions justified, and the method adopted to calculate the substance flows explained. To avoid overburdening the text with numerical data, we shall concentrate here on the principal steps, leaving the detail to the appendix.

In accordance with the overall objectives of the study, the assumptions, estimates and comparisons made are chosen in accordance with the significance of the individual materials and products in relation to the total system. The resulting data should not, therefore, be used outside the present study.

5.1 Trade in products

This chapter deals with the use of the flame retardants under study in semi-finished and finished products. Both previous and present uses of the product groups concerned are illustrated.

Following a general review, the areas to be considered are classified. The following sections concern data acquisition (Section ***Fehler! Verweisquelle konnte nicht gefunden werden.****), detailed considerations of products (Section* ***Fehler! Verweisquelle konnte nicht gefunden werden.*** *-* ***Fehler! Verweisquelle konnte nicht gefunden werden.****) and finally the calculation of the flows of materials and substances (Section* ***Fehler! Verweisquelle konnte nicht gefunden werden.*** *ff).*

Throughout the world, brominated flame retardants are and have been used almost exclusively in the plastics industry. Other current areas of application are for impregnating textiles and as additives to paints.

According to information obtained from the bromine industry [BSEF, 1999], the use of pentaBDPE as hydraulic fluid (in the form of a mixture) in petroleum borings and mining was discontinued 10-20 years ago. As no consumption data for this application could be found in the literature, it was not included in the present study. However, it must be mentioned that this historical, heavily emissive, use of pentaBDPE requires urgent investigation. Moreover, current studies (e.g. [Allchin et al., 1999]) have indicated the presence of significant concentrations of pentaBDPE in the environment.

5.1.1 Classification of products

A general distinction is made between:

- **chemicals and semi-finished products**: flame retardants (PBDE, TBBPA), unmoulded plastics (master batches), plastic components (printed circuit boards, plastic casings)
- **finished products**: electrical and electronic appliances (EE appliances), vehicles, building materials, furniture, textiles

Tab. 5-1: Classification of finished products

Classification of product groups	Classification according to place of use	Classification according to products containing flame retardants
EE products: - EDP equipment (computers, printers) - office equipment (copying machines, calculators) - communications technology (telephone, fax machines) - household electronics (TV, audio, video, toys and games) - small household appliances - large household appliances (in kitchen and bathroom incl. sewing machines, vacuum cleaners, Air-conditioners) - special appliances (laboratory, medicine, process control, vending machines, electric tools) - small EE components (plugs, switches, transformers, fuse boxes, lighting appliances, cables)	**Private households (PHH):** (examples given in column at left) - EDP equipment - household electronics - communications technology (PHH) - household appliances - special appliances (electric tools) - small EE components (PHH) - private cars, motorcycles - building materials and interior decoration (PHH)	**Printed circuit boards**: - in computers - in copying machines, printers, fax machines - in telephones - in household electronics - in household appliances - in other appliances

Vehicles: - motorised vehicles (cars, lorries, motorcycles) - trains - aircraft	**Industry, trades, services, administration (IS):** - EDP equipment (IS) - office equipment - communications technology (IS) - special appliances (IS) - small EE components (IS) - company cars and public transport - building materials and materials for interior decoration (IS)	**Plastic casings**: - computers - copying machines, printers, fax machines - household electronics (TV+HiFi) - household appliances - vehicles (textiles, upholstery and large plastic components) - other appliances

Classification according to product group	Classification according to place of use	Classification according to products containing flame retardants
Building materials and textiles: - foam insulation materials - sheeting and coatings - resins and adhesives - textiles and upholstery		**others**: - small EE components (cables, lamp holders, plugs, switches, electronic components, transformers) - building materials and materials for interior decoration

Note: In this study, the term ‘computer’ refers to the actual computer plus the monitor, keyboard and mouse

The determination of flame retardant flows was based on a classification of products according to components containing flame retardants (see Tab. 5-1, right-hand column). Finally, the data were applied to product groups, and, wherever possible, assigned to place of use.

5.1.2 Problems in determining FR flows in products

- Manufacturers of EE appliances (electrical and electronic appliances) mostly have no information on the FR contained in new products. Information is only available on the fire protection class to be fulfilled [Wegmann et al., 1999]. Where the supplier of a component changes, appliances of the same type may contain different types and quantities of FR.
- PCs are a key product in the FR market [Danish EPA, 1999]. The product is subject to rapid change both concerning assembly, type of plastic and additives. Development times from design to production are short (approx. 6-8 months), and new PC versions appear on the market about every six months [Atlantic Consulting, 2000].
- The composition of EE appliances, vehicles and building materials has changed radically in recent decades. Not only the plastics content, but also the types of plastics and flame retardants used, have in some cases altered completely. Thus the material constitution found in new appliances is not always applicable to appliances in current use.
- Usually, manufacturers have no information on flame retardants in older appliances.
- Further, data acquisition is made more difficult by the fact that most EE appliances are produced outside Europe, from where they are imported. A German study [Leisewitz & Schwarz, 2000] states that for IT appliances, the proportion imported is high, and the appliances produced in Switzerland and the rest of Europe (as given in the statistics) are assembled using a larger or smaller proportion of imported components.
- The number of EE appliances sampled so far is small in relation to the total number of appliances in circulation. Extrapolations from the FR concentration found in the samples to the entire Swiss market are therefore subject to a high degree of uncertainty. This is illustrated by the Danish study which analysed the FR content in the casings of about 150 EDP equipment, and then applied this to total sales of 130 000 units.
- Owing to the high percentage of imported components in the majority of EE appliances and vehicles, and the dearth of information on imported appliances, no conclusions could be drawn on the percentages of plastics used in these. In Denmark, the fraction of imported EE appliances amongst those sold amounts to 90% [Danish EPA, 1999].

- No information was available on the FR concentration in the various types of plastics available on the world market.

To obtain reliable results in the face of the problems mentioned above, other ways of determining the flow of flame retardants were applied, and the results compared.

Tab. 5-2: Methods of determining flame retardant flows

REQUIRED FLOWS AND CONCENTRATIONS IN CONSUMER PRODUCTS	METHODS OF DETERMINATION
Material flows	1. Customs statistics, micro census
	2. Comparison with other European countries (Germany, Denmark)
Flame retardant flows	1. Material flows and flame retardant concentrations in all relevant individual EE products (PCs, copying machines, …)
	2. Flows of types of plastic within product groups (EE appliances, vehicles, building materials) in combination with the percentages and typical concentrations of flame retardants
	3. Comparison with other Central European countries (Germany, Denmark)
	4. Determination based on worldwide consumption of flame retardants

The stock in consumption could only be roughly estimated owing to the large number of unknowns. The average service life of products was available from the literature.

5.1.3 Electrical and electronic products (EE products)

In this section, a rough estimate is first made of the flows of plastics and flame retardants based on European, German and Swiss statistics. The components (printed circuit boards, casings, small components) and their use in products and product groups are then dealt with. The assignment of EE products to product groups is given in Tab. 5-1.

In 2000, the consumption of plastics in EE products in Western Europe amounted to 2.67 million t, i.e. 25.4% higher than in 1995 ([APME, 2001] and [APME, 1995]). Assuming a linear increase, the annual growth rate in the consumption of EE plastics amounts to approx. 4.6%. However, the growth rate varies greatly for individual products[1]:

- household electronics (TV, audio, video, DVD appliances): - 1.4% (negative)
- computers: + 31%
- EE office equipment (copying machines, fax machines) and printers: + 18%
- small EE components: + 2.1%

Before dealing with individual products, the following table provides a rough orientation in the form of reference values. The data given in the reports of the Association of Plastic Manufacturers in Europe ([APME, 2001], [APME, 1995]) is used throughout. The calculations are given in the appendix under national and worldwide comparisons.

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[1] A detailed breakdown and calculations of growth rate are given in Tab. 9-2.

Tab. 5-3: Consumption of EE products in Switzerland in 1998 and the plastics and flame retardants contained therein

CONSUMPTION OF EE PRODUCTS	Appliances	Plastics	Plastics treated with flame retardants		Brominated flame retardants	
	1000 t	1000 t	%	t	%	t
Household electronics	21.36	5.243	34%[1)]	1788	83%	1484
EDP equipment (excl. printers)	27.70	5.928	65%	3853	83%	3198
Telecommunications	2.74	1.624	0%[2)]	0	0%	0
EE office equipment	10.49	1.505	20%	301	83%[5)]	250
Small household appliances	7.26	3.090	2%	62	50%[6)]	31
Large household appliances	63.57	11.725	1%	117	50%[6)]	59
Cables	88.34	22.146	n.a.	n.a.	n.a.	n.a.
Small EE components	65.28	4.325	20%[2)]	865	54%	467
Electric tools	2.26	0.225	2%[3)]	5	50%[6)]	2
Vending machines	1.14	0.205	20%[4)]	41	50%[6)]	20
Toys and games	0.26	0.164	2%[3)]	3	50%[6)]	2
Medical appliances	2.94	0.094	20%[4)]	19	50%[6)]	9
Lighting appliances	2.16	0.061	20%[4)]	12	50%[6)]	6
Monitoring and control instruments	0.12	0.061	20%[4)]	12	50%	6
Subtotal IT+telecom.	40.9	9.1		4154		3448
Subtotal EE appliances	142.0	29.9		5903		5068
TOTAL EE sector	295.6	56.4	12%	6768		5535

Note: Product flows are always quoted without plugs, disconnectors and cables. The subtotal IT+telecommunications also includes EDP and EE office equipment. The subtotal EE appliances comprises all equipment except cables and small EE components. Sources: Tables 9-2: fraction of FR plastics [APME, 2001] and fraction of brominated FR [APME, 1995]

n.a.: not available

(1) for TV and certain audiovisual appliances: 55%. Household electronics total: 34% (calculated).
(2) [APME, 1995]
(3) assumption: same as small household appliances
(4) assumption: same as office equipment
(5) assumption: same as EDP equipment and household electronics
(6) own assumption

5.1.3.1 Printed circuit boards

Printed circuit boards consist of an electrically insulated carrier material (base material), on which conducting structures are superimposed (copper foil, EE components). Printed circuit boards can be designed as single-sided, double-sided, multi-layer or flexible structures.

Non-reinforced (flexible) laminates consist of polyester or polyamide, with low market volume (7-8 % market share in Germany [Achternbosch & Brune, 1996]) in comparison to reinforced laminates. Owing to their low market volume, and as no detailed information on their BFR content could be found, these laminates are not further considered in the present study.

The base material is of reaction resin and a reinforcing material, and is mostly covered on one or both sides with copper foil (in which case it is termed a laminate). Non-covered base materials are also referred to as prepregs (*pre*im*preg*nated sheets of paper or fabric). Laminates consist of 45% by weight resin, 45% by weight reinforcement and 9% by weight copper [Behrendt et al., 1998]. The weight of (electrical and electronic) components mounted on the printed circuit board is approximately the same as that of the laminate itself [Schütte, 1997].

The fire protection standard of the resin to be used is laid down in the UL94 test (Underwriters Laboratory, USA) as V0. This requires the materials to be self-quenching in less than 10 minutes in case in fire. The following table provides details of the most common carrier materials.

Tab. 5-4: Printed circuit board laminates treated with flame retardants [Leisewitz & Schwarz, 2000]

designation[1]	Reaction resin	Reinforcement material	Uses
FR1	Phenolic	Resin bonded paper	Inexpensive household electronics (video, CD, remote control)
FR2	Phenolic[2)]	Resin bonded paper	Household electronics (televisions, radio, video) vehicle electronics, white goods (washing machines, kitchen appliances, etc.)
FR3	Epoxy	Resin bonded paper	Same as FR2, telecommunications
FR4	Epoxy	Glass cloth	Office equipment, telecommunications, luxury household and vehicle electronics, process control, measuring instruments, medical and military appliances, space flight
FR5	Epoxy	Glass cloth	Same as FR4 (for higher thermal loads)
CEM1	Epoxy	Core: paper Covering: fibreglass laminate	White goods (fittings), vehicle electronics (fittings), telecommunications (tabletop appliances), luxury household electronics (TV)
CEM3	Epoxy	Core: fibreglass mat Covering: fibreglass laminate	Same as FR4, measuring instruments, telephone exchanges

Note: the laminates with the highest market share are shown in bold type. CEM1 + CEM3 are so-called composites comprising a core and a covering.

1) acc. to DIN or NEMA standards (National Electrical Manufacturers Association, USA)

2) in addition to the classical FR2 laminates (pure phenolic resins), FR2 types, to which epoxy resin (up to 90% of the resin volume) is added [Leisewitz & Schwarz, 2000], are marketed.

The percentage of laminates in annual production is shown in the following table. Approx. 50% of FR4 laminates and over 70% of FR2 laminates are produced in South-East Asia. A detailed analysis is given in the appendix under printed circuit boards.

Tab. 5-5: International market for laminates 1998 (original data from [Leisewitz & Schwarz, 2000][1])

	% surface area	Specific weight [kg/m^2]	Percentages by weight
FR4	**56 %**	3	**66 %**
High-Perform$^{1)}$	3 %	2	2.4 %
FR2	32 %	2	25 %
Composites	9 %	2	7 %
Total	100 %	-	100 %

Note: 100% surface area = 216 million m^2 and 100% percentage by weight = 550 000 t. Market share of other laminates in Germany: FR1 negligible; FR3 0.9%; FR5 1.6%.

1) High-Perform laminates are based on reaction resins other than epoxy or phenolic, i.e. polyimide, bismalein imide/triazine resins [BT], BT epoxy blends, polyphenyl ethers, etc.).

The detailed study was limited to FR2 and FR4 laminates. It was assumed that FR2 laminates are used in pocket calculators, household electronics (except in toys, games and musical instruments) and EE household appliances (except in scales and clocks), and that FR4 laminates are used in other products (see Tab. 5-4).

5.1.3.1.1 BFR in printed circuit boards

Although BFR are mainly used in laminates, they also occur in plastic coverings of electrical components and plastic components on printed circuit boards. The two most frequently occurring laminates are described here in more detail.

FR4 laminates

The assumption is made that this laminate is used in all EDP, office and special appliances [Danish EPA, 1999]. FR4 is usually treated with reactive TBBPA (18-20% bromine in the resin [Leisewitz & Schwarz, 2000]), to which antimony trioxide is frequently added. Although TBBPA-free flame retardation is technically possible today, the anticipated future market share is only 5% (partly owing to the approx. 30% higher price) [Leisewitz & Schwarz, 2000]. For the present study, the TBBPA content given in the Danish study [Danish EPA, 1999] of approx. 0.42 kg/m^2 was used.

FR2 laminates

These laminates are used for electronic household appliances, and according to the Danish study [Danish EPA, 1999] they contain additive FR. Contrary to the Danish study, the German study [Leisewitz & Schwarz, 2000] states that when the resin concerned is a mixture of phenolics and epoxy, the FR are applied **reactively.** In subsequent calculations, it is therefore assumed that half the TBBPA is applied reactively (for resin mixtures with a bromine content of 4.5% in the resin [Leisewitz & Schwarz, 2000]) and the other half additively (for pure phenolic resins).

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[1] p.145

Traditionally, PBDE were used for FR2 laminates [Leisewitz & Schwarz, 2000][1]. In the early 1990s, FR2 laminates produced in Europe were treated with TBBPA, those in Asia with pentaBDPE flame retardants [Danish EPA, 1999]. In Asian production, pentaBDPE was first substituted by decaBDPE and then by TBBPA. The analyses of dismantled FR2 printed circuit boards in electrical scrap, show that about 35% of the PBDE used consist of pentaBDPE [Leisewitz & Schwarz, 2000]. The assumption is made that 25% of FR2 laminates in older appliances contain pentaBDPE, 65% decaBDPE and 10% TBBPA as flame retardants.

On a world scale, FR2 with brominated FR dominate, whereas in Germany non-brominated FR are dominant [Leisewitz & Schwarz, 2000]. The assumption is made that 90% of the FR2 laminates produced today are treated with BFR. It is further assumed that approx. 30% of the FR2 laminates produced today contain PBDE (i.e. decaBDPE) as given in the Danish study [Danish EPA, 1999].

In TV appliances, FR2 laminates are mostly used, whereas in new products it can be assumed that no PBDE are used [Danish EPA, 1999] (market share of FR: 90% TBBPA, 10% others).

Plastic sheathing and electronic components [Danish EPA, 1999]

Tab. 5-6: Market share and concentration of FR in printed circuit boards

FLAME RETARDANTS IN PRINTED CIRCUIT BOARDS	FR USED				FR CONCENTRATION			
	Penta-BDPE	Octa-BDPE	Deca-BDPE	TBBPA	Penta-BDPE	Octa-BDPE	Deca-BDPE	TBBPA
	[%]	[%]	[%]	[%]	[g/m²]	[g/m²]	[g/m²]	[g/m²]
New products (1998)								
FR2 laminates	0	0	30	60	0	0	36	36
FR2 laminates for TV	0	0	0	90	0	0	0	36
FR4 laminates	0	0	0	100	0	0	0	420
Older products (1990)								
FR2 laminates	25	0	65	10	36	0	36	36
FR2 laminates for TV	25	0	65	10	36	0	36	36
FR4 laminates	0	0	0	100	0	0	0	420

Note: A distinction was made between previous applications (older products produced in 1990) and present-day applications (produced in 1998). In the above table, the % values under 'FR USED' mean that x % of the printed circuit boards consumed annually in Switzerland are treated with the given FR. The g/m^2 values under 'FR CONCENTRATION' indicate the specific weight of FR in the printed circuit board.

The plastic sheathing of the electrical components on printed circuit boards consists mainly of epoxy resin treated with TBBPA flame retardants[2] (approx. 90g/m^2) [Danish EPA, 1999]. It is assumed that the PBDE (decaBDPE) content of plastics in electronic components takes the maximum value of 10 g/m^2. The percentage in the other plastic components of printed circuit boards is 4.5% of the weight of the board itself.

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[1] p.163

[2] in the German study [Leisewitz & Schwarz, 2000], it is assumed that in addition to the laminate, the sheathing contains 20% TBBPA. The resulting content in FR4 laminates is approx. 84 g/m^2.

5.1.3.1.2 Printed circuit board production

Although no printed circuit board panels are produced in Switzerland, they are assembled there. The waste off-cuts amount to <5 – 20 % of the panels. The total Swiss market for printed circuit board panels is estimated at 300 000 – 350 000 m^2 annually [Grangier, 2001], [Gallana, 2001]. The resulting volume of waste amounts to <15 000 – 70 000 m^2 per year. According to information obtained from two printed circuit board assembly firms, the waste off-cuts are delivered to municipal waste incineration plants [Grangier, 2001], [Gallana, 2001].

It may be assumed that the greater part of printed circuit boards produced in Switzerland is based on FR4 laminates and the remainder on FR2 laminates. In the early 1990s, European laminates (FR4 and FR2) already contained TBBPA flame retardants only. However, the possibility cannot be entirely ruled out that laminates from the USA and Asia may find their way to Europe.

As a basis for estimating the material flow resulting from printed circuit board assembly waste, it is assumed that 20% of the printed circuit boards assembled in Switzerland are of type FR2. The material flows are summarised in *Tab. 5-16*.

5.1.3.2 Casings

Tab. 5-7: Percentage of brominated outer casings of certain EE appliances [Leisewitz & Schwarz, 2000]

Brominated casings	Prod. 1990 1)	Prod. 1999 1)	Prod. 1997-2000 2)	Prod. 1997/98 3)	Prod. 1998 4)	Prod. 1997 5)
Monitors	50 %	25 %	11-28 %	28 %	33 %	45-80 %
Computers				22 %	33 %	45 %
Notebooks			29-30 %			30 %
Keyboards				11 %		
Inkjet printers	33 %	33 %	0-36 %			30 %
Laser printers	80 %	50 %	43-100 %			100 %
Copying machines	80 %	50 %				100 %
Fax machines, telex						100 %
TV appliances (rear covers)	50 %	10 %	7-11 %			10 %

1) [Leisewitz & Schwarz, 2000] p.262
2) Stiftung Warentest (Germany) [Leisewitz & Schwarz, 2000] p.244: no PBDE were found
3) Reader survey BUND (Germany) [Leisewitz & Schwarz, 2000] p.238
4) LGA Bavaria (Germany) [Leisewitz & Schwarz, 2000] p.240
5) [Danish EPA, 1999] p.213

The term 'casings' applies to the outer casings of EE appliances with large surface area, but not to internal casings. Outer casings mostly consist of styrene polymers (HIPS, ABS) and polymer blends (mixtures) of these.

For new and older appliances, the German study estimates the percentage of casings containing BFR (see Tab. 5-7). The average decline in the prevalence of brominated casings according to this estimate lies around 50%. According to the Danish study [Danish EPA, 1999], TBBPA and PBDE account for about 70% of all brominated flame retardants used in casings.

The European plastics statistics document the use of plastics for the entire EE sector (i.e. products sold in Western Europe). In 1995 [APME, 1995], the use of polystyrene (incl. PS blends) was of the same order as ABS (incl. ABS blends). According to [APME, 2001], the consumption of ABS in 2000 (incl. ABS blends) was about 70% higher than for polystyrene (incl. PS blends).

For outer casings, the trend in the use of plastics shifted from the market leader ABS (1990s) towards PC/ABS and HIPS. For monitors and computers, PC/ABS dominate at present, while for TV appliances, HIPS dominate [Leisewitz & Schwarz, 2000]. At the beginning of the 1990s, HIPS represented the largest (30%) field of application for decaBDPE, and ABS the largest (95%) for octaBDPE [Danish EPA, 1999].

The casings of computers and monitors produced in Europe today contain ABS or PC/ABS, but not BFR. Casings of computers and monitors produced outside Europe may contain HIPS or PPE/HIPS. Their market share is about 80% [Leisewitz & Schwarz, 2000].

Today, only ABS and HIPS casings contain BFR (70% TBBPA used additively or other FR) [Leisewitz & Schwarz, 2000]. An estimate prepared by BASF shows that the market share of ABS casings was about 60% in 1996, and that of PC/ABS casings about 80% in 1999. For new appliances, it is assumed that 10% of casings are of HIPS, and that these contain TBBPA flame retardants.

At the beginning of the 1990s, PBDE dominated the flame retardant market for plastic casings, these being substituted in the course of time by TBBPA and other flame retardants. PBDE are now rarely found in casings [Leisewitz & Schwarz, 2000].

No information is available on the quantities of plastics and flame retardants used, and these are also very difficult to estimate [Leisewitz & Schwarz, 2000]. To estimate the order of magnitude of the FR employed, attention was directed to the percentages of plastics consumed. Formulae of plastic compounds were obtained from FR manufacturers, and the results of market research studies analysed (see Tab. 5-8).

Tab. 5-8: Rough estimate of the use and concentration of FR in plastics for casings

FLAME RETARDANTS IN PLASTICS FOR CASINGS OF EE APPLIANCES	**FR USED**				**FR CONCENTRATION**			
	Penta-BDPE [%]	**Octa-BDPE [%]**	**Deca-BDPE [%]**	**TBBPA [%]**	**Penta-BDPE [g/kg]**	**Octa-BDPE [g/kg]**	**Deca-BDPE [g/kg]**	**TBBPA [g/kg]**
New products (1998)								
Monitors	0	1	5	15	0	154	115	190
Computers	0	1	5	15	0	154	115	190
Notebooks	0	0	0	25	0	0	0	190
Keyboards	0	0	5	5	0	0	115	190
Inkjet printers	0	1	5	15	0	154	115	190
Laser printers	0	2	15	20	0	154	115	190
Copying machines	0	2	15	20	0	154	115	190
Fax machines, telex	0	2	15	20	0	154	115	190
TV appliances (rear cover)	0	0	3	5	0	0	115	170
Older products (1990)								
Monitors	0	15	10	15	0	200	110	200
Computers	0	15	10	15	0	200	110	200
Notebooks	0	15	10	15.0	0	200	110	200
Keyboards	0	10	10	10.0	0	200	110	135
Inkjet printers	0	10	5	10.0	0	200	110	200
Laser printers	0	30	20	10.0	0	200	110	200
Copying machines	0	30	20	10.0	0	200	110	200
Fax machines, telex	0	30	20	10.0	0	200	110	200
TV appliances (rear cover)	0	20	20	5.0	0	200	110	135

Note: A distinction was made between previous applications (older products produced in 1990) and present-day applications (produced in 1998). In the above table, the % values under 'FR USED' mean that x % of the products consumed annually in Switzerland were treated with the given FR. The g/kg values under 'FR CONCENTRATION' indicate the concentration of FR in the plastic casings. The FR concentration values in the plastics shown were obtained from FR manufacturers.

Sources: German study [Leisewitz & Schwarz, 2000] (p.224-245, 262-264), own assumptions and Appendix: 'Outer casings of EE appliances' (Section **Fehler! Verweisquelle konnte nicht gefunden werden.**): Tab. 5-7, Tab. 9-10, Tab. 9-16, Tab. 9-17, Tab. 9-18.

Concerning the FR content of products that were included in the study, but not shown in Tab. 5-8, assumptions were made by the authors based on the literature [APME, 1995] (also see Appendix: 'Outer casings of EE appliances' (Chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**)):

- pocket calculators: FR content is 20% of the FR content of a normal keyboard
- household electronics: 10% of the appliances (excl. car radios and older photographic equipment) have comparable casings to computers. The casings of the remaining appliances do not contain flame retardants
- EE household appliances, EE toys and games, musical instruments and special appliances: casings do not contain flame retardants

5.1.3.3 Small plastic components in EE appliances

The remaining plastic components in EE appliances are e.g. cable sheathing, switches, plugs, transformers, relays, coils, condensers and resistances.

According to the plastics statistics for Western Europe [APME, 1995], only the interior components of household appliances are treated with flame retardants. The percentage of plastics treated with flame retardants in these appliances is about 2%, whereas for household appliances it is about 1%. The German study [Leisewitz & Schwarz, 2000] states that about half the small components in EE appliances are treated with flame retardants, and that of these, 80% consist of PBB, decaBDPE, TBBPA or TBBPA derivatives.

A study of TV appliances [Behrendt et al., 1998] gives the percentage of plastics in electronic components as about 3% of the total weight, or about one-sixth of the weight of the casing.

The assumption is made that the percentage of plastics in small components is about 3% of the total weight of EE appliances. For large EE household appliances and special appliances, the percentage is estimated somewhat lower at 2%.

It is further assumed that 5% of these plastics are treated with octaBDPE, 15% with decaBDPE and 10% with TBBPA flame retardants.

Tab. 5-9: Market share and concentration of FR used in printed circuit boards

FLAME RETARDANTS IN SMALL COMPONENTS OF EE APPLIANCES	**FR USED**				**FR CONCENTRATION**			
	Penta-BDPE	**Octa-BDPE**	**Deca-BDPE**	**TBBPA**	**Penta-BDPE**	**Octa-BDPE**	**Deca-BDPE**	**TBBPA**
	[%]	**[%]**	**[%]**	**[%]**	**[g/kg]**	**[g/kg]**	**[g/kg]**	**[g/kg]**
In new and older appliances	0	5	15	10	0	150	150	150

Note: The % values under 'FR USED' mean that x % of the small components consumed annually in Switzerland are treated with the given FR. The g/kg values under 'FR CONCENTRATION' indicate the concentration of FR with respect to the weight of small plastic components.

5.1.4 Vehicles

This section concerns road and rail vehicles. An estimate of the content of flame retardants in aircraft was made based on their content in rail vehicles.

5.1.4.1 Road vehicles

BFR are used in printed circuit boards, large plastic components, textiles, upholstery and small EE components (switches, transformers, lighting appliances). The most intensive study was for cars, and based on this, conclusions were drawn concerning lorries, motorcycles and other vehicles.

The numbers of private cars sold and put on the roads in Switzerland was estimated using data from Austria. The FR concentrations and flows of large plastic components, textiles and upholstery were based on data for Denmark (see Chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**), and are summarised in the following table. The figures are based on the total weight of plastics in vehicles.

Tab. 5-10: Concentration of BFR used in plastics of road vehicles

FLAME RETARDANTS IN PLASTICS OF ROAD VEHICLES	**PentaBDPE**		**OctaBDPE**		**DecaBDPE**		**TBBPA**	
	new	*old*	new	*old*	new	*old*	new	*old*
	[g/kg]	*[g/kg]*	[g/kg]	*[g/kg]*	[g/kg]	*[g/kg]*	[g/kg]	*[g/kg]*
Cars	0.044	0.089	0.017	0.085	0.625	1.8	0.63	0.75

Note: The FR concentration is quoted with respect to the total weight of plastics in cars exclusive of EE plastic components (switches, transformers, lighting appliances). The FR concentration refers only to the substances under study, not to commercial FR products. A distinction was made between older vehicles (old) and brand new vehicles (new).

The FR concentration in other components is given in Section 5.1.3.1 'Printed circuit boards' and Section 5.1.3.3 'Small plastic components in EE appliances', whereby it can be assumed that the printed circuit boards used in private cars are based on FR4 laminates. For EE components, it can be assumed that they amount to about 10% of the total weight of the plastics used [APME, 1999].

5.1.4.2 Rail vehicles

BFR are used in printed circuit boards, large plastic components and small EE components (switches, transformers, lighting appliances).

The FR flows in large plastic components were derived from German values [Leisewitz & Schwarz, 2000]. For the market share of FR, the authors made their own assumptions.

The content of plastics in rail vehicles is approximately 5% by weight, of which about 75% are UP (unsaturated polyester) resins, approx. 10% PVC and 15% other materials. As a rule of thumb, an average of 400-500 kg of UP resin may be assumed per coach. For calculation purposes an average of 450 kg was taken for passenger coaches and motorised vehicles alike.

Up to the end of the 1980s, 100% of all UP resins were treated with BFR, whereby primarily decaBDPE, but also pentaBDPE and TBBPA, were employed. The use of FR in other plastics was not considered. Thus the values in the following table apply only to the UP resins used.

The FR concentration in other components is described in Chapter 5.1.3.1 'Printed circuit boards' and in Chapter 5.1.3.3 'Small plastic components in EE appliances', whereby it can be assumed that the printed circuit boards in rail vehicles are based on FR4 laminates. The weight of plastics contained in EE components was roughly estimated at 10% of the mass of the UP resins used.

Tab. 5-11: Market share and concentration of BFR used in UP resins in rail vehicles

FLAME RETARDANTS IN UP RESINS OF RAIL VEHICLES	**FR USED**				**FR CONCENTRATION**			
	Penta-BDPE [%]	**Octa-BDPE [%]**	**Deca-BDPE [%]**	**TBBPA [%]**	**Penta-BDPE [g/kg]**	**Octa-BDPE [g/kg]**	**Deca-BDPE [g/kg]**	**TBBPA [g/kg]**
Values for 1990	0	0	5	1	0	0	85	50
Values for 1980	5	0	50	5.0	50	0	85	50

Note: The FR concentration given refers only to commercial FR products, not to the substances under study. The % values under 'FR USED' mean that x % of the products consumed annually in Switzerland were treated with the given FR. The g/kg values indicate the concentration of FR in the UP resin.

5.1.4.3 Aircraft

For aircraft, the same plastics composition was assumed as for rail vehicles, i.e. that plastics account for 5% of the total weight, of which 75% are UP (unsaturated polyester) resins. The values for aircraft were thus taken from Tab. 5-11.

5.1.5 Building materials and textiles

This section concerns flame retardants in plastics and textiles used in the building industry, materials for interior decoration, and protective clothing, specifically:

- PUR, EPS and XPS insulating foams
- plastic sheeting in the building industry
- epoxy resins and polycarbonates in the building industry
- flexible PUR foams for furniture upholstery
- coated textiles for interior decoration and protective clothing.

The service life of building materials is given in a SAEFL study at 30-50 years [Arx, 1995].

The percentage of TBBPA and PBDE in building materials and textiles was given in the Danish study [Danish EPA, 1999, p.110] as 2.5% based on the total weight of TBBPA and PBDE in finished products. It can therefore be assumed that where quantity is concerned, this product group plays only a minor role in Switzerland. The very rough assumptions made here to estimate the flows and stocks are thus adequate to satisfy the aims of the study.

5.1.5.1 PUR, EPS, XPS and PE insulating foams

In Denmark, about 5% of the EPS insulating foams used, and about 80% of XPS foams, are treated with flame retardants, whereby almost exclusive use is made of HBCD. The Danish study [Danish EPA, 1999] gives the HBCD concentration in EPS at 0.5 – 1.0% and in XPS at 1.0 – 2.0% (pp. 77, 80).

In 1994, some 6 000 -12 000 t polyurethane were used in rigid expanded plastics for heat insulation, and some 13 000 t EPS, in the building industry in Switzerland, [Arx, 1995]. EPS is treated with about 1-1.5% by weight of HBCD flame retardant [Arx, 1995].

The assumption is made that in Switzerland, the consumption of EPS in 1998 was slightly higher at 15 000 t/a, and that the consumption of XPS was the same as in Germany [Leisewitz & Schwarz, 2000] (p.97) i.e. about one-fifth of the weight of EPS, i.e. approx. 3000 t/a. Prior to that, decaBDPE was the favoured flame retardant for XPS. By reducing the extrusion temperature, complete conversion to HBCD was possible. It is assumed here that 80% of the XPS in older products contain 2% by weight of decaBDPE.

According to studies in Denmark and Germany, neither TBBPA, PBDE nor HBCD are used as flame retardants in PUR foam. Previously, TBBPA and pentaBDPE were used for PUR foam fillers [Leisewitz & Schwarz, 2000] (p.74), although no data are available on the percentages and quantities used. The assumption is made that one-quarter of the foam fillers used previously were treated with pentaBDPE and one-third with TBBPA flame retardants. The FR concentration of foam fillers is about 22% by weight, i.e. significantly higher than that of other PUR foams (4-13%) [Leisewitz & Schwarz, 2000] (p.85). The percentage of foam fillers used today amounts to approx. 20% by weight of all PUR insulation foams [Leisewitz & Schwarz, 2000] (p.85).

To a lesser extent, PE foams are used for the insulation of hot water pipes, and these may be treated with HBCD or PBDE flame retardants. In Denmark, the annual consumption of PE foam is given at 30-50 t/a and of PBDE at approx. 0-1 t/a [Danish EPA, 1999] (p.78). Under the assumption that decaBDPE is employed for this, this results in an annual quantity of some 0.67 t/a decaBDPE for Switzerland (from among the total of 54 t/a PE foam).

In Germany, some 1 million t PUR insulating foam (without foam filler) was used in buildings in the period 1967-1997 [Leisewitz & Schwarz, 2000] (p.93). The corresponding stock of foam filler is estimated from present consumption at 0.26 million t [Leisewitz & Schwarz, 2000] (p.85). In Germany, the percentages of EPS and XPS remained almost constant (see Tab. 9-25), their stocks being estimated at approx. 2.4 million t and 0.46 million t respectively. The stock of PE foam is estimated on the basis of the relative proportion of EPS to PE.

The existing stocks in Switzerland are estimated in relation to the resident population as follows:

EPS: 210 000 t
XPS: 40 000 t
PUR incl. foam filler: 110 000 t
PE foam: 750 t

The following table shows a breakdown of the values used in the calculation:

Tab. 5-12: Market share and concentration of BFR used in insulating foams

	FR USED				FR CONCENTRATION			
	Penta-BDPE [%]	Octa-BDPE [%]	Deca-BDPE [%]	TBBPA [%]	Penta-BDPE [g/kg]	Octa-BDPE [g/kg]	Deca-BDPE [g/kg]	TBBPA [g/kg]
New products (1998)								
EPS insulating foam	0	0	0	0	0	0	0	0
XPS insulating foam	0	0	0	0	0	0	0	0
PUR insulating foam	0	0	0	0	0	0	0	0
PE insulating foam	0	0	50	0	0	0	20	0
Older products (1990)								
EPS insulating foam	0	0	0	0	0	0	0	0
XPS insulating foam	0	0	80	0	0	0	20	0
PUR insulating foam	5	0	0	6.7	220	0	0	220
PE insulating foam	0	0	0	0	0	0	0	0

Note: The FR concentration given refers only to commercial FR products, not to the substances under study. A distinction was made between previous (older products) and present-day (new products) applications. The % values under 'FR USED' mean that x % of the products consumed annually in Switzerland were treated with the given FR. The g/kg values indicate the concentration of FR in the plastic.

5.1.5.2 Plastic sheeting

Plastic sheeting is made from thermoplastics (PE, PP, etc.) and duroplastics (e.g. PVC).

In most applications, PVC is not treated with flame retardants [Danish EPA, 1999] (p.78). When treated with flame retardants, about 5% of FR containing phosphate are used [Arx, 1995]. However, a textbook on plastics [Gächter & Müller, 1987] cites an example of PVC containing 4.9% by weight of pentaBDPE as flame retardant, while an FR manufacturer [Dead Sea Bromine, 2001] recommends decaBDPE as PVC flame retardant.

According to a study for Denmark, 10-20% of the plastic sheeting used in bridges and underground structures are possibly treated with flame retardants [Danish EPA, 1999] (p.79).

Thermoplastic sheeting is treated with PBDE, HBCD and other BFR at a concentration of between 1.3-5% by weight [Danish EPA, 1999] (p.78). However, the above-mentioned plastics textbook and the FR manufacturer mostly cite higher FR concentrations as follows:

- PP with 4.8-24% by weight decaBDPE according to fire protection standard [Dead Sea Bromine, 2001]
- PP with 5.2% by weight TBBPA for low fire protection standard [Dead Sea Bromine, 2001]
- PE in building materials with 20-24% by weight decaBDPE [Dead Sea Bromine, 2001]
- HDPE with 5.0% by weight octaBDPE for low fire protection standard [Gächter & Müller, 1987]

- HDPE with 10.0% by weight decaBDPE for high fire protection standard [Gächter & Müller, 1987]
- LDPE with 4.9% by weight octaBDPE for low fire protection standard [Gächter & Müller, 1987]

As no detailed information could be found on the use of FR, a series of assumptions was made based on values from the literature mentioned above (see Tab. 5-13).

Tab. 5-13: Market share and concentration of BFR in plastic sheeting

	FR USED				**FR CONCENTRATION**			
	Penta-BDPE	**Octa-BDPE**	**Deca-BDPE**	**TBBPA**	**Penta-BDPE**	**Octa-BDPE**	**Deca-BDPE**	**TBBPA**
	[%]	**[%]**	**[%]**	**[%]**	**[g/kg]**	**[g/kg]**	**[g/kg]**	**[g/kg]**
New products (1998)								
PE plastic sheeting	0	0	10	0	0	0	100	0
PP plastic sheeting	0	0	10	10	0	0	100	52
PVC plastic sheeting	0	0	5	0	0	0	50	0
Older products (1990)								
PE plastic sheeting	0	10	20	0	0	50	100	0
PP plastic sheeting	0	0	20	10	0	0	100	52
PVC plastic sheeting	5	0	10	0	49	0	50	0

Note: The FR concentration given refers only to commercial FR products, not to the substances under study. A distinction was made between earlier applications (older products) and present applications (new products). The % values under 'FR USED' mean that x % of the products consumed annually in Switzerland were treated with the given FR. The g/kg values indicate the concentration of FR in the films.

5.1.5.3 Epoxy resins and polycarbonates in the building industry

Tab. 5-14: Market share and concentration of BFR in epoxy resins and polycarbonates

	FR USED				**FR CONCENTRATION**			
	Penta-BDPE	**Octa-BDPE**	**Deca-BDPE**	**TBBPA**	**Penta-BDPE**	**Octa-BDPE**	**Deca-BDPE**	**TBBPA**
	[%]	**[%]**	**[%]**	**[%]**	**[g/kg]**	**[g/kg]**	**[g/kg]**	**[g/kg]**
New products (1998)								
Epoxy resin	0	0	0	10	0	0	0	20
Polycarbonate	0	0	0	10	0	0	0	20
Older products (1990)								
Epoxy resin	0	0	0	10	0	0	0	20
Polycarbonate	0	0	0	10	0	0	0	20

Note: The FR concentration given refers only to commercial FR products, not to the substances under study. A distinction was made between earlier applications (older products) and present applications (new products). The % values under 'FR USED' mean that x % of the products consumed annually in Switzerland were treated with the given FR. The g/kg values indicate the concentration of FR in the plastic.

TBBPA is used reactively as an FR in epoxy resins and polycarbonates. Epoxy resins are used in the building industry as surface and corrosion protection for floor panels, plaster and concrete floors and as adhesives in building construction. In 1990, ca. 120 000 t/a of epoxy resin and ca. 35 000 t/a of polycarbonate were used in the building industry in Western Europe [Arx, 1995]. Under Swiss conditions, this amounts to about 4 000 t/a of epoxy resins and about 1 400 t/a of polycarbonate.

Since no other data were available on the percentage and concentration of FR, these could not be quantified. (The TBBPA concentration in the epoxy resin sheathing of electrical components is given as 2% [Danish EPA, 1999]).

5.1.5.4 Textiles

This section concerns protective clothing, tarpaulins (tents and tarpaulins for railway wagons), textiles for the interior decoration of buildings (carpets, curtains, furniture coverings) and upholstery.

An important application of decaBDPE and HBCD lies in the fire protection of upholstery and polypropylene curtains and covers. FR is applied in the form of a latex composite as a backing layer to textiles [Drohmann, 2000].

The fibres may also be treated directly. For example decaBDPE is used for polyester and cellulose fibres (tents, marquees and furniture coverings, and also wagon tarpaulins) [Leisewitz & Schwarz, 2000] (p.291).

The entire flame retardant flow in textiles used in Germany in 1997 has been estimated at 1250 t [Leisewitz & Schwarz, 2000] (p.296). Although the use of decaBDPE and pentaBDPE is assumed here to be negligible, that is not to say that their use can be entirely ruled out.

The use of pentaBDPE in flexible PUR foams seems to have been discontinued [Danish EPA, 1999]. In the past, TBBPA and decaBDPE have never been, and are still not, used as flame retardants in textiles. In 1997, the percentage of decaBDPE in textiles in Denmark was quoted as less than 5 t. Under Swiss conditions, this is equivalent to less than 7 t/a.

5.1.6 Process: ‘production, trade and consumption’

A detailed breakdown of the data and a discussion will be found in Appendix 1: trade in products; Chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**

5.1.6.1 Bandwidth of the data

The bandwidth of material and substance flows was determined on the assumption that all parameters lie between a realistic minimum and maximum. The parameters concerned comprise all flows and factors necessary for the calculation, and these are listed in previous sections. The bandwidth of the individual parameters is either taken directly, or derived, from the literature, or based on our own assumptions.

The bandwidths of the parameters used in the calculation are given relative to the average values[1] as determined in the above sections:

- material flows: minimum consumption of building materials 20%, and of all other products (except computers) 10%, less than the average value. Maximum sales of vehicles and household and special electrical appliances 30%, of building materials and small EE components 20%, and of other products (except computers) 10%, higher than the average value
- concentration: based on the bandwidth given in the literature (ca. ± 10 %)
- market share of flame retardants: the market share of FR relative to the total market was increased or reduced by 5%. Depending on the average market share (e.g. 10% or 25%), this results in different levels of uncertainty (e.g. ± 50 % or ± 20 %)
- component weight and printed circuit board area: ± 10 %
- service life: based on the bandwidth given in the literature (ca. ± 30 %)
- percentage of older products (up to 1990) in the stock and landfill material: this was increased or reduced by 10% with respect to the total stock or the total landfill material respectively.

5.1.6.2 Process: ‘production’

While none of the BFR under study are produced in Switzerland, significant quantities of plastic raw materials, semi-finished plastic products and finished products are manufactured there.

5.1.6.2.1 Finished products produced

As no detailed statistics[2] (except for computers) were available, the flow of finished products was estimated using a mass balance from the process: ‘trade’. It was assumed there that the stock (if any) in trade has not changed since the end of the 1990s.

To account for the fact that the products produced in Switzerland contain far lower concentrations of PBDE than imported products, the concentrations in EDP, office, telecommunication and TV appliances were reduced to one-tenth of their original value. To compensate for this, the concentration of PBDE in imported appliances was set slightly higher[3].

No export or import figures were available for special appliances, building materials or textiles. For reasons of simplification, it was assumed that these products are produced entirely within Switzerland.

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[1] The values concerned are not strictly arithmetical averages but values most nearly approximating to reality

[2] The flows of plastic raw materials and semi-finished plastic products that were traded and processed were taken from the Statistical Yearbook 1998 of the Schweiz. Kunststoffverband, Aarau. However, no details were given there of their use in finished products, so that no conclusions could be drawn on FR flows.

[3] For imported appliances, slightly higher PBDE concentrations were used in order to correct the mass balance, and to adjust the average concentration of PBDE for the sum of appliances produced and imported to accord with previous assumptions.

Tab. 5-15: Material and substance flows in finished products (CH, 1998)

PRODUCTS PRODUCED IN Switzerland in 1998	Material flow [1000 t/a]	PentaBDPE [t/a]	OctaBDPE [t/a]	DecaBDPE [t/a]	TBBPA [t/a]
EDP and office electronics	**38.3**	**0**	**1**	**12**	**301**
Computers+monitors (private households)	1.2	0	0.0	0.2	11.9
Computers+monitors (business)	3.5	0	0.1	0.6	35.7
Servers	0.0	0	0.0	0.0	0.2
Notebooks	0.0	0	0.0	0.0	0.0
Laser printers	0.0	0	0.0	0.0	0.0
Inkjet printers	0.0	0	0.0	0.0	0.0
Copying machines	32.8	0	0.8	10.8	249.8
Calculators	0.8	0	0.0	0.1	3.7
Communications technology	**2.5**	**0**	**0**	**0**	**13**
Household electronics	**4.6**	**0**	**0**	**3**	**15**
Household appliances, small	**10.4**	**0**	**0.8**	**7.0**	**6.4**
Household appliances, large	**30.5**	**0**	**1.6**	**13.8**	**9.7**
Special appliances	**11.7**	**0**	**0.6**	**6.3**	**58.0**
Small EE components	**160.8**	**0**	**1.2**	**13.3**	**13.1**
Vehicles	**3.8**	**0**	**0.0**	**0.5**	**0.2**
Building materials and textiles	**47.5**	**0**	**0.0**	**72.1**	**17.5**
Total	**310.1**	**0**	**5**	**128**	**435**

5.1.6.2.2 Solid waste and emission from the production process

EDP equipment and a large number of other EE products are assembled in Switzerland from components that are usually imported. It can safely be assumed that no emission or waste containing FR arise from this process.

