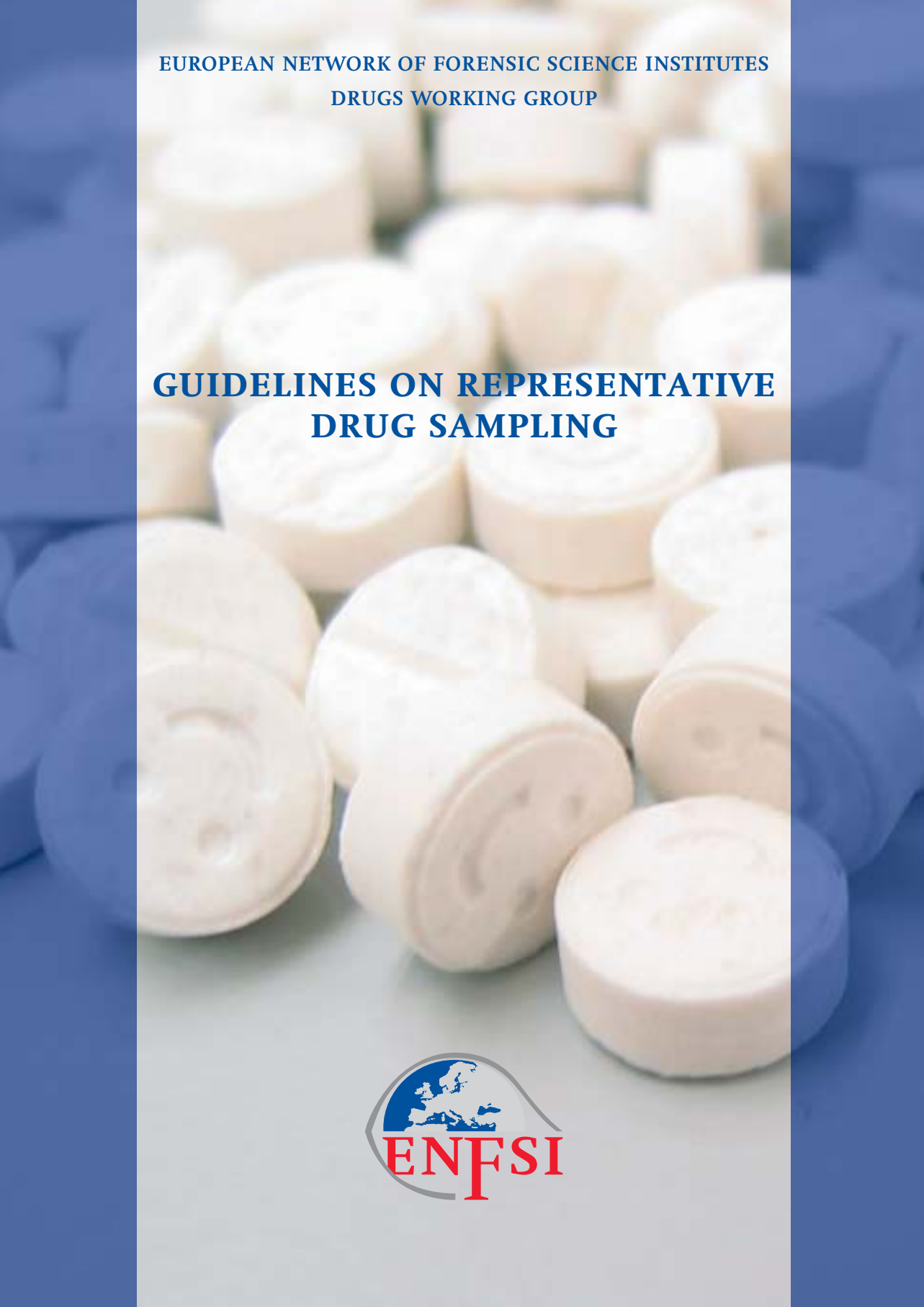
EUROPEAN NETWORK OF FORENSIC SCIENCE INSTITUTES

DRUGS WORKING GROUP

GUIDELINES ON REPRESENTATIVE DRUG SAMPLING



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ENFSI WG Drugs

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Design
Optima Forma bv, Voorburg

Print
Opmeer Drukkerij bv, Den Haag

Printing of this booklet was possible thanks to a grant from the Netherlands Forensic Institute

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THIS DOCUMENT INCLUDES A MACRO FOR CALCULATIONS
(file ENFSI Sampling Software Version 1_7 date 230204;
latest version available via website www.ENFSI.org)

Foreword

In the ENFSI Working Group (WG) Drugs, quality assurance (QA) and best practice are important topics. QA is an extensive field where a lot of documentation and various guidelines are already available. For this reason, the WG Drugs meeting in Krakow in 2000 decided to focus on a number of other topics that were more or less specific for the WG Drugs. So far, two targets were chosen, the first one being sampling (sampling strategy), the second one being drugs reference compounds.

In the Madrid meeting of 2001, many members of the WG showed their interest and offered help with the realisation of a manual or a discussion document on sampling. Out of these members the steering committee composed a subcommittee with - for practical reasons - a limited number of colleagues. The composition was such that members had own practical experience with at least one of the sampling methods. A first draft was sent in March 2002 by email and presented in May 2002 at the WG meeting in Oslo. The comments, discussions and responses resulted in the document that is presented here and was adopted at the ENFSI WG Drugs meeting in Istanbul 2003.

The primary task of the subcommittee was to identify and describe common sampling procedures. From this, a discussion could be initiated whether there was a sampling method that was superior to the other ones. In the meantime it became clear that a mere collection of possible sampling strategies was not sufficient. So, on the EU level a sampling proposal was submitted by the Spanish presidency (2002) to the Drugs Trafficking Working Party; it comprised the use of an arbitrary sampling method as the EU standard; later the proposal was extended with another (different) method. Since ENFSI's Working Group Drugs was working on sampling, the discussion of the proposal was postponed. From that time on, there seemed parallel lines between the development of the ENFSI sampling document and an ENFSI advice on sampling to the Police Co-operation Working Group (PCWG). During the Greek presidency an ENFSI advice on this matter was urgently requested, as decisions had to be made by June 2003.

The WG steering committee was pleased to have, as requested, the draft sampling document (except foreword and introduction) ready in spring 2003. This document formed the basis of the advice, which was formulated and accepted by both the sampling subcommittee and the WG steering committee. The (draft) document and the advice were presented by the WG's chairman to the PCWG on June 17th 2003 in Brussels. In the course of the year 2003 the introduction, the foreword and the computer programs were added and some text corrections were made. This version and the slightly reformulated sampling advice was approved by the ENFSI board on November 21-22nd and sent to the PCWG, followed by a presentation on Dec 4th, 2003 in Brussels.

The steering committee is proud of the realisation of this sampling document.
We wish to express our thanks to the chairperson and members of the subcommittee on sampling for their excellent work.

The ENFSI WG Drugs,

Dr Henk Huizer
(Chairperson 2000-2002)

Dr Erkki Sippola
(Chairperson 2002-)

Chapter 1

Introduction

The sampling document describes a number of sampling methods, from arbitrary methods to methods with a statistical background. The document focuses on sampling in cases where large numbers of relatively homogeneous material are available. It does not deal with so-called tactical sampling, which may be applied for house-searches or in clandestine laboratory investigations. These cases are characterised by different materials, sometimes in different amounts, different packages and/or sometimes with different suspects; these cases are considered as so specific and so dependent on the situation (also in legal aspects) that a guideline would be inadequate in many cases. Thus, the document contains a number of sampling strategies for cases with large numbers of items of relatively homogeneous material. However, from the descriptions of the sampling methods, it is not automatically clear which strategy should be preferred (or would be optimum). This is mainly due to the fact that it is not possible to define a sampling strategy, if the requirements have not been defined. This is the main reason why it was decided to refrain from giving advice at local, regional or national level.
ENFSI cannot give such a fine-tuned advice as is possible in a specific agreement between prosecutor, police, and chemist and laboratory management.

However, at the EU level, an advice was requested and the steering committee felt that if one group were competent to produce one, it would be the ENFSI WG Drugs. The resulting advice for international cases is mainly based on a number of aspects, which are discussed in the chapter 'Considerations and Recommendations'. Here, the advantages and disadvantages of various methods, also in relation with sampling practice, are brought up. It seems that a Bayesian approach is a reasonable one in many cases, but its complexity might be a major drawback, especially for court. Luckily enough, the hypergeometric and Bayesian approaches appear to show more or less the same results in cases where no prior probability is used.

Since sampling is often carried out by police and customs, we did not want to give an advice where the number of samples must be calculated for each separate case; this would be confusing and bother them with computers or lists with Bayesian and hypergeometric tables. Therefore the final sampling advice just mentions the (*minimum*) number of samples to be taken (5, 8 or 11, the number of samples being dependent on the circumstances). The forensic laboratory can then, if necessary, perform the final evaluation and probability calculations.

