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Evaluation of the Dutch National Food Consumption Survey with respect to dietary exposure assessment of chemical substances

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Abstract

The current Dutch National Food Consumption Survey (DNFCS), consisting of a core survey and additional surveys for special groups, are generally very suitable for dietary exposure assessment of chemical substances. Nevertheless it is recommended to improve its suitability in a number of ways. The most important recommendations are the following: Firstly, to collect food consumption data of very young children (<1 year), which are presently not available. As the food consumption of this age group differs substantially from other young children, it is recommended to perform a food consumption survey for this group of children. Two other suggested improvements of the DNFCS aim at a better estimate of the consumption frequencies of incidentally consumed foods, namely by 1) increasing the number of survey days to three and 2) using the information from food frequency questionnaires. With these two additional sources of information the exposure assessment of substances which only occur in this type of foods can be improved. Furthermore, the quality of dietary exposure assessment of chemical substances can be increased by improving three 'factors' outside the DNFCS, namely the concentration data, the linking process of concentration and consumption data and the uncertainty analysis of the exposure assessment. The improvement of these three factors is considered at least as important as the proposed changes of the DNFCS itself.

Key words: dietary exposure, chemicals, food consumption survey

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1 Introduction

In the Netherlands, the National Institute for Public Health and the Environment and RIKILT-Institute of Food Safety perform national dietary exposure assessments to chemical substances when requested by the Dutch government. The consumption data that are used for these assessments originate predominantly from the Dutch National Food Consumption Surveys (DNFCS).

In the project ‘Evaluation of the DNFCS with respect to exposure assessments of chemical substances’ (Question 9.4.12, 2009), financed by the Dutch Food and Consumer Product Safety Authority, the use of these food consumption data for the estimation of dietary exposure to potentially harmful chemical substances is examined. The project addresses the following questions:

- a. Are the current design and method of the DNFCS suitable for the estimation of dietary exposure to chemical substances?
- b. Is the sample size of these surveys sufficient? Which age groups can be formed? What is the minimum number of persons per age group required to draw conclusions on the exposure to chemical substances?
- c. Should the DNFCS be adjusted to achieve more reliable exposure assessments?

Food consumption data give insight into the consumption of foods and nutritional trends. Furthermore, in combination with concentration data, they can be used to estimate the intake of macro- and micro-nutrients and the exposure to chemical (toxic) substances¹. The DNFCS is coordinated by the Centre for Nutrition and Health of the RIVM. Originally the surveys were set up for the evaluation of the intake of energy and nutrients. In a later stage, the scope of the surveys was broadened to the dietary intake to chemical substances. At present, the DNFCS is used in dietary intake and exposure assessments to estimate:

- The population’s distribution of intake of energy, nutrients or chemical substances;
- The percentage of the population that fulfills the recommended intake level or exceeds the safe upper intake level for particular nutrients;
- The percentage of the population that fulfills the ‘guidelines for healthy diet’;
- The percentage of the population that exceeds health based limit values for chemical substances.

Dietary intake assessment of nutrients and chemical substances is performed by combining food consumption data of the DNFCS with concentration data of nutrients or substances. Whereas at the RIVM the intake of *nutrients* is assessed at the Centre of Nutrition and Health (CVG), the dietary exposure to potentially harmful *chemical substances* is estimated at the Centre of Substances and Integrated Risk Assessment (SIR). The main differences between the dietary intake assessment of nutrients and chemical substances are:

- For the estimation of the intake of nutrients the long-term average intake is relevant, while for chemical substances not only the long-term, but also the short-term intake may be important, depending on the health effects considered;
- Some contaminants are not present in the raw agricultural product but are formed during processing (baking, frying; e.g. acrylamide), or the concentration can be reduced by e.g. boiling, washing. Nutrients, on the other hand, are always present in the raw agricultural product. Due to processing they can either diminish or become better available.
- With respect to health limits: For nutrients there is both a Recommended Dietary Allowance (which is a limit below which health effects may occur) and an Acceptable Upper Limit (above which health effects may occur). In contrast, for chemical (toxic) substances there is only an

¹ Note that for chemical substances the terms ‘intake’ and ‘exposure’ are both used (having the same meaning in this case), whereas for nutrients ‘intake’ is used but not ‘exposure’.

- upper limit (an Acceptable/Tolerable Daily Intake or an Acute Reference Dose). As a consequence, for nutrients there is interest in both the low and high percentiles of the intake distribution, while for chemical substances the main interest is in the high percentiles of intake.
- The intake of nutrients is mostly expressed in absolute daily amounts (e.g. in μg or mg per day), while the intake of chemicals is always expressed relative to the body weight (e.g. ng/kg body weight/day).

These differences between intake estimations of nutrients and exposure estimations of chemical substances may pose specific demands on the design of the food consumption survey (for example, methodology used to assess the consumption of foods, sample size, etc). In the present report these issues are evaluated with respect to the dietary exposure assessment of chemical substances. The intake of nutrients and energy is not addressed.

Chapter 2 of the report describes the current design and method of the DNFCS and the practicability of this survey for dietary exposure assessment of chemical substances. In this chapter also the ideal design of a survey to be used for dietary exposure assessments is addressed. The sample size needed for reliable dietary exposure assessments will be explained in chapter 3.

In addition to improvements of the DNFCS the current report describes some other possibilities to improve dietary exposure assessment of chemical substances. Besides food consumption data, other input data for this type of assessments are data on concentrations, recipes and food processing. These have been included in the evaluation, because of their important role in dietary exposure assessments (chapter 4). In addition, a short evaluation of another method for assessing dietary exposure to chemical substances, namely duplicate diet studies, is presented in chapter 4. This part of the report focuses on the (dis-)advantages of duplicate diets compared to the exposure assessments in which consumption data are combined with concentration data. Chapter 5 summarizes the conclusions and recommendations of the report.

2 Current method of the DNFCS and dietary exposure assessment

This chapter describes and evaluates the design and method of the DNFCS. Firstly, a short description of the current design and method of the Dutch National Food Consumption Surveys is given (section 2.1). More information can be found at the website www.rivm.nl/vcp. In section 2.2 the current design and method is evaluated from the perspective of dietary exposure assessment of chemical substances.

2.1 Current design and method of DNFCS

Since 2003 a new system for dietary monitoring has been implemented in the Netherlands, consisting of five modules (Ocké et al., 2005), see figure 1.