The quantities of EE components and of specific building materials produced in Switzerland could not be determined. As a result, waste flows and emission from production could not be given in their entirety, but estimates for particular areas were made.

For Denmark, it was found that the waste and emission from production was low in comparison to the process: ‘consumption’ [Danish EPA, 1999]. The largest FR flow in production waste arises from printed circuit board assembly. For Switzerland, this area was estimated as follows:

Tab. 5-16: Production waste from printed circuit board assembly

Printed circuit board assembly in Switzerland		**Material flow**	**DecaBDPE**	**TBBPA**
		[t/a]	**[t/a]**	**[t/a]**
Production waste	Min.	**45**	**0.03**	**5.1**
	Average	**135**	**0.09**	**14.4**
	Max.	225	0.15	23.7

5.1.6.3 Process: 'trade'

The figures for import and export of finished products were taken from the Federal Customs Administration. No import and export figures were available for special appliances, building materials or textiles. To obtain a rough estimate, it was assumed that these product groups are produced entirely within Switzerland and that exports are negligible.

Tab. 5-17: Material and substance flows in imported finished products (CH, 1998)

PRODUCTS IMPORTED INTO Switzerland in 1998	**Material flow [1000 t/a]**	**PentaBDPE [t/a]**	**OctaBDPE [t/a]**	**DecaBDPE [t/a]**	**TBBPA [t/a]**
EDP and office electronics	**46.6**	**0.00**	**16**	**204**	**476**
Computers+monitors (private households)	5.3	0.00	1.1	11.4	53.4
Computers+monitors (business)	14.8	0.00	3.1	32.3	149.4
Servers	1.1	0.00	0.2	1.9	10.7
Notebooks	0.6	0.00	0.0	0.6	13.7
Laser printers	8.9	0.00	2.1	29.5	88.3
Inkjet printers	13.4	0.00	2.1	22.2	142.4
Copying machines	2.0	0.00	7.4	103.8	15.0
Calculators	0.6	0.00	0.1	2.3	3.0
Communications technology	**3.1**	**0.00**	**0.5**	**5.1**	**17**
Household electronics	**21.6**	**0.00**	**1.9**	**30**	**57**
Household appliances, small	**14.2**	**0.00**	**1.1**	**9.7**	**9.6**
Household appliances, large	**89.7**	**0.00**	**4.6**	**40.5**	**27.8**
Special appliances	**3.6**	**0.00**	**0.2**	**1.6**	**1.1**
Small EE components	**33.2**	**0.00**	**0.0**	**0.0**	**0.0**
Vehicles	**586.1**	**1.91**	**11.8**	**125.1**	**103.1**
Building materials and textiles	n.a.	n.a.	n.a.	n.a.	n.a.
Total	**798.1**	**2**	**36**	**423**	**692**

n.a. = not available

Tab. 5-18: Material and substance flows in exported finished products (CH, 1998)

PRODUCTS EXPORTED FROM Switzerland in 1998	**Material flow [1000 t/a]**	**PentaBDPE [t/a]**	**OctaBDPE [t/a]**	**DecaBDPE [t/a]**	**TBBPA [t/a]**
EDP and office electronics	**56.0**	**0.00**	**12**	**161**	**482**
Computers+monitors (private households)	0.7	0.00	0.1	1.3	7.2
Computers+monitors (business)	2.0	0.00	0.3	3.6	20.1
Servers	0.1	0.00	0.0	0.3	1.4
Notebooks	0.1	0.00	0.0	0.1	1.4
Laser printers	7.3	0.00	1.7	24.4	72.9
Inkjet printers	11.1	0.00	1.7	18.3	117.6
Copying machines	33.7	0.00	7.9	110.8	256.1
Calculators	1.1	0.00	0.1	1.8	5.0
Communications technology	**2.2**	**0.00**	**0**	**2**	**12**
Household electronics	**3.8**	**0.00**	**0**	**5**	**10**
Household appliances, small	**8.4**	**0.00**	**0.6**	**5.7**	**7.5**
Household appliances, large	**64.8**	**0.00**	**3.3**	**29.3**	**20.1**
Special appliances	**0.2**	**0.00**	**0.0**	**0.1**	**0.1**
Small EE components	**38.0**	**0.00**	**0.0**	**0.0**	**0.0**
Vehicles	**134.7**	**0.41**	**2.6**	**27.7**	**22.4**
Building materials and textiles	n.a.	n.a.	n.a.	n.a.	n.a.
Total	**308.0**	**0.41**	**19**	**230**	**554**

n.a. = not available

5.1.6.4 Process: 'consumption'

5.1.6.4.1 FR flows in consumer products

The substance flows in finished consumer products were determined from the material flows and the concentrations of the substances:

Tab. 5-19: Material and substance flows in consumer products (CH, 1998)

CONSUMER PRODUCTS Switzerland in 1998	**Material flow [1000 t/a]**	**Penta-BDPE [t/a]**	**Octa-BDPE [t/a]**	**Deca-BDPE [t/a]**	**TBBPA [t/a]**

CONSUMER PRODUCTS	Material flow	Penta-BDPE	Octa-BDPE	Deca-BDPE	TBBPA
Switzerland in 1998	[1000 t/a]	[t/a]	[t/a]	[t/a]	[t/a]
EDP and office electronics	**28.9**	**0.00**	**5.0**	**55**	**295**
Computers+monitors (private households)	5.7	0.00	1.0	10.3	58.0
Computers+monitors (business)	16.3	0.00	2.8	29.4	165.0
Servers	0.9	0.00	0.2	1.7	9.4
Notebooks	0.5	0.00	0.0	0.5	12.3
Laser printers	1.5	0.00	0.4	5.1	15.4
Inkjet printers	2.3	0.00	0.4	3.9	24.8
Copying machines	1.1	0.00	0.3	3.8	8.7
Calculators	0.4	0.00	0.0	0.6	1.7
Communications technology	**3.3**	**0.00**	**0.3**	**3.6**	**18.0**
Household electronics	**22.4**	**0.00**	**1.8**	**28.5**	**62.7**
Household appliances, small	**16.2**	**0.00**	**1.2**	**11.0**	**8.5**
Household appliances, large	**55.4**	**0.00**	**2.8**	**25.1**	**17.4**
Special appliances	**15.2**	**0.00**	**0.8**	**7.9**	**59.0**
Small EE components	**156.0**	**0.00**	**1.2**	**13.3**	**13.1**
Vehicles	**455.3**	**1.50**	**9.2**	**98.0**	**80.9**
Building materials and textiles	**47.5**	**0.00**	**0.0**	**79.1**	**17.5**
Total	**800.2**	**1.50**	**22**	**322**	**573**

5.1.6.4.2 Alternative calculation of FR flows in consumer products

This chapter provides an estimate of the FR contained in vehicles in Switzerland based on comparisons with other nations and the worldwide use of FR.

The sole purpose of the assessments made in this section is to provide rough estimates and enable validation of external calculations, so they are only applicable to the present study. Naturally, the Swiss market and the habits of consumers in Switzerland are only partly comparable to those of other European countries.

A comparison is made of consumption and use of consumer products that contain the FR under study. The most relevant product groups are EE appliances and road vehicles. Due to the fact that the import quotient in the EU is generally high (for example 90% of the PCs sold in Denmark are imported [Danish EPA, 1999]), it can safely be assumed that the composition of products sold in the individual EU countries is similar.

Tab. 5-20: Rough estimate of flame retardants in consumer products in Switzerland

FR in consumer products	**PentaBDPE-FS[4)]**	**OctaBDPE-FS[4)]**	**DecaBDPE**	**TBBPA**
	[t/a]	**[t/a]**	**[t/a]**	**[t/a]**
Switzerland, 1997, minimum[1)]	3.8	1.7	24	240
Switzerland, 1997, average value[1)]	9.5	4.3	61	360
Switzerland, 1997, maximum[1)]	15	6.8	98	480
Switzerland, 1999, average value[2)]	n.a.	n.a.	87	330
Switzerland, 1999, average value[3)]	39	18	250	560

1) Data basis: substance flow analysis for Denmark [Danish EPA, 1999] (p.88), world production of PBDE in 1999 acc. to BSEF [Leisewitz et al., 2000] (vol. I, p.20)
2) Data basis: estimated FR flows of FR manufacturers and traders in Germany [Leisewitz et al., 2000] (vol. I, p.27, 31)
3) Data basis: worldwide FR flows from sales acc. to BSEF data (Bromine Science and Environmental Forum) [Leisewitz et al., 2000] (vol.I,p.20)
4) The pentaBDPE and octaBDPE FR flows refer to commercial products containing about 59% pentaBDPE and about 34% octaBDPE.

In Tab. 5-20, the flow of flame retardants is given based on national and worldwide comparisons. The calculations are given together with FR production data in the Appendix '**Fehler! Verweisquelle konnte nicht gefunden werden.** [[National and worldwide comparisons]], Chapter **Fehler! Verweisquelle konnte nicht gefunden werden.** [[9.1.1]]. The calculated values are of the same order of magnitude as those calculated conventionally from the material flows and the concentrations of the substances (Tab. 5-19). The values for pentaBDPE are somewhat higher, and those for octaBDPE and decaBDPE somewhat lower than those obtained conventionally.

5.1.6.4.3 FR in the stock of consumer products and in solid municipal waste

The estimation of the stock of electrical and electronic appliances in households is subject to considerable uncertainty. Usually, only a small part of the appliances taken out of service is disposed of as required by the regulations on the return, acceptance and disposal of electrical and electronic appliances (VREG). It seems fairly certain that large quantities of old radios, tape recorders, PCs, vacuum cleaners, etc., are present in cellars and attics in almost every home, meaning that the BFR stock in households is significantly higher, and the BFR flow in municipal waste significantly lower, than quoted.

Tab. 5-21: Material and substance flows in landfill material (CH, 1998)

LANDFILL MATERIAL IN Switzerland in 1998	**Material flow [1000 t/a]**	**PentaBDPE [t/a]**	**OctaBDPE [t/a]**	**DecaBDPE [t/a]**	**TBBPA [t/a]**
EDP and office electronics	**13.7**	**0**	**16**	**33**	**134**
Computers+monitors (private households)	2.4	0.0	2.5	5.5	24.8
Computers+monitors (business)	6.9	0.0	7.2	15.6	70.5
Servers	0.4	0.0	0.4	0.9	4.0
Notebooks	0.2	0.0	0.2	0.4	4.8
Laser printers	1.1	0.0	2.4	4.1	8.6
Inkjet printers	1.6	0.0	1.3	2.6	15.7
Copying machines	0.8	0.0	1.8	3.0	4.5
Calculators	0.3	0.0	0.1	0.6	1.1
Communications technology	**2.7**	**0.0**	**0.9**	**3.1**	**14.0**
Household electronics	**13.2**	**0.60**	**23.4**	**48.6**	**31.7**
Household appliances, small	**14.8**	**0.00**	**1.1**	**10.0**	**7.8**
Household appliances, large	**42.6**	**0.03**	**2.2**	**19.3**	**13.3**
Special appliances	**10.2**	**0.00**	**0.5**	**5.3**	**39.7**
Small EE components	**71.1**	**0.00**	**3.3**	**42.2**	**16.2**
Vehicles	**329.8**	**2.37**	**9.0**	**106.2**	**66.3**
Building materials and textiles	**23.7**	**27.4**	**5.2**	**102.1**	**66.2**
Total	**521.7**	**30**	**62**	**369**	**389**

The material and substance flows in landfill material were calculated from the time series of consumption values and the service life of individual products and product groups (see Appendix). For older appliances (up to 1990), other – mostly higher – concentrations of the substances were used.

The percentages of older appliances in the stock were estimated to be:

- computers: 50%
- printers, office equipment, communications technology and small household appliances: 70%
- others: 100%

The stock of materials in the anthroposphere (process: 'consumption') was calculated from the time series of consumption values and service lives of individual products and product groups. For older appliances (up to 1990) other – mostly higher – concentrations of substances were used. The percentage of older appliances in the stock was estimated as follows:

- computers: 10%
- printers, office equipment, communications technology and small household appliances: 20%
- others: 60%

Tab. 5-22: Stocks of materials and substances in finished products in use (CH, 1998)

PRODUCTS in use in Switzerland in 1998	Material stock [1000 t]	PentaBDPE [t]	OctaBDPE [t]	DecaBDPE [t]	TBBPA [t]
EDP and office electronics	**105**	**0.07**	**43**	**218**	**1 057**
Computers+monitors (private households)	19	0.00	6	35	188
Computers+monitors (business)	53	0.00	18	100	536
Servers	3	0.00	1	6	30
Notebooks	2	0.00	0	2	39
Laser printers	8	0.00	7	29	79
Inkjet printers	13	0.00	4	21	131
Copying machines	6	0.00	5	21	44
Calculators	2	0.07	0	4	9
Communications technology	**20**	**0.00**	**3**	**22**	**109**
Household electronics	**278**	**7.53**	**304**	**753**	**711**
Household appliances, small	**109**	**0.00**	**8**	**73**	**57**
Household appliances, large	**715**	**0.28**	**36**	**324**	**223**
Special appliances	**200**	**0.00**	**10**	**104**	**779**
Small EE components	**1 944**	**0.00**	**60**	**760**	**335**
Vehicles	**6 614**	**34**	**143**	**1 685**	**1 127**
Building materials and textiles	**549**	**455**	**69**	**1 661**	**1 163**
Total	**10 534**	**498**	**678**	**5 601**	**5 561**

5.1.6.4.4 Emission from the consumption process

The emission of BFR to the atmosphere occurs mainly in connection with products containing additive BFR. With products containing reactive BFR (e.g. FR4 printed circuit boards in office equipment), only very small quantities of BFR that were not chemically combined during production may be emitted. The percentage of reactively used TBBPA that is not chemically combined is only about 0.0004% [Danish EPA, 1999], so that for the purposes of the present study the resulting emission can be neglected. Emission from FR2 printed circuit boards can become significant if the boards are heated during use.

Unpublished data of the University of Stockholm as quoted in the Danish study [Danish EPA, 1999] show that even at temperatures as low as 30°-40°C, significant quantities of FR are emitted in gaseous form. In aqueous solution, FR can even be emitted at room temperature [Riess, 1999].

Emission factors are subject to high uncertainty. In the present study, the maximum possible emission factors given in the Danish study [Danish EPA, 1999] are used.

Tab. 5-23: Worst-case emission factors [Danish EPA, 1999]

Brominated flame retardants (BFR)	**Fraction of world market 1992**	**Annual emission factor**
DecaBDPE (decabromodiphenyl ether)	20 %	0.038 %
OctaBDPE (octabromodiphenyl ether)	4 %	0.054 %
PentaBDPE (pentabromodiphenyl ether)	2.7 %	0.39 %
TBBPA (tetrabromobisphenol A) reactive	36 %	0 %
TBBPA (tetrabromobisphenol A) additive	4 %	0.05 %
Other BFR, reactive	14 %	0 %
Other BFR, additive	14 %	0.05 %
Total BFR	**100 %**	

Note: about 10% of the TBBPA flame retardants produced worldwide are used additively.

The BFR emitted are attached to particles, and also to dust, in electronic appliances. If these are not removed by vacuum cleaning during use or recycling, they are released to the atmosphere. In the present report, the most unfavourable case is assumed, namely that the entire quantity of BFR is released to the atmosphere.

The FR flows in municipal waste water were based on estimates for Denmark [Danish EPA, 1999] (p.77). During the washing of textiles (protective clothing, curtains, carpets), approx. 70 kg of decaBDPE is released to the effluent. Also, up to 0.38 t decaBDPE finds its way into the effluent via the use of roof coverings treated with BFR.

The FR flows in municipal waste water and diffuse emission are summarised in Tab. *6-3*.

5.1.6.4.5 BFR in foodstuffs

Since the early days, several studies containing data on the concentration of PBDE and TBBPA in foodstuffs have been carried out. The concentration in milk products is of the order of 10^{-12} kg/kg [Ryan & Patry, 2001]. The daily uptake of PBDE in foodstuffs in Sweden (Uppsala) is cited as 9.7 ng/day (minimum), 56.9 ng/day (maximum) and 27 ng/day (average) [Lind et al., 2001].

5.2 Subsystem: ‘waste management’

The data in the subsystem: 'waste management' are not generally classified according to product. Rather, the quantities and concentrations, or alternatively the aggregated substance flows of entire waste fractions, are known on the input side. On the output side, transfer coefficients for the substances present in the processes are sometimes known. It is also possible that the concentrations and quantities of the products of waste management will have been recorded.

The waste arises from the process: ‘trade in products’, and is treated or disposed of in the various processes ‘waste water purification’, ‘reuse’, ‘incineration’ and ‘landfill’.

In the following sections, the waste categories relevant to the BFR under study and the output products arising in the individual waste treatment processes (slag, purified waste water, etc.) are described and quantified for Switzerland. Further, BFR concentrations in the waste fractions taken from the literature are reviewed. Where transfer coefficient describing the distribution of FR in the output products from disposal are given in the literature, these also presented.

5.2.1 Waste collection

General

Both at the beginning and at the end of the 1990s, about 80% of the municipal waste collected was delivered to municipal waste incineration plants and 20% to landfills. In 1992, 77% of municipal waste was incinerated, and in 1998 81% [SAEFL, 1999a]. Various waste materials were, and still are, collected separately and passed on for disposal or possibly for reprocessing. The following section deals with separately collected waste and gives details of the quantities disposed of via the municipal waste collection service.

Separate collection

Electrical and electronics waste

In 1999, 36 500 t of electrical and electronic appliances and components from appliances were accepted and processed in Switzerland by the S.EN.S (cf. Tab. 5-24) and 17 000 t by the SWICO Recycling Guarantee (cf. *Tab. 5-25*). This amounts to a total of 53 000 t of electrical and electronics waste. An estimate shows that this flow corresponds to about 50% of the anticipated total quantity of waste from the electrical and electronics sector [S.EN.S, 1999]. Combustible waste from separate collection that was unsuitable for reuse was delivered to municipal waste incineration plants, cement factories and high temperature incineration plants. This quantity includes all of the plastics fractions and components of appliances containing organic pollutants. Expressed in terms of quantity, this amounts to approx. 25% or 13 300 t. Thus all materials from the separate collection of electrical and electronics waste treated with BFR were disposed of in municipal waste incineration plants. It is not known how this was divided between the various types of incineration [S.EN.S, 1999]. In total, approx. 10 000 t of electrical and electronics scrap accrued in Switzerland in 1999 [S.EN.S, 1999]. The quantity of electrical and electronics scrap not collected separately was approx. 50 000 t. Disposal of this was probably via the normal municipal waste collection service, and thus approx. 80% or 40 000 t were disposed of in municipal waste incineration plants. The remaining 20% or 10 000 t were deposited in landfills together with other municipal waste.

Tab. 5-24: Appliances processed by S.EN.S [S.EN.S, 1999]

MATERIAL	QUANTITY [1999] [t]
Fractions	4 000
Large appliances	9 900
Refrigeration appliances	6 500
Small electrical and electronic appliances	16 100
Total	36 500

Tab. 5-25: Number of appliances returned to SWICO Recycling Guarantee (figures rounded) [SWICO, 2000]

MATERIAL	QUANTITY [1999] [t]
Cables	400 t
Plastics	3300 t
Cathode ray tubes	2000 t
Printed circuit boards and plugs	1000 t
Pollutants and special waste	150 t
Ferrous and non-ferrous metals	9300 t
Remaining materials	750 t
Total	16 900 t

Studies in connection with the subsystem: 'trade in products' resulted in the following BFR flows in EE waste in Switzerland: 1 t/a pentaBDPE, 47 t/a octaBDPE, 161 t/a decaBDPE and 257 t/a TBBPA.

In a Danish study [Danish EPA, 1999], the BFR quantities in Danish waste were estimated. Under Swiss conditions, this results in a quantity of approx. 110 t PBDE. At the beginning of the 1990s, FR2 printed circuit boards treated with pentaBDPE flame retardants were increasingly employed [Danish EPA, 1999]. However, no details are available on the quantities occurring in earlier years. When the results of the Danish study [Danish EPA, 1999] are applied to Switzerland, approx. 5 t/a pentaBDPE and 100 t/a TBBPA from the electrical and electronics scrap fraction result. With regard to pentaBDPE, this value is significantly higher, and for TBBPA significantly lower, than the data quoted in this study in Chapter 5.1. Based on the latter, the sum of all PBDEs for Switzerland was calculated as 110 t/a. This value, too, only amounts to approximately half the value estimated under Swiss conditions. No data for octaBDPE or decaBDPE are available from the Danish study.

Building waste

In 1998, 327 000 t of combustible building waste was delivered to disposal plants in Switzerland (1992: 390 000 t) [SAEFL, 1999a]. A substantial part of this consisted of cumbersome waste from building demolition and waste wood from industrial works. In Switzerland, some 430 000 t of combustible building waste and waste wood from the building industry accrues annually [SAEFL, 1999a]. Analytical calculations show that among the building waste delivered to the disposal plants in 1998, some 150 000 t were ‘genuine’ combustible building waste, and of this, approx. 80% or 120 000 t were incinerated, and 20% or 30 000 t deposited in landfills [SAEFL, 1999a]. Thus assuming a similar distribution of combustible building waste as in 1998, approx. 180 000 t of ‘genuine’ combustible building waste arose in 1992. However, as opposed to 1998, approx. 75% or 135 000 t of the combustible waste was deposited in landfills, and only 25% or 45 000 t incinerated, in 1992 [SAEFL, 1999a].

In Denmark, substance flows of 1 t PBDE and 0.35 t TBBPA from building waste are assumed [Danish EPA, 1999]. Applied to Switzerland, this results in the following quantities in 1998: 1.34 t PBDE and 0.47 t TBBPA. In 1992, the quantities determined via the amounts of building waste were as follows: 1.60 t PBDE and 0.56 t TBBPA.

For the subsystem: 'trade in products', the following BFR flows result for Switzerland via building waste: 27 t/a pentaBDPE, 5 t/a octaBDPE, 102 t/a decaBDPE and 66 t/a TBBPA. However, the figures determined under Swiss conditions differ significantly from those for Denmark. This may be explained by the fact that for the Swiss study, more detailed data prepared for the FR study in Germany [Kruse et al., 2001] could be used, and also since the flow of plastics in building waste was assumed to be higher.

Waste from textiles and furniture

In 1998, 31 000 t of textiles were collected separately in Switzerland (1991: 12 000 t). This corresponds to approx. 40% of the total quantity of approx. 78 000 t collected [SAEFL, 1999a]. Assuming the same total quantity for 1991, this corresponds to 15%. Of the remaining quantity, 80% (1998: approx. 38 000 t, 1991: 53 000 t) may be assumed to have been incinerated in municipal waste incineration plants and 20% (1998: 9 000 t, 1991: 14 000 t) deposited in landfills.

No details on the annual quantity of furniture to be disposed of in Switzerland are available [SAEFL, 1999b]. This is normally collected separately as cumbersome waste and, as with the municipal collection service, 80% of it is disposed of via the MWIP and 20% is deposited in landfills.

In Denmark, substance flows of 2.6 t PBDE and 0 t TBBPA arising from textile and furniture waste were assumed [Danish EPA, 1999]. Applied to Switzerland, the following quantities result: PBDE: 3.5 t and TBBPA: 0 t.

As no data are available on the BFR content of textiles and furniture waste, calculations had to be based on product characteristics. The only information offered in the literature is that no TBBPA arises from textile waste [Danish EPA, 1999]. In Switzerland, the flows of substances and their stocks in furniture and textiles could not be determined for the process: ‘trade in products’. The substance flows in these waste fractions were therefore not considered.

Waste from vehicles

The exact quantities of waste arising from the trains, ships and aircraft are not available in the literature. These quantities are presumably included in industrial waste. There are estimated under the subsystem: 'trade in products'.

For road vehicles, data availability is more satisfactory. From the approx. 150 000 cars that are scrapped annually (1991 and 1998), some 26% or 52 000 t of RESH accrued in 1998 and 50 000 t in 1991 [IGEA, 2001a, b]. In 1998, 38 200 t of this were disposed of in Switzerland. Of this again, 32 200 t were incinerated in MWIP and 6 000 t deposited in landfills. The remaining

13 800 t RESH were exported [IGEA, 1998]. In 1991, 100% or 50 000 t RESH were deposited in landfills. No material was exported [IGEA, 2001b].

RESH consists of the following material groups [IGEA, 1995]:

Wood fibres , cardboard	4%
Textiles, leather	6%
Paint dust, rust, etc.	11%
Metals	1%
Glass, sand	16%
Elastomers	29%
Plastics	33%

As it may be assumed that all of the BFR are present in the RESH fraction, the average BFR content in RESH can be calculated from the total quantity of BFR in road vehicles. In a Danish study, the quantity of TBBPA was given as 179 g/car. With regard to the other BFR considered in this study, the sum of these only was stated, namely as 193 g of PBDE [Danish EPA, 1999]. Under these assumptions, some 29 t of PBDE arise in vehicle waste. From these figures, it is not possible to determine the quantities of the individual PBDEs. Under the assumptions made in the Danish study, the flow of TBBPA via vehicle waste may be taken as 27 t/a at the end of the 1990s.

As against the values given in the study for Denmark, higher FR values were used (see Chapter 5.1.4.1), since a larger quantity of small plastic components was considered (for the electrical system, lighting appliances and in the engine compartment).

The analysis for the subsystem: 'trade in products' resulted in the following BFR flows in Switzerland via vehicle waste: 2 t/a pentaBDPE, 9 t/a octaBDPE, 106 t/a decaBDPE and 66 t/a TBBPA.

Biogenic waste
In 1998, 503 000 t of compost were collected separately in Switzerland (1991: 300 000 t) [SAEFL, 1999a].

Studies on foodstuffs in Finland have shown a BFR content in vegetable foodstuffs (sum of BDE 47, 99, 100, 153 and 154) of 0.0013 µg/kg in potatoes to 0.016 µg/kg in cereals. These are a factor of 50 to 500 lower than the value for fish of 0.850 µg/kg [Kiviranta, 2001]. The average value for bio-waste is taken to be the same as the average for potatoes and vegetables. Under this assumption, the actual values have certainly been overestimated, since bio-waste consists in the main of unpolluted shredded material. The content of individual BFR is given in Tab. 5-26. For each BFR, the sum of the individual congeners is given.

Tab. 5-26: BFR content in foodstuffs in Finland [Kiviranta, 2001]

MATERIAL	CONCENTRATION [1997-1999] [μg/kg]
PentaBDPE (BDE 47, 99, 100)	0.0079
OctaBDPE (BDE 153, 154)	0.0010
DecaBDPE (BDE 209)	not available
TBBPA	not available

For separately collected compost, the following quantities of BFR may be carried into the soil via compost: 4*10-6 t/a pentaBDPE (BDE 47, 99, 100) and 5*10-7 t/a octaBDPE (BDE 153, 154). No details are available for decaBDPE (BDE 209) and TBBPA. As a first approximation, these flows have been ignored for the purposes of the present study.

Plastics waste

In 1998, a total of 47 000 t of plastics were recovered and returned to the trade and industrial cycles. In 1998, about 14 000 t of plastic-sheathed cable waste (of which approx. 7 000 t were plastics) was recovered (incl. the quantity recovered by SWICO). It is assumed that this waste contains no relevant quantities of BFR. It is difficult to assess to what extent this assumption is justified, since no information is available on the composition of the separately collected plastics waste from trade and industry.

Thermoplastics containing PBDE are not recyclable [Leisewitz & Schwarz, 2000] (p.257). Where the casings of EE appliances are concerned, plastics recycling only rarely takes place [Leisewitz & Schwarz, 2000] (p.260), since the plastics containing PBDE cannot be separated from those free of PBDE[1]. It was assumed for this reason that taken as a group, reused plastics do not contain brominated flame retardants. However, this premise must be investigated in detail in future studies.

Production waste from printed circuit boards

The production waste concerned is treated in Section 5.1.6.2 (process: ‘production’).

5.2.2 Reprocessing

The recovery of plastics containing BFR presents serious problems, since on the one hand there is a danger of the formation of dioxins and furans, and on the other there is no market for recycled raw materials [Leisewitz et al., 2000].

In Switzerland, none of the plastics containing BFR from the separate collection of electrical and electronic appliances are reprocessed (i.e. neither by SWICO nor by S.EN.S) (approx. 25% being thermally reused). Reprocessing is confined to other fractions, i.e. to metal, cathode ray tube glass and, to some extent, foamglass ($^2/_3$ of the total quantity) [SWICO, 2000], [S.EN.S, 1999]. Approximately 10% is deposited in landfills (i.e. non-reusable glass from cathode ray tubes and the residue from incineration and reprocessing plants).

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[1] As an exception, a small quantity of plastic casings are recycled industrially. Here, however, the manufacturers of EE household appliances only accept their own products in return.

Whether or not fabrics from textile reprocessing that contain BFR are returned to circulation (e.g. via rag carpets, floorcloths, etc.) is not known.

A total of 47 000 t of plastics were reprocessed in 1998 in Switzerland and returned to the trade and industrial cycles. In 1998, some 14 000 t of plastics sheathed cable waste (containing approx. 7 000 t of plastics) was recycled (including that recycled by SWICO). The waste arising from this was disposed of thermally [SAEFL, 1999a; SAEFL, 2001].

By virtue of the fact that all the plastics fractions were disposed of thermally, the corresponding BFR can only enter the product cycle via textile recycling.

For combustible building waste, it is assumed that this is either incinerated (80%) or deposited in landfills (20%).

The quantities of waste containing BFR reprocessed are shown in Tab. 5-27.

Tab. 5-27: Quantity of waste (t/a) containing BFR reprocessed at the end of the 1990s

Type of waste	**Waste flow t/a**	**Percentage of total quantity (remainder in municipal waste)**
Electrical and electronics waste	53 500	52 %
Textile waste	31 000	40 %
Vehicles (RESH)	52 000	100 %

Of the 53 500 t/a of separately collected EE waste, approx. 35 000 t/a (metal, glass) is recovered and returned to the subsystem: 'trade in products' (assumption: contains no relevant quantities of BFR). For the rest, 7 000 t/a of plastics are incinerated, 4 000 t/a glass (containing no relevant quantities of BFR) are deposited in landfills, and approx. 4 000 t/a of printed circuit board waste is exported.

Concerning textile waste, 100% (authors’ assumption) are returned to the subsystem: 'trade in products'.

Of the waste arising from vehicles (53 500 t/a), 32 200 t/a are incinerated, 6 000 t/a deposited in landfills and 13 800 t/a exported.

The total quantities of BFR input to the process: ‘reuse' can be estimated based on the values given in Tab. 5-27 and on the BFR quantities estimated for waste in Switzerland in the subsystem: ‘trade in products’. In addition, if the way in which the materials input to the process: ‘reuse' are divided among the output is taken into account (see above), the output quantities of BFR from ‘reuse’ can be determined.

Tab. 5-28: Input and output quantities of BFR for the process: 'reuse' at the end of the 1990s [t].

	Input to reuse	**Output from reuse in the target process**		
		Incineration	**Landfill**	**Export**
PentaBDPE	2.5	1.2	0.25	1
OctaBDPE	33	31	1.1	2.3
DecaBDPE	190	146	13	32
TBBPA	200	109	8	83

General assumptions:

- for pentaBDPE: EE waste: contained entirely in the printed circuit boards (100% of which is exported); vehicle waste: contained entirely in RESH (100% of which is incinerated)
- for octaBDPE: contained entirely in plastics: EE waste: 100% incinerated; RESH: 62% incinerated, 12% deposited in landfills, 27% exported
- for decaBDPE: transport (RESH) 62% incinerated, 112% deposited in landfills, 27% exported; EE waste: 4% in printed circuit boards (100% exported), remainder in plastics (100% incinerated)
- for TBBPA: RESH: 62% incinerated, 12% deposited in landfills, 27% exported; EE waste: 49% in printed circuit boards (100% exported), remainder in plastics (100% incinerated).

5.2.3 Waste water treatment

In 1998, 4.4 million t of wet sewage sludge (94% water content) arose from approx. 1.3 billion m^3 of waste water [SAEFL, 1999a], [AWEL, 1998]. Of this, approx. 200 000 t of fermented dry matter (solids) had to be disposed of. In 1998, 42% or 84 500 t of solids were applied in agriculture, and 58% or 116 000 t dehydrated, and incinerated or deposited in landfills. In 1998, 7% or 13 200 t were deposited in landfills, and 51% or 102 100 t incinerated [SAEFL, 1999a]. In 1988, 260 000 t of sewage sludge (solids) accrued [SAEFL, 1991]. Extrapolated from the values of 1998, this corresponds to approx. 1.7 billion m^3. Of this, 64 000 t or approx. 25% were incinerated, 45% applied in agriculture (approx. 120 000 t), and the rest (30% or 76 000 t) were deposited in landfills [SAEFL, 1991].

No measured results relating to BFR in purified waste water could be found in the literature. In waste water purification plants, owing to the low solubility and other physical and chemical properties of BFR, the major part of it remains in the sludge. Based on investigations of other substances, e.g. PCB, it can safely be assumed that less than 10% of the BFR are finally present in the purified waste water.

Tab. 5-29 gives values for the solubility of the four BFR under study:

Tab. 5-29: Solubility of pentaBDPE, octaBDPE, decaBDPE and TBBPA [Ra, 2000a], [Kruse et al., 2001], [Human Health Assessment, 2000]

MATERIAL	SOLUBILITY
PentaBDPE	2.4 μg/l
OctaBDPE	< 0.5μg/l
DecaBDPE	< 1μg/l / 20-30μg/l (20°C)
TBBPA	0.72 mg/l (15°C) / 0.08 mg/l (21°C) / 4.16 mg/l (25°C) *

* Despite the fact that TBBPA is about one-thousand times more soluble, the quantity of TBBPA in ground and surface waters is not higher than that of the other BFR considered [Kruse et al., 2001], [Yokoyama, 2000].

Details of the content of BFR in sewage sludge are to be found in the literature. A selection of these (considered by the authors to be relevant) is given in Tab. 5-30. No measurements have till now been carried out in Switzerland.

Based on the concentration ranges given in Tab. 5-30, the annual production of sewage sludge in Switzerland may be calculated, and the following realistic assumptions made for the quantities of BFR in Swiss sewage sludge: pentaBDPE: 0.04 t/a; octaBDPE: not available; decaBDPE: 0.05 t/a; TBBPA: 0.02 t/a. Taken for Switzerland as a whole, these values are probably too high, since the BFR content quoted in Tab. 5-30 relates to sewage sludge from purely urban areas.

Tab. 5-30: Content of pentaBDPE, octaBDPE, decaBDPE and TBBPA in sewage sludge [Leisewitz et al., 2001], [Kruse et al., 2001], [Hakk, 2001], [Hale, 2001], [Wit, 2001] and [Hagemaier et al.,1992]

SUBSTANCE	CONCENTRATION
PentaBDPE	Four regions of the USA: 1100 – 2290 μg/kg DM (in Europe, the values are assumed to be ten times lower, i.e. 110–230 μg/kg DM) Samples of sewage sludge from Stockholm (1998): 60- 150 ng/g DM (sum of BDE-99 and BDE-100) In Germany (13 samples): congeners of pentaBDPE: 0.00022-0.0075 mg/kg DM
OctaBDPE	not available
DecaBDPE	3 waste water treatment plants in Stockholm: 160 – 260 μg/kg DM Sweden: 56 ng/g DM (with plastics factory upstream of waste water treatment plant) Sweden: 31 ng/g DM (in the absence of plastics factory upstream of waste water treatment plant) Sweden: Stockholm: 2.9-76 ng/g DM
TBBPA	Stockholm waste water treatment plant: up to 76 μg/kg DM Waste water treatment plant serving plastics factory, in which, however, no TBBPA was used: 31 – 56 μg/kg DM

According to studies of the Syracuse Research Corporation Epiwin Software, 1999, it may be assumed that decaBDPE does not decompose significantly in waste water treatment plants, and that approx. 90% of the decaBDPE is retained in combined form in the sewage sludge. The retention probably increases at higher levels of bromination. On the assumption that less than 10% BFR is not retained, the following quantities of BFR are estimated in purified waste water: pentaBDPE: 0.004 t/a; octaBDPE: not available; decaBDPE: 0.005 t/a; TBBPA: 0.002 t/a.

The following estimates are made of the deposition of dust particles from the atmosphere: 10% of the BFR emitted via the process: ‘trade in products’ are deposited directly on the ground and are carried into waste water treatment plants together with municipal waste water. Based on this, the input to municipal waste water is as follows: 0.19 t/a pentaBDPE, 0.04 t/a octaBDPE, 0.21 t/a decaBDPE and 0.03 t/a TBBPA. The BFR input from landfill seepage water is estimated as follows: 0.005 t/a pentaBDPE, 0.006 t/a octaBDPE, 0.044 t/a decaBDPE and 0.134 t/a TBBPA (see Section **Fehler! Verweisquelle konnte nicht gefunden werden.**) [[5.2.5]].

In a hypothetical worst case, where no decomposition of the substances occurs, these quantities will occur in the sewage sludge. In this case, the BFR quantities in sewage sludge given above would represent lowest conceivable figures. It is also assumed that a negligible part (<<1%) of the BFR input to waste water treatment is carried to the spent air. No data on this are available in the literature. In this connection, and as a first approximation, the flows are neglected.

5.2.4 Municipal waste incineration plants (MWIP)

Tab. 5-31 gives the quantities of waste containing BFR incinerated in Switzerland. These are composed of the waste delivered directly to the MWIP and that passed on for recycling. Overall, 1.99 million t of municipal waste were incinerated in Switzerland in 1998 and 2.14 million t in 1992 [SAEFL, 1999a].

Tab. 5-31 Quantities of waste containing BFR incinerated in MWIP in Switzerland in 1998

SUBSTANCE	**QUANTITIES [t]**
Electrical and electronics scrap	40 000
Building waste	120 000
Waste from textiles and plastic furniture	38 000
Waste from vehicles	31 000
Production waste from printed circuit boards	150-750
Waste from recycling	20 000
Sewage sludge	102 000[1]
Total (rounded)	350 000

Sources: [S.EN.S, 1999], [SWICO, 2000], [BUWAL, 1991, 1999a], [IGEA, 1998, 2001a, b], [Kiviranta, 2001], [Grangier, 2001], [Gallana, 2001], [Danish EPA, 1999]

Based on the figures determined in the present study, the quantity of BFR transferred from the subsystem: 'trade in products' to the process: ‘incineration’ at the end of the 1990s may be given as follows: 5.8 t/a pentaBDPE, 22 t/a octaBDPE, 143 t/a decaBDPE and 152 t/a TBBPA. The following quantities are transferred via the process: ‘reuse’ to the process: ‘incineration’: 1.2 t/a pentaBDPE, 30 t/a octaBDPE, 146 t/a decaBDPE and 109 t/a TBBPA. The quantities from the waste water treatment plant that must be incinerated are negligible. This signifies that a total of 7 t/a pentaBDPE, 52 t/a octaBDPE, 290 t/a decaBDPE and 261 t/a TBBPA must be disposed of thermally. The bromine flow associated with this amounts to a total of approx. 450 t/a.

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[1] Of the 102 100 t accruing in 1998, only 18 400 t were incinerated in MWIP. The rest was delivered to cement works (20 500 t) and to special kilns (63 200 t)

Tange [Tange et al., 2001] cites bromine concentrations in municipal waste at 30 - 100 mg/kg. Measurements of recent date at two MWIP in Switzerland [Morf, 2000] showed bromine concentrations in Swiss municipal waste (incl. max. 10% RESH fraction) of 50 - 280 mg/kg (St. Gallen MWIP) and 180 – 300 mg/kg (Weinfelden MWIP) for various time periods in 2000. Based on the average measured bromine concentration of approx. 230 mg/kg FR, a bromine flow of approx. 460 t/a results for municipal waste treated thermally in MWIP in Switzerland. Based on these spot measurements, the minimum flow is 100 t/a and the maximum flow 600 t/a. If, as in [Danish EPA, 1999], the assumption is made that half the bromine fraction in municipal waste is attributable to flame retardants, a bromine flow of 50 - 300 t per annum results (average: 230 t/a).

Comparing the results of these two estimates, it is seen that the bromine flow determined as input to the process: ‘incineration’ is larger than that resulting from the spot measurement at MWIP on the assumption that 50% of the bromine stems from its use in flame retardants. This discrepancy may have several causes. One lies in the estimate of the stock of consumer goods in the process: ‘trade in products’ that was based on the average service life of consumer goods in households. The larger the difference between the service life and the retention time of these goods in households (typically, where they are stored in the cellar), the larger the stock in households, and the smaller the flow to the waste management processes. The discrepancy can only be explained by measurements of the time variation of the material and substance flows. Further possible causes are the assumptions concerning the percentage of bromine used as flame retardant in consumer products, assumptions concerning the disposed fraction of building waste, and differences in the bromine content in the areas served by the various MWIP. For the present study, the quantities of BFR determined in Chapter 5.1 and mentioned above, will be used.

According to a Swedish study, it may be assumed that all the BFR are destroyed by normal incineration in an MWIP [Söderström, 2001]. Measurements for Japan were given at the Stockholm conference [Sakai et al., 2001]. In an investigation of 2900 g PBDE/t of waste, 1.7 g/t of waste (0.058 %) was found in the solid residue (slag plus ash), and 0.00097 g/t of waste (3.3×10^{-8} %) in the filtered flue gas. In another investigation of 3400 g TBBPA/t of waste, 78 g/t of waste (2.3%) was found in the solid residue, and 0.034 g/t of waste (1×10^{-6} %) in the filtered flue gas. From their own investigations, Söderström & Marklund [Söderström & Marklund, 2001] conclude that after incineration of waste in MWIP, no polybrominated flame retardants (decaBDPE and TBBPA) are present in the filtered flue gas.

Tab. 5-32: Estimated transfer coefficients for PBDE and TBBPA for Swiss MWIP based on the literature [Sakai et al., 2001].

	Transfer coefficient [-]			
SUBSTANCE	**Slag**	**Ash**	**Waste water**	**Flue gas**
PentaBDPE	0.00029	0.00029	0	3.3×10^{-10}
OctaBDPE	0.00029	0.00029	0	3.3×10^{-10}
DecaBDPE	0.00029	0.00029	0	3.3×10^{-10}
PBDE	0.00029	0.00029	0	3.3×10^{-10}
Tetrabromobisphenol A TBBPA	0.0115	0.0115	0	1×10^{-6}

In Switzerland no studies are available on the behaviour of PBDE and TBBPA under thermal treatment in MWIP. The transfer coefficients taken from the above-mentioned studies are specified in Tab. 5-32. For this, the following simplifications were made: for pentaBDPE, octaBDPE and decaBDPE, analogous distributions are assumed as for the total of PBDEs. Neutralisation sludge from MWIP is neglected; transfer to waste water is taken as zero, and equal quantities are assumed in the two residual substances slag and ash. The output quantities calculated from the transfer coefficients are shown in Tab. 5-33.

Tab. 5-33: Estimated substance flows in the MWIP products in Switzerland (t/a) based on the waste input flows and transfer coefficients.

Substance	INPUT	BFR flows in products			
		Slag	Ash	Waste water	Flue gas
PentaBDPE	7	0.002	0.002	0	2.3E-9
OctaBDPE	54	0.02	0.02	0	1.8E-8
DecaBDPE	289	0.08	0.08	0	9.6E-9
TBBPA	275	3.1	3.1	0	1E-5

Based on the literature (SAEFL, 1998a, 1998b), it is assumed that in the 1990s, the products from the MWIP were disposed as of follows: slag: 100% in landfills for slag waste; ash and particles: 75% exported (salt mines); 25% deposited in landfills in Switzerland (of this, estimated: approx. 1/5 with slag in landfills for slag waste; 4/5 loose/consolidated in landfills for residual waste). Tab. 5-34 shows the target processes of the BFR flows assigned to the process: ‘incineration’.

Tab. 5-34: Input and output quantities of BFR in the process: ‘incineration’ at the end of the 1990s [t/a].

Substance	INPUT	Target processes		
		Landfill	Export	Emission
PentaBDPE	7	0.003	0.002	2.3E-9
OctaBDPE	54	0.02	0.01	1.8E-8
DecaBDPE	289	0.1	0.06	9.6E-9
TBBPA	275	3.8	2.4	1E-5

5.2.5 Landfills

Based on the data given in Chapters 5.2.1 to 5.2.3, the quantities of waste relevant to BFR deposited in landfills in Switzerland are given in Tab. 5-35.

The investigations carried out in this study show that at the end of the 1990s, 22 t/a pentaBDPE, 6 t/a octaBDPE, 36 t/a decaBDPE and 38 t/a TBBPA were delivered direct to the process: ‘landfill’ from the subsystem: 'trade in products'. Relatively insignificant quantities of 0.009 t/a pentaBDPE, 0.019 t/a octaBDPE, 0.07 t/a decaBDPE and 3.8 t/a TBBPA find their way into landfills from the process: ‘incineration’. The quantities from ‘reuse’ are 0.25 t/a pentaBDPE, 1.1 t/a octaBDPE, 13 t/a decaBDPE and 8 t/a TBBPA. The total annual input to landfills at the end of the 1990s therefore amounts to 5.5 t/a pentaBDPE, 7.1 t/a octaBDPE and 50 t/a each for decaBDPE and TBBPA.

Tab. 5-35: Quantities of material containing BFR deposited in landfills

MATERIAL	**QUANTITY 1998** [t]
Electrical and electronics scrap	10 000
Building waste	30 000
Waste from textiles and plastic furniture	9 000
Waste from vehicles	21 000
Production waste from printed circuit boards	40 – 180
Recycling waste	0
Sewage sludge	13 200
Total (rounded)	83 000

The stock of FR in landfills was determined from a time series of data on solid waste and its assumed FR content. From this it was estimated that the first products containing BFR came onto the market around the beginning of the 1970s, that waste containing BFR first required disposal in 1975, and that since 1975, 20% of the waste requiring disposal was deposited in landfills. For waste containing PUR filler foam with pentaBDPE flame retardants, it is assumed that since 1975, approx. 80% were deposited in landfills.

Practically no measurements or values are available from the literature to enable emissions from landfills to the air and seepage water to be estimated.

No direct investigations of the behaviour of PBDE and TBBPA in landfills are available [Leisewitz et al., 2001] and [Kruse et al., 2001]. Although BFR have low solubility in water (cf. Tab. 5-29, Section 5.2.3), landfill seepage water must be monitored. Their solubility in other fluids is much higher. For example, the solubility of pentaBDPE in methanol is 1 g/100 g [RA, 2000a], of TBBPA in ethanol 98.4% and TBBPA in acetone 240 g/100 g. At higher temperatures, the solubility is increased [Kruse et al., 2001]. The mobility in pure water (agitated at 23°C) was 0.3% of the initial TBBPA content [Riess, 1999]. The mobilisability of flame retardants in Hi-polystyrene is given as 0.03%, rising to 3.4% with increasing lipophility of the surrounding medium [Riess, 1999].