The subcommittee on sampling has studied and considered sampling procedures and drafted and finalised this document. But also many other members and steering committee members have contributed either by their written response or comments in any other form; their suggestions and support were a fruitful input for the subcommittee. We wish to express our thanks to the contributors and their laboratory management. We are convinced that the members of the ENFSI WG Drugs and other colleagues working in the field of drug analysis will benefit from this work; it provides them with a reference on which they can develop an appropriate good working practice.

Dr. Sergio Schiavone
Chairperson of the Sampling Subcommittee
November 2003

Chapter 2

Definitions

1. Seizure

The entire quantity of items seized. This may consist of a single population or a number of populations.

2. Population

The collection of items under discussion. A population may be real or hypothetical; finite or infinite; homogeneous or heterogeneous.
For the purposes of this booklet, the term population will refer to a real, finite homogeneous population unless otherwise specified.

3. Package

A container for a single unit, a number of units or a number of other sub-packages.

4. Unit

A single individual element of a population (e.g. a single tablet or a single package containing powder etc.).

5. Sample

A unit or a number of units selected from a population.

6. Mean

This is the average value of a set of measurements. The mean can refer to either:

(i) The arithmic mean of a *population*. This is the true mean calculated from the entire population.
It is denoted by μ

or

(ii) The arithmetic mean of a *sample*. This is an estimate of μ calculated from a sample of the population.
It is denoted by $\overline{X}$

Unless otherwise stated, the term 'mean' will refer to the arithmetic mean of a sample as described in 6 (ii).

7. Standard Deviation

This is a measure of the variation in the values of a set of measurements.
The standard deviation can refer to either:

(i) The standard deviation of a *population*. This is the true standard deviation calculated from the entire population.
It is denoted by σ

or

(ii) The standard deviation of a *sample*. This is an estimate of calculated from a sample of the population.
It is denoted by s

Unless otherwise stated, the term 'standard deviation' will refer to the standard deviation of a sample as described in 7 (ii).

Symbols

P = probability
N = population size
N_1 = number of positives in the population
n = sample size
X = number of positives in the sample
x = the value of number of positives in the sample
$r = n - x$ = the value of the number of negatives in the sample
$\theta = \frac{N_1}{N}$ = proportion of positives in the population
K = threshold number of positives guaranteed in the population
$k = K/N$ = ratio of positives guaranteed in the population
α = threshold index for evaluation of confidence
$(1 - \alpha)*100\%$ = confidence level
a = first parameter of beta function
b = second parameter of beta function
Y = number of positives in the unexamined units
μ = the arithmetic mean in the population
$\overline{X}$ = the arithmetic mean in the sample
σ = the standard deviation in the population
s = the standard deviation in the sample
w = the total weight in the sample
W = total estimated weight in the population
P_{corr} = correction factor in weight estimation
Q_{corr} = correction factor in weight estimation

Chapter 3

Representative sampling techniques

A representative sampling procedure can be performed on a population of units with sufficient similar external characteristics (e.g. size, colour). The decision on how to perform it is left to the discretion of the examiner. An example about what is meant by similar external characteristics is very important. Considering a group of heroin street doses, which are packed in similar packaging, we can apply a sampling rule to this population. So, if you have 100 street doses with different groups of external characteristics, you have to separate your 100 street doses in as many groups as dissimilarities. Each group will be considered as a whole population and will be sampled alone. In some rare cases, although the external characteristics look the same, when we open the units (sampling), we may notice huge differences in the powder appearance among the units. In this case, you have to stop the sampling procedure according to the above mentioned criteria. In general it happens when you don't look thoroughly at the external characteristics of the packages.

The theoretical way to select a truly random, unbiased representative sample from a population is to individually number each item in the population and then use a random number generator to choose which item to select. This is not possible in practice, especially not for large populations containing many thousands of units.
When sampling, we must ensure that two principles are maintained:

1. the properties of the sample are a true reflection of the properties of the population from which the samples were taken.
2. each unit in the population has an equal chance of being selected.

In reality, it is more difficult to adhere to these principles than it first seems. As was mentioned before, the decision in selecting the samples is left to the discretion of the examiner because, when the population is high, it is impossible to number all the units and use a protocol based on a random selection of numbers. So, considering a subjective choice, it happens that sometimes the expert tends to choose similar sized units, instead of running a real random sampling.

The practical solution is quite easy: after having observed that the external characteristics are the same, you can put all the units in a “black box” (plastic bag or any other idea) and take out your sample without choosing. This kind of solution can be applied to practical cases such as seizures of a thousand heroin street doses in similar external packages or a thousand tablets. In this case you can apply this “black box” sampling method to eliminate (or at least reduce to a minimum) any bias that may be introduced by the person selecting the samples. When we refer to a “black box” method we mean any method that will prevent the sampler from consciously selecting a specific item from the population.
These methods are not standardised yet and we can refer to the example given above.

Chapter 4

Arbitrary sampling

The following are various arbitrary sampling methods. They are often used in practice and work well in many situations. However they have no statistical foundation and may lead to a very large sample in case of large seizures. Not all existing sampling procedures are given; some laboratories use variations of these.

1. All ($n = N$)

   Advantage(s): 100% certainty about the composition of the population.
   Disadvantage(s): Excessive sample sizes for larger populations.

2. $n = 0.05N$, $n = 0.1N$, etc.

   Advantage(s): Simple approach.
   Disadvantage(s): Excessive sample sizes for larger populations.

3. $n = \sqrt{N}$, $n = 0.5\sqrt{N}$, $n = \sqrt{\frac{N}{2}}$, etc.

   Advantage(s): Widely accepted approach.
   Disadvantage(s): The number of samples may be too small when the population is small. Excessive sample sizes for larger populations.

4. $n = 20 + 10\%(N - 20)$ (*where* $N > 20$)

   Advantage(s): Heterogeneous populations likely to be discovered before analysis is complete.
   Disadvantage(s): Excessive sample sizes for larger populations.

5. *for* $N < x$ $n = N$
   $x \leq N \leq y$ $n = z$
   $N > y$ $n = \sqrt{N}$
   (where x, y and z are arbitrary numbers; $x < y$ and $x \leq z < y$)

   Advantage(s): United Nations Drug Control Program recommended method ($x = 10$, $y = 100$, $z = 10$).
   Disadvantage(s): Excessive sample sizes for larger populations.

6. $n = 1$

   Advantage(s): Minimum amount of work.
   Disadvantage(s): Least amount of information on the characteristics of the seizure.

Chapter 5

Statistical sampling methods

Introduction

The methods discussed in this chapter provide statistically founded ways to determine the sample size. The first two methods concern a frequentist approach, while the third method describes a Bayesian approach.

The assumption behind a frequentist approach is that a fixed but unknown proportion of the seizure contains drugs. The proportion of drugs in a sample (= the sampled units) can estimate this seizure proportion. The proportion of drugs in the sample will, however, vary over different samples. Therefore, the frequentist methods provide a confidence, $(1 - \alpha)100\%$ (for instance 95% if α is selected to be 0.05), that with a given sample proportion the seizure proportion is at least $k100\%$ (for instance 90% if k is selected to be 0.9). In other words, one would be correct about a seizure containing at least 90% drugs in 95 out of 100 cases.

The assumption behind a Bayesian approach is that the sample proportion is known and fixed. This proportion is used to calculate probabilities on certain values of the unknown seizure proportion that at that point is still assumed variable. With this approach it is possible to incorporate some knowledge about the seizure that you may possibly have. The seizure proportion is not known but often some ideas about this proportion exist. For instance, if all plants in a hemp nursery appear similar they probably are all hemp plants. It is also possible that there is no clue about the amount and type of drugs in a seizure. These various forms of prior information will result in different mathematical models to estimate a desired sample size in the Bayesian approach.

1. The hypergeometric distribution

Application

The probability that a sample of size n contains X positives (units containing illegal drugs), given that the population of size N contains N_1 positives, can be calculated by

$$P(X = x \mid N_1, N, n) = \frac{\binom{N_1}{x}\binom{N - N_1}{n - x}}{\binom{N}{n}}$$

This is the hypergeometric distribution. The first (and mostly used) frequentist method is based on this distribution.

In sampling drug units, the numbers of positives, N_1, and negatives, $N - N_1$ are unknown. To determine these numbers exactly the whole seizure has to be analysed. If some uncertainty is allowed, the hypergeometric distribution can be used to calculate a sample size of n units that have to be analysed such that at least K (= kN) units are positive with $(1 - \alpha)100\%$ confidence. For instance, calculate n such that with 95% confidence at least 90% of the packages contains illegal drugs. These choices of the numbers for α and k depend on laboratory guidelines, costs, legal requirements and so on.

