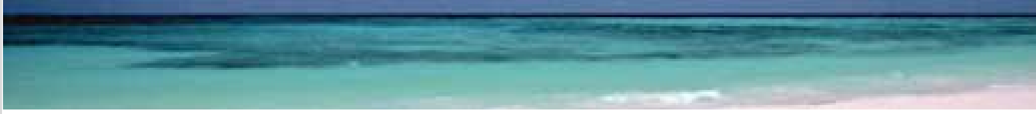

GGAS

Greenhouse Gas Benchmark Rule
(Generation) No.2 of 2003

Methane Energy Uncertainty Methodology

GUIDANCE DOCUMENT

Version 1.0, February 2009

Document Control

Version	***Date***	***Notes***
Version 1.0	18 February 2009	Methane Energy Uncertainty Methodology

Further Assistance

General assistance on the Methane Energy Uncertainty Methodology can be sought by contacting the Greenhouse Gas Scheme Administrator.

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Fax Number:	02 9290 2063
Street Address:	Level 8 1 Market Street SYDNEY NSW 2000
Postal Address:	Greenhouse Gas Reduction Scheme Administrator PO Box Q290 QVB POST OFFICE NSW 1230
Email Address:	mail@greenhousegas.nsw.gov.au

For specialist technical assistance, it may be necessary to engage a suitable consultant. The GGAS Audit and Technical Services Panel website provides a list of possible sources of assistance (www.greenhousegas.nsw.gov.au/audit/members.asp).

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1 BACKGROUND

This methodology, known as the Methane Energy Uncertainty Methodology (MEUM), has been developed by the Greenhouse Gas Reduction Scheme Administrator for Generators seeking to use the actual energy content of a waste methane gas for the purposes of Equations 13 (fugitive methane emissions avoided through the use of Waste Coal Mine Gas) and 16 (fugitive methane emissions avoided through the use of Landfill Gas and Sewage Gas) of the Greenhouse Gas Benchmark Rule (Generation Rule) No.2 of 2003.

The methodology provides Abatement Certificate Providers (ACPs) with a tool to determine the uncertainty associated with the measurement of actual energy content by using actual calibration data of the Methane Analyser over a Measurement Period to be nominated by the ACP, and approved by the Scheme Administrator.

1.1 How the Methodology works

At a minimum, three components are required to determine actual energy content. These comprise:

- a flow meter;
- a gas (methane) analyser; and
- a flow computer (the flow computer integrating volumetric flow over time).

Of these components it is the methane analyser which returns the largest source of error. This is due to the analyser's sensitivity to other hydrocarbons, temperature, pressure and moisture. Whilst the MEUM does consider the performance of the other components, the principle focus is the methane analyser. This is because landfill and sewage gas (and waste coal mine gas, to a lesser extent) is not a clean gas; rather it is a gas which has no consistent chemical composition, and one that can contain contaminants which can foul instrumentation. Accordingly, the analyser's performance requires a great deal of monitoring, and this is invariably achieved through site maintenance and testing regimes.

The MEUM utilises the results of methane analyser calibrations recorded on a weekly (or other agreed periodic) basis by maintenance staff of the ACP. The calibration results provide a snapshot of how the analyser is performing in reference to a NATA-certified test gas of known methane concentration.

In using the framework to determine the uncertainty, the ACP can calculate the number of NGACs which may be created from the accredited activity, adjusting the number of NGACs by the uncertainty determined.

That is, if the ACP determined the Measurement Period upper-limit uncertainty to be +3%, then the ACP would discount its NGAC creation by 3%. Similarly, if the upper-limit uncertainty was found to be -3% then the ACP would upwardly adjust its NGAC claim by 3%.

In the event of meter failure, or in the event of an unfavourable Measurement Period system performance, the ACP is entitled to create NGACs over that Measurement Period using the 36% default factor.

This framework supersedes any previous guidance from the Scheme Administrator regarding actual energy content determination.

2 INTRODUCTION

For the purposes of this document, the energy content of waste methane will be described as ‘Methane Energy’ and the uncertainties associated with the measurement of the energy content of waste methane will be described as ‘Methane Energy Uncertainty’ (“MEU”).

This document outlines the methodology to be used to determine the MEU based on:

- the specified instrument uncertainty using the manufacturer’s data sheets, and
- the deviation of the methane content reading from the calibration gas before recalibration.

The MEU, based on the deviation of the methane content reading from the calibration gas before recalibration, is required to ensure that the methane content analysis equipment is operating within the specified uncertainty of the manufacturer’s data sheets. The Scheme Administrator requires this additional uncertainty determination as a result of findings from Scheme audits, whereby the deviation of the methane content reading from the calibration gas has been observed to be much higher than expected (based on the manufacturer’s data sheets) at a number of sites.

2.1 International Consistency

The uncertainty assessment approach is based around the ISO Guide to the Expression of Uncertainty in Measurement, such that it is consistent with recognised standards and codes. The main source of information used to develop this document is the “*NMI Monograph 1: Uncertainty in Measurement, The ISO Guide, 11th Edition*”. The following includes an introduction to the key concepts of uncertainty related to the determination of Methane Energy Uncertainty and it is recommended that the full text be obtained if complete understanding is required.

3 UNCERTAINTY BASED ON THE EQUIPMENT SPECIFICATIONS

Metering required to determine the Methane Energy of a fuel typically consists of temperature, pressure, flow and methane content measurement instruments. The uncertainty of the methane energy content is determined from the uncertainties of the instruments measuring these variables, together with the uncertainty of the gas used to calibrate the methane analyser. The analysis of these uncertainties as they apply to this application, and the methodology used to determine the uncertainty of the methane energy from the measurement uncertainties, is as follows.

Uncertainty is defined in the ISO Guide as follows:

> *A parameter, associated with the result of a measurement, which characterises the dispersion of the values that could reasonably be attributed to the measurand*.

A measurement with its uncertainty is usually expressed in the following way:

Equation 1

$$T = T_m \pm U$$

Where,

- T is the true value of the parameter being measured,
- T_m is the measured value
- ± U is the uncertainty in T_m.

The uncertainty has confidence limits associated with it which is defined as the percentage of true values which would be within the uncertainty. With a confidence limit of 68% (the confidence limits of a standard uncertainty) there would be a 68% chance that the difference between the reading and the true value would be inside the uncertainty value. For an uncertainty with a confidence limit of 95% (the confidence limits of an expanded uncertainty) there would be a 95% chance that the difference between the reading and the true value would be inside the uncertainty value.

The setting of a confidence limit therefore affects the uncertainty value, in that the higher the confidence limit, the higher the uncertainty that the true value is within that confidence limit. For Gaussian distributions, an uncertainty value with a confidence limit of 95% is 1.96 times the corresponding uncertainty value with a confidence limit of 68%.

A 95% confidence limit has been selected for the determination of MEU. That is, there is a 95% confidence that the true value of T is within T_m + U and T_m – U.

In some cases there is an offset error where the true value of the parameter being measured, T, is equal to the measured value, T_m, plus an offset a.

For example, when measuring methane energy, the mean of a number of calibration readings could be thought of as the offset a and the uncertainty of those calibration results would be U.

Equation 2

$$T = T_m + a \pm U$$

In equation 2, the most conservative approach for calculating the Methane Energy Uncertainty value is to add the upper level of uncertainty ($a + U$). For the purposes for this document, the value of ($a + U$) will be referred to as the 'upper 95% Methane Energy Uncertainty' ("$\text{MEU}_{95\%\text{upper}}$").

The following provides detailed guidance for the steps used to obtain the Methane Energy Uncertainty.

3.1 Step 1: Develop a Model for the Determination of Methane Energy

The desired measurand (in this case Methane Energy) is determined from the measurements of a number of other parameters (input quantities). The first step is therefore to develop a model that expresses the dependence of the measurand (Methane Energy) on all input quantities. This can be done using a spreadsheet or using an appropriate program. It is important that complete dependence on all input quantities is expressed in the model.

