Uncertainty Analysis in Emission Inventories

Simon Eggleston

Head, Technical Support Unit,
IPCC Task Force on Inventories

Remember…

- Most important is producing high quality “Good Practice” emission and removal estimates
- Effort on uncertainty analysis should be small in comparison to effort on inventory estimates themselves
- Data collection activities should consider data uncertainties
  - This will ensure the best data is collected & ensures good practice estimates
  - As you collect data you should assess how “good” it is
- **At its simplest a well planned uncertainty assessment should only take a few extra hours!**

Why are you making an inventory?

- As part of compulsory reporting (e.g. NC)
- Policy development
  - Mitigation
  - Adaption
- Monitoring impacts of mitigation policies
- Look for co-benefits (or impacts of non-climate policies on GHG emissions/removals)
  - Urban or regional air quality
  - Energy efficiency

As part of compulsory reporting

- Non Annex I parties have to produce inventories as part of their National Communications
- Uncertainty assessment is part of any inventory that complies with Good Practice Guidance
- Uncertainty assessment should be part of any scientific estimate
- Reducing uncertainties means making the estimates better reflect the specific national circumstances
- You may wish to do the minimum necessary but remember – others will use your inventory to develop their policies…
  - Its always best for everyone to use the best figures

Policy development

- Inventories form the basis of any rational policy development.
  - They indicate the major sectors where abatement will have a real impact
  - They can be used to predict the impact of proposed policies
  - They are used to chose cost-effective options
- However, the results are only as reliable as the emission inventories uncertainty
  - ⇨ Minimising uncertainty improves results
  - ⇨ Knowledge of uncertainty tells users the limits of the results (i.e. their uncertainty)

Monitor impacts of mitigation policies

- Policy makers need to know if policies are working
- Inventory methods should be chosen to reflect mitigation measures
- Uncertainty will indicate the minimum changes that can be seen by the emission inventory
  - reducing uncertainties enables smaller effects to be detected
- Improving uncertainties will ensure the inventory better reflects the real situation in a country

Look for co-benefits:
Impacts of non-climate policies:

Many policy areas have multiple benefits

ENERGY EFFICIENCY	***SOIL CARBON IN CROPLANDS***
•Reduced Costs	•Improved water availability
•Energy Security	•Improved drought tolerance
•Reduced Air Pollution	•Improved soil fertility (biodiversity)
•Reduced CO_2 Emissions	•Carbon sequestration

- Emission Inventories enable policy choices to be based on an proper understanding of these issues
- Emission Inventories enable GHG benefits to be claimed and acknowledged
  - Uncertainty assessment is an important part to add credibility to this process

Benefits of Uncertainty Analysis

Credibility

Inventories are estimates – uncertainty analysis gives a clear statement on what we do and do not know.

Utility

Users of the inventory need to know how reliable the numbers are – especially if they are input into policy or inventory improvement actions

Requirement

Uncertainty analysis is a requirement of all good practice inventories

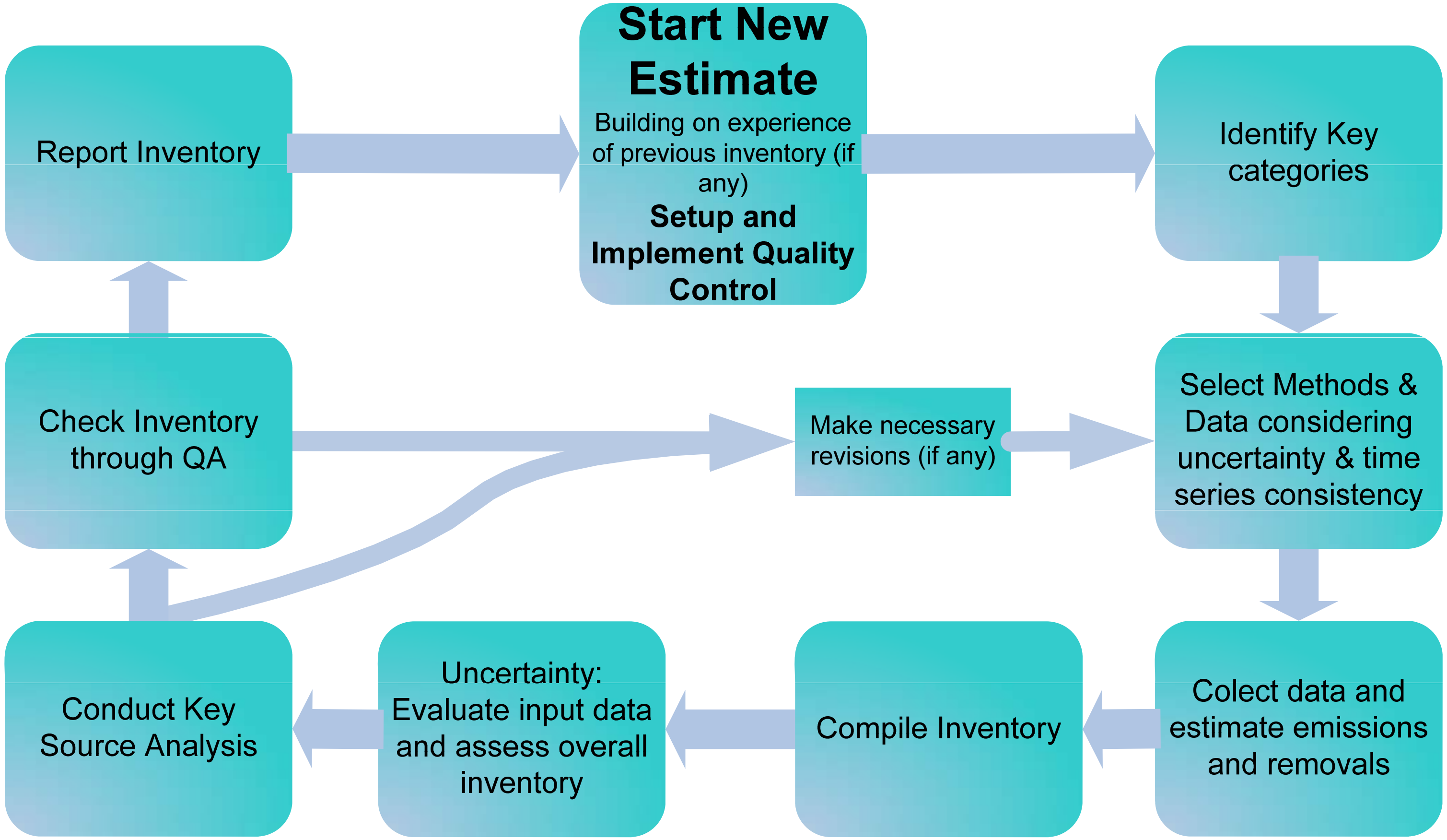
Scientific

All scientific analysis should include an uncertainty assessment

Comparable Inventories

- This is the aim of the IPCC guidelines
- They allow for choice of methods by inventory compilers
- Methods have to be demonstrably consistent
- GPG is way to ensure comparable inventories and uncertainty assesment is a part of this
- Inventory should be
  - Transparent
  - Complete
  - Consistent
  - Comparable
  - Accurate

Inventory Cycle



Start New Estimate
Building on experience of previous inventory (if any)
Setup and Implement Quality Control

Identify Key categories

Select Methods & Data considering uncertainty & time series consistency

Colect data and estimate emissions and removals

Compile Inventory

Uncertainty: Evaluate input data and assess overall inventory

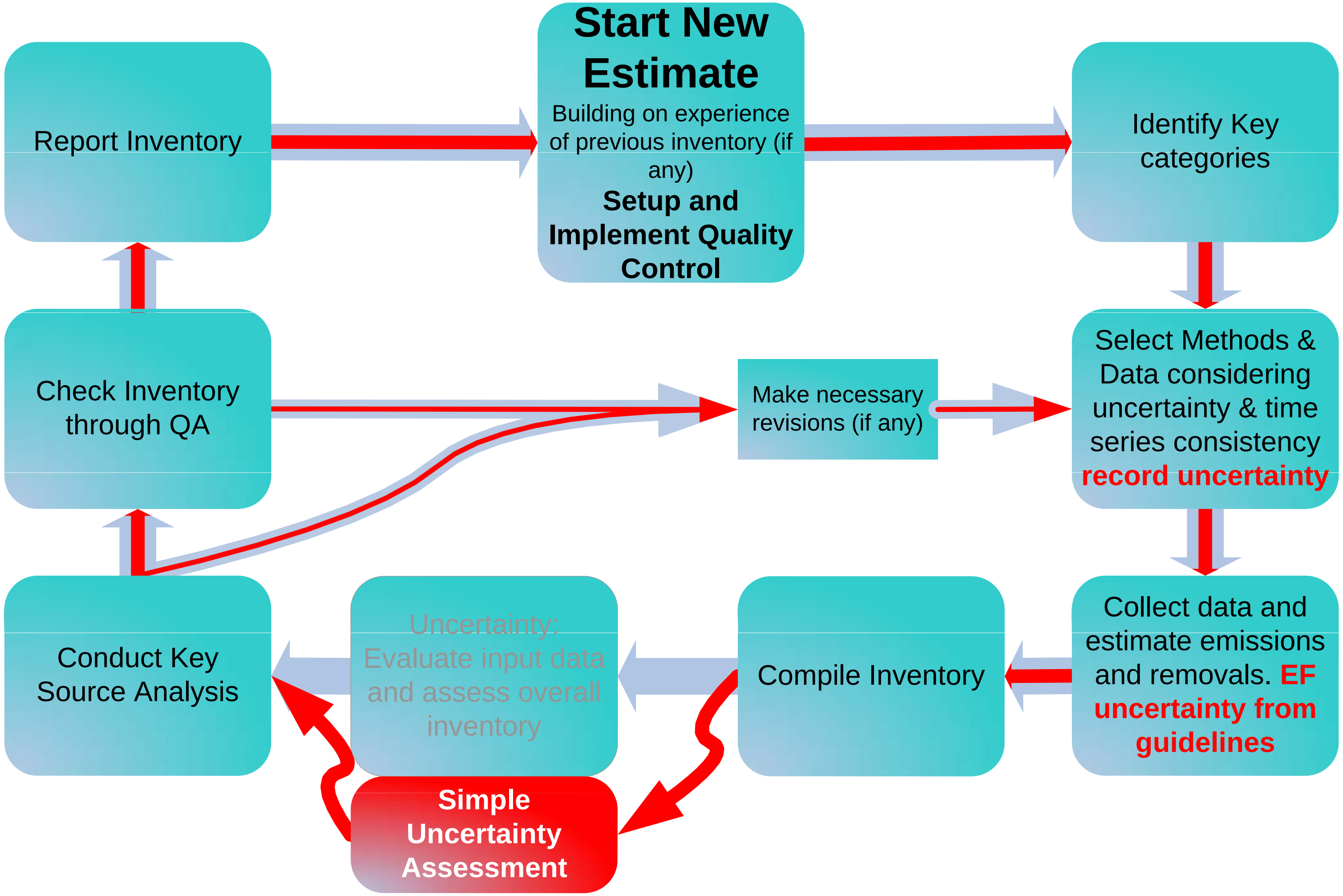
Conduct Key Source Analysis

Check Inventory through QA

Make necessary revisions (if any)

Report Inventory

Inventory Cycle


Report Inventory

Start New Estimate

Building on experience of previous inventory (if any)

Setup and Implement Quality Control

Identify Key categories

Select Methods & Data considering uncertainty & time series consistency **record uncertainty**

Make necessary revisions (if any)

Check Inventory through QA

Collect data and estimate emissions and removals. **EF uncertainty from guidelines**