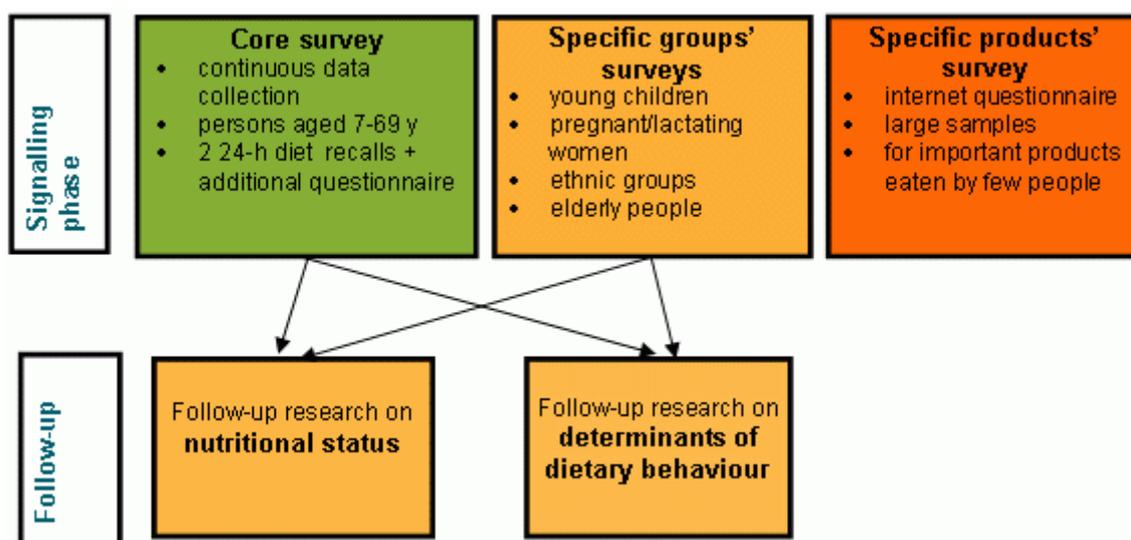


Figure 1 The system for dietary monitoring in the Netherlands (Ocké et al. 2005).

Design

The core of the DNFCS system is a (semi)-continuous data collection (rolling system) in the general population (ages 7 to 69 years). The core data collection started in 2007. Data analysis and reporting will take place every 3 years. For specific target groups that require a different recruitment or different methodology (young children, elderly, ethnic groups, pregnant and lactating women) separate surveys are performed. In 2005/2006 a specific survey on young children has been performed (Ocké et al., 2008) and a survey on elderly is currently in preparation. Participants for the core data collection and the survey on young children were drawn from representative consumer panels.

Method

The dietary assessment method in the DNFCS has changed during the years. Since 2003, data have been collected by means of a general questionnaire and subsequently through two non-consecutive 24-h dietary recalls equally distributed over the week and the year, using the EPIC-Soft computer program

(Slimani et al., 2000). The 24-h dietary recalls are administered by trained dietitians by telephone, or in case the respondent is under 15 years of age by a face-to-face interview at home. Portion sizes of the products and meals consumed are estimated by using photographs and standard units (weight and/or volume).

All data are entered into the EPIC-Soft computer program, which is specifically developed to process food consumption data from highly standardized 24-hour dietary recalls (Slimani et al., 2000). The program is structured by food consumption occasion (three main meals and in-between meals). For each consumption occasion (time/place) all consumed foods are entered, resulting in a detailed description of all consumed foods, including specifics such as fat content, brand name and estimated portion size. The self-administered general questionnaire covers various background and life style factors such as physical activity, educational level and smoking. Frequencies of consumption of specific foods and dietary supplements are also included in the questionnaire.

For surveys that focus on specific groups, e.g. young children, a different dietary assessment method may be used if considered more appropriate for the study population. For the survey on young children a 24h dietary recall by telephone is not possible for obvious reasons. Instead, the carer of the child recorded all foods and drinks the child had consumed on two non-consecutive days in pre-structured diaries. The data from the diaries are entered into the EPIC-Soft computer program by trained dietitians to obtain the same general data format as for the 24-h recalls. The diaries are structured according to food consumption occasion, and associated information on all consumed foods (e.g. fat content, flavor, brand name, preparation method, estimated portion size) is entered. Portion sizes of the products and meals consumed by the child are estimated by the carer by using photographs, domestic measures (a small and a large spoon were supplied to standardise estimates) and standard units (weight and/or volume).

Earlier surveys

In 1987/88, 1992 and 1997/98, food consumption surveys of around 6000 individuals (1-97 years of age) in about 2500 household were performed. Data were collected by means of a 2-day dietary record method, equally distributed over the week and the year. These surveys are called DNFCS 1, 2 and 3. Presently, data of DNFCS 3 is still being used for intake calculations, as it is the most recent population-wide food consumption survey.

2.2 Method of dietary exposure assessment

2.2.1 Classification of consumed foods

Before a dietary exposure assessment can start the consumed foods in the DNFCS need to be coded in such a way that they can be linked to information on their content. Since a similar procedure is required for the intake assessment of nutrients, at RIVM's Centre of Nutrition and Health the consumed food items from the EPIC-Soft dataset (so, in EPIC-Soft codes) are matched with the Dutch food composition database, NEVO. This transformation of consumed food products from EPIC-Soft codes into NEVO codes is also used in dietary exposure assessment of chemical substances.

For this transformation, the detailed description (facets) of the food items in EPIC-Soft is used to find the best match for each product. Depending on the food group, a selection of the following facets is available in the EPIC-Soft dataset: source, physical state/form, cooking method, preservation method, packing medium, flavored/added component, sugar content, fat content, type of packing, food production, enriched/fortified, brand name, skin consumed, visible fat consumed, type of fat used and type of liquid used. Based on the available information the best matching product in the NEVO database is chosen for a product with an EPIC-Soft code plus available facets. If a product cannot be matched to an existing NEVO code a new code is added especially for the specific survey, or the

product can be matched to a comparable product in the NEVO database. It has to be noted that the comparability of the product is based on the comparability of the nutrient value of the products. In practice the number of reported foods as specified by EPIC-Soft is much larger than the number of available NEVO codes. As a consequence, the information present in the NEVO codes is often less detailed than the information in the facets of EPIC-Soft. Hence, the transformation from the EPIC-Soft codes (plus facets) into NEVO codes may lead to a loss of information, e.g. on the preservation method, packing medium etc.