As a first step in the development of a model, determine the sensitivity coefficient, c_i for each input quantity using Equation 3.

Equation 3

$$\text{Sensitivity coefficient,} \quad c_i = \frac{\text{resultant change in measurand}}{\text{Small change in input quantity}}$$

Sensitivity coefficients are not required for intermediate quantities that are calculated but not directly measured.

3.2 Step 2: Develop a realistic and thorough list of all errors

List all errors that affect each measurement. The list is developed by working through the measurement chain (or process) and itemising all contributions to the measurement of Methane Energy, including assumptions. All sources of error should be listed at this stage as it may be found that what was thought to be an insignificant error is found to be a highly significant one.

The eight main types of uncertainty are detailed below:

Calibrated Instruments

1) The calibration uncertainty. Note: A calibration uncertainty (even if derived from random uncertainty components) will become a systematic uncertainty, as the net effect will be a bias;
2) The uncertainty for the use of an instrument that differs from those applying during its calibration, including the effect of different ambient conditions. This includes drift (resulting in a bias or zero error), and change in characteristics following calibration. It also includes uncertainty due to a lack of representativeness of the measurement (e.g. for the temperature in a large duct);
3) Random or Type A uncertainty. The uncertainty in the mean of ‘n’ readings taken with the instrument, calculated to be $s / \sqrt{n}$, where ‘s’ is the standard deviation of the individual readings (which may have been determined on a previous occasion);
4) The resolution or rounding error of the instrument (already included in (3) for random uncertainties).

Errors arising from such factors as: transmitting and storage of data; noise; rounding error; and resolution error, can be characterised as having either a random and/or a systematic uncertainty.

Uncalibrated Instruments

In this case uncertainty types (1) to (4) would apply, however, as no calibration would have been done, a number of the errors are often combined and expressed in the manufacturer's specification data as the 'maximum accuracy', and are dependent upon the class or type of instrument.

Reference Values, Data and Constants

5) The uncertainty in all reference data and constants used in the calculation of the measurand is to be considered. Note: This should exclude data in which scientific uncertainty arises, either where the science is being developed (e.g. emission factors) or where the uncertainty is low (e.g. steam properties).

Data Fitting and Interpolation

6) If the measurement or calibration is performed over a range of values, uncertainties in a fitted curve, and interpolation to intermediate values, may apply.

Environmental Effects

7) Environmental effects (such as temperature, humidity and pressure) can have a significant source of error for certain measurements.

Assumptions

8) The errors due to assumptions or measurements also need to be considered

3.3 Step 3: Characterise all Error Components

This step is perhaps the most complex and time consuming. Three parameter values are required for each error:

U_i, Expanded uncertainty;

For a Gaussian distribution, the standard deviation, ± σ, equates to a 68 % confidence level.

U_i is described as the 'expanded uncertainty', as the confidence limits are 'expanded' from a 68% to a 95% confidence limit. The 'expanded uncertainty', U_i for each error, is related to the 'standard uncertainty', u_c as follows:

Equation 4

$$U_i = k\,u_c$$

Where

'i' is the i^{th} error component

Where k (known as the coverage factor), converts the 68 % confidence level to a 95 % confidence level, and also takes into account the accuracy of the data used to determine the estimate (for example the higher the number of samples or readings the lower the uncertainty).

k_i, Coverage Factor;

For a Gaussian distribution 68% of all data points lie within ± σ of the mean, and 95% of the data points lie within ± 1.96 σ. Therefore, assuming a Gaussian distribution, if σ is known (very accurately), we could use U = 1.96 σ.

However, we only know ‘s’, an estimate of the true standard deviation ‘σ’, calculated from a limited data set. The effect of uncertainty in s needs to be included in converting to a 95 % value.

The accuracy of the estimate of σ is taken into account through the calculation of the ‘number of effective degrees of freedom’, v_{eff}. Once the ‘number of effective degrees of freedom’ has been calculated, ‘k’ is determined using Student’s ‘t’ tables (of k versus number of degrees of freedom).

Alternatively the following Equation can be used, without significant loss of accuracy:

Equation 5

$$k_i = 1.96 + \frac{2.5}{V_{i\,eff}} + \frac{2.3}{V_{i\,eff}^{\;2}} + \frac{2.5}{V_{i\,eff}^{\;3}} + \frac{3.7}{V_{i\,eff}^{\;4}}$$

Where:

k_i Coverage factor
V_{ieff} Number of effective degrees of freedom (see Equation 13)
‘i’ is the i^{th} error component

V_i Degrees of Freedom;

In determining the standard deviation of each source of error, some are accurate representatives of the ‘true’ standard deviation and some are poor, being estimates. The ‘number of degrees of freedom’ is used to reflect the quality of the estimate for each error source in the final outcome of the calculation, the expanded uncertainty U, and is given the symbol v_i.

For random uncertainties, the degrees of freedom ‘vi’ is equal to (n – 1), where ‘n’ is the number of data points. The more information or data points that are available to be used, the better the estimate.

For systematic uncertainty, it is not as clear how to determine the degrees of freedom for each error source. The recommended values when other estimates are not available are v_i = 3 (rough), 10 (reasonable), 30 (good) and 100 (excellent).

For each identified error, sources of data need to be identified to be able to determine the three parameters identified above. This includes use of data obtained during a stable period (for random uncertainty components), manufacturer’s specifications and estimation from experience.

Manufacturer’s specification data can be used to estimate U_i, k_i and v_i. However, it needs to be used with some care, as the coverage probability is needed in conjunction with the uncertainty. Often this is not given. However, it can be assumed that the variability covers most of the full range of variability for the device, and that the coverage probability is 95% (ie it matches the coverage probability adopted for this application). If a different coverage probability is given, then the uncertainty (or specified tolerance) can be scaled using Student ‘t’ values.

Care also needs to be taken where it is known that in practice the actual uncertainty is higher than the manufacturer’s specified tolerance. The difference between the actual uncertainty and the manufacturer’s tolerance may be due to a number of reasons including:

- The local environment for instrumentation location,
- Failure to meet the manufacturer’s recommended calibration and maintenance schedules, or

- the age and condition of the equipment.

A decision should be made as to whether each error is a random or a systematic uncertainty, as this will impact on how the above three values are determined for each error.

3.3.1 Random or Type A Components

For random or Type A error components, taking a number of measurements for each Measurement Period reduces the error.

The average of a number of readings is more reliable in determining the mean value of a measurement than any one individual reading. Specifically, there is a reduction in the distribution of the averaged measured quantity (about the mean) for batches of data points. That is, the larger the numbers of data points per batch, the tighter the distribution and the more likely any one mean, x, will be closer to the 'true' mean μ. Or in other words, the standard deviation of the mean is smaller than the standard deviation of the raw data.

The term ESDM (experimental standard deviation of the mean) is used in consideration of the above, and is related to the standard deviation of the raw data, s, as follows:

Equation 6

$$\mathrm{ESDM} = u = \frac{s}{\sqrt{n}}$$

Where,

ESDM	Experimental standard deviation of the mean
n	Number of readings
s	Standard deviation
u	Standard uncertainty

This principle is of considerable importance in the determination of the uncertainty of the Methane Energy, or any measurement used to determine Methane Energy, as the more measurements that are taken, the lower the uncertainty of random error components. Hence, by taking multiple measurements of values which have a random error component, the random uncertainty in determining the Methane Energy is reduced.

It should be noted that if a systematic uncertainty has a constant bias, taking more readings will not reduce that bias.

Care needs to be taken to exclude process variation from the random variation (where the standard deviation 's' is determined from either the current set of data or an earlier set, and "n" is the number of measurements taken for the Measurement Period), otherwise an overestimate of uncertainty may result.

For random or Type A components, the degrees of freedom v_i, for each error is given by n – 1.

3.3.2 Systematic or Type B Error Components

An error is classified as a systematic error if it is a bias and does not differ with each repeated measurement. A systematic error may drift with time but remains constant in the short term.