Compile Inventory

Uncertainty: Evaluate input data and assess overall inventory

Conduct Key Source Analysis

Simple Uncertainty Assessment

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

UNEP

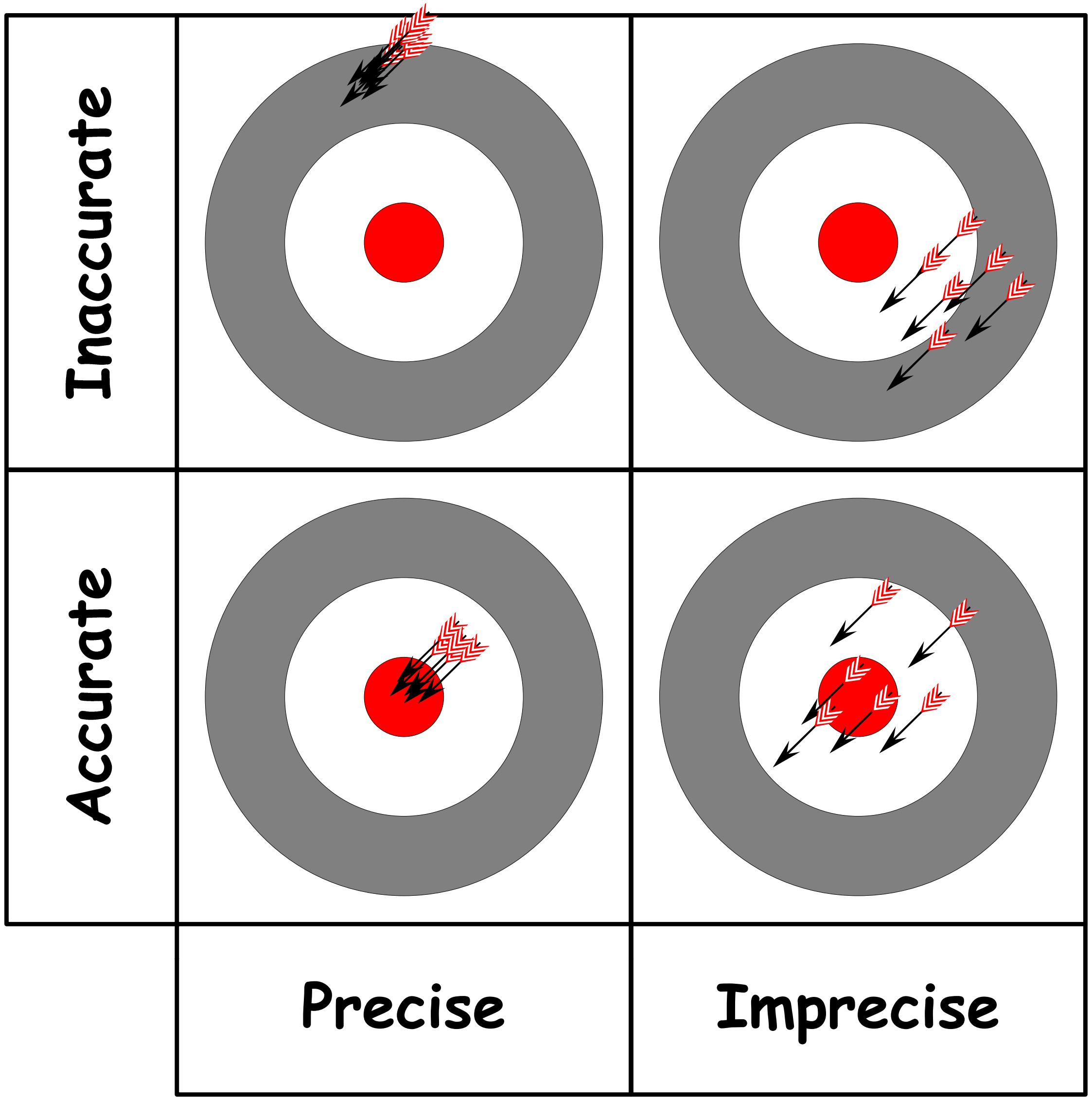
WMO

Task Force on Inventories

IPCC

Some Concepts

Accuracy & Precision

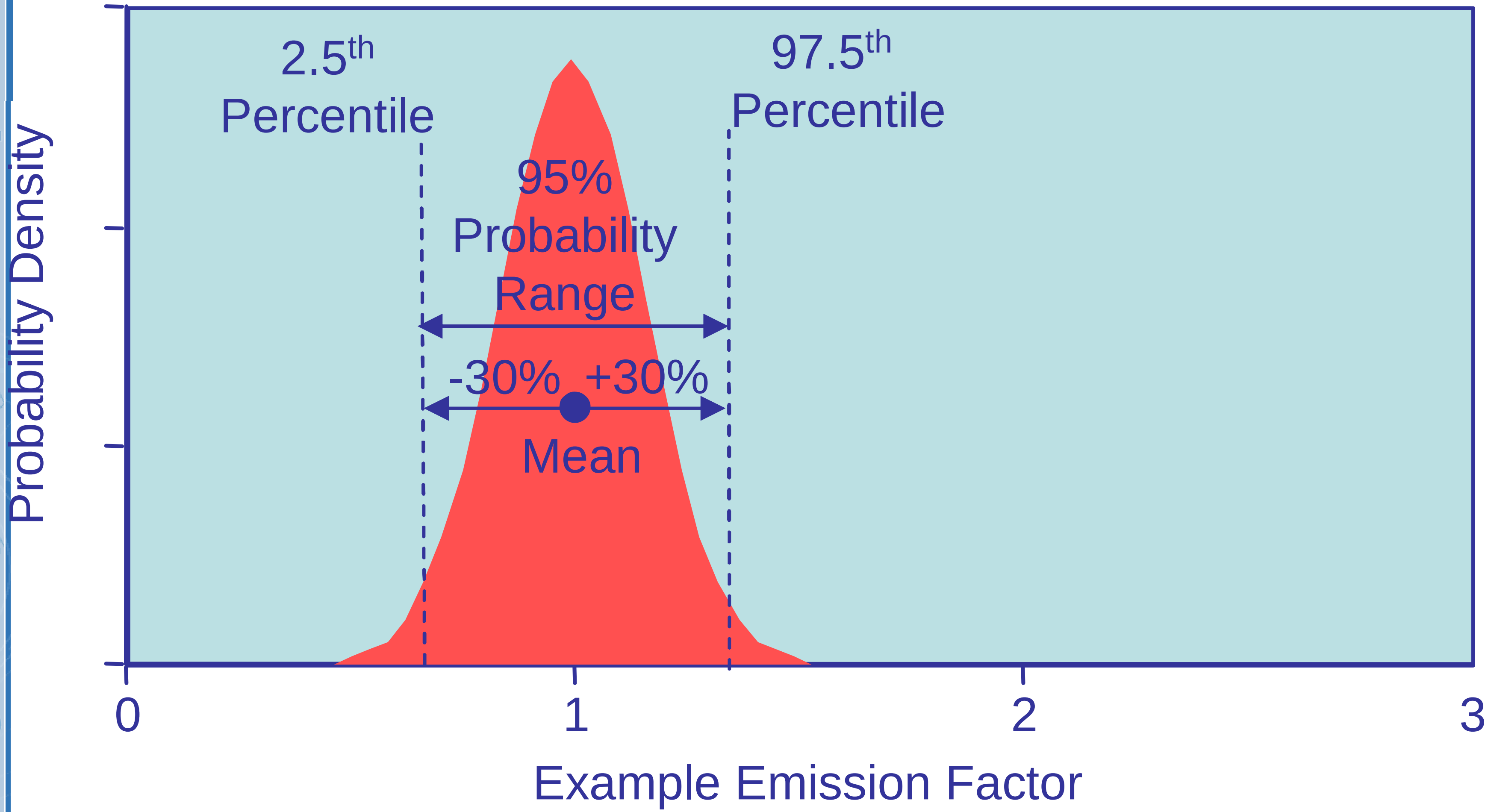


Specifying Uncertainty

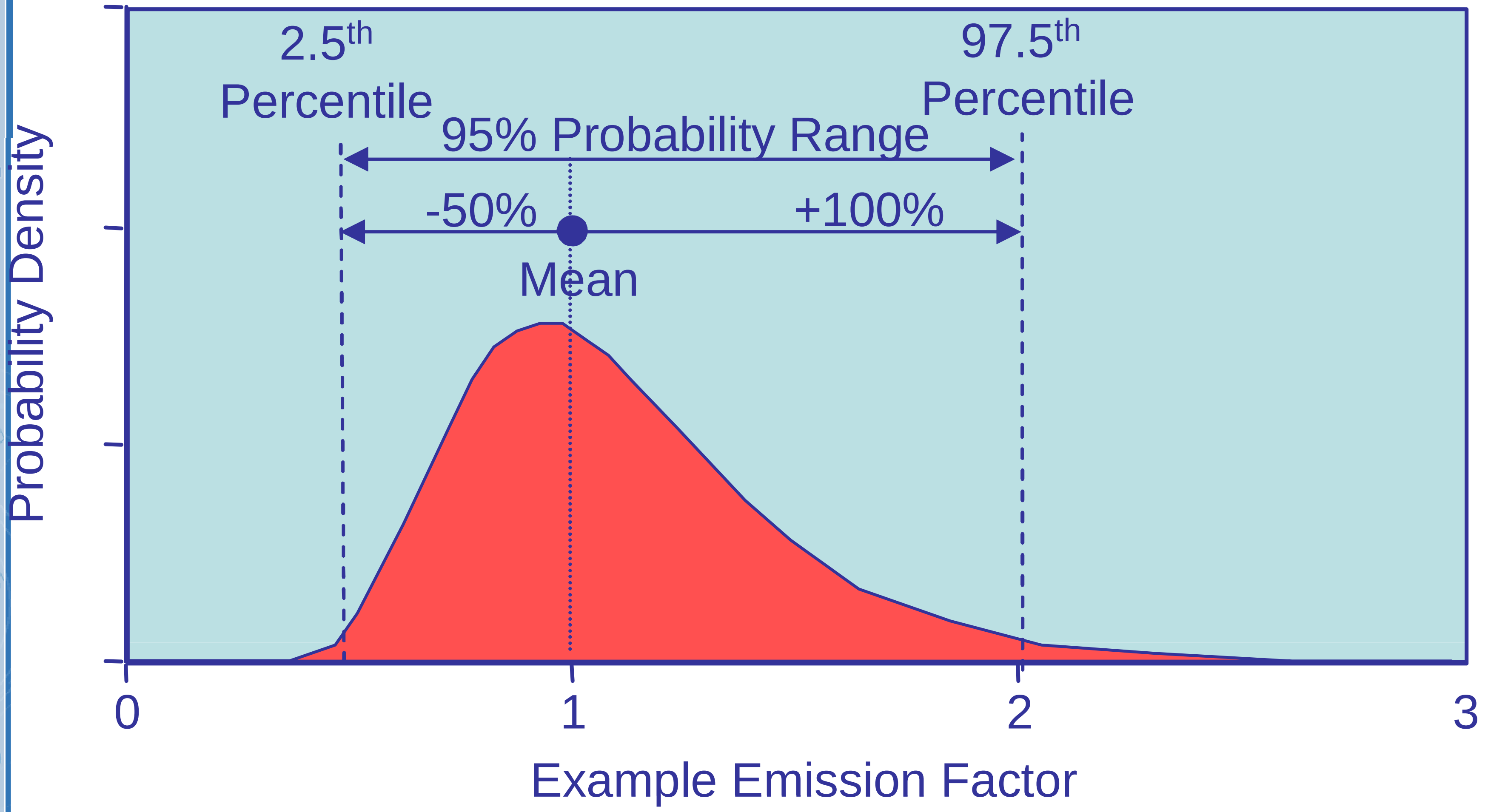
- Uncertainty is quoted as the 2.5 and 97.5 percentile i.e. bounds around a 95% confidence interval

- This can be expressed as
  - 234 ± 23%
  - 26400 (- 50%, + 100%)
  - 2000 (a factor of 2) (i.e. - 50%, + 100%)
  - 10 an order of magnitude (i.e. 1 to 100)

Probability Density



Probability Density



Determining Data Uncertainties

Simplified Approach

Sources of Uncertainty

- Assumptions and methods
  - These method may not accurately reflect the emission. Good Practice requires that biases be reduced as much as possible. Guidelines aim to be as unbiased and complete as possible.
- Input Data
  - Measured values have errors and emission factors may not be truly representative
- Calculation errors
  - Good QA/QC to stop these

