

# GUIDANCE NOTE 18

## UNCERTAINTY IN CALCULATED ENERGY INPUTS AND OUTPUTS

### Scope

#### GN18.1

This GN gives detailed guidance to enable Responsible Persons to:

- assign realistic uncertainties to calculated values of energy inputs and outputs as required for the completion of Scheme details in the submission journey
- take account of uncertainties in determining the power and heat efficiencies of a Scheme when completing a self-assessment submission

Note that the following are not “calculated values” within the context of this GN:

- data processing, such as conversion of units, which may include the application of factors such as specific enthalpy, or calorific values for conventional fuels
- the summation of the reported values for a number of meters (GN13.14).
- the deduction of a metered or calculated steam flow that is used within the Scheme boundary (e.g. steam to hot well or deaerator, or gas turbine steam injection (GN19.21)

### Calculated Values

#### GN18.2

A calculated value of an energy input or output (hereafter referred to as a **calculation output, CO**) may be determined from a number of **calculation inputs**, which themselves may be **measured values** or “**given values**” (GN18.3), each with its own uncertainty. In such cases the influence of the uncertainty for each of the calculation inputs on the uncertainty in the calculated output value must be determined.

#### GN18.3

A “**given value**” is an un-metered input that may be required in the determination of a calculated value. Such values may be estimated based on design data (e.g. gearbox and generator losses) or based on a detailed energy audit of the plant (e.g. ducting or boiler casing heat losses; gas turbine cooling losses). As for metered calculation inputs, a level of uncertainty must be assigned to given values and the influence of these uncertainties on the uncertainty of the calculated output should be included in the assessment.

#### GN18.4

An example of a **calculation output** would be where the steam energy output sent to process across the Scheme boundary is not metered directly. For example, this would be the case where the high-pressure steam to a back-pressure steam turbine is metered, but the exhaust steam that is supplied to the site across the Scheme boundary is not metered nor is its condition (pressure and temperature) monitored. Example GN18-1 illustrates a calculation of this type. A further example of a calculation output could be the calculation of an unmetered quantity of steam used

within the Scheme boundary for deaeration or preheating of boiler feedwater where this is taken after the steam meter that is used in self-assessment of heat outputs. The treatment of the resulting energy flow, which is negative (i.e. a deduction from the metered steam), is dealt with in GN19.

## GN18.5

It may also be appropriate to use the methods given in this GN to determine the uncertainty of a **complex** metered value. For example, the calculation of energy input derived from a by-product fuel gas that is metered as a volumetric flow but is of variable composition and calorific value.

## Calculation Method

### GN18.6

The principle behind the method to be used to determine the overall uncertainty in a calculation output is the same as that described in GN17.25 and used in Table GN17-1 to determine the overall uncertainty in a metered value. The overall uncertainty of the calculation output is the square root of the sum of the squares of each input value uncertainty multiplied by its sensitivity coefficient (as defined in GN17.25 and illustrated below).

### Calculation Method for Uncertainty in a Calculated Value

Illustration:

For calculation inputs

$I_1, I_2, I_3 \dots \dots \dots$  Etc.

Each with its own uncertainty

$U_1, U_2, U_3, \dots \dots \dots$  etc,

and the contributions of each of these to the uncertainty of the calculation output are:

$$U_{e1} = S_1 \times U_1$$

$$U_{e2} = S_2 \times U_2$$

$$U_{e3} = S_3 \times U_3$$

Where  $S_1, S_2$  &  $S_3$  are sensitivity coefficients and  $U_{e1}, U_{e2}$  &  $U_{e3}$  are “effective uncertainties” determined by calculation.

$$\text{Overall Uncertainty } U_o = [U_{e1}^2 + U_{e2}^2 + U_{e3}^2 + \dots \dots]^{0.5}$$

### GN18.7

The method is described in GN18.8 – GN18.12. With the use of a spreadsheet as described in GN18.13, the method is not as difficult to apply as it may at first appear. This is best illustrated by means of examples (see Example GN18-1 and Example GN18-2 below).

### GN18.8

The calculation method requires that each of the calculation inputs has a known value ( $I_1, I_2$ , etc.) and can be assigned an uncertainty ( $U_1, U_2$ , etc.). It is important that the inputs are as far as possible independent of each other (in particular they must not be derived from other inputs to the calculation). Some individual uncertainties cannot be derived rigorously; these should be assigned a best estimate based on a working

knowledge of the process. The effect of different values of such estimates on the final outcome can be easily investigated within a spreadsheet solution.

### GN18.9

The value of the calculation output is first determined using **all** of the input values. This may require a number of steps wherein intermediate values are determined, which in turn are used to arrive at the final value of the calculation output (CO).