If the choices about α and k are made and if an assumption is made about the number of positives to be expected in the sample (usually x), the sample size n can be solved from the above formula. Take for the cumulative probability $P(X \geq x) = (1 - \alpha)$ and for $N_1 = K$. Table 5.1 (tables are listed in appendix A) provides the required sample sizes for some standard choices of α and k with different population sizes, if all sampled units are believed to be positive. Table 5.2 provides the same information if 1 or 2 of the sampled units are expected to be negative (contain no drugs). Sample sizes can also be calculated with a macro in software such as Excel®, as included in this document (latest version will be made available via the www.enfsi.org).

Table 5.1 Hypergeometric distribution.
Required sample size to guarantee with 95% or 99% confidence that the seizure contains at least a proportion of k drugs, if expected that all sampled units contain drugs.

population size *N*	95% confidence			99% confidence		
	k=0.5	*k*=0.7	*k*=0.9	*k*=0.5	*k*=0.7	*k* =0.9
10	3	5	8	4	6	9
20	4	6	12	5	9	15
30	4	7	15	6	10	20
40	4	7	18	6	10	23
50	4	8	19	6	11	26
60	4	8	20	6	11	28
70	5	8	21	7	12	30
80	5	8	22	7	12	31
90	5	8	23	7	12	32
100	5	8	23	7	12	33
200	5	9	26	7	13	38
300	5	9	27	7	13	40
400	5	9	27	7	13	41
500	5	9	28	7	13	41
600	5	9	28	7	13	42
700	5	9	28	7	13	42
800	5	9	28	7	13	42
900	5	9	28	7	13	43
1000	5	9	28	7	13	43
5000	5	9	29	7	13	44
10000	5	9	29	7	13	44

Example 1
Suppose that a population contains 100 packages. To guarantee with 95% confidence that at least 90% of the packages contains illegal drugs, a sample of 23 packages has to be drawn and all of these packages have to contain illegal drugs (see Table 5.1).

The assumption that all sampled units contain drugs is often made. This assumption can be made because this is learned from many years of experience in the field, or simply by reasoning that it makes no sense to

Table 5.2 Hypergeometric distribution.

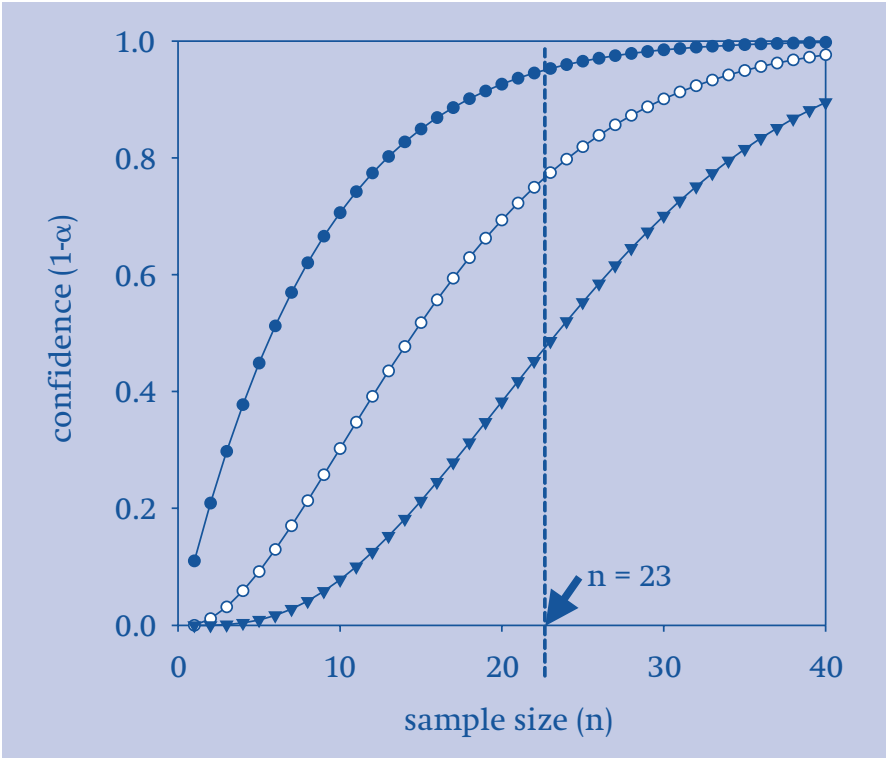
Required sample size to guarantee with 95% or 99% confidence that the seizure contains at least a proportion of k drugs, if expected that either 1 or 2 sampled units do not contain drugs (1 or 2 negatives).

Population size *N*	95% confidence						99% confidence					
	k=0.5		*k*=0.7		*k*=0.9		*k*=0.5		*k*=0.7		*k*=0.9	
	1 neg	2 neg	1 neg	2 neg	1 neg	2 neg	1 neg	2 neg	1 neg	2 neg	1 neg	2 neg
10	5	5	7	7	9	9	5	5	7	7	9	9
20	6	8	10	13	17	18	8	10	12	14	18	18
30	7	9	11	14	22	27	8	11	14	17	25	27
40	7	9	12	15	26	32	9	11	15	18	30	35
50	7	10	12	16	29	36	9	12	16	20	34	41
60	7	10	12	16	31	39	9	12	16	20	38	45
70	7	10	13	17	32	41	10	12	17	21	40	48
80	7	10	13	17	34	43	10	12	17	21	42	51
90	7	10	13	17	35	45	10	13	17	21	44	54
100	7	10	13	17	36	46	10	13	17	22	46	56
200	8	10	14	18	40	53	10	13	18	24	54	67
300	8	10	14	19	42	55	10	13	19	24	57	71
400	8	11	14	19	43	57	10	13	19	24	58	74
500	8	11	14	19	44	58	10	14	19	24	59	75
600	8	11	14	19	44	58	10	14	19	25	60	76
700	8	11	14	19	44	59	11	14	19	25	61	77
800	8	11	14	19	44	59	11	14	19	25	61	77
900	8	11	14	19	45	59	11	14	19	25	61	78
1000	8	11	14	19	45	59	11	14	19	25	62	78
5000	8	11	14	19	46	59	11	14	20	25	64	81
10000	8	11	14	19	46	61	11	14	20	25	64	81

mix the drugs with no-drugs, apart from maybe a layer of distraction material on top. However, occasionally one or more units in the sample may not contain drugs. In that case, the guaranteed confidence or the minimum proportion drugs in the population drops. Figure 5.1 shows for the sample size of 23, that the confidence to guarantee a proportion drugs of at least 90% drops from 95% to about 77% if one sampled unit did not contain drugs instead of 0 (*N*=100). Alternatively and probably more useful for presentation at the court, the probability can be maintained at 95%

Figure 5.1

Confidence against sample size (N = 100; k = 0.9) for 0, 1, and 2 negatives. Lines -●- for 0 negatives; -○- for 1 negative; -▼- for 2 negatives

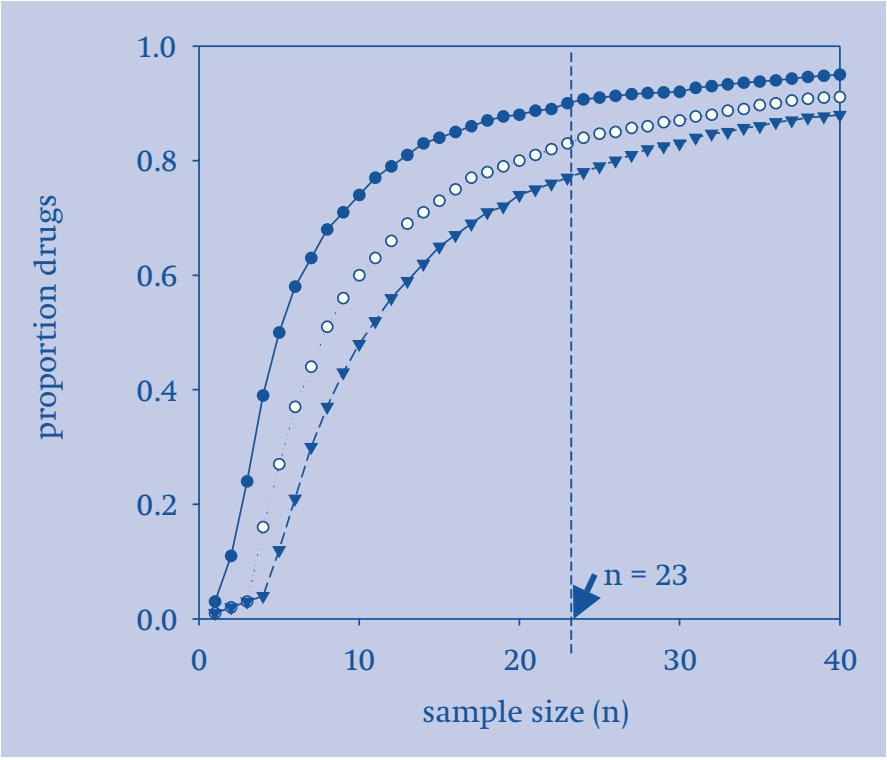


and then the minimum proportion of drugs calculated. Figure 5.2 shows that the guaranteed proportion at a confidence of 95% drops from 90% to 84 % (for sample size = 23, one negative instead of 0, *N*=100). Table 5.2 shows that a sample of 36 was needed to guarantee with 95% confidence that at least 90% of the population contained drugs if one negative in the sample was assumed beforehand.