Gaseous emission of TBBPA was demonstrated in a test on biological degradation [BFRIP, 1989]. This test involved three different types of soil and was carried out both under aerobic and anaerobic conditions. Further, in case of a landfill fire, all the BFR and their degradation and transformation products such as polybrominated dibenzodioxins and furans can be released [Kruse et al., 2001].

While decaBDPE, pentaBDPE and octaBDPE are regarded as being decidedly persistent [Leisewitz et al., 2001], [Kruse et al., 2001] and [Dungey, 2001], TBBPA is degradable both under aerobic and anaerobic conditions [BFRIP, 1989].

As a worst case, it is assumed here that for PBDE, 0.1%, and for TBBPA, 0.3%, of the input quantities find their way into the seepage water. It is assumed that for Switzerland as a whole, over 90% of the seepage water is delivered to waste water treatment plants. The estimated input and output flows from the various data sources are given in Tab. 5-36.

Tab. 5-36: BFR quantities at input and output to landfills

SUBSTANCE	**QUANTITIES**		
	INPUT **[t]**	**Seepage water delivered to waste water treatment plants** [t]	**Landfill emission** [t]
PentaBDPE	21.7	0.022	0.002
OctaBDPE	7.1	0.007	0.0007
DecaBDPE	50	0.05	0.005
TBBPA	50	0.15	0.015

5.2.6 Subsystem: 'environment'

The subsystem: ‘environment’ comprises the four sub-processes ‘atmosphere’, ‘hydrosphere’, ‘pedo/lithosphere’ and ‘biota’. In the subsystem: ‘environment’, the flow of substances takes place via the air, water, solid material from deposition processes (sewage sludge, compost, sedimentation, deposition) and decomposition processes (erosion), and biomass. Flue gases and waste water treatment products, as well as emission from landfills (seepage water) all arise from the subsystem: 'waste management', while waste gases arise from the use of products in the process: ‘trade in products’.

Measurements are available for the BFR concentration in materials in the environmental compartments. Reliable reviews on this topic are contained in the abstracts of the second international workshop on brominated flame retardants [BFR, 2001], [Wit, 2000], and [Kruse et al., 2001]. The various risk assessments also contain data on the subject. However, most of the measurements were sporadic, do not cover all substances, and only a few are suitable for use in substance flow analyses. The following sections summarise data for the individual environmental compartments taken from the literature. No current measurement results are available for Switzerland.

An increase in the stock in this subsystem results from sedimentation (to the hydrosphere) and from increases in the stocks in the soil and the biota. Estimates of the stock in the various compartments are based on concentration data given in the literature and on our own estimates. The values given in Tab. 5-37 on the distribution of BFR in the environment were assumed in the calculations [Leisewitz et al., 2001] and [Kruse et al., 2001].

Tab. 5-37: Distribution of BFR in the environment

SUBSTANCE	**SEDIMENT**	**SOIL**	**WATER**	**AIR**
TBBPA	54%	45%	1%	$4*10^{-7}$%
DecaBDPE	52.1%	46%	1.8%	0.132%
PentaBDPE	not available	not available	not available	not available
OctaBDPE	not available	not available	not available	not available

5.2.7 Atmosphere

In the atmosphere, BFR are first transported, then deposited under wet or dry conditions. It is assumed that none or negligible stocks are formed in the atmosphere.

PentaBDPE
The concentration of pentaBDPE in the atmosphere is assumed to be very low [RA, 2000a]. In remote areas of Sweden, 4.4 pg/m^3 was measured (sum of 2,2'4,4'-tetraBDPE, 2,2'4,4',5-pentaBDPE and 2,2'4,4',6-pentaBDPE). The concentration of the tetraBDPE and pentaBDPE congeners taken together is given as 100 to 270 pg/m^3 [RA, 2000a]. In electronics recycling works, the air at the workplace shows the highest concentration of pentaBDPE, namely 8 – 64 ng/m^3 (sum of BDE-47, 85, 99, 100, 153, 154 and 183) [Sjödin et al., 1999]. In their summary [Peltola & Ylä-Mononen, 2001] state that the concentration of PBDE in the air lies between 1 and 10 pg/m^3.

OctaBDPE
For octaBDPE, data were only available on indoor air in electronics recycling works. The values lie between 7 – 56 ng/m^3 (sum of BDE-153, 154 and 183) [Sjödin et al., 1999]. An estimated regional air concentration of 1.1E-7mg/m3 is given in [Human Health Assessment, 2000].

DecaBDPE
In the 'Risk Assessment' [RA, 1998], anticipated values for the concentration of decaBDPE in outdoor air are cited as lying in the lower nanogram region. However, the data on which they are based are subject to uncertainty, so that they may only be taken as a rough guide [Kruse et al., 2001]. No decaBDPE was found in air samples taken in the Berlin region (detection limit 0.9pg/m^3) [Kemmlein, 2000]. Outdoor concentrations of up to 25 μg decaBDPE/m^3 were found in the vicinity of industrial works [Zweidinger et al., 1979]. The highest DecaBDPE concentrations of 12 – 70 ng/m^3 were found in the air at workplaces in electronics recycling works [Sjödin et al., 1999]. Debromination of decaBDPE in the atmosphere is possible through photolytic reduction. However, owing to the long half-life of 94 days, it is assumed that decaBDPE is deposited before it decomposes.

Only rough estimates are available on the release of decaBDPE during manufacture and during the use of products containing decaBDPE. In the 'Risk Assessment' [RA, 1998], emission to the air is estimated at 26 t/a for the whole of the EU.

TBBPA

As the volatility of TBBPA is low, the transfer from the soil to the air is assumed to be negligible [Leisewitz et al., 2001] and [Kruse et al., 2001]. The half-life of TBBPA exposed to UV radiation and hydroxyl radicals is given as 5-6 days [Eriksson & Jakobsson, 1998]. A concentration of 1.8 μg TBBPA/m^3 was found in the vicinity of a TBBPA production works [Zweiginger et al., 1979]. Apart from that, no TBBPA was detected in outdoor air [Bergmann et al., 1999].

Practically no measurements are available on the deposition of PBDE and TBBPA. The atmospheric deposition for the sum of all PBDEs was determined in Sweden [Schure & Larsson, 2001]. Deposition rates of 5.2 ng/m^2 (in particulate form) and 2.8 ng/m^2 (in soluble form) were found over a period of 14 days. The authors showed that deposition occurs mainly in particulate form. The mean concentration for the sum of all PBDEs in rainwater is given as 127± 57 pg/l. For Switzerland, which has an average rainfall of 600 - 1000 mm/a, this results in an annual deposition of 40 - 200 ng/m^2, or 2 - 8 kg of PBDE for the whole country. Together with the approx. 200 ng/m^2 of PBDE bound to particles, this gives a rough estimate of deposition for the sum of all PBDEs of 4 - 0 kg per year.

In the present study, deposition was determined from diffuse emission estimated in the subsystem: 'trade in products' in the form of (a) particle deposition (10% of input) that enters waste water treatment in built-up areas, and (b) atmospheric deposition (90% of emission) that enters the process: 'soil'. The corresponding values of 1.9 t/a for pentaBDPE, 0.37 t/a for octaBDPE, 2.1 t/a for decaBDPE and 0.3 t/a for TBBPA are clearly higher than the figures from the other literature sources mentioned above, i.e. assuming worst-case scenarios of emission from consumption.

The very rough stock estimate shown in Tab. 5-38 is based on average concentrations of the substances for the entire compartment.

Tab. 5-38: Estimate of atmospheric stock

SUBSTANCE	**Concentration**	**Stock (g)**
PentaBDPE	4.4E-3 ng/m3	90
OctaBDPE	1.1E-4 ng/m3	2
DecaBDPE	0.9E-3 ng/m3	20
TBBPA	n.d.	n.d.

Assumption: first 500 m above Switzerland; average density of the atmosphere 1.5 [???].

5.2.8 Hydrosphere

PentaBDPE

No values have been specified for pentaBDPE in water. The only relevant analyses available are for hexabromodiphenyl ether, of which 4 - 8% is present in commercial pentaBDPE. The substance was not found in any of the 225 test samples taken in the comprehensive water analyses carried out in Japan between 1987 and 1988 [RA, 2000a].

OctaBDPE

Owing to the low solubility of octaBDPE in water (cf. Tab. 5-29), low concentrations in ground and surface waters may be assumed. As for pentaBDPE, the Japanese studies [RA, 2000a] mentioned above may be taken as a guide.

DecaBDPE
The half-life of decaBDPE during photolytic breakdown in water is cited as >90 days [Norris et al., 1973, Norris et al.,1975], with no low-brominated diphenyl ethers detected [IPCS, 1994b]. In Japanese waters, no decaBDPE was detected at a detection limit of 60 ng/l [RA, 2000b]. DecaBDPE concentrations of 0.0023 µg/l (continental) and 0.081 µg/l (regional) were calculated for surface waters based on analytical models. This data is, however, subject to very considerable uncertainty [RA, 1998].

TBBPA
Owing to its adsorptive behaviour and low solubility in water (cf. Tab. 5-29), it can be assumed that in the environment, TBBPA is strongly bound to particles [IPCS, 1995]. No TBBPA was found in any of the 150 water samples taken in Japan over the period 1988-89 (detection limit 0.04 µg/l) [Environmental Agency Japan, 1989, 1991]. However, in one of the 75 water samples taken in 1995, 0.05 µg/l of TBBPA were found [IUCLID, 1995].

Owing to a lack of data, it was not possible to estimate the sedimentation and erosion (from the hydrosphere to the pedo/lithosphere and vice-versa) nor the assimilation in biota. The input to the atmosphere is treated in the subprocess: 'atmosphere'. The figure for export via the hydrosphere is estimated based on data found in the literature. The values are roughly estimated at 0.012 t/a pentaBDPE, 0.33 t/a octaBDPE, 0.03 t/a decaBDPE and 0.004 t/a TBBPA.

The very rough estimate of stocks in
Tab. *5-39* is based on average concentrations of substances over the entire compartment:

Tab. 5-39: Estimate of stocks in the hydrosphere

Substance	**Concentration (ng/l)**	**Stock (t)**
PentaBDPE	40	3
OctaBDPE	n.d.	n.d.
DecaBDPE	80	7
TBBPA	50	4

Assumptions used to determine the mass of surface water: average depth 50 m; average density 1 kg/l.

5.2.9 Pedo and lithosphere

(a) Sediment

PentaBDPE
Owing to its persistence, pentaBDPE accumulates in sediment [RA, 2000a]. In sediments of the River Rhine, 2.7 µg pentaBDPE/kg dry weight were found, and tetrabromodiphenyl ether was also detected [RA, 2000a]. Downstream of a Swedish factory, values of 840 - 1200 µg

pentaBDPE/kg dry weight [RA, 2000a] were found. The 'Risk Assessment' [RA, 2000a] assumes a regional concentration of 32 µg pentaBDPE/kg of wet sediment. The values for England are summarised in [Wit, 2000]. For DE-71 (pentaBDPE), the concentration varies between <0.38 and 366 ng/g dry matter, with the majority of values below 7 ng/g dry matter.

OctaBDPE
Wit [Wit, 2000] summarises the data given in Allchin [Allchin et al., 1999]. The values for octaBDPE in 13 English rivers (in the form of DE-79) lie between <0.44 and 1405 ng/g dry matter, while most of the values are below 400 ng/g dry matter.

DecaBDPE
Owing to its persistence, decaBDPE accumulates in sediment [Leisewitz et al., 2001], [Kruse et al., 2001]. Concentrations of up to 200 µg decaBDPE/kg were measured in samples taken from rivers in urban areas that had mostly been polluted by waste water treatment plants, the tendency being for the values to increase with time [Kemmlein, 2000]. The concentration in Rhine sediment was 16 µg decaBDPE/kg dry weight [Sellström et al., 1999]. Measurements of DE-83 (decaBDPE) in 13 English rivers showed concentrations of between <0.6 and 3190 ng/g dry matter, with the majority of values below 20 ng/g dry matter [Allchin, 1999]. According to [KEMI, 1996], sediment samples incubated over a period of 4 months showed neither degradation nor transformation of decaBDPE. The assumption is therefore made that all of the decaBDPE accumulated in the past still remains in the sediment stock (worst case).

TBBPA
A TBBPA concentration of 330 mg/kg was found in sediment in the vicinity of a TBBPA production works in Arkansas [IUCLID, 1995]. In Sweden, a value of 50 µg TBBPA/kg was measured in the sediment upstream, and 430 µg TBBPA/kg in sediment downstream, of a TBBPA production works [Sellström et al., 1990]. In urban areas, samples of sediment taken from rivers mostly polluted by waste water treatment plants showed TBBPA concentrations of between 0.13 and 1868 µg/kg. Finally, the sediment taken from a lake polluted by atmospheric deposition from an urban area contained 2.41 µg TBBPA/kg [Kemmlein, 2000].

The very rough estimates of stocks shown in Tab. 5-40 are based on average concentrations over the entire compartment.

Tab. 5-40: Estimate of stock in sediment

Substance	**Concentration (µg/kg dry matter)**	**Stock (kg)**
PentaBDPE	2.7	140
OctaBDPE	0.44	20
DecaBDPE	20	1000
TBBPA	2.4	120

Assumptions used to determine sediment mass: first 2 cm in depth; average density 1.5 t/m^3.

(b) Soil

PentaBDPE

In the 'Risk Assessment', regional values for arable soils are given as 130 µg pentaBDPE/kg of wet soil and for natural, industrial and urban soils as 160 µg pentaBDPE/kg of wet soil. Since pentaBDPE is persistent, these values could increase with time [RA, 2000a].

OctaBDPE
No values for octaBDPE in soils could be found.

DecaBDPE
Owing to its persistence, decaBDPE accumulates in the soil. No values are available for the decaBDPE content of soils [Leisewitz et al., 2001], [Kruse et al., 2001]. The 'Risk Assessment' [RA, 1998] gives the following rough (regional) estimates based on calculation: 27.1 mg decaBDPE/kg of wet soil for arable soils; 0.08 mg decaBDPE/kg of wet soil for natural soils; 0.97 µg decaBDPE/l for interstitial water. These values are stated to be unusually high [Leisewitz et al., 2001], [Kruse et al., 2001], and should therefore be treated with caution.

TBBPA
TBBPA is strongly attached to organic particles in the soil, and its mobility is therefore expected to be low [Larsen, 2001]. In the soil in the vicinity of a TBBPA production works, 0.222 µg TBBPA/kg were found [IUCLID, 1995].

Practically nothing is known concerning the assimilation by biota of PBDE and TBBPA from the soil. For decaBDPE (and probably for octaBDPE) no significant assimilation is to expected owing to their low bioaccumulation and bioconcentration potentials. in this connection, mention is made of the greater significance of low-brominated DPE, which may also arise via the degradation of decaBDPE in the environment [RA, 1998]. No values are available for any of the PBDEs, neither is any information available for TBBPA.

The very rough estimate of stocks shown in Tab. 5-41 is based on average concentrations over the entire compartment:

Tab. 5-41: Estimate of stock in the soil

Substance	**Concentration (mg/kg dry matter)**	**Stock (t)**
PentaBDPE	0.13	37
OctaBDPE	n.a.	n.a.
DecaBDPE	0.08	23
TBBPA	0.22	62

Assumption for soil: volume 1300 km^3 (first 30 cm); average density 1.5.

5.2.10 Biota

PentaBDPE
A large number of measurements have been made for pentaBDPE in plants and animals. These are reviewed, among others, by [RA, 2000a]. To give an example, the following values are quoted for Sweden: mammals 0.04 - 0.24 µg/kg fat content, muscles of freshwater fish 10 – 50 µg/kg, with individual values up to 1000 µg/kg fat content. For cow’s milk in Germany,

0.0025 -0.0045 mg/kg fat content and for freshwater fish 0.018 - 0.94 mg/kg fat content are given [Wit, 1999].

OctaBDPE
In [Human Health Assessment, 2000], several concentrations were estimated from an analytical model as follows: fish 2.9E-4 mg/kg; plant root fibres 1.82 mg/kg; leaves of plants 0.023 mg/kg; meat 0.11 mg/kg; milk 0.034 mg/kg. DE-79 (octaBDPE) was found in fish in English rivers (50 - 1200 ng/g fat content) [Allchin et al., 1999]. Only very few data are available in the literature.

DecaBDPE
The assertion of Hardy [Hardy, 1993] that decaBDPE does not bioconcentrate in fish, is disproved by the results of an 8-week study, which showed bioaccumulation (BCF<4) of a mixture of decaBDPE in carp [CBC, 1982]. A Japanese study on carp over 42 days also showed a bioconcentration factor (BCF<5) at a dose rate of 60 µg/l [CITI,1992]. The levels of decaBDPE in fish and mussels were below the detection limit of 1.2 µg/kg in all samples (approx. 250) except for one (1.4 µg/kg fresh weight). The majority of the samples were taken in areas with potential exposure to decaBDPE. In the 'Risk Assessment', it is concluded from this that the bioconcentration potential is only slight, and accumulation in the food chain improbable. In the EU, no decaBDPE was detected in a range of aquatic fauna (although the detection limit was not specified) [Hardy, 2000]. In Germany, no traces of decaBDPE were found in samples of cow's milk at a detection limit of 0.1 µg/kg fat content [Kemmlein, 2000]. Also, no decaBDPE was detected in fat samples down to a detection limit of 10 µg/kg fat content.

TBBPA
Hardly any studies or data are available on TBBPA concentrations in biota. TBBPA was detected in fat cells at low ppb levels [Hakk, 2001]. In Japan, no TBBPA was detected between 1987 and 1988 down to the detection limit of 1 µg/kg fresh weight [Environment Agency Japan, 1989], [Environment Agency Japan, 1991].

No estimate was made of stock accumulation in biota.

6 Results

This section presents tables and diagrams with the results of the material flow analysis (material flows, substance flows and stocks), and discusses these. The calculations are given in Chapter 5.

The three subsystems are treated first, then the complete system. To facilitate the discussion of gaps in our knowledge and of reliability, the balances of the four substances are given in the form of flow diagrams and tables.

6.1 Data quality

6.1.1 Data gaps and range of error in the subsystem: 'trade in products'

The data for this subsystem and the calculation of material flows are given in Chapter 5.1. The calculations of ranges of error in the material flows are given in Chapter 5.1.6.1.

Data gaps and range of error
In Switzerland, it was not possible to completely determine the processes in which FR, or plastic components containing FR, are used owing to a lack of detailed information. The FR flows in manufactured and exported semi-finished products, in production flue gases and in waste water could not be determined. For production waste, the investigation was restricted to the manufacture of printed circuit boards. It may be assumed that this is the most important application where TBBPA is concerned.

For finished products, the flows were determined for the sum of the FR under study in the most important area of application, namely EE products, based on the large amount of information available in the literature. For the remaining areas of application, i.e. vehicles, building materials and textiles, the data was scarcer. Information was particularly wanting for FR in textiles, upholstery and fittings for interior decoration, so that no values could be determined. It was only possible to estimate the FR flow from the annual consumption of products, and that carried into municipal waste water from washing of textiles containing FR.

Range of error
The data given in the present study represent realistic 'average' values. The ranges of error of the data were determined by varying the values for material flows, concentrations, market shares, component weight and life cycles. The error varies approximately by a factor of two. It was assumed that all the parameters lie within realistic minima and realistic maxima.

The range of error of the results was calculated from the range of error of the raw data in combination with our own assumptions. Since for certain products (textiles, upholstery, fittings for interior decoration and conveyor belts) gaps exist in the data concerning the use of FR, the actual ranges of error are possibly larger still.

In general, the range of error of the calculated material flows is 2 to 3 times the average value. The ranges of error for the individual BFR and the individual materials differ (see Tab. 6-1, Tab. 6-2 and Tab. *6-3*).

Owing to the more satisfactory nature of the data for TBBPA, the range of error for the TBBPA flows (see Tab. 6-4) is slightly smaller than those of octaBDPE and decaBDPE. The calculated range of error for the pentaBDPE flows is likewise smaller. However, it must be assumed that the range of error is in fact larger, since there are gaps in the data for some major areas such as textiles, upholstery and conveyor belts.

For material flows, the ranges of error for the import and export of finished products are somewhat lower than for the other flows. The ranges of error for municipal waste, stock in consumption and gaseous emission lie somewhat higher than those for consumed finished products, since the uncertainty in the life cycles of these exerts an additional influence.

The following three tables show the ranges of error and average values (in bold type) of the substance flows in the three processes of the subsystem: 'trade in products'.

Tab. 6-1: Ranges of error and average values of the substance flows in the process: 'production'

MATERIALS in the PROCESS: 'PRODUCTION'			**PentaBDPE**	**OctaBDPE**	**DecaBDPE**	**TBBPA**
			[t/a]	**[t/a]**	**[t/a]**	**[t/a]**
IN	**Import of semi-finished products**	min	0	1.4	75	292
		average	**0**	**5.2**	**128**	**435**
		max	0	14.9	375	806
OUTPUT	**Finished products**	min	0	1.4	75	292
		average	**0**	**5.2**	**128**	**435**
		max	0	14.9	375	806
	Export of semi-finished products	**average**	**0**	n.d.	n.d.	n.d.
	Production waste	min	0		0.03	5
		average	**0**	n.d.	**0.09**	**14**
		max	0		0.15	24
	Production waste water	**average**	**0**	n.d.	n.d.	n.d.
	Production flue gas	**average**	**0**	n.d.	n.d.	n.d.

Note: n.d.: not determined.

Tab. 6-2: Ranges of error and average values of the material flows in the process: 'trade'

	MATERIALS in the PROCESS: 'TRADE'		**PentaBDPE [t/a]**	**OctaBDPE [t/a]**	**DecaBDPE [t/a]**	**TBBPA [t/a]**
I	**Import finished products**	min	1.0	12	228	469
N		**average**	**1.9**	**36**	**423**	**692**
P		max	3.5	68	784	1 150
U	**Finished products**	min	0.00	1.4	75	292
T		**average**	**0.00**	**5.2**	**128**	**435**
		max	0.00	15	375	806
O	**Export finished products**	min	0.24	7	130	387
U		**average**	**0.41**	**19**	**230**	**554**
T		max	0.62	37	396	824
P	**Products consumed**	min	0.8	7	172	374
U		**average**	**1.5**	**22**	**322**	**573**
T		max	2.9	46	763	1 133

Note: n.d.: not determined; assumption: no stock.

Tab. 6-3: Ranges of error and average values of the material flows in the process: 'consumption'

	MATERIALS in the PROCESS: CONSUMPTION'		**PentaBDPE [t/a]**	**OctaBDPE [t/a]**	**DecaBDPE [t/a]**	**TBBPA [t/a]**
I	**Products consumed**	min	0.77	7	172	374
N		**average**	**1.5**	**22**	**322**	**573**
		max	2.9	46	763	1 133
O	**Solid waste**	min	8	23	122	173
U		**average**	**30**	**62**	**369**	**389**
T		max	50	142	894	772
P	**Municipal waste water**	min			0.45	
U		**average**	n.d.	n.d.	**0.55**	n.d.
T		max			0.65	
	Gaseous emission	min	0.87	0.14	1.0	0.14
		average	**1.9**	**0.37**	**2.1**	**0.28**
		max	4.0	0.92	6.0	0.63
L	**Additions to stock**	min	0.77	7	172	374
A		**average**	**1.5**	**22**	**322**	**573**
G		max	2.9	46	763	1133
E	**Removals from stock**	min	9	23	124	173
R		**average**	**32**	**62**	**372**	**389**
		max	54	143	900	772
	Total stock	min	*224*	*254*	*2 575*	*2 862*
		average	***498***	***678***	***5 601***	***5 561***
		max	*1 038*	*1 706*	*15 907*	*12 597*

Note: n.d.: not determined. The total stock (in italics) is given in tonnes [t].

A comparison of the ranges of error for the individual product groups (see Tab. 6-4) shows that these are of approximately the same order. This means that despite the plethora of data on EE products, the reliability of the results in this area is similar to that for vehicles and building materials. The ranges of error differ more markedly where materials or substances are concerned.

The large range of error for finished products is caused mainly by uncertainties in the quantities of FR in products. In effect, manufacturers of finished products (particularly EE appliances) very often do not know which FR are contained in the products they market, nor in what concentrations. Mostly, the only information available is a statement to the effect that the fire protection regulations have been fulfilled, and sometimes that PBDE have not been not used.

Tab. 6-4: Relative ranges of error and substance flows according to product group

MATERIALS AND STOCKS	**SUBSTANCES**	**±**	Computer	EE products	Vehicles	Building materials	**Total**
Products consumed	Penta-BDPE	-%			-50%		**-50%**
		+%			+95%		**+95%**
	Octa-BDPE	-%	-45%	-65%	-70%		**-70%**
		+%	+160%	+150%	+45%		**+110%**
	Deca-BDPE	-%	-40%	-50%	-55%	-35%	**-45%**
		+%	+100%	+200%	+110%	+50%	**+140%**
	TBBPA	-%	-30%	-30%	-50%	-60%	**-35%**
		+%	+60%	+95%	+120%	+35%	**+100%**
Stock in consumption and gaseous emission	Penta-BDPE	-%		-55%	-55%	-55%	**-55%**
		+%		+1100%	+150%	+90%	**+110%**
	Octa-BDPE	-%	-55%	-70%	-65%	-25%	**-65%**
		+%	+270%	+150%	+220%	+40%	**+150%**
	Deca-BDPE	-%	-50%	-65%	-60%	-35%	**-55%**
		+%	+180%	+270%	+140%	+110%	**+180%**
	TBBPA	-%	-35%	-45%	-55%	-50%	**-50%**
		+%	+100%	+130%	+140%	+110%	**+130%**
Municipal waste	Penta-BDPE	-%		-45%	-70%	-75%	**-75%**
		+%		+850%	+110%	+40%	**+65%**
	Octa-BDPE	-%	-75%	-65%	-70%	-60%	**-65%**
		+%	+190%	+120%	+250%	+5%	**+130%**
	Deca-BDPE	-%	-75%	-65%	-70%	-65%	**-65%**
		+%	+230%	+210%	+120%	+60%	**+140%**
	TBBPA	-%	-60%	-50%	-65%	-70%	**-55%**
		+%	+100%	+100%	+130%	+60%	**+100%**

Note: the percentage values are given with respect to the average values (see material flow diagrams). Empty cells indicate that the substance is not used in the product group concerned.

No precise data could be given on the percentages of TBBPA, decaBDPE or other BFR with which a product was treated (EE appliances, cars, building materials). To calculate the quantities of FR used, assumptions had to be made based partly on analyses of older EE products and of new products. Thus both for new and older products, the percentages of FR used are subject to greater uncertainty than the other data (i.e. for FR concentration and component mass).

Tab. 6-4 shows a breakdown of the ranges of error of the principal material flows and stocks, classified according to product group. The percentage values are given with respect to the average values cited in the previous tables and in the material flow diagrams given later.

6.1.2 Data gaps and range of error in the subsystem: 'waste management'

Data gaps

In waste management, very few data are available (from test measurements in Japan) on the behaviour of the substances concerned in the subsystem: 'incineration' (MWIP). No information is available on the presence of substances in the products of the remaining processes, so that here, assumptions had to be made. For this, reliance had to be made on individual measurements of concentrations in a small selection of products (e.g. sewage sludge). Practically no data are available on flows from the processes: 'waste water treatment', 'reuse' and 'landfill' to the environment, with the exception of very rough estimates. In the present work, these were therefore estimated.

Range of error

As mentioned above, the uncertainty in the material flows in the subsystem: 'trade in products' is approximately a factor of 2-3 times the average value. With few exceptions, this relationship was also applied to the flows in waste management. Other errors in the subsystem: 'waste management' were not further considered owing, among other things, to the lack of reliable transfer coefficients. Thus the minima and maxima given are not based on statistical data but represent rough estimates. This is true to an even greater extent for the flows (e.g. of 'seepage water to waste water treatment' and 'deposition to municipal waste water'), which could only be roughly estimated. Only when measurements of the individual material flows have been performed will it be possible to obtain statistically accurate ranges of error.

The following four tables show the ranges of error and average values (in bold type) of the substance flows in the four processes of the subsystem: 'waste management'.

Tab. 6-5: Ranges of error and average values of the substance flows in the process: 'reuse'

MATERIALS in the PROCESS: 'REUSE'			**PentaBDPE [t/a]**	**OctaBDPE [t/a]**	**DecaBDPE [t/a]**	**TBBPA [t/a]**
IN	**Separately collected waste**	min	1	17	95	100
		average	**2.5**	**33**	**190**	**200**
		max	5	66	380	400

MATERIALS in the PROCESS: 'REUSE'			**PentaBDPE [t/a]**	**OctaBDPE [t/a]**	**DecaBDPE [t/a]**	**TBBPA [t/a]**
OUTPUT	**Residual materials to incineration**	min	0.6	15	73	55
		average	**1.2**	**30**	**146**	**109**
		max	2.4	60	292	218
	Export from reuse	min	0.5	1.2	16	42
		average	**1**	**2.3**	**32**	**83**
		max	2	4.6	64	166
	Landfill material from reuse	min	0.12	0.6	7	4
		average	0.24	1.1	13	8
		max	**0.5**	**2.2**	**26**	**16**
	Emission from reuse		n.d.	n.d.	n.d.	n.d.

Note: n.d.: not determined.

The following flows and stocks were not determined: input: import to reuse, incineration residues to reuse; output: waste reused

Tab. 6-6: Ranges of error and average values of the substance flows in the process: 'waste water treatment'

MATERIALS in the PROCESS: 'WASTE WATER TREATMENT'			**PentaBDPE**	**OctaBDPE**	**DecaBDPE**	**TBBPA**
			[t/a]	**[t/a]**	**[t/a]**	**[t/a]**
INPUT	**Waste water**	min	0.0	0.0	0.3	0.0
		average	**0.0**	**0.0**	**0.6**	**0.0**
		max	0.0	0.0	1.1	0.0
	Deposition to municipal waste water	min	0.0	0.0	0.0	0.0
		average	**0.19**	**0.04**	**0.21**	**0.03**
		max	0.38	0.07	0.42	0.06
	Seepage water to waste water treatment	min	0.011	0.004	0.025	0.075
		average	**0.022**	**0.007**	**0.05**	**0.15**
		max	0.044	0.014	0.10	0.30
OUTPUT	**Residues from waste water treatment to incineration**	min	0.01		0.01	0.005
		average	**0.02**	n.d.	**0.02**	**0.01**
		max	0.08		0.08	0.04
	Purified waste water	min	0.002		0.003	0.001
		average	**0.004**	n.d.	**0.005**	**0.002**
		max	0.008		0.010	0.004
	Sewage sludge to agriculture	min	0.018		0.023	0.009
		average	**0.036**	n.d.	**0.045**	**0.018**
		max	0.14		0.18	0.07
	Landfill material from waste water treatment	min	0.002		0.002	0.001
		average	**0.003**	n.d.	**0.003**	**0.001**
		max	0.012		0.012	0.004

Note: n.d.: not determined; ranges of error for sewage sludge to agriculture, residues from waste water treatment to incineration, and landfill material from waste water treatment: upper limit 4 times average value instead of only 2 times average value (owing to greater variability of published data)

Tab. 6-7: Ranges of error and average values of the substance flows in the process: 'incineration'

MATERIALS in the PROCESS: 'INCINERATION'			PentaBDPE	OctaBDPE	DecaBDPE	TBBPA
			[t/a]	[t/a]	[t/a]	[t/a]
INPUT	**Thermally treated waste**	min	2.9	11	72	84
		average	**5.8**	**22**	**143**	**166**
		max	12	44	287	332
	Residual materials to incineration	min	0.6	15	73	55
		average	**1.2**	**31**	**146**	**109**
		max	2.4	62	292	218
	Residues from waste water treatment to incineration	min	0.01		0.01	0.005
		average	**0.02**	n.d.	**0.02**	**0.01**
		max	0.08		0.08	0.08
OUTPUT	**Incineration residues to landfill**	min	0.001	0.01	0.05	2
		average	**0.003**	**0.02**	**0.1**	**4**
		max	0.006	0.04	0.2	8
	Emission from incineration	min	0.0E+00	0.0E+00	0.0E+00	0.0E+00
		average	**2.3E-09**	**1.8E-08**	**9.5E-08**	**1E-05**
		max	4.6E-09	3.7E-08	1.9E-07	2E-05
	Export from incineration	min	0.001	0.005	0.03	1.1
		average	**0.002**	**0.01**	**0.06**	**2.4**
		max	0.004	0.02	0.12	4.5

Note: n.d.: not determined. The following flows and stocks were not determined: import to incineration (input), incineration residues to reuse (output)

Tab. 6-8: Ranges of error and average values of the substance flows in the process: 'landfill'

MATERIALS in the PROCESS: 'LANDFILL'			PentaBDPE	OctaBDPE	DecaBDPE	TBBPA
			[t/a]	[t/a]	[t/a]	[t/a]
INPUT	**Landfill material**	min	11	2.8	18	19
		average	**22**	**5.5**	**36**	**38**
		max	44	11	72	76
	Landfill material from reuse	min	0.0	0.6	7	4
		average	0.0	1.1	13	8
		max	**0.0**	**2.2**	**26**	**16**
	Landfill material from waste water treatment	min	0.002		0.002	0.001
		average	**0.003**	n.d.	**0.003**	**0.001**
		max	0.012		0.012	0.004
	Incineration residues to landfill	min	0.0015	0.01	0.05	2
		average	**0.003**	**0.02**	**0.1**	**4**
		max	0.006	0.04	0.2	8

MATERIALS in the PROCESS: 'LANDFILL'			PentaBDPE [t/a]	OctaBDPE [t/a]	DecaBDPE [t/a]	TBBPA [t/a]
OUTPUT	**Seepage water to waste water treatment**	min	0.011	0.004	0.025	0.075
		average	**0.022**	**0.007**	**0.05**	**0.15**
		max	0.044	0.014	0.10	0.30
	Emission from landfill	min	0.001	0.0004	0.003	0.008
		average	**0.002**	**0.0007**	**0.005**	**0.015**
		max	0.004	0.0014	0.010	0.030
STOCK	**Additions to stock**	min	8.8	2.84	20	20
		average	**22**	**7.1**	**50**	**50**
		max	55	18	125	125
	Removals from stock	min	0.01	0.003	0.02	0.07
		average	**0.02**	**0.008**	**0.06**	**0.17**
		max	0.06	0.02	0.15	0.43
	Total stock	*min*	*43*	*43*	*207*	*237*
		average	***130***	***130***	***620***	***710***
		max	*325*	*325*	*1550*	*1775*

Note: n.d.: not determined; the total stock (in italics) is given in tonnes [t].

6.1.3 Data gaps and range of error in the subsystem: ‘environment’

Data gaps

With the exception of the calculated input flows from the subsystems: ‘trade in products’ and ‘waste management’, it is practically impossible to determine the flows in the process: ‘environment’. No measurements are available for Switzerland. Insofar as data exist at all, these mostly concern concentration measurements in individual materials in one environmental compartment (e.g. river sediments downstream of industrial outlets, various species of fish, plants, etc.). The deposition rates available from the literature must be regarded as very approximate.

Ranges of error

As mentioned above, the range of error of the material flows in the subsystem: 'trade in products' is approximately a factor 2 to 3 with respect to the average value. The corresponding ranges of error, and the equivalent ranges for the material flows from waste management, were applied to the input flows to the environment. The error estimates for flows and stocks in the subsystem, as well as for exports from it, are very rough and can be improved only by measurement.

The following three tables show the ranges of error and average values (in bold type) of the substance flows in the three processes of the subsystem: ‘environment’.

Tab. 6-9: Ranges of error and average values of the substance flows in the process: 'atmosphere'

MATERIALS in the PROCESS: 'ATMOSPHERE'			PentaBDPE	OctaBDPE	DecaBDPE	TBBPA
			[t/a]	**[t/a]**	**[t/a]**	**[t/a]**
INPUT	**Emission from production, trade and transport**	min	0.9	0.1	1.0	0.1
		average	**1.9**	**0.4**	**2.1**	**0.3**
		max	4.1	0.9	6.0	0.6
	Emission from waste management	min	0.0E+00	0.0E+00	0.0E+00	0.0E+00
		average	**2.3E-09**	**1.8E-08**	**9.5E-08**	**1E-05**
		max	4.6E-09	3.7E-08	1.9E-07	2E-05
OUTPUT	**Deposition hydrosphere**	min	0.0001	0.0001	0.0008	0.0002
		average	**0.0001**	**0.0001**	**0.0013**	**0.0006**
		max	0.0002	0.0002	0.0017	0.0010
	Deposition biota		n.d.	n.d.	n.d.	n.d.
	Deposition pedo/lithosphere	min	1.20	0.23	1.32	0.18
		average	**1.71**	**0.33**	**1.89**	**0.25**
		max	2.22	0.43	2.46	0.33
	Deposition municipal waste water	min	0.00	0.00	0.00	0.00
		average	**0.19**	**0.04**	**0.21**	**0.03**
		max	0.38	0.07	0.42	0.06
STOCK	**Additions to stock**	min	0	0	0	0
		average	**1.9**	**0.37**	**2.1**	**0.28**
		max	5.7	1.11	6.3	0.84
	Removals from stock	min	0	0	0	0
		average	**1.9**	**0.37**	**2.1**	**0.28**
		max	5.7	1.11	6.3	0.84
	Total stock	*min*	*0*	*0*	*0*	*0*
		average	***0.00005***	***0.00005***	***0.00005***	***0.00005***
		max	*0.00010*	*0.00010*	*0.00010*	*0.00010*

Note: n.d.: not determined. Total stock (in italics) is given in tonnes [t]. The average value of the stock corresponds to half the estimated maximum (assumption).
The following flows and stocks were not determined: imported air, exported air.

Tab. 6-10: Ranges of error and average values of the substance flows in the process: 'pedo/lithosphere'

MATERIALS in the PROCESS: 'PEDO/LITHOSPHERE'			PentaBDPE	OctaBDPE	DecaBDPE	TBBPA
			[t/a]	**[t/a]**	**[t/a]**	**[t/a]**
INPUT	**Sewage sludge to agriculture**	min	0.009	n.d.	0.011	0.005
		average	**0.036**	**n.b.**	**0.045**	**0.018**
		max	0.144	n.b.	0.180	0.072
	Deposition pedo/lithosphere	min	1.2	0.2	1.3	0.2
		average	**1.7**	**0.3**	**1.9**	**0.3**
		max	2.2	0.4	2.5	0.3
	Sedimentation		n.d.	n.d.	n.d.	n.d.

MATERIALS in the PROCESS: 'PEDO/LITHOSPHERE'			**PentaBDPE**	**OctaBDPE**	**DecaBDPE**	**TBBPA**
			[t/a]	**[t/a]**	**[t/a]**	**[t/a]**
O	**Uptake by biota**		n.d.	n.d.	n.d.	n.d.
	Erosion		n.d.	n.d.	n.d.	n.d.
		min	*20*	*n.d.*	*10*	*30*
S	***Total stock***	***average***	***40***	***n.d.***	***20***	***60***
		max	*80*	*n.d.*	*40*	*120*

Note: n.d.: not determined. Total stock (in italics) is given in tonnes [t].

Tab. 6-11: Ranges of error and average values of the substance flows in the process: 'hydrosphere'

MATERIALS in the PROCESS: 'HYDROSPHERE'			**PentaBDPE**	**OctaBDPE**	**DecaBDPE**	**TBBPA**
			[t/a]	**[t/a]**	**[t/a]**	**[t/a]**
		min	0.002		0.003	0.004
I	**Waste water in waste management**	**average**	**0.006**	n.d.	**0.010**	**0.017**
N		max	0.024		0.040	0.068
P		min	0.00009	0.00006	0.0008	0.0002
U	**Deposition to hydrosphere**	**average**	**0.00012**	**0.00013**	**0.0013**	**0.0006**
T		max	0.00016	0.00019	0.0017	0.0010
	Erosion		n.d.	n.d.	n.d.	n.d.
O		min	0.01	0.17	0.02	0.00
U	**Export from hydrosphere**	**average**	**0.012**	**0.33**	**0.03**	**0.004**
T		max	0.02	0.66	0.06	0.01
	Uptake by biota		n.d.	n.d.	n.d.	n.d.
	Sedimentation		n.d.	n.d.	n.d.	n.d.
S		min	0.003	0.00005	0.005	0.01
T	**Additions to stock**	**average**	**0.006**	**0.0001**	**0.01**	**0.02**
O		max	0.012	0.0002	0.02	0.04
C		min	0.006	0.02	0.015	0.002
K	**Removals from stock**	**average**	**0.012**	**0.33**	**0.03**	**0.004**
		max	0.024	0.66	0.06	0.008
		min	*1*		*2*	*1*
	Total stock	***average***	***3***	*n.d.*	***7***	***4***
		max	*9*		*21*	*12*

Note: n.d.: not determined. Total stock (in italics) is given in tonnes [t].

For the process: ‘biota’, no flows or stocks could be determined.

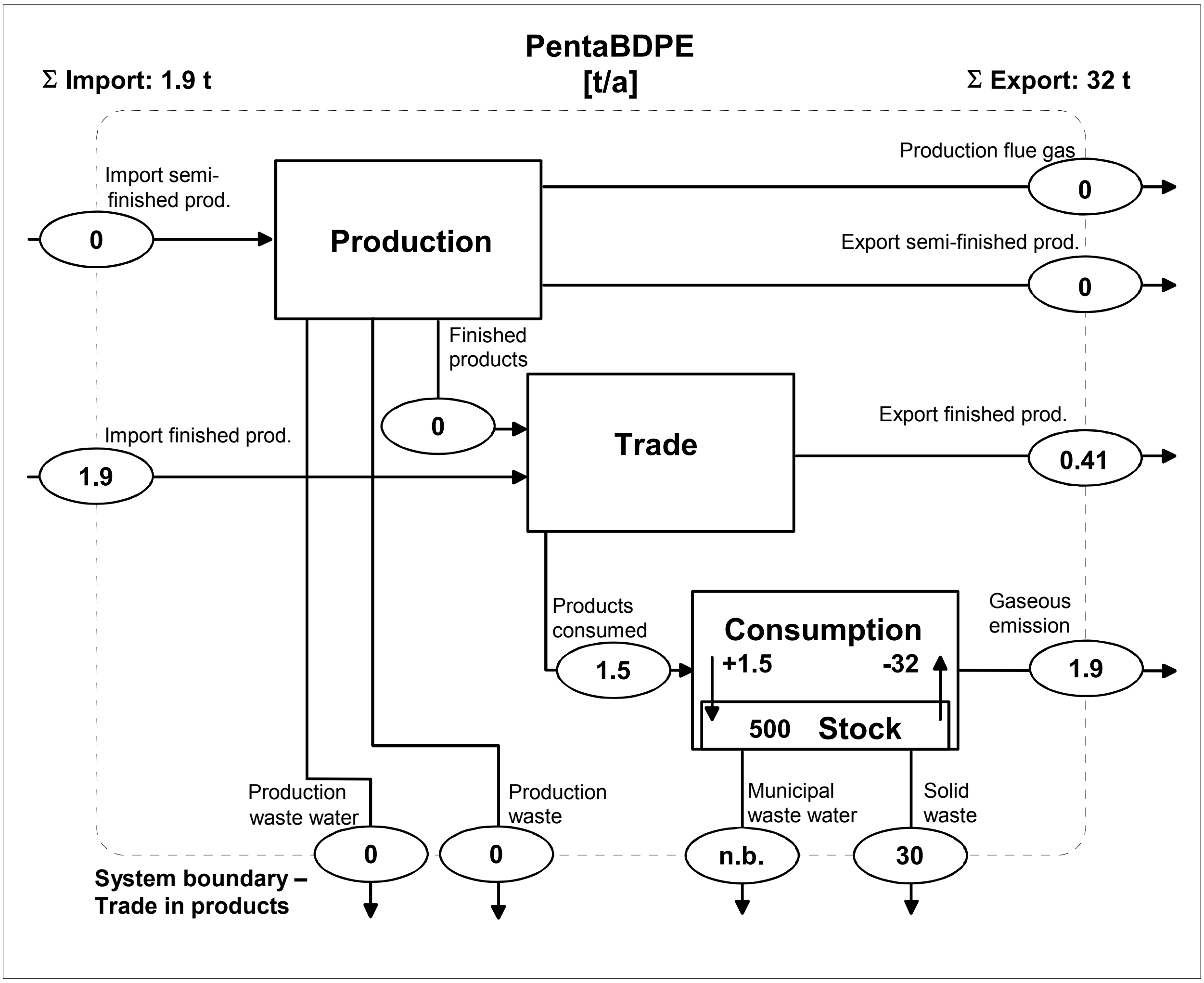
6.2 Flows of substances in subsystems

6.2.1 Subsystem: 'trade in products'

This subsystem comprises the three areas of 'production', 'trade' and 'consumption' in Switzerland and is discussed under those headings. Consumption applies both to the private and the industrial sectors.

6.2.1.1 PentaBDPE (pentabromodiphenyl ether)

Fig. 6-1: PentaBDPE flows in the subsystem: 'trade in products'



World consumption of pentaBDPE for use as flame retardant increased heavily over the past decade from 4000 t in 1991 to 8500 t in 1999. However, it can be assumed that in the European market, the consumption of products containing pentaBDPE has declined as a result of national restrictions in conjunction with voluntary commitments in certain industries. In 1999, as compared with total PBDE (pentaBDPE, octaBDPE and decaBDPE), pentaBDPE flame retardants accounted for about 13 % of use worldwide, and in Europe for about 2.5% (210 t/a). The world and European figures for the consumption of pentaBDPE refer to commercial flame retardant products having an average content of approx. 59% of the pure substance pentaBDPE.

At the end of the 1990s (1998 figures), imports of pentaBDPE via finished products to the subsystem: 'trade in products' amounted to ca. 1.9 t/a, of which approx. 22% were re-exported in the form of finished products. At present, no semi-finished or finished products containing pentaBDPE are manufactured or processed in Switzerland. For this reason, no emission of pentaBDPE from the production sector to the environment is expected. At the end of the 1990s, the presence of pentaBDPE flame retardants in motor vehicles was attributable entirely to imports of finished products. Where the upholstery (flexible PUR foams), textiles and plastics contained in these vehicles are concerned, the flows of pentaBDPE dominate. PBDE are universally employed in motor vehicles, and the assumption is made that a small percentage (approx. 10%) of this occurs in the form of pentaBDPE.