Uncertainties arise in Input Data…

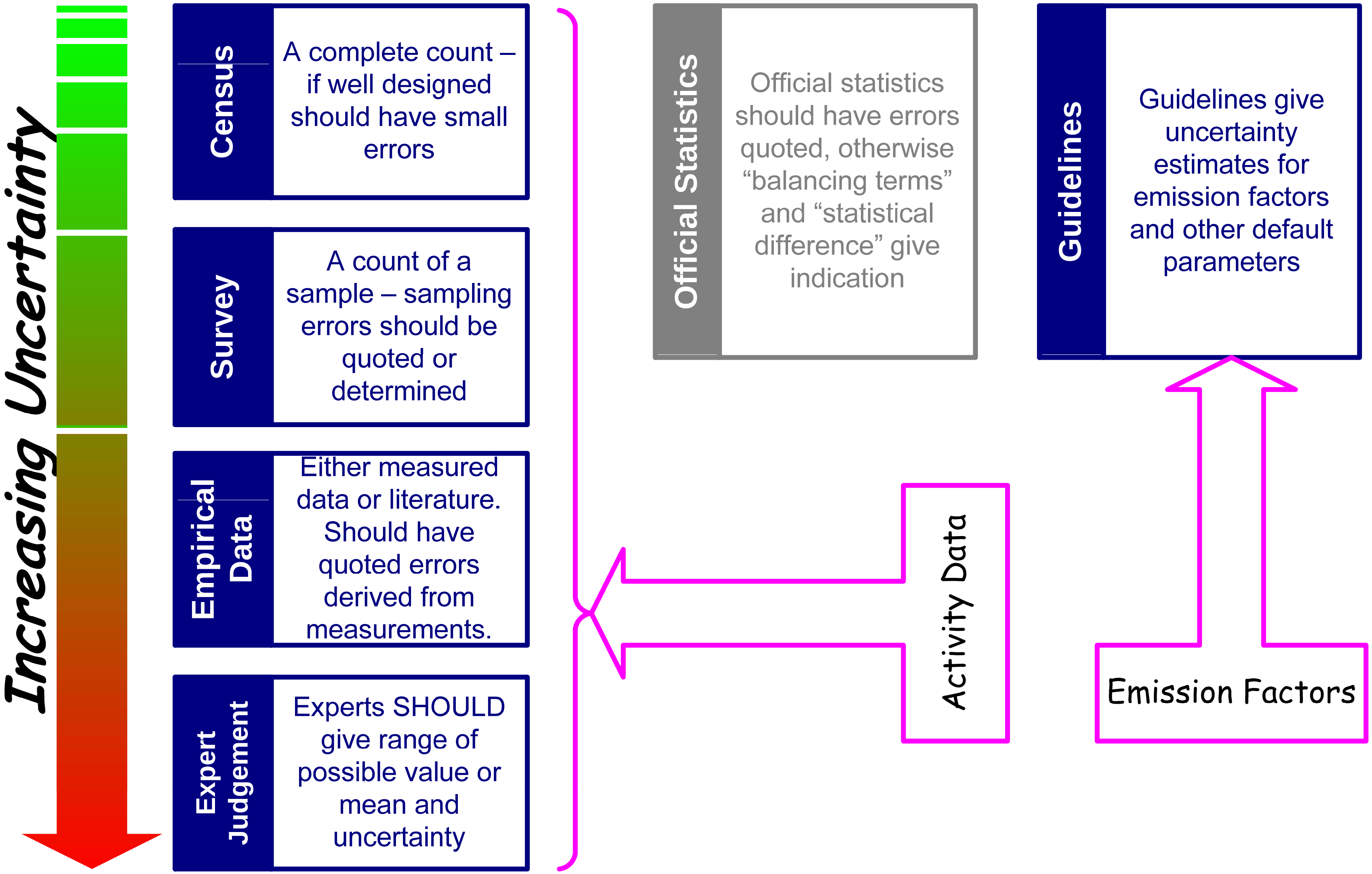
- Lack of data
  - Use of proxies, extrapolation etc.
  - Missing data
- Data not truly representative
- Statistical Random Sampling Error
- Measurement error
- Misreporting

- **Consideration of these during data collection phase will minimise errors**

Sources of data

- National Statistics Agencies
- Sectoral experts, stakeholder organisations
- Other national experts
- IPCC Emission Factor Database
- Other international experts
- International organisations publishing statistics e.g., United Nations, Eurostat or the International Energy Agency, OECD and the IMF (which maintains international activity as well as economic data)
- Reference libraries (National Libraries)
- Scientific and technical articles in environmental books, journals and reports.
- Universities
- Web search for organisations & specialists
- National Inventory Reports from Parties to the United Nations Framework Convention on Climate Change

Uncertainty Information



Increasing Uncertainty

Census
A complete count – if well designed should have small errors

Survey
A count of a sample – sampling errors should be quoted or determined

Empirical Data
Either measured data or literature. Should have quoted errors derived from measurements.

Expert Judgement
Experts SHOULD give range of possible value or mean and uncertainty

Official Statistics
Official statistics should have errors quoted, otherwise “balancing terms” and “statistical difference” give indication

Guidelines
Guidelines give uncertainty estimates for emission factors and other default parameters

Activity Data

Emission Factors

Expert Judgement

- In many cases empirical data are not available.
- A practical solution is using well-informed judgements from experts.
  - Possible biases: Availability bias, representativeness bias, anchoring and adjustment bias, motivational bias, managerial bias…
  - Solution: use formal expert elicitation protocols
- Expert elicitation

Expert judgement

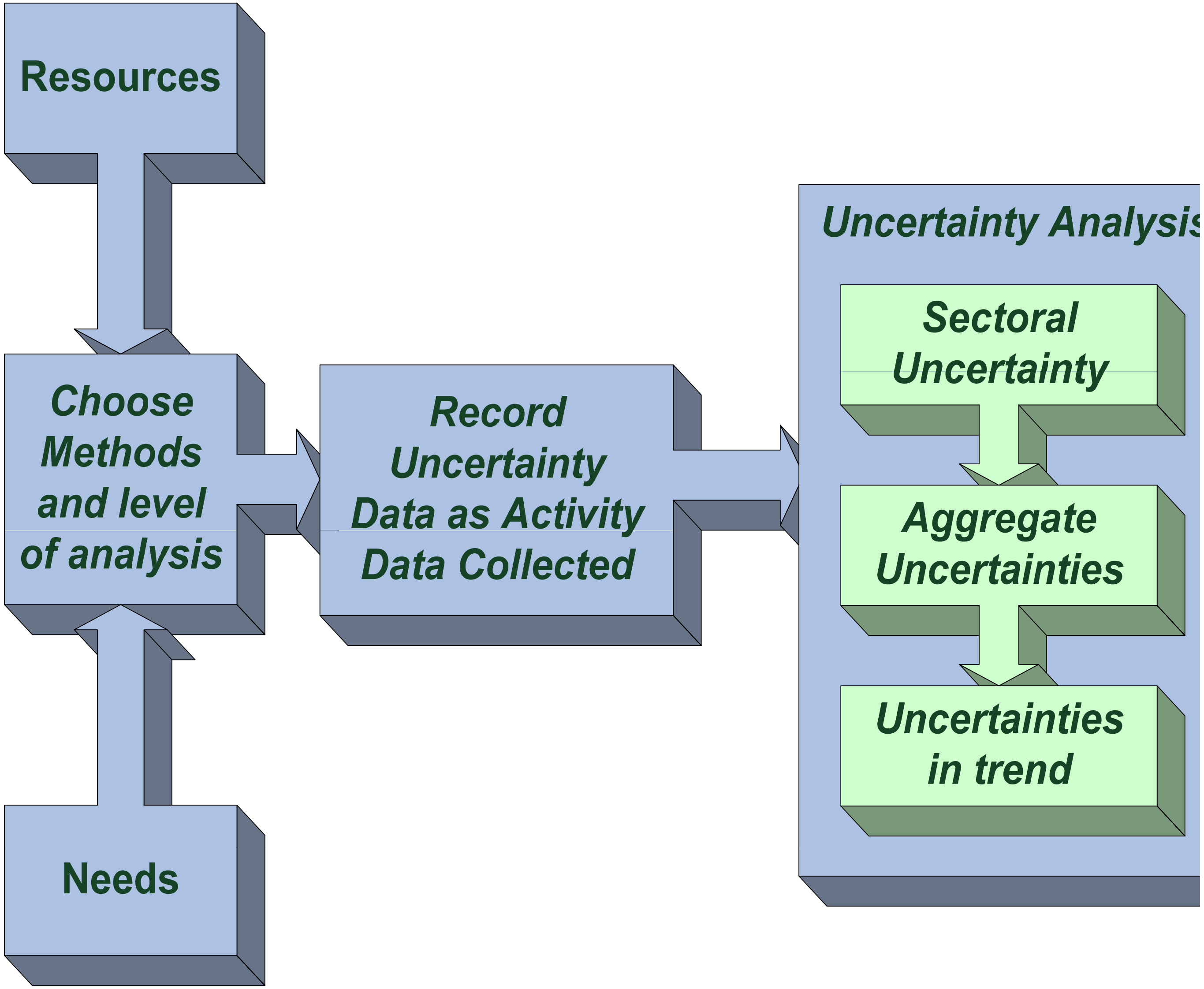
- Expert judgement on methodological choice and choice of input data to use is ultimately the basis of all inventory development and sector specialists can be of particular use to fill gaps in the available data, to select data from a range of possible values or make judgements about uncertainty ranges as described in Section 3.2.2.3. Experts with suitable backgrounds can be found in government, industrial trade associations, technical institutes, industry and universities.

  The goal of expert judgement may be choosing the proper methodology; the parameter value from ranges provided; the most appropriate activity data to use; the most appropriate way to apply a methodology; or determining the appropriate mix of technologies in use. A degree of expert judgement is required even when applying classical statistical techniques to data sets, since one must judge whether the data are a representative random sample and, if so, what methods to use to analyze the data. This requires both technical and statistical judgement. Interpretation is especially needed for data sets that are small, highly skewed or incomplete[1]. In all cases the aim is to be as representative as possible in order to reduce possible bias and increase accuracy. Formal methods for obtaining (or eliciting) data from experts are known as expert elicitation, see Annex 2A.1 for details.

[1] Methods for characterising sampling distributions for the mean are described by Cullen and Frey (1999), Frey and Rhodes (1996), and Frey and Burmaster (1999).

- Wherever possible, expert judgement should be elicited using an appropriate protocol. An example of a well-known protocol for expert elicitation, Stanford/SRI protocol, has been adapted and is described below.
  Motivating: Establish a rapport with the expert, and describe the context of the elicitation. Explain the elicitation method to be used and the reason it was designed that way. The elicitor should also try to explain the most commonly occurring biases to the expert, and to identify possible biases in the expert.
  Structuring: Clearly define the quantities for which judgements are to be sought, including, for example, the year and country, the source/sink category, the averaging time to be used (one year), the focus activity data, emission factor or, for uncertainty, the mean value of emission factors or other estimation parameter, and the structure of the inventory model. Clearly identify conditioning factors and assumptions (e.g., resulting emissions or removals should be for typical conditions averaged over a one-year period).
  Conditioning: Work with the expert to identify and record all relevant data, models, and theory relating to the formulation of the judgements.
  Encoding: Request and quantify the expert's judgement. The specific qualification will differ for different elements and be present in the form of a probability distribution for uncertainty, and an activity or emission factor estimate for activity data and emission factors. If appropriately managed, information on uncertainty (probability density function) can be gathered at the same time as gathering estimates of activity or emission factor. The section on encoding in Chapter 3 describes some alternative methods to use for encoding uncertainty.
  Verification: Analyze the expert's response and provide the expert with feedback as to what has been concluded regarding his or her judgement. Is what has been encoded really what the expert meant? Are there inconsistencies in the expert's judgement?