For dietary exposure assessment the combined dataset with the NEVO codes is exported to RIKILT, where the data are prepared for the use in dietary exposure assessment using the computer program Monte Carlo Risk Analysis (MCRA; De Boer and Van der Voet, 2007).

2.2.2 Dietary exposure assessment of substances

Both RIVM and RIKILT use MCRA to perform dietary exposure assessments of substances (De Boer and Van der Voet, 2007). MCRA combines consumption data and concentration data of foods to obtain the dietary intake of the Dutch population in a probabilistic way. Thus, it answers questions like: ‘What is the range of the intakes in the population?’ and ‘How certain are we of these values?’ By using probabilistic methods, the variability in intakes among individuals is considered, i.e. the whole range of possible intakes in the population is estimated. In addition, the uncertainty in the intake estimates can be calculated: confidence intervals are given together with the best estimate for a certain percentile of the intake distribution (e.g. the P50 is 80, the 95%-confidence interval is 65-110). For the MCRA software the food consumption data and concentration data are the two main inputs. Two other databases, a conversion database and a database with processing factors are used to link these two main inputs. In the following paragraph, the method of MCRA is briefly explained. Detailed information on the linking process as well as recommendations for improvement are given in Boon et al. (2008).

The first step of the assessment is to select the data on food consumption by the relevant population and on the concentrations of the compound of interest in the consumed foods (Figure 2). Next, it is necessary to link the concentration data with the consumption data, since the food products for which concentrations are available do not always correspond to the same level of detail in the consumption data (e.g. pizza is consumed, but only concentration data of wheat are available). For this linking process, recipe information is used. For example, the product pizza contains the ingredients tomato, cheese, wheat, water and salami. For each ingredient the fraction in pizza is obtained from the conversion database Conversion Programme for Agricultural Products (CPAP, Van Dooren et al., 1995) and the fractions are combined with the concentrations of the substance in the respective ingredients. In addition to recipes, the conversion database CPAP contains additional information needed for the linking of consumed and analysed food products (e.g. information on the aggregation of NEVO-codes in food groups as ‘bread’ and ‘beef’).

In addition, the processing (peeling, washing, cooking etc.) of food products is taken into account in this step. The next step for MCRA consists of the multiplication of the consumption and concentration data, and summation over the consumed products on one day by one individual (= a person day), to obtain the dietary intake related to this person day. This procedure is repeated for all person-days to obtain the whole range of intakes in the participants. In the final step of the assessment, the calculated intakes are analysed using statistical models, e.g. to estimate confidence intervals. As children have a higher consumption per kg body weight than adults, the dietary intake of substances is preferably estimated as a function of age.

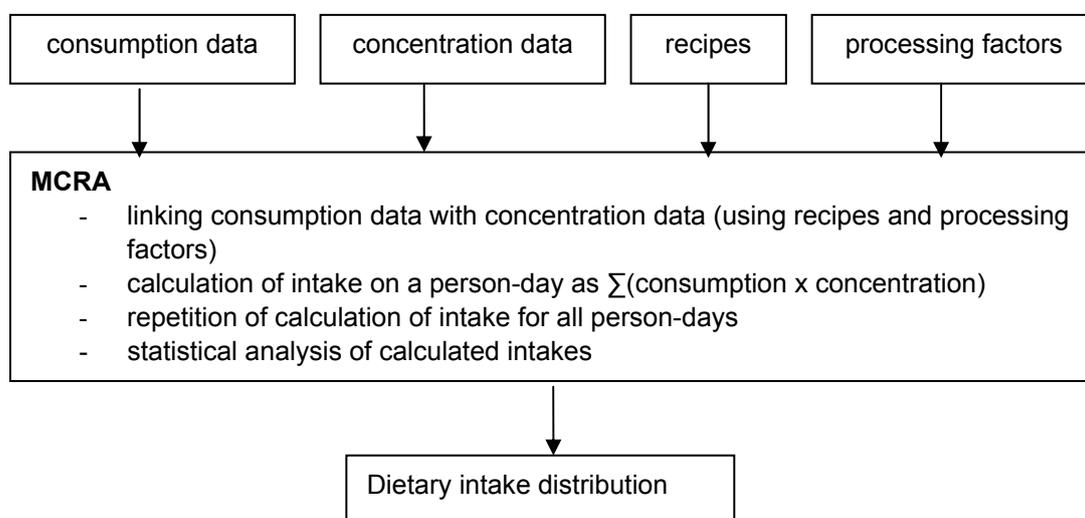


Figure 2. Scheme for the estimation of dietary exposure assessment by MCRA. Three steps can be distinguished: acquiring consumption data and concentration data, the linking of concentration and consumption data, and subsequently the estimation of dietary intake with MCRA, based on statistical modelling.

2.2.3 Usual intake

The statistical models mentioned in the previous section include models for the calculation of the usual intake. The usual intake is calculated for chemical substances that are present in concentrations that exert chronic health effects. Usual intake is defined as the average intake of an individual over an unspecified longer time period (including potential zero-intake days). The distribution of the usual intake is estimated from the observed intakes on two survey days for each person. Statistical models that are available for this include the ISUF model (Iowa State University model for Foods; Nusser et al., 1996; Dodd et al., 2006) and the BBN model (Betabinomial-normal model; Slob 2006; De Boer et al., 2009). These models take into account that for many compounds intake occurs only on a fraction of days (which varies among individuals), by estimating the distribution of the intake frequency. Both the ISUF and BBN model are implemented in MCRA.

For most substances the intake (per kg body weight) decreases with increasing age of the participants, as children consume more food per kg body weight than adults. When there is an effect of age on the intake, the BBN model is the preferred method to estimate the chronic exposure. However, for some compounds the BBN model is not applicable due to the multimodal character of the exposure distribution (e.g. see Boon et al., 2009). In those cases, the ISUF model is often preferred. However, it has been recently shown that this model does not handle multimodal intakes any better than the BBN model, and other options need to be investigated (Slob et al., 2009).