The use of products containing pentaBDPE in Switzerland has led to a stock of some 500 t being built up in consumption over the past two decades. This stock is accounted for mainly by building materials incorporated in the infrastructure, and consumer products (household electronics, cars) containing pentaBDPE in private households.

Despite the uncertainty concerning the quantity of pentaBDPE in building materials and consumer products, it may be assumed that this stock is now declining rapidly. While 1.9 t/a are input annually to the stock, removals amount to some 32 t/a. Thus although pentaBDPE is present only in small quantities in new products, it is passed on in large quantities to the waste sector by virtue of the diminution in stock. On the assumption that this trend continues, it will take a further 16 years for the stock in consumption of products containing pentaBDPE to be eliminated.

The main products in relation to stock and emission of pentaBDPE are given in the list below. In detail, the stock comprises:

- approx. 86 % pentaBDPE in PUR foam fillers
- approx. 5 % pentaBDPE in PVC coverings
- approx. 7 % pentaBDPE in upholstery and textiles in cars
- approx. 2 % pentaBDPE in printed circuit boards (FR2) in household electronic appliances

The flow of pentaBDPE of approx. 30 t/a disposed of via waste results from residual building waste (25 t/a pentaBDPE in PUR foam fillers and 2 t/a in PVC coverings). This is approximately 90% of the total flow to waste management. Since only a very small proportion of PUR foam fillers can be separated from residual building waste, it is assumed that these are largely deposited in landfills (80%), or are incinerated in MWIP together with other combustible building waste (20%). To what extent these assumptions are realistic can only be assessed on the basis of more detailed data. Approximately 2.4 t pentaBDPE are disposed of annually via used cars. A further 0.7 t pentaBDPE are contained in FR2 printed circuit boards in electronics scrap.

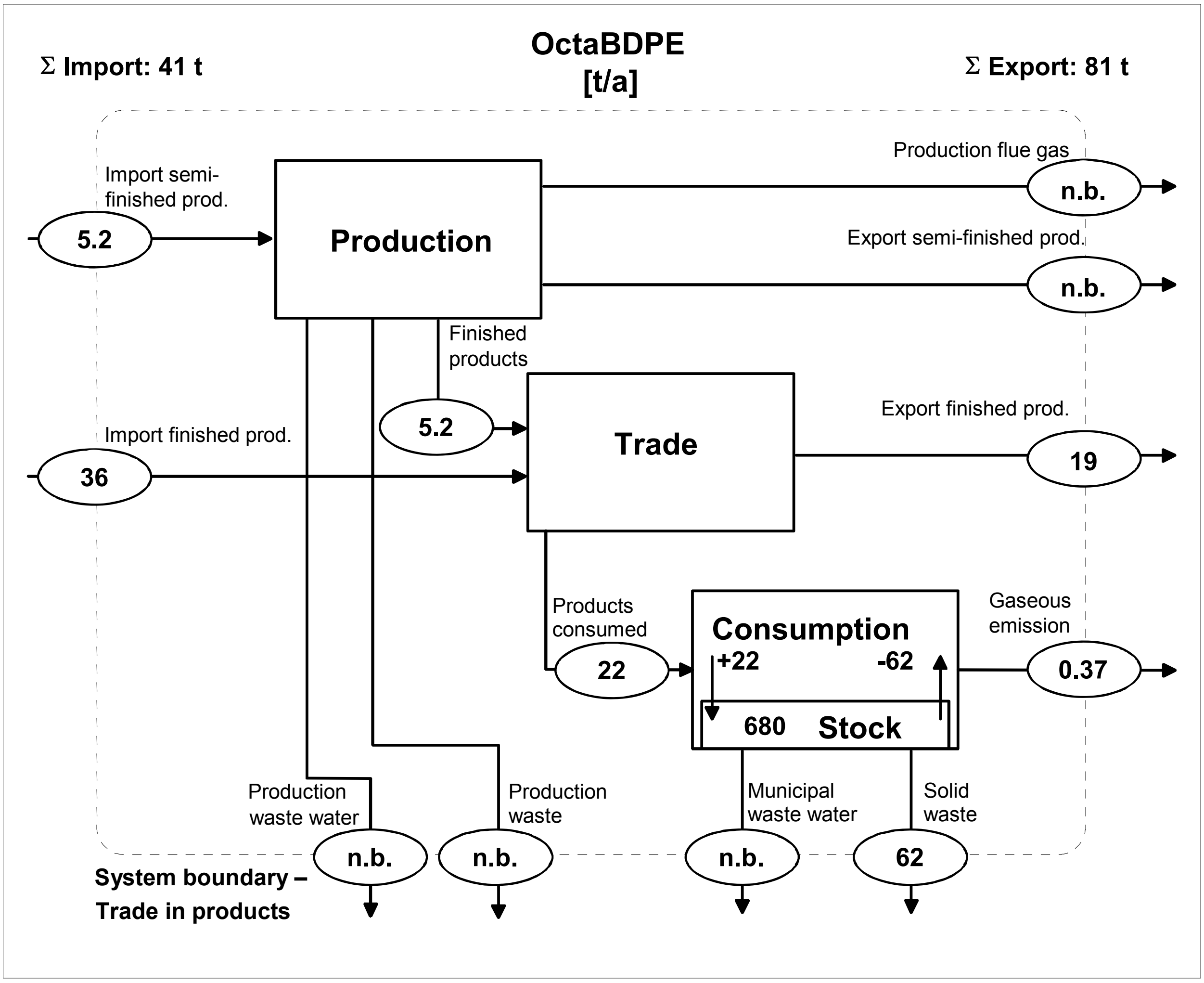
The diffuse emission of approx. 1.9 t/a resulting from the use of products containing pentaBDPE is ecologically significant. About 86% of this is attributable to PUR foam fillers used in building. Since worst-case emission rates were assumed in the calculations, and neither the use nor the mode of application of PUR foam were considered in detail, it can be assumed that the emission is in fact lower. To obtain the highest possible figure for pollution, it is assumed that all emission is to the atmosphere.

Data gaps and ranges of error

As insufficient data were available on flame retardants in flexible PUR foams (e.g. upholstery), textiles and rubber (e.g. conveyor belts), neither the consumption, stock nor waste could be quantified for these. However, it was possible to make estimates for one significant application of pentaBDPE – namely in flexible PUR foams in cars.

6.2.1.2 OctaBDPE (octabromodiphenyl ether)

Fig. 6-2: OctaBDPE flows in the subsystem: 'trade in products'



The worldwide consumption of octaBDPE flame retardants declined markedly by (38%) over the past decade from 6000 t in 1991 to 3800 t in 1999. The principal application of octaBDPE was in ABS plastics in EE (electrical and electronics) appliances, which have a market share of 85%. For ABS blends containing alternative flame retardant substances, the market share of octaBDPE has declined sharply. World consumption of octaBDPE flame retardants in relation to total PBDE (pentaBDPE, octaBDPE and decaBDPE) consumed in 1999 was approx. 5.7%. In Europe it was of the same order, i.e. approx. 5.5% (450 t/a). The world and European figures for the consumption of octaBDPE refer to commercial flame retardant products having an average content of approx. 34% of the pure substance octaBDPE.

At the end of the 1990s, the average import of octaBDPE via semi-finished and finished products to the subsystem: 'trade in products' was approx. 41 t/a, of which approx. 46% were re-exported in the form of finished products. The percentage of finished products containing octaBDPE that are manufactured in Switzerland was very low at approx. 14% of imports.

The import of octaBDPE flame retardants in finished products is mainly accounted for by EE appliances (some 67%), whereby EDP and office equipment dominate. Upholstery (flexible PUR foams), textiles and plastics in motor vehicles that contain flame retardants represent a further significant fraction (approx. 33%) of imports. For these applications, PBDE are usually employed, and it is assumed that a small percentage (approx. 8%) of this occurs in the form of octaBDPE.

The octaBDPE flow in home-produced finished products is accounted for entirely by EE appliances assembled from imported components containing octaBDPE. No chemicals containing octaBDPE are processed in Switzerland.

In comparison to imports, home production accounts for only a small flow of octaBDPE of approx. 5.2 t/a (13%). The export of semi-finished products containing octaBDPE could not be determined. For this reason, the quantity of octaBDPE used in the production sector might be higher than the 5.2 t/a estimated. This difference could, for example, arise from semi-finished products containing octaBDPE that are traded, but not processed or consumed, in Switzerland.

The flow of octaBDPE in finished products destined for consumption (approx. 22 t/a) is about the same as that in exported finished products (approx. 19 t/a). Most of the octaBDPE flow in consumed finished products (approx. 59%) is attributable to EE appliances. EDP equipment account for approx. 22%, and large household appliances approx. 13%, of the total flow. In addition to EE appliances, plastic components in cars represent an important field of application of octaBDPE. Approximately 41% of the annual consumption of octaBDPE in finished products is attributable to motor vehicles. At the end of the 1990s, building materials destined for consumption no longer contained octaBDPE flame retardants.

The stock in consumption built up in Switzerland over the last two decades through the use of products containing octaBDPE is approx. 680 t octaBDPE. This is mainly composed of consumer goods containing octaBDPE used in private households (EE appliances, cars) and building materials containing octaBDPE that form part of the infrastructure.

Although about 22 t/a of products containing octaBDPE are added to the stock, approximately three times this amount (62 t/a) is removed from the stock, so that this is now diminishing rapidly. Although the use of octaBDPE flame retardants is now declining in Switzerland, large quantities (62 t/a) are still being passed on to waste management through the elimination of stock. On the assumption that the trend towards reduced application of octaBDPE in new products continues, it will take a further 17 years for the stock of products in consumption that contain octaBDPE to be eliminated.

The main products in relation to stock and emission of octaBDPE are EE appliances, which account for approx. 69% of the stock, and cars, which account for 21%. In detail, the stock comprises:

- approx. 42 % octaBDPE in TV appliances
- approx. 21 % octaBDPE in cars
- approx. 10 % octaBDPE in building materials (plastic sheeting)
- approx. 9 % octaBDPE in small electrical components (plugs and switches)
- approx. 7 % octaBDPE in smaller and larger EE household appliances

- approx. 6 % octaBDPE in EDP + office equipment
- approx. 5 % octaBDPE in other EE appliances (household electronics, electrical appliances in industry)

The major part of the approximately 62 t/a octaBDPE disposed of via waste results from electronic appliances (approx. 77%), of which TV appliances account for some 36% and EDP + office equipment for 26%. Approximately 9 t octaBDPE are disposed of annually via used cars, and a further 5.2 t are contained in PE films in residual building waste.

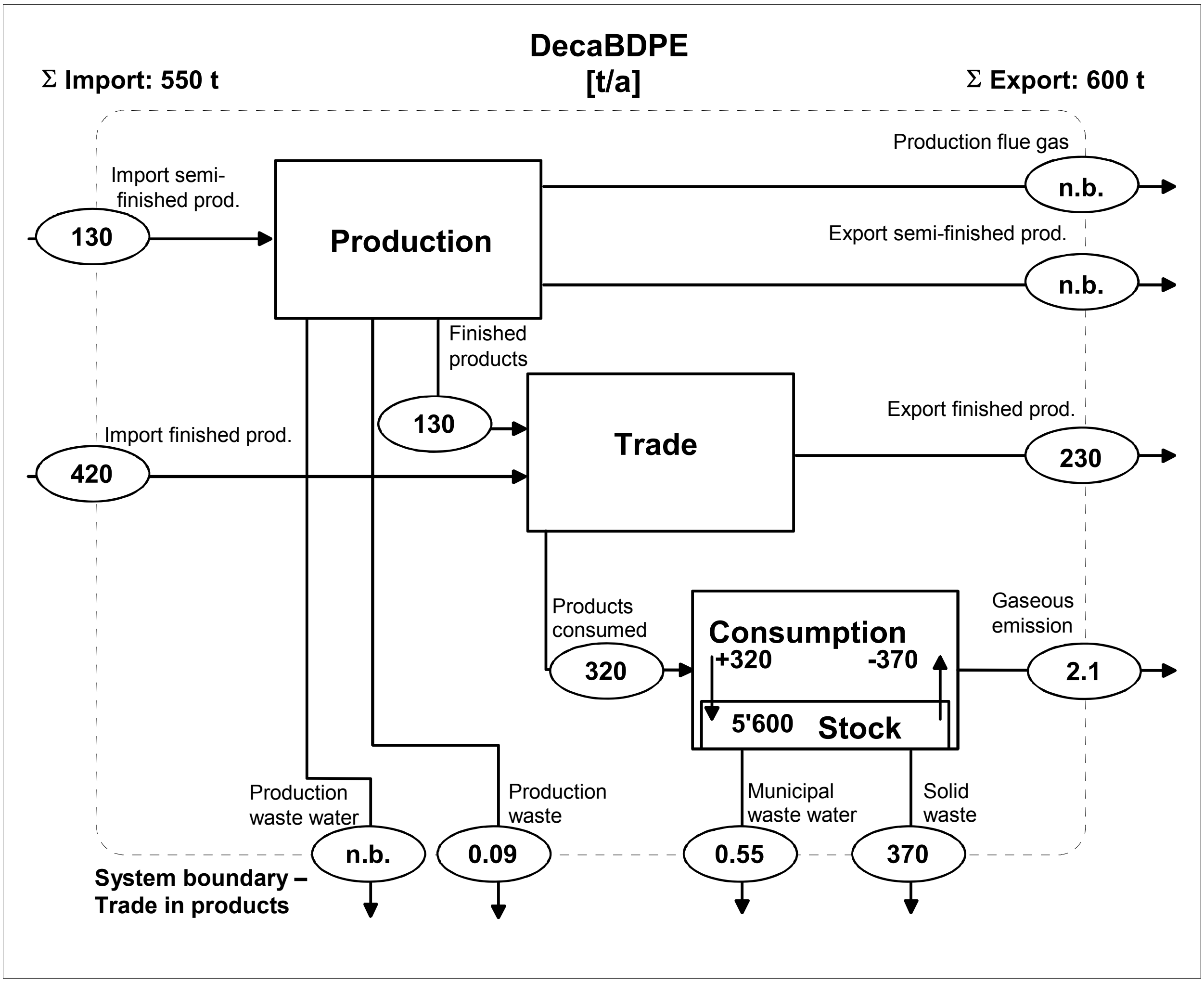
The diffuse emission from the use of products containing octaBDPE of about 0.37 t/a is ecologically significant. Of this, 69% is attributable to EE appliances in private households. Since worst-case emission rates were applied in the calculations, it can be assumed that the emission is in fact lower. To obtain the highest possible figure for pollution, it is assumed that the emission takes place entirely to the atmosphere. In comparison to the other two PBDEs (pentaBDPE and decaBDPE), diffuse emission of octaBDPE represents about one-fifth. This is attributable to the fact that the emission rate of octaBDPE is an order of magnitude lower than that of pentaBDPE, and that the stock of products containing octaBDPE is only about one-eighth of that containing decaBDPE.

Data gaps and range of error

Concerning the foremost application of octaBDPE in this study (i.e. in ABS plastics), realistic estimates were made based on the lists of plastics constituents obtained from FR manufacturers. However, it was necessary to make certain assumptions concerning the market share of flame retardants used in ABS plastics and on the percentage of plastics used in products.

6.2.1.3 DecaBDPE (decabromodiphenyl ether)

Fig. 6-3: DecaBDPE flows in the subsystem: 'trade in products'



World consumption of decaBDPE flame retardants increased heavily over the past decade from 30 000 t in 1991 to 54 800 t in 1999. The foremost application of decaBDPE (30 - 85% according to estimates) was, and has remained, in HIPS plastics for casings of EE appliances. Further significant outlets are thermoplastic polyesters, polyamides and latex textile coverings. Referred to total PBDE flame retardants processed in 1999 (pentaBDPE, octaBDPE and decaBDPE), the share of decaBDPE on the world market was approx. 82%. In Europe it was approx. 92% (7500 t/a). The world and European figures for the consumption of decaBDPE refer to commercial flame retardant products having an average content of some 98% of the pure substance decaBDPE.

The annual import of decaBDPE via semi-finished and finished products to the subsystem: 'trade in products' at the end of the 1990s was approx. 550 t/a, of which approx. 42% was re-exported in finished products. The present proportion of finished products manufactured in Switzerland that contain decaBDPE is comparatively low at one-third of imports.

The import of finished products containing decaBDPE is largely accounted for by EE appliances (approx. 69%), whereby EDP and office equipment dominate. Upholstery (flexible PUR foam), textiles and plastics treated with flame retardants in motor vehicles represent a further significant fraction of imports (some 30%). As no details were available for imports and exports of building materials, it was assumed that Swiss requirements are met entirely within the country.

In comparison to imports (or consumption), production within Switzerland, which includes the assembly of appliances, contributes only slightly (some 23%) to the total decaBDPE flow in finished products of approx. 130 t/a. The export of semi-finished products containing decaBDPE could not be determined, so that the quantity in the area: 'production' might be higher than 130 t/a decaBDPE. This difference could, for example, arise from semi-finished products containing decaBDPE that are traded, but not processed or consumed, in Switzerland.

Where finished products produced in Switzerland are concerned, decaBDPE flows are to be found in approximately equal quantities in plastic sheeting for building purposes (approx. 56%) and EE appliances (approx. 43%). However, not the plastic sheeting used in buildings, bridges and underground construction is treated with flame retardants, and flame retardants other than decaBDPE are also used. As no data were available in the literature, it was assumed that 10% of all PE films destined for the building industry were treated with decaBDPE flame retardants.

The largest fraction (approx. 45%) of the decaBDPE flow in consumed finished products (approx. 320 t/a) is to be found in EE appliances, of which EDP equipment represent some 17% and household electrical appliances some 11%, of the total flow. Further important applications of decaBDPE in addition to EE appliances are for plastic components in cars and building materials. Some 30% of the flow of decaBDPE in consumed finished products occurs in cars and lorries, and some 25% in building materials (PE films).

As a result of the use of products containing decaBDPE, a stock of some 5600 t decaBDPE has built up in consumption in Switzerland over the last two decades. This is present primarily in consumer goods (EE appliances, cars) in private households, and in building materials that form part of the infrastructure.

Despite the input of new products containing decaBDPE (approx. 320 t/a) to the stock, this is gradually declining (approx. 50 t/a) owing to the greater annual disposal of waste containing decaBDPE (approx. 370 t/a). Where inputs remain unchanged at a high level, no significant reduction in the stock is to be expected in the foreseeable future.

The main products in relation to the stock and emission of decaBDPE are EE appliances (some 40%), building materials and cars. In detail, the stock comprises:

- approx. 30 % decaBDPE in building materials (plastic sheeting, insulating foams)
- approx. 30 % decaBDPE in cars
- approx. 14 % decaBDPE in small electrical components (plugs and switches)
- approx. 13 % decaBDPE in household electronic appliances
- approx. 7 % decaBDPE in small and large EE household appliances
- approx. 4 % decaBDPE in EDP + office equipment
- approx. 2 % decaBDPE in other EE appliances

The major part of the 370 t/a decaBDPE disposed of via waste results from electronic appliances (approx. 44%). Approximately 110 t decaBDPE are disposed of via used cars, and a further approx. 100 t decaBDPE via PE films and XPS insulating panels contained in residual building waste.

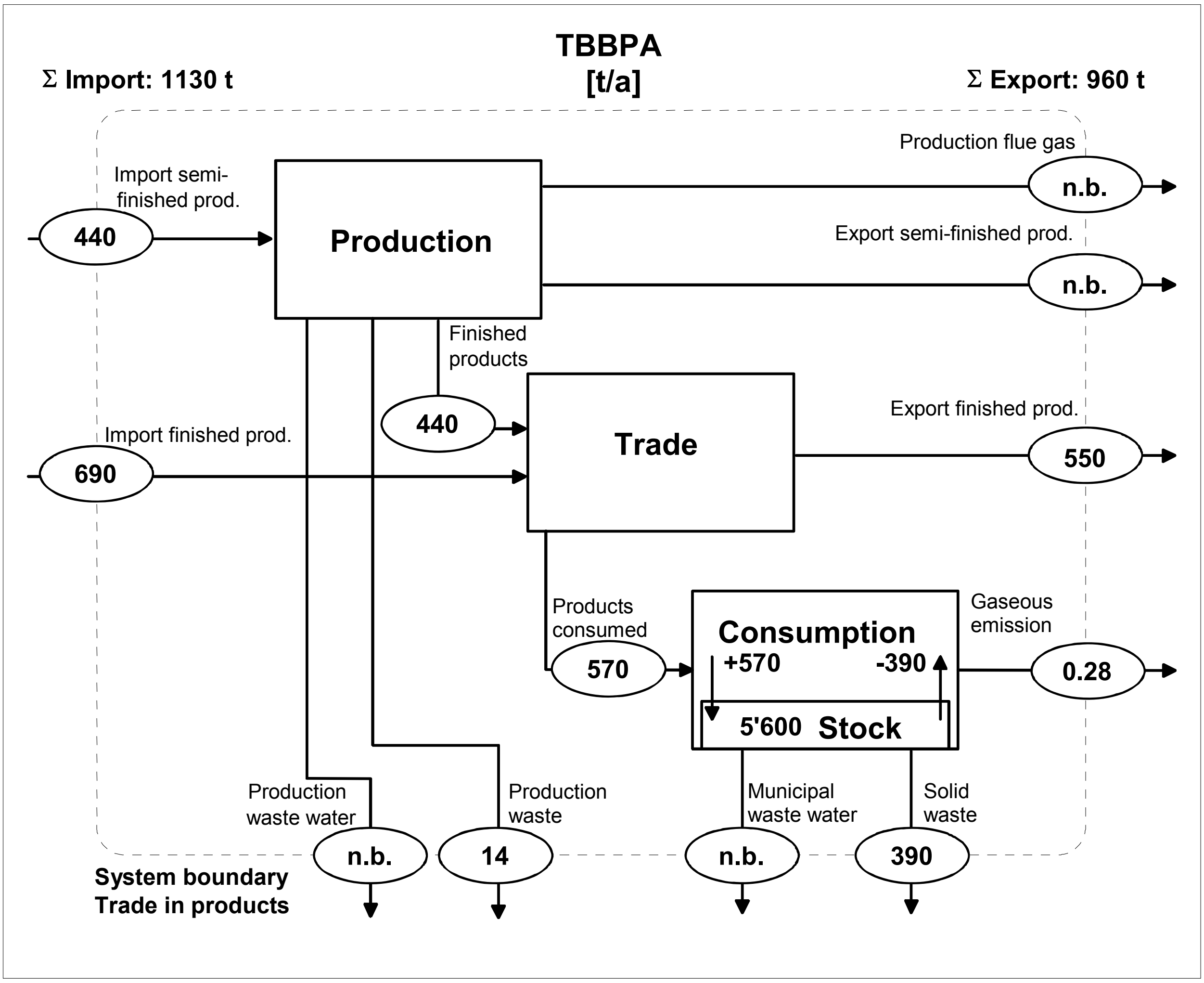
The diffuse emission resulting from the use of products containing decaBDPE of some 2.1 t/a is ecologically significant. Approximately 40% of this stems from EE appliances in private households. Since worst-case emission rates were applied, it may be assumed that the emission is in fact lower. To obtain the highest possible figure for pollution, it is assumed that emission takes place entirely to the atmosphere.

Data gaps and range of error

Concerning the principal uses of decaBDPE (in plastics for EE appliances), it was possible to make realistic estimates based on the lists of constituents obtained from FR manufacturers. However, assumptions had to be made concerning the market share of the flame retardants used in the different types of plastics, and for the percentage of plastics used in products.

6.2.1.4 TBBPA (tetrabromobisphenol A)

Fig. 6-4: TBBPA flows in the subsystem: 'trade in products'



The world consumption of TBBPA flame retardants increased slightly over the past decade from 100 000 t in 1991 to 121 000 t in 1999. The most significant application of TBBPA (approx. 70%) is, and has remained, in epoxy resins for printed circuit boards. Further important applications are in plastics (ABS, HIPS) for casings of EE appliances, whereby PBDE have partly replaced TBBPA over the years. Approximately 10% of the worldwide annual production of TBBPA is used in the production of TBBPA derivates.

In Europe, some 13 800 t/a of TBBPA flame retardants were processed in 1999. The worldwide and European figures for the consumption of TBBPA refer to commercial flame retardant products having an average content of some 98.5% of the pure substance TBBPA.

At the end of the 1990s, some 1130 t/a TBBPA were imported into the subsystem: 'trade in products' via semi-finished and finished products, of which approximately half were re-exported in the form of finished products. The TBBPA flow in finished products produced today in Switzerland is slightly lower (approx. two-thirds of imports).

The prevalence of finished products that contain TBBPA is mainly due to imports of EE appliances (approx. 85%), whereby EDP and office equipment preponderate. Textiles and plastics in motor vehicles treated with flame retardants represent only a small proportion of imports (approx. 15%). Owing to the fact that no data were available for imports and exports of building materials, it was assumed that Swiss requirements are met entirely within the country.

The TBBPA flow in finished products produced within Switzerland almost all results from EE appliances (approx. 96%).

The greater part (approx. 83%) of the TBBPA flow in consumed finished products (approx. 570 t/a) also results from EE appliances, of which computers account for some 43% and household electronic appliances for some 11% of the total flow.

A stock in consumption of some 5600 t TBBPA has built up in Switzerland over the last two decades via the use of products containing TBBPA. This stock consists primarily of consumer goods (EE appliances, cars) containing TBBPA in private households, and building materials containing TBBPA that form part of the infrastructure.

At present, some 50% more TBBPA is being input to the stock (approx. 570 t/a) than is being output (approx. 390 t/a), so that the stock is growing. If the input remains unchanged, this means that no reduction in stock may be expected in the foreseeable future. Indeed, on the assumption that the trend towards increased use of TBBPA in new products continues, the stock will double in approximately three decades.

The main products in relation to the stock and emission of TBBPA are EE appliances (approx. 59%), building materials and cars. In detail, the stock comprises:

- approx. 21 % TBBPA in building materials (PUR foam and epoxy resins)
- approx. 20 % TBBPA in cars (plastic components and printed circuit boards)
- approx. 18 % TBBPA in EDP equipment
- approx. 14 % TBBPA in industrial appliances (measuring instruments, process control appliances)
- approx. 13 % TBBPA in household electronic appliances (TV appliances)
- approx. 6 % TBBPA in small electronic components (plugs and switches)
- approx. 8 % TBBPA in other EE appliances

Among the approx. 390 t/a TBBPA disposed of via waste, electronic appliances (approx. 66%) are decisive for the flow. Some 66 t TBBPA are disposed of yearly via used cars, and a further 66 t TBBPA via residual building waste.

The diffuse emission of some 0.28 t/a resulting from the use of products containing TBBPA is ecologically significant. Of this, approximately 60% stems from EE appliances in private households. In comparison to the size of the stock and to the magnitude of the other flows considered, this material flow is small, since the major part of the TBBPA flame retardants is reactively combined with the plastics, and cannot therefore diffuse.

As worst-case emission rates were applied here, it may be assumed that the emission is in fact lower. To obtain the highest possible figure for pollution, it is assumed that the emission takes place entirely to the atmosphere.

Data gaps and range of error

For the principal applications of TBBPA (printed circuit boards), it was possible to make realistic estimates based on the extensive data in the literature. Some uncertainty remains regarding the area of printed circuit boards per appliance taken from the Danish study. Also, where plastics for casings and building materials are concerned, assumptions had to be made about the market share of flame retardants used in the various types of plastics, and about the percentage of plastics used in products.

6.2.2 Subsystem: ‘waste management’

This subsystem comprises the disposal processes: ‘reuse’, ‘incineration’ and ‘landfill’ for solid waste, and the process: ‘waste water treatment’ for household and industrial waste water in Switzerland.

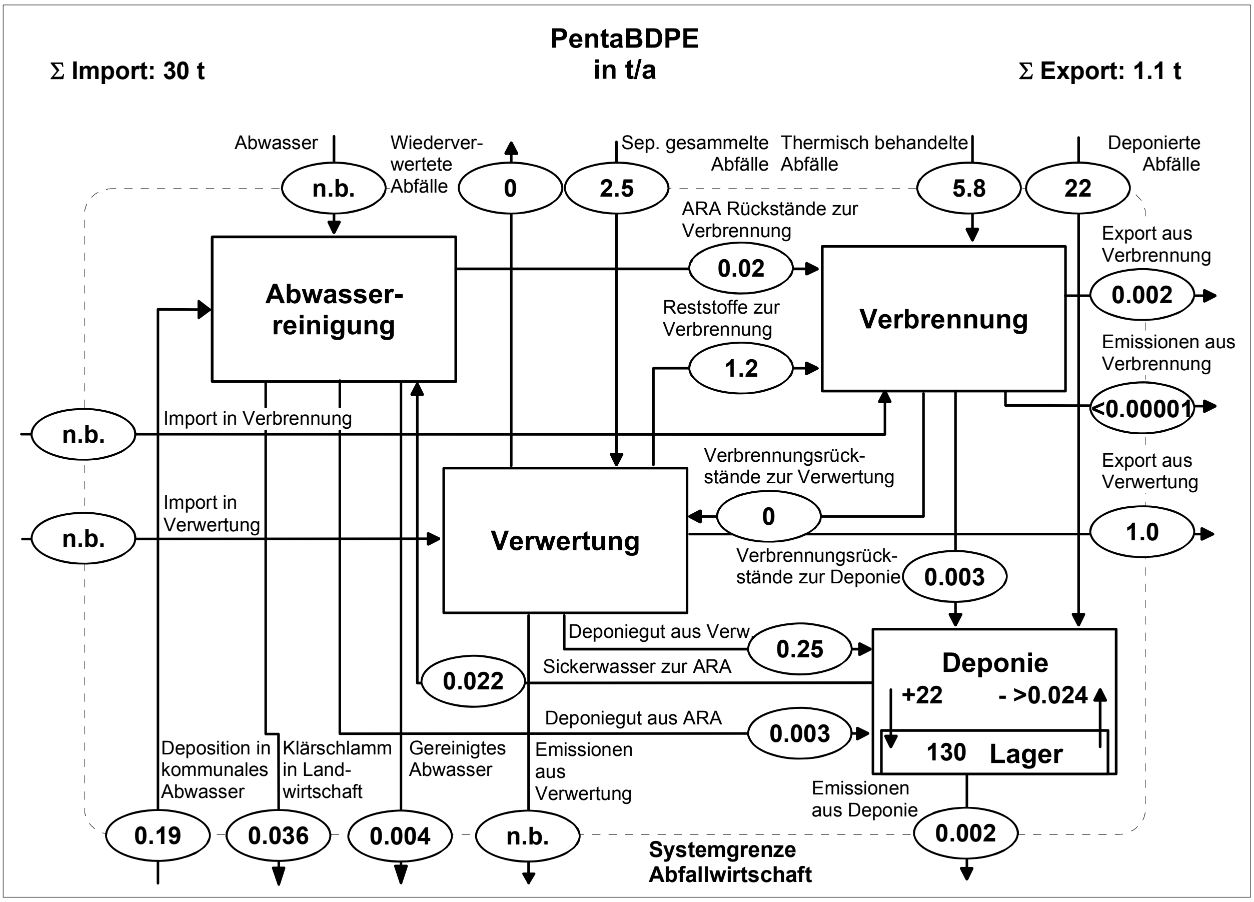
6.2.2.1 PentaBDPE (pentabromodiphenyl ether)

Among the 2.5 t/a pentaBDPE contained in separately collected waste destined for reuse, approximately half consists of residual substances to be incinerated, a further 40% is exported, and approx. 10% deposited in landfills. No data on emission from ‘reuse’ are presently available, but these could conceivably be environmentally significant.

A total of 5.8 t/a pentaBDPE (>99.9%) are destroyed by thermal treatment in the process: ‘incineration’. The output from the incineration process therefore amounts to 0.0056 t/a. Of this, 0.002 t/a are exported and 0.003 t/a of incineration residues (slag and ashes) are deposited in landfills. Emission to the environment (via flue gases and to waste water) is estimated at less than 0.00001 t/a.

PentaBDPE was detected in sewage sludge in Sweden and Germany. Applying these measurements to Switzerland, a pentaBDPE flow of 0.036 t/a results. On the assumption that 10% of the input to waste water treatment is retained in the purified waste water, this would imply a pentaBDPE flow of 0.004 t/a to the environment **[Satz wiederholt weiter unten???]**. The main input flow to waste water treatment results from dust particles in the atmosphere to the waste water treatment system (‘deposition to municipal waste water'). This flow is estimated at 0.19 t/a, based on the assumption that approximately 10% of the diffuse gaseous emission from consumption is attached to dust particles, which are then deposited in the waste water treatment system. The seepage water input from landfills is estimated at 0.022 t/a. On the assumption that approx. 10% of the input to waste water treatment is retained in the purified waste water, this would imply a pentaBDPE flow of 0.004 t/a to the environment. Thus the input to waste water treatment of 0.2 t/a is only partly offset by the output of 0.04 t/a. The substantial difference between the input and output of pentaBDPE in the process: ‘waste water treatment’ cannot be explained at present. No further information will be available until new measurements have been made in Swiss waste water treatment plants. This is particularly important since the emission occurring via the waste water system probably represents the largest inflow to the environment.

Fig. 6-5: PentaBDPE flows in the subsystem: ‘waste management’



The total quantity of pentaBDPE deposited in landfills in Switzerland at the end of the 1990s amounted to 22 t/a. Emission from landfills (via seepage water) is estimated at 0.002 t/a. For all four flame retardants considered, it is assumed that 10% are released to the environment and 90% are passed on to waste water treatment. The stock of pentaBDPE in landfills is estimated at approx. 130 t.

Approximately 1.1 t pentaBDPE is output per year from the subsystem: ‘waste management’. This output corresponds to approx. 3 % of the input. The greater part of the input (77 %) is almost completely destroyed by thermal treatment. Approximately 20 % of the entire input is deposited in landfills within the subsystem. It is assumed that no pentaBDPE is returned to the subsystem: ‘trade in products’ with reused products. To what extent this is justified could not be assessed. The diffuse emission to the environment from waste management via flue gases, seepage water, sewage sludge and waste water (excluding possible emission from the process: ‘reuse’) amounts to some 40 kg/a (< 0.1 %).

6.2.2.2 OctaBDPE (octabromodiphenyl ether)

The input of octaBDPE from consumption to Swiss waste management at the end of the 1990s was estimated at a total of 62 t/a. As with the other BFR, the entire quantity of octaBDPE occurs in the solid waste fraction. This may be divided into separately collected waste (53 %), thermally treated waste (37 %) and landfill material (10 %). From the estimates made in the subsystem: ‘trade in products’, an input via waste water is regarded as improbable.

A total of 33 t octaBDPE were contained in the separately collected waste assigned to reuse. Of this, 2.3 t/a were exported, some 31 t/a passed on in the form of residual substances to incineration, and the remaining 1.1 t/a deposited in landfills. No data are available on emission from ‘reuse’. This could possibly be relevant to the environment.

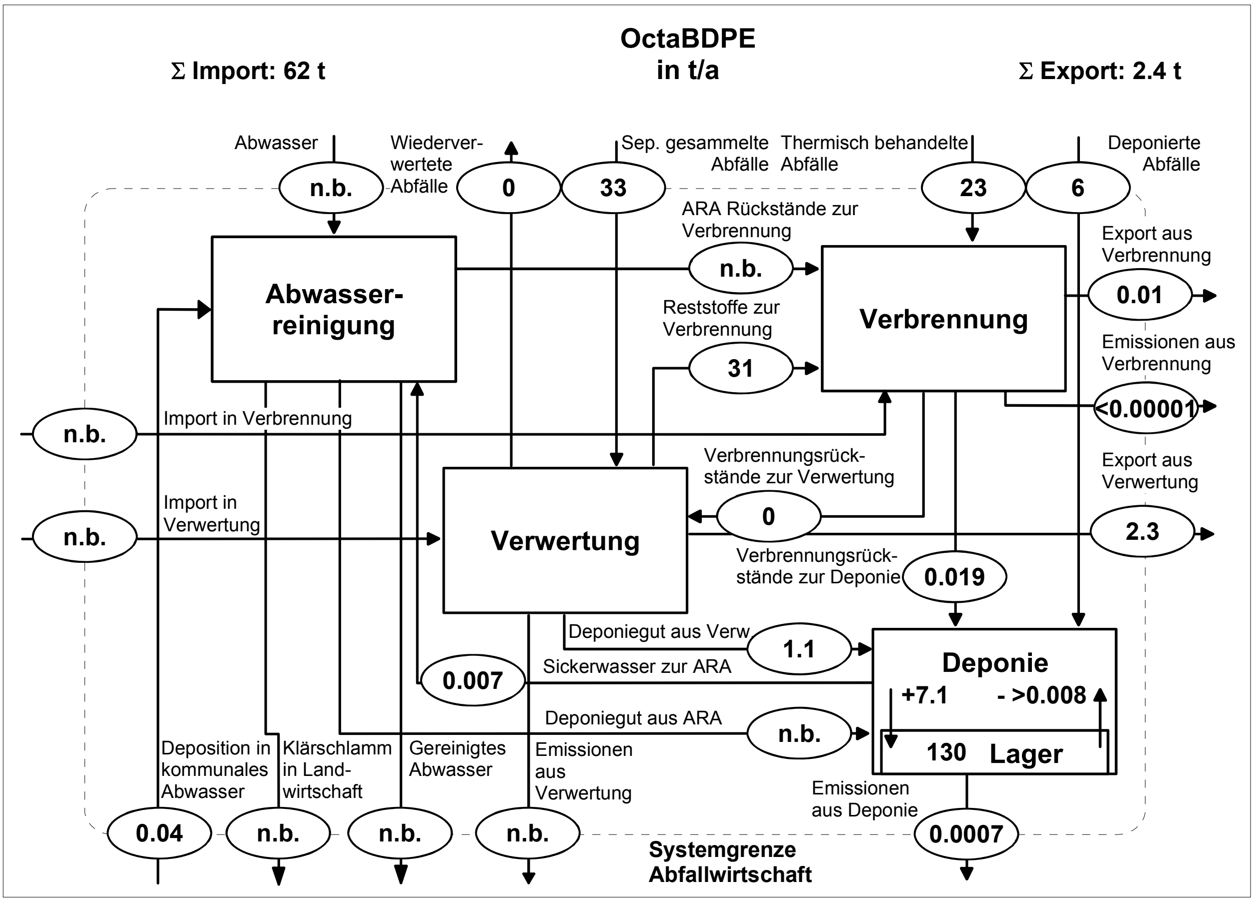
Almost all of the 54 t/a of octaBDPE treated thermally in the process: ‘incineration’ is destroyed (to >99.9 %). The total output from incineration amounts to 0.029 t/a. Of this, exports amount to 0.01 t/a (ash), and incineration residues to landfills 0.019 t/a (slag and ash). For octaBDPE, emission to the environment (flue gases and waste water) is estimated at <0.00001 t/a.

No measurements are available for octaBDPE in sewage sludge. OctaBDPE flows in sewage sludge and purified waste water were therefore not estimated. The input from the atmosphere (via deposition of dust particles) to the waste water treatment system is estimated at 0.04 t/a, amounting to 10 % of the emission from consumption in Switzerland. Also, approx. 0.007 t/a is carried over into waste water via seepage water.

At the end of the 1990s, approx. 7.1 t/a octaBDPE were deposited in landfills (of which 1.1 t/a arose from the process: ‘reuse’ and 6 t/a directly in the form of waste from the subsystem: ‘trade in products’). Emission from landfills is estimated at 0.0007 t/a. It is assumed that 10 % of the emission in seepage water finds its way directly to the environment, and the rest to waste water treatment. Gaseous emission is neglected. The landfill stock is estimated at approx. 130 t.

The total output of octaBDPE from the subsystem: ‘waste management’ amounts to an annual 2.4 t. Although this represents only 4 % of input, the flow is twice that for pentaBDPE. Approximately 10 % (7.1 t/a) of the total input are deposited in landfills within the subsystem, and 86 % are almost completely destroyed by thermal treatment. It is assumed here that no decaBDPE is carried back into the subsystem: ‘trade in products’ via reused products. To what extent this assumption applies could not be assessed. Diffuse emission to the *environment* (excluding possible emission of waste water from the process: ‘reuse’) is estimated at 6 kg/a (< 0.01 %).

Fig. 6-6: OctaBDPE flows in the subsystem: 'waste management'



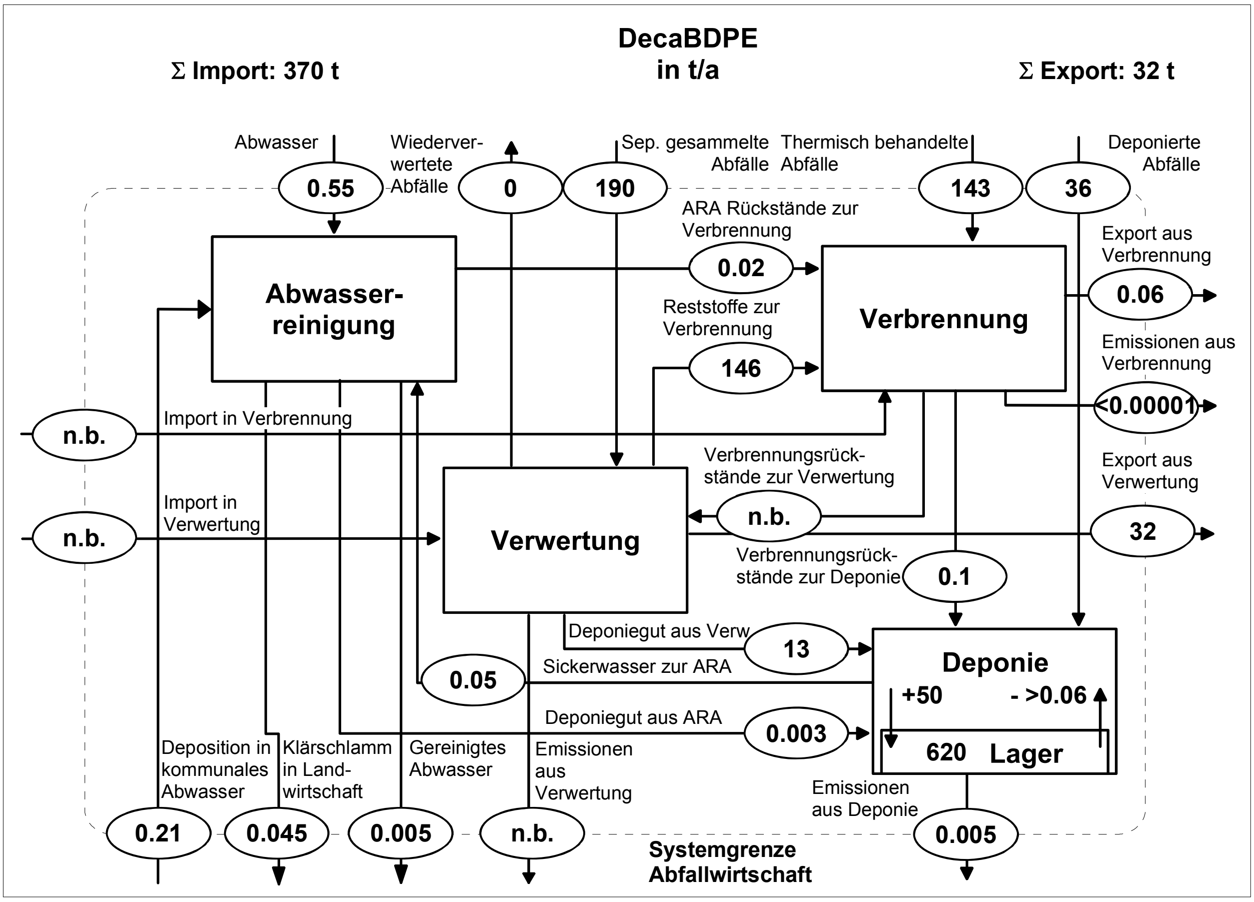
6.2.2.3 DecaBDPE (decabromodiphenyl ether)

The *decaBDPE input* from consumption *to waste management* at the end of the 1990s amounted to approx. 370 t/a. This is some 12 times and 7 times greater than the pentaBDPE and octaBDPE flows respectively. Only an estimated 0.55 t/a are input to the subsystem: 'waste management' via waste water. Thus practically 100 % of the solid waste is transferred from consumption to waste management. Some 51 % of this comes from separately collected waste (190 t/a). A further 39 % (143 t/a) is in thermally treated waste and 10 % is deposited in landfills.

Of the decaBDPE occurring in separately collected waste, it is estimated that 32 t/a are exported from the process: 'reuse'. Some 146 t/a decaBDPE are passed on to incineration via the residual substances. This quantity is approximately equal to the flow passed on directly from consumption to incineration. Some 13 t/a from the process: 'reuse' were deposited in landfills in Switzerland at the end of the 1990s. For decaBDPE, no estimates for could be made for emission from the process: 'reuse'. These flows could possibly be relevant to humans and the environment, particularly where decomposition in the environment (debromination to low-brominated compounds) occurs.

DecaBDPE is also destroyed in the process: 'incineration' (to >99.9 %). From the total input of decaBDPE to incineration of 289 t/a, an estimated output of 0.16 t/a remains. Of this, 0.06 t/a (ash) were exported and 0.1 t/a residual incineration waste (slag and ash) were deposited in landfills. Emission to the environment (flue gases and waste water) is estimated at <0.00001 t/a.

Fig. 6-7: DecaBDPE flows in the subsystem: 'waste management'



Applying the Swedish and German measurements to Switzerland, a decaBDPE flow in sewage sludge of 0.045 t/a is obtained. It is assumed that 10 % of the input to waste water treatment is retained in the purified waste water (0.005 t/a). The input from the atmosphere (via dust particles) to the waste water system amounts to an estimated 0.21 t/a (i.e. 10 % of the emission from Swiss consumption). The input from seepage water from landfills is estimated at 0.05 t/a. Thus the input to waste water treatment of 0.76 t/a is only partly offset by the output of 0.05 t/a. The large difference between the decaBDPE flows in the process: 'waste water treatment' cannot be explained at present. No further information will be available until measurements have been carried out on Swiss waste water treatment plants.