It is statistically not correct to sample another 13 units on top of 23 if one of these 23 –upon analysis– does not contain drugs. Before sampling a decision should be made how many negatives in the sample are expected. Afterwards, when one or more sampled units are found to be negative this has consequences for the confidence and/or the proportion levels. This property makes the sampling with the hypergeometric distribution (and other frequentist methods) hard to understand intuitively.

Figure 5.2

Proportion of drug in seizure against sample size (N = 100; P = 0.95) for 0, 1, and 2 negatives expected. Lines -●- for 0 negatives; -○- for 1 negative; -▼- for 2 negatives



Example 2

If it is sufficient to guarantee with a high probability (say 95%) that drugs are present in the majority (> 50%) of the exhibit (of 100), then only a sample of 5 is necessary provided that no negative is found (see Table 5.1).

Theory

This section is for those who want more background information on the hypergeometric distribution and the calculation of the table values.

The hypergeometric distribution, and thus the theory below, assumes that samples are taken without replacement. The sample size to be taken from a population of size *N* is calculated by testing the null hypothesis that the number of positives in the population is less than *K* against the alternative hypothesis that the number of positives is at least *K*.

$$H_0 : N_1 < K \text{ and } H_1 : N_1 \geq K$$

To prosecute people for all the seized units it is desired that $N_1 \geq K$. Evidence has to be found to reject the null-hypothesis. However, no big mistakes are allowed. This means that the probability that the null hypothesis is rejected, while it is true, should be small, say $\alpha 100\%$. This provides a confidence level of $(1 - \alpha)100\%$. The hypotheses are tested with the number of positives in the sample, X, as the test statistic. The null-hypothesis is rejected when X is larger than a certain number. If this number is taken as the number of positives expected in the sample, x, then, n should be selected such that

$$P(X \geq x \,|\, N_1 < K) \leq \alpha$$

In words, the sample size n should be selected such that under the null-hypothesis the probability that the number of positives in the sample is larger than x, is smaller than α. This hypergeometric distribution decreases as N_1 decreases, therefore all probabilities with values for $N_1 < K$ are smaller than the probability where $N_1 < K - 1$. Thus, select n such that

$$P(X \geq x \,|\, N_1 < K) = \sum_{i=x}^{n} \frac{\binom{K-1}{i}\binom{N-K+1}{n-i}}{\binom{N}{n}} \leq \alpha$$

When $x = n$, this reduces to

$$\frac{\binom{K-1}{n}\binom{N-K+1}{0}}{\binom{N}{n}} \leq \alpha$$

This is

$$P_0 = \frac{(K-1)!(N-n)!}{(K-n-1)!N!} = \frac{(K-1)(k-2)\ldots(K-n)}{N(N-1)\ldots(N-n+1)} \leq \alpha$$

For one “negative” in the sample the inequality reduces to

$$P_0 \left[1 + \frac{n(N-K+1)}{(K-n)} \right] \leq \alpha$$

and for two "negatives" the inequality reduces to

$$P_0\left[1+\frac{n(N-K+1)}{(K-n)}\left\{1+\frac{(n-1)(N-K)}{2(K-n+1)}\right\}\right] \leq \alpha \qquad \text{and so on.}$$

2. The binomial distribution

Application

This is the second method using a frequentist approach. It is an easier method, but can only be used in special cases. The binomial distribution assumes sampling with replacement. This means that a unit is placed back after it is sampled and analysed before the next unit is sampled. Of course this is not practiced in drugs sampling. However, in situations where the seizure is very large (at least 50, preferably larger) and the sample is relatively small the hypergeometric distribution can be approximated by the less complex binomial distribution. In that case, the probability that a sample of size n contains X positives (units containing illegal drugs), given that the population of size N contains a proportion of $\theta = \frac{N_1}{N}$ positives, is

$$P(X = x \mid \theta, n) = \binom{n}{x} \theta^x (1-\theta)^{n-x}$$

Similarly, as with the hypergeometric distribution, the binomial distribution can be used to calculate a sample size n such that with $(1-\alpha)100\%$ confidence can be stated that at least a proportion of $k100\%$ is positive. The calculations with the binomial distribution are easier than the ones with the hypergeometric distribution. However, it should be kept in mind that the binomial distribution is an approximation. The sample size estimated with it will be slightly overestimated. Only in very large seizures (sometimes of several thousands) the sample sizes calculated from both distributions will be exactly equal.

If no negatives are expected the sample size n, that with $(1-\alpha)100\%$ confidence can be stated that at least a proportion of $k100\%$ is positive, can be calculated by the minimum value for which

$$n \leq \frac{\log \alpha}{\log \theta}$$

regardless of the population size. If negatives are found in the sample conclusions have to be adapted in a similar way as with the hypergeometric distribution. Again tables or the included software can be used.

Example 1
A large seizure is made. Experienced police people can see that this is most probably all heroin. Even if only half of it is heroin this will still be a large seizure. Therefore a sample that guarantees with 95% confidence that at least 50% of the seizure is drugs may be sufficient. Table 5.3 shows that in that case the sample size will be 5, if no negatives are assumed.

Example 2
To guarantee with 95 % confidence that at least 90% of the pills contain drugs a sample of 29 should be drawn (if no negatives in the sample are assumed). Compare this with the hypergeometric distribution when a sample has to be drawn from a population of 100. Then the sample size is only 23. Only when the population is as large as 1600, the results from the binomial distribution are coinciding with that of the hypergeometric distribution for this particular values of $(1 - \alpha)100\%$ and k.

Theory

The theory behind the binomial distribution is similar to that of the hypergeometric distribution. The hypotheses are

$H_0 : \theta < k$
$H_1 : \theta \geq k$

Table 5.3 Binomial distribution.
Required sample size to guarantee with 95% or 99% confidence that the seizure contains at least a proportion of k drugs if expected that 0, 1 or 2 sampled units do not contain drugs (0, 1 or 2 negatives). Use this only for large seizures.

population size N	95% confidence			99% confidence		
	k=0.5	k=0.7	k=0.9	k=0.5	k=0.7	k =0.9
0 negatives	5	9	29	7	13	44
1 negative	8	14	46	11	20	64
2 negatives	11	19	61	14	25	81

To select n, the equation to be solved is

$$P(X \geq x \mid \theta < k) = \sum_{i=x}^{n} \binom{n}{x} \theta^{x}(1-\theta)^{n-x} \leq \alpha$$

Thus in case $x = n$, the equation to be solved is

$$\theta^{n} \leq \alpha$$

That is, find the minimum value for which

$$n \leq \frac{\log \alpha}{\log \theta}$$

The binomial distribution is an approximation of the hypergeometric distribution. The value for n found with the binomial distribution will always be equal to or greater than the value found with the hypergeometric distribution.

3. Bayesian approach

Application

Within the Bayesian approach (like the frequentist approach) a distinction can be made between sampling with replacement and sampling without replacement. Again sampling with replacement is easier and can be used as an approximation for situations where the population size is at least 50 and the sample relatively small. Here, an overestimate is not such a problem as with the binomial distribution. That is why the sampling with replacement approximation is much more used in the Bayesian approach.

Bayesians assume that, although the population proportion is not known, there may be some ideas about the size of this proportion. These ideas are represented by a probability distribution $p(\theta)$, the so-called prior distribution of the proportion. This uncertain knowledge is combined with the information provided by the sample to a so-called posterior distribution of the proportions, given the sample results. With this posterior distribution it is possible to calculate directly the probability that the proportion of drugs is at least k (given the sample results) without using tests or confidence intervals. This is because Bayesians calculate $P(\theta > k \mid x,n)$ directly instead of $P(X > x \mid \theta > k,n)$ as the frequentists do.

Seizure containing more than 50 units

If a population is large ($N > 50$) and the sample is relatively small compared to the population, the probability density function for the proportion θ of positives, given that a sample of size n contains x positives is

$$f(\theta \mid x,n,a,b) = Be(x + a,\ n - x + b) = \frac{\theta^{x+a-1}(1-\theta)^{n-x+b-1}}{B(x + a,n - x + b)}$$

This is the beta distribution with parameters $x + a$ and $n - x + b$.
The parameters a and b have to be selected beforehand based on prior knowledge or assumptions about θ. The prior knowledge together with the information about the data (the sample size n and number of positives in the sample x) form the above presented posterior distribution. Be stands for the beta distribution and B stands for the beta function. For more details see the theory section.