2.3 Evaluation of current design and method for dietary exposure assessment

The 'ideal' food consumption survey

In dietary exposure assessments of chemical substances food consumption data are needed to assess the intake. For this purpose, food consumption data should ideally have the following properties:

- A large enough sample (see chapter 3) of individual participants (i.e. not households), including all age groups from <1 year to 80 years, representative for the Dutch population, in one survey;
- Dietary information of these participants on a number of independent, non-consecutive days, together with a FFQ that gives consumption frequencies and identifies non-consumers for a list of non-regularly consumed food products that are most relevant for chemical substances;
- The dietary data present accurate amounts of consumed food products, which are described in detail (e.g. brand names, preparation method, origin of product);
- Accurate information on age, sex and body weights of participants;
- Additional information on illness, following a diet, celebration, or other specific circumstances making the consumption on that day different from usual (for that participant);
- The survey is repeated every year, with different participants.

Evaluation of current DNFCS with respect to ideal food consumption survey

The current design and method of the DNFCS have several strong points, corresponding with the ideal food consumption survey sketched above:

- o The sample size (number of participants) is sufficiently large (see chapter 3);
- o Individuals are interviewed, rather than whole households;
- o The (two) interview days are independent (not consecutive);

On the other hand, the deviations of the current method of DNFCS from the ideal food consumption survey are listed below (ranked by importance)²:

- o The 24-hour recall method generally gives an accurate description of consumed food products, at the same level at which foods are generally analysed (see Table 1). Especially the description of raw agricultural products (fruits, vegetables, meat, dairy) is sufficiently detailed. However, problems may arise for substances that are formed during (home) processing, such as polycyclic aromatic hydrocarbons (PAHs), furans, and heterocyclic amines. For a dietary assessment of these substances, information on food preparation is required. This information is presently not always sufficiently used (e.g. grilling of meat), because it is not included in the NEVO codes. It is, however, present in the 'raw' EPIC-Soft data (facet strings) and could be made available. But at the same time it should be noted that currently concentrations in prepared foods are rarely measured in the Netherlands. In addition, processing factors, which could be used in combination with concentration data on raw food products, are scarce.

² Note that most of the weaknesses of DNFCS with respect to the exposure assessment of chemical substances also hold for the dietary intake assessment of nutrients.

Table 1. Level of detail in the description of foods in consumption databases according to NEVO code and according to EPIC-Soft codes and facets.

Type of substances	Analysed foods	Accurate description of consumed foods in NEVO codes?	Accurate description of consumed foods in EPIC-Soft?
Additives	Specific products, such as non-alcoholic beverages (intense sweeteners), sweets (colorants)	No	Yes, information on brandname and flavour of the product is present in the facets
Mycotoxins	Cereals, cereal-based products, (dried) fruits, a.o.	Yes ¹	Yes ¹
Pesticides, nitrate	Raw agricultural products	Yes ¹	Yes ¹
Persistent organic pollutants (POPs, e.g. dioxins, PCBs, brominated flame retardants)	Meat, dairy, fruits, vegetables, fish	Yes ^{1,2}	Yes ^{1,2}
Acrylamide	Specific starch-containing products such as French fries, crisps, cookies, spiced nuts	Not always	Yes
Other processing contaminants like PAHs, furans, heterocyclic amines	Prepared food products (e.g. meat)	No	Yes, information on the method of preparation is present in the facets

¹ Information on the origin of the foods (also if foods are biologically grown) is not available and may be useful if this information can be incorporated in the exposure model and if concentration data are available for the different origins.

² Information on packaging materials is not present and may be useful since some POPs (e.g. perfluorinated alkylsulfonates) may migrate from these.

- It is important to include younger children in a survey. The consumption of very young children is highly relevant, because it is not only quantitatively but also qualitatively quite different from the rest of the population. So, it is recommended to collect information on food consumption from birth.
- The DNFCS-Young children's (2005-2006) lowest age category is 2 years. Originally, inclusion of children aged 1 to 6 years was planned for this survey. However, since recent information on consumption of younger children was already available at the start of the survey, children younger than 2 years were not included. The information for younger children came from a survey conducted by TNO and Nutricia in 2002, called the VIO (Voedingsstoffen Inname Onderzoek), in which the consumption of children aged 8-20 months was investigated. The difference in dietary consumption methods used in the two studies may make an assessment using both surveys less reliable.
- The results from the survey are likely to be biased due to the fact that participants of the surveys are members of a consumer panel. People willing to participate in those panels are likely to be more health conscious.
- For the dietary exposure assessment of substances it is preferred that the intake is estimated as a function of age. Hence, consumption data for all age groups, in the same period of time, are

preferred. Presently, a rolling system is used where several age groups are interviewed in separate surveys (young children 1-6 y, basic group 7-70 y, elderly > 70 y). For the exposure assessment the data from the separate surveys need to be merged. Apart from being impractical, merging different datasets has two other drawbacks:

- The datasets do not cover the same time period (e.g. young children in 2005/2006 and the 7 to 70 year olds in 2007-2010);
- Different dietary consumption methods are used for different datasets (e.g. for young children 2-d dietary record, for 7 to 70 year olds 2×24 h recall).

One dataset for the whole population (at once), just as done in the earlier surveys (DNFCS 1-3), would be better suitable and more practical for the exposure assessment. However, as the differences in methodology between subgroups (e.g. recalls vs. diaries) will be present in this latter option as well, additionally calibration studies need to be performed to take these differences into account.

- The number of interview days (two) is rather low. More interview days (e.g. 5-10) should give a better estimate of the consumption frequency, in particular for less frequently consumed food products (Slob 2005). However, it is also known from the literature that an extension to 4 or more survey days results in an increase in underreporting (Moreno et al. 2005). Therefore, three interview days appears a good compromise and is therefore recommended.
- The origin of consumed food products (e.g. country of origin) is not recorded. Food products of different origins may have very different concentrations of particular substances. Examples are methylmercury (concentrations in wild vs. cultured fish) and mycotoxins (Dutch vs. imported wheat).
- The fact that biologically grown food products are consumed may be of importance for the intake of pesticides and mycotoxins, such as patulin. It is suggested to include a question on the consumption of biologically grown products for different food categories (e.g. meat, dairy, bread) in the FFQ (rather than ask for this information during the recall for each product separately). Note that information on the fraction of consumed foods that was biologically grown can only be used if this information can be incorporated in the exposure model and if concentration data are available for (non)-biologically grown foods.
- Body weight is self-reported in most DNFCS (except for the survey on young children where body weight was measured by an independent person). Hence, underreporting of body weights may be expected.
- The core survey is repeated every three years. Although this is not as regular as the 'ideal' yearly survey, it appears regular enough, considering the rate by which dietary habits change.
- The consumed amount of a food product is estimated from photographs and standard measures. This is not as accurate as weighing the food products. However, weighing foods has unwanted side-effects: due to a higher workload the response for the survey with weighed foods is expected to be lower. In addition, weighing each food product will likely lead to a different consumption pattern of the participants, so it will likely lead to bias. Hence, the present method of estimation of portion sizes is satisfying.