### GN18.10

The next stage is to change the value of the first input only, by an amount equal to its uncertainty (e.g. if  $I_1 = 100$  and  $U_1 = 10\%$ , new value of  $I_1(a) = 100 \times 1.10 = 110$ ). The calculation is then repeated with this new input value together with the original values for all the other inputs, to give a new value of the calculation output, CO (a). The value of  $U_{e1}$  is the percentage change in CO:

$$U_{e1} = [CO(a) - CO] \times 100 / CO \text{ (and sensitivity coefficient } S_1 = U_{e1} / U_1 \text{)}$$

### GN18.11

This procedure is then repeated, changing each input value in turn (with all of the other inputs held at their original values) to determine the effective uncertainty for that input, until the values for all of the inputs ( $U_{e1}$ ,  $U_{e2}$ ,  $U_{e3}$ , etc) have been calculated. The overall uncertainty in the calculation output can then be determined as shown in the illustration in GN18.6 above.

### GN18.12

Excess uncertainty, above the  $\pm 2\%$  required for best practice, is treated in the same way as for other inputs and outputs.

## Spreadsheet Computation

### GN18.13

The calculation procedure is greatly aided by the use of a spreadsheet and is best illustrated by means of examples. **Example GN18-1** shows the basic calculation of an output value and **Spreadsheet 1** below shows the calculation of the uncertainty of this output value.

## EXAMPLE GN18-1 - UNCERTAINTY IN A CALCULATED VALUE

### A calculation of energy in steam supplied to site

It is required to calculate the monthly steam energy output to site in the exhaust steam from a back-pressure steam turbine. The monthly steam flow is metered through meter M1 and its energy content determined, but only before the steam passes into the steam turbine. The uncertainty associated with the totalised monthly steam energy passing into the steam turbine was established as 1.6%, using the method prescribed in GN17.

The steam turbine generates electricity, which is metered by a Class 1 meter (meter M2), with an uncertainty of 1%. The condition (pressure and temperature) of the steam discharged from the turbine is not measured and is variable depending on load, so an indirect calculation of the monthly heat to site is necessary.

The required calculation output (CO) is the totalised monthly energy from the steam

sent to site.

### Calculation method

Input values consist of measurement of the totalised monthly steam flow (and its energy content) before the steam turbine, electricity generation and “given values” that are required to compute the steam energy to site. The input values are used to perform the intermediate calculations that are required to arrive at the ultimate calculation output.

#### Input values:

$I_1$  – totalised energy of steam before steam turbine, 14,880 MWh (1 month),  
uncertainty  $U_1 = 1.6\%$

$I_2$  - electricity generated by steam turbine, 1,440 MWh,  
uncertainty  $U_2 = 1.0\%$

$I_3$  - generator efficiency, 95-97%, average 96%,  
uncertainty  $U_3 = 1.0\%$  (i.e.  $\pm 1 / 96$ )

$I_4$  - steam turbine mechanical losses, 6-10%, average 8%,  
uncertainty  $U_4 = 25.0\%$  (i.e.  $\pm 2 / 8$ )

Note: Items  $I_3$  and  $I_4$  have been determined from manufacturer’s data sheets.

#### Intermediate calculations:

$C_1$  - steam turbine shaft power, MWh =  $I_2 \times 100 / I_3 = 1500.0$  MWh

$C_2$  - steam turbine energy drop, MWh =  $C_1 \times 100 / (100 - I_4) = 1630.4$  MWh