The probability that the population proportion is larger than k can be calculated with $P(\theta > k \mid x,n)$. This can be used to select a sample size n such that the probability that $\theta > k$ is $(1 - \alpha)100\%$. For instance, select n such that the probability is 95% that at least 90% of the pills contains illegal drugs. The calculations are independent of the population size. Calculations on the beta distribution to find such an n can best be carried out with the aid of a computer program. Table 5.4 is based on computer calculations with the macro included in this document. Like in the frequentist methods you have to assume beforehand what the number of positives in your sample will be, and adapt your conclusions if afterwards this number is not correct. Again in most cases no negatives will be expected.

Besides the expected number of positives in the sample, a prior distribution has to be selected. In general this is a beta distribution. One suggestion is to take both parameters a and b equal to 1, if there is no prior idea about the contents of the pills. The prior distribution then equals the uniform distribution. Another suggestion is to take them both equal to 0.5 if there is a prior that either all pills contain drugs or no pills at all contain drugs. Take $b = 1$, and $a = 3$ (or even higher) if there is a prior belief, based on visual inspection and experience or so, that probably all is drugs. For instance, 100 similar packages are found, all containing powder with exactly the same type of white colour, same structure and all having the same weight. Sampling a hemp nursery may even be a more extreme case.

Table 5.4 Beta distribution (with parameters $x + a$ and $n - x + b$).
Required sample size to guarantee with a probability of 95% or 99% that the seizure contains at least a proportion of k drugs if expected that 0, 1, or 2 sampled units do not contain drugs (0, 1 or 2 negatives). A large seizure is assumed (N > 50). Use (a=1, b=1) if no prior information is known, (a=0.5, b=0.5) if it is reasonable to assume that either everything is drugs or nothing is drugs (a=3, b=1, or more extreme values) if there are reasons to believe that all or most of the seizure contains drugs.

a = 1 b = 1	95% confidence			99% confidence		
	k=0.5	k=0.7	k=0.9	k=0.5	k=0.7	k=0.9
0 negatives	4	8	28	6	12	43
1 negative	7	13	45	10	19	63
2 negatives	10	18	60	13	24	80

a = 3 b = 1	95% confidence			99% confidence		
	k=0.5	k=0.7	k=0.9	k=0.5	k=0.7	k=0.9
0 negatives	2	6	26	4	10	41
1 negative	5	11	43	8	17	61
2 negatives	8	16	58	11	22	78

a = 0.5 b = 1	95% confidence			99% confidence		
	k=0.5	k=0.7	k=0.9	k=0.5	k=0.7	k=0.9
0 negatives	3	6	18	5	10	32
1 negative	6	12	38	9	17	55
2 negatives	9	17	54	12	22	73

Example 1
To be sure, without any prior knowledge (see Table 5.4 with a=1, b=1, 0 negatives), with 95% probability that at least 90% of all pills contain illegal drugs, a sample of size 28 is needed with the Bayesian approach. This is higher than with the hypergeometric distribution, where only 23 (see Table 5.1) samples are needed. However, if it is very clear that we are dealing with drugs, and we combine this with the practical knowledge that then probably all are drugs the sample size drops to 26 (a = 3, b =1) even 19 (a = 10, b = 1; note: calculated value, not shown in a table).

Example 2
To guarantee with a probability of 95% that at least half of the seizure contains drugs, only a sample size of 4 is needed (when no negatives are expected in the sample). In very extreme cases this number can be reduced or increased by one or two. In general, to guarantee at least 50% of drugs (with a probability of 95%) a sample size of 4 is an easy guideline.

Seizure containing less than 50 units

If the seizure is small ($N < 50$), it is better to look at the number of positives in the unexamined units instead of the proportion of positives. The probability density function for the number of positives in the unexamined units Y, given that a sample of size n contains x positives is.

$$f(Y \mid x,n,(N-n),a,b) = \frac{\Gamma(n+a+b)\binom{N-n}{y}\Gamma(y+x+a)\Gamma(N-x-y+b)}{\Gamma(x+a)\Gamma(n-x+b)\Gamma(N+a+b)}$$

This is the beta-binomial distribution.
The probability that the number of positives in the unexamined pills is larger than y can be calculated with $P(Y \geq y \mid x,n,N)$. This can be used to select a sample size n such that the probability that $Y > y$ is $(1-\alpha)100\%$. Calculations on the beta-binomial distribution to find such an n have to be done with a computer (statistical software, Excel macro) or at least a scientific calculator. Like in the frequentist methods you have to assume beforehand what the number of positives in your sample will be, and adapt your conclusions if afterwards this number is not correct. Again in most cases no negatives will be expected.

In contrast to the binomial Bayesian method for large seizures, the calculated sample size for small seizures depends on the seizure size. Furthermore, calculations on the proportion can not be very precise, because of the small numbers. Therefore it is probably best to use the hypergeometric distribution for small seizures or alternatively use the sample sizes calculated with the Bayesian method for large seizures as an approximation for small seizures.

Theory

This section is for those who want to know where the numbers in the tables come from.

The Bayes approach allows the use of prior information about a parameter (such as the drug proportion in a seizure); by combining this prior information with the results from the sampling, it comes to a posterior information about that parameter. Let θ be the parameter of interest and x the data from the sample; the Bayes theorem is then:

$$P(\theta \mid x) = \frac{P(x \mid \theta)p(\theta)}{P(x)}$$

This is often rewritten as Bayes formula

$$P(\theta \mid x) \propto L(\theta \mid x)p(\theta)$$

Here, $p(\theta)$ is the prior distribution, representing the uncertainty about the knowledge of θ. If no knowledge or ideas exist about θ, any value (between 0 and 1, if θ is a proportion) is as likely as any other. Then $p(\theta)$ is a uniform distribution. This is a special case of the beta distribution. In general, a beta distribution with parameters a and b is assumed.

The beta distribution $Be(a, b)$ is given by

$$f(\theta \mid a,b) = \frac{\theta^{a-1}(1-\theta)^{b-1}}{B(a,b)}$$

with the beta function $B(a,b) = \int_0^1 y^{a-1}(1-y)^{b-1}dy.$

This can also be written as $B(a,b)=\Gamma(a)\Gamma(b)/\Gamma(a+b)$, where we have used the gamma function Γ.

In case of no prior belief about the seizure a and b both equal to 1 (the uniform distribution). In case more information is available, for instance, all units of the seizure show the same (visual) characteristics, other values of a and b have to be used. If all pills look similar it is most likely that all pills contain drugs or no pills at all contain drugs, then $a = 0.5$ and $b = 0.5$. If there is a founded suspicion that drugs are involved, so that θ is very likely high, a could be 3 and $b = 1$, or even stronger: $a = 10$, and $b = 1$. In the estimation of the value for a, the results of spot tests could also be considered.

In Bayes formula $L(\theta|x)$ is the likelihood function. This function contains information about the data. In fact it is the same probability function as the frequentists use when $N>50$ (the binomial distribution), except that it is the data (x) that are assumed constant and the parameter θ is assumed variable.

The likelihood function combines with the prior information to the posterior distribution of the proportion θ given the data

$$f(\theta|x,n,a,b) = Be(x+a, n-x+b) = \frac{\theta^{x+a-1}(1-\theta)^{n-x+b-1}}{B(x+a, n-x+b)}$$

If all sampled pills contain drugs ($x = n$) this is

$$f(\theta|n,n,a,b) = Be(n+a,b) = \frac{\theta^{n+a-1}(1-\theta)^{b-1}}{B(n+a,b)}$$

To calculate the sample size n such that with a probability of $(1-\alpha)100\%$ at least $k100\%$ of all pills contains drugs, the equation

$$P(\theta > k|n,n,a,b) = \int_k^1 \theta^{n+a-1}(1-\theta)^{b-1}d\theta / B(n+a,b) = (1-\alpha)100\%$$

has to be solved.

The same Bayesian theory concerning Bayes theorem is true for the case of small seizures. Then the distribution of $P(Y|N-n,\theta)$ is binomial. When this is combined with the prior beta distribution for θ the resulting posterior distribution of $P(Y|n,N-n,\theta,a,b)$ is beta-binomial.

Chapter 6

Considerations and recommendations

In the previous chapters a number of sampling strategies were (briefly) described. Although advantages and disadvantages of certain methods were given, no real preference was mentioned. This chapter attempts to bring up a number of considerations about the use of (some of) the methods and to mention and discuss a number of related aspects, with the aim to support laboratories in the selection of their recommended method(s) or 'best practice'.

The basis of sampling

The basis of sampling is that the composition found in the samples taken reflects, in principle, the composition of the whole lot. As a consequence, only a fraction of the total packages in a seizure can be investigated. Sampling is an intentional choice to refrain from doing things to (unnecessary or impossible) perfection, for reasons of efficiency and cost effectiveness. As an example: if one sample out of a population of 10 is taken, and the analysis of the sample shows cocaine, the hypothesis that this is the only one containing cocaine is much more unlikely (10%) than the hypothesis that the majority of the 10 items contains cocaine (more than 50%).