Unlike random errors which produce a scatter in the measurement data, the systematic error is a bias or offset which gives no indication of its presence or magnitude, based on the measurements taken. The only method of determining a bias is to compare the measurement with one taken by an instrument with a known uncertainty.

For systematic uncertainty, it is not as clear how to determine the degrees of freedom. The recommended values when other estimates are not available are v_i = 3 (rough), 10 (reasonable), 30 (good) and 100 (excellent).

The choice of coverage factor, k_i, for systematic components is fairly complex. Some general guidance is provided below:

- For reasonable reliable estimates (to ± 20% or $v_i > 10$), the coverage factor, k_i, should be chosen, depending upon the assumed distribution type, as follows: 2.00 for Gaussian, 1.73 for rectangular distribution;
- For less reliable estimates, use a coverage factor, k_i, of 3, for all distribution types.

3.3.3 Calibration Uncertainty

The use of calibration is an important approach for simplifying and reducing uncertainty values. Calibration is the measurement or adjustment of the systematic error of an instrument. Random errors, due to their nature, cannot be adjusted.

If instruments are calibrated, the calibration error would need to be determined by conducting an error analysis (ie identifying error causes, characterising the error components and determining the overall calibration uncertainty).

Care should be taken as the uncertainty following calibration may increase due to instrument drift. Therefore some account of the elapsed time from the calibration to the Measurement Period may need to be included in the uncertainty assessment.

The results of calibration history can be used to estimate this uncertainty component. Some components of the uncertainty may still need to be included in the uncertainty determination, and not excluded as a result of the ‘calibration’.

An example of the use of calibration results to determine Methane Uncertainty in practice is provided in Section 4.

3.3.4 Correlated Errors

Some errors may be correlated in their effect on the measurand. In other words, the errors are related in some way and are not completely independent. The effect of correlated errors should be considered, and an appropriate approach developed for each.

Handling of correlated errors is complex, and reference should be made to the GUM.

3.4 Step 4 Determine the Uncertainty of the Components

The standard uncertainty for each error, $u(x_i)$ is then calculated as follows:

Equation 7

$$u(x_i) = \frac{U_i}{k_i}$$

Where

$u(x_i)$ Standard uncertainty for each error source

U_i Expanded uncertainty for each error source

k_i Coverage factor for each error source

U_i and k_i are obtained from Step 3.

The uncertainties of the components are converted to standard uncertainty to ensure the confidence levels of the uncertainty components are at the same level, 68%.

The corresponding uncertainty in the measurand (for each error) is calculated using the sensitivity coefficients, c_i (calculated in Step 1) and the standard uncertainty, $u(x_i)$ (calculated above), as follows:

Equation 8

$$\text{Uncertainty in the measurand } = |c_i| u(x_i)$$

Where 'i' is the ith error component.

Note that there will normally be more components of uncertainty than there are input quantities. The sensitivity component will be the same for each error component for a given input quantity, and the value of the standard uncertainty, $u(x_i)$ will vary for each error component.

Note also the importance of ensuring that the correct units are used for c_i and $u(x_i)$, such that the correct units are achieved for the 'uncertainty in the measurand' for all error sources.

3.5 Step 5 Determine the Combined Standard Uncertainty

All values of standard uncertainty, $u(x_i)$ calculated in Step 4 are combined to obtain the combined standard uncertainty, u_c for the measurand.

Equation 9

$$u_c^2 = \sum_{i=1}^{N} |c_i u(x_i)|^2$$

or:

Equation 10

$$u_c = \sqrt{\sum_{i=1}^{N} |c_i u(x_i)|^2}$$

Where

c_i Sensitivity coefficient for each error source

u_c Combined standard uncertainty

$u(x_i)$ Standard uncertainty for each error source

Extra terms are required in Equation 9 if the error sources are correlated.

3.6 Step 6 Determine the Expanded Uncertainty

The expanded uncertainty, U, that relates to the measurand (in this case methane energy) is calculated from

Equation 11

$$\mathrm{U} = \mathrm{k}\, u_c$$

Where

k Coverage factor from equation 12 below

u_c Combined standard uncertainty from equation 10 above

U Expanded uncertainty

The coverage factor, k, associated with the expanded uncertainty of the measurand, U, is required. This is calculated using either Student ‘t’ tables or using Equation 12.

Equation 12

$$\mathrm{k} = 1.96 + \frac{2.5}{\mathrm{v}_{\mathrm{eff}}} + \frac{2.3}{\mathrm{v}_{\mathrm{eff}}^{2}} + \frac{2.5}{\mathrm{v}_{\mathrm{eff}}^{3}} + \frac{3.7}{\mathrm{v}_{\mathrm{eff}}^{4}}$$

Where :

k Coverage factor

$\mathrm{v}_{\mathrm{eff}}$ Number of effective degrees of freedom from equation 13

Both approaches require the ‘effective number of degrees of freedom’, $\mathrm{v}_{\mathrm{eff}}$ calculated using the ‘degrees of freedom’, vi for each error using Equation 13.

Equation 13

$$\mathrm{v}_{\mathrm{eff}} = \frac{u_c^4}{\sum_{i=1}^{N} \frac{\left|\mathrm{c}_i \mathrm{u}(\mathrm{x}_i)\right|^4}{v_i}}$$

Where

c_i Sensitivity coefficient for each error source

u_c Combined standard uncertainty

$\mathrm{u}(\mathrm{x}_i)$ Standard uncertainty for each error source

$\mathrm{v}_{\mathrm{eff}}$ Number of effective degrees of freedom for u_c

v_i Number of degrees of freedom for each error source

4 METHANE ENERGY UNCERTAINTY BASED ON THE READING ERRORS BEFORE CALIBRATION

The following is an example of the methodology used in determining the Methane Energy Uncertainty of the direct gas Metering Systems **based on the values of the methane content reading errors before calibration**.

An NGAC creation period of one month with one reading every seven days has been used in this example. Longer or shorter NGAC creation periods, and different timing between readings may be used depending on the requirements of the ACP and the level of uncertainty.

This example is based on the following reading error data set (against a calibration gas of approximately 50.4% ±0.2% methane). It should be noted that for April there is only one reading (to demonstrate its impact on a monthly uncertainty calculation).

- **Table 4.1 Calibration reading error data set**

Period ID	Calibration date	Initial reading	Test Gas	Reading error	Reading error as a percent of test gas
1	8 January 2008	51.0%	50.4%	0.6%	1.2%
1	15 January 2008	50.4%	50.4%	0.0%	0.0%
1	22 January 2008	50.7%	50.4%	0.3%	0.6%
1	29 January 2008	52.2%	50.4%	1.8%	3.6%
2	5 February 2008	50.2%	50.4%	-0.2%	-0.4%
2	12 February 2008	51.1%	50.5%	0.6%	1.2%
2	19 February 2008	50.6%	50.5%	0.1%	0.2%
2	26 February 2008	51.1%	50.5%	0.6%	1.2%
3	4 March 2008	49.6%	50.1%	-0.5%	-1.0%
3	11 March 2008	49.7%	50.1%	-0.4%	-0.8%
3	18 March 2008	50.2%	50.1%	0.1%	0.2%
3	25 March 2008	50.6%	50.1%	0.5%	1.0%
4	22 April 2008	49.6%	50.1%	-0.5%	-1.0%
5	6 May 2008	49.6%	50.1%	-0.5%	-1.0%
5	13 May 2008	49.7%	50.1%	-0.4%	-0.8%
5	20 May 2008	50.5%	50.1%	0.4%	0.8%
5	27 May 2008	49.6%	50.1%	-0.5%	-1.0%
6	3 June 2008	50.4%	50.1%	0.3%	0.6%
6	10 June 2008	49.6%	50.1%	-0.5%	-1.0%
6	17 June 2008	49.7%	50.1%	-0.4%	-0.8%
6	24 June 2008	48.5%	50.1%	-1.6%	-3.2%
7	1 July 2008	51.5%	50.1%	1.4%	2.8%
7	8 July 2008	47.2%	50.1%	-2.9%	-5.8%
7	15 July 2008	51.5%	50.1%	1.4%	2.8%

A conservative approach has been used in estimating the uncertainty of the methane content of the gas for the NGAC creation period of one month. This approach assumes that the error in the methane content determined before calibration is applied for the total period since last calibration, and that the error is a systematic or type “B” error. This conservative approach has been used due to the small data set and the unknown nature of the errors in the methane content between calibrations.