Uncertainty Analysis



Resources

Choose Methods and level of analysis

Needs

Record Uncertainty Data as Activity Data Collected

Uncertainty Analysis

Sectoral Uncertainty

Aggregate Uncertainties

Uncertainties in trend

Methods to combine uncertainties

1. Error Propagation
   - ❖ Simple - Standard Spreadsheet can be used
     - ✓ Guidelines give explanation and equations
   - ❖ Difficult to deal with correlations
   - ❖ Strictly (standard deviation/mean) < 0.3
     - ✓ A simple solution is provided
2. Monte-Carlo Simulation
   - ❖ More complex - Use specialised software
   - ❖ Needs shape of pdf
   - ❖ Suitable where uncertainties large, non-Gaussian, complex algorithms, correlations exist and uncertainties vary with time

From 2006 Guidelines:

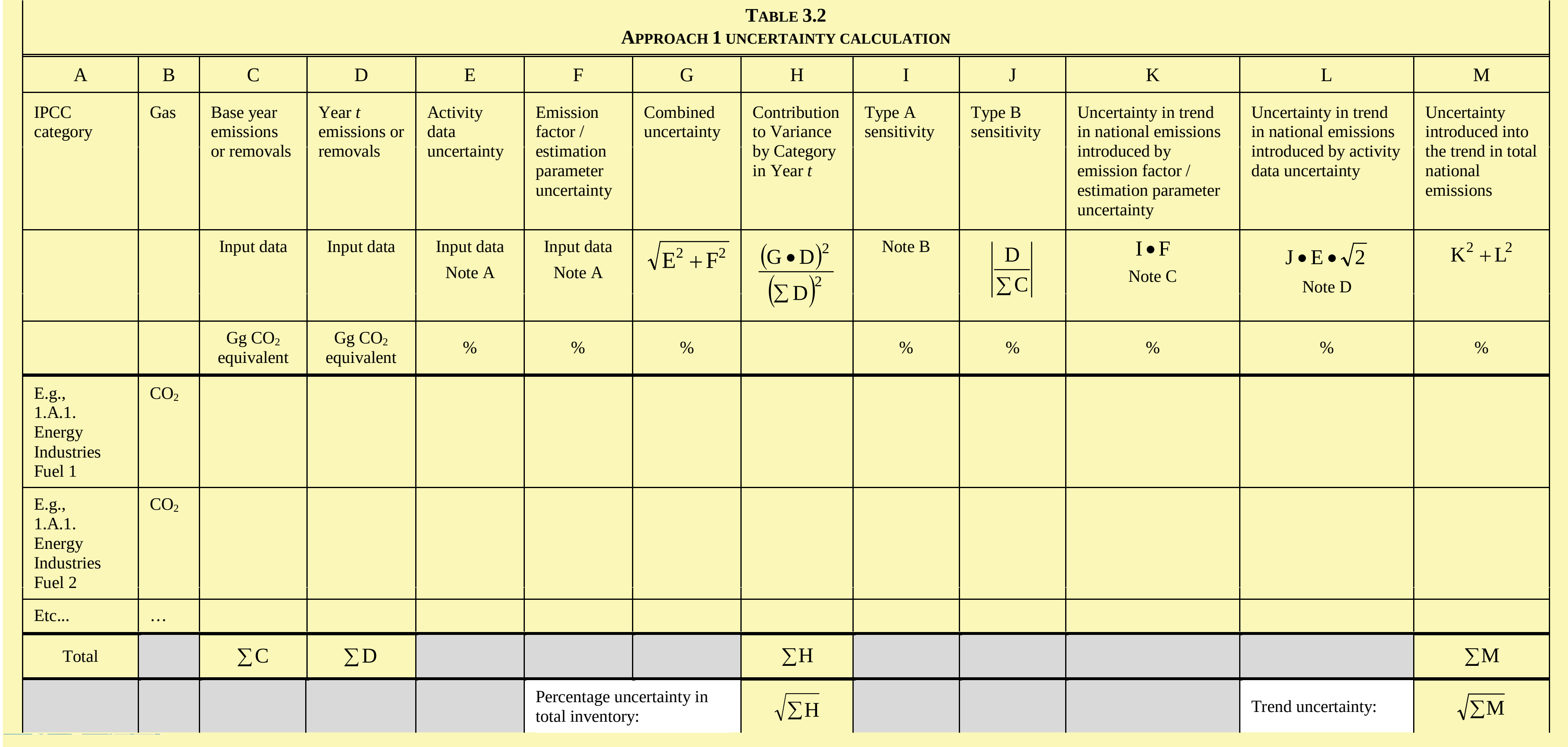


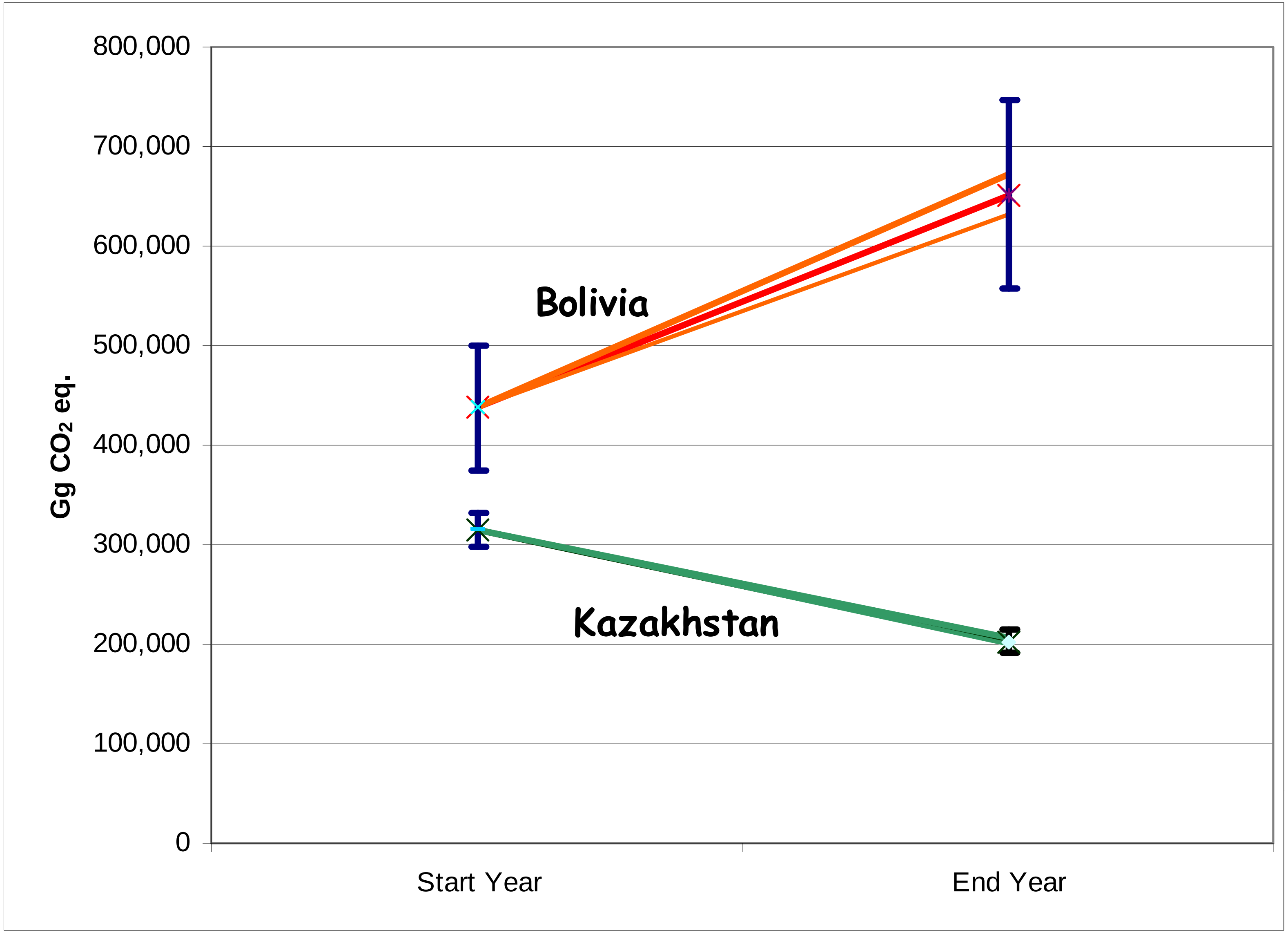
TABLE 3.2
APPROACH 1 UNCERTAINTY CALCULATION

A	B	C	D	E	F	G	H	I	J	K	L	M
IPCC category	Gas	Base year emissions or removals	Year *t* emissions or removals	Activity data uncertainty	Emission factor / estimation parameter uncertainty	Combined uncertainty	Contribution to Variance by Category in Year *t*	Type A sensitivity	Type B sensitivity	Uncertainty in trend in national emissions introduced by emission factor / estimation parameter uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
		Input data	Input data	Input data Note A	Input data Note A	$\sqrt{E^2+F^2}$	$\frac{(G \bullet D)^2}{(\sum D)^2}$	Note B	$\left\lvert\frac{D}{\sum C}\right\rvert$	$I \bullet F$ Note C	$J \bullet E \bullet \sqrt{2}$ Note D	K^2+L^2
		Gg CO_2 equivalent	Gg CO_2 equivalent	%	%	%		%	%	%	%	%
E.g., 1.A.1. Energy Industries Fuel 1	CO_2											
E.g., 1.A.1. Energy Industries Fuel 2	CO_2											
Etc...	…											
Total		$\sum C$	$\sum D$				$\sum H$					$\sum M$
					Percentage uncertainty in total inventory:		$\sqrt{\sum H}$				Trend uncertainty:	$\sqrt{\sum M}$