#### Final calculation:

**Energy in the steam to site, (CO)** =  $I_1 - [(I_2 \times 100 / I_3) \times (100 / (100 - I_4))]$

$$\therefore (\text{CO}) = I_1 - C_2$$

$$= 14,880 - 1630.4 = \mathbf{13,249.6 \text{ MWh}}$$

| Spreadsheet 1 - Calculation of Energy in Steam to Site and its Uncertainty                                    |                 |      |                       |                  |                                                                             |         |         |         |
|---------------------------------------------------------------------------------------------------------------|-----------------|------|-----------------------|------------------|-----------------------------------------------------------------------------|---------|---------|---------|
| A                                                                                                             | B               | C    | D                     | E                | F                                                                           | G       | H       | I       |
| Calculated variable                                                                                           |                 |      |                       |                  |                                                                             |         |         |         |
| Energy in steam to site (CO)                                                                                  |                 |      |                       |                  |                                                                             |         |         |         |
| Input variable                                                                                                | Symbol          | Unit | Value                 | Uncertainty U, % | Adjusted values of Inputs                                                   |         |         |         |
|                                                                                                               |                 |      | Inputs to calculation |                  | Adjustment of each value in turn to determine impact on calculated variable |         |         |         |
| Steam energy before steam turbine (Meter M1)                                                                  | I <sub>1</sub>  | MWh  | 14880                 | 1.6              | 15118.1                                                                     | 14880   | 14880   | 14880   |
| Electricity generated by steam turbine (Meter M2)                                                             | I <sub>2</sub>  | MWh  | 1440                  | 1                | 1440                                                                        | 1454.4  | 1440    | 1440    |
| Generator efficiency                                                                                          | I <sub>3</sub>  | %    | 96                    | 1                | 96                                                                          | 96      | 96.96   | 96      |
| Steam turbine mechanical losses                                                                               | I <sub>4</sub>  | %    | 8                     | 25               | 8                                                                           | 8       | 8       | 10      |
| Intermediate calculations                                                                                     |                 |      |                       |                  |                                                                             |         |         |         |
| Steam turbine shaft power                                                                                     | C <sub>1</sub>  | MWh  | 1500.0                |                  | 1500.0                                                                      | 1515.0  | 1485.1  | 1500.0  |
| Steam turbine heat drop                                                                                       | C <sub>2</sub>  | MWh  | 1630.4                |                  | 1630.4                                                                      | 1646.7  | 1614.3  | 1666.7  |
| Calculated variable                                                                                           |                 |      |                       |                  |                                                                             |         |         |         |
| Energy in steam to site                                                                                       | CO              | MWh  | 13249.6               |                  | 13487.6                                                                     | 13233.3 | 13265.7 | 13213.3 |
| Impact on calculated variable = Effective Uncertainty of input variable (Ue <sub>1</sub> to Ue <sub>4</sub> ) | Ue              | %    |                       |                  | 1.797                                                                       | -0.123  | 0.122   | -0.273  |
| Square of each value of Ue                                                                                    | Ue <sup>2</sup> |      |                       |                  | 3.2288                                                                      | 0.0151  | 0.0148  | 0.0748  |
| Sum of all Ue <sup>2</sup> values                                                                             | Ue <sup>2</sup> |      | 3.3336                |                  |                                                                             |         |         |         |
| Combined uncertainty (= root sum of squares)                                                                  | Uo              | %    | 1.83                  |                  |                                                                             |         |         |         |

The basic calculation is shown in columns A-D in the upper part of Spreadsheet 1 shown above. The input values I<sub>1</sub> – to I<sub>4</sub> (in red) are entered in Column D. Below these, again in column D, are the values for the intermediate calculations C<sub>1</sub> and C<sub>2</sub>, derived from the input data using the formulae given above. The final calculation output, energy in steam to site (CO) of 13,249.6 MWh in column D is computed using CO = I<sub>1</sub>-C<sub>2</sub>.

Column E shows the uncertainty assigned to each calculation input (in red). Column D is then copied across to Columns F – I (one column is required for each input value), and then a **single** adjustment is made to one of the input values in each column (in blue font and highlighted by a grey background).

For example, in Column F the value of I<sub>1</sub> only is adjusted with the adjusted value given by:

$$\text{Adjusted value of } I_1 = 14,880 \times (100 + 1.6) / 100 = 15,118.1$$

This process is then repeated in Columns G – I for each of the other input values in

turn. The effect on each input can be seen by looking at the grey shaded cells which progress diagonally downwards across the spreadsheet, through columns F to I. In this way each column gives a slightly different value of the calculated output (i.e. of the adjusted values for CO) and shows the effect of the uncertainty of each of the input values. This is then expressed as a percentage change in the following row entitled “Effective Uncertainty of input variable” (Ue<sub>1</sub> to Ue<sub>4</sub>):

$$\text{Effective Uncertainty, \%} = 100 \times \frac{(\text{adjusted value of CO} - \text{original value of CO})}{\text{Original value of CO}}$$

e.g. For Column F:  $Ue = 100 \times (13487.6 - 13249.6) / 13249.6 = +1.797 \%$

The final steps are simply to calculate the sum of the values of Ue<sup>2</sup>, the square root of which is the overall uncertainty, Uo, of the calculated output.

i.e. sum of the Ue<sup>2</sup> values = 3.3336, so the overall uncertainty U = 1.83%

**Result:        Energy in steam to site = 13,249.6 MWh**

**Overall Uncertainty (Uo) = 1.83%**

#### **GN18.14**

All calculation procedures for the determination of calculated variables (calculation outputs), and their associated uncertainties, should be based on the above methods and shall be submitted to CHPQA for approval before being used for self- assessment.