Estimating actual yield in clandestine laboratory syntheses of methamphetamine

Nicholas G. Powell
Forensic & Industrial Science Limited
P Box 67-087
Mt Eden
Auckland 1003 New Zealand
methlab@forensicscience.co.nz

introduction

This paper discusses the topic of yield and examines specifically the assumptions that underpin drug yield estimation methods currently used for forensic purposes in various jurisdictions.

Over the last few years in New Zealand, there has been a decline in the abuse of natural illicit drugs such as cocaine and opiates and a concomitant increase in the abuse of synthetic drugs that are manufactured from precursor substances and other reagents. Yield estimation is hence becoming an increasingly important forensic subject.

When issues to do with yield arise, forensic scientists need to provide unambiguous answers to questions of the following sort:

- what is the maximum amount of drug that the accused could have made with this amount of precursor substance?

- what is a realistic estimate of amount of drug that could have made with this amount of precursor?

- how much drug could have been produced from the precursor extracted from the tablets represented now only by their tailings (insoluble remnants)?

Reliable yield calculations are also needed to assist a Court in making well-informed sentencing decisions. It is clearly desirable that a sentence imposed in relation to possession of a precursor substance for a particular drug is proportional to sentences imposed in relation to possession of a different precursor used for the manufacture of the same particular drug.

A forensic scientist can directly determine yield by carrying out a synthesis under conditions that duplicate a particular clandestine laboratory method (see for example Sibley's (1996) detailed semi-quantitative study on the products of heroin "homebaking"), and a clandestine chemist's own notes may provide information of varying degrees of reliability on the yield of the method they have employed. There are few if any published experimental studies that deal with the topic of methamphetamine yield (Gietzen 2004b), and it is not practical to recreate clan lab conditions for every case, so the forensic scientist has little choice but to estimate yield. The scientific basis for making yield estimates is explained below.

scientific basis for yield estimates

Yield estimates rely on two different types of information.

The first sort of information needed to estimate yield comes from knowledge of the stoichiometry of the chemical reaction that is used to synthesize the drug from a particular precursor. The second type of information required to estimate yield comes from knowledge of how efficient each step of the manufacturing method is.

It is convenient to define and illustrate the concepts of theoretical yield, actual yield, stoichiometry and efficiency with reference to a straightforward example based on parts of the "homebaking" process once used widely in New Zealand to illicitly prepare morphine and diacetylmorphine (heroin) from a codeine precursor.

Considering first the concept of **stoichiometry**: this term means the quantitative relationship between reactants and products in a chemical reaction. Each molecule of codeine demethylated during "homebaking" can theoretically yield one molecule of morphine. The stoichiometry of a particular chemical reaction is invariant, regardless of the processing method, because for a given chemical reaction the stoichiometric ratio of reagent to product, in this example 1:1, does not change.

Because a morphine molecule has a weight that is 0.953 times that of the precursor codeine molecule, each gram of codeine demethylated will yield 0.953 grams of morphine. The **theoretical yield** of the reaction codeine to morphine is therefore 95.3% or 0.953.

The second type of information required to estimate yield comes from knowledge of how efficient

each step of the manufacturing method is. Using homebaking as an example again, if codeine is reacted with pyridine hydrochloride, some of the codeine is converted to morphine and some persists unchanged. If 25% of the codeine reacts to form morphine, the **efficiency** for this step is 25% or 0.25. Unlike reaction stoichiometries which are constants, reaction efficiencies vary according to method, conditions, and the skill of the individual chemist.

Multiplying the theoretical yield of 0.953 by the reaction efficiency of 0.25 gives the **actual yield** – in this example 0.238 or 23.8%. Mass of morphine produced from a given mass of precursor codeine is simply obtained by multiplying the mass of the precursor by the actual yield for the manufacturing method. Three grams of codeine would in this example yield 3 x 0.238 = 0.714 grams morphine.