Approach 1 uncertainty calculation

A	B	C	D	E	F	G	H	I	J	K	L	M
IPCC category	Gas	Base year emissions or removals	Year *t* emissions or removals	Activity data uncertainty	Emission factor / estimation parameter uncertainty	Combined uncertainty	Contribution to Variance by Category in Year *t*	Type A sensitivity	Type B sensitivity	Uncertainty in trend in national emissions introduced by emission factor / estimation parameter uncertainty	Uncertainty in trend in national emissions introduced by activity data uncertainty	Uncertainty introduced into the trend in total national emissions
		Input data	Input data	Input data	Input data	$\sqrt{E^2+F^2}$	$\frac{(G \bullet D)^2}{(\sum D)^2}$	Note B	$\left\lvert\frac{D}{\sum C}\right\rvert$	$I \bullet F$	$J \bullet E \bullet \sqrt{2}$	K^2+L^2
		Gg CO_2 equivalent	Gg CO_2 equivalent	%	%	%		%	%	%	%	%
1.A.1. Energy Industries	CH4	35.5346662	32.9951217	5	25	25.50	0.0	3.20506E-05	0.00010495	0.000801264	0.000742109	1.19275E-06
1.A.2. Manufacturing Industries and Constructior	CH4	57.0302899	51.8776096	5	25	25.50	0.0	4.80131E-05	0.000165011	0.001200328	0.001166804	2.80222E-06
1.A.3. Transport	CH4	81.7067834	37.1466612	5	25	25.50	0.0	-4.94664E-05	0.000118155	-0.00123666	0.000835483	2.22736E-06
1.A.4. Other Sectors	CH4	1041.24025	428.554682	5	25	25.50	0.0	-0.000772946	0.001363136	-0.019323647	0.009638828	0.00046631
1.A.5. Other	CH4	330.338228	97.5658895	5	25	25.50	0.0	-0.000367351	0.000310335	-0.009183772	0.002194401	8.91571E-05
1.B.1. Solid Fuels	CH4	24867.6834	12364.38	10	25	26.93	2.7	-0.011678579	0.039328314	-0.291964463	0.556186352	0.394586505
1.B.2. Oil and Natural Gas	CH4	12570.348	4022.34735	10	25	26.93	0.3	-0.012988732	0.012794183	-0.324718297	0.180937071	0.138180196
2.B. Chemical Industry .	CH4	40.53	37.5018	10	25	26.93	0.0	3.61373E-05	0.000119285	0.000903433	0.001686942	3.66196E-06
4.A. Enteric Fermentation.	CH4	14054.9863	7346.85	15	30	33.54	1.5	-0.005462727	0.023368679	-0.163881819	0.495724537	0.272600067
4.B. Manure Management.	CH4	1903.28061	1199.63088	15	30	33.54	0.0	-8.88245E-05	0.003815756	-0.002664735	0.080944413	0.006559099
4.C. Rice Cultivation.	CH4	522.9	338.94	10	30	31.62	0.0	5.3609E-06	0.001078092	0.000160827	0.015246523	0.000232482
4.F. Field Burning of Agricultural Residues.	CH4	64.3314	37.59	20	30	36.06	0.0	-1.24107E-05	0.000119565	-0.000372321	0.003381819	1.15753E-05
6.A. Solid Waste Disposal on Land.	CH4	1959.72	3738.63	15	30	33.54	0.4	0.00787088	0.011891742	0.236126385	0.252261939	0.119391756
6.B. Wastewater Handling.	CH4	787.08	747.18	15	30	33.54	0.0	0.000761896	0.002376612	0.022856865	0.050415547	0.003064164
1.A.1. Energy Industries	CO2	102607.31	95966.95	5	5	7.07	11.2	0.094441853	0.305249301	0.472209267	2.158438506	4.881838378
1.A.2. Manufacturing Industries and Constructior	CO2	33991.06	30164.34	5	5	7.07	1.1	0.02618491	0.095945987	0.130924551	0.678440577	0.477422855
1.A.3. Transport	CO2	23987.07	8406.48	5	5	7.07	0.1	-0.022453294	0.026739124	-0.11226647	0.189074157	0.048352797
1.A.4. Other Sectors	CO2	44532.52	11784.04	5	5	7.07	0.2	-0.053800014	0.037482383	-0.269000072	0.265040472	0.14260749
1.A.5. Other	CO2	8370.16	4124.19	5	5	7.07	0.0	-0.004052209	0.013118122	-0.020261045	0.092759127	0.009014766
1.B.2. Oil and Natural Gas	CO2	3408.21	5171.49583	10	15	18.03	0.2	0.009456387	0.016449366	0.141845811	0.232629165	0.074236563
2.A. Mineral Products.	CO2	5744.63	2507.20146	10	15	18.03	0.0	-0.003809586	0.007974844	-0.057143788	0.112781331	0.015985041
2.B. Chemical Industry .	CO2	1355.56	171.93456	10	15	18.03	0.0	-0.002233954	0.000546885	-0.033509311	0.007734125	0.001182691
2.C. Metal Production.	CO2	12932.6799	10507.4715	10	15	18.03	0.9	0.006887639	0.033421905	0.103314586	0.47265712	0.234078657
5.A. Changes in Forest and Other Woody Bioma	CO2	97.19		50	80	94.34	0.0	-0.000199385	0	-0.015950798	0	0.000254428
5.A. Changes in Forest and Other Woody Bioma	CO2	-7810.79	-7721.7341	50	80	94.34	12.9	-0.008539362	0.024561101	-0.683148991	1.736732102	3.482930938
5.B. Forest and Grassland Conversion.	CO2	6.26	280.43888	25	75	79.06	0.0	0.00087917	0.000892013	0.065937785	0.031537424	0.005342401
1.A.1. Energy Industries	N2O	388.516902	328.741673	5	50	50.25	0.0	0.000248607	0.001045653	0.012430334	0.007393886	0.000209183
1.A.2. Manufacturing Industries and Constructior	N2O	112.709781	114.844426	5	50	50.25	0.0	0.000134069	0.000365294	0.006703468	0.002583021	5.16085E-05
1.A.3. Transport	N2O	57.3319301	21.6195922	5	50	50.25	0.0	-4.88495E-05	6.87671E-05	-0.002442474	0.000486257	6.20212E-06
1.A.4. Other Sectors	N2O	194.497577	46.1816455	5	50	50.25	0.0	-0.000252117	0.000146893	-0.01260587	0.001038693	0.000159987
1.A.5. Other	N2O	27.4386549	13.5195061	5	50	50.25	0.0	-1.3288E-05	4.30025E-05	-0.000664398	0.000304074	5.33886E-07
4.B. Manure Management.	N2O	375.1	198.4	15	30	33.54	0.0	-0.000138451	0.000631066	-0.004153541	0.013386927	0.000196462
4.D. Agricultural Soils(2).	N2O	25217.694	9798.17	20	30	36.06	3.0	-0.020551916	0.031165777	-0.616557485	0.881501284	1.157187646
4.F. Field Burning of Agricultural Residues.	N2O	24.304	21.297	20	30	36.06	0.0	1.78812E-05	6.7741E-05	0.000536437	0.001916004	3.95884E-06
6.B. Wastewater Handling.	N2O	452.6	384.4	15	30	33.54	0.0	0.000294175	0.00122269	0.008825264	0.025937172	0.000750622
Keep Blank!	…									0		
Total		314388.7626	202771.1719			∑ H	34.6				∑ M	11.4670044
					Percentage uncertainty in total inventory:		5.880740472				Trend uncertainty:	3.386296561

Example Results



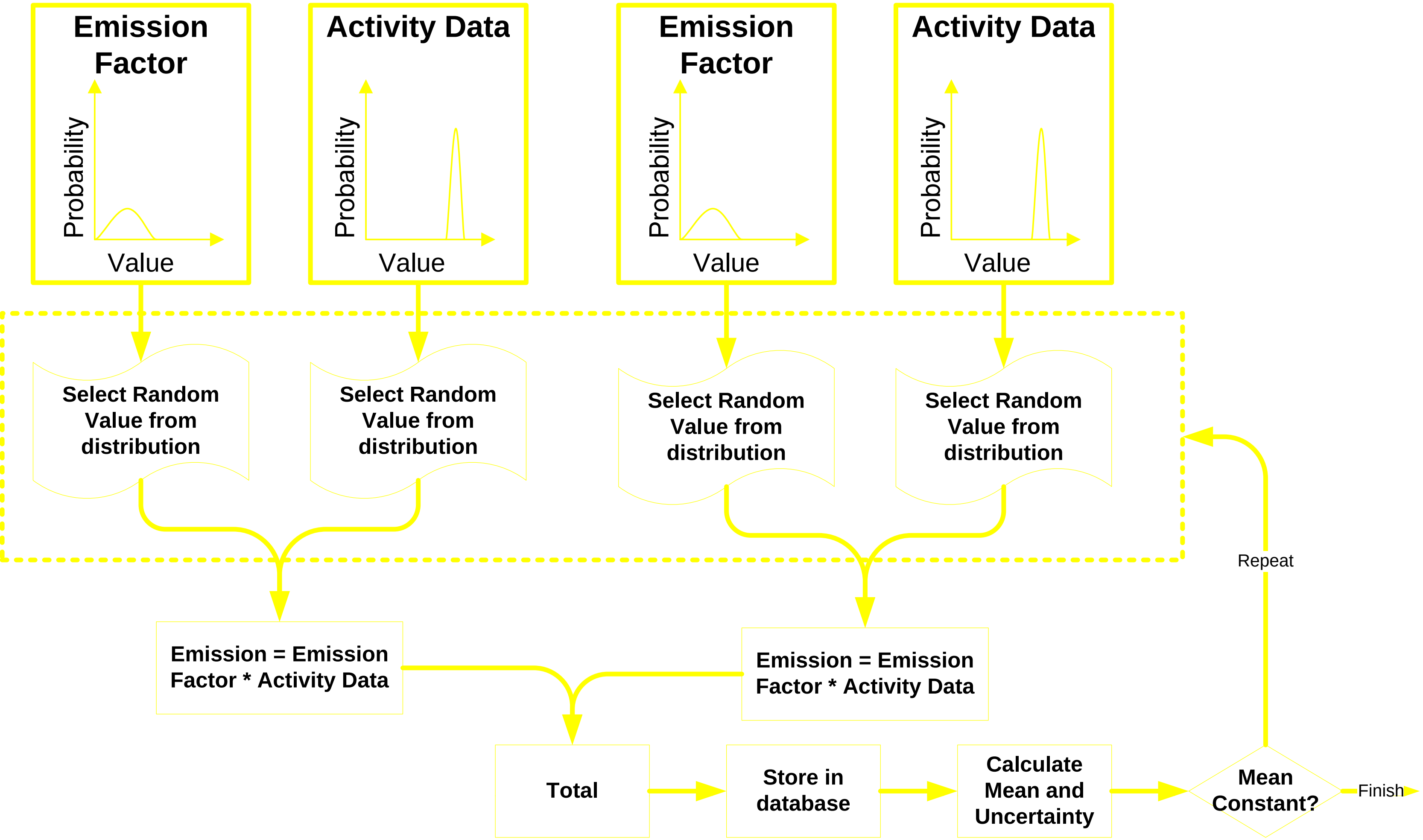
Results

	Kazakhstan			Bolivia		
Emissions	Changes in Forest and Other Woody Biomass Stocks.	CO2	86%	Enteric Fermentation	CH4	95%
	Energy Industries	CO2		Forest and Grassland Conversion	N2O	
	Agricultural Soils	N2O		Agricultural Soils	N2O	
	Solid Fuels	CH4		Forest and Grassland Conversion	CO2	
Varience	Energy Industries	CO2	69%	Enteric Fermentation	CH4	72%
	Manufacturing Industries and Construction	CO2		Agricultural Soils	N2O	
	Solid Fuels	CH4		Forest and Grassland Conversion	N2O	
	Other Sectors	CO2			CO2	

Monte-Carlo Method

- Key Requirements
  - Not just uncertainties but also probability density function (pdf)
    - Mean
    - Width
    - Shape (e.g. Normal, Log-normal, Weibul, Gamma, Uniform, Triangular, Fractile, …)
- Principal
  - Select random values of input parameters form their pdf and calculate the corresponding emission. Repeat many times and the distribution of the results is the pdf of the result, from which mean and uncertainty can be estimated