The aim of sampling

Actually, a sampling strategy is fully dependent on the question and thus the problem that has to be solved. There may be different needs for prosecution of possession, production, or trafficking. The question usually arises from the national law, or from a national policy (habit) or sometimes directly from the prosecutor's opinion or from the police staff.

Simplified, in a sequence of increasing workload:

i) Is a drug present? Minimal sampling (this may require 1 positive result).
ii) Is a drug present in (more than) a specified proportion of the items? Increased sampling.
iii) Is a drug present in *all* the items? Maximum sampling (this will require full analysis of all items, which will lead to unrealistic costs, especially for large number of units).

It is clear that, for large seizures, the situation ii) is widely considered as a reasonable approach, often allowing a scientist to include a statistical approach. In this case, we can choose the desired confidence level.
An increase in confidence from 95% to 99% will result in an increase of the number of samples to be taken; depending on the conditions, it could mean more than doubling. In statistics 95 % is very common and widely accepted; for this reason we advise to adopt this 95% confidence as the standard.

Law of Diminishing Returns

Except with fixed national sampling policies, a leading question in all statistical approaches is what (minimum) proportion of the lot at least must be proven 'positive' for drugs. This has a strong influence on the number of samples to be taken. It includes the questions why and at what costs? The Table 6.1 shows the number of samples to be taken for

Table 6.1 Hypergeometric distribution.
Number of samples to be taken for describing (with 95% confidence) a certain proportion of drugs in a seizure, assuming 0 negatives in the sample.

Proportion of seizure at least positive for drugs	For a seizure consisting of 100 units	For a seizure consisting of 1000 units
50%	5	5
60%	6	6
70%	8	9
80%	12	14
90%	23	28
95%	39	56

declaring a certain proportion (%) in the seizure positive for drugs, with a 95% confidence (assuming the whole sample is found positive for drugs). Clearly, the higher the requested positive proportion, the higher the sample size has to be. However, over a certain proportion (70-80%), a relative small increase in proportion requires a relative large increase in the number of samples, as is generally known as the "Law of Diminishing Returns". This is also clearly demonstrated graphically in Figure 5.2; for a proportion of over 70-80% the slope is declining, indicating a negative cost-benefit ratio. Equilibrium has to be found between the costs of exponential increasing sample sizes and the increase in the guaranteed drugs proportion gained from this.

Hypergeometric and Bayesian methods

Although many different methods are in use, the hypergeometric approach seems to be the most widely accepted one; it has been well-described and is one of the two recommended by the UNDCP (renamed in UNODC) and SWGDRUG. This does not mean that this approach should automatically be adopted by ENFSI. In the first place, the aim of this ENFSI document is to look for practical methods that are 'fit for the purpose' in Europe. Secondly, the hypergeometric method is quite rigid and results often in a very large – sometimes superfluous- number of samples; for this reason a number of European laboratories chose the Bayesian approach; this method allows the use of other relevant, so-called prior information (e.g. external characteristics).

The main problem with the hypergeometric method is that it is blind. It does not take into account additional aspects. Visual inspection, smelling, pre-testing etc. can contribute to the investigation of the seizure, but there is no way to incorporate this in the hypergeometric approach. This problem can be best demonstrated with an example. When investigating a hemp field of 5000 plants, hypergeometric tables show a number of 29 samples to be taken. That seems a bit much, especially for an expert who has been working with hemp for years, he smells it, notices the lamps, the nutrition, the books about hemp nursery and so on; and if the suspect admits that he is breeding hemp. Do we still need those 29 samples? In many of these cases a single sampling looks sufficient. More abstractly formulated: in cases where more information is contributing, the strict use of the hypergeometric

approach leads to an unrealistic high number of samples. The friction between the hypergeometric model and the reality is also demonstrated when we approach the hemp field from the other side. Let's say that 29 samples have been taken and all were hemp indeed. The hypergeometric conclusion has to be that there is a 95% probability that at least 90% of the plants are hemp indeed. This conclusion sounds unrealistic and by all means too low (even ridiculous) for those having been in the hemp field or seen the pictures. Again a friction is felt between the mathematical approach and the 'common sense'.

The Bayesian approach can incorporate above-mentioned additional information in its model, by the use of a prior distribution. In general the prior distribution is a beta distribution with parameters '*a*' and '*b*'.
The more additional information, in the sense that is clear that we are dealing with drugs and that all units contain drugs, the higher the parameter '*a*' should be. When the plants all look the same, and can be visually identified as hemp, and the assumption that all the plants consist of another plant can be rejected, a very high value for '*a*' may be selected (e.g. 40). Then the number of samples to be taken will be 1 indeed.
The choice of the exact value of '*a*', however, may be a subject for discussion since there is no standard rule available. A similar but less evident situation is in the case of a body packer ("mule") seized at the airport, arriving from a South American destination, with 80 of these plastic and rubber wrapped packages. Upon collection they all seem to be similar. Opening of 2 of them shows a white powder. Both are sent for laboratory investigation.
The difference with the hemp field is a lower information value of the powder, the similarity lies in the conditions and situations. Within the framework of the Bayesian approach, a prior distribution with a high value for '*a*', but much lower than in the previous case, can be chosen.

The importance of experience in a profession is generally recognised; this expertise can not be linked to the hypergeometric distribution.
So, already Sutherland in 1992 mentioned that in cases with large numbers of packages, containing similar material upon visual inspection, they always all appeared to contain the same drug (Note: This consideration is in qualitative analysis only!). In import/export cases, by its nature the seizure is logically composed of drugs; experience in The Netherlands shows that mixtures with non-drugs were extremely rare; as an indication, in many ten-thousands of cases only one case was found

where some negative samples were present. This experience can be linked to the Bayesian approach; however, there are no standard rules for it (yet).

The hypergeometric distribution can successfully be used in court in a case such as the body packer. The defence may argue that maybe the 78 other packages that were not measured do not contain drugs. However, the probability that only the two measured packages contain drugs is

$$\frac{\binom{2}{2}\binom{78}{0}}{\binom{80}{2}} = 0.000316$$

about 3 in 10000. This is a very small probability. If the fact that all packages of all body packers measured always contained drugs is incorporated and the Bayesian approach is used, this probability will be even much smaller.

In general, it can be stated that Bayesian methods should be preferred when much prior information is available, even though one can argue that they imply subjective prior beliefs. In situations where one wants to be completely free of subjective hypotheses or where there is hardly any prior information available, frequentist methods (hypergeometric and binomial) seem attractive because they are easier to understand and to explain. However, they always provide sample sizes on the very safe side. This has the advantage that the defence in court can hardly object to it, but the costly disadvantage of (often) too many samples, as shown in the above mentioned two examples. The binomial models are not designed for small seizures. For these, only the Bayesian (with beta-binomial distribution) and the hypergeometric models are applicable, the latter being more widely applied.
When the majority (at least 50%) of all units should be guaranteed to contain drugs the results of the hypergeometric distribution and the Bayesian method do not differ that much. Only in very extreme cases (like with the hemp plants) the Bayesian method provides lower sample sizes. In most other cases the sample size will be around 5.

Practical aspects

The sampling of tablets may give some specific complications.
What is a realistic sampling of 2000 tablets, all in one bag, all with the same external characteristics including all the same logo?

Again the hypergeometric approach would lead to 29 samples (for 90% proportion and 95% probability). Intuitively, this is a large number, and intuitively it is very unlikely that negative samples will be present in the whole lot. A question to be considered is the previous situation, but now the 2000 similar tablets are not in one bag, but in 4 bags with each 500 tablets. Does this mean 4 times 29 samples, giving a total of 116 samples? From a purely statistical standpoint, maybe yes. From a practical standpoint probably "no". From the standpoint of cost effectiveness also probably not. The statistically correct approach would be to combine the 4 packages (only allowed with similar material) and then sample accordingly; this approach has also disadvantages.

In addition to the collection of (numerous) samples it has been discussed how to treat a high number of samples in the laboratory. In some laboratories it is common practice to do a spot test on all, maybe then TLC on all or on a large selection, and then – when no differences have been found – end with a very selective analytical technique on only a small number of samples. This strategy looks reasonable, but so far, a solid statistical basis has not yet been presented. However, it can be expected that the approach fits within the Bayesian approach. If so, much laboratory work can be avoided. SWGDRUG however, recommends the full analysis of all samples, if statistical conclusions must be drawn. In addition, another strategy is mentioned where sub-samples are all tested with a screening technique; followed by a full analysis of one sub-sample and a mixture of all other sub-samples. The latter strategy will be difficult to explain in terms of statistics.

'Bulking'of samples may be described as the preparation of one mixture, composed of a number of samples. If bulking can be arranged in such a way that the composition of the mixture reflects the total composition, it seems a very effective strategy to reduce workload. Such a mixture may be easy to prepare. A disadvantage will appear in relatively inhomogeneous lots; by definition bulking shows the average and no information about the specific item (although some improvement in this aspect could be obtained by a prior investigation with spot tests).