The following outlines the methodology used to determine of the energy value uncertainty for a NGAC creation period of one month.

4.1 Standard deviation of errors in the period

The standard deviation of the errors recorded over the NGAC creation period is given by the following:

Equation 14

$$\sqrt{\frac{\sum(x-\bar{x})^2}{(n-1)}}$$

The standard deviation cannot be determined from one reading i.e. if $n=1$

The data set for January is given in Table 4.2. This data set has an average value, $\bar{x}$ of 1.35% and a standard deviation, s, of 1.58% (based on a rounded number).

- **Table 4.2 Calibration reading error data set for period 1**

Calibration date	Initial reading	Test Gas	Reading error	Reading error as a percent of test gas (rounded)	$(x-\bar{x})^2$
8 January 2008	51.0%	50.4%	0.6%	1.2%	0.0002%
15 January 2008	50.4%	50.4%	0.0%	0.0%	0.0182%
22 January 2008	50.7%	50.4%	0.3%	0.6%	0.0056%
29 January 2008	52.2%	50.4%	1.8%	3.6%	0.0506%

The standard uncertainty of the average methane content for a month is less than the standard deviation of the reading, due to the random nature of the errors. The following relationship is therefore used to determine the uncertainty of the methane energy for the period.

Equation 15

$$\frac{u}{\sqrt{n}}$$

Where

u = the standard uncertainty of each reading for the month, 1.58%

n = the number of readings in the determination of the value for the month, 4

Uncertainty of the value for the period of the month of January 2008 is therefore:

$$\frac{1.58\%}{\sqrt{4}} = 0.79\%$$

To determine the uncertainty of the monthly energy value, the gas flow, pressure measurement and temperature measurement uncertainties need to be combined with the methane uncertainty as follows. These values are the same as has been used in section 3 above.

4.2 Flow meter uncertainty

For this example the flow meter has an uncertainty of 0.5% of the flow rate. This uncertainty is taken to be a systematic or type “B” uncertainty (which does not reduced if the value is made up of a large number of readings). Assumed to have a confidence limit of 95%.

4.3 Pressure measurement uncertainty

For this example the pressure measurement is in kPa absolute and has an uncertainty of 0.024% for the base error and 0.105% for the temperature error.

This uncertainty is taken to be a systematic or type “B” uncertainty (which does not reduce if the value is made up of a large number of readings) resulting in a combined uncertainty of 0.13%.

4.4 Temperature measurement

For this example the temperature measurement has an uncertainty 0.39%. This uncertainty is taken to be a systematic or type “B” uncertainty (which does not reduced if the value is made up of a large number of readings). Assumed to have a confidence limit of 95%.

4.5 Calibration gas uncertainty

The uncertainty of the calibration used for this application gas is typically 0.2% with a confidence limit of 95%.

4.6 Energy calculation

The calculation of the energy in the gas is determined based on the relationship given in Equation 16. The actual equation can vary from site to site depending on the direct measurement equipment arrangement.

Equation 16

$$Energy = Q \times \left[\frac{273.15}{T + 273.15} \times \frac{P}{101.325} \right] \times Vol\% \times E$$

Where

Q The gas flow as determined by the flow meter

T The gas temperature as determine by the temperature sensor

P The gas Pressure as determine by the pressure sensor

$Vol\%$ The percentage of methane in the gas as determined by the methane analyser

E The heating value of Methane

At 273.15 K and 101.325 kPa absolute the “National Greenhouse Accounts (NGA) Factors” document from the Department of Climate Change, January 2007, gives the heating value of Methane of 39.3 MJ/m^3.

The sensitivity coefficient for each of the uncertainties is given in Table 4.3 below (based on Equation 16). The initial methane energy before the 1% change is 18,992 GJ.

- **Table 4.3 Sensitivity coefficients**

	Units	Initial Value	Value after 1% Change	Methane energy after change, GJ	Percentage change %energy /%unit c_i
Temperature, T	ºC	21.0	21.21	18,979	0.071
Pressure, P	kPa Absolute	114.80	115.95	19,182	1.000
Flow, Q	m^3	1,000,000	1,010,000	19,182	1.000
Calibration gas, Vol%	% by volume	50.40	54.035	19,182	1.000
Methane content, Vol%	% by volume	50.40	54.035	19,182	1.000
Heating value of methane, E	MJ/m^3	35.81	36.166	19,182	1.000

The spreadsheet associated with this document calculates the sensitivity coefficient for the methane content separate from the other uncertainty components to simplify the amount of information on one sheet. The sensitivity coefficient for the methane content is calculated on the “Period uncertainty” sheet and the other uncertainty components are calculated on the “Flow Uncertainty” sheet, in combination with the uncertainty calculation

4.7 Energy Uncertainty

The measurement uncertainties are given in Table 4.4 together with the coverage factor and degrees of freedom.

The uncertainty of the methane analyser error has a coverage factor of 1, as it is a standard uncertainty with a confidence limit of 68%, whereas the other uncertainty components in Table 4.4 have confidence limits of 95% and therefore a coverage factor of 2. This difference in the confidence limits is due to the uncertainty of the methane analyser being determined from the standard deviation of the errors, whereas the other uncertainty components are derived from manufacture's specifications.

- **Table 4.4 Uncertainty of the measurements associated with the determination of methane energy**

	Uncertainty Ui	Coverage Factor ki	Degrees of freedom v_i
Temperature, T	0.39%	2	100
Pressure, P	0.13%	2	100
Flow, Q	0.50%	2	100
Calibration gas, Vol%	0.20%	2	100
Methane analyser error, Vol%	0.79%	1	3
Heating value of methane, E	0.00%	2	100

The degrees of freedom, v_i of the methane analyser error is 3 for a set of 4 readings $(n-1)$. With the estimation of the uncertainty of the other components being determined as 'excellent', the degrees of freedom of these components are taken to be 100.