3 Sample size needed for dietary assessment of substances

3.1 Sample size for intake of nutrients versus chemical substances

The calculation of the required sample size for DNFCS has been described in detail elsewhere (Ocké et al., 2005). These calculations were based on the intake of food groups (vegetables and fruit) and nutrients in each age group. The sample size of the DNFCS is not constant for each age: sample sizes of children are larger than those of adults, due to their more divergent food consumption patterns. In most cases these results cannot be used to estimate the sample size needed for dietary assessment of substances. The equations are therefore not presented here. The equations are based on a lognormal distribution of intake and this is often not the case with intake of chemical substances. Nutrients are generally present in everyone's diet, but chemical substances are often present in specific, individual food products (for example an artificial sweetener in a non-alcoholic beverage). Consequently the required sample size for dietary exposure assessment depends on the products containing the substance, which again depends on the substance of interest. If the compound is only present in infrequently consumed products (e.g. offal) a larger sample size will be needed for accurate estimates of exposure, because the number of consumption days is relatively low. It is also important to be able to identify true non-consumers. This can be done with information from FFQs, as mentioned in section 2.2.

3.2 Evaluation of sample size

To evaluate if the current sample size of the various surveys is sufficient for dietary exposure assessment two types of assessments need to be distinguished: for some substances the long-term (usual) intake needs to be assessed, while for others the acute intake is more relevant. For environmental contaminants such as mycotoxins and persistent organic pollutants long-term health effects are usually relevant, while acute intake estimations are generally more appropriate for pesticides.

Usual intake

To assess the appropriateness of the sample size used in DNFCS for long-term dietary exposure of substances the results from the recent report on young children (Boon et al., 2009) are presented in table 2. The survey consisted of 1279 children, aged 2 to 6 years.

Table 2. Dietary exposure to chemical substances (percentiles + 95% confidence intervals) of young children (N=1279) (based on appendix H in Boon et al., 2009).

Substance	Age (years)	P50 (95% CI)	P95 (95% CI)
Acrylamide	2-6	0.7 (0.6-0.8)	1.2 (1.0-1.4)
Dioxins	2	1.5 (1.3-1.6)	2.8 (2.4-3.4)
Aflatoxin B	2-6	0.8 (0.6-0.9)	2.7 (2.0-3.6)
Patulin	2-6	0.03 (0.03-0.04)	0.2 (0.2-0.3)
Nitrate (summer)	2	1.9 (1.8-2.3)	4.7 (4.3-6.0)

For some substances the exposure of the whole sample (2-6 years) is reported in the table, while for others the exposure is reported for one age group, e.g. 2 year olds. The method used for calculating exposure takes all data into account, e.g. if data on 2 year olds is presented, also the data of 3 to 6 years olds were included in the analysis. Therefore, sample size considerations relate to the number of subjects in the overall study, and not to the number of children in a single age group.

From the confidence intervals presented in table 2 it can be seen that the sample size of 1279 children resulted in reasonably precise estimates (upper and lower confidence limit have a ratio of about 1.4) of relevant exposure characteristics³. Since the sample sizes of DNFCS 3 (6250) and the presently running DNFCS-core survey (4000) are higher than those of DNFCS-Young children (1279), the sample sizes of the former two surveys would also have been sufficient for these substances. As an example, dietary exposure estimates of PBDE 47 based on data from DNFCS 3 are given in Table 3. These results have relatively small confidence intervals as well (ratio of upper and lower limit of 1.1).

Table 3. Percentiles of age-dependent dietary intake of PBDE-47 (pg/kg bw/day). Between brackets: 95% confidence interval. (Adapted from Noorlander et al. 2009).

	P50 (95% CI)		P95 (95% CI)	
	male	female	male	female
life-long average intake PBDE-47 2008	811 (794-862)	751 (734-797)	1328 (1298-1421)	1230 (1200-1313)

Results of simulation studies (Slob, 2005) indicate that a consumption frequency distribution with an expected frequency as low as 0.0065 (=0.65%, which corresponds to about 80 consumptions in DNFCS 3) can still be estimated reasonably well from food surveys like the DNFCS 3. Hence, the sample size of the current DNFCS is also considered sufficient for substances only present in incidentally consumed foods, as long as the frequency is not extremely low (i.e. not lower than 0.65%). Nevertheless, the sample size of the consumption surveys may not be sufficient for substances which are only present in very rarely consumed foods (consumption frequency lower than 0.65%) and for which only a very low number of consumptions will be recorded in the DNFCS. In that case there is not sufficient information in the data to estimate the distribution of the consumption frequency (= probability of nonzero consumption on a single day), and possibly not for the distribution of consumed amounts as well. Therefore, the DNFCS is not very suitable for such substances, and exposure

³ Note that the confidence intervals in the results of table 2 stem from both the uncertainty in the sampling of participant and the uncertainty in the sampling of foods. Intake calculations which only include the sampling uncertainty of the participants and not that of the food concentrations (for example the estimations for PBDE 47 in 2008, see Table 3) will have smaller confidence intervals.

estimates are bound to be less precise, even when additional information from food questionnaires is used.

Acute intake

For assessment of acute dietary exposure (acute refers to 24 h in this report), a high percentile of the intake distribution (as calculated for each person-day from the DNFCS) is often determined as a parameter of interest. Analogous to the situation of long-term intake, the number of participants in the current design is adequate for substances which are ingested by (almost) all individuals in the population, while problems may arise when the number of zero intakes is large.