Sampling strategies must be relatively easy in order to be practical. This requirement is not really met by the UNDCP or SWGDRUG guidelines. From a table, a number of samples must be read, and on some unknown grounds a decision must be made if it is expected that one or two of the samples will not contain drugs. The basis of such an expectation is unclear. So, it would probably mean that a first sample set is collected, analyzed, and that, if negative samples have been found, a re-sampling will be done. That seems rather complicated and even impossible if the seizure is destroyed immediately after the sampling. And always using a standard sampling strategy as if 2 negatives are expected leads to an increase in the number of samples (always 50-60); this may seem a bit exaggerated when in almost all cases no negatives are found. Especially when police or customs are doing the sampling, they should be guided by easy-to-understand instructions. In that context, tables or computer programs are less attractive. Some colleagues have solved the problem by the instruction to always take a fixed number of samples, (e.g. 25).

Is there an optimum sampling strategy

In the preceding chapters a number of approaches have been described for sampling plus some considerations about appropriate strategies. From them, however, it can not be concluded which strategy is the optimum one and under which conditions. This is because many relevant aspects play a role, including differences in type of drugs, size of drug seizures, and aim of the investigation, experience of the drug chemists and courts, and economical constraints.

Having recognized this, the subcommittee on sampling and the steering committee of the WG Drugs have decided to refrain from any advice on sampling on the national or regional level. There, an appropriate choice should be made from the strategies described; the main aim here is that a strategy meets the needs for the prosecution and courts in their specific situation, thereby considering costs and laboratory management aspects.

As mentioned in the introduction, for cases with an international character ENFSI as an international body has been asked by the EU (PCWG) to give an advice on sampling. This advice has been formulated by the steering committee and the sampling committee; the basis for this

advice were the strategies and aspects brought up in this document, thereby considering both scientific and practical aspects. This advice is included and explained in Appendix C.

Chapter 7

Estimation of weight

The Student *t*-distribution, relative to df degrees of freedom (see Table 7.1), can be used to calculate an interval that contains with $(1 - \alpha)100\%$ probability the weight of a drug unit in a population.

Application

Using the Student-t distribution theory, we can estimate the average weight of a drug unit in a population within a given confidence $(1 - \alpha)100\%$.

Table 7.1 Student-t distribution.
The solving values of the equation for some degrees of freedom df and a threshold index α.

df	α	
	0.05	0.01
1	12.706	63.657
2	4.303	9.925
3	3.182	5.841
4	2.776	4.604
5	2.571	4.032
6	2.447	3.707
7	2.365	3.499
8	2.306	3.355
9	2.262	3.250
10	2.228	3.169
11	2.201	3.106
12	2.179	3.055
13	2.160	3.012
14	2.145	2.977
15	2.131	2.947
16	2.120	2.921
17	2.110	2.898

df	α	
	0.05	0.01
18	2.101	2.878
19	2.093	2.861
20	2.086	2.845
21	2.080	2.831
22	2.074	2.819
23	2.069	2.807
24	2.064	2.797
25	2.060	2.787
26	2.056	2.779
27	2.052	2.771
28	2.048	2.763
29	2.045	2.756
30	2.042	2.750
40	2.021	2.704
60	2.000	2.660
120	1.980	2.617
∞	1.960	2.576

This can be expressed by the following relation:

$$\bar{X} - \frac{s}{\sqrt{n}} t_{\alpha} \leq \mu \leq \bar{X} + \frac{s}{\sqrt{n}} t_{\alpha}$$

where:
μ = the average weight of the drug unit in the population;
$\bar{X}$ = the average weight of the drug unit in the sample;
s = the standard deviation of the measurements;
n = the sample size;
and t_{α} is the solving value of the Student-t distribution with $df = n - 1$ degrees of freedom within the confidence coefficient α (Table 7.1).
In practice, an appropriate software application can be used to assist with the determination of the confidence interval applied to the estimated weight of the drug unit.
In common practice, an acceptance criterion is that the sampling results are taken into consideration if the ratio between the standard deviation s and the average weight $\bar{X}$ of a drug unit in the sample is less than 0.1 (RSD<10%). Otherwise, an increase of the sample size is required in order to reach the target percentage. (If this cannot be reached because the sample weight is not a normally distributed random variable, we could be forced to weigh the entire exhibit, not using statistical inference any more).
The estimation of the total weight of the exhibit (W) can be obtained by multiplication by N of the average value and the standard deviation as follows.

If $w = N\bar{X}$ and $\sigma = Ns$, then the estimation of the total weight W is

$$w - \frac{\sigma}{\sqrt{n}} t_{\alpha} \leq W \leq w + \frac{\sigma}{\sqrt{n}} t_{\alpha}$$

The same approach can be used for the estimation of the total weight of illicit drug in an exhibit, after quantification of the drug present in each sample unit.

If r negative results are obtained after the analysis of the drug units, for the estimation weight of the total (positive) drug exhibit,

a corrector factor $P_{corr} = \frac{n - r}{n}$ should be used:

$$P_{corr}\, w - \frac{P_{corr}\,\sigma}{\sqrt{n}}\, t_{\alpha} \leq W \leq P_{corr}\, w + \frac{P_{corr}\,\sigma}{\sqrt{n}}\, t_{\alpha}$$

Moreover, for a population where $\frac{n}{N} > 0.1$, a further correction factor

$Q_{corr} = \sqrt{\frac{N-n}{N}}$

should be applied, giving:

$$P_{corr}\, w - Q_{corr}\, \frac{P_{corr}\,\sigma}{\sqrt{n}}\, t_{\alpha} \leq W \leq P_{corr}\, w + Q_{corr}\, \frac{P_{corr}\,\sigma}{\sqrt{n}}\, t_{\alpha}$$

Example 1

Let's suppose that an exhibit of suspected heroin is contained in 100 packages. We want to estimate the average weight of a drug unit in the population with a probability of 95%.

According to the applied representative sampling theory, following the example indicated in the paragraph about the hypergeometric distribution, a sample of 23 units is taken and each of them weighed and analysed.

The average net weight of the powder in the 23 units is $\bar{X}$ = 0.265 *g* with the standard deviation *s* of 0.023 g. Since the error is 8.7%, the acceptance criterion is satisfied.

The value of t_{α} from the Table 7.1 is 2.074, the corrector factor Q_{corr} is 0.877 and the estimate weight for the total exhibit *W* is:

$$(26.500 - 0.873)\ g \leq W \leq (26.500 + 0.873)\ g$$

If one negative result is obtained after the analysis of the drug units, the correction factors are $P_{corr} = 35/36$ and $Q_{corr} = 0.800$. So assuming, for the sake of this example, that the additional sample size does not change the values of $\bar{X}$ and *s*, then the estimate weight for the total positive drug exhibit is W_1 is:

$$(25.764 - 0.605)\ g \leq W_1 \leq (25.764 + 0.605)\ g$$

In the same way, if two negatives results are obtained, the correction factors are $P_{corr} = 44/46$ and $Q_{corr} = 0.735$. So we have

$$(25.348 - 0.480)\ g \leq W_2 \leq (25.348 + 0.480)\ g$$

Theory

The *t*-Student distribution theory may solve problems of estimation of the average of a number of measurements n.
The definition of the *t*-Student distribution, relative to df degrees of freedom, is:

$$f(t) = \frac{\Gamma\left[\frac{1}{2}(df+1)\right]}{\Gamma\left(\frac{df}{2}\right)\sqrt{\pi df}}\left(1+\frac{t^2}{df}\right)^{-\frac{1}{2}(df+1)}$$

If α is a threshold index, the value t_α according to which the probability calculated between $-t_\alpha$ and t_α is equal to $1-\alpha$, can be calculated from the following equation:

$$P_\alpha = 1-\alpha = \frac{\Gamma\left[\frac{1}{2}(df+1)\right]}{\Gamma\left(\frac{df}{2}\right)\sqrt{df\pi}}\int_{-t_\alpha}^{t_\alpha}\left(1+\frac{t^2}{df}\right)^{-\frac{1}{2}(df+1)}dt$$

The solving values of the equation for some values of df and α are listed in Table 7.1.

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Appendix A

Tables

Figures

Appendix B

Software instructions

The software is a Microsoft Excel 2000 application. You will need to have the 'Analysis ToolPak' add-in installed (select: Tools / Add ins... / Analysis ToolPak). The 'protection' option (without a password) is enabled so that users may only enter data in specific required cells. This protection option can be disabled if you wish to experiment with the package.

Excel can handle numbers up to about 1E+308. If a number (either in a result or an intermediate calculation) exceeds this value, then an overflow error occurs and a '#NUM' error result is returned. Users must be aware of this when dealing with large numbers. For example: 100000 tablets, 0.99 confidence, k = 0.99, expected negatives = 2 will give an invalid result for the sample size. No laboratory would ever use such unrealistic levels. However users should be aware of the limitations of the software.

The graph is for display purposes only. The sample size scale is set from 1 to 100 as this range will cover most results.