The total quantity of decaBDPE deposited in landfills in Switzerland at the end of the 1990s amounts to some 50 t/a. This is about 10 times greater than the corresponding quantities of pentaBDPE and octaBDPE. The output via seepage water is estimated at 0.005 t/a. At the end of the 1990s, the landfill stock amounted to some 620 t.

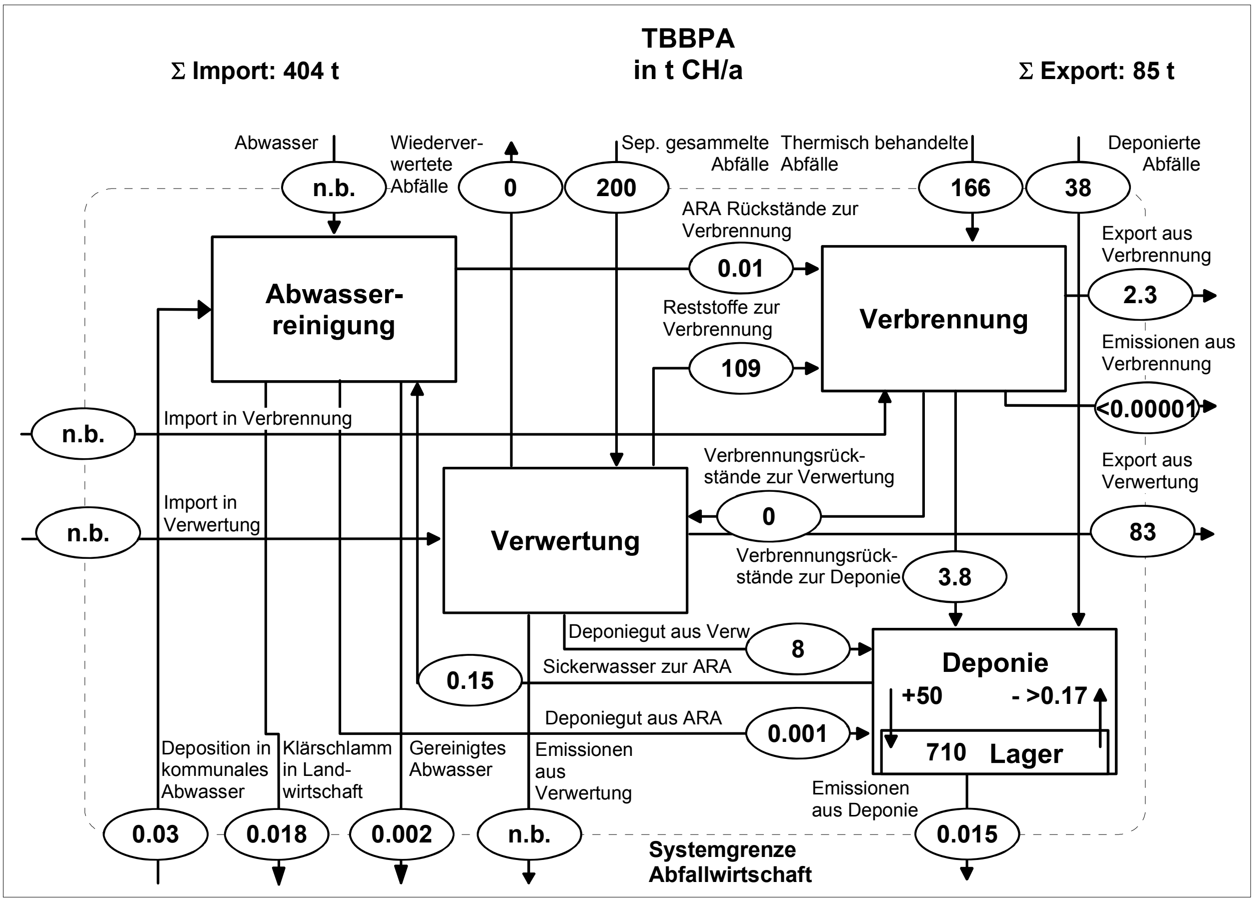
The total output of decaBDPE from the subsystem: 'waste management' amounts to more than 30 t annually. This is equivalent to 8 % of the input. Approximately 14 % of the input is retained in landfills in the subsystem, and 78 % are almost completely destroyed by thermal treatment. It is also assumed that no decaBDPE is reintroduced to the subsystem: 'trade in products' via reused products. To what extent this assumption is justified could not be assessed. A total diffuse emission of approx. 55 kg/a (< 0.1 %) is released to the environment via flue gases, seepage water, sewage sludge and waste water.

6.2.2.4 TBBPA (tetrabromobisphenol A)

The annual TBBPA flow from consumption *to waste management* amounted to some 390 t/a at the end of the 1990s, and is thus of the same order of magnitude as for decaBDPE. It is assumed that no relevant quantities of TBBPA are input directly from the subsystem: 'trade in products' to the subsystem: 'waste management' via waste water. Of the total quantity of solid waste, some 51 % is attributable to separately collected waste and 39 % occurs in thermally treated waste. At the end of the 1990s, some 10 % of the input to waste management was deposited directly in landfills.

Of the 200 t TBBPA in separately collected waste that was passed on to reuse, approx. 83 t/a were exported. Approx. 109 t/a in the residual substances are passed on to incineration. This flow corresponds to $^2/_3$ of the quantity directly incinerated. At the end of the 1990s, approx. 8 t from the process: 'reuse' were passed on to Swiss landfills. Although no data are available at present on emission from 'reuse', emission from this source is somewhat unlikely due to the predominantly reactive application of TBBPA. However, emission cannot be entirely excluded owing to the presence of product impurities and to the additive applications of the substance.

Fig. 6-8: TBBPA flows in the subsystem: 'waste management'



TBBPA is almost entirely destroyed in the process: 'incineration'. The total input of TBBPA to the process: 'incineration' of 261 t/a may be compared to the total output of 6.1 t/a. This output is significantly higher than that of individual PBDEs. To what extent the data on the thermal treatment of plastics containing PBDE and TBBPA are correct can only be determined on the basis of measurement. Of the total output, 2.3 t/a TBBPA are exported (ash), and 3.9 t/a are deposited in conjunction with incineration residues (slag and ash) in landfills in Switzerland. Emission to the environment in the form of flue gases and waste water is estimated at less than 0.00001 t/a.

Based on measurements in sewage sludge in Sweden and Germany, the flow of TBBPA in sewage sludge in Switzerland amounts to 0.018 t/a. The assumption is made that 10 % of the input to waste water treatment is retained in the purified waste water (0.002 t/a). The deposition from the atmosphere to the waste water disposal system via dust particles is estimated by the authors at 0.03 t/a (i.e. 10 % of the emission from Swiss consumption). The input from seepage water from landfills is estimated at 0.15 t/a. The input from waste water treatment of 0.18 t/a is only partly offset by the output of 0.02 t/a, the difference being 0.16 t/a. Here, too, the input from waste water treatment lies significantly above the output forecast.

As for decaBDPE, the total quantity of TBBPA deposited in landfills at the end of the 1990s amounted to some 50 t/a. The output via emission (seepage water) was estimated at a fairly high 0.015 t/a. At the end of the 1990s, the landfill stock amounted to some 710 t.

The *total annual output flow* of TBBPA from the subsystem: 'waste management' amounted to over 85 t/a, i.e. about 22 % of the input. Approximately 13 % of the total input is deposited in landfills within the subsystem, and the rest (65 %) is to a large extent destroyed by thermal treatment. The further assumption is made that no TBBPA is reintroduced to the subsystem: 'trade in products' via recycled products. To what extent this assumption is justified could not be assessed. Diffuse emission of approx. 34 kg/a (< 0.1 %) is released to the environment via flue gases, seepage water, sewage sludge and waste water.

6.2.3 Subsystem: 'environment'

This subsystem comprises the processes: 'atmosphere', 'hydrosphere', 'pedo/lithosphere' and 'biota'.

Flows to and from the process: 'biota' could not be reliably estimated from the literature. Also, flows within the subsystem: 'environment' could be only very roughly quantified, or not at all. Although these flows may appear to be negligible, they are in fact of major importance owing to the relatively large risk to the environment. More precise data on diffuse emission from consumption and waste management, and on input to the waste water system via dust particles, deposition to the pedo/lithosphere, and, where possible, measurements in the individual environmental compartments in Switzerland, will enable more precise estimates to be made.

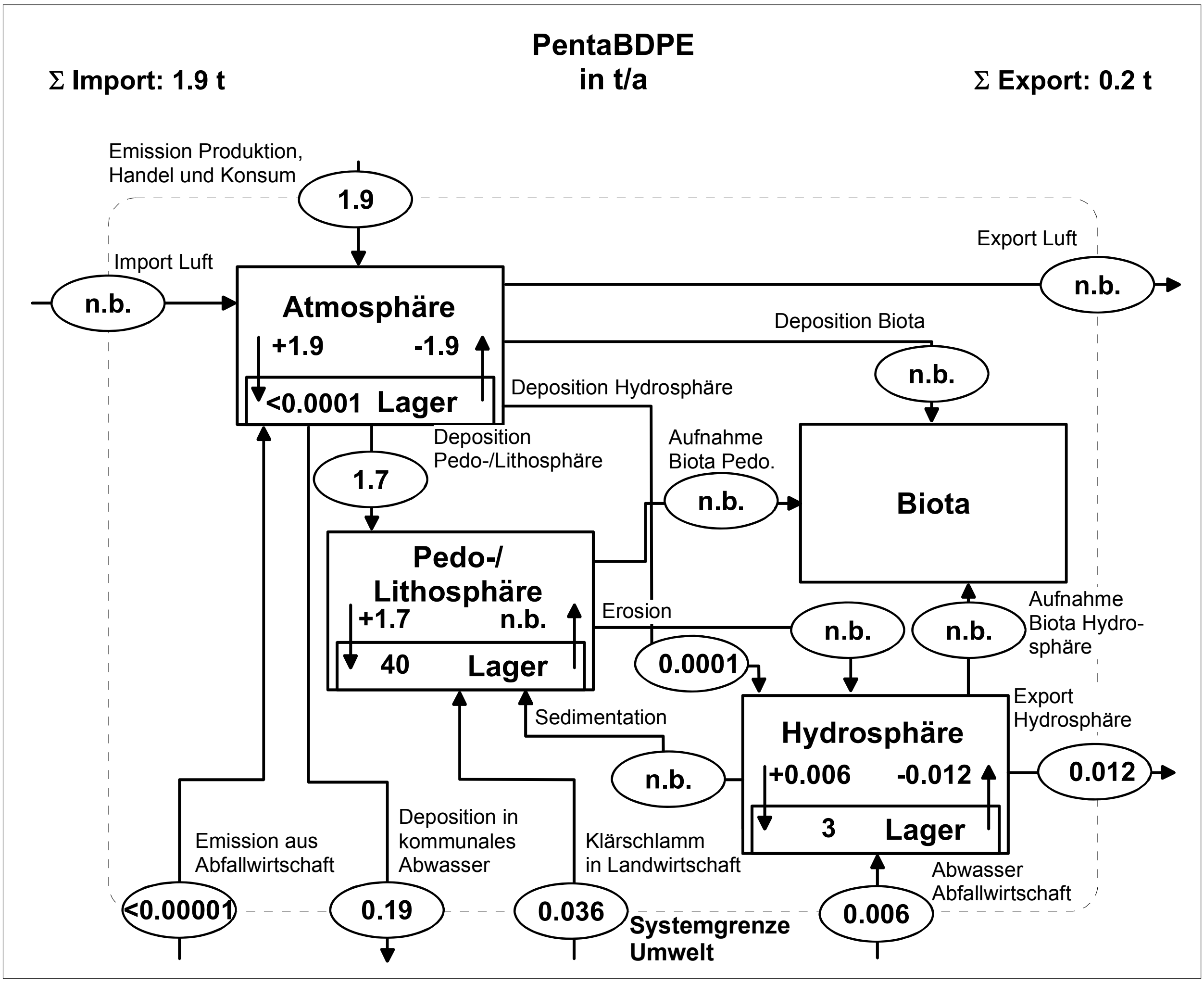
6.2.3.1 PentaBDPE (pentabromodiphenyl ether)

The *input to the environment* is estimated at a total of 1.9 t per annum at the end of the 1990s, where emission to the atmosphere from the subsystem: 'trade in products' accounts for almost the entire flow. Emission to the atmosphere from the subsystem: 'waste management' (excluding reuse processes) plays a subordinate role, being estimated at <0.00001 t/a. The input from 'waste management' to the pedo/lithosphere is estimated at 0.036 t (sewage sludge), and that to the hydrosphere at 0.006 t/a (waste water).

The deposition to municipal waste water from the atmosphere (via dust particles) is estimated at 0.19 t/a (=10 % of the emission from the process: 'trade in products'), and accounts for the most significant output from the subsystem: 'environment' to the subsystem: 'waste management'. The export via ground and surface waters is estimated at 0.012 t/a. Export and import via the atmosphere are neglected.

A rough estimate of the stock of pentaBDPE in the environment was performed based on data found in the literature for the concentration in the atmosphere, the pedo/lithosphere and the hydrosphere, together with the estimated weights of these compartments. The results show that <0.0001 t pentaBDPE are present in the atmosphere, some 3 t pentaBDPE in the hydrosphere and 40 t pentaBDPE in the pedo/lithosphere.

Fig. 6-9: PentaBDPE flows in the subsystem: 'environment'



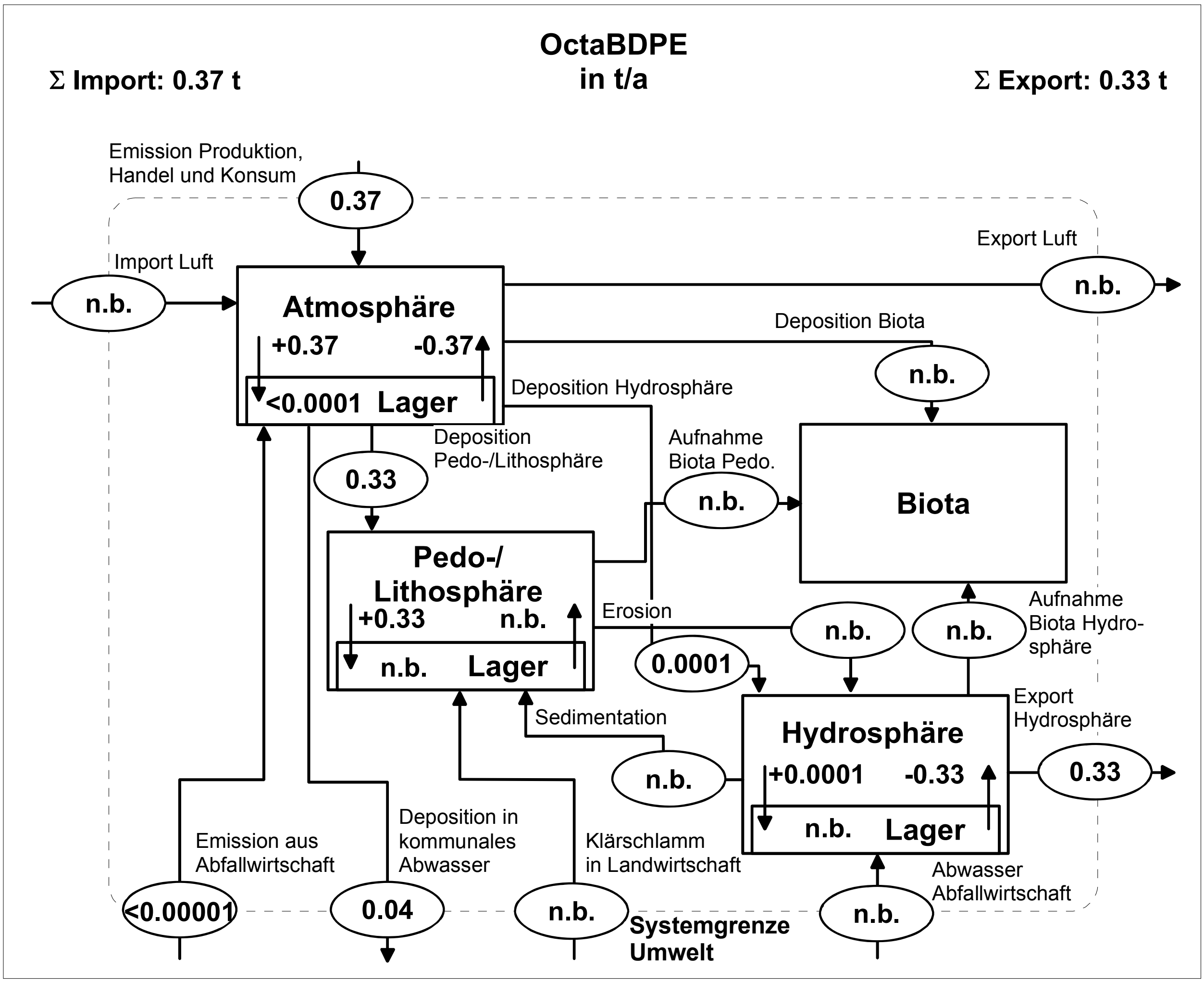
6.2.3.2 OctaBDPE (octabromodiphenyl ether)

The input of octaBDPE *to the environment* was estimated at a total of 0.37 t/a at the end of the 1990s. This input consists in the main of emission to the atmosphere from the subsystem: 'trade in products'. Emission from the subsystem: 'waste management' to the atmosphere (excluding reuse processes) plays a subordinate role, amounting to <0.00001 t/a. No estimates of the input of octaBDPE to the environment via sewage sludge or compost, nor of waste water from waste management, could be made.

The estimated export of 0.33 t/a via the hydrosphere (Rhine and Rhone) is the most significant output from the subsystem: 'environment'. The estimated deposition to municipal waste water via particle deposition from the atmosphere of 0.04 t/a (=10 % of the emission from the process: 'trade in products') to the subsystem: 'waste management' is an order of magnitude lower. Exports and imports via the atmosphere are neglected.

A rough estimate of the stock of octaBDPE in the environment was made based on data found in the literature for the concentration in environmental compartments and estimated compartment weights for the atmosphere, the pedo/lithosphere and the hydrosphere. The results show that <0.0001 t octaBDPE are present in the atmosphere. However, no estimates of the stocks in the hydrosphere or the pedo/lithosphere could be made.

Fig. 6-10: OctaBDPE flows in the subsystem: 'environment'

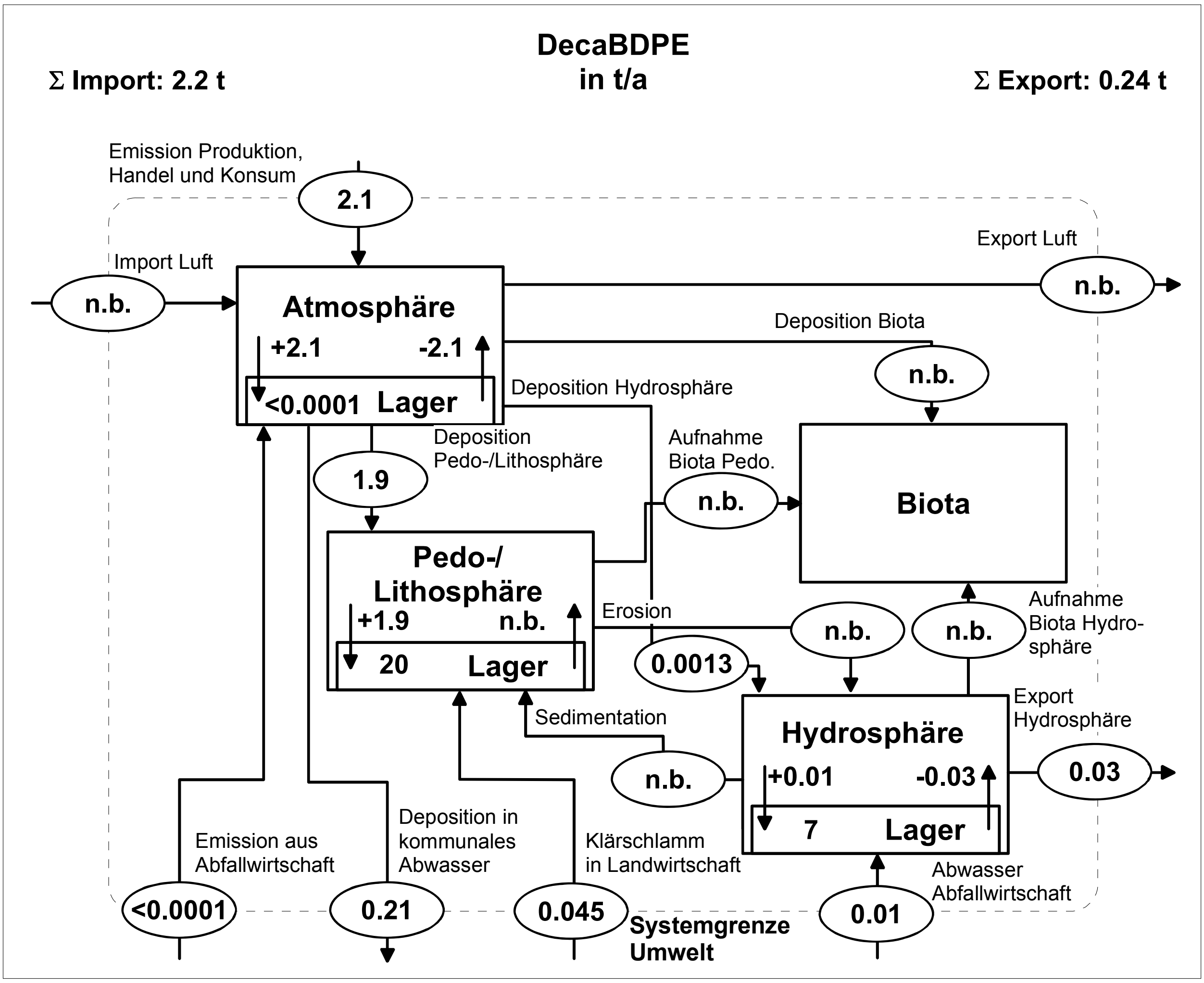


6.2.3.3 DecaBDPE (decabromodiphenyl ether)

The total decaBDPE *input to the environment* was estimated at 2.2 t/a at the end of the 1990s, and is thus of the same order of magnitude as that of pentaBDPE. The input consists almost entirely of emission to the atmosphere from the subsystem: 'trade in products'. Emission from the process: 'waste management' to the atmosphere (excluding reuse processes) plays a subordinate role, amounting to <0.00001 t/a. The input of decaBDPE to the environment (pedosphere) via sewage sludge is estimated at approx. 0.045 t/a. Approximately 0.01 t/a flows to the hydrosphere via waste water from waste management.

The estimated export via the hydrosphere (Rhine and Rhone) of 0.03 t/a from the subsystem: 'environment' is about an order of magnitude below the estimated deposition to municipal waste water from the atmosphere (via particle deposition) of 0.21 t/a (=10 % of the emission from the process: 'trade in products') to the subsystem: 'waste management'. Exports and imports via the atmosphere are neglected.

Fig. 6-11: DecaBDPE flows to the subsystem: 'environment'



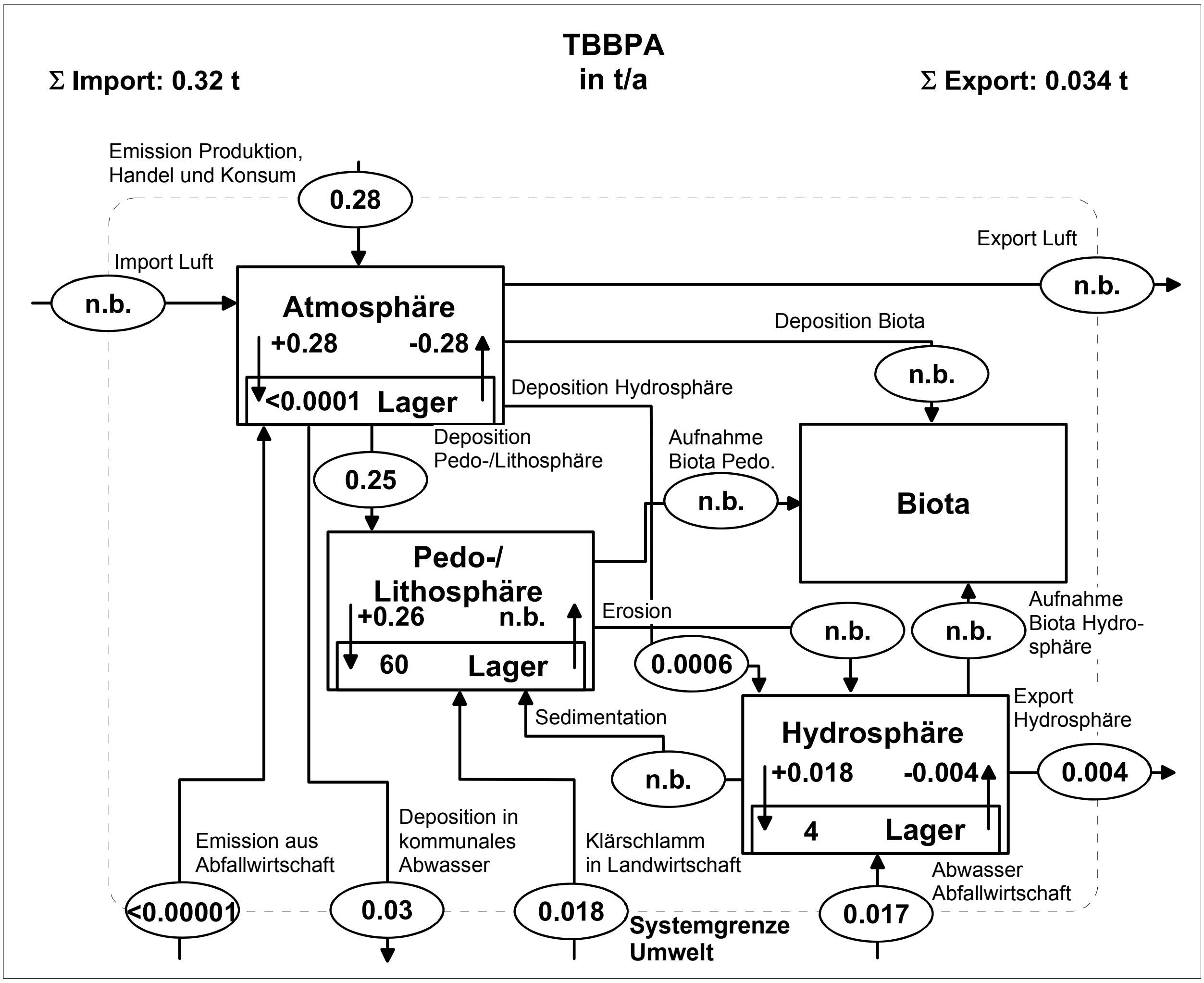
A rough estimate of the stock of decaBDPE was made based on data found in the literature for the concentration in the atmosphere, the pedo/lithosphere and the hydrosphere together with the estimated weights of these compartments. The results show that <0.0001 t decaBDPE is present in the atmosphere, some 7 t decaBDPE in the hydrosphere and approx. 20 t decaBDPE in the pedo/lithosphere.

6.2.3.4 TBBPA (tetrabromobisphenol A)

The TBBPA *input to the environment* was estimated at an annual total of 0.32 t at the end of the 1990s. This input is of the same order as that of octaBDPE. The input consists in the main of emission to the atmosphere from the subsystem: 'trade in products' of 0.28 t/a. Emission from the subsystem: 'waste management' to the atmosphere (excluding reuse processes) plays a subordinate role, amounting to <0.00001 t/a. The input to the environment (pedosphere) in sewage sludge is estimated at approx. 0.018 t/a. A quantity of some 0.017 t/a TBBPA is carried into the hydrosphere via waste water from waste management.

The estimated export via the hydrosphere (Rhine and Rhone) of 0.004 t/a from the subsystem: 'environment' is about an order of magnitude below the estimated deposition to municipal waste water from the atmosphere (via particle deposition) of 0.03 t/a (=10 % of the emission from the process: 'trade in products') to the subsystem: 'waste management'. Exports and imports via the atmosphere are neglected.

Fig. 6-12: TBBPA flows in the subsystem: 'environment'



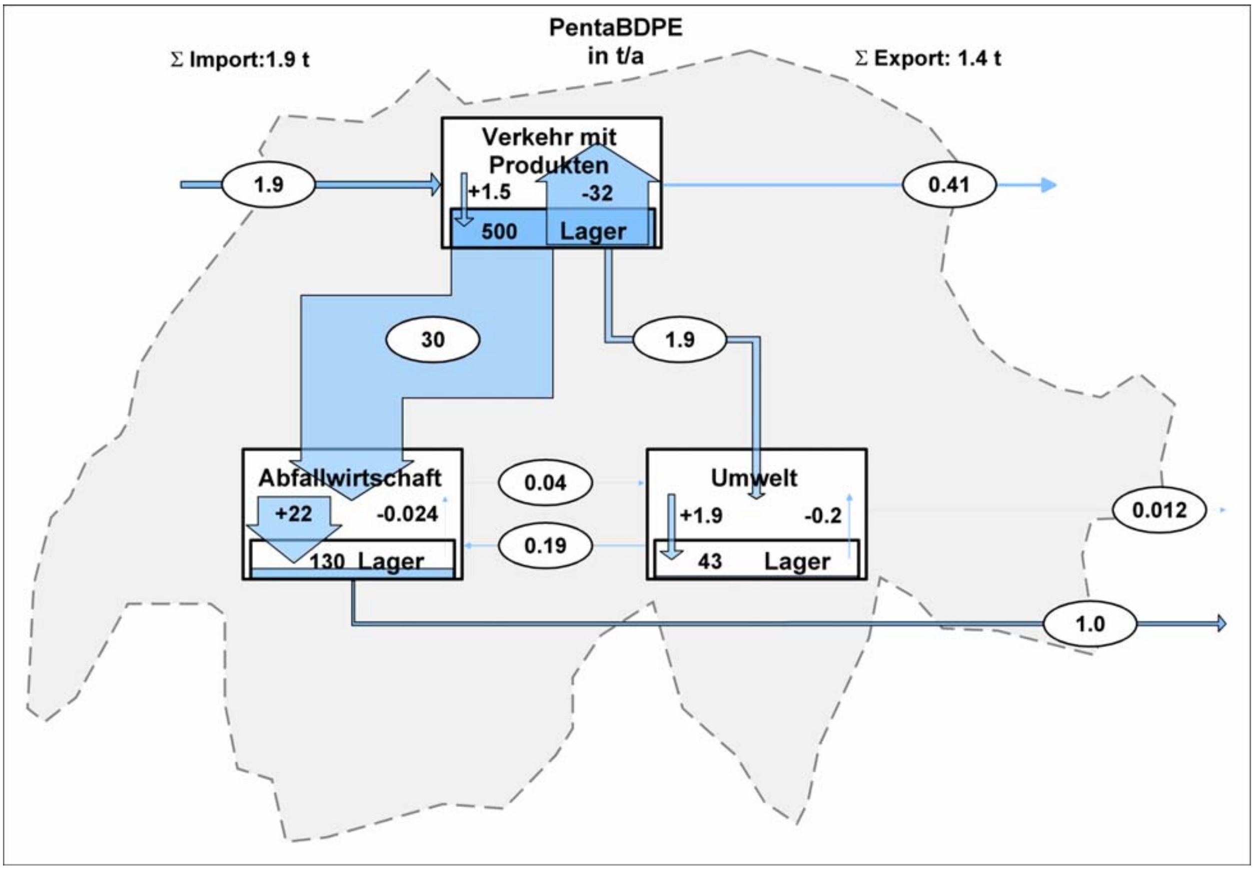
A rough estimate of the stock of TBBPA was made based on data found in the literature for the concentration in environmental compartments, together with estimated compartment weights for the atmosphere. The results show that <0.0001 t TBBPA are present in the atmosphere. The quantities present in the hydrosphere and the pedo/lithosphere could not be determined.

6.3 Flows of substances in the complete system

6.3.1 PentaBDPE (pentabromodiphenyl ether) – overall balance for Switzerland

In comparison to the other flame retardants, only very small quantities of products (materials) containing pentaBDPE were employed in Switzerland at the end of the 1990s. Approximately 1.9 t/a of pentaBDPE continued to be imported in finished products, of which some 22 % (0.41 t/a) were re-exported. The imports of pentaBDPE are attributable entirely to motor vehicles.

Fig. 6-13: PentaBDPE flows in Switzerland at the end of the 1990s



Over the last two decades, pentaBDPE was employed in a variety of ways, resulting in a stock of 500 t being built up in consumption (trade in products). The stock is present both in building materials containing pentaBDPE (91 %) that form an integral part of the total building mass, and in consumer goods (mainly textiles and printed circuit boards) (9 %), whose retention time in the anthroposphere is comparatively short. An investigation of the pentaBDPE stock shows clearly that this is now diminishing at the rate of about 30 t/a.

Of the 30 t pentaBDPE input annually to waste management at the end of the 1990s, only a small proportion (approx. 20 %) was thermally treated and thereby largely destroyed. The major part (72 %) found its way to landfills in Switzerland.

A non-negligible flow of 1.9 t diffuses annually from the stock in the anthroposphere to the environment. The major part of this (1.7 t/a) is input to the stock in the pedo/lithosphere. A very rough estimate of the pentaBDPE stock in the pedo/lithosphere shows that approx. 40 t are present in this process. Thus the percentage of pentaBDPE in the pedo/lithosphere of over 90 % of the total stock in the environment (43 t) is sizeable. The remaining 10 % are present in the hydrosphere.

A comparison of the three stocks of pentaBDPE in consumption (trade in products), in waste management and in the environment, shows that at the end of the 1990s, the largest stock of ca. 500 t was present in consumption. However, this is presently being depleted rapidly at the rate of 31 t per annum. Just under 70 % of this are disposed of in waste management in landfills. Should this trend continue, the stock in waste management will increase to some 280 t within the next 7 to 10 years to become the key anthropogenic stock.

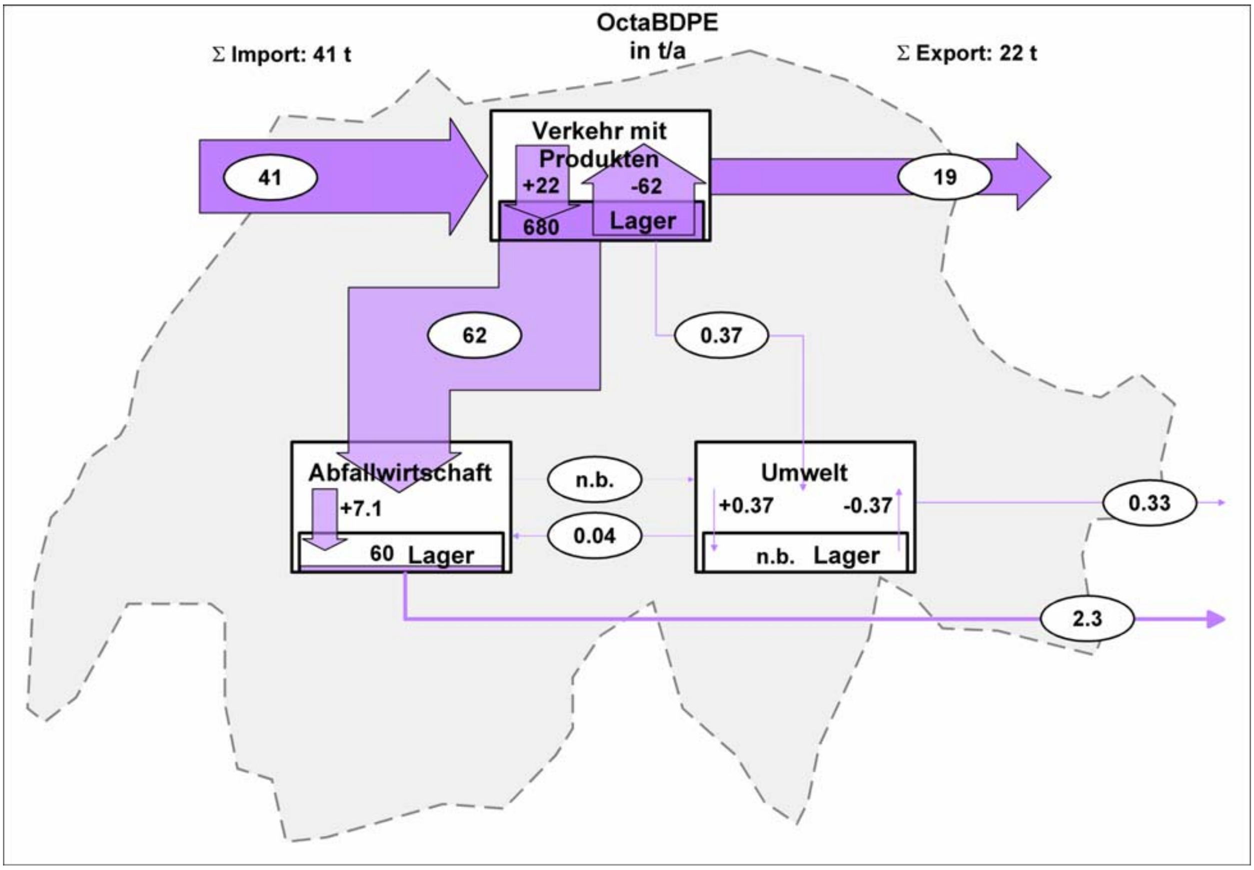
6.3.2 OctaBDPE (octabromodiphenyl ether) – overall balance for Switzerland

Over the past ten years, the consumption of octaBDPE flame retardants has declined worldwide by nearly 40 %. At the end of the 1990s, some 41 t octaBDPE were imported to Switzerland in the form of flame retardants in products. Almost half (46 %) of the imported products are re-exported. The octaBDPE imported is present in EE appliances (67 %) and in upholstery, textiles and plastics in motor vehicles (33 %).

Similarly to pentaBDPE, a stock of 680 t octaBDPE built up in consumption (trade in products) over the last two decades. This stock is mainly accounted for by EE appliances (69 %) and motor vehicles (21 %). The remaining 10 % of the stock is found in building materials containing octaBDPE that were no longer employed in new products at the end of the 1990s. As for pentaBDPE, the stock of octaBDPE in the anthroposphere had already been eliminated at the end of the 1990s. An annual quantity of 22 t octaBDPE are input to the stock, while approx. 62 t/a are passed on to waste management.

Of the 62 t octaBDPE that were passed on annually to waste management at the end of the 1990s, about 53 % was in separately collected waste, and of this, approx. 94 % contained in the residual materials was treated thermally. Also, of the octaBDPE contained in the 23 t of waste passed on directly for thermal treatment, approx. 87 % (contained in the solid waste) was treated thermally and thereby largely destroyed, and approx. 10 % was passed on to landfills in Switzerland. The remainder (3-4 %) was exported.

Fig. 6-14: OctaBDPE flows in Switzerland at the end of the 1990s



An annual 0.4 t octaBDPE diffuses from the stock in consumption to the environment. Compared to the other two PBDEs (pentaBDPE and decaBDPE), the diffuse emission of octaBDPE amounts to about one-fifth. This flow is largely (0.3 t/a) input to the stock in the pedo/lithosphere. The stock of octaBDPE in the environment could not be determined.

A comparison of the stock in consumption (trade in products) with that in waste management shows that at the end of the 1990s, the largest stock of octaBDPE (680 t) was present in consumption. This stock is presently diminishing at the rate of 40 t per annum. Approximately 11 % of the waste concerned is disposed of in landfills in waste management. Assuming that this trend continues, it will take about 13-18 years (i.e. about twice the time required for pentaBDPE) for the stock in waste management to become the key anthropogenic stock (then amounting to approx. 160 t).

6.3.3 DecaBDPE (decabromodiphenyl ether) – overall balance for Switzerland

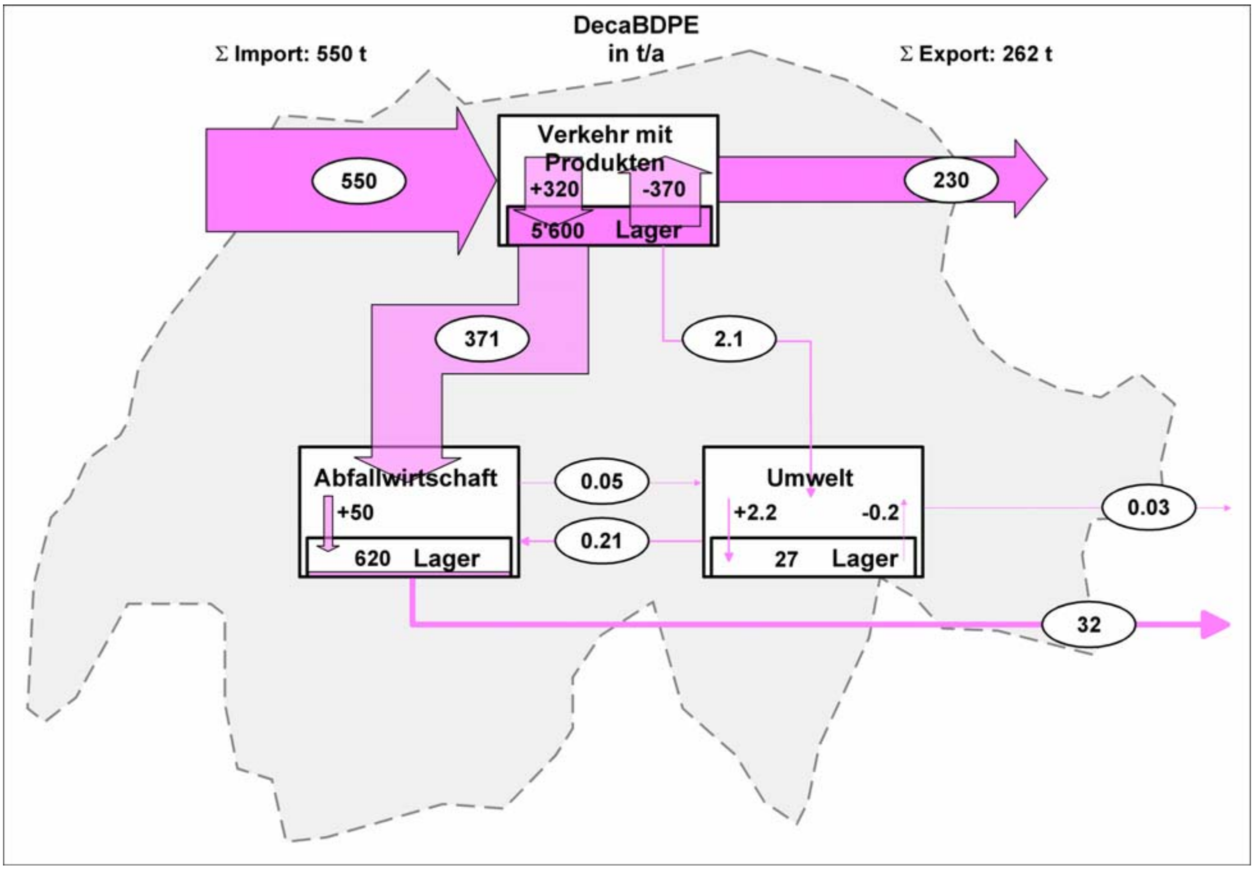
At the end of the 1990s, 550 t decaBDPE flame retardants were imported into Switzerland in products (materials), of which 24 % were present in semi-finished products and the remainder in finished products. Approximately 42 % of the decaBDPE imported were finally re-exported. About 45 % of the decaBDPE consumed in Switzerland are present in EE appliances (EDP and office equipment), some 30 % in imported motor vehicles and about 25 % in building materials (PE films).

The decaBDPE stock of 5600 t that has built up in past decades in consumption (trade in products) is very sizeable. This stock is present in EE appliances containing pentaBDPE (40 %), in building materials (30 %) and in motor vehicles (30 %). As opposed to pentaBDPE and octaBDPE, the stock of decaBDPE is in equilibrium, i.e. the annual input and output from the stock are equal.

Of the 371 t decaBDPE disposed of annually in waste management at the end of the 1990s, some 51 % was in separately collected waste, and of this, 77 % contained in the residual materials was treated thermally. Also, of the decaBDPE contained in the waste (143 t) passed on directly for thermal treatment, some 77 % (contained in the solid waste) was thermally treated and thereby largely destroyed, and some 20 % was disposed of in landfills in Switzerland.

An annual approx. 2.1 t/a of decaBDPE diffuses from the stock in consumption (trade in products) to the environment. This flow is largely (1.9 t/a) input to the stock in the pedo/lithosphere. The pentaBDPE stock in the pedo/lithosphere is estimated at 20 t.

Fig. 6-15: DecaBDPE flows in Switzerland at the end of the 1990s



The stock of decaBDPE in consumption amounts to 5600 t, exceeding that of pentaBDPE by a factor of 10. Despite this, the annual diffuse emission to the environment of ca. 2.1 t is about the same as for pentaBDPE.