Acute exposure assessment is relevant for deriving acute product limits of pesticides (Maximum Residue Levels, MRLs). In the current approach, a “worst case” intake is calculated based on the so-called ‘large portion’ (LP), which is the P97.5 of the observed consumption distribution for the raw agricultural products. Here, only the “consumption days” are taken into account, i.e. the person-days with an observed nonzero consumption. Van der Velde *et al.* (RIVM-report in preparation) determine this percentile by simply taking the sample percentile from the observed nonzero consumptions⁴. For the estimation of a 97.5th percentile at least 40 consumptions would be needed (in that case the highest reported consumption amount is the 97.5th percentile). However, when percentiles are estimated by more appropriate statistical methods, there are no bounds in the required number of consumption days: the only thing that can be stated is that the precision of the estimates will decrease with a lower number of consumption days. These more appropriate statistical methods will also provide the associated confidence intervals, which indicate the precision that was actually reached.

⁴ More precisely: the observed nonzero consumptions of the food products which have the relevant commodity as ingredient, on the condition that the commodity of interest is an important (> 75 %) ingredient of the food product.

4 Discussion and conclusions

As discussed in sections 2.3 and 3.2, the current Dutch National Food Consumption Survey, consisting of the core survey and special groups surveys, is, in general, very suitable for dietary exposure assessment of chemical substances. The food consumption data obtained with the current design, method and sample size appear appropriate for estimating the dietary exposure of most chemical substances. Exceptions are formed by those substances that only occur in very rarely consumed foods. Some suggestions for improvement of the current DNFCS in this regard are presented below (section 4.1). In addition, some other potential improvements in dietary exposure assessment of chemical substances are discussed in section 4.2. The discussion on improvements of DNFCS and other aspects of dietary exposure estimation should be considered in relation to other methods for the dietary exposure assessment of chemical substances. Another method which gives detailed information on the dietary exposure of chemicals is duplicate diet studies. For that reason, in section 4.3 the (dis-)advantages of duplicate diet studies in relation to dietary exposure estimations using food consumption data in combination with concentration data are described.

4.1 Possible improvements in design and method of DNFCS

Very young children

Since the consumption of very young children is highly relevant, as it is both quantitatively and qualitatively different from that of other children, it is recommended to collect information on food consumption from birth.

If the collection of data on the consumption of breast milk is considered too difficult, the consumption of all foods that are consumed in addition to breast milk should be surveyed. Therefore it is recommended to perform a separate survey for the young children aged 4 months to 1 year.

Additionally, it should be noted that children < 1 year do not form a homogenous group, and decisions on sample sizes should be based on monthly age groups, for instance.

Sample size

For substances which generally occur in our diet, the sample size of the DNFCS (about 4000 participants in the age class of 7-70 y) is sufficient. The results from the survey on young children showed that a smaller number of participants (around 1300) also results in reasonably accurate estimates of exposure of substances that are ingested every day by all individuals in the population. However, the sample size may not be sufficient for those substances that only occur in rarely consumed foods, i.e. those with a consumption frequency lower than ~1% in a survey of 6250×2 person days. For surveys with a lower number of person days this 'critical' percentage will be higher. Therefore, the current number of person days should be maintained.

It is important to note that there is no absolute minimum sample size, but that the lower the number of consumptions of foods containing the substance, the higher the uncertainty regarding the estimated exposure of this substance.

Number of survey days

As mentioned in section 2.3 the number of survey days used (two) is relatively small. Especially in the case of an incidentally consumed food, a higher number of survey days may result in a more reliable estimate of the consumption frequency of this food. Computer simulations indicated that the optimum number of days per respondent would be 5-10 (Slob, 2005). However, increasing the number of days could lead to more underreporting, as was described above. A number of three days appears a good

compromise and is therefore recommended for the dietary exposure assessment of chemicals. In contrast, for the dietary intake assessment of nutrients, a number of two days is considered sufficient

For the improvement of the estimation of the consumption frequency of foods, it is additionally recommended to make better use of the food frequency questionnaires (FFQs) that are carried out during the survey. In the DNFCS, participants complete a questionnaire in which they answer questions on how often they consume specific incidentally consumed food products. The food products mentioned in the questionnaire are the ones relevant for chemical food safety (e.g. fried potato products for acrylamide and specific fatty fish for dioxins). In this way information is obtained on the consumption frequency distribution of these foods, which may complement (or validate) the information as given by the statistical model using the DNFCS data. The information in these questionnaires is presently not used in dietary exposure estimation. How to use this information in the future and which products need to be included in the FFQ is a subject of research within RIVM. In addition, the information of FFQs should be used to identify true non-consumers, and the FFQ should be specifically designed for that purpose.

Nevertheless, although the number of food products on the FFQ list is fairly large, it does not cover all food products. Since it is not always known beforehand for which food products the information on the consumption frequency is needed, it may occur that a specific product appears relevant for chemical food safety but is not present in the questionnaire.

On the other hand, it is not always necessary to include a specific product. If a product is consumed in a constant (and known) ratio to a product group then a question on the intake of the product group can be sufficient to include information on the product in the calculations. For example, a question on intake of vegetables can be sufficient to estimate the intake of leafy vegetables.

In conclusion, it is recommended to increase the number of survey days to three. Additionally, the FFQ data should be used to get a better view on the consumption frequency of rarely consumed foods.

Age range of survey

As mentioned in section 2.3, it is preferred to estimate the dietary intake of substances as a function of age. In the present set-up of the DNFCS, consumption data of different age groups relate to different surveys: the most recent survey on young children dates from 2005/2006, while food consumption data of the age category 7-70 years are being collected from 2007-2010. A survey for older people is planned in the near future. So, to estimate the dietary intake of a substance as a function of the age for the whole age range, the data from these surveys need to be combined in future dietary exposure assessments. This will be done under the assumption that the differences between the 24-h recall (as used in the age group 7-70 y) and the dietary record (as was used for the young children) are small and that the rate of changing consumption habits is fairly low. (Note that in both approaches EPIC-Soft will be/was used to record the food consumption.) Although a combination of different surveys can be done in practice, it would be more convenient to have food consumption data covering the whole age range from a single survey. It should be noted that independent of whether one overall survey or separate surveys for each age group are performed, the difference between the recall and record method will nonetheless exist. As a consequence, a calibration study to investigate the differences between the two methods is still desirable. Alternatively, a systematic influence of the used method (record vs. recall) on the intake may be estimated by comparing the (age-dependent) intakes of children for which different methods were used (e.g. the intakes of 4, 5 and 6 year olds compared to those of 7, 8 and 9 year olds). It is suggested to collect of food consumption data for children < 1 year of age in a separate survey, because of the large qualitative differences of their diet with diets of older children.