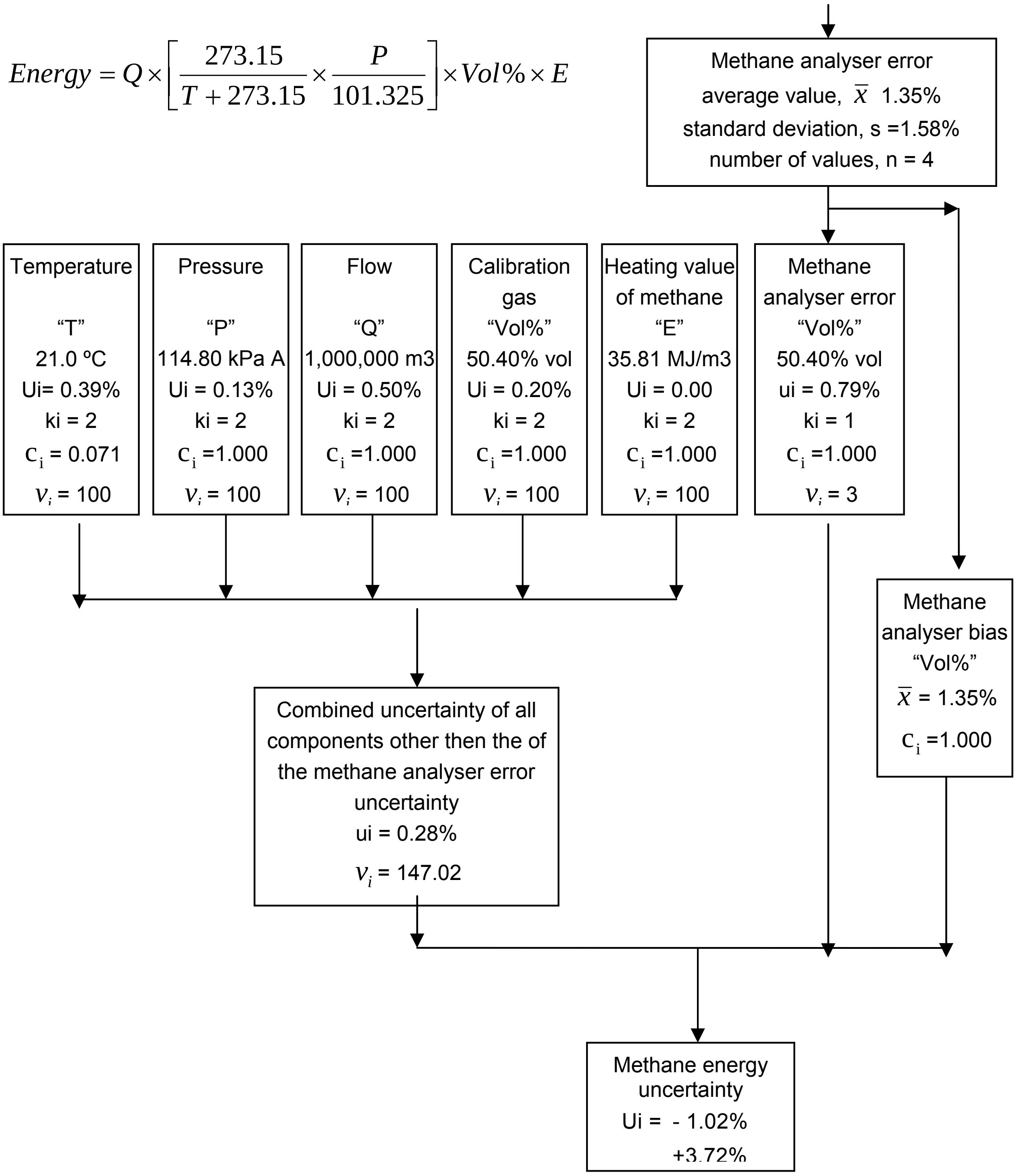
The MEU is calculated from this information in two parts. First is the combined uncertainty of all components other than the methane analyser error uncertainty. Secondly, the combined uncertainty is then used with the methane analyser error uncertainty to determine the MEU. The methane energy is calculated in this way due to the uncertainty of components (other than the methane analyser error uncertainty) remaining constant, whereas the methane analyser error uncertainty can change from period to period.

The methodology used for the calculation of the uncertainty of the energy value is given in Figure 1 (overleaf) for the month of January 2008. This uncertainty calculation is based on the methods and principles given in "National Measurement Institute Monograph 1: Uncertainty in Measurement, The ISO Guide, 11th Edition"

Figure 1 Uncertainty calculation flowchart

Calibration date	Reading error as a percent of test gas
8 January 2008	1.2%
15 January 2008	0.0%
22 January 2008	0.6%
29 January 2008	3.6%

$$Energy = Q \times \left[\frac{273.15}{T + 273.15} \times \frac{P}{101.325} \right] \times Vol\% \times E$$



As the average methane content error reading is 1.35% and the methane content sensitivity is 1 there is a bias for the methane energy of 1.35%. This bias results in the MEU being +3.72% and -1.02%.

The Period upper limit 95% Methane Energy Uncertainty, $MEU_{95\%upper,}$ is therefore 3.72%.

5 SPREADSHEET USER GUIDE

This section provides guidance on the use of the spreadsheet "*Methane Measurement Uncertainty Framework Version 7.xls*" associated with this document.

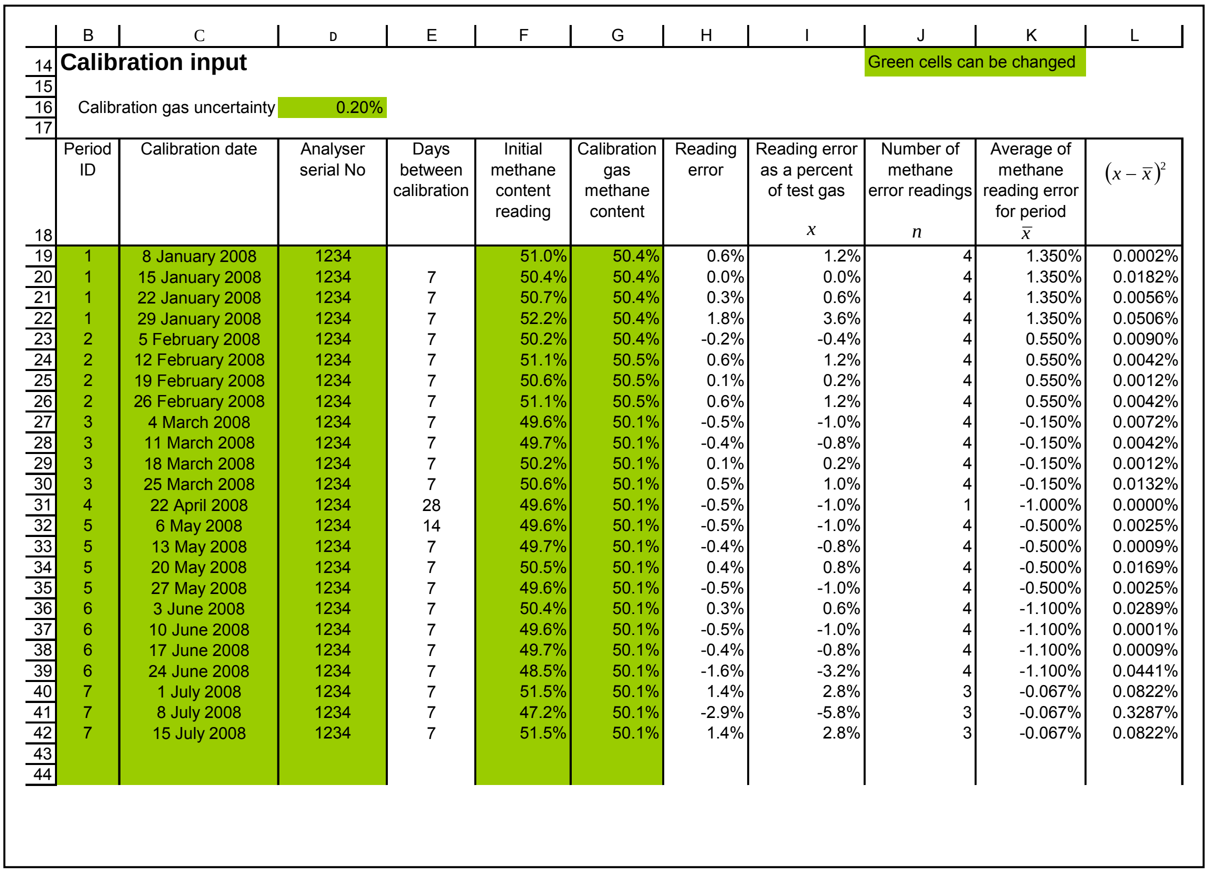
5.1 Calibration data entry sheet

The data on the methane reading errors observed before the instrument is calibrated are entered on the "Calibration input" sheet, as shown in Figure 2. This sheet has a period identifier, "Period ID", located in column "B" which is used to group the data into the NGAC creation periods on the "Period uncertainty" sheet. The "Period ID" needs to match the "Period ID" on the "Period uncertainty" sheet.

The 'calibration date' entered in column "C", the 'Analyser serial No' in column "D" and the 'Days between calibrations' in column "E" are provided for reference and are not used in any other calculation.

The uncertainty of the calibration gas used to calibrate the methane analyser is entered in the cell at row 16, column "D". The uncertainty for this gas is typically 0.20%. The "Initial reading" is entered in column "F" and the "Test Gas" in column "G". This information is used to calculate the error in the methane reading, and the standard deviation for the period, via columns "H" to "L".