In practice, illicit drug manufacturing methods commonly involve several reaction, extraction or separation steps, each with an associated efficiency that must be incorporated into the equation for estimating actual yield. Examples are discussed later in this paper with reference to the manufacture of methamphetamine hydrochloride by the reduction of a pseudoephedrine precursor by iodine (or hydriodic acid) in the presence of red phosphorus (or hypophosphorous acid). This is the methamphetamine manufacturing method that currently is most commonly encountered in New Zealand clandestine laboratories.

overview of methamphetamine manufacture using pseudoephedrine, red phosphorus and hydriodic acid

Manufacture of methamphetamine hydrochloride from a pseudoephedrine hydrochloride precursor involves:

- extraction of pseudoephedrine hydrochloride from tablets, capsules or elixirs;
- reaction of extracted pseudoephedrine hydrochloride with hydriodic acid and hypophosphorous acid at high temperature in a reaction vessel to synthesize methamphetamine base, which is an oily liquid at room temperature;
- extraction of methamphetamine from the cooled and basified reaction mixture into a solvent such as toluene;

- precipitation of solid methamphetamine hydrochloride from the solution containing methamphetamine free base by bubbling hydrogen chloride gas through the solution;

- filtration and drying of the precipitated crystalline methamphetamine hydrochloride.

current basis for yield estimates in New Zealand

In New Zealand, prosecution experts usually suggest that conversion of pseudoephedrine hydrochloride to methamphetamine hydrochloride by the red phosphorus – iodine method results in a methamphetamine hydrochloride yield of 50-75% of the mass of the precursor pseudoephedrine hydrochloride.

This yield estimate is the same as that given in a paper by Harry F. Skinner published in 1990 in the journal *Forensic Science International* (Skinner 1990).

Skinner (1990) writes: *"The theoretical yield is 92% by weight of the precursor ephedrine, whereas the clandestine yields range from 50 to 75% by weight of the precursor ephedrine"*.

While Skinner discusses ephedrine (he means ephedrine hydrochloride), the theoretical estimate applies also to pseudoephedrine hydrochloride, which has the same formula and molecular weight as ephedrine hydrochloride but a different structural configuration.

Skinner's (1990) estimate of clandestine laboratory yield of methamphetamine hydrochloride from pseudoephedrine hydrochloride precursor is not however substantiated by reference to any previous studies by others, nor does Skinner refer to any experimental work on yield that he himself might have carried out to determine what typical clandestine laboratory yields might actually be.

Donnell R. Christian in *Forensic Investigation of Clandestine Laboratories* (Christian 2003) considers (page 156) that while the expert witness can state their estimates of actual yield, they should be able to describe how they arrived at the estimate, either through published data, or by their own experiments, or from notes kept by the clandestine laboratory operator. Skinner (1990) does not support his estimates of clandestine laboratory methamphetamine yields in these ways. Estimates of clandestine laboratory methamphetamine hydrochloride yields for the red phosphorus – hydriodic acid method relied on in New Zealand may thus not be as thoroughly supported by experimental data as is desirable.

While high actual yields of 75% for methamphetamine hydrochloride produced by the red phosphorus - hydriodic acid method from pseudoephedrine hydrochloride could probably be achieved in a well-appointed laboratory staffed by skilled chemists working under ideal conditions, this manufacturing efficiency would be difficult to achieve in a clandestine laboratory setting. Such facilities are typically makeshift, and their operators normally have little or no formal training in chemistry, so a substantially reduced manufacturing efficiency and relatively low actual yield could reasonably be anticipated. Christian (2003) notes that the sophistication and operational status of clandestine laboratories should always be taken into account when estimating actual yields.

I consider below some of the factors that influence actual yield of a clandestine laboratory synthesis and in light of these examine current assumptions about methamphetamine yields.

efficiencies achieved in clandestine laboratories and factors affecting yield

Estimating actual yield requires that the theoretical yield (the yield expected if all available precursor is converted to the drug substance of interest) is multiplied by the manufacturing efficiency.

actual yield = theoretical yield x manufacturing efficiency

The manufacturing efficiency is the product of all the efficiencies that are achieved in each step of the manufacturing process, including preparation of precursor, synthesis, conversion of free base drug to a usable salt form, and post-synthesis purification.

manufacturing efficiency = efficiency (step A) x efficiency (step B) x efficiency (step C) .....

Some examples: A manufacturing process involving step A (80% efficient), step B (60%) and step C (70%) would have an overall manufacturing efficiency of 0.8 x 0.6 x 0.7 = 0.336 or 33.6%. A manufacturing process involving five stages, each 80% efficient, would have an overall manufacturing efficiency of 0.8^5 (0.8 x 0.8 x 0.8 x 0.8 x 0.8) = 0.328 or 32.8%.