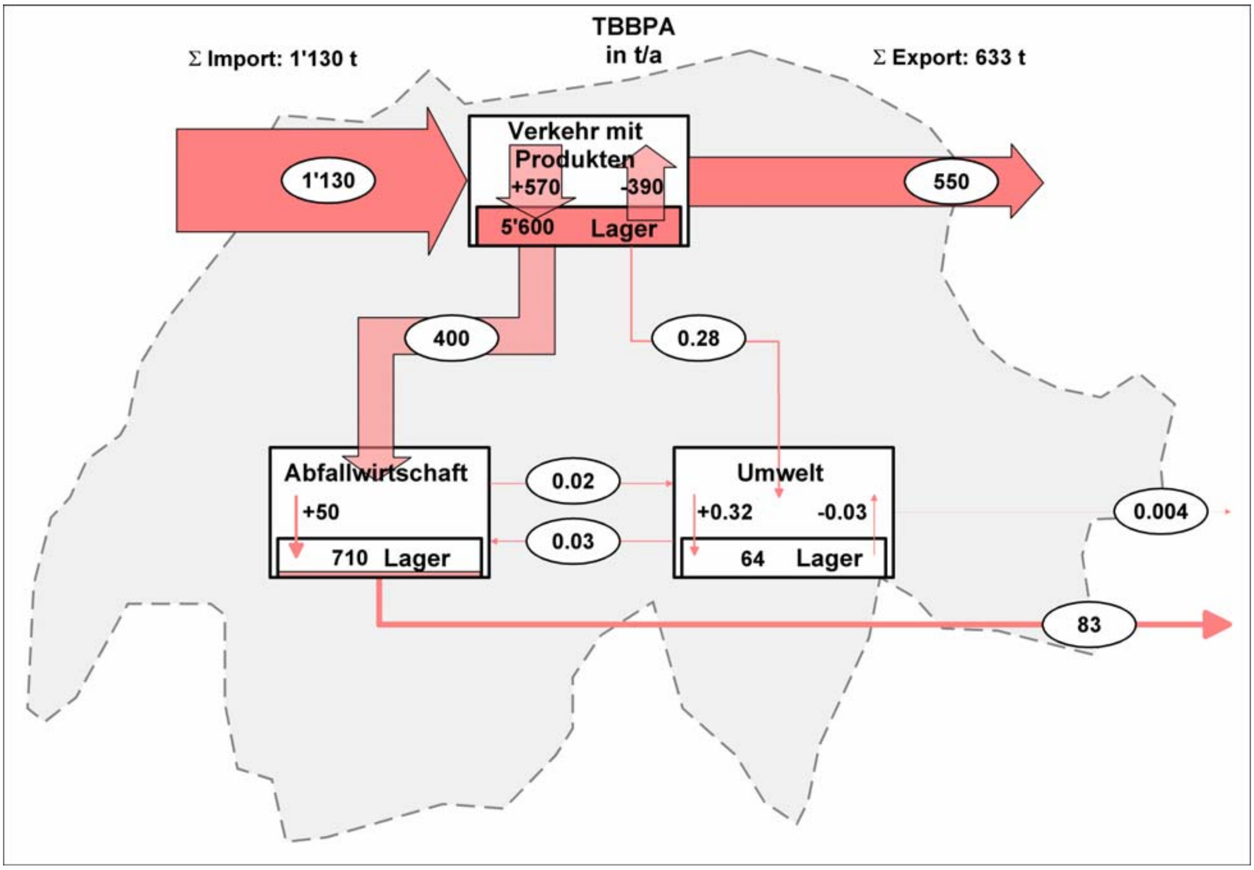
A comparison of the three decaBDPE stocks in consumption, waste management and the environment shows that at the end of the 1990s, the largest stock was in consumption, amounting to approx. 5600 t. This stock was approximately in dynamic equilibrium. If this trend continues, the stock in consumption (approx. 4500 t - 5000 t) will remain the most significant anthropogenic stock over the next 20 years.

6.3.4 TBBPA (tetrabromobisphenol A) – overall balance for Switzerland

At the end of the 1990s, 1130 t TBBPA flame retardants were imported in products (materials) to Switzerland, of which 40 % was present in semi-finished products and the remainder in finished products. Some 48 % of the TBBPA imported was finally re-exported. Some 83 % of the TBBPA consumed in Switzerland is present in computers, and approx. 11 % in imported household electronic appliances.

The stock of 5600 t TBBPA that has built up in consumption (trade in products) in Switzerland in past decades is estimated to be about the same as that of decaBDPE. This is present in EE appliances containing pentaBDPE (59 %) and in approximately equal quantities in building materials and motor vehicles (20 % each). As opposed to decaBDPE, the TBBPA stock is not in equilibrium, but is expanding by about 180 t annually.

Fig. 6-16: TBBPA flows in Switzerland at the end of the 1990s



Of the 400 t TBBPA disposed of annually in waste management at the end of the 1990s, approx. 50 % occurred in separately collected waste, and of this, approx. 55 % contained in the residual materials was treated thermally. Also, of the TBBPA contained in the waste (166 t) passed on directly for thermal treatment, approx. 68 % (contained in the solid waste) was treated thermally and thereby to a large extent destroyed, and approx. 22 % disposed of in landfills in Switzerland.

Annually approx. 0.3 t/a TBBPA diffuses from the stock in consumption to the environment. Among the four flame retardants under study, this is the least significant diffuse emission. The TBBPA flow is mainly input to the stock in the pedo/lithosphere. The TBBPA stock in the pedo/lithosphere is estimated at 60 t.

A comparison of the three stocks of TBBPA in consumption (trade in products), waste management and the environment, shows that at the end of the 1990s, the largest stock (5600 t) was present in consumption. This stock is increasing by about 180 t annually. If this trend continues, the stock in consumption (approx. 9000 t) will remain the most important anthropogenic stock.

7 Conclusions

7.1 Introduction

Consumption patterns of the four brominated flame retardants (pentaBDPE, octaBDPE, decaBDPE and TBBPA) under study have altered significantly over the last ten years. While world consumption of octaBDPE has declined markedly, that of pentaBDPE, decaBDPE and TBBPA has increased heavily. Consumption of the four flame retardants taken together has almost doubled worldwide over the period.

Brominated flame retardants have been the subject of controversial discussion now for more than 15 years. Today, more is known of the **behaviour and potential hazards to humans and the environment** of brominated flame retardants than was known at the time about PCB, when their use and production were prohibited. The hazard potential of the flame retardants under study arises mainly from the fact that they are persistent, and that they accumulate in the food chain (e.g. pentaBDPE and TBBPA), that dioxins and furans may be formed during thermal processes (e.g. decaBDPE), and from indications of their carcinogenic potential (e.g. decaBDPE) and possible estrogenic effects (i.e. pentaBDPE).

In Europe (particularly in Scandinavia) the prohibition – or at least renunciation of the use – of certain brominated flame retardants, is at present under discussion. The voluntary undertaking of Japanese industry not to produce or import pentaBDPE under the OECD 'Risk Reduction Program' has had no noticeable effect on global consumption. World consumption of pentaBDPE has doubled over the last ten years. The **globalisation of markets,** particularly in the electronics and electrical appliances sectors, makes it extremely difficult to trace the flow of brominated flame retardants contained in finished and semi-finished products via consumption to disposal. Their journey takes them across the length and breadth of the globe. The EU (or the OECD where appropriate) are therefore under pressure to take more effective action to alleviate this situation. Indeed, measures need to be applied not only to the flame retardants studied here, but to other brominated flame retardants as well.

Under a commitment signed in 1995, industry voluntarily undertook to adopt the best available technologies with a view to minimising the emission from production. Regarded from a global perspective, however, it is now clear that it is not so much the emission of problematical substances from isolated production processes, but the **diffuse emission** of these during the consumption, disposal and recycling of the products treated with flame retardants, that is the main cause of the increasingly apparent environmental pollution.

7.2 Metabolism of the flame retardants under study in Switzerland

The four brominated flame retardants (BFR) under study enter Switzerland via imported semi-finished and finished products at an annual flow of some 1700 t. Of this, approx. 46 % are re-exported in finished products, while the remainder finds its way to the stock in the anthroposphere. The main inputs to the anthroposphere in Switzerland are as follows: pentaBDPE: motor vehicles (upholstery, textiles); octaBDPE: electrical and electronic appliances and motor vehicles; decaBDPE: EE appliances (EDP and office equipment), motor vehicles and building materials (PE films); TBBPA: EE appliances (computers) and EE appliances.

Since no BFR are produced in Switzerland, **isolated emission of pollutants can be excluded.**

The dominant process at the end of the 1990s was 'trade in products', in which the stock in consumption (consumer goods and buildings in use) played a major part. Over the past 20 years, a **stock** of approx. **12 000 t BFR,** and possibly significantly more, has built up in Switzerland via the **consumption of products that had been treated with flame retardants.** At present, while the stocks of pentaBDPE and octaBDPE are diminishing, those of TBBPA are growing, and those of decaBDPE are approximately in dynamic equilibrium. As opposed to its presence in newly imported products, the stock of pentaBDPE is found mainly in building materials, that of octaBDPE in EE appliances and motor vehicles, of decaBDPE in EE appliances, and of TBBPA in building materials. Approximately 900 t of products treated with flame retardants leave the stock in consumption annually, and almost all of this is passed on in the form of solid waste to waste management.

In **waste management,** the greater part of the BFR contained in the solid waste (65 - 85 % depending on the substance) is disposed of via **thermal treatment** in controlled incineration processes such as those used in MWIP. Although few measurements have yet been made in incineration processes, it is safe to assume that the brominated flame retardants are almost completely destroyed during controlled incineration. The quantities remaining in incineration residues in Switzerland were estimated in this study. However, no information could be found in the literature on the significance of these quantities in an environmental context.

No information is available at present on the extent and significance of the emission resulting from the **reuse** of waste containing flame retardants. It is well known that recycling processes can present a problem at the workplace (since significantly higher quantities of BFR were found in exposed persons). Increased attention will need to be paid to this aspect in future. In practice, the reuse of plastics materials containing BFR proves to be a serious problem, since on the one hand there is a danger that dioxins and furans will be formed, and on the other there is no market for the recycled materials.

Alongside the stock in consumption, a ten-fold smaller one of 1500 t of BFR has built up in Swiss **landfills.** This stock is growing by approx. 130 t per year. If unsuitably managed, this, too, could represent a potential future hazard to humans and the environment. Little or nothing is known at present of the quantity of BFR emitted from **uncontrolled incineration** (of building waste and plastics), from landfill gases, or from diffuse emission arising from the reintroduction of **reused materials** to production or export**.** One very significant theme that was not covered in the discussion of brominated flame retardants in the present study, is that of **brominated dioxins and furans.** Little is known today about the production or significance of these compounds, which can arise during the disposal and utilisation of BFR at high temperatures.

In the absence of up-to-date measurements for Switzerland, only very rough estimates of the flows to the **environment** from the anthroposphere and from waste management could be made. In this connection it is important to note that even quite small deviations from the assumptions made (e.g. concerning the gaseous emission of BFR from products) may alter the calculated substance flows – which are very small in comparison to those within the anthroposphere – by a large margin. Provisional estimates were nevertheless made based on data for other countries found in the literature. Since the substances under study are often found attached to dust particles, and are lipophilic, their emission to the atmosphere – and resulting deposition over wide areas – represents the main input channel to the environment. The input to municipal waste water via dust particles was estimated in the present study as a fraction of total emission to the atmosphere. Measurements are required to precisely quantify this relationship.

7.3 Data reliability

The flows and stocks in the anthroposphere could only be roughly estimated for Switzerland. The data given represent probable 'average' values. The range of error in the data given for the **subsystem: 'trade in products'** was determined by varying the material flows, concentrations, market shares, component weights and life cycles. For most of the flows, the error margin is a factor of two for the case where all parameters assume their maximum values, and approximately a factor of three for minimum parameters. The uncertainty in the stock, as well as in the emission resulting from this, is a factor of 2.5 in both directions. To obtain statistical values, coordinated and suitably planned analyses of consumer products (including data on production year, market share, etc.), and intensified cooperation with the producers of the materials and/or plastics, and with the manufacturers of consumer products, are required. With the aid of these, ranges of error and their probabilities could be determined.

The estimate of the stock of electrical and electronic appliances present in households was based on the assumption of an average service life of these consumer goods. Of course, the larger the difference between the service life and the actual retention time of these goods in households (resulting, for example, from storage of unserviceable consumer goods in cellars), the greater is the uncertainty in the volume of the stock.

The uncertainties in the **subsystems: 'waste management' and 'environment'** are difficult to quantify. Since no direct measurements were available for Switzerland, these could not be calculated. The range of error of the material flows was either taken directly from the subsystem: 'trade in products', or the latter value increased by an additional margin (e.g. to account for uncertainties in the transfer coefficients). The uncertainties specified for the material flows in these two subsystems (normally a factor of 2 - 3) were estimated. To what extent the assumptions are justified cannot at present be assessed. This will not be possible until measurements have been performed in Switzerland.

7.4 Data gaps, required action and research

The uncertainty of the data in the **subsystem: 'trade in products'** is mainly attributable to the large volume of products consumed, and to a lack of knowledge concerning the type and concentration of the flame retardants employed.

To establish national substance flow analyses, a sufficiently precise data basis is required. The statistics available from the Swiss customs authorities are insufficiently precise to determine the product flows (i.e. import, export) by weight. In most cases, an infrastructure that would permit the preparation of substance flow analyses is lacking. Indeed, even the material flows themselves are not satisfactorily ascertainable. **The Federal Customs Administration and the Federal Statistical Office in Switzerland are therefore called on to provide a suitable data basis.**

Random inquiries at electrical and electronics companies revealed that little or no information is available to them on the flame retardants contained in their products. **It is essential for purposes of precautionary environmental protection that companies are informed on the potential risks to health and the environment of the products they market. Where this knowledge is lacking, companies must take steps to acquire it. A possible approach to the optimisation of manufacturing processes would be the introduction of substance flow balance sheets.**

In cooperation with the manufacturers of basic materials, semi-finished and finished products, an analysis is required at global level to trace the product paths, and – following from this – the material flows, 'from the cradle to the grave'. **Over and above existing product labelling, the ultimate aim should be to include information on the flow of critical substances with the product, or at least to make this data available. It may also be necessary to reconsider the criteria for the award of marks of excellence to products.**

The interrelationship between the flows to the anthroposphere and their effect on the global environment are still mostly not known in detail. This makes it extremely difficult to establish a correlation between the environment and the anthroposphere. **As a basis for further research (e.g. 'Risk Assessment' and national studies), it would be useful to make available a global breakdown of material flows.**

Only scant information is available from existing studies on the stock of flame retardants in consumer goods. While for certain areas the magnitude and composition of this could be estimated by the authors, for others (textiles, upholstery and rubber treated with flame retardants) this was not possible. However, comprehensive quantification of the stock is essential for the determination of diffuse emission. Although diffuse emission may appear to be negligible in comparison to overall metabolism [???], it is central to the environment and to questions of human health. **The stock of flame retardants needs to be analysed and quantified. This will enable (a) the stock to be actively managed, (b) the emission to be estimated, (c) future waste flows to be forecast, and (d) flows into landfills and diffuse emission from these to be controlled and minimised, permitting suitable landfill rehabilitation programs to be established. The greatest need is for concerted monitoring and management of the stocks of products treated with flame retardants, together with their disposal and recycling paths. In addition, alternatives (substitutes) to brominated flame retardants should be included in the monitoring to forestall possible hazards arising from these.**

Our knowledge on the transformation and degradation of substances during use, and in the environment, is at present wanting and entirely inadequate. **To provide precise information on substance flows into and within the environment, further studies are therefore required on debromination and the formation of dioxins and furans.**

Likewise, there is a complete lack of knowledge on diffuse emission to the environment from the consumption of products containing BFR. Till now, the statements made on this topic have been very contradictory. Since even a small fraction of the quantities produced worldwide would represent a potential problem if they were to be released directly to the environment in the form of diffuse emission, special attention should be paid to this aspect. In the past, studies were concerned exclusively with measurements in the human body, no consideration having been given to the correlation with BFR in products. **Intensified studies will be needed in future to determine the emission behaviour of flame retardants in consumer products. These must be performed in such a way as to permit quantitative conclusions to be drawn on the flows.**

Owing to the fact that waste management must absorb large flows of substances from consumption, suitable technological treatment of these is of prime importance. Non-negligible quantities of BFR contained in untreated form in waste continue to find their way into landfills. This represents a further source of diffuse emission to the environment. The actual volume of emission resulting from waste management processes today is either little known (e.g. in the case of incineration) or completely unknown (e.g. in the case of reuse, landfills and uncontrolled disposal). A knowledge of these flows is, of course, fundamental to effective management, not only at the production stage, but also during the disposal and reuse phases. **It is therefore essential to perform measurements on the principal waste management processes, i.e. in MWIP, landfills, reuse processes and waste water treatment.**

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9 Appendix

9.1 Appendix 1 – trade in products

This appendix is concerned with the calculation of the flame retardant flows presented in Chapter 5.1. The structure corresponds to that of Chapter 5.1.

9.1.1 National and international comparisons

This part is concerned with the calculation of the flame retardant flows presented in Chapter 5.1.6.4.2.

9.1.1.1 Basic data

Where not otherwise stated, comparisons between the European nations are based on population figures.

Tab. 9-1: Population data [Statistics for Austria, 1999]

POPULATION 1999	Million inhabitants	Factor for Switzerland
Industrial countries[1)]	1185.00	0.00603
Europe (incl. Russia)	729.00	0.00979
Europe (excl. Russia)	582.00	0.01227
Western Europe	183.00	0.03902
Germany	**82.09**	**0.08698**
Denmark	**5.33**	**1.34034**
France	59.10	0.12081
Austria	8.09	0.88224
Sweden	8.86	0.80614
Switzerland	**7.14**	**1.00000**

Source: www.statistik.at: Statistical Yearbook 2001: Table 37.01 (world population 1950 to 2050 divided according to region) and Table 37.03 (area, population and population density)

1) North America, Japan, Western Asia, Europe, Australia, New Zealand

9.1.1.2 Plastics

Tab. 9-2: Consumption of EE products and of plastics contained in them in Western Europe in 2000 and 1998 (determined from [APME, 2001] and [APME, 1995])

CONSUMPTION OF EE PRODUCTS IN WESTERN EUROPE	**2000**		**Growth 1998 -2000**		**1998**		**1998**	
	Appliances	Plastics	Appliances	Plastics	Appliances	Plastics	Plastics	Plastics concentration
	1000 t	1000 t	%	%	1000 t	1000 t	%	%
Household electronics	916	217	0.70%	-2.86%	910	223	9.1%	24.6%
EDP equipment (excl. printers)	1647	431	29.26%	41.89%	1274	304	12.3%	23.9%
Telecommunications	124	74	5.79%	7.13%	117	69	2.8%	59.2%
EE office equipment	508	89	12.40%	29.07%	452	69	2.8%	15.3%
Small household appliances	312	151	0.91%	13.19%	309	133	5.4%	43.1%
Large household appliances	2826	481	4.27%	-3.76%	2710	500	20.3%	18.4%
Cables	3969	995	5.28%	5.29%	3770	945	38.4%	25.1%
Small EE components	2892	192	3.92%	4.12%	2783	184	7.5%	6.6%
Electric tools	97	11	0.91%	13.19%	96	10	0.4%	10.1%
Vending machines	49	10	0.91%	13.19%	49	9	0.4%	18.2%
Toys and games	11	8	0.91%	13.19%	11	7	0.3%	64.8%
Medical appliances	125	4	0.00%	0.00%	125	4	0.2%	3.2%
Lighting appliances	93	3	0.91%	13.19%	92	3	0.1%	2.9%
Monitoring and control instruments	5	3	0.91%	13.19%	5	3	0.1%	53.5%
Subtotal IT+ telecom.	2279	595	23.63%	34.43%	1843	443	18.0%	24.0%
Subtotal EE appliances	6713	1483	10.95%	11.99%	6150	1334	54.2%	21.7%
TOTAL EE sector	**13 574**	**2670**	**7.70%**	**8.82%**	**12 703**	**2464**	100.0%	19.4%

Notes: all product flows are quoted without plugs, disconnectors and cables. The subtotal IT+ telecommunications includes EDP equipment and EE office equipment. Subtotal EE appliances comprises everything except cables and small EE components. The annual growth rates were determined from the growth values for 1995 to 2000 assuming a linear increase. Since the statistics for 1995 do not specify electric tools, vending machines, lighting appliances and monitoring instruments separately, it was assumed that the growth rates for these were equal to those for small household appliances.

The percentages of consumed plastics in EE products produced in Western Europe in 2000 were 27 % for Germany and 19 % for France [APME, 2001]. The Swiss consumption was derived from that in Germany based on population (see following table). When the calculation was performed for France, the same value (19 %) was obtained. According to the Danish study [Danish EPA, 1999], the percentage of TBBPA and PBDE in relation to total BFR was 100 % in printed circuit boards, some 70 % in casings and approximately one-third in other components.

Tab. 9-3: Consumption of EE products and plastics, and of flame retardants contained in them, in Switzerland in 1998

CONSUMPTION OF EE PRODUCTS	Appliances	Plastics	Plastics treated with flame retardants		Plastics treated with brominated flame retardants	
	1000 t	1000 t	%	t	%	t
Household electronics	21.36	5.247	34%1)	1789	83%	1485
EDP equipment (excl. printers)	29.92	7.140	65%	4641	83%	3852
Telecommunications	2.75	1.630	0%2)	0	0%	0
EE office equipment	10,62	1.624	20%	325	83%5)	270
Small household appliances	7.26	3.133	2%	63	50%6)	31
Large household appliances	63.65	11.738	1%	117	50%6)	59
Cables	88.53	22.193	n.a.		n.a.	
Small EE components	65.35	4.331	20%2)	866	54%	468
Electric tools	2.26	0.228	2%3)	5	50%6)	2
Vending machines	1.14	0.207	20%4)	41	50%6)	21
Toys and games	0.26	0.166	2%3)	3	50%6)	2
Medical appliances	2.94	0.094	20%4)	19	50%6)	9
Lighting appliances	2.16	0.062	20%4)	12	50%6)	6
Monitoring and control instruments	0.12	0.062	20%4)	12	50%	6
Subtotal IT+telecom	43.3	10.4		4966		4122
Subtotal EE appliances	144.4	31.3		6077		5743
TOTAL EE sector	298.3	57.9	12%	6943		6211

Note: see notes for Tab. 9-2.

Sources: previous table, percentage of plastics treated with FR from [APME, 2001] and percentages of brominated FR from [APME, 1995]

n.a.: not available

1) TV and a small number of audiovisual appliances: 55%. Remainder: almost none. Household electronics total: 34% (calculated)

2) [APME, 1995]

3) assumption: same as small household appliances

4) assumption: same as office equipment

5) assumption: same as EDP equipment and household electronics

6) authors' assumption

The percentage of plastics in EE products on the Western European market differed greatly between 1995 and 2000, particularly for PVC and PE (see Tab. 9-4). This is attributable to the fact that in 2000, plugs, disconnectors and cables were not included in EE appliances. PVC was used mainly for cable sheathing.

Tab. 9-4: Types of plastics used in the EE sector in Western Europe in 1995 and 2000, and rough estimate for Switzerland in 1998 [APME, 2001]

PLASTICS IN EE APPLIANCES	**W. Europe 1995 incl. cables etc.1) [%]**	**W. Europe 2000 excl. cables etc.1) [%]**	**W. Europe 1995 incl. cables etc.1) [1000 t]**	**W. Europe 2000 excl. cables etc.1) [1000 t]**	**Switzerland 1998 excl. cables etc.2) [t]**
PE	**18.9%**	0.5%	403	8	169
PBT_PET	1.1%	1.3%	24	19	401
POM	0.4%	1.8%	8	26	549
PA	5.5%	3.0%	117	45	951
UP	0.8%	3.3%	16	49	1035
PC	1.9%	3.6%	41	53	1120
PVC	**25.4%**	3.6%	541	54	1141
EP	0.9%	3.7%	19	55	1162
PUR	6.7%	8.4%	142	125	2641
PP	11.6%	17.9%	247	266	5620
PS	13.3%	19.4%	283	287	6064
ABS-ASA-SAN	13.5%	33.4%	288	496	10 479
Total EE appliances	**100.0%**	**100.0%**	**2129**	**1483**	**31 332**

1) In distinction to 1995, the statistics for 2000 showed EE appliances without plugs, disconnectors and cables

2) Composition of plastics assumed as for Western Europe in 2000

9.1.1.3 Flame retardants

Tab. 9-5: Sales markets for flame retardants [t/a]

Region	**Year**	**Unit**	**PentaBDPE**	**OctaBDPE**	**DecaBDPE**	**Sum of PBDEs**	**TBBPA**
Asia1)	1999	t/a	0	2000	23 000	25 000	85 900
America1)	1999	t/a	8290	1375	24 300	33 965	21 600
Europe1)	1999	t/a	210	450	7500	8160	13 800
World1)	1999	t/a	8500	3825	54 800	67 125	121 300
World2)	1998	t/a	<10 000	<20 000	>50 000	80 000	>50 000
World3)	1990/91	t/a	4000	6000	30 000	40 000	60 000
World4)	(1993)	t/a	-	-	-	-	41 000

1) Data from BSEF (Bromine Science and Environmental Forum) [Leisewitz et al., 2000] (vol. I, p.20)
2) Estimate according to the 'Great Lakes' BFR manufacturer cited in [Kuhn, 1999]
3) Data for TBBPA from [OECD, 1994] (p.125). All other values from [European Commission, 1996] p.15
4) [IPCS, 1995, p. 35]

Future trends in the world market for BFR were forecast by one manufacturer (Great Lakes Chemical [Kuhn, 1999]) as follows:

- decaBDPE and TBBPA: increasing
- octaBDPE: heavy decline
- pentaBDPE: constant

Tab. 9-6: Percentage of pentaBDPE, octaBDPE and decaBDPE in PBDE markets

Region	Year	PentaBDPE	OctaBDPE	DecaBDPE	PBDE
Asia1)	1999	0.0%	8.0%	92.0%	100%
America1)	1999	24.4%	4.0%	71.5%	100%
Europe1)	1999	2.6%	5.5%	91.9%	100%
World1)	1999	12.7%	5.7%	81.6%	100%
World2)	1998	12.5%	25.0%	62.5%	100%
World3)	1991	10.0%	15.0%	75.0%	100%

1) Data from BSEF (Bromine Science and Environmental Forum) [Leisewitz et al., 2000] (vol. I, p.20)
2) According to estimate made by "Great Lakes" BFR manufacturer, cited in [Kuhn, 1999]
3) [IPCS, 1994b, p. 34]

Tab. 9-7: Estimate of flame retardant flows in consumed final products based on annual production of flame retardants

Flame retardants and plastics in 1999	**Penta-BDPE**	**Octa-BDPE**	**Deca-BDPE**	**TBBPA**	**Plastics2)**	
Production and content in final products	t/a	t/a	t/a	t/a	million t/a	%
World production 19991)	8500	3825	54 800	121 300	168.000	100%
Final products consumed in Germany	448	202	2890	6397	8.860	5.27%
Final products consumed in Denmark	29.1	13.1	188	415	0.575	0.34%
Final products consumed in Switzerland	39.0	17.5	251	556	0.771	0.46%

Note: The FR flow in final products in Germany in 1999 was derived from world FR production on the basis of the ratio of world plastics production to the plastics flow in final products consumed in Germany.

1) Data from BSEF (Bromine Science and Environmental Forum) [Leisewitz et al., 2000] (vol. I, p.20)
2) World production according to [VKE, 2000] and final products consumed in Germany according to [Consultic, 2000]

In 1999, some 10.2 million t of plastics were converted to final products in Germany [Consultic, 2000]. According to a study carried out by the UBA in Berlin [Leisewitz et al., 2000] (vol. I, p.27 and p.31) these final products contained some 1000 t decaBDPE and 3800 t TBBPA.

The plastics content of final products consumed in Germany in 1999 (some 8.9 million t [Consultic, 2000]) is about 13 % lower than that of final products produced. It can, however, be assumed that the flow of flame retardants in consumed final products is higher than in produced final products [Leisewitz et al., 2000] (vol. I, p.17, 2nd footnote), since

- A high proportion of the consumer goods that dominate the FR flow (e.g. EE appliances, TV, cars) are imported
- in comparison to products produced inside Germany, imported products (e.g. from Asia or America) generally have a higher content of FR.

To obtain a rough estimate, it is assumed that the flame retardant flow in consumed final products is approximately the same as that in produced final products. It should, however, be mentioned that this assumption probably underestimates the flows.

Tab. 9-8: Plastics and BFR in consumed final products in Germany ([Consultic, 2000], [Leisewitz et al., 2000] (vol. I, p.27 and p.31) as applied to Switzerland)

Plastics and BFR [t/a]	Plastics	DecaBDPE	TBBPA
Germany, 1999	8 860 000	1000	3800
Conversion Switzerland, 1999	771 000	87	331

Note.: no data available for pentaBDPE or octaBDPE

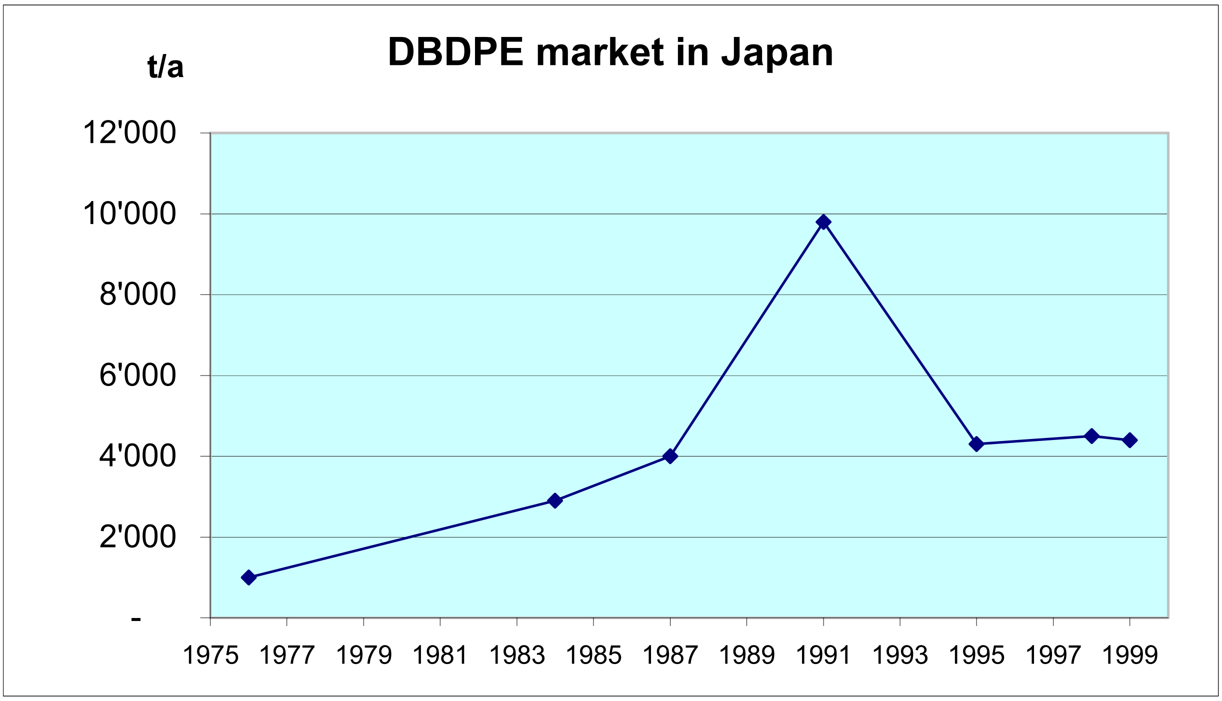
Tab. 9-9: Flame retardants in consumed final products in Denmark ([Danish EPA, 2000, p.88) as applied to Switzerland)

FR in consumed final products	PentaBDPE [t/a]	OctaBDPE [t/a]	DecaBDPE [t/a]	PBDE [t/a]	TBBPA [t/a]
Denmark, 1997, minimum	3.8	1.7	24	30	180
Denmark, 1997, average	9.5	4.3	61	75	270
Denmark, 1997, maximum	15.2	6.8	98	120	360
Switzerland, 1997, minimum	5.1	2.3	33	40	241
Switzerland, 1997, average	12.7	5.7	82	101	362
Switzerland, 1997, maximum	20.4	9.2	131	161	483

Note: Breakdown of PBDE into pentaBDPE, octaBDPE and decaBDPE based on their percentage of world production in 1999 (see Tab. 9-6)

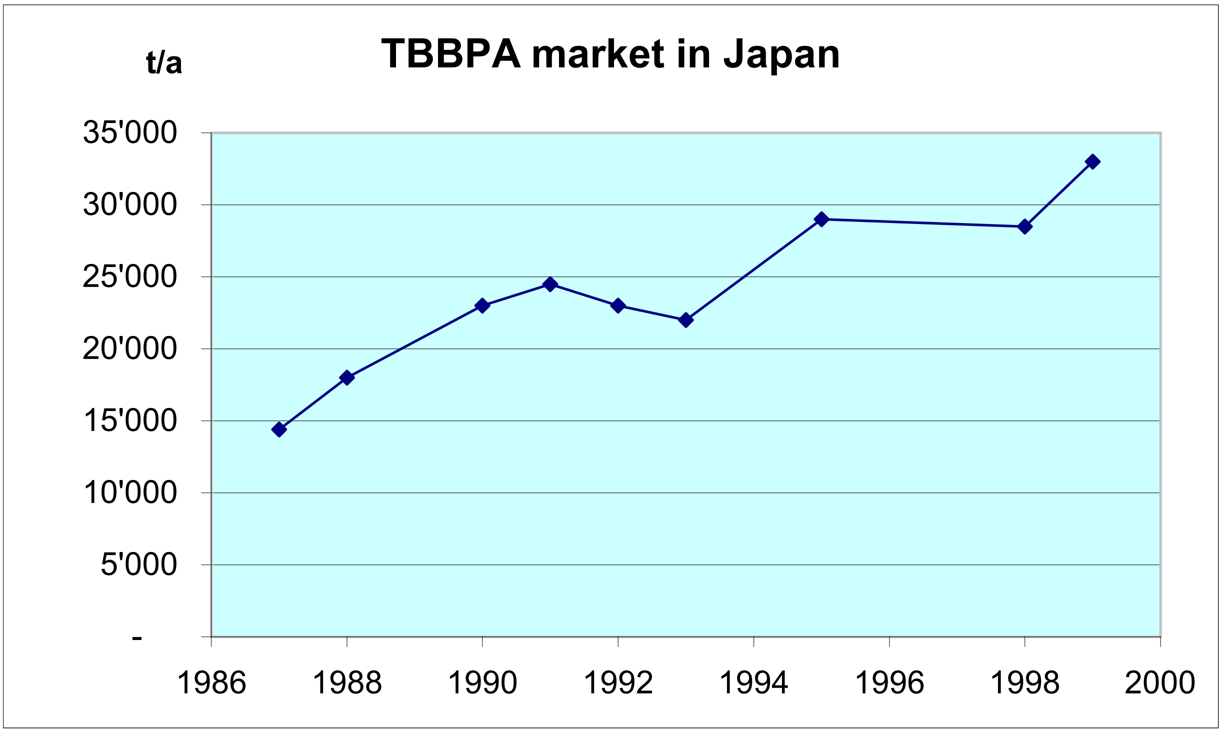
Market analyses show that the world market is increasing both for FR in general (3.5 - 4.0 % annually [Davenport, 1999]), and for BFR in particular (8.0 % annually [Danish EPA, 1999]). Very few data are available to forecast market trends for pentaBDPE, octaBDPE, decaBDPE and TBBPA, but certain results can be obtained from the trend in the Japanese market.

Fig. 9-1: DecaBDPE market in Japan according to information from FR manufacturers and traders



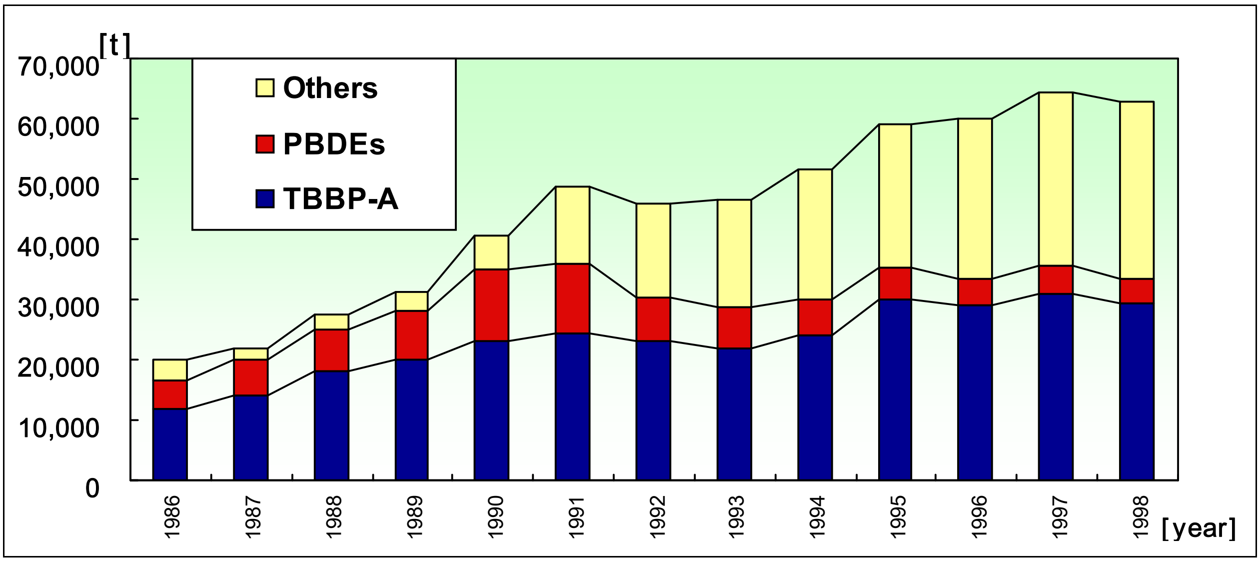
Data sources: 1976-1991 [IPCS, 1994b, p.71], 1995-1999 firm of TOSOH [Kuhn, 1999]

Fig. 9-2: TBBPA market in Japan according to information from FR manufacturers and traders



Data sources: 1976-1993 [IPCS, 1995, p.35], 1995-1999 firm of TOSOH [Kuhn, 1999]

Fig. 9-3: Consumption of organic brominated FR in Japan [Sakai et al., 2001]



Expected trends in the world BFR market were forecast by one manufacturer (Great Lakes Chemical [Kuhn, 1999]) as follows:

- decaBDPE and TBBPA: increasing
- octaBDPE: heavy decline
- pentaBDPE: constant

9.1.2 Formulations of plastics

Tab. 9-10: Flame retardant concentrations in plastics

	Penta-BDPE	Octa-BDPE	Deca-BDPE	TBBPA	Other FR	Sb_2O_3	Source
HDPE V2		5.0%			1.6%	3.5%	1
HDPE V0			10.0%			10.0%	1
LDPE V2					6.0%	3.5%	1
LDPE V2		4.9%			1.6%	3.6%	1
PE (cables, building materials)			20-24%			mostly	2
PP					3.5%	2.0%	1
PP V1					27.0%	13.0%	1
PP V2			4.8%			1.6%	2
PP V2				5.2%		1.7%	2
PP V0			24.0%			12.0%	2
PP V1			21.7%			10.9%	2
PP			23.0%			8.0%	4
PVC	4.9%				13.2%		1
PVC			possible				2
HIPS V1					15.0%	5.0%	1
Impact PS V0		15.0%				5.0%	1
Crystal PS V2					3.0%		1

	Penta-BDPE	**Octa-BDPE**	**Deca-BDPE**	**TBBPA**	**Other FR**	**Sb_2O_3**	**Source**
PS foam V0			13.0%			5.0%	1
PS			12.0%			4.0%	4
PS				15.0%		4.0%	4
HIPS V0			11.0%			4.4%	2
HIPS V0			12.0%			4.0%	3
HIPS V0				17.0%		4.0%	3
HIPS previous			10-12%			3-4%	5
HIPS previous				12-15%		3-4%	5
HIPS V0 new				17.0%			5
ABS V1					17.0%	5.0%	1
ABS V0		13.0%				5.0%	1
ABS V0		15.4%				5.6%	2
ABS V0				17.0%		6.0%	2
ABS				20.4%		4.0%	3
ABS		20.0%				6.0%	4
ABS				20.0%		4.0%	4
ABS previous		18-22%				4-8%	5
ABS previous				18-22%		4-8%	5
ABS V0 new		15.4%				0.5-2%	5
ABS V0 new				19.0%		0.5-2%	5
PC/ABS				rarely	mostly		5
PPE/HIPS					always		5
PA6 V0-V1			10.0%			6.0%	1
PA16 V0			10.0%			5.0%	1
Textile coatings			10.0%			5.0%	2
Nylon6 V0			17.5%			6.7%	2
Saturated polyester V0		8.0%				4.0%	1
Unsaturated polyester					possible		2
Polyester + glass fibre V0			9.0%			4.0%	1
PC V0			5.0%			1.9%	1
PUR foam					possible		2
Polyterephthalate			12.0%			4.0%	4

Note: V0, V1, V2 fire protection category according to UL tests.

Sources:

1) Plastics Handbook [Gächter & Müller, 1987]
2) FR manufacturer [Dead Sea Bromine, 2001]
3) FR manufacturer [Albemarle, 2001]
4) FR manufacturer [OECD, 1994]
5) FR manufacturer [Leisewitz & Schwarz, 2000]

9.1.3 Electrical and electronic appliances (EE appliances)

9.1.3.1 Market analyses for EE appliances

In early 1999, some 3.8 million computers were in use in Switzerland, of which about 1.8 million were in offices, 0.55 million were portable and the rest (1.8 million) were located in households [Weiss, 2000].

Fig. 9-4: Numbers of computers sold in Switzerland [Weiss, 2000]

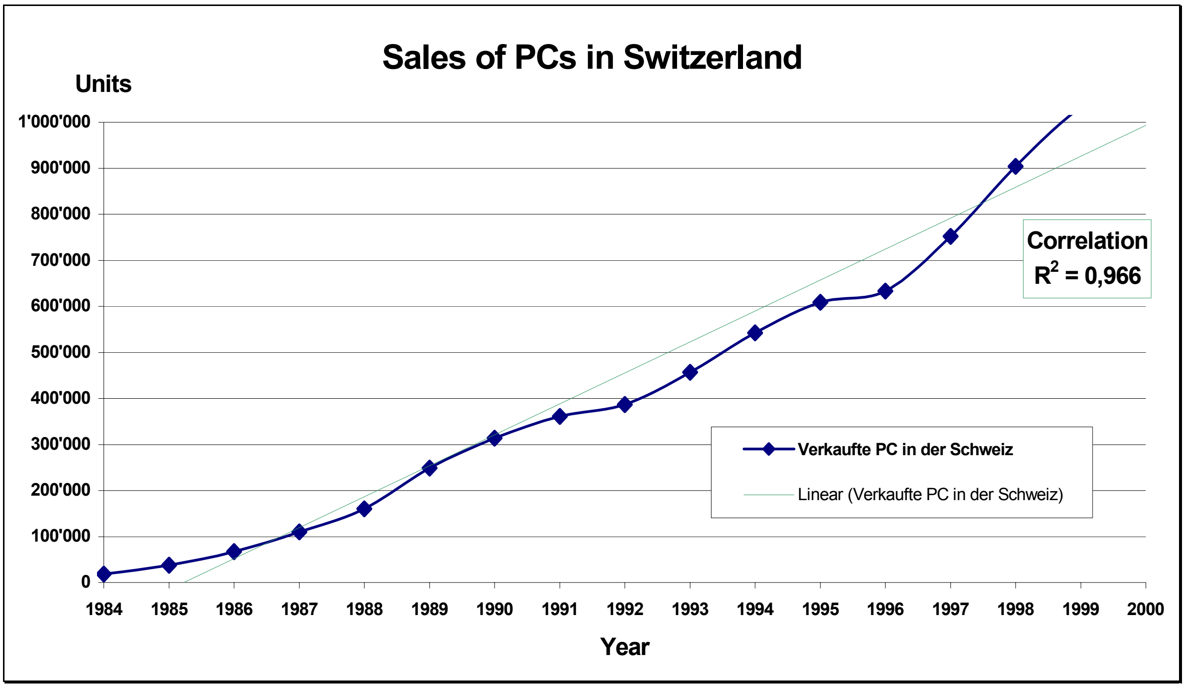
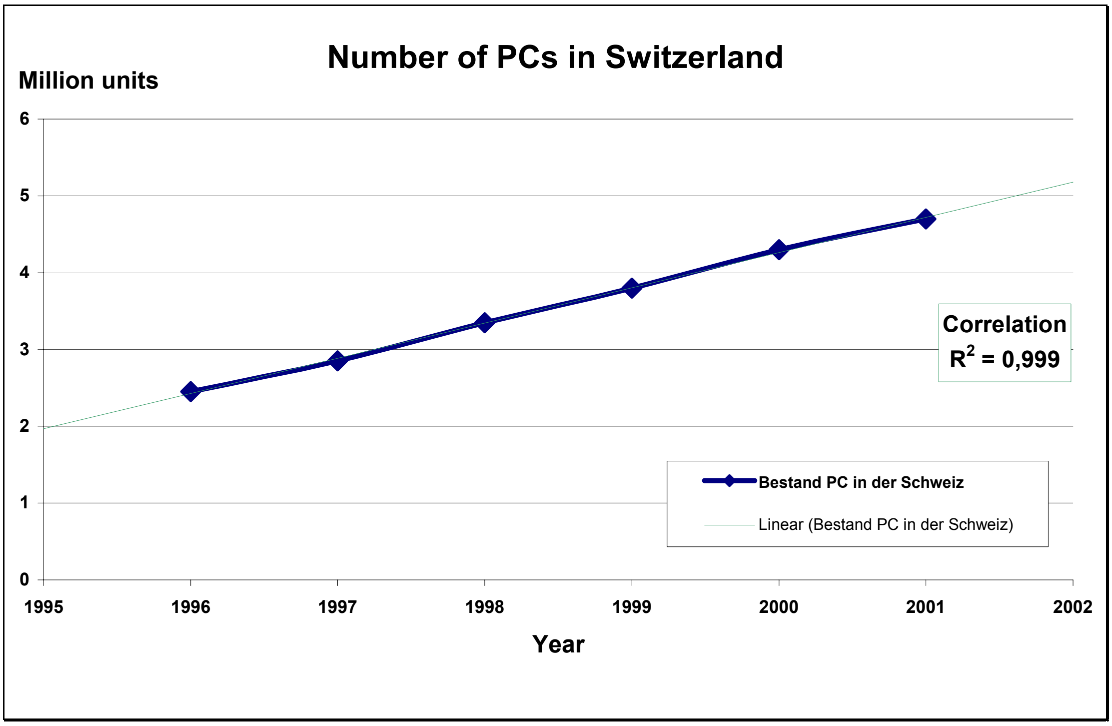


Fig. 9-5: Numbers of computers installed in Switzerland [Weiss, 2000]



As shown by the two previous figures, the numbers both of computers sold and of those installed in Switzerland increased approximately linearly. Calculations based on these time series showed the service life of computers to be about 5.9 years, the average increase in consumption between 1997 and 1998 was 10.5 %, the quantity disposed of in 1998 approximately 390 000 units, and the increase in the stock about 510 000 units.

According to the White Paper [Weiss, 2000], the following numbers of computers were sold in Switzerland in 1998:

904 000	total
724 500	desktop
30 500	servers
149 000	portable (notebooks)
188 500	home computers
536 000	office computers

In 1998, Swiss assembly firms built some 170 000 computers.