- **Figure 2 Methane analyser calibration data entry.**



	B	C	D	E	F	G	H	I	J	K	L
14	**Calibration input**								Green cells can be changed		
15											
16	Calibration gas uncertainty		0.20%								
17											
18	Period ID	Calibration date	Analyser serial No	Days between calibration	Initial methane content reading	Calibration gas methane content	Reading error	Reading error as a percent of test gas x	Number of methane error readings n	Average of methane reading error for period $\overline{x}$	$(x-\overline{x})^2$
19	1	8 January 2008	1234		51.0%	50.4%	0.6%	1.2%	4	1.350%	0.0002%
20	1	15 January 2008	1234	7	50.4%	50.4%	0.0%	0.0%	4	1.350%	0.0182%
21	1	22 January 2008	1234	7	50.7%	50.4%	0.3%	0.6%	4	1.350%	0.0056%
22	1	29 January 2008	1234	7	52.2%	50.4%	1.8%	3.6%	4	1.350%	0.0506%
23	2	5 February 2008	1234	7	50.2%	50.4%	-0.2%	-0.4%	4	0.550%	0.0090%
24	2	12 February 2008	1234	7	51.1%	50.5%	0.6%	1.2%	4	0.550%	0.0042%
25	2	19 February 2008	1234	7	50.6%	50.5%	0.1%	0.2%	4	0.550%	0.0012%
26	2	26 February 2008	1234	7	51.1%	50.5%	0.6%	1.2%	4	0.550%	0.0042%
27	3	4 March 2008	1234	7	49.6%	50.1%	-0.5%	-1.0%	4	-0.150%	0.0072%
28	3	11 March 2008	1234	7	49.7%	50.1%	-0.4%	-0.8%	4	-0.150%	0.0042%
29	3	18 March 2008	1234	7	50.2%	50.1%	0.1%	0.2%	4	-0.150%	0.0012%
30	3	25 March 2008	1234	7	50.6%	50.1%	0.5%	1.0%	4	-0.150%	0.0132%
31	4	22 April 2008	1234	28	49.6%	50.1%	-0.5%	-1.0%	1	-1.000%	0.0000%
32	5	6 May 2008	1234	14	49.6%	50.1%	-0.5%	-1.0%	4	-0.500%	0.0025%
33	5	13 May 2008	1234	7	49.7%	50.1%	-0.4%	-0.8%	4	-0.500%	0.0009%
34	5	20 May 2008	1234	7	50.5%	50.1%	0.4%	0.8%	4	-0.500%	0.0169%
35	5	27 May 2008	1234	7	49.6%	50.1%	-0.5%	-1.0%	4	-0.500%	0.0025%
36	6	3 June 2008	1234	7	50.4%	50.1%	0.3%	0.6%	4	-1.100%	0.0289%
37	6	10 June 2008	1234	7	49.6%	50.1%	-0.5%	-1.0%	4	-1.100%	0.0001%
38	6	17 June 2008	1234	7	49.7%	50.1%	-0.4%	-0.8%	4	-1.100%	0.0009%
39	6	24 June 2008	1234	7	48.5%	50.1%	-1.6%	-3.2%	4	-1.100%	0.0441%
40	7	1 July 2008	1234	7	51.5%	50.1%	1.4%	2.8%	3	-0.067%	0.0822%
41	7	8 July 2008	1234	7	47.2%	50.1%	-2.9%	-5.8%	3	-0.067%	0.3287%
42	7	15 July 2008	1234	7	51.5%	50.1%	1.4%	2.8%	3	-0.067%	0.0822%
43											
44											

5.2 Other Uncertainties sheet

The “Other uncertainties sheet” shown in Table 4.4 calculates the uncertainty in the measurement of the methane energy content excluding the uncertainty associated with the methane analyser. The MEU is calculated in this way due to the uncertainty of all components (other than the methane analyser error uncertainty) remaining constant, whereas the methane analyser error uncertainty can change from period to period. This separation simplifies the calculation procedure on the spreadsheet.

The uncertainty components are entered in column “B” in rows 23 to 38 inclusive. The units of the value of the measurement associated with the uncertainty component are entered in the adjacent column “C”. The information entered in both these columns is for reference only, and are not used in the calculation of the methane energy uncertainty.

The typical value of the measurement associated with the uncertainty component is entered in column “D”. These values are used in column “E” (together with the methane energy equation), to determine the initial methane energy. The methane energy equation used in this spreadsheet applies to a particular arrangement of the measurement equipment and may need to be revised for other equipment arrangements.

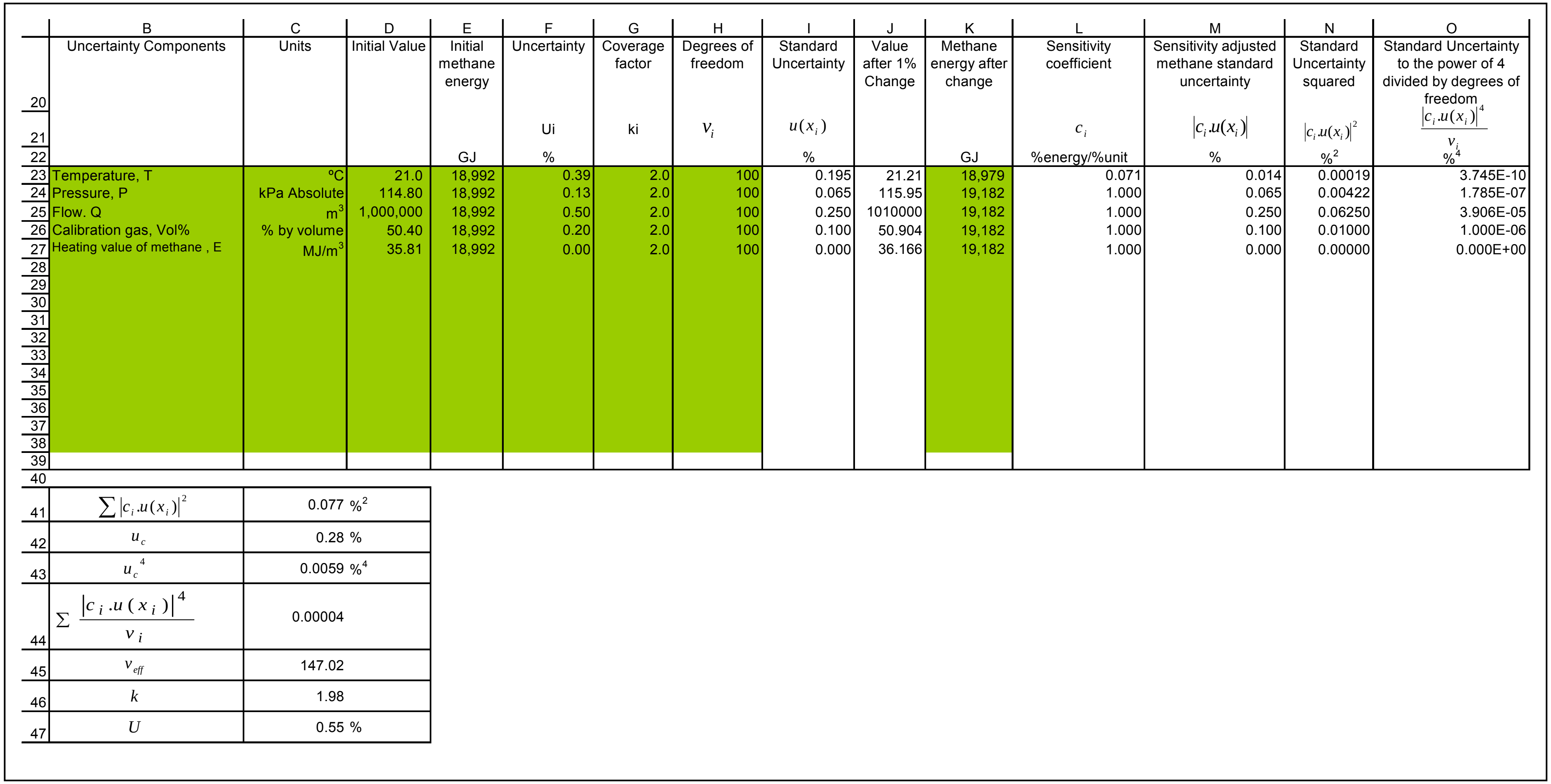
The uncertainty, coverage factor and degrees of freedom are entered in rows “F”, “G” and “H” respectively for each uncertainty component. The uncertainty and coverage factor are used to calculate the standard uncertainty in column “I”.