Monte-Carlo Method



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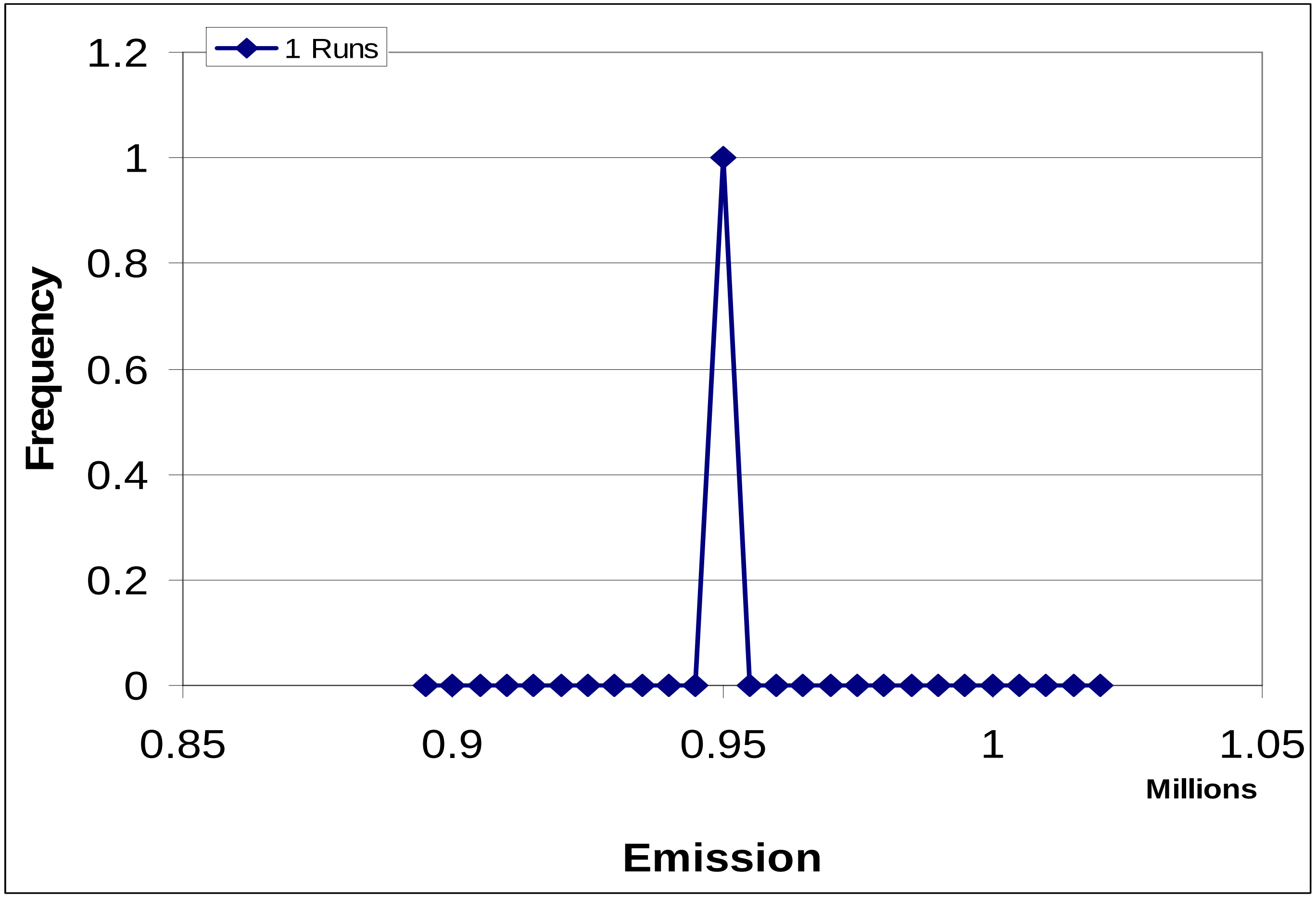
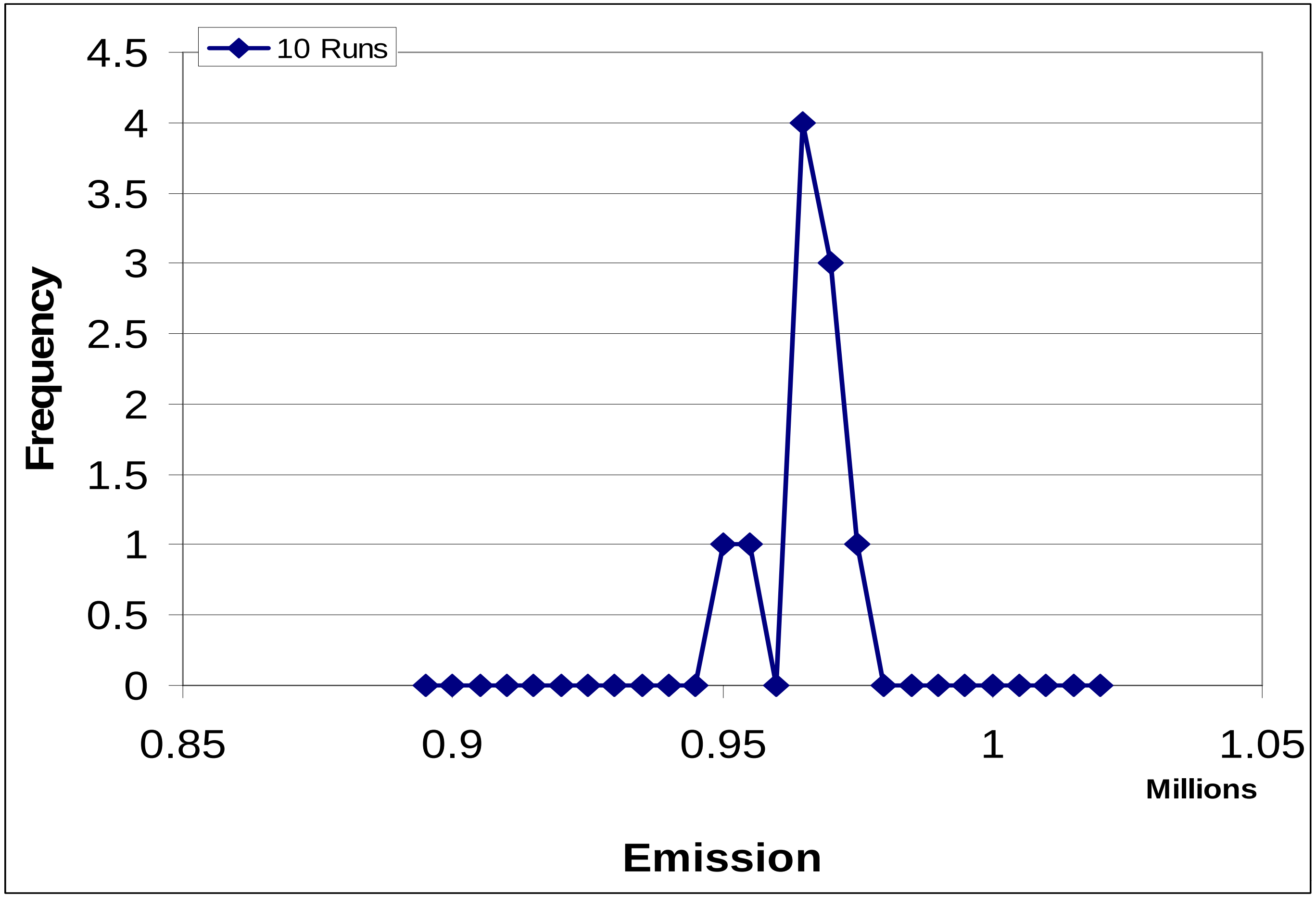
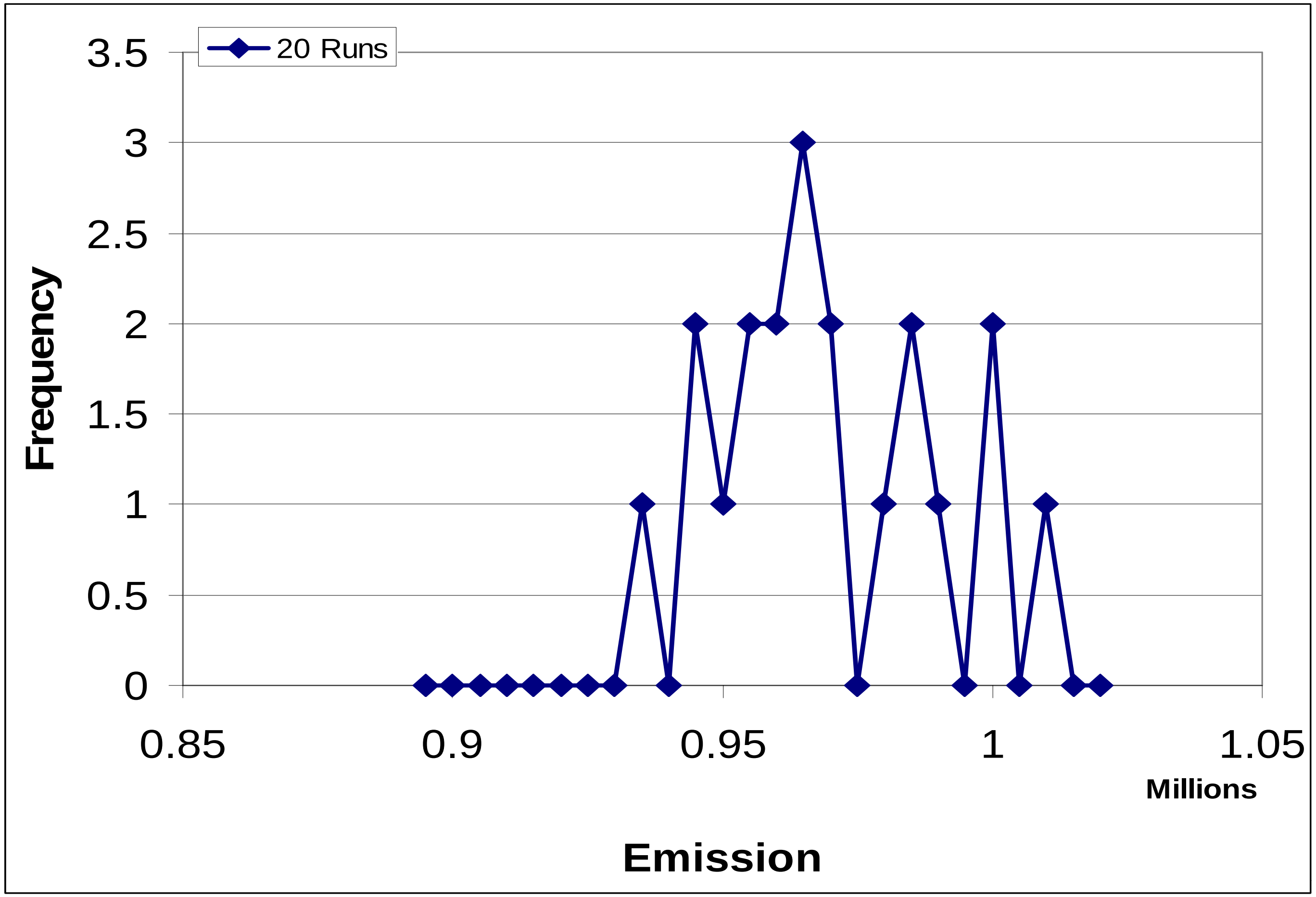