Calculation of the overall efficiency of a manufacturing process is analogous to calculation of the value of a depreciable asset using the diminishing value method. The greater the number of years an asset is retained, the less its residual value becomes; similarly, the more steps that are involved in

a manufacturing process, the lower the overall manufacturing efficiency.

Efficiencies involved in each step of manufacture of methamphetamine hydrochloride are considered below in order of the manufacturing sequence.

Extraction efficiency of pseudoephedrine hydrochloride

Extraction of precursor from over-the-counter medications is often the first step in the manufacture of methamphetamine hydrochloride.

Preliminary studies by Gietzen (2004a, 2004b) have examined the extraction efficiency of pseudoephedrine from tablets under clandestine laboratory conditions. Gietzen tested four different extraction methods known to be used in clandestine laboratories, and found in tests on three different types of cold tablets available in the US that extraction efficiencies ranged from 57.09 - 89.08%, the average efficiency being 69.71%. 100% extraction of pseudoephedrine hydrochloride from over-the-counter tablet or capsule preparations is clearly unrealistic.

In calculating the average extraction efficiency, Gietzen (2004a) omitted a 0% extraction efficiency value. This value relates to a type of tablet that had been formulated to foils attempts by clandestine laboratory operators to extract pseudoephedrine.

Extraction efficiencies from elixirs that contain ephedrine, pseudoephedrine or their salts are probably higher, and may even approach 100%. Where elixirs are involved, yield calculations should not assume extraction efficiencies to lie in the ranges applicable to tablets and capsules.

reaction efficiency

The physicochemical and other conditions of synthesis influence reaction efficiency and hence methamphetamine yield. These conditions include:

- duration of synthesis (longer reaction times increases yield);
- temperature (too low reduces synthesis efficiency, too high denatures product and generates highly toxic phosphine gas);
- pressure (‘Par bomb’ pressure vessel synthesis gives higher synthesis efficiency than

synthesis at ambient pressure);

- proportion of pseudoephedrine, red phosphorus and iodine (optimal ratio maximises reaction efficiency);

- production of unwanted congeners (byproducts) during synthesis in response to conditions conducive to their formation reduces synthesis efficiency: those typically generated in the course of a red phosphorus – hydriodic acid synthesis of methamphetamine include 1-phenyl-2-propanone, 1,3-dimethyl-2-phenylnaphthalene and 1-benzyl-3-methylnaphthalene.

Pre- and post synthesis processing

Production efficiency can also be reduced by:

- spillage of solutions containing precursor ephedrine hydrochloride or pseudoephedrine hydrochloride (alkaline pseudoephedrine-bearing residues representing spillage and loss of pseudoephedrine hydrochloride are common at clandestine laboratory scenes);

- volatilisation of methamphetamine base during "cooking" (fugitive methamphetamine vapour condenses on indoors surfaces and becomes a problematic contaminant);

- spillage of reaction mixture;

- aerosolisation of methamphetamine base during conversion of base to hydrochloride ("salting out"). This results in loss of concentrated methamphetamine solution and contributes to surface contamination;

- loss of methamphetamine as the hydriodide by dissolution during final acetone washing or 'flash'.

estimates of manufacturing efficiencies and actual yields

It is instructive to consider what manufacturing efficiencies and actual yields are likely to be achieved under optimum and less than optimum conditions of manufacture.

The table below summarises efficiencies and estimated yields for the following three scenarios:

Scenario A: Inexpert extraction of precursor from tablets (extraction efficiency of 0.57 after Gietzen 2004a), low synthesis efficiency (60% or 0.6) during synthesis in reaction vessel at ambient pressure with makeshift condenser, and losses of 3% (i.e. efficiencies of 0.97) during each filtration step, each transfer of solution, during 'salting out' and final rinsing. This scenario is probably applicable to clandestine manufacturing operations using makeshift equipment and where there is sloppy handling of materials.

Scenario B: Careful extraction of precursor from tablets (extraction efficiency of 0.89 after Gietzen 2004a), good synthesis efficiency (0.8) during synthesis in reaction vessel at ambient pressure with condenser functioning well and optimal proportions of ingredients in reaction mixture, and losses of 1% (i.e. efficiencies of 0.99) during filtration, transfer of solutions, 'salting out' and final rinsing. This scenario is probably applicable to manufacturing operations run by careful and knowledgeable clandestine chemists.