Prevention of bias

The recruitment of participants for DNFCS is performed by sampling from consumer panels. This may lead to bias, because people that participate in those panels are likely to be more health conscious. For the DNFCS-elderly recruitment will be done by drawing a sample from the population register to obtain a more random and representative study population. This method is expected to lead to lower bias. However, a drawback could be that it may be less easy to obtain a representative sample on characteristics like education (because the education level of the potential participants is not known beforehand, and lower educated people need to be over-sampled because they generally give a lower response to participation in a food consumption survey). In addition it is expected that the sampling costs will be higher. Overall, the recruitment using the population register appears preferable over the recruitment through consumer panels.

4.2 Other improvements in dietary exposure assessment of substances

In addition to improvements to the design and method of the DNFCS, there are several other ways to improve dietary exposure assessment of substances. The most important ones are listed below, ranked from high to lower importance.

Concentration data

In addition to food consumption data, the concentration data for the food products need to be suitable for a reliable dietary exposure assessment. While the quality of the food consumption data is fairly good, the quality of available concentration data varies. In many cases the concentration data are limited (only few foods analysed), or of poor quality for dietary exposure assessment (non-random samples, inadequate description). At present, the monitoring programmes in The Netherlands (and also in other countries) are primarily conducted to check compliance of analysed concentrations with maximum residue limits and not to assess exposure with these data. The use of concentration data that is not primarily suitable for the purpose of dietary exposure assessment likely poses a larger problem in dietary exposure assessments than the quality of the consumption data.

Ideally, concentration data for dietary exposure assessment should have the following properties: Firstly, it is important that a sufficient number of foods is analysed. Secondly, the measured foods should be adequately described (e.g. a description as ‘remaining food products’ is useless in an exposure assessment). Furthermore, the analysis methods should be reproducible and with sufficiently low limits of detection and/or quantification. The numerical information on the analytical error and the value of the limit of quantification should be available to the exposure assessors. Finally, it is very important to have detailed information on the samples: Was it random or targeted sampling? Were the samples pooled or not? What is the origin of the samples?

These topics were discussed in a workshop organized by RIKILT in September 2009. In this workshop information on methods and procedures was shared between exposure assessors and analytical chemists from the Dutch Food and Consumer Product Safety Authority. It was concluded that a better communication between the two groups would lead to an improved dietary exposure assessment. A follow-up of this workshop with indications how to improve the communication is desirable.

Of course, information on the origin of the samples that were sampled is only useful if the origin of the consumed foods in the survey is also reported. As the average participant of the DNFCS will generally not be aware of the origin of consumed foods (e.g. cultured fish versus wild caught fish, Dutch wheat versus imported wheat, etc.), this information should be obtained from the food industry, e.g. the

Commodity Boards (in Dutch: productschappen). The information can subsequently be used in dietary exposure assessments, e.g. by using probabilistic modelling techniques.

Information on food processing

Almost all contaminants' concentrations (including pesticide residues) are influenced by food processing. In food processing, the absolute amount of the compound is changed. For example cooking, frying, washing, and other processing can reduce the content of the contaminant in the product. Concentrations of substances are often measured in raw agricultural products rather than ready-to-eat food products, since the analyses are performed with the purpose of enforcement of product limits. Hence, the influence of processing needs to be taken into account by using food processing factors, obtained from literature. The data regarding food processing factors are generally scarce and if available often highly variable. At RIKILT, the available information on pesticide residues as collected by the Bundesinstitut für Risikobewertung (BfR; www.bfr.bund.de) has been put into a database for use in dietary exposure assessments with MCRA. Extending this database with other substances is desirable. Also for the food consumption data information on processing should be available. At present, facets in the EPIC-Soft codes cover cooking, baking and grilling but not washing. This latter would be desirable if washing is known to affect chemical concentrations (like the effect of washing on captan concentrations), and factors for washing are available (and significantly different from 1), which is at present generally not the case.

Data conversion for dietary exposure modelling

Presently, as explained in section 2.3, accurate descriptions of consumed processed foods are not always sufficiently present in the food consumption survey, because the information is not included in the NEVO codes. It is, however, present in the 'raw' EPIC-Soft data (facet strings). The conversion of consumed food products from the descriptive codes in EPIC-Soft (EPIC-Soft code plus a number of facets) to NEVO-codes leads to loss of information. For example, a description of 'prepared meat' in NEVO does not give information on whether this meat has been fried, grilled or baked before consumption. It would be useful to make a 'conversion table' which links the EPIC-Soft codes, including processing information, directly to the chemical concentration data. In that case, the translation step to NEVO-codes can be 'cut out' of the process, the detailed information can be kept intact and can be used in the dietary exposure assessment if information on processing is also present for the concentration data.

The EPIC-Soft program contains more information on recipes than is presently used in the dietary exposure assessment of chemicals. This is because presently the NEVO-codes are used as a starting point to link consumed food products to measured foods in CPAP (e.g. relevant to link concentrations analysed in RACs to consumed foods, such pesticide residues, mycotoxins, doxins, etc). In a letter report on the linkage of food consumption data with concentration data for dietary exposure assessment Boon et al.(2008) recommended to invest in the full use of the food consumption data by updating CPAP. It was also advised to perform two case studies to review the work needed for such an update. Updating the conversion model using information stored in EPIC-Soft will improve the dietary exposure assessments and result in more realistic estimates of exposure for chemicals analysed at RAC level (Boon et al. 2008). The present report supports the recommendations of Boon et al. (2008).

Uncertainty analysis

A final suggestion to improve dietary exposure assessments is to quantify and evaluate more sources of uncertainty, and thus to improve the interpretation of the assessment results. Uncertainty analyses can also highlight those factors that are the major sources of uncertainty in the dietary exposure assessment. This offers the opportunity to focus on the most (cost-)effective ways of improving the exposure

assessment by reducing important uncertainties, e.g. by collecting more or other data. In a recent RIVM report Van Ooijen et al. (2009) recommended to add extra modules to MCRA concerning the uncertainty in standard portions, recipe variability, the composition of food samples, and, in particular, analytical measurement uncertainty. With the inclusion of modules to calculate the uncertainty of these model inputs, the major sources of model input uncertainty are covered within MCRA. As a consequence, a better view of the overall uncertainty will be obtained.