Hypergeometric Sampling

1. The Excel sheet has five tabs at the bottom (Instructions, Hypergeometric, Bayesian, Binomial and Estimation of Weight).
2. Select the *Hypergeometric* tab.
3. Enter the desired values for steps 1, 2, 3 and 4.
4. The required sample size will be given at step 5 (cell B5).

The Excel hypergeometric distribution function used here is as follows:

$$P = \text{HYPGEOMDIST}\ ((n-r),\ n,\ (N^{*}k)-1,\ N)$$

This gives the probability of finding $n-r$ positives in a sample of size n taken from a population N containing $N^{*}k-1$ positives.

In the case of 0 negatives expected (r = 0):
If *P* gives the probability of finding *n* positives, then 1-*P* gives the probability of not finding this number of positives. In other words 1-*P* gives the probability of finding at least one negative. A sample size *n* is chosen to give a value for 1-*P* which exceeds the desired confidence level $(1 - \alpha)$.

Note: It may happen that a number of samples have been taken, assuming that there would be zero negatives; however, upon analysis one of the samples appeared to be negative. What can then be said about the proportion of the seizure that is positive for drugs? The macro can also calculate this proportion. (Note: depending on the setting of your Excel program, points or commas must be used for decimals)

Scenario:
Seizure of 1000 tablets
Proportion of positives = 0.9
Expected negatives = 0
Confidence level = 0.95

This requires a sample size of 28.

Suppose you have analysed these 28 tablets and found one negative, what proportion of the seizure can you still be 0.95 confident to contain positives?

Step 1: Start at the begin position. Scroll down until sample size 28 is visible on the screen (This has a current probability value of 0.951419384)
Step 2: Change the 'expected negatives' value from 0 to 1.
(This will reduce the probability value for sample size 28 to 0.793866654)
Step 3: Reduce the value for 'proportion of positives' continuously until the probability for sample size 28 reaches or exceeds 0.95 again
(this happens when *k*=0.84)

Therefore we can be 95% confident that 84% of the seizure contains positives.

Bayesian Sampling

1. Select the *Bayesian* tab.

2. Enter the desired values for steps 1, 2, 3, 4, 5 and 6.

Note 1: Although population size is not used in the calculations for the beta distribution, it is necessary to enter the population size so that the software can decide whether to use beta or beta-binomial distribution in the calculations.
Note 2: The values selected for steps 2 and 3 (a and b values) will depend on the analyst's prior knowledge or assumptions about θ.
3. The required sample size will be given at step 7 (cell B7).

$$N >= 50$$

The Excel **beta distribution** function used here is as follows:

$P(\theta>k)$=BETADIST (k,a +(n-r), b + r, lower limit for k, upper limit for k).

$$N < 50$$

The $\Gamma(x)$ function can be calculated in Excel by using a combination of the EXP and GAMMALN worksheet functions as follows:
$GAMMALN(x) = LN(\Gamma(x))$
The EXP function is the inverse of the LN function therefore:
$EXP(GAMMALN(x)) = \Gamma(x)$

This function is incorporated into the **beta-binomial distribution** equation as follows:

$P(Y>=y)=$
(EXP(GAMMALN(n+a+b))*COMBIN(N-n,y) * EXP(GAMMALN(y+x+a)) *
EXP(GAMMALN(N-x-y+b)) / (EXP(GAMMALN(x+a) *
EXP(GAMMALN(n-x+b)) * EXP(GAMMALN(N+a+b))

Binomial Sampling

1. Select the *Binomial* tab.
2. Enter the desired values for steps 1, 2 and 3.
3. The required sample size will be given in step 4 (cell B4).

The Excel binomial distribution function used here is as follows:

$$P = \text{BINOMDIST}(n\text{-}r,\ n,\ k,\ \text{FALSE})$$

Estimation of Weights

1. Select the *Estimation of Weight* tab.
2. Enter the desired values for steps 1 to 6.
3. The confidence interval is given in cells B12: D12

The confidence interval is calculated as follows:

$$\text{C.I.} = \text{mean weight} \pm t^{*}s/\sqrt{n}$$

In the event of any negatives being detected in the samples, a correction factor $(n\text{-}r)/n$ is applied as follows:

$$\text{C.I.} = (\text{mean weight}) * (n\text{-}r)/n \pm (t^{*}s/\sqrt{n}) * (n\text{-}r)/n$$

For smaller populations where $n/N > 0.1$ a further correction factor $\sqrt{((N\text{-}n)/N)}$ is applied giving:

$$\text{C.I.} = (\text{mean weight}) * (n\text{-}r)/n \pm (t^{*}s/\sqrt{n}) * (n\text{-}r)/n^{*}\sqrt{((N\text{-}n)/N)}$$

Note: This software has not yet been validated

Appendix C

ENFSI guidelines on representative sampling of drugs

Executive summary. Presented by Kimmo Himberg, ENFSI chairman, to the EU Police Co-operation WG dated November 26th, 2003

Sampling on the national / regional / laboratory level

Sampling is a strategy and its intensity is highly dependent on the ultimate purpose of the results, the original question, and the final aims of the investigation. National laws and legal practices dictate most of them. In practice, sampling is not strictly defined and thus regional police forces, courts and the laboratories have the possibility to develop their own sampling strategies. Sampling should be fit for the purpose, i.e. it should be satisfactory for the customer, easy to understand, adapted to the workload of the laboratory, and cost effective. Further, experience with the local drugs market should be taken into consideration.
For sampling in regional or national level, a *general* rule seldom yields perfect solution. In other words, a general sampling advice may result almost by definition in too few or too many samples; too few samples being insufficient, and too many samples wasting time and money.
In conclusion, the ENFSI advice on sampling cannot override those rules defined on national or regional level.

Thus, ENFSI considers that no specific sampling procedure should be recommended on the national level. It is up to the national authorities to choose and develop an appropriate fine-tuned sampling strategy, satisfactory to and accepted by all relevant parties (police, prosecutors, courts). However, ENFSI strongly recommends documentation of the sampling strategy and, when appropriate, providing the police and/or customs with written instructions.

Sampling on the international level

ENFSI has been asked to consider sampling of large seizures with clearly international aspects, e.g. in cases where suspects are located in more than one country. It was felt as necessary to have a reasonable strategy that is broadly supported by the forensic laboratories in EU countries and that can be used as a guideline for police and customs officers.

Also here the starting point is the sampling strategy. Since the final purpose of the results of sampling and the subsequent chemical analysis are unknown and may vary from case to case, only a general strategy can be recommended.

As mentioned above, there is no single perfect solution; any sampling strategy is by definition a compromise between level of perfection and workload, and strongly driven by the various needs. As a consequence, there is no single strategy fully supported by all parties involved. Nevertheless, ENFSI seeks a solution with a broad support, giving individual European organisations the possibility to do more in cases where they consider that as appropriate. In particular cases the forensic chemist has to explain the principles of sampling. This is especially important when applying approaches such as the Bayesian theory, which may be difficult to be understood by a layman.

The ENFSI advice on the sampling strategy for international cases:

a) must have a basis easy to explain in terms of statistics;
b) must be practical and easy to understand, also when used by the police and customs officers;
c) must be realistic, and not result in an increase in the workload of the laboratories (i.e. enable acceptable turn round times);
d) must be defendable in court.

Based on these requirements, ENFSI advises that the minimum standard to be included for sampling of large international cases should:

1. result in a detailed report on the seizure (description of samples, sample numbers, weights, packages, origin, external characteristics, appearance, pictures, etc.) by the law enforcement authorities, for the use by the forensic experts and the court.
2. utilise a sampling technique based on the hypergeometric or Bayesian methods with 95 % confidence level and 50 % proportion level (at least half of the items).

Note 1: This means that *a minimum* of 5 samples must be taken for chemical investigation, if it is expected that all sampled units contain drugs.

Note 2: If re-sampling is not possible, 8 samples are recommended. These 8 samples are based on the possible (but unlikely) finding that 1 of these samples appears to be negative. In that case still 50 % of the packages can be guaranteed to be positive for drugs.

Note 3: If the material gives rise to some doubt, at least 11 samples are recommended. This is based on the possible (but unlikely) finding that 2 of these samples appear to be negative. In that case still 50 % of the packages can be guaranteed to be positive for drugs.

Note 4: If a forensic laboratory carries out the sampling or the sub-sampling the number of samples can be influenced by the actual findings of the chemical analysis. Hypergeometric or Bayesian tables can be used to calculate the sample size.

The document ENFSI Guidelines on Representative Drug Sampling contains detailed descriptions of various sampling techniques.

Appendix D

Abbreviations

ENFSI	European Network of Forensic Science Institutes
EU	European Union
QA	Quality Assurance
TLC	Thin-layer Chromatography
SWGDRUG	Scientific Working Group on Drugs
UNDCP	United Nations Drug Control Program
UNODC	United Nations Office on Drugs and Crime
WG	Working Group

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version 1-1 2003