1 Runs
Frequency
1.2
1
0.8
0.6
0.4
0.2
0
0.85
0.9
0.95
1
1.05
Millions
Emission

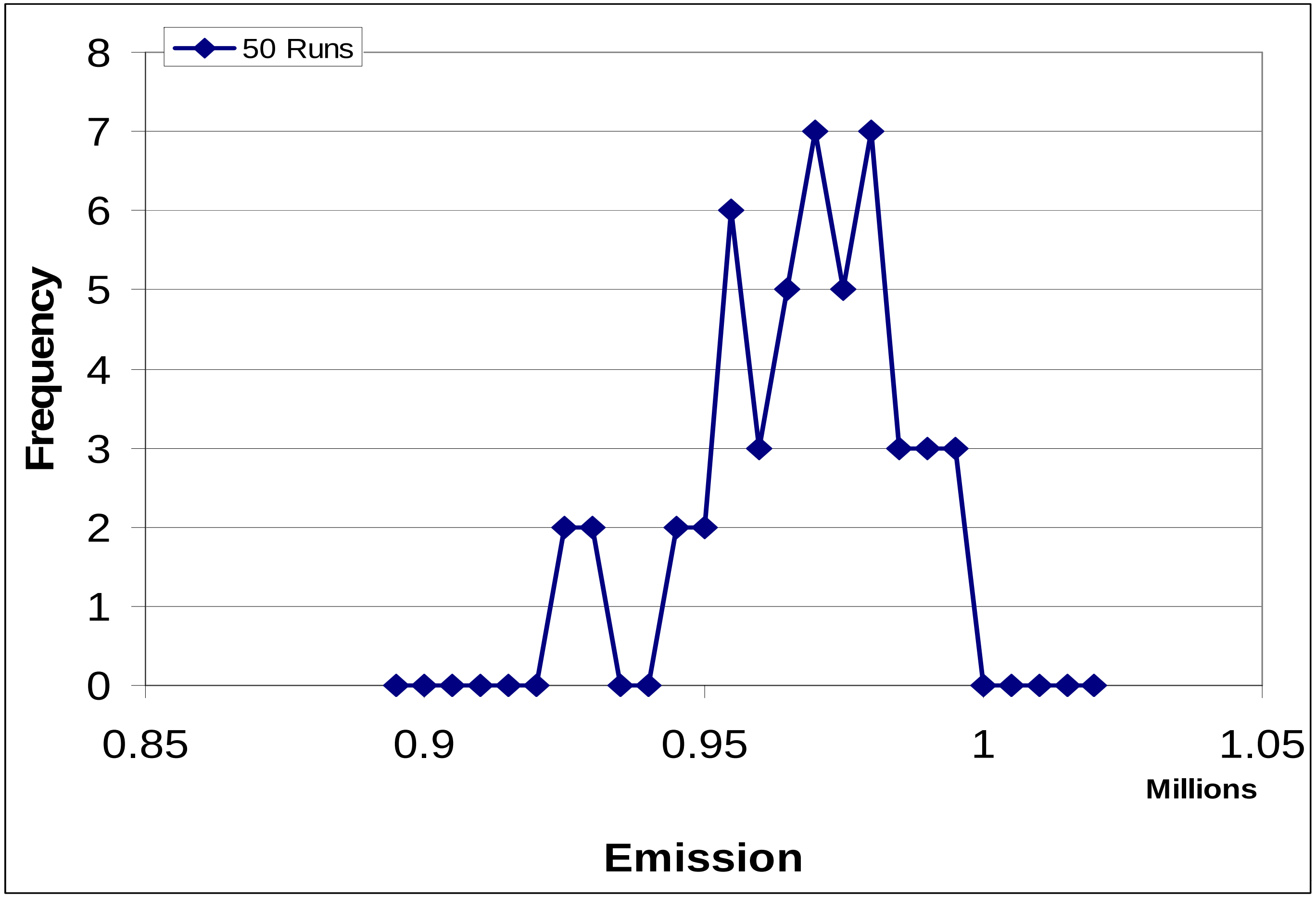
10


10 Runs
Frequency
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0.85
0.9
0.95
1
1.05
Millions
Emission

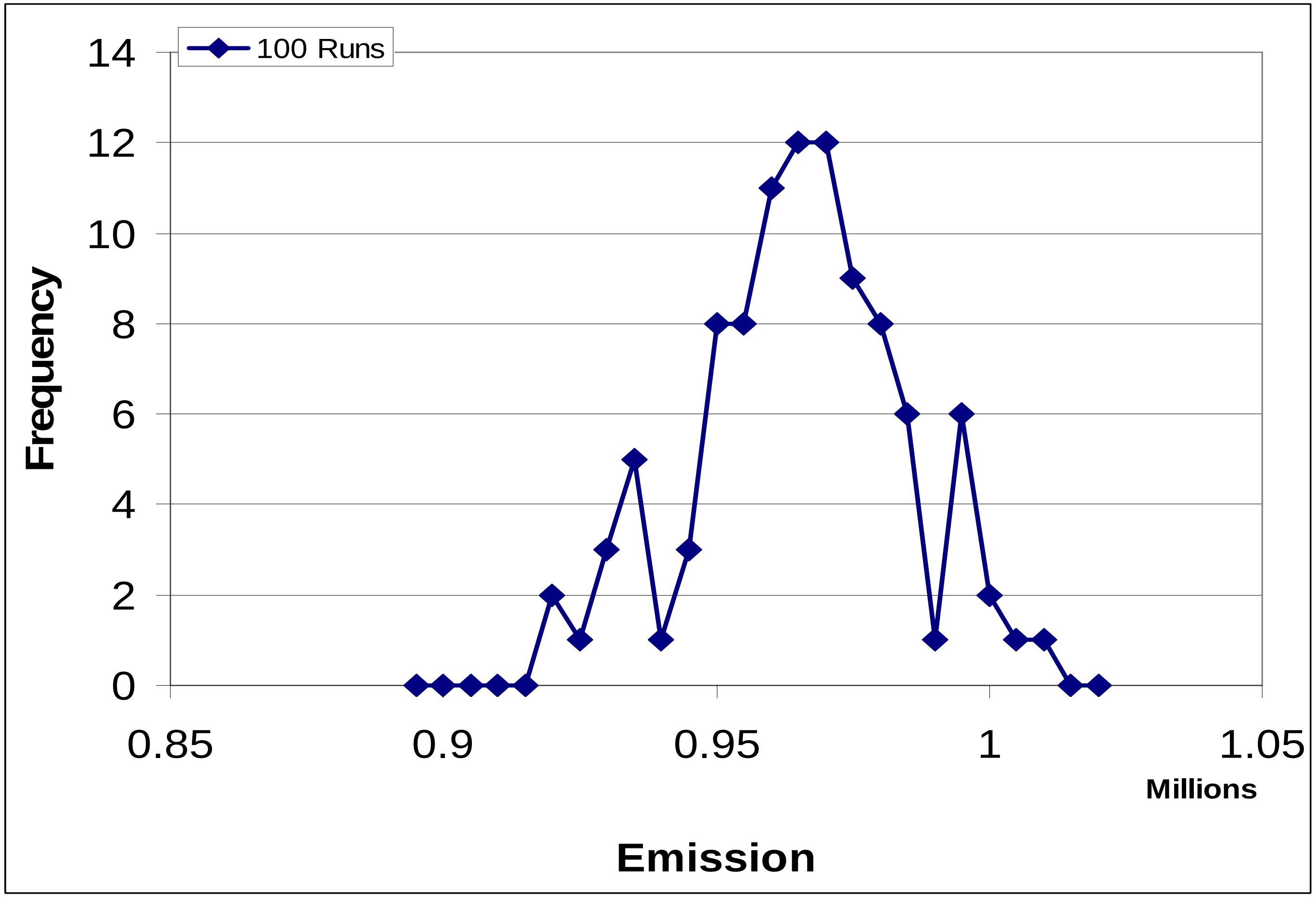
20


20 Runs
3.5
3
2.5
2
1.5
1
0.5
0
Frequency
0.85
0.9
0.95
1
1.05
Millions
Emission

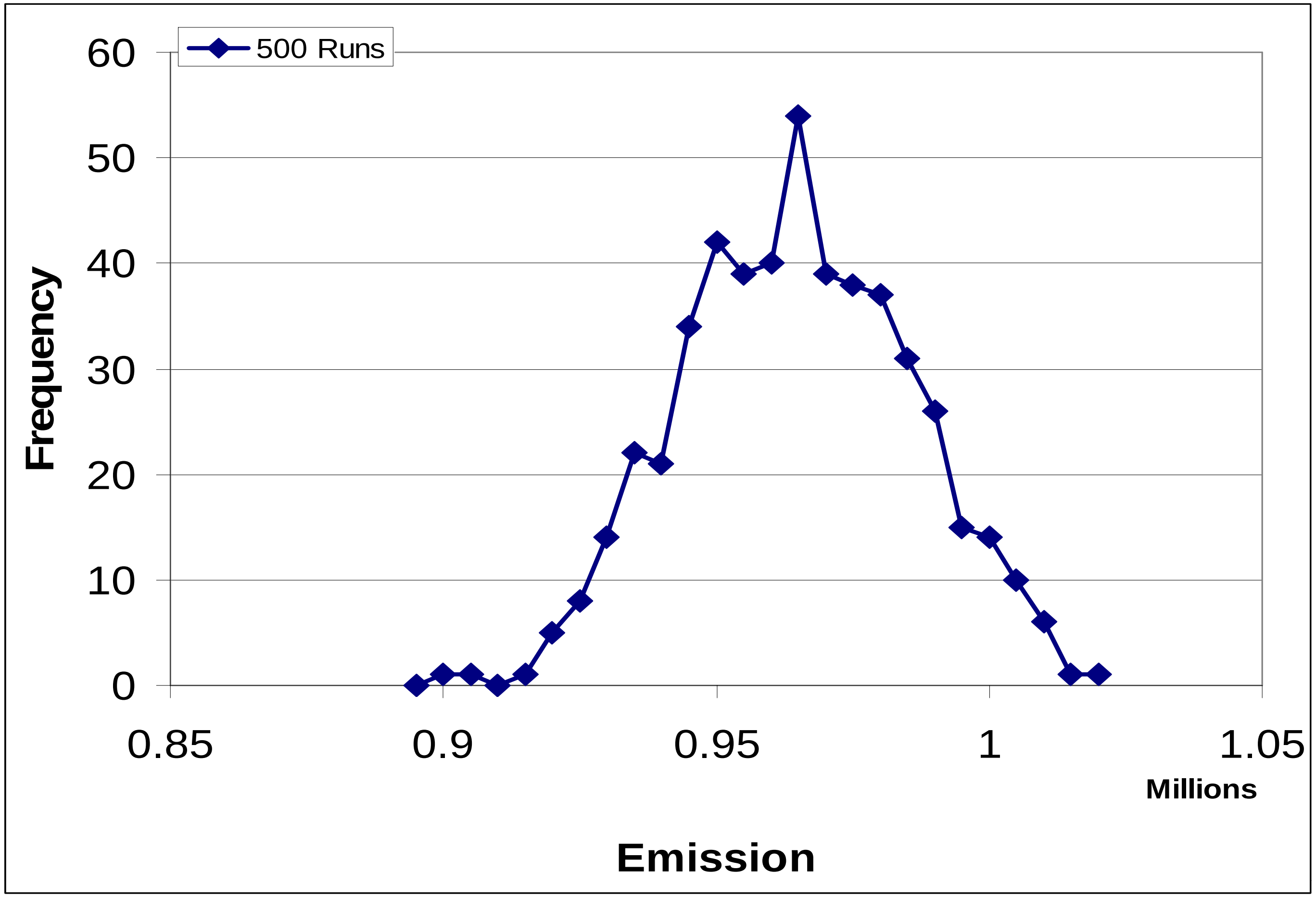
50


50 Runs
Frequency
8
7
6
5
4
3
2
1
0
0.85
0.9
0.95
1
1.05
Millions
Emission

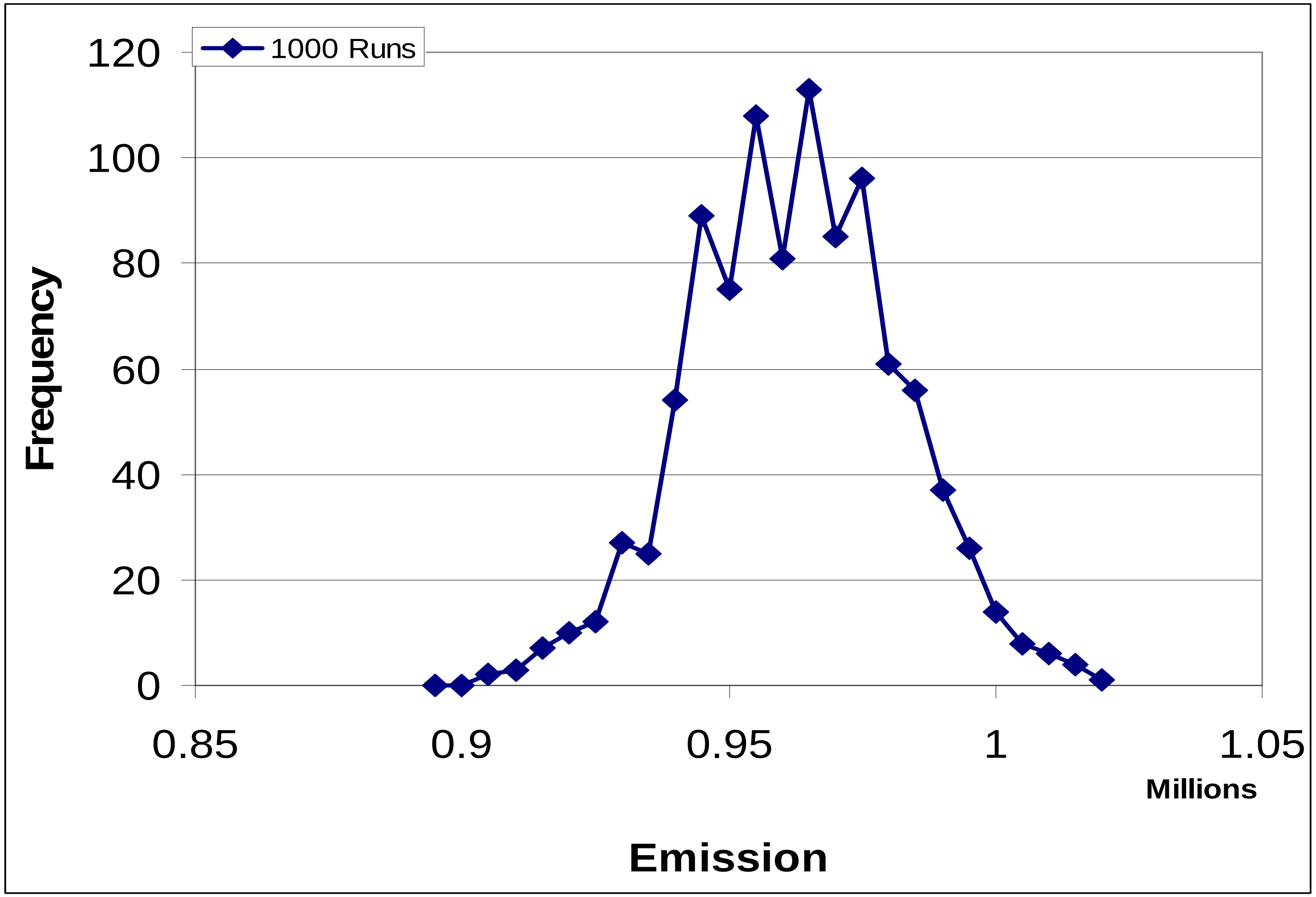
100


100 Runs
Frequency
14
12
10
8
6
4
2
0
0.85
0.9
0.95
1
1.05
Millions
Emission

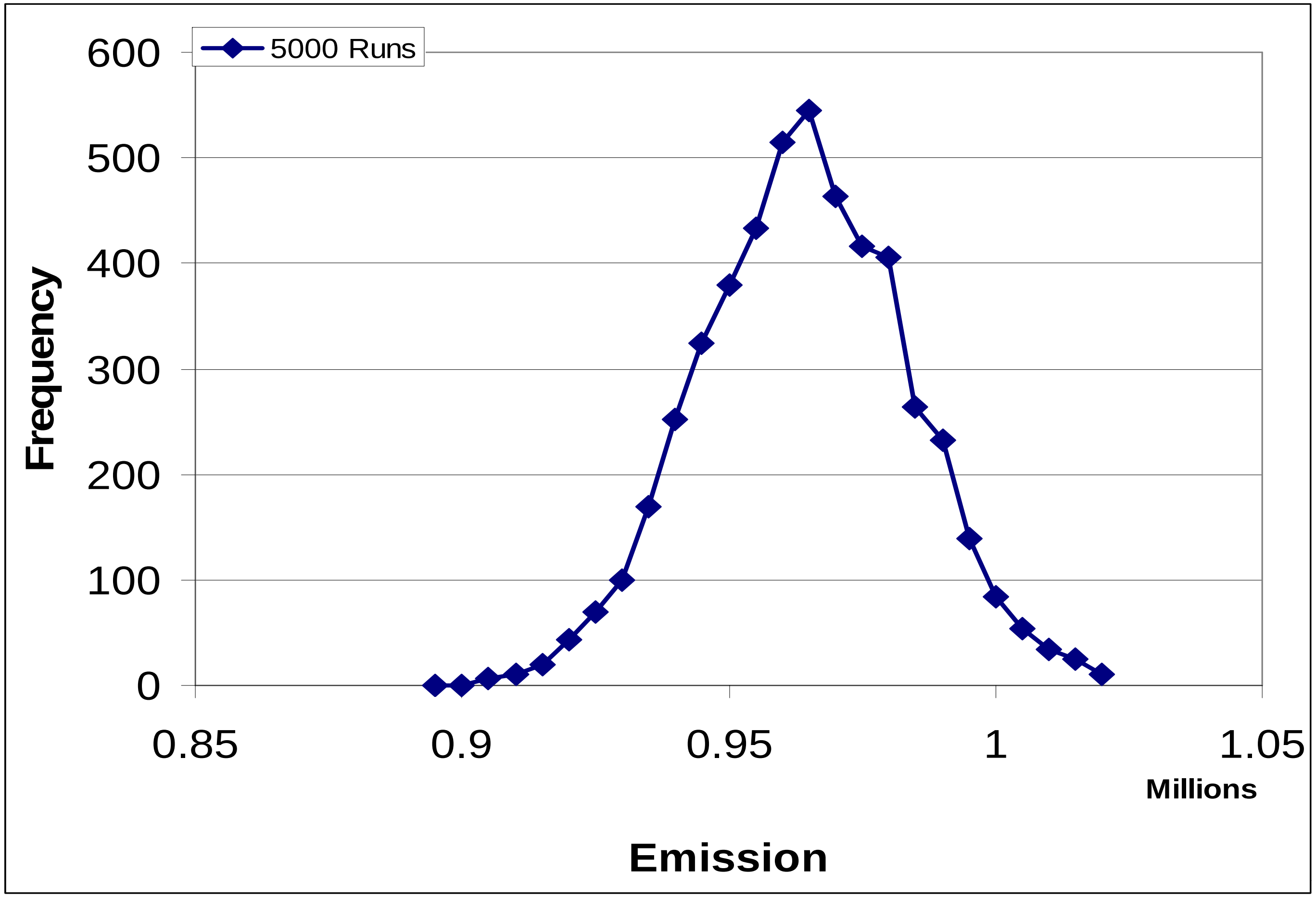
500


500 Runs
Frequency
60
50
40
30
20
10
0
0.85
0.9
0.95
1
1.05
Millions
Emission

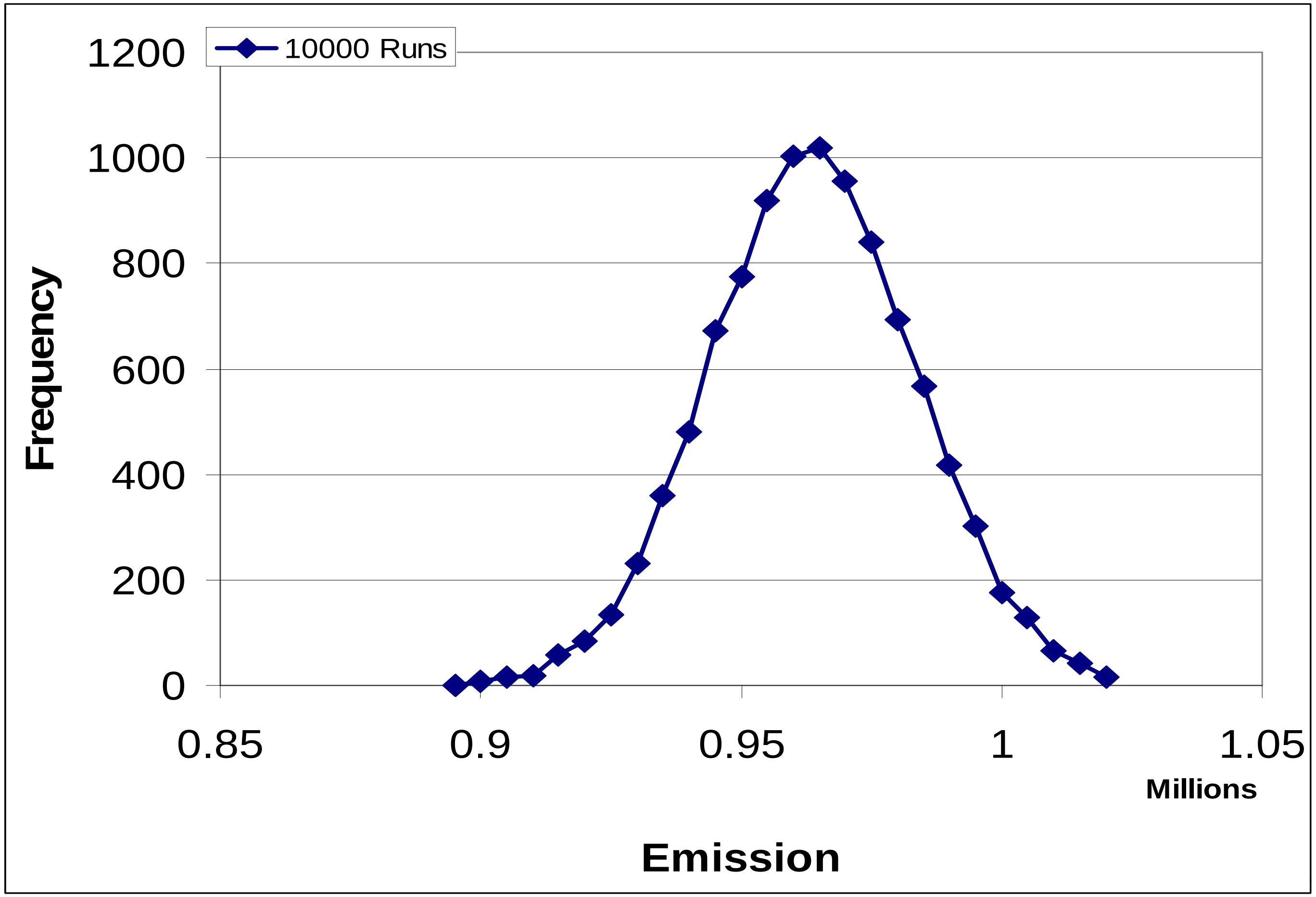
1 000


1000 Runs
Frequency
120
100
80
60
40
20
0
0.85
0.9
0.95
1
1.05
Millions
Emission