The typical value of the measurement associated with the uncertainty component in column “D” is increased by 1% in column “J” and the resultant methane energy value based on this 1% change is calculated in column “K” using the methane energy equation. The change in the methane energy, due to a change in the measurement associated with the uncertainty component, is the sensitivity coefficient of that component and is given in column “L”.

The sensitivity adjusted methane standard uncertainty; the standard uncertainty squared; and the standard uncertainty to the power of 4 divided by degrees of freedom, are calculated in columns “M”, “N” and “O” respectively. The information in these three columns are used in column “C” rows 41 to 47 to calculate the uncertainty in the measurement of the methane energy content (excluding the uncertainty associated with the methane analyser) and the degrees of freedom.

The sheet “Period uncertainty” uses these values to calculate the uncertainty of the methane energy.

- **Figure 3 Uncertainty components not associated with the methane analyser**



	B	C	D	E	F	G	H	I	J	K	L	M	N	O
20	Uncertainty Components	Units	Initial Value	Initial methane energy	Uncertainty	Coverage factor	Degrees of freedom	Standard Uncertainty	Value after 1% Change	Methane energy after change	Sensitivity coefficient	Sensitivity adjusted methane standard uncertainty	Standard Uncertainty squared	Standard Uncertainty to the power of 4 divided by degrees of freedom
21					Ui	ki	v_i	$u(x_i)$			c_i	$\lvert c_i.u(x_i)\rvert$	$\lvert c_i.u(x_i)\rvert^2$	$\frac{\lvert c_i.u(x_i)\rvert^4}{v_i}$
22				GJ	%			%		GJ	%energy/%unit	%	$\%^2$	$\%^4$
23	Temperature, T	ºC	21.0	18,992	0.39	2.0	100	0.195	21.21	18,979	0.071	0.014	0.00019	3.745E-10
24	Pressure, P	kPa Absolute	114.80	18,992	0.13	2.0	100	0.065	115.95	19,182	1.000	0.065	0.00422	1.785E-07
25	Flow. Q	m^3	1,000,000	18,992	0.50	2.0	100	0.250	1010000	19,182	1.000	0.250	0.06250	3.906E-05
26	Calibration gas, Vol%	% by volume	50.40	18,992	0.20	2.0	100	0.100	50.904	19,182	1.000	0.100	0.01000	1.000E-06
27	Heating value of methane , E	MJ/m^3	35.81	18,992	0.00	2.0	100	0.000	36.166	19,182	1.000	0.000	0.00000	0.000E+00
28														
29														
30														
31														
32														
33														
34														
35														
36														
37														
38														
39														
40														

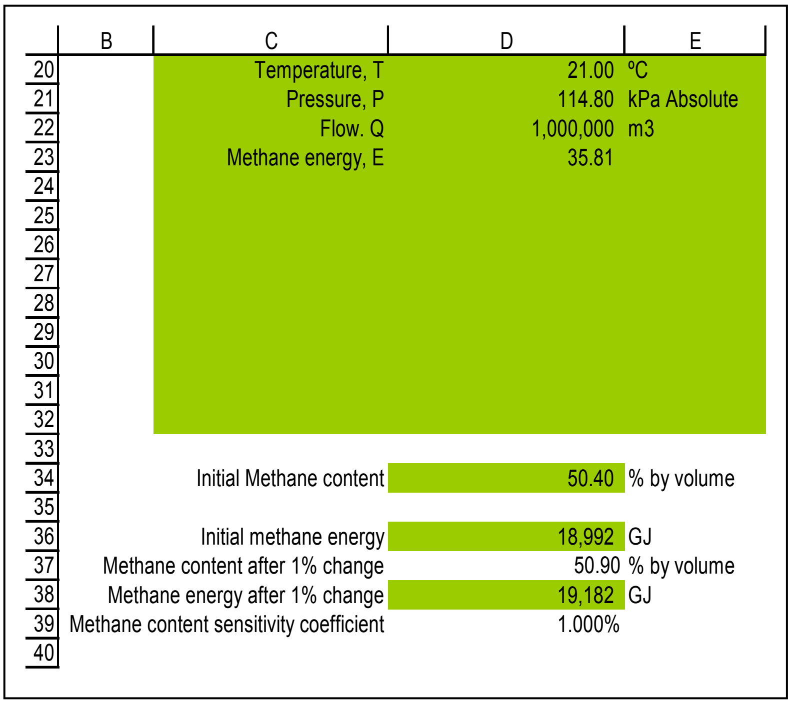
41	$\sum \lvert c_i.u(x_i)\rvert^2$	0.077 $\%^2$
42	u_c	0.28 %
43	$u_c{}^4$	0.0059 $\%^4$
44	$\sum \frac{\lvert c_i.u(x_i)\rvert^4}{v_i}$	0.00004
45	v_{eff}	147.02
46	k	1.98
47	U	0.55 %

5.3 Period Uncertainty sheet

The “Period uncertainty” sheet is used to calculate the Period Methane Energy uncertainty based on the data on the “Calibration input” and the “Other Uncertainties” sheets.

There are two parts to the sheet. The first part, rows 20 to 39, calculates the methane content sensitivity coefficient as shown in Figure 4. The second part of the sheet, rows 45 to 70, calculates the methane energy uncertainty for each NGAC creation period as shown below in Figure 5.

- **Figure 4 Part of the “Period uncertainty” sheet calculating the methane content sensitivity coefficient.**



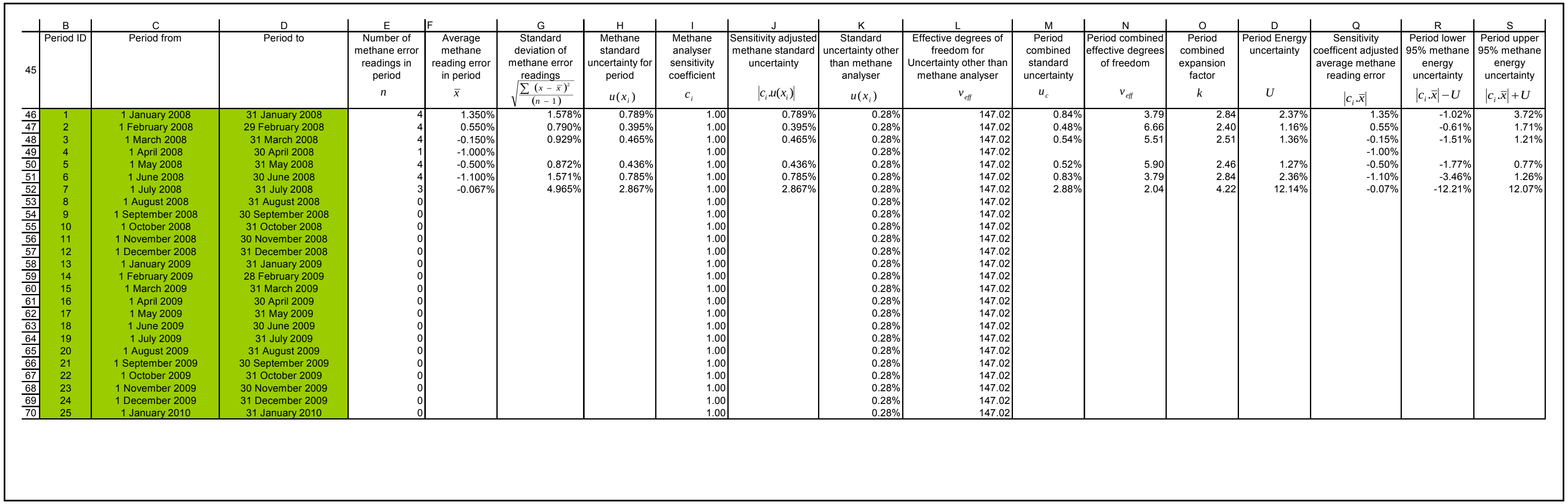
	B	C	D	E
20		Temperature, T	21.00	ºC
21		Pressure, P	114.80	kPa Absolute
22		Flow. Q	1,000,000	m3
23		Methane energy, E	35.81	
24				
25				
26				
27				
28				
29				
30				
31				
32				
33				
34		Initial Methane content	50.40	% by volume
35				
36		Initial methane energy	18,992	GJ
37		Methane content after 1% change	50.90	% by volume
38		Methane energy after 1% change	19,182	GJ
39	Methane content sensitivity coefficient		1.000%	
40				

The typical values of the measurements associated with determination of the methane energy are entered in column “D” rows 20 to 32 except for the methane content which is entered in row 34. The initial methane content is calculated from these values in row 36.