Scenario C: Pure precursor (no extraction required, so efficiency of 1.0 (100%)), good synthesis efficiency (0.9) during reaction in Par bomb pressure reaction vessel, optimal proportions of ingredients in reaction mixture, and no losses of any material during filtration, transfer of solutions, 'salting out' and final rinsing. These parameters represent a best-case scenario that is probably never achieved.

scenario	A	B	C
Step or procedure	**efficiencies**		
extraction of precursor	0.57	0.89	1.00
loss to spillage and filters	0.97	0.99	1.00
synthesis efficiency	0.60	0.80	0.90
volatilisation of free base	0.97	0.99	1.00
post-synthesis loss (spillage, filters)	0.97	0.99	1.00
aerosolisation during 'salting out'	0.97	0.99	1.00
losses during final purification	0.97	0.99	1.00
overall manufacturing efficiency	**0.294**	**0.677**	**0.90**
theoretical yield	0.92	0.92	0.92
actual yield	**27.0%**	**62.3%**	**82.8%**

In the above table, manufacturing efficiencies are simply the arithmetic product of all efficiencies involved. The theoretical yield (0.92) reflects the fact that a molecule of methamphetamine hydrochloride has a mass that is 0.92 time that of a molecule of pseudoephedrine hydrochloride (or ephedrine hydrochloride).

Actual yield is the manufacturing efficiency multiplied by the theoretical yield and is expressed as a percentage. This value is the mass of methamphetamine hydrochloride actually manufactured expressed as a percentage of the mass of the pseudoephedrine hydrochloride (or ephedrine hydrochloride) precursor used.

Although the above represents a partly theoretical assessment of manufacturing efficiencies and actual yields, and while exact efficiency values might be open to question, it illustrates the following points:

- overall manufacturing efficiency is heavily dependent on efficiency with which precursor is extracted from tablets or capsules;

- overall manufacturing efficiency is also heavily dependent on synthesis efficiency;

- 'sloppy' handling of materials, inefficient extraction of precursor and inefficient synthesis is likely to result in actual methamphetamine hydrochloride yields of 30% or less;

- achieving actual yields of much more than 70% is difficult if precursor is obtained from tablets or capsules;

- actual yields greatly in excess of 70% probably require pressure vessel synthesis *and* pure precursor starting material *and* careful materials handling and processing.

discussion

Discussion above sets forth the scientific basis for actual yields falling short of theoretical yields. Examination of the efficiencies involved in the manufacturing process coupled with knowledge of procedures used in clandestine methamphetamine laboratories in New Zealand suggests that actual yields achieved are unlikely to exceed the range of values (50%-75%) given by Skinner (1990) unless high synthesis efficiencies are achieved in sophisticated clandestine laboratories. Yields

actually achieved in makeshift manufacturing operations may fall well below Skinner's (1990) range of values.

In light of the potential for actual yield to vary greatly, and perhaps because the range of values given by Skinner (1990) seem somewhat optimistic, attempts have been made in the United States to relate estimated actual yield to amount of precursor substance by a standard factor.

In May 2001, the United States Sentencing Commission implemented Amendment 611, which is concerned with methamphetamine yield estimates. This amendment replaced the theoretical maximum yield estimate of 92% of the mass of precursor pseudoephedrine hydrochloride with an estimate of actual yield of 50% of the theoretical yield – i.e. 46% by weight of the precursor.

The prevailing view in the US appears to be that while estimates of methamphetamine production can be based on the most abundant precursor available (*United States v Smith,* 240 F3d 927 (11th Cir.2001)), such estimates must be "reasonably fair, accurate, and conservative, and not merely speculative" (*United States v Zapata,* 13 F.3d 1355, 1359 (11th Cir.1998)).

In New Zealand, considerable reliance has to date been placed on Skinner's (1990) published estimates of actual yield (50-75% by weight of the amount of precursor involved) when estimating methamphetamine hydrochloride production from a pseudoephedrine hydrochloride precursor by the red phosphorus – hydriodic acid method. The US Sentencing Commission has recently seen fit to reduce the estimate of actual yield to 50% of the theoretical yield, which is equivalent to 46% by weight of the amount of precursor involved.

In light of this, it would seem timely for the New Zealand forensic science community to reconsider the basis for estimating actual yield of methamphetamine hydrochloride manufactured from a pseudoephedrine hydrochloride precursor.

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