Tab. 9-11: EDP equipment consumed in Switzerland in 1998

Equipment sold [units]	**Consumption**	**Consumption**	**Difference**
	Switzerland '98	Switzerland '98	
	Danish study [Danish EPA, 1999]	White Paper '99 [Weiss, 2000]	[%]
Home appliances	166 480	188 500	113.2%
Office equipment	403 561	536 000	132.8%
Servers	31 452	30 500	97.0%
Notebooks	85 156	149 000	175.0%
Total	686 649	904 000	131.7%

As no data were available for Switzerland, the number of EE appliances sold in Switzerland was derived from market analyses for Denmark. Swiss market analyses are, however, available for computers. These show that the numbers for Denmark are of the same order as those for Switzerland, being only 30 % lower. The Danish values for EDP, telecommunications, office and household electronic appliances were correspondingly increased by 30 %.

Tab. 9-12: Product consumption figures for Western Europe [APME, 1995], [APME, 2001]

Appliances sold in Western Europe [1000 t/a]	**1980**	**1992**	**1995**	**1998**	**2000**
Household electronics	428	861	900	**910**	916
EDP equipment (excl. printers)	27	**537**	715	**1 274**	1 647
Communications technology	55	98	107	**117**	124
Office equipment	37	327	368	**452**	508
Small household appliances	201	287	305	**309**	312
Large household appliances	1 970	2 426	2 537	**2 710**	2 826
Cables	**1 607**	2 753	3 471	**3 770**	3 969
Small EE components	**1 374**	2 468	2 619	**2 783**	2 892
Medical equipment	70	125	125	**125**	125
Subtotal IT+ telecom.	119	962	1 190	**1 843**	2 279
Subtotal EE appliances	2788	4 661	5 057	**5 898**	6 458
TOTAL EE sector	5 769	9 882	11 147	**12 450**	13 319

Note: values for 1998 calculated on the assumption of a linear increase in consumption.

Tab. 9-13: Product life cycles [APME, 1995]

Life cycle	**Percentage in life cycle range**					**Life cycle**	
years	2-5	5-10	10-20	20-40	40-	**Average**	**Source**
Household electronics	5%	15%	**70%**	10%	0%	14.8	calculated
EDP equipment (excl. printers)	**40%**	**40%**	20%	0%	0%	(7.4) **5.9**	1
Communications technology	20%	**70%**	10%	0%	0%	7.5	calculated
Office equipment	**40%**	**40%**	20%	0%	0%	7.4	calculated
Small household appliances	20%	**70%**	10%	0%	0%	7.5	calculated
Large household appliances	5%	15%	70%	10%	0%	14.8	calculated
Cables	5%	20%	**50%**	20%	5%	17.7	calculated
Small EE components	0%	10%	**40%**	**40%**	10%	23.8	calculated
Medical equipment	10%	30%	**50%**	10%	0%	13.1	calculated
Building materials						40	2
Cars						13	3
Rail vehicles						35	4

Note: Calculated values determined from percentage within the life cycle range, together with the average value of the range. For the range designated as "40-", an average value of 50 years was assumed. Data sources:

1) For these appliances, a value of 7.4 years was calculated from the life cycle ranges. In the present study, however, a calculated value of 5.9 years as quoted in a Swiss market analysis [Weiss, 2000] was used.
2) [Arx, 1995]
3) [APME, 1999]
4) [SBB, 2001]

Tab. 9-14: Estimated percentages of plastics and FR in EE products, and in total plastics

	Plastics[1)]	Plastics treated with flame retardants[2)]	Plastics containing BFR[3)]	Plastics containing TBBPA or PBDE[4)]	Mass of TBBPA+ PBDE[5)]
Duroplastics	7.70%	6.93%	6.72%	6.72%	1.28%
Thermoplastics	92.30%	15.41%	6.17%	4.62%	0.32%
Sum	**100%**	**22.34%**	**13.10%**	**11.35%**	**1.60%**

Note: all percentage figures are quoted in relation to total plastics in EE appliances.

1) [Leisewitz & Schwarz, 2000] p.120
2) almost all duroplastics (assumption: 90 %) and one-sixth of all thermoplastics are treated with flame retardants [Leisewitz & Schwarz, 2000] p.121
3) brominated plastics: duroplastics calculated using the values in the tables given in Appendix ‘printed circuit boards’ (97 % BFR). Thermoplastics (40 %) [Leisewitz & Schwarz, 2000] p.120
4) some 75 % of all BFR in casings are either TBBPA or PBDE. See estimates in Appendix ‘outer casings of EE appliances’
5) duroplastics: lower value (19 %) used for commonest laminates (FR4). Thermoplastics (7 %) [Leisewitz & Schwarz, 2000] p.121

9.1.3.2 Printed circuit boards

Tab. 9-15: International market for laminates in 1998 (basic data from [Leisewitz & Schwarz, 2000] p. 145)

Laminate market in 1998 areas and weights	FR4	High perform	FR2	Composites	**Sum**
USA [million m²]	31	3.4	0.0	3.1	38
SE Asia [million m²]	46	0.2	50	4.7	101
Japan [million m²]	19	2.3	11	8.1	41
EU (+ exUSSR) [million m²]	25	0.6	6.9	3.3	35
Sum [million m²]	121	6.5	68	19	215
Percentage area [%]	56%	3.0%	32%	9.0%	100%
Specific weight [kg/m²]	3.0	2.0	2.0	2.0	-
Weight [million t]	**362**	**13**	**136**	**38**	**550**
Weight [%]	66%	2.4%	25%	7.0%	100%

Note: approximately 50 % of FR4 laminates and over 70 % of FR2 laminates are manufactured in SE Asia.

9.1.3.3 Outer casing of EE appliances

In connection with the materials used for casings, the available publications show large uncertainties in the data as to which appliances (or parts of appliances) have been treated with flame retardants, and which flame retardants, if any, were used.

The most reliable data concern appliances whose casings are not treated with flame retardants (i.e. communications technology, EE household appliances). Even so, there is some uncertainty concerning appliances imported from outside Europe, as well as for older appliances.

The percentage weights of casings in EE appliances given in the literature differ considerably. For computers (computer + monitor + keyboard), the German study [Leisewitz & Schwarz, 2000] assumes the percentage weight of the casing to be 18 %, and the average total weight to be 30.5 kg. From this, the weight of plastics in casings amounts to 5.5 kg. However, the value quoted in the substance flow analysis for Denmark [Danish EPA, 1999] is only 1.7 kg.

Tab. 9-16: Plastic casings of EE appliances in Switzerland in 1999 [Leisewitz & Schwarz, 2000]

	Consumption Germany	Consumption Switzerland	Unit weight	Percentage plastics	Percentage casing	Consumption	Plastics	Casing
	Million units	Million units	kg/unit	%	%	t	t	t
Computers	7.5	0.65	13.5	22%	15%	**8 807**	1 937	1 321
Monitors	7.5	0.65	16	22%	20%	**10 438**	2 296	2 088
Keyboards	18.5	1.61	1 1)	70% 1)	50% 1)	**1 609**	1 126	805
Inkjet printers	5.74	0.50	6.5	18.5%	15%	**3 245**	600	487
Laser printers	2.46	0.21	10	18.5%	15%	**2 140**	396	321
Scanners	1.9	0.17	5 1)	15% 1)	12% 1)	**826**	124	99
Copying machines	0.3	0.03	35	20%	15%	**913**	183	137
Fax machines	1.3	0.11	10 2)	18.5% 2)	15% 2)	**1 131**	209	170
TV	5.7	0.50	25	20%	15% 3)	**12 395**	2 479	1 859 3)
EE office equipment 4)	10.4	0.90	7.9	18.3%	14.7%	**7 125**	1 303	1 044
EE scrap				22%	15%			

Sources:

1) authors' assumption
2) assumption: values as for laser printers
3) of this, only half (i.e. the rear cover) is treated with flame retardants
4) printers, scanners and copying machines

For Switzerland, the flows of plastics and FR (see Tab. 9-17) were calculated from the German study [Leisewitz & Schwarz, 2000]. An important result of the present calculations is that in 1999, only half as many casings of the appliances concerned (EDP, office, TV) were treated with brominated flame retardants as in 1990.

Tab. 9-17: Outer casings of selected EE appliances treated with brominated flame retardants (derived from [Leisewitz & Schwarz, 2000] p. 262)

Brominated flame retardants in plastic casings	**Percentage brominated casings 1990**	**Percentage brominated casings 1999**	**Casings 1999**	**Brominated casings 1999**	Reduction in percentage 1999/1990
Switzerland 1999	**%**	**%**	**t**	**t**	%
Monitors	50%	25%	2088	522	50%
Keyboards	40%1)	10%	805	80	25%
Inkjet printers	33%	33%	487	161	100%
Laser printers	80%	50%	321	160	63%
Copying machines	80%	50%	137	68	63%
TV appliances (rear cover)	50%	10%	930	93	20%
Sum			4766	1085	46%

1) authors' assumption

Tab. 9-18: Estimate of market share and concentration of FR in plastics for casings

	OctaBDPE				**DecaBDPE**				**TBBPA**			
	New products		Older products		New products		Older products		New products		Older products	
	[%]	[g/kg]	[%]	[g/kg]	[%]	[g/kg]	[%]	[g/kg]	[%]	[g/kg]	[%]	[g/kg]
ABS	10	154	50	200	0		0		10	190	20	200
PC/ABS	0		0		0		0		0		10	200
HIPS	0		0		10	115	30	110	10	170	10	135
PPE/HIPS	0		0		0		10	110	0		10	135

Source: FR manufacturers and German study [Leisewitz & Schwarz, 2000]

Tab. 9-19: Analyses of EE appliances [Leisewitz & Schwarz, 2000]

Percentage appliances	**Plastic**				**Flame retardant**						
[%]	ABS	HIPS	others	total	octa-BDPE	deca-BDPE	TBBPA	BFR total	other FR	without FR	total
PC monitor casings 1990 (78 units)	44%	18%	38%	100%	10.3%	2.6%	12.8%	43.5%	34.6%	21.9%1)	100%
TV casings 1990 (108 units)	25%	69%	26%	100%	16.7%	17.6%	0%	48%	7.4%	44.4%1)	100%

Note: octaBDPE is only present in ABS, while decaBDPE is usually only present in HIPS

1) value probably lower, since PPE/HIPS casings were not tested for organic phosphorus flame retardants

9.1.4 Vehicles

This section presents basic data for the determination of flows and concentrations for this product group.

Tab. 9-20: Total quantity of vehicles and newly registered vehicles in Austria [Statistics for Austria, 1999]

Numbers of road vehicles	**Motor scooters / mopeds**	**Motorcycles**	**Cars**	**Lorries**
Total number 1997	362 953	212 791	3 782 544	803 955
Registered 1998	20 419	25 147	295 865	44 085

Note: Registration only applies to new vehicles. The lorry category includes buses and other vehicles. The figures for Switzerland were obtained using a factor of 0.882 based on the population figures.

In Denmark, more than half the cars consumed in 1997 were manufactured outside Europe [Danish EPA, 1999]. It is expected that significantly more PBDE were brought into circulation via imported vehicles than via those manufactured in Europe

The average percentage of plastics used in cars is rising slightly, and now amounts to some 9.3 % of total weight in the whole of Europe (1998). Somewhat more than 10 % of this occurs in small EE components (i.e. in electrical components and lighting appliances) [APME, 1999].

For lorries, the same quantity of plastics was assumed as for cars. For motorcycles and mopeds, the percentage by weight for cars was used.

Tab. 9-21: Plastics and FR content of cars [Danish EPA, 1999]

Car	**Unit**	**Minimum**	**Average**	**Maximum**
Plastics in cars(1)	[kg]	110	110	110
BFR in cars(2)	[kg]	0.175	0.275	0.375
BFR in plastics	[g/kg]	1.591	2.500	3.409

Note: for older vehicles, the percentage of flame retardants was assumed to be twice as high
BFR=brominated flame retardants

1) [APME, 1999] plastic components excl. small plastic components (in electronic and lighting appliances)
2) [Danish EPA, 1999] p.83 and p.84

For Denmark, the proportion of TBBPA and PBDE in total BFR is given as approximately one-quarter. A similar proportion is taken for Switzerland. The PBDE are divided into pentaBDPE, octaBDPE und decaBDPE based on world production as shown in the following table.

Tab. 9-22: Percentage of individual BFRs and total BFR in cars

Flame retardant	**New vehicle**	**Older vehicle (1990)**
PentaBDPE	3%	3%
OctaBDPE	2%	5%
DecaBDPE	25%	35%
TBBPA	25%	15%
Total BFR	100%	100%

BFR = brominated flame retardant

The percentages of FR are based on the total mass of commercial FR products and not on the substances

The Swiss Federal Railways (SFR) quote the average life expectancy of rail vehicles at 20-50 years. The age distribution of rail vehicles in service is given on the SFR internet website.

Tab. 9-23: Total number of rail vehicles in Switzerland [SBB, 2001]

Number of rail vehicles	**Locomotives**	**Passenger coaches**
Total number 1998	2032	3993

9.1.5 Building materials and textiles

This section presents the basic data for the determination of flows and concentrations for this product group.

Tab. 9-24: Consumption and flame retardant content of EPS and XPS in Denmark [Danish EPA, 1999] (p.80)

Denmark 1997	Density	Consumption		Percentage treated with flame retardants	HBCD concentration
	[kg/m³]	[m³/a]	[t/a]		
EPS	18	250 000	4 500	5 %	0.75 %
XPS	40	40 000	1 600	80 %	1.5 %

Applied to Switzerland, this would amount to a consumption of polystyrene foam (EPS and XPS) of about 8200 t/a. Owing to the much colder climate in Switzerland, the quantity must be assumed to be very much higher.

Tab. 9-25: EPS, XPS and PUR in Germany [Leisewitz et al., 2000] (p.93 and p.96 ff)

Germany	density	Consumption 1993		Consumption 1998		Consumption increase	Stock 1967-1997
	[kg/m³]	[million m³/a]	[1000 t/a]	[million m³/a]	[1000 t/a]	1993-98	[million t]
EPS	15-30	7.354	165	9.5	214	129%	2.40
XPS	20-60	0.766	31	1.098	44	143%	0.46
PUR	15-100	1.134	68	1.5	90	132%	1.00

Notes: excluding PUR foam filler. The present percentage of PUR foam filler in total PUR is 20.9% [Leisewitz et al., 2000] p.85. In 1993, the percentages by weight of EPS, XPS and PUR were approximately the same as in 1998, i.e. 62 %, 12 % and 26 % (excl. foam filler) respectively. These percentages were adopted for the determination of the EPS and XPS stocks. The stock of PUR (excl. foam filler) amounts to approximately 1.0 million t [Leisewitz et al., 2000] (p.93 and p.96 ff).

Tab. 9-26: Consumption of PE, PP and PVC in building materials in Germany in 1999 [VKE, 1999]

Germany 1999	Consumption in building materials 1999	Consumption in films and coverings 1999	Stocks 1967-1997
	[1000 t/a]	[1000 t/a]	[1000 t]
PE	352	70	780
PP	76	3.8	42
PVC	1076	32	360

Notes: consumption of plastics in the production of building materials. Since in the building sector approximately the same quantity of plastics is processed (by industry) as is consumed (by consumers), the above data can be used as a first approximation for the quantities consumed. The percentage of films and coverings in building products was estimated based on the situation in Western Europe [VKE, 1999]. The stock was estimated by analogy with insulation materials (PUR) (see Tab. 9-25).

The following table gives the calculation of TBBPA consumption in epoxy resins and polycarbonates. The quantities calculated by the various methods appear to be unusually high. For this reason, the figures were not used in the present report, attention being drawn instead to the need for more precise data to obtain a quantitative estimate.

Tab. 9-27: Epoxy resins and polycarbonates in the building sector

	Consumption in Western Europe 1990	Consumption in Switzerland 1990	Consumption in Switzerland 1998	TBBPA in use CH 1998	Stock epoxy resins + polycarbonates
	[1000 t/a]	[1000 t/a]	[1000 t/a]	[t/a]	[1000 t]
Epoxy resins	120	4.68	6.1	116	68
Polycarbonates	35	1.37	1.8	34	20
Total	155	6.05	7.9	150	88

Notes: consumption data for Western Europe from [Arx, 1995], on the assumption that 10 % of all resins and polycarbonates are treated with 19 % TBBPA by weight (also see Chapter 5.1.5.3). Conversion of Western European data to Switzerland based on population. Conversion from 1990 to 1998 based on the 31 % increase in the total consumption of plastics in the building sector [VKE, 1999]. The stock was estimated as for insulating materials (PUR) (see Tab. 9-25).

9.1.6 Summary of data for products

Tab. 9-28: Unit weight, component weight and area of printed circuit boards in products

CHARACTERISTIC FIGURES FOR PRODUCTS	**Unit weight**		**Printed circuit board**		**Casing**		**Components[9)]**
	[kg/unit]	*source*	[cm²/unit]	*source*	[kg/unit]	*source*	[kg/unit]
EDP and office electronics							
Computers+monitors (households)	30.5	3	2 700	2	5.49	3	0.92
Computers + monitors (office)	30.5	3	2 700	2	5.49	3	0.92
Servers	30.5	3	2 700	2	5.49	3	0.92
Notebooks	3.5	1	1 000	2	0.63	3	0.11
Laser printers	10.0	3	750	2	1.50	3	0.30
Inkjet printers	6.5	3	750	2	0.98	3	0.20
Copying machines	35.0	3	1 000	2	5.25	3	1.05
Calculators	0.3	1	100	2	0.09	7	0.01
Communications technology							
Telephones	1.0	1	100	2	0.44	4	0.03
Mobile telephones	1.0	1	50	2	0.44	4	0.03
Fax machines	6.0	1	1 000	2	0.90	3	0.18
Household electronics							
CD players	2.0	1	650	2	0.36	4	0.06
Amplifiers	8.8	1	650	2	1.584	4	0.26
Radio receivers	5.0	1	650	2	0.9	4	0.15
Tape recorders	1.4	1	650	2	0.252	4	0.04
Record players	4.5	1	0	2	0.81	4	0.14
Portable hi-fi appliances	0.5	1	300	2	0.09	4	0.02
TV monitors	25.0	3	1 200	2	4.5	6	0.75
Video recorders	6.0	1	850	2	1.08	4	0.18
Video cameras	2.5	1	500	2	0.45	4	0.08

CHARACTERISTIC FIGURES	**Unit weight**		**Printed circuit board**		**Casing**		**Components9)**
FOR PRODUCTS	[kg/unit]	*source*	[cm²/unit]	*source*	[kg/unit]	*source*	[kg/unit]
Photo cameras	0.7	1	35	2	0.126	4	0.02
Electric toys and games	1.0	7	150	2	0.49	4	0.03
Electric musical instruments	4.0	1	900	2	0.72	4	0.12
Small household appliances							
Small household appliances	4.5	1	0	2	1.44	4	0.14
Electric heaters	5.0	1	0	2	1.6	4	0.15
Scales	2.0	7	50	2	0.64	4	0.06
Alarm clocks	0.2	1	6	2	0.064	4	0.01
Large household appliances							
Tumbler driers	50.0	1	0	2	7	4	1.00
Household refrigerators	40.0	1	0	2	5.6	4	0.80
Deep-freezers	74.3	1	0	2	10.402	4	1.49
Washing machines	80.0	1	200	7	11.2	4	1.60
Sewing machines	8.0	1	50	2	1.12	4	0.16
Vacuum cleaners	6.4	1	0	2	0.896	4	0.13
Dishwashers	47.0	1	200	7	6.58	4	0.94
Espresso machines	5.0	1	50	7	0.7	4	0.10
Microwave ovens	18.0	1	50	2	2.52	4	0.36
Ovens, cookers, hotplates	55.0	1	0	2	7.7	4	1.10
Air-conditioners, ventilators	0.8	1	0	2	0.112	4	0.02
Special appliances							
Process control systems	1.0	7	1 000	2	0.4	4	0.02
Measuring instruments (analysers)	1.5	1	1 500	2	0.036	4	0.03
Laboratory equipment	30.0	1	500	2	0.72	4	0.60
Life-saving equipment	5.0	7	1 000	2	0.12	4	0.10
X-ray equipment	50.0	7	1 000	2	1.2	4	1.00
Optical appliances	50.0	7	1 000	2	1.2	4	1.00
Electronic deposit boxes	50.0	7	75	2	1.2	7	1.00
Vending machines	300.0	7	1 000	2	42	4	6.00
Electric tools	5.0	7	0	2	0.38	4	0.10
Vehicles							
Cars	1 200.0	1	500	2	111.6	5	11.16
Car radios	1.8	1	200	2	0	7	0.00
Lorries	3 500.0	1	400	7	111.6	8	11.16
Motorcycles	150.0	1	300	7	13.95	8	1.40
Motor scooters/moped	78.0	1	250	7	7.254	8	0.73
Trains (locomotives)	25 000	1	5 000	7	450	7	45.00
Trains (passenger coaches)	10 000	1	500	7	450	3	45.00
Aircraft >15t	50 000	1	50 000	7	2 250	7	225.00
Small EE components					[g/kg]		
Plugs, switches, etc.			0	2	66	4	
Lighting appliances			0	2	32	4	
Cables			0	2	251	4	

Sources:

1) [EZV, 2000]
2) [Danish EPA, 1999]
3) [Leisewitz & Schwarz, 2000]
4) [APME, 1995], [APME, 2001]
5) [APME, 1999]
6) [Behrendt et al., 1998]
7) authors' assumption
8) authors' assumption: percentage or flow as for cars
9) see Chapter 5.1.3.3. For vehicles, 10 % of weight of casing; for large household and special appliances 2 % of total weight, and for the remaining 10 % of the casing weight of 3 % [???]

Tab. 9-29: FR concentration in finished products

FLAME RETARDANTS IN PRODUCTS [g/kg]	**PentaBDPE**		**OctaBDPE**		**DecaBDPE**		**TBBPA**	
	new	*old*	new	*old*	new	*old*	new	*old*
	[g/kg]	*[g/kg]*	[g/kg]	*[g/kg]*	[g/kg]	*[g/kg]*	[g/kg]	*[g/kg]*
EDP and office electronics								
Computers+monitors (households)	0.00	0.00	0.17	1.91	1.80	2.74	10.09	10.36
Computers+monitors (office)	0.00	0.00	0.17	1.91	1.80	2.74	10.09	10.36
Servers	0.00	0.00	0.17	1.91	1.80	2.74	10.09	10.36
Notebooks	0.00	0.00	0.08	1.91	0.96	2.94	23.57	20.42
Laser printers	0.00	0.00	0.23	3.14	3.34	4.05	9.98	7.28
Inkjet printers	0.00	0.00	0.16	1.10	1.65	1.62	10.61	9.33
Copying machines	0.00	0.00	0.23	3.14	3.29	4.00	7.61	4.91
Calculators	0.00	0.18	0.08	0.48	1.71	2.45	4.74	4.38
Communications technology								
Telephone appliances	0.00	0.00	0.077	0.077	0.775	0.775	5.550	5.550
Mobile telephones	0.00	0.00	0.077	0.077	0.725	0.725	3.000	3.000
Fax machines	0.00	0.00	0.234	3.137	3.429	4.142	14.650	11.950
Household electronics								
CD players	0.00	0.173	0.086	0.260	1.45	1.96	4.59	4.03
Amplifiers	0.00	0.039	0.086	0.260	0.93	1.12	1.79	1.68
Radio receivers	0.00	0.069	0.086	0.260	1.05	1.31	2.41	2.21
Tape recorders	0.00	0.247	0.086	0.260	1.74	2.42	6.14	5.34
Record players	0.00	0.000	0.077	0.077	0.68	0.68	0.45	0.45
Portable hi-fi appliances	0.00	0.319	0.086	0.260	2.03	2.88	7.66	6.61
TV monitors	0.00	0.025	0.077	2.525	1.34	4.80	2.57	2.11
Video recorders	0.00	0.075	0.086	0.260	1.07	1.35	2.54	2.32
Video cameras	0.00	0.106	0.086	0.260	1.19	1.54	3.20	2.86
Photo cameras	0.00	0.027	0.086	0.077	0.88	0.84	1.52	0.92
Electric toys and games	0.00	0.000	0.077	0.077	0.83	0.83	8.10	8.10
Electric musical instruments	0.00	0.000	0.077	0.077	0.90	0.90	11.93	11.93
Small household appliances								
Small household appliances	0.00	0.00	0.077	0.077	0.675	0.675	0.450	0.450
Electric heaters	0.00	0.00	0.077	0.077	0.675	0.675	0.450	0.450
Scales	0.00	0.00	0.077	0.077	0.700	0.700	1.725	1.725
Alarm clocks	0.00	0.00	0.077	0.077	0.705	0.705	1.980	1.980
Large household appliances								

FLAME RETARDANTS IN PRODUCTS [g/kg]	**PentaBDPE**		**OctaBDPE**		**DecaBDPE**		**TBBPA**	
	new	*old*	new	*old*	new	*old*	new	*old*
	[g/kg]	*[g/kg]*	[g/kg]	*[g/kg]*	[g/kg]	*[g/kg]*	[g/kg]	*[g/kg]*
Tumbler driers	0.000	0.0000	0.051	0.051	0.45	0.45	0.30	0.30
Household refrigerators	0.000	0.0000	0.051	0.051	0.45	0.45	0.30	0.30
Deep-freezers	0.000	0.0000	0.051	0.051	0.45	0.45	0.30	0.30
Washing machines	0.000	0.0013	0.051	0.051	0.46	0.46	0.33	0.32
Sewing machines	0.000	0.0033	0.051	0.051	0.46	0.47	0.37	0.36
Vacuum cleaners	0.000	0.0000	0.051	0.051	0.45	0.45	0.30	0.30
Dishwashers	0.000	0.0023	0.051	0.051	0.46	0.46	0.35	0.34
Espresso machines	0.000	0.0053	0.051	0.051	0.47	0.48	0.41	0.39
Microwave ovens	0.000	0.0015	0.051	0.051	0.46	0.46	0.33	0.33
Ovens, cookers, hotplates	0.000	0.0000	0.051	0.051	0.45	0.45	0.30	0.30
Air-conditioners, ventilators	0.000	0.0000	0.051	0.051	0.45	0.45	0.30	0.30
Special appliances								
Process control systems	0.00	0.00	0.051	0.051	1.45	1.45	51.30	51.30
Measuring instruments (analysers)	0.00	0.00	0.051	0.051	1.45	1.45	51.30	51.30
Laboratory equipment	0.00	0.00	0.051	0.051	0.47	0.47	1.15	1.15
Life-saving equipment	0.00	0.00	0.051	0.051	0.65	0.65	10.50	10.50
X-ray equipment	0.00	0.00	0.051	0.051	0.47	0.47	1.32	1.32
Optical appliances	0.00	0.00	0.051	0.051	0.47	0.47	1.32	1.32
Electronic deposit boxes	0.00	0.00	0.051	0.051	0.45	0.45	0.38	0.38
Vending machines	0.00	0.00	0.051	0.051	0.45	0.45	0.47	0.47
Electric tools	0.00	0.00	0.051	0.051	0.45	0.45	0.30	0.30
Small EE components								
Plugs, switches, etc.	0.00	0.00	0.018	0.101	0.20	1.29	0.20	0.50
Lighting appliances	0.00	0.00	0.009	0.049	0.15	0.62	0.10	0.24
Cables	0.00	0.00	0.000	0.000	0.00	0.00	0.00	0.00
Vehicles								
Cars	0.004	0.008	0.025	0.032	0.27	0.37	0.22	0.23
Car radios	0.000	0.059	0.000	0.000	0.23	0.37	1.24	1.04
Lorries	0.001	0.003	0.009	0.011	0.09	0.13	0.07	0.08
Motorcycles	0.004	0.008	0.025	0.032	0.27	0.37	0.30	0.31
Motor scooters/mopeds	0.004	0.008	0.025	0.032	0.27	0.38	0.36	0.37
Trains (locomotives)	0.000	0.027	0.005	0.005	0.12	0.81	0.05	0.08
Trains (passenger coaches)	0.000	0.066	0.011	0.011	0.29	2.01	0.09	0.18
Aircraft >15 t	0.000	0.066	0.011	0.011	0.29	2.01	0.14	0.23
Building materials and textiles								
EPS foam	0.00	0.00	0.00	0.00	0.0	0.0	0.0	0.0
XPS foam	0.00	0.00	0.00	0.00	0.0	16.0	0.0	0.0
PUR foam	0.00	6.49	0.00	0.00	0.0	0.0	0.0	14.7
PE foam	0.00	0.00	0.00	0.00	10.0	0.0	0.0	0.0
PE films	0.00	0.00	0.00	1.70	10.0	20.0	0.0	0.0
PP films	0.00	0.00	0.00	0.00	10.0	20.0	5.2	5.2
PVC films	0.00	1.45	0.00	0.00	2.5	5.0	0.0	0.0
Epoxy resins	0.00	0.00	0.00	0.00	0.0	0.0	2.0	2.0

FLAME RETARDANTS IN PRODUCTS [g/kg]	PentaBDPE		OctaBDPE		DecaBDPE		TBBPA	
	new [g/kg]	*old [g/kg]*	new [g/kg]	*old [g/kg]*	new [g/kg]	*old [g/kg]*	new [g/kg]	*old [g/kg]*
Polycarbonates	0.00	0.00	0.00	0.00	0.0	0.0	2.0	2.0
Textiles and upholstery	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

n.d.: not determined

9.1.7 Flows and stocks in subsystem: 'trade in products'

Contents:

- process: 'production': flows of finished products
- process: 'trade': flows of imported and exported finished products
- process: 'consumption': flows of consumed products and household waste, and stocks of products.

9.1.7.1 Process: 'production'

Tab. 9-30: Flows of materials and substances in finished products – detail (CH, 1998)

PRODUCTS MADE IN Switzerland 1998	Material flow [1000 t/a]	Penta-BDPE [t/a]	Octa-BDPE [t/a]	Deca-BDPE [t/a]	TBBPA [t/a]
EDP and office electronics	**38.3**	**0**	**1**	**12**	**301**
Computers+monitors (households)	1.2	0	0.0	0.2	11.9
Computers+monitors (office)	3.5	0	0.1	0.6	35.7
Servers	0.0	0	0.0	0.0	0.2
Notebooks	0.0	0	0.0	0.0	0.0
Laser printer	0.0	0	0.0	0.0	0.0
Inkjet printers	0.0	0	0.0	0.0	0.0
Copying machines	32.8	0	0.8	10.8	249.8
Calculators	0.8	0	0.0	0.1	3.7
Communications technology	**2.5**	**0**	**0**	**0**	**13**
Telephone appliances	2.2	0	0.0	0.2	12.2
Mobile telephones	0.3	0	0.0	0.0	0.8
Fax machines	0.0	0	0.0	0.0	0.0
Household electronics	**4.6**	**0**	**0**	**3**	**15**
CD players	0.0	0	0.0	0.0	0.0
Amplifiers	0.1	0	0.0	0.1	0.2
Radio receivers	0.0	0	0.0	0.0	0.0
Tape recorders	0.0	0	0.0	0.0	0.0
Record players	0.0	0	0.0	0.0	0.0
Portable hi-fi appliances	0.3	0	0.0	0.7	2.6
TV monitors	2.5	0	0.0	0.3	6.5
Video recorders	1.4	0	0.1	1.5	3.6
Video cameras	0.0	0	0.0	0.0	0.0

PRODUCTS MADE IN	Material flow	Penta-BDPE	Octa-BDPE	Deca-BDPE	TBBPA
Switzerland 1998	[1000 t/a]	[t/a]	[t/a]	[t/a]	[t/a]
Photo cameras	0.0	0	0.0	0.0	0.0
Electric toys and games	0.0	0	0.0	0.0	0.0
Electric musical instruments	0.2	0	0.0	0.2	2.6
Small household appliances	**10.4**	**0**	**0.8**	**7.0**	**6.4**
Small household appliances	9.1	0	0.7	6.2	4.1
Electric heaters	0.0	0	0.0	0.0	0.0
Scales	0.7	0	0.1	0.5	1.1
Alarm clocks	0.6	0	0.0	0.4	1.2
Large household appliances	**30.5**	**0**	**1.6**	**13.8**	**9.7**
Tumbler driers	2.0	0	0.1	0.9	0.6
Household refrigerators	5.9	0	0.3	2.7	1.8
Deep-freezers	0.0	0	0.0	0.0	0.0
Washing machines	14.4	0	0.7	6.6	4.7
Sewing machines	0.0	0	0.0	0.0	0.0
Vacuum cleaners	0.0	0	0.0	0.0	0.0
Dishwashers	0.0	0	0.0	0.0	0.0
Espresso machines	1.6	0	0.1	0.8	0.7
Microwave ovens	0.0	0	0.0	0.0	0.0
Ovens, cookers, hotplates	2.1	0	0.1	1.0	0.6
Air-conditioners, ventilators	4.4	0	0.2	2.0	1.3
Special appliances	**11.7**	**0**	**0.6**	**6.3**	**58.0**
Process control system	0.5	0	0.0	0.8	28.2
Measuring instruments (analysers)	0.5	0	0.0	0.7	24.3
Laboratory equipment	0.1	0	0.0	0.0	0.1
Life-saving equipment	0.0	0	0.0	0.0	0.1
X-ray equipment	0.0	0	0.0	0.0	0.0
Optical appliances	1.3	0	0.1	0.6	1.7
Electronic deposit boxes	8.1	0	0.4	3.7	3.1
Vending machines	1.0	0	0.0	0.4	0.4
Electric tools	0.2	0	0.0	0.1	0.1
Small EE components	**160.8**	**0**	**1.2**	**13.3**	**13.1**
Plugs, switches, etc.	65.4	0	1.2	12.9	12.9
Lighting appliances	2.2	0	0.0	0.3	0.2
Cables	93.3	0	0.0	0.0	0.0
Vehicles	**3.8**	**0**	**0.0**	**0.5**	**0.2**
Cars	0.0	0	0.0	0.0	0.0
Car radios	0.0	0	0.0	0.0	0.0
Lorries	0.0	0	0.0	0.0	0.0
Motorcycles	0.0	0	0.0	0.0	0.0
Motor scooters/mopeds	0.0	0	0.0	0.0	0.0
Trains (locomotives)	3.4	0	0.0	0.4	0.2
Trains (passenger coaches)	0.5	0	0.0	0.1	0.0
Aircraft >15 t	0.0	0	0.0	0.0	0.0
Building materials and	**47.5**	**0**	**0.0**	**72.1**	**17.5**

PRODUCTS MADE IN Switzerland 1998	Material flow	Penta-BDPE	Octa-BDPE	Deca-BDPE	TBBPA
	[1000 t/a]	[t/a]	[t/a]	[t/a]	[t/a]
textiles					
EPS foam	18.6	0	0.0	0.0	0.0
XPS foam	3.8	0	0.0	0.0	0.0
PUR foam	7.8	0	0.0	0.0	0.0
PE foam	0.1	0	0.0	0.5	0.0
PE films	6.1	0	0.0	61.2	0.0
PP films	0.3	0	0.0	3.3	1.7
PVC films	2.8	0	0.0	7.0	0.0
Epoxy resins	6.1	0	0.0	0.0	12.2
Polycarbonates	1.8	0	0.0	0.0	3.6
Textiles and upholstery	n.d.	0	n.d.	n.d.	n.d.
Total	**310.1**	**0**	**5**	**128**	**435**

n.d.: not determined

9.1.7.2 Process: ‘trade’

The imports and exports of finished products were determined from data of the Federal Customs Administration. No export figures were available for E+G-Geräte [???], building materials and raw textiles. It was assumed that these product groups are produced in Switzerland, and that exports are negligible.

Tab. 9-31: Flows of materials and substances in imported finished products - detail (CH, 1998)

PRODUCTS IMPORTED INTO Switzerland 1998	Material flow	Penta-BDPE	Octa-BDPE	Deca-BDPE	TBBPA
	[1000 t/a]	[t/a]	[t/a]	[t/a]	[t/a]
EDP and office electronics	**46.6**	**0.00**	**16**	**204**	**476**
Computers+monitors (households)	5.3	0.00	1.1	11.4	53.4
Computers+monitors (office)	14.8	0.00	3.1	32.3	149.4
Servers	1.1	0.00	0.2	1.9	10.7
Notebooks	0.6	0.00	0.0	0.6	13.7
Laser printer	8.9	0.00	2.1	29.5	88.3
Inkjet printers	13.4	0.00	2.1	22.2	142.4
Copying machines	2.0	0.00	7.4	103.8	15.0
Calculators	0.6	0.00	0.1	2.3	3.0
Communications technology	**3.1**	**0.00**	**0.5**	**5.1**	**17**
Telephone appliances	1.2	0.00	0.2	2.4	6.5
Mobile telephones	1.5	0.00	0.1	1.2	4.4
Fax machines	0.4	0.00	0.1	1.4	6.1
Household electronics	**21.6**	**0.00**	**1.9**	**30**	**57**
CD players	0.4	0.00	0.0	0.6	1.8
Amplifiers	0.9	0.00	0.1	0.9	1.7
Radio receivers	2.7	0.00	0.2	2.9	6.6

PRODUCTS IMPORTED INTO Switzerland 1998	**Material flow** [1000 t/a]	**Penta-BDPE** [t/a]	**Octa-BDPE** [t/a]	**Deca-BDPE** [t/a]	**TBBPA** [t/a]
Tape recorders	0.2	0.00	0.0	0.4	1.3
Record players	0.1	0.00	0.0	0.1	0.0
Portable hi-fi appliances	0.1	0.00	0.0	0.3	0.9
TV monitors	14.9	0.00	1.3	23.0	38.2
Video recorders	1.4	0.00	0.1	1.5	3.6
Video cameras	0.2	0.00	0.0	0.2	0.7
Photo cameras	0.4	0.00	0.0	0.3	0.5
Electric toys and games	0.2	0.00	0.0	0.2	1.9
Electric musical instruments	n.d.	n.d.	n.d.	n.d.	n.d.
Small household appliances	**14.2**	**0.00**	**1.1**	**9.7**	**9.6**
Small household appliances	5.4	0.00	0.4	3.7	2.4
Electric heaters	6.5	0.00	0.5	4.4	2.9
Scales	1.4	0.00	0.1	1.0	2.4
Alarm clocks	0.9	0.00	0.1	0.7	1.9
Large household appliances	**89.7**	**0.00**	**4.6**	**40.5**	**27.8**
Tumbler driers	2.6	0.00	0.1	1.2	0.8
Household refrigerators	11.1	0.00	0.6	5.0	3.3
Deep-freezers	8.2	0.00	0.4	3.7	2.5
Washing machines	10.8	0.00	0.6	4.9	3.6
Sewing machines	0.3	0.00	0.0	0.2	0.1
Vacuum cleaners	2.5	0.00	0.1	1.1	0.7
Dishwashers	5.2	0.00	0.3	2.4	1.8
Espresso machines	1.9	0.00	0.1	0.9	0.8
Microwave ovens	2.0	0.00	0.1	0.9	0.7
Ovens, cookers, hotplates	5.5	0.00	0.3	2.5	1.6
Air-conditioners, ventilators	39.5	0.00	2.0	17.8	11.8
Special appliances	**3.6**	**0.00**	**0.2**	**1.6**	**1.1**
Process control system	n.d.	n.d.	n.d.	n.d.	n.d.
Measuring instruments (analysers)	n.d.	n.d.	n.d.	n.d.	n.d.
Laboratory equipment	n.d.	n.d.	n.d.	n.d.	n.d.
Life-saving equipment	n.d.	n.d.	n.d.	n.d.	n.d.
X-ray equipment	n.d.	n.d.	n.d.	n.d.	n.d.
Optical appliances	n.d.	n.d.	n.d.	n.d.	n.d.
Electronic deposit boxes	n.d.	n.d.	n.d.	n.d.	n.d.
Vending machines	n.d.	n.d.	n.d.	n.d.	n.d.
Electric tools	3.6	0.00	0.2	1.6	1.1
Small EE components	**33.2**	**0.00**	**0.0**	**0.0**	**0.0**
Plugs, switches, etc.	n.d.	n.d.	n.d.	n.d.	n.d.
Lighting appliances	n.d.	n.d.	n.d.	n.d.	n.d.
Cables	33.2	0.00	0.0	0.0	0.0
Vehicles	**586.1**	**1.91**	**11.8**	**125.1**	**103.1**
Cars	398.2	1.64	10.1	106.6	87.2
Car radios	0.7	0.00	0.0	0.2	0.9
Lorries	**180.4**	0.25	1.6	16.6	13.3

PRODUCTS IMPORTED INTO Switzerland 1998	Material flow	Penta-BDPE	Octa-BDPE	Deca-BDPE	TBBPA
	[1000 t/a]	[t/a]	[t/a]	[t/a]	[t/a]
Motorcycles	3.6	0.02	0.1	1.0	1.1
Motor scooters/mopeds	1.4	0.01	0.0	0.4	0.5
Trains (locomotives)	0.8	0.00	0.0	0.1	0.0
Trains (passenger coaches)	0.3	0.00	0.0	0.1	0.0
Aircraft >15 t	0.6	0.00	0.0	0.2	0.1
Building materials and textiles	n.d.	n.d.	n.d.	n.d.	n.d.
Total	**798.1**	**2**	**36**	**423**	**692**

n.d.: not determined

Tab. 9-32: Flows of materials and substances in exported finished products – detail (CH, 1998)

PRODUCTS EXPORTED FROM Switzerland 1998	Material flow	Penta-BDPE	Octa-BDPE	Deca-BDPE	TBBPA
	[1000 t/a]	[t/a]	[t/a]	[t/a]	[t/a]
EDP and office electronics	**56.0**	**0.00**	**12**	**161**	**482**
Computers+monitors (households)	0.7	0.00	0.1	1.3	7.2
Computers+monitors (office)	2.0	0.00	0.3	3.6	20.1
Servers	0.1	0.00	0.0	0.3	1.4
Notebooks	0.1	0.00	0.0	0.1	1.4
Laser printer	7.3	0.00	1.7	24.4	72.9
Inkjet printers	11.1	0.00	1.7	18.3	117.6
Copying machines	33.7	0.00	7.9	110.8	256.1
Calculators	1.1	0.00	0.1	1.8	5.0
Communications technology	**2.2**	**0.00**	**0**	**2**	**12**
Telephone appliances	2.1	0.00	0.2	1.6	11.4
Mobile telephones	0.2	0.00	0.0	0.1	0.5
Fax machines	0.0	0.00	0.0	0.0	0.1
Household electronics	**3.8**	**0.00**	**0**	**5**	**10**
CD players	0.1	0.00	0.0	0.1	0.3
Amplifiers	0.7	0.00	0.1	0.6	1.2
Radio receivers	0.2	0.00	0.0	0.2	0.4
Tape recorders	0.2	0.00	0.0	0.3	1.0
Record players	0.0	0.00	0.0	0.0	0.0
Portable hi-fi appliances	0.0	0.00	0.0	0.0	0.2
TV monitors	2.4	0.00	0.2	3.2	6.1
Video recorders	0.1	0.00	0.0	0.1	0.3
Video cameras	0.0	0.00	0.0	0.0	0.1
Photo cameras	0.1	0.00	0.0	0.1	0.2
Electric toys and games	0.0	0.00	0.0	0.0	0.3
Electric musical instruments	n.d.	n.d.	n.d.	n.d.	n.d.
Small household appliances	**8.4**	**0.00**	**0.6**	**5.7**	**7.5**
Small household appliances	1.5	0.00	0.1	1.0	0.7
Electric heaters	4.2	0.00	0.3	2.8	1.9
Scales	1.5	0.00	0.1	1.1	2.6

PRODUCTS EXPORTED FROM Switzerland 1998	**Material flow** [1000 t/a]	**Penta-BDPE** [t/a]	**Octa-BDPE** [t/a]	**Deca-BDPE** [t/a]	**TBBPA** [t/a]
Alarm clocks	1.2	0.00	0.1	0.8	2.3
Large household appliances	**64.8**	**0.00**	**3.3**	**29.3**	**20.1**
Tumbler driers	0.1	0.00	0.0	0.1	0.0
Household refrigerators	5.3	0.00	0.3	2.4	1.6
Deep-freezers	0.4	0.00	0.0	0.2	0.1
Washing machines	10.0	0.00	0.5	4.5	3.3
Sewing machines	0.0	0.00	0.0	0.0	0.0
Vacuum cleaners	0.4	0.00	0.0	0.2	0.1
Dishwashers	0.6	0.00	0.0	0.3	0.2
Espresso machines	3.2	0.00	0.2	1.5	1.3
Microwave ovens	0.0	0.00	0.0	0.0	0.0
Ovens, cookers, hotplates	1.3	0.00	0.1	0.6	0.4
Air-conditioners, ventilators	43.5	0.00	2.2	19.6	13.0
Special appliances	**0.2**	**0.00**	**0.0**	**0.1**	**0.1**
Process control system	n.d.	n.d.	n.d.	n.d.	n.d.
Measuring instruments (analysers)	n.d.	n.d.	n.d.	n.d.	n.d.
Laboratory equipment	n.d.	n.d.	n.d.	n.d.	n.d.
Life-saving equipment	n.d.	n.d.	n.d.	n.d.	n.d.
X-ray equipment	n.d.	n.d.	n.d.	n.d.	n.d.
Optical appliances	n.d.	n.d.	n.d.	n.d.	n.d.
Electronic deposit boxes	n.d.	n.d.	n.d.	n.d.	n.d.
Vending machines	n.d.	n.d.	n.d.	n.d.	n.d.
Electric tools	0.2	0.00	0.0	0.1	0.1
Small EE components	**38.0**	**0.00**	**0.0**	**0.0**	**0.0**
Plugs, switches, etc.	n.d.	n.d.	n.d.	n.d.	n.d.
Lighting appliances	n.d.	n.d.	n.d.	n.d.	n.d.
Cables	38.0	0.00	0.0	0.0	0.0
Vehicles	**134.7**	**0.41**	**2.6**	**27.7**	**22.4**
Cars	85.0	0.35	2.1	22.8	18.6
Car radios	0.1	0.00	0.0	0.0	0.1
Lorries	44.2	0.06	0.4	4.1	3.3
Motorcycles	0.3	0.00	0.0	0.1	0.1
Motor scooters/mopeds	0.0	0.00	0.0	0.0	0.0
Trains (locomotives)	4.2	0.00	0.0	0.5	0.2
Trains (passenger coaches)	0.2	0.00	0.0	0.1	0.0
Aircraft >15 t	0.6	0.00	0.0	0.2	0.1
Building materials and textiles	n.d.	n.d.	n.d.	n.d.	n.d.
Total	**308.0**	**0.41**	**19**	**230**	**554**

n.d.: not determined

9.1.7.3 Process: ‘consumption'

The stock and household waste in the process: ‘consumption’ were calculated from changes in consumption (see Tab. 9-12) and life cycles (see Tab. 9-13) of the products, and from an estimate of the age distribution of the products (see Tab. 9-33).