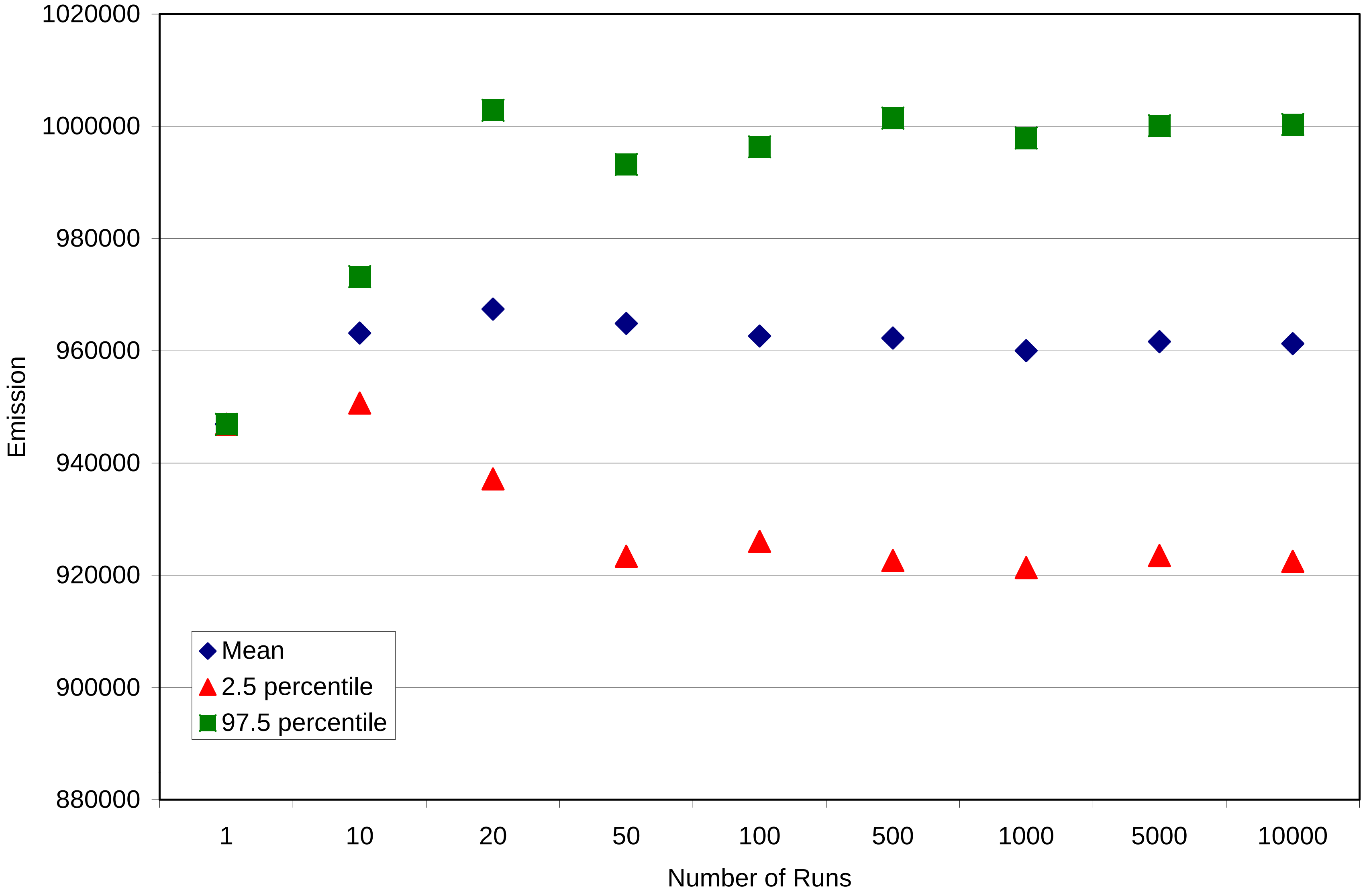
5 000


5000 Runs
Frequency
600
500
400
300
200
100
0
0.85
0.9
0.95
1
1.05
Millions
Emission

10 000


10000 Runs
1200
1000
800
600
400
200
0
Frequency
0.85
0.9
0.95
1
1.05
Millions
Emission

Summary Results



Summary

- Even simple uncertainty estimates give useful information
- Good QA/QC and careful consideration of methods can reduce uncertainty
- Assessment of uncertainty in the input parameters should be part of the standard data collection QA/QC
- There are two approaches to combining uncertainty - or a hybrid approach can be used
- For simple estimates
  - Uncertainty in activity data assesssed as data collected
  - Uncertainty in emission factors from guidelines
  - Aggregate categories to independent groups of sources/sinks
  - Use Approach 1 - spreadsheet requires little statistical knowledge

Thank-you

Any Questions?