The methane content is increased by 1% in row 37 and the resultant methane energy value based on this 1% change is calculated in row 38. The change in the methane energy due to a change in the measurement associated with the methane content is the sensitivity coefficient of methane content and is given in row 39. This sensitivity coefficient is used in the second part of this sheet.

The second part of the sheet is shown in the Figure 5 overleaf.

- **Figure 5 Part of the “Period uncertainty” sheet calculating the methane energy uncertainty for each NGAC creation period**



	B	C	D	E	F	G	H	I	J	K	L	M	N	O	D	Q	R	S
45	Period ID	Period from	Period to	Number of methane error readings in period n	Average methane reading error in period $\bar{x}$	Standard deviation of methane error readings $\sqrt{\frac{\sum (x-\bar{x})^2}{(n-1)}}$	Methane standard uncertainty for period $u(x_i)$	Methane analyser sensitivity coefficient c_i	Sensitivity adjusted methane standard uncertainty $\lvert c_i.u(x_i)\rvert$	Standard uncertainty other than methane analyser $u(x_i)$	Effective degrees of freedom for Uncertainty other than methane analyser v_{eff}	Period combined standard uncertainty u_c	Period combined effective degrees of freedom v_{eff}	Period combined expansion factor k	Period Energy uncertainty U	Sensitivity coefficent adjusted average methane reading error $\lvert c_i.\bar{x}\rvert$	Period lower 95% methane energy uncertainty $\lvert c_i.\bar{x}\rvert - U$	Period upper 95% methane energy uncertainty $\lvert c_i.\bar{x}\rvert + U$
46	1	1 January 2008	31 January 2008	4	1.350%	1.578%	0.789%	1.00	0.789%	0.28%	147.02	0.84%	3.79	2.84	2.37%	1.35%	-1.02%	3.72%
47	2	1 February 2008	29 February 2008	4	0.550%	0.790%	0.395%	1.00	0.395%	0.28%	147.02	0.48%	6.66	2.40	1.16%	0.55%	-0.61%	1.71%
48	3	1 March 2008	31 March 2008	4	-0.150%	0.929%	0.465%	1.00	0.465%	0.28%	147.02	0.54%	5.51	2.51	1.36%	-0.15%	-1.51%	1.21%
49	4	1 April 2008	30 April 2008	1	-1.000%			1.00		0.28%	147.02					-1.00%		
50	5	1 May 2008	31 May 2008	4	-0.500%	0.872%	0.436%	1.00	0.436%	0.28%	147.02	0.52%	5.90	2.46	1.27%	-0.50%	-1.77%	0.77%
51	6	1 June 2008	30 June 2008	4	-1.100%	1.571%	0.785%	1.00	0.785%	0.28%	147.02	0.83%	3.79	2.84	2.36%	-1.10%	-3.46%	1.26%
52	7	1 July 2008	31 July 2008	3	-0.067%	4.965%	2.867%	1.00	2.867%	0.28%	147.02	2.88%	2.04	4.22	12.14%	-0.07%	-12.21%	12.07%
53	8	1 August 2008	31 August 2008	0				1.00		0.28%	147.02							
54	9	1 September 2008	30 September 2008	0				1.00		0.28%	147.02							
55	10	1 October 2008	31 October 2008	0				1.00		0.28%	147.02							
56	11	1 November 2008	30 November 2008	0				1.00		0.28%	147.02							
57	12	1 December 2008	31 December 2008	0				1.00		0.28%	147.02							
58	13	1 January 2009	31 January 2009	0				1.00		0.28%	147.02							
59	14	1 February 2009	28 February 2009	0				1.00		0.28%	147.02							
60	15	1 March 2009	31 March 2009	0				1.00		0.28%	147.02							
61	16	1 April 2009	30 April 2009	0				1.00		0.28%	147.02							
62	17	1 May 2009	31 May 2009	0				1.00		0.28%	147.02							
63	18	1 June 2009	30 June 2009	0				1.00		0.28%	147.02							
64	19	1 July 2009	31 July 2009	0				1.00		0.28%	147.02							
65	20	1 August 2009	31 August 2009	0				1.00		0.28%	147.02							
66	21	1 September 2009	30 September 2009	0				1.00		0.28%	147.02							
67	22	1 October 2009	31 October 2009	0				1.00		0.28%	147.02							
68	23	1 November 2009	30 November 2009	0				1.00		0.28%	147.02							
69	24	1 December 2009	31 December 2009	0				1.00		0.28%	147.02							
70	25	1 January 2010	31 January 2010	0				1.00		0.28%	147.02							

The “Period ID” in column “B” rows 46 to 70 is used to group the data into the periods and has to match the “Period ID” on the “Calibration input” sheet. The dates in columns “C” and “D” for the “NGAC creation period from” and “NGAC creation period to” are for reference and are not used in the calculation.

Columns “E” to “S” calculate the NGAC creation period upper 95% Methane Energy Uncertainty, $\text{MEU}_{95\%\text{upper},}$ which is given in column “S”.

6 DOCUMENTS REQUIRED BY THE SCHEME ADMINISTRATOR

In order for the Scheme Administrator to consider applications by Generators to use the actual energy content of waste methane for the purposes of Equations 13 and 16 of the Generation Rule, the Generator must provide the following information in one document:

1. Details of the type of metering technology used to determine the actual energy content of the waste methane fuel (landfill gas, sewage gas or waste coal mine gas). Technical specifications for all metering equipment are to be included.
2. Details of the operational performance of the metering system, including:
    a. Commissioning and test results;
    b. Calibration frequency; and,
    c. Maintenance and testing regime.
3. The proposed Measurement Period for the purposes of uncertainty calculations. (Note: this does not necessarily need to reflect your NGAC creation timings).
4. Details of record keeping arrangements in place for documents relevant to the uncertainty calculations. These may include, but are not limited to, responsibility for calibration records and quality control.

7 USING THE OUTPUT IN NGAC CALCULATIONS

A five-step approach to incorporate the uncertainty into NGAC calculations is described below:

1. A measurement period for uncertainty calculation and a calibration regime for that period is to be proposed by the ACP and agreed by the Scheme Administrator. The measurement period will be no greater than 1 year, no less than 1 month; the calibration regime will be no less than weekly;
2. At any time within the agreed period, NGACs can be registered by the ACP using the 36% default factor for abatement that has occurred to that point;
3. At the end of the measurement period, calibration readings are used to calculate the Methane Energy Uncertainty (“±MEU”), using a standardised methodology agreed by the Scheme Administrator;
4. NGACs are subsequently calculated for the measurement period (using Equations 13 or 16), with Methane Energy data for the period being adjusted by the upper limit ‘MEU’ to give a corrected number of NGACs for the period; and
5. Where the number of NGACs already registered up to the end of the agreed measurement period is less than the NGACs calculated in Step 4, the balance may be registered.