Tab. 9-33: Age distribution in stock and waste

Age distribution	**Percentage of older products (produced 1990)**	
	in stock (consumption)	in household waste
EDP equipment (excl. printers)	10%	50%
Office equipment and communications technology	20%	70%
Household electronics	60%	100%
Small household appliances	20%	70%
Large household and special appliances and small EE components	60%	100%
Vehicles	60%	100%
Building materials	60%	100%

Note: the percentage of older appliances was determined on the basis of *Tab. 9-13* and our own assumptions.

The following three tables show the flows of materials and substances and the stock in the process: ‘consumption’, i.e. ‘consumed products’, ‘household waste’ and ‘stock in consumption’.

Tab. 9-34: Flows of materials and substances in consumed products – detail (CH, 1998)

CONSUMED PRODUCTS	**Material flow**	**Penta-BDPE**	**Octa-BDPE**	**Deca-BDPE**	**TBBPA**
Switzerland 1998	[1000 t/a]	[t/a]	[t/a]	[t/a]	[t/a]
EDP and office electronics	**28,9**	**0,00**	**5,0**	**55**	**295**
Computers+monitors (households)	5,7	0,00	1,0	10,3	58,0
Computers+monitors (office)	16,3	0,00	2,8	29,4	165,0
Servers	0,9	0,00	0,2	1,7	9,4
Notebooks	0,5	0,00	0,0	0,5	12,3
Laser printer	1,5	0,00	0,4	5,1	15,4
Inkjet printers	2,3	0,00	0,4	3,9	24,8
Copying machines	1,1	0,00	0,3	3,8	8,7
Calculators	0,4	0,00	0,0	0,6	1,7
Communications technology	**3,3**	**0,00**	**0,3**	**3,6**	**18,0**
Telephone appliances	1,3	0,00	0,1	1,0	7,3
Mobile telephones	1,6	0,00	0,1	1,1	4,7
Fax machines	0,4	0,00	0,1	1,4	6,0
Household electronics	**22,4**	**0,00**	**1,8**	**28,5**	**62,7**
CD players	0,3	0,00	0,0	0,5	1,5
Amplifiers	0,4	0,00	0,0	0,4	0,7
Radio receivers	2,6	0,00	0,2	2,7	6,2

CONSUMED PRODUCTS	**Material flow**	**Penta-BDPE**	**Octa-BDPE**	**Deca-BDPE**	**TBBPA**
Switzerland 1998	[1000 t/a]	[t/a]	[t/a]	[t/a]	[t/a]
Tape recorders	0,0	0,00	0,0	0,1	0,3
Record players	0,1	0,00	0,0	0,0	0,0
Portable hi-fi appliances	0,4	0,00	0,0	0,9	3,4
TV monitors	15,0	0,00	1,1	20,2	38,6
Video recorders	2,7	0,00	0,2	2,9	6,9
Video cameras	0,2	0,00	0,0	0,2	0,6
Photo cameras	0,2	0,00	0,0	0,2	0,4
Electric toys and games	0,2	0,00	0,0	0,2	1,7
Electric musical instruments	0,2	0,00	0,0	0,2	2,6
Small household appliances	**16.2**	**0.00**	**1.2**	**11.0**	**8.5**
Small household appliances	13.0	0.00	1.0	8.8	5.9
Electric heaters	2.3	0.00	0.2	1.6	1.0
Scales	0.5	0.00	0.0	0.4	0.9
Alarm clocks	0.4	0.00	0.0	0.3	0.7
Large household appliances	**55.4**	**0.00**	**2.8**	**25.1**	**17.4**
Tumbler driers	4.5	0.00	0.2	2.0	1.4
Household refrigerators	11.7	0.00	0.6	5.3	3.5
Deep-freezers	7.9	0.00	0.4	3.5	2.4
Washing machines	15.3	0.00	0.8	7.0	5.0
Sewing machines	0.4	0.00	0.0	0.2	0.1
Vacuum cleaners	2.1	0.00	0.1	1.0	0.6
Dishwashers	4.5	0.00	0.2	2.1	1.6
Espresso machines	0.3	0.00	0.0	0.1	0.1
Microwave ovens	2.0	0.00	0.1	0.9	0.7
Ovens, cookers, hotplates	6.3	0.00	0.3	2.8	1.9
Air-conditioners, ventilators	0.4	0.00	0.0	0.2	0.1
Special appliances	**15.2**	**0.00**	**0.8**	**7.9**	**59.0**
Process control system	0.5	0.00	0.0	0.8	28.2
Measuring instruments (analysers)	0.5	0.00	0.0	0.7	24.3
Laboratory equipment	0.1	0.00	0.0	0.0	0.1
Life-saving equipment	0.0	0.00	0.0	0.0	0.1
X-ray equipment	0.0	0.00	0.0	0.0	0.0
Optical appliances	1.3	0.00	0.1	0.6	1.7
Electronic deposit boxes	8.1	0.00	0.4	3.7	3.1
Vending machines	1.0	0.00	0.0	0.4	0.4
Electric tools	3.7	0.00	0.2	1.7	1.1
Small EE components	**156.0**	**0.00**	**1.2**	**13.3**	**13.1**
Plugs, switches, etc.	65.4	0.00	1.2	12.9	12.9
Lighting appliances	2.2	0.00	0.0	0.3	0.2
Cables	88.5	0.00	0.0	0.0	0.0
Vehicles	**455.3**	**1.50**	**9.2**	**98.0**	**80.9**
Cars	313.2	1.29	7.9	83.9	68.6
Car radios	0.6	0.00	0.0	0.1	0.8
Lorries	136.1	0.19	1.2	12.5	10.0

CONSUMED PRODUCTS Switzerland 1998	Material flow [1000 t/a]	Penta-BDPE [t/a]	Octa-BDPE [t/a]	Deca-BDPE [t/a]	TBBPA [t/a]
Motorcycles	3.3	0.01	0.1	0.9	1.0
Motor scooters/mopeds	1.4	0.01	0.0	0.4	0.5
Trains (locomotives)	0.0	0.00	0.0	0.0	0.0
Trains (passenger coaches)	0.5	0.00	0.0	0.2	0.1
Aircraft >15 t	0.0	0.00	0.0	0.0	0.0
Building materials and textiles	**47.5**	**0.00**	**0.0**	**79.1**	**17.5**
EPS foam	18.6	0.00	0.0	0.0	0.0
XPS foam	3.8	0.00	0.0	0.0	0.0
PUR foam	7.8	0.00	0.0	0.0	0.0
PE foam	0.1	0.00	0.0	0.5	0.0
PE films	6.1	0.00	0.0	61.2	0.0
PP films	0.3	0.00	0.0	3.3	1.7
PVC films	2.8	0.00	0.0	7.0	0.0
Epoxy resins	6.1	0.00	0.0	0.0	12.2
Polycarbonates	1.8	0.00	0.0	0.0	3.6
Textiles and upholstery	n.d.	n.d.	n.d.	7.0	n.d.
Total	**800.2**	**1.50**	**22**	**322**	**573**

n.d.: not determined

Tab. 9-35: Flows of materials and substances in waste disposed of – detail (CH, 1998)

WASTE DISPOSED OF Switzerland 1998	Material flow [1000 t/a]	Penta-BDPE [t/a]	Octa-BDPE [t/a]	Deca-BDPE [t/a]	TBBPA [t/a]
EDP and office electronics	**13.7**	**0**	**16**	**33**	**134**
Computers+monitors (households)	2.4	0.0	2.5	5.5	24.8
Computers+monitors (office)	6.9	0.0	7.2	15.6	70.5
Servers	0.4	0.0	0.4	0.9	4.0
Notebooks	0.2	0.0	0.2	0.4	4.8
Laser printer	1.1	0.0	2.4	4.1	8.6
Inkjet printers	1.6	0.0	1.3	2.6	15.7
Copying machines	0.8	0.0	1.8	3.0	4.5
Calculators	0.3	0.0	0.1	0.6	1.1
Communications technology	**2.7**	**0.0**	**0.9**	**3.1**	**14.0**
Telephone appliances	1.1	0.0	0.1	0.8	5.9
Mobile telephones	1.3	0.0	0.1	0.9	3.8
Fax machines	0.3	0.0	0.7	1.3	4.2
Household electronics	**13.2**	**0.60**	**23.4**	**48.6**	**31.7**
CD players	0.2	0.0	0.0	0.4	0.8
Amplifiers	0.2	0.0	0.1	0.3	0.4
Radio receivers	1.5	0.1	0.4	2.0	3.4
Tape recorders	0.0	0.0	0.0	0.1	0.2
Record players	0.0	0.0	0.0	0.0	0.0

WASTE DISPOSED OF Switzerland 1998	Material flow [1000 t/a]	Penta-BDPE [t/a]	Octa-BDPE [t/a]	Deca-BDPE [t/a]	TBBPA [t/a]
Portable hi-fi appliances	0.3	0.1	0.1	0.7	1.7
TV monitors	8.9	0.2	22.3	42.4	18.7
Video recorders	1.6	0.1	0.4	2.2	3.7
Video cameras	0.1	0.0	0.0	0.2	0.3
Photo cameras	0.1	0.0	0.0	0.1	0.1
Electric toys and games	0.1	0.0	0.0	0.1	1.0
Electric musical instruments	0.1	0.0	0.0	0.1	1.5
Small household appliances	**14.8**	**0.00**	**1.1**	**10.0**	**7.8**
Small household appliances	11.9	0.0	0.9	8.0	5.3
Electric heaters	2.1	0.0	0.2	1.4	1.0
Scales	0.5	0.0	0.0	0.3	0.8
Alarm clocks	0.3	0.0	0.0	0.2	0.7
Large household appliances	**42.6**	**0.03**	**2.2**	**19.3**	**13.3**
Tumbler driers	3.5	0.0	0.2	1.6	1.0
Household refrigerators	9.0	0.0	0.5	4.1	2.7
Deep-freezers	6.0	0.0	0.3	2.7	1.8
Washing machines	11.7	0.0	0.6	5.4	3.8
Sewing machines	0.3	0.0	0.0	0.1	0.1
Vacuum cleaners	1.6	0.0	0.1	0.7	0.5
Dishwashers	3.5	0.0	0.2	1.6	1.2
Espresso machines	0.2	0.0	0.0	0.1	0.1
Microwave ovens	1.5	0.0	0.1	0.7	0.5
Ovens, cookers, hotplates	4.8	0.0	0.2	2.2	1.4
Air-conditioners, ventilators	0.3	0.0	0.0	0.1	0.1
Special appliances	**10.2**	**0.00**	**0.5**	**5.3**	**39.7**
Process control system	0.4	0.0	0.0	0.5	19.0
Measuring instruments (analysers)	0.3	0.0	0.0	0.5	16.4
Laboratory equipment	0.1	0.0	0.0	0.0	0.1
Life-saving equipment	0.0	0.0	0.0	0.0	0.0
X-ray equipment	0.0	0.0	0.0	0.0	0.0
Optical appliances	0.9	0.0	0.0	0.4	1.1
Electronic deposit boxes	5.4	0.0	0.3	2.5	2.1
Vending machines	0.6	0.0	0.0	0.3	0.3
Electric tools	2.5	0.0	0.1	1.1	0.7
Small EE components	**71.1**	**0.00**	**3.3**	**42.2**	**16.2**
Plugs, switches, etc.	32.3	0.0	3.3	41.5	16.0
Lighting appliances	1.1	0.0	0.1	0.7	0.3
Cables	37.7	0.0	0.0	0.0	0.0
Vehicles	**329.8**	**2.37**	**9.0**	**106.2**	**66.3**
Cars	258.8	2.1	8.2	96.4	59.7
Car radios	0.5	0.0	0.0	0.2	0.5
Lorries	68.1	0.2	0.7	8.7	5.3
Motorcycles	1.7	0.0	0.1	0.6	0.5
Motor scooters/mopeds	0.7	0.0	0.0	0.3	0.3

WASTE DISPOSED OF	Material flow	Penta-BDPE	Octa-BDPE	Deca-BDPE	TBBPA
Switzerland 1998	[1000 t/a]	[t/a]	[t/a]	[t/a]	[t/a]
Trains (locomotives)		0.0	0.0	0.0	0.0
Trains (passenger coaches)		0.0	0.0	0.0	0.0
Aircraft >15 t	0.0	0.0	0.0	0.0	0.0
Building materials and textiles	**23.7**	**27.4**	**5.2**	**102.1**	**66.2**
EPS foam	9.3	0.0	0.0	0.0	0.0
XPS foam	1.9	0.0	0.0	30.6	0.0
PUR foam	3.9	25.4	0.0	0.0	57.4
PE foam	0.0	0.0	0.0	0.0	0.0
PE films	3.1	0.0	5.2	61.2	0.0
PP films	0.2	0.0	0.0	3.3	0.9
PVC films	1.4	2.03	0.0	7.0	0.0
Epoxy resins	3.1	0.0	0.0	0.0	6.1
Polycarbonates	0.9	0.0	0.0	0.0	1.8
Textiles and upholstery	n.d.	n.d.	n.d.	n.d.	n.d.
Total	**521.7**	**30**	**62**	**369**	**389**

n.d.: not determined

Tab. 9-36: Stocks of materials and substances in finished products in use – detail (CH, 1998)

PRODUCTS IN USE	Material stock	Penta-BDPE	Octa-BDPE	Deca-BDPE	TBBPA
Switzerland 1998	[1000 t]	[t]	[t]	[t]	[t]
EDP and office electronics	**105**	**0.07**	**43**	**218**	**1057**
Computers+monitors (households)	19	0.00	6	35	188
Computers+monitors (office)	53	0.00	18	100	536
Servers	3	0.00	1	6	30
Notebooks	2	0.00	0	2	39
Laser printer	8	0.00	7	29	79
Inkjet printers	13	0.00	4	21	131
Copying machines	6	0.00	5	21	44
Calculators	2	0.07	0	4	9
Communications technology	**20**	**0.00**	**3**	**22**	**109**
Telephone appliances	8	0.00	1	6	45
Mobile telephones	10	0.00	1	7	29
Fax machines	3	0.00	2	9	35
Household electronics	**278**	**7.53**	**304**	**753**	**711**
CD players	4	0.41	1	7	17
Amplifiers	5	0.11	1	5	8
Radio receivers	32	1.32	6	39	73
Tape recorders	1	0.09	0	1	3
Record players	1	0.00	0	1	0
Portable hi-fi appliances	5	1.05	1	14	38
TV monitors	186	2.85	288	636	427

PRODUCTS IN USE Switzerland 1998	Material stock [1000 t]	Penta-BDPE [t]	Octa-BDPE [t]	Deca-BDPE [t]	TBBPA [t]
Video recorders	34	1.52	6	42	81
Video cameras	2	0.14	0	3	6
Photo cameras	3	0.05	0	3	4
Electric toys and games	3	0.00	0	2	20
Electric musical instruments	3	0.00	0	2	32
Small household appliances	**109**	**0.00**	**8**	**73**	**57**
Small household appliances	87	0.00	7	59	39
Electric heaters	16	0.00	1	10	7
Scales	3	0.00	0	2	6
Alarm clocks	2	0.00	0	2	5
Large household appliances	**715**	**0.28**	**36**	**324**	**223**
Tumbler driers	58	0.00	3	26	17
Household refrigerators	151	0.00	8	68	45
Deep-freezers	101	0.00	5	46	30
Washing machines	197	0.16	10	90	64
Sewing machines	5	0.01	0	2	2
Vacuum cleaners	27	0.00	1	12	8
Dishwashers	59	0.08	3	27	20
Espresso machines	4	0.01	0	2	2
Microwave ovens	26	0.02	1	12	8
Ovens, cookers, hotplates	81	0.00	4	36	24
Air-conditioners, ventilators	5	0.00	0	2	2
Special appliances	**200**	**0.00**	**10**	**104**	**779**
Process control system	7	0.00	0	11	372
Measuring instruments (analysers)	6	0.00	0	9	321
Laboratory equipment	1	0.00	0	1	1
Life-saving equipment	0	0.00	0	0	1
X-ray equipment	0	0.00	0	0	0
Optical appliances	17	0.00	1	8	22
Electronic deposit boxes	107	0.00	5	48	40
Vending machines	13	0.00	1	6	6
Electric tools	49	0.00	2	22	15
Small EE components	**1.944**	**0.00**	**60**	**760**	**335**
Plugs, switches, etc.	878	0.00	59	747	330
Lighting appliances	29	0.00	1	13	5
Cables	1.038	0.00	0	0	0
Vehicles	**6.614**	**34**	**143**	**1.685**	**1.127**
Cars	4.005	26	116	1.324	904
Car radios	8	0	0	2	9
Lorries	2.482	6	25	281	189
Motorcycles	28	0	1	9	9
Motor scooters/mopeds	25	0	1	8	9
Trains (locomotives)	34	1	0	18	2
Trains (passenger coaches)	32	1	0	42	5

PRODUCTS IN USE **Switzerland 1998**	**Material stock** [1000 t]	**Penta-BDPE** [t]	**Octa-BDPE** [t]	**Deca-BDPE** [t]	**TBBPA** [t]
Aircraft >15 t	0	0	0	0	0
Building materials and textiles	**549**	**455**	**69**	**1.661**	**1.163**
EPS foam	207	0	0	0	0
XPS foam	40	0	0	385	0
PUR foam	110	428	0	0	968
PE foam	1	0	0	3	0
PE films	68	0	69	1.089	0
PP films	4	0	0	59	19
PVC films	31	27	0	125	0
Epoxy resins	68	0	0	0	136
Polycarbonates	20	0	0	0	40
Textiles and upholstery	n.d.	n.d.	n.d.	n.d.	n.d.
Total	**10 534**	**498**	**678**	**5 601**	**5 561**

n.d.: not determined

9.2 Appendix 2 – waste management and environment

9.2.1 Basic data and assumptions

The present section summarises the basic data for the determination of the flows and stocks in environmental compartments.

Basic data for the calculations:

Tab. 9-37: Land areas in Switzerland

Total area of Switzerland	4 128 400 ha
Total agricultural area 1990	945 760 ha
Built-up area	240 000 ha
Area of lakes and rivers	170 000 ha

Tab. 9-38: Volumes and masses of environmental compartments

	Sediment upper 2 cm	**Soil upper 2 cm**	**Water average: 50 m**	**Air first 500 m**	**Unit**
Area	170 000	945 760	170 000	4 128 400	ha
Volume	34 000 000	189 152 000	85 000 000 000	2.0642E+13	m^3
Mass	51 000 000	283 728 000	85 000 000 000		t

9.2.2 Flows in the subsystem: 'waste and waste water management'

The data in tables Tab. 9-40 to Tab. 9-43 form the basis for the results section in the report (Chapter 6). The data are taken mainly from the flows estimated for the subsystem: 'trade in products' as applied to Switzerland. These are supplemented where necessary by data from other literature sources (e.g. [Danish EPA, 1999]).

In addition to the substance flow values already quoted in the results section, Tab. 9-40 to Tab. 9-43 also show the estimated ranges. As no direct measurements are available for the waste management sector, the error values are taken from the worst-case range of error from the subsystem: 'trade in products' (i.e. of the order of factor 2). The errors arising in the calculation through the use of uncertain transfer coefficients and the assignment of flows to the various processes within waste management are no longer determined or treated explicitly.

The assignment of the total quantities of BFR determined in the subsystem: ‘trade in products’ to the individual waste management processes is performed using the distribution coefficients (transfer coefficients) given in Tab. 9-39.

Tab. 9-39: Assignment of the BFR flows from the subsystem: ‘trade in products’ to the individual waste management processes (Pe: pentaBDPE, O: octaBDPE, D: decaBDPE, TBBPA), quantities in [t/a], distribution in [-].

Consumer products disposed of in CH 1998					**Distribution between waste management processes**		
	Pe	**O**	**D**	**TBBPA**	**Incineration**	**Reuse**	**Landfill**
EE	1	47	161	257	0.384	0.519	0.096
Transport	2	9	106	66	0.000	1.000	0.000
Building	27	5	102	66	0.8*	0.000	0.2*
Textiles	0	0	0	0	0.000	0.000	0.000

* for pentaBDPE, the distribution is: 80 % landfill, 20 % incineration

Tab. 9-40: Input and output flows, and stock, for the process: ‘reuse’

PROCESS		**DESIGNATION OF MATERIAL**		**PentaBDPE flow**	**OctaDBPE flow**	**DecaDBPE flow**	**TBBPA flow**	**Rem.**
				t/a	**t/a**	**t/a**	**t/a**	
Reuse	**IN**							
			Min.	1	17	95	100	
		Separately collected waste	av.	3	33	190	200	1
			Max.	5	66	380	400	
			Min.	0	0	0	0	
		Import to reuse	av.	0	0	0	0	
			Max.	0	0	0	0	
			Min.	0	0	0	0	
		Incineration residues to reuse	av.	0	0	0	0	
			Max.	0	0	0	0	
	OUT							
			Min.	0	0	0	0	
		Reused waste	av.	0	0	0	0	2
			Max.	0	0	0	0	
			Min.	0.6	16	73	55	
		Residual materials to incineration	av.	1.2	31	146	109	3
			Max.	2.4	62	292	218	
			Min.	0.5	1.2	16	42	
		Export from reuse	av.	1.0	2.3	32	83	4
			Max.	2.0	4.6	64	166	
			Min.	0.13	0.6	7	4	
		Landfill material from reuse	av.	0.25	1.1	13	8	5
			Max.	0.50	2.2	26	16	
			Min.	?	?	?	?	
		Emission from reuse	av.	?	?	?	?	6
			Max.	?	?	?	?	
	Stock							
				0	0	0	0	
		Stock		0	0	0	0	
				0	0	0	0	

1) determined in Chapter: ‘trade in products’, assigned to the process: ‘reuse’ according to Tab. 9-39.
2) assumption: negligible quantities of BFR in reused plastics (applies particularly to reuse within industry).
3) according to method in Chapter 5.2 subsystem: ‘waste management’
4) according to method in Chapter 5.2 subsystem: ‘waste management’
5) according to method in Chapter 5.2 subsystem: ‘waste management’
6) no well-founded estimate possible owing to lack of data

The flows: 'import to reuse', 'incineration residues to reuse', and the stock were not determined.

Tab. 9-41: Input and output flows, and stock, for the process: 'waste water treatment'

PROCESS		DESIGNATION OF MATERIAL		PentaBDPE flow	OctaDBPE flow	DecaDBPE flow	TBBPA flow	Rem.
				t/a	t/a	t/a	t/a	
	IN							
Waste water treatment		Waste water	Min.	0.0	0.0	0.3	0.0	
			av.	0.0	0.0	0.6	0.0	7
			Max.	0.0	0.0	1.1	0.0	
		Deposition in municipal waste	Min.	0.00	0.00	0.00	0.00	
			av.	0.19	0.04	0.21	0.03	8
			Max.	0.38	0.07	0.42	0.06	
		Seepage water to waste water treatment	Min.	0.011	0.004	0.025	0.075	
			av.	0.022	0.007	0.050	0.150	9
			Max.	0.044	0.014	0.100	0.300	
	OUT							
		Residues from waste water to incneration	Min.	0.010	?	0.010	0.005	
			av.	0.020	?	0.020	0.010	10
			Max.	0.080	?	0.080	0.040	
		Purified waste water	Min.	0.002	?	0.003	0.001	
			av.	0.004	?	0.005	0.002	11
			Max.	0.008	?	0.010	0.004	
		Sewage sludge to agriculture	Min.	0.018	?	0.023	0.009	
			av.	0.036	?	0.045	0.018	12
			Max.	0.140	?	0.180	0.070	
		Landfill material from waste water treatment	Min.	0.002	?	0.002	0.001	
			av.	0.003	?	0.003	0.001	13
			Max.	0.012	?	0.012	0.004	
	Stock							
		Stock	Min.	0	0	0	0	
			av.	0	0	0	0	
			Max.	0	0	0	0	

7) determined in Chapter: 'trade in products'.
8) estimated on the assumption that 10 % of the emission from 'trade in products' finds its way to municipal waste water disposal in waste water treatment plants via the atmosphere
9) assumption: 90 % of landfill seepage water flow is passed on to the waste water treatment plants
10) according to method in Chapter 5.2 subsystem: 'waste management'
11) according to method in Chapter 5.2 subsystem: 'waste management'
12) according to method in Chapter 5.2 subsystem: 'waste management'
13) according to method in Chapter 5.2 subsystem: 'waste management'

The stock is assumed to be zero.

Tab. 9-42: Input and output flows, and stock, for the process: 'incineration'

PROCESS		DESIGNATION OF MATERIAL		PentaBDPE flow	OctaDBPE flow	DecaDBPE flow	TBBPA flow	Rem.
				t/a	t/a	t/a	t/a	
Incineration	**IN**							
			Min.	2.9	11	72	83	
		Thermally treated waste	av.	5.8	22	143	166	14
			Max.	12	44	287	332	
			Min.	0.6	16	73	55	
		Residual materials to incineration	av.	1.2	31	146	109	15
			Max.	2.4	62	292	218	
			Min.	0.01	?	0.01	0.005	
		Residues from waste water to incineration	av.	0.02	?	0.02	0.010	16
			Max.	0.08	?	0.08	0.040	
			Min.	0	0	0	0	
		Import to incineration	av.	0	0	0	0	17
			Max.	0	0	0	0	
	OUT							
			Min.	0.0013	0.010	0.052	2.0	
		Incineration residues to landfill	av.	0.0025	0.019	0.105	4.0	18
			Max.	0.0051	0.038	0.210	7.9	
			Min.	0	0	0	0	
		Incineration residues to reuse	av.	0	0	0	0	19
			Max.	0	0	0	0	
			Min.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
		Emission from incineration	av.	2.31E-09	1.75E-08	9.54E-08	1.00E-05	20
			Max.	4.62E-09	3.50E-08	1.91E-07	5.20E-04	
			Min.	0.001	0.01	0.030	1.1	
		Export from incineration	av.	0.002	0.01	0.060	2.3	21
			Max.	0.004	0.02	0.120	4.5	
	Stock							
			Min.	0	0	0	0	
		Stock	av.	0	0	0	0	
			Max.	0	0	0	0	

14) determined in Chapter: 'trade in products', assignment to process: 'incineration' according to Tab. 9-39.
15) see Tab. 9-40
16) Tab. 9-41
17) see Tab. 9-43
18) according to method in Chapter 5.2 subsystem: 'waste management'
19) according to method in Chapter 5.2 subsystem: 'waste management' (flows are zero)
20) according to method in Chapter 5.2 subsystem: 'waste management'
21) according to method in Chapter 5.2 subsystem: 'waste management'

The flows 'import to incineration', 'incineration residues to reuse', and the stock are assumed to be zero.

Tab. 9-43: Input and output flows and stocks for the process: 'landfill'

PROCESS		DESIGNATION OF MATERIAL		PentaBDPE flow	OctaDBPE flow	DecaDBPE flow	TBBPA flow	Rem.
				t/a	t/a	t/a	t/a	
Landfill	IN							
			Min.	11	2.8	18	19	
		Dumped waste	av.	22	5.5	36	38	22
			Max.	43	11.0	72	76	
			Min.	0.13	0.6	7	4	
		Landfill material from reuse	av.	0.25	1.1	13	8	23
			Max.	0.50	2.2	26	16	
			Min.	0.002	?	0.002	0.001	
		Landfill material from waste water treatment	av.	0.003	?	0.003	0.001	24
			Max.	0.012	?	0.012	0.004	
			Min.	0.001	0.010	0.052	2.0	
		Incineration residues to landfill	av.	0.003	0.019	0.105	4.0	25
			Max.	0.005	0.038	0.210	7.9	
	OUT							
			Min.	0.011	0.004	0.025	0.075	
		Seepage water to waste water treatment	av.	0.022	0.007	0.050	0.150	26
			Max.	0.044	0.014	0.100	0.300	
			Min.	0.0010	0.0004	0.003	0.008	
		Emission from landfill	av.	0.0020	0.0007	0.005	0.015	27
			Max.	0.0040	0.0014	0.010	0.030	
	Stock							
			Min.	43	43	207	237	
		Stock	av.	130	130	620	710	28
			Max.	325	325	1 550	1 775	

22) determined in Chapter: 'trade in products', assignment to process: 'landfill' as in Tab. 9-39.
23) see Tab. 9-40
24) Tab. 9-41
25) See Tab. 9-42
26) according to method in Chapter 5.2 subsystem: 'waste management'
27) according to method in Chapter 5.2 subsystem: 'waste management'
28) according to method in Chapter 5.2 subsystem: 'waste management'

The stock was estimated from the input to the subsystem: 'trade in products'.

9.2.3 Flows in the subsystem: 'environment'

The data in the following tables form the basis of the results section in the subsystem: 'environment'.

Tab. 9-44: Input and output flows, and stock, for the process: 'atmosphere'

PROCESS		DESIGNATION OF MATERIAL		Material flow	PentaBDPE flow	OctaDBPE flow	DecaDBPE flow	TBBPA flow	Rem.
				1000 t/a	t/a	t/a	t/a	t/a	
Atmosphere	IN								
			Min.		0.9	0.1	1.0	0.1	
		Emission prod., trade and consumption	av.		1.9	0.4	2.1	0.3	1
			Max.		4.1	0.9	6.0	0.6	
			Min.		0.0E+00	0.0E+00	0.0E+00	0.0E+00	0
		Emission from waste	av.		2.3E-09	1.7E-08	9.5E-08	2.8E-04	2
			Max.		4.6E-09	3.5E-08	1.9E-07	5.5E-04	
			Min.		0.00	0.00	0.00	0.00	
		Imported air	av.		0.00	0.00	0.00	0.00	3
			Max.		0.00	0.00	0.00	0.00	
	OUT								
			Min.		0.00	0.00	0.00	0.00	
		Exported air	av.		0.00	0.00	0.00	0.00	3
			Max.		0.00	0.00	0.00	0.00	
			Min.		?	?	?	?	
		Atmospheric deposition to biota	av.		?	?	?	?	4
			Max.		?	?	?	?	
			Min.		0.0001	0.0001	0.0008	0.0002	
		Atmospheric deposition to hydrosphere	av.		0.0001	0.0001	0.0013	0.0006	5
			Max.		0.0002	0.0002	0.0017	0.0010	
			Min.		1.20	0.23	1.32	0.18	
		Atmospheric deposition to pedo/lithosphere	av.		1.71	0.33	1.89	0.25	6
			Max.		2.22	0.43	2.46	0.33	
			Min.		0.00	0.00	0.00	0.00	
		Deposition to municipal waste water	av.		0.19	0.04	0.21	0.03	7
			Max.		0.38	0.07	0.42	0.06	
	Stock								
			Min.		?	?	?	?	
		Stock	av.		<0.0001	<0.0001	<0.0001	<0.0001	
			Max.		?	?	?	?	

1) determined in Chapter: 'trade in products'
2) determined in Chapter: 'waste management'
3) assumption: assumed zero
4) no reliable or usable data available
5) atmospheric deposition to land area of Switzerland assigned proportionately
6) atmospheric deposition to land area of Switzerland assigned proportionately
7) assumption: 10 % of the atmospheric deposition to Swiss land area (emission from process: 'trade in products')

Stocks estimated as in Chapter: 'subsystem: environment'.

Tab. 9-45: Input and output flows, and stock, for the process: 'hydrosphere'

PROCESS		DESIGNATION OF MATERIAL		Material flow	PentaBDPE flow	OctaDBPE flow	DecaDBPE flow	TBBPA flow	Rem.
				1000 t/a	t/a	t/a	t/a	t/a	
Hydrosphere	IN								
			Min.		0.003	?	0.005	0.009	
		Waste water from waste management	av.		0.006	?	0.010	0.017	8
			Max.		0.012	?	0.020	0.034	
			Min.		0.00009	0.00006	0.0008	0.0002	
		Atmospheric deposition to hydrosphere	av.		0.00012	0.00013	0.0013	0.0006	9
			Max.		0.00016	0.00019	0.0017	0.0010	
			Min.		?	?	?	?	
		Erosion	av.		?	?	?	?	
			Max.		?	?	?	?	
	OUT								
			Min.		0.01	0.17	0.02	0.00	
		Export from hydrosphere	av.		0.012	0.33	0.03	0.004	10
			Max.		0.02	0.66	0.06	0.01	
			Min.		?	?	?	?	
		Uptake by biota	av.		?	?	?	?	
			Max.		?	?	?	?	
			Min.		?	?	?	?	
		Sedimentation	av.		?	?	?	?	
			Max.		?	?	?	?	
	Stock								
			Min.		?	?	?	?	
		Stock	av.		3	?	7	4	
			Max.		?	?	?	?	

8) determined in Chapter: 'waste management'

9) atmospheric deposition to land area of Switzerland distributed proportionately

10) calculated from sediment quantity and export via Rhine and Rhone

No reliable or usable data available for erosion, uptake by biota or sedimentation.

Tab. 9-46: Input and output flows and stock for the process: 'pedo/lithosphere'

PROCESS		DESIGNATION OF MATERIAL		Material flow	PentaBDPE flow	OctaDBPE flow	DecaDBPE flow	TBBPA flow	Rem.
				1000 t/a	t/a	t/a	t/a	t/a	
Pedo/ lithosphere	IN								
		Deposition from production, trade and consumption	Min.		?	?	?	?	
			av.		?	?	?	?	
			Max.		?	?	?	?	
			Min.		0.018	?	0.023	0.009	
		Sewage sludge in agriculture	av.		0.036	?	0.045	0.018	11
			Max.		0.140	?	0.180	0.070	
			Min.		1.2	0.2	1.3	0.2	
		Atmospheric deposition pedo/lithosphere	av.		1.7	0.3	1.9	0.3	12
			Max.		2.2	0.4	2.5	0.3	
			Min.		?	?	?	?	
		Sedimentation	av.		?	?	?	?	
			Max.		?	?	?	?	
	OUT								
			Min.		?	?	?	?	
		Uptake by biota	av.		?	?	?	?	
			Max.		?	?	?	?	
			Min.		?	?	?	?	
		Erosion	av.		?	?	?	?	
			Max.		?	?	?	?	
	Stock								
			Min.		?	?	?	?	
		Stock	av.		40	?	20	60	
			Max.		?	?	?	?	

11) percentage of sewage sludge applied in agriculture as determined in Chapter: 'waste management', but reduced by concentration of sewage sludge taken from the literature. For biogenic waste (compost), no data are available from the literature. Assumption: zero

12) see Tab. 9-44

No reliable or usable data are available for erosion, uptake by biota or sedimentation.

Tab. 9-47: input and output flows and stocks for the process: 'biota'

PROCESS		DESIGNATION OF MATERIAL		Material flow	PentaBDPE flow	OctaDBPE flow	DecaDBPE flow	TBBPA flow	Rem.
				1000 t/a	t/a	t/a	t/a	t/a	
Biota	IN								
			Min.		?	?	?	?	
		Atmospheric deposition to biota	av.		?	?	?	?	
			Max.		?	?	?	?	
			Min.		?	?	?	?	
		Uptake by biota	av.		?	?	?	?	
			Max.		?	?	?	?	
			Min..		?	?	?	?	
		Uptake by biota from pedo/lithosphere	av.		?	?	?	?	
			Max.		?	?	?	?	
	OUT								
			Min.		?	?	?	?	
		Output from biota to prod. and consumption	av.		?	?	?	?	
			Max.		?	?	?	?	
	Stock								
			Min.		?	?	?	?	
		Stock	av.		?	?	?	?	
			Max.		?	?	?	?	

No reliable or usable data are available for the process: 'biota'.

9.3 Appendix 3 – properties of the flame retardants under study

The following tables 9-48 to 9-51 provide details of the substances under study and were taken from [ALTEC, 2000]. The literature citations are designated by lower case letters as given in the following list:

(a) Final report of the Swedish FSM project [KEMI, 1996]
(b) IUCLID dataset (European Commission, European Chemicals Bureau)
(c) Danish substance flow analysis [Danish EPA, 1999]
(d) Study on steam pressure [Tittlemier + Tomy, 2000]
(e) EU Risk Assessment [RA, 2000a]
(f) EU Risk Assessment [RA, 2000b]
(g) Environmental Health Criteria (EHC 192) [IPCS, 1997]
(h) Environmental Health Criteria (EHC 172) [IPCS, 1995]
(i) Report in 'Environmental Science & Technology' [Renner, 2000]
(j) Environmental Health Criteria (EHC 162) [IPCS, 1994b]

9.3.1 PentaBDPE

Tab. 9-48: Principal properties of pentaBDPE

General data	
Name of substance	pentabromodiphenyl ether
Commercial name	e.g. DE-71
CAS no.	32534-81-9
Application	
Application	only in PUR foam (f) textiles, PUR foam (g)
Additive / reactive	additive
Content in final product	5-30% (a)
Quantity consumed [t/a]	8500 (i). 5000 in 1992 (a)
Chemical and physical properties	
Molecular weight [g/mol]	564.6
Boiling point [°C at 101.3 kPa]	decomposes (e)
Vapour pressure [mm Hg] or [Pa]	4.69E-5 Pa at 21°C, saturation at 7E-4 (f); 10E-5.11 to 10E-6.12 Pa at 25°C (d); low (a)
Solubility in water	13.3 µg/l (f); low (a)
Log Kow	6.57 (f)
Human toxicity	
Acute tox (LD50) oral [mg/kg]	low acute tox (f), (a)
Acute tox (LD50) dermal [mg/kg]	low acute tox (f), (a)
Acute tox (LD50) inhalative [mg/l]	low acute tox (f), (a)
Irritation (skin, eyes, respiratory tract)	skin and eyes negative, inhalative only at very high doses (f)
Sensitivity [???](dermal, inhalative)	negative (f)
Subacute, subchronic to chronic tox	NOAEL1 mg/kg/d, indications of chloracne (f)
Mutagenicity (Ames test etc.)	negative (a), (f)
Carcinogenicity	nd (f), (a)
Reproductive tox, developmental tox, teratogenicity	no indications (f). Indications of estrogenic effects (new investigation Meerts, Bergman et. al)
Toxic kinetics human/mammalian	rapid assimilation, low metabolism, potentially bioaccumulative (f), for some congeners, long biological half-life of 6-17 weeks in rats (a)
Ecotoxicity	
LC50 fish (96 h) [mg/l]	nd (j), (a)
EC50 daphnia (48 h) [mg/l]	0.014 (f)
EC50 algae (72 h) [mg/l]	nd (j), (a)
EC50 microorganisms (30 min.) [mg/l]	nd (j), (a), (f)
Long-term tox (NOEC 21-90 d) [mg/l]	fish 0.0089 mg/l, daphnia 0.0053 mg/l, sediment 15.5 mg/kg (f)
Environmental behaviour	
Biological degradation	persistent (a), (f)
Photolytic degradation	atmospheric t1/2 12.6 d (f)
Hydrolytic degradation	
Accumulation (BCF)	14350 (f), >10 000 in carp (a)

9.3.2 OctaBDPE

Tab. 9-49: Principal properties of octaBDPE

General data	
Name of substance	octabromodiphenyl ether
Commercial name	e.g. DE-79, Saytex 111
CAS no.	32536-52-0
Application	
Application	ABS (g) often with Sb_2O_3 (a)
Additive / reactive	additive
Content in final product	5-30% (a)
Quantity consumed [t/a]	3825 (i). 5000 in 1992 (a)
Chemical and physical properties	
Molecular weight [g/mol]	801.4
Boiling point [°C at 101.3 kPa]	decomposes (f)
Vapour pressure [mm Hg] or [Pa]	6.59E-6 Pa at 21°C, saturation at 30 μg/m3 (e), low (a)
Solubility in water	<0.5ug/l (e); low (a)
Log Kow	6.29 (e)
Human toxicity	
Acute tox (LD50) oral [mg/kg]	> 5000 (e); low acute tox (a)
acute tox (LD50) dermal [mg/kg]	>2000 (e)
Acute tox (LD50) inhalative [mg/l]	>17-50 (e)
Irritation (skin, eyes, respiratory tract)	skin and eyes negative, inhalative no indications (e)
Sensitivity [???] (dermal, inhalative)	dermal negative (e)
sub acute, sub chronic to chronic tox	NOAEC 0.6 mg/m3, LOAEL 7-10 mg/kg/d
Mutagenicity (Ames test etc.)	negative (a), (e)
Carcinogenicity	nd (a),(e)
Reproductive tox, developmental tox, teratogenicity	NOAEL 2mg/kg/d (e), no clear indications (a)
Toxic kinetics human/mammalian	some congeners have a high biological half-life of 6-17 weeks in rats (a)
Ecotoxicity	
LC50 fish (96 h) [mg/l]	nd (j), (a)
EC50 daphnia (48 h) [mg/l]	nd (j), (a)
EC50 algae (72 h) [mg/l]	nd (j), (a)
EC50 micro organisms (30 min.) [mg/l]	nd (j), (a)
Long-term tox (NOEC 21-90 d) [mg/l]	nd (j), (a)
Environmental behaviour	
Biological degradation	persistent (a)
Photolytic decomposition	possible debromination to low brominated BDE (a)
Hydrolytic decomposition	
Accumulation (BCF)	2 in carp (a)

9.3.3 DecaBDPE

Tab. 9-50: Principal properties of decaBDPE

General data	
Name of substance	decabromodiphenyl ether
Commercial name	e.g. DE-83, DE-83R, Saytex 102E, Adine 505
CAS no.	1163-19-5
Application	
Application	PS, polyester, PA, textiles (g) EEE, textile coverings, polymers etc., often with Sb_2O_3 (a)
Additive / reactive	additive
Content in final product	5-30% (a)
Quantity consumed [t/a]	54 800 (i). 30 000 in 1992 (a)
Chemical and physical properties	
Molecular weight [g/mol]	959
Boiling point [°C at 101.3 kPa]	decomposes (e)
Vapour pressure [mm Hg] or [Pa]	4.63E-6 Pa at 21°C, saturation at 25 ug/m3 (e), low (a)
Solubility in water	<1µg/l at 25°C or 20-30µg/l under unknown conditions (e); low (a)
Log Kow	6.265 (e)
Human toxicity	
Acute tox (LD50) oral [mg/kg]	>2000-5000 (e) low acute tox (a)
acute tox (LD50) dermal [mg/kg]	>2000 (e)
Acute tox (LD50) inhalative [mg/l]	>48.2 (j)
Irritation (skin, eyes, respiratory tract)	skin and eyes negative (a),(e)
Sensitivity [???] (dermal, inhalative)	dermal negative (e)
sub acute, sub chronic to chronic tox	NOAEL 1100- 7000 mg/kg/d (e)
Mutagenicity (Ames test etc.)	negative (a), (e)
Carcinogenicity	classified as non-carcinogenic for humans (e); liver tumours in mice at very high doses (2.5-5% in feed over 2 years)
Reproductive tox, developmental tox, teratogenicity	no clear indications (a)
Toxic kinetics human/mammalian	slow gastro-intestinal assimilation, low bioaccumulative potential, rapid excretion (a), (e)
Ecotoxicity	
LC50 fish (96 h) [mg/l]	nd (j), (a)
EC50 daphnia (48 h) [mg/l]	nd (j), (a)
EC50 algae (72 h) [mg/l]	less than 50% inhibition at 1mg/l acetone (j)
EC50 micro organisms (30 min.) [mg/l]	nd (j), (a)
Long-term tox (NOEC 21-90 d) [mg/l]	nd (j), (a)
Environmental behaviour	
Biological degradation	persistent (a)
Photolytic decomposition	possible debromination to low brominated BDE (a)
Hydrolytic decomposition	
Accumulation (BCF)	<5 or <50 in carp (a)

9.3.4 TBBPA

Tab. 9-51: Principal properties of TBBPA

General data	
Name of substance	tetrabromobisphenol A
Commercial name	e.g. BA-59P, Saytex RB-100
CAS no.	79-94-7
Application	
Application	additive in ABS, PBT, PS, often with Sb_2O_3; reactive in epoxy, PC resins, polyester resin, unsaturated polyester (a), (g)
Additive / reactive	additive und reactive
Content in final product	11-20%, often together with approx. 5% SbO3 (a)
Quantity consumed [t/a]	121 300 (i). 10 000-50 000 (b)
Chemical and physical properties	
Molecular weight [g/mol]	543.9
Boiling point [°C at 101.3 kPa]	316 (a)
Vapour pressure [mm Hg] or [Pa]	<1 mm Hg at 20°C (a) 4.15E-5 mmHg (without temperature data) = 5.52E-3 Pa (c)
Solubility in water	4.16 mg/l at 25°C (a), (b)
Log Kow	4.54 (a), (b)
Human toxicity	
Acute tox (LD50) oral [mg/kg]	> 2000 (a)
acute tox (LD50) dermal [mg/kg]	> 2000 (b)
Acute tox (LD50) inhalative [mg/l]	>0.5 (b), 0.5 to 2.5 (a)
Irritation (skin, eyes, respiratory tract)	skin negative (a), eyes negative (b)
Sensitivity [???] (dermal, inhalative)	dermal negative (b)
sub acute, sub chronic to chronic tox	NOAEL inhalative > 18mg/l; NOAEL oral >100mg/kg to >2500 mg/kg (b)
Mutagenicity (Ames test etc.)	negative, but too few data (a), (b)
Carcinogenicity	nd (b)
Reproductive tox, developmental tox, teratogenicity	negative, but too few data (a)
Toxic kinetics human/mammalian	slow gastro-intestinal absorption, half-life in rats (fatty tissues) 71h, in liver 10h (a)
Ecotoxicity	
LC50 fish (96 h) [mg/l]	0.4-0.54 (b), 0.51 (a)
EC50 daphnia (48 h) [mg/l]	0.96 (a), (b)
EC50 algae (72 h) [mg/l]	0.09 -1 (a), (b)
EC50 micro organisms (30 min.) [mg/l]	0.09-0.89 or 0.13-1 (h)
Long-term tox (NOEC 21-90 d) [mg/l]	fish 0.16 (b)
Environmental behaviour	
Biological degradation	partial degradation, incomplete (a)(b). Indications of degradation to dimethoxy derivates in the environment and organisms (a)
Photolytic decomposition	
Hydrolytic decomposition	
Accumulation (BCF)	200-3200 in aquatic organisms (a), 20-720 (b)