4.3 Duplicate diet studies

An alternative way to estimate the intake of compounds present in food is to determine these compounds in duplicate diets. By directly measuring a compound in duplicate diets, all foods are taken into account, while in exposure assessment based on food consumption surveys only the foods that have been analysed are considered. Therefore, duplicate diet studies should give an *unbiased* estimate of the typical daily exposure in the average individual. Other advantages of duplicate diets are:

- The influence of food preparation (cooking, baking etc.) is taken into account
- Duplicate diets can be stored (frozen and/or freeze dried), so additional analyses can be done at a later time⁵.

On the other hand, there are a number of drawbacks to the duplicate diet method:

- The number of individual intakes obtained with this method is limited by the relative low sample sizes of these studies. As a consequence, the distribution of acute intakes cannot be reliably estimated (to be able to do this, a sample size similar to the sample size of the DNFCs is required);
- Since only one pooled 24-hr sample is available for each individual, it is not possible to estimate the distribution of usual intakes (at least 2×24 h is needed to be able to do this);
- By pooling all foods consumed on one day in one duplicate diet sample, the information on the contribution of the various food items to the overall exposure is lost. At best, some information on important sources may be found by recording the foods (and amounts) in each duplicate food sample;
- Due to a strong dilution of contaminated foods with uncontaminated ones the measurement of substances in the duplicate diet may be difficult. Nevertheless, for a number of substances this problem has been reduced due to the development of more sensitive analytical methods.

In the Netherlands, duplicate diet studies have been performed once every decade since 1974. The duplicate diet samples of about 120 participants have been analysed for many substances e.g. mycotoxins, pesticides and brominated flame retardants (e.g. Van Egmond, 2000; Sizoo et al., 2004).

Results of the two methods (duplicate diet and combining consumptions and concentrations) are sometimes found to be similar, in other cases they are not. For some substances the difference was within 20%, e.g. for ochratoxin A in the whole population (Bakker en Pieters, 2003), PBDE 47 in the whole population (Te Biesebeek 2009) and DON in 2- 6 y old children (Boon et al. 2009). For other substances, however, the results of duplicate diets were found to be a factor of 2 to 3 higher than the results of intake assessments based on combined consumption and concentration data, such as for DON in 8-12 months old infants (Schothorst et al. 2005) and for PBDE 99 (Te Biesebeek et al.

⁵ Note that this can also be done with samples of food products taken specifically with the aim of dietary exposure estimation.

2009). Possible explanations may be that 1) not all sources of these substances are known and not all relevant foods may have been analysed and 2) the foods consumed in the duplicate diet study may have been different (e.g. in origin, year, season) from the foods analyzed for the intake calculations.

On the other hand, the children's duplicate diet results for aflatoxin B₁ and M₁, fumonisin B₁ and ochratoxin A in 2-6 y old children were sometimes more than a factor of three lower than the estimated intakes with DNFCS (Boon et al. 2009). This large difference was probably due to (partly) targeted sampling of food products, which led to too high concentrations used in the dietary exposure estimation.

Overall, the comparison of results from duplicate diet studies and from DNFCS indicates that the latter might result in biased estimates of exposure, either too high or too low. The most effective way of reducing this bias is probably by improving concentration measurements. Obviously, this would be particularly relevant in situations where the estimated exposure is close to the human limit values. From the perspective that the possible bias in the exposure estimates can be a factor of about three, an estimated exposure that is a factor three lower than the health based limit value should definitely be considered as close to the health based limit value.

In conclusion, dietary intake estimation using DNFCS and MCRA or using duplicate diet studies both have advantages and drawbacks. The results from MCRA are more informative, e.g. by providing information on the distribution of the usual intake, in relation to other factors such as age and sex, while the duplicate diet method probably results in a more reliable (= unbiased) point estimate of the mean exposure. In addition, for cases in which the concentration data are lacking or are difficult to obtain (e.g. process contaminants like PAHs and furans) a duplicate diet study can give rapid insight in (emerging) risks.

In general, estimating exposure based on the DNFCS would be favourable as a first tier, given the relatively low costs. In situations where the estimated exposure comes close to the health based limit value, either better concentration data or duplicate diet studies should be considered as a next step. In addition, the use of biomarkers to validate the exposure estimation could be contemplated.

5 Conclusions and recommendations

The current DNFCS (consisting of a core survey and special groups surveys) is generally very suitable for dietary exposure assessment of chemical substances. Notwithstanding, a number of improvements are proposed to increase the suitability of the DNFCS for this purpose, with a ranking of priority (low, medium, high) between brackets:

- Include younger children (<1 years) in a separate survey (high);
- Increase the number of survey days to three (and maintain the present total number of person days), (high);
- Make better use of FFQs to estimate consumption frequencies of rarely consumed foods (high);
- Reconsider broadening the age range of the core data collection: include younger children and the elderly all in one survey and over-sample very young children (more than at present), (medium);
- Add a question on the use of biological grown products (per food group) in the FFQ (medium);
- Reconsider the sampling framework of DNFCS to achieve a more representative basis (use of population register in stead of consumer panels), (low);
- Reconsider the sample size as a function of age: define age groups based on a qualitative change of consumption behaviour rather than on the number of birthdays (low).

In addition, dietary exposure assessment of chemical substances may be improved in three other areas, namely concentration data, linking processes and uncertainty:

Concentration data:

- Improve information on sampling, food description and analysis methods, including the limit of detection in the concentration data, by better communication between exposure assessors and analyzing laboratories and a follow-up of the workshop of 2009 (high);
- When consumed foods originate from other countries and also, when the effect of processing is unknown, the concentration of chemical substances should be analysed in the products as they are consumed, e.g. processed foods and foods from retail stores (high).

Linking consumption data to concentration data:

- Construct a conversion table to link foods coded with EPIC-Soft codes to chemical concentration data, including processing (high);
- Improve the conversion of foods as eaten to raw agricultural commodities (as done in model CPAP) with information from EPIC-Soft (high);
- Collect more information on the behaviour of chemical substances during food processing (high);
- Obtain the origin of the consumed foods in the survey from the food industry, e.g. the Commodity Boards (medium).

Uncertainty of dietary exposure estimate:

- Improve the uncertainty analysis of dietary exposure assessment as suggested by Van Ooijen et al. (2009) (high);
- In situations where the estimated exposure comes close to the health based limit value, either better concentration data, duplicate diet studies, or biomarker studies should be considered as a next step (high).

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