

GUM Workbench

User Manual

for

Version 1.3, 2.3 and 2.4

Metrodata | Datenverarbeitung
GmbH | für Messtechnik und
Qualitätssicherung

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GUM Workbench – User Manual for Version 1.3, 2.3 and 2.4

ISBN 978-3-00-032973-9, printed in Germany.

GUM Workbench was created and is being continuously developed by:

**Metrodata
GmbH** | Datenverarbeitung
für Messtechnik und
Qualitätssicherung
Im Winkel 15-1
D-79576 Weil am Rhein
Germany
Tel: +49 (0)7621/70 56 813
Fax: +49 (0)7621/70 56 818
web: www.metrodata.de
e-mail: info@metrodata.de

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ID: MD-UM2011/16

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The screen views shown in this manual are dependent on the screen settings and the version of the operating system. They might look different on the user computer screen.

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Table of Contents

1	Introduction	1
2	Installation and Setup Procedure	3
2.1	Network Installation	9
3	Running GUM Workbench	10
4	Performing an Uncertainty Analysis	11
5	Using GUM Workbench	12
5.1	The <i>Model View</i>	13
5.2	The <i>Observation View</i>	15
5.3	The <i>Correlation Matrix View</i>	15
5.4	The <i>Uncertainty Budget View</i>	16
5.5	The <i>Result View</i>	21
6	The Model Equation	22
6.1	The <i>Equation Field</i>	22
6.2	Structure of the Model Equation	23
6.3	Independent Quantities	30
6.4	The Name of a Quantity	30
6.5	Editing the Model Equation	32
6.6	Examples of Model Equations	35
6.7	Interim Results	36
6.8	List of Quantities	38
6.9	Use of Units	39
7	Quantities	40
7.1	<i>Quantity Data View</i>	41
7.2	Result	43
7.3	Interim Result	44
7.4	Type A Quantities Determined by Statistical Methods	44
7.5	Type B: Quantities Determined by Other Than Statistical Methods.	50
7.6	Constant	55
7.7	Working with Imported Quantities	55
7.8	Import from Microsoft Excel®	58
7.9	Multiple File Import	60
7.10	Change Order of quantities	60
8	Readings and Observations	63
8.1	<i>Import Observations</i> Dialog	63
8.2	Correlation Analysis for Type A	65

9	Multiple Results	69
9.1	Result Display Options	69
9.2	Multiple Budget View	70
9.3	Limitations and Performance	70
10	Printing and Export	71
10.1	Automatic Documentation	71
10.2	Document Information Fields	71
10.3	<i>Print Report</i> Command	72
10.4	Export Command	76
11	Loading and Saving Files	79
11.1	Save Command	79
11.2	Read Only Option	79
11.3	Save as Command	80
11.4	The Open Command	80
12	Working with Graphics and Pictures	82
12.1	Requirements	82
12.2	User Interface	82
12.3	Picture menu commands	83
12.4	Picture Printing	84
12.5	Multiple Pictures	85
12.6	Picture Storage	85
12.7	Performance Considerations	86
13	Unit Validation	87
13.1	The SI System of Units	87
13.2	Prefix Notation	88
13.3	Other Derived Units	89
13.4	Non SI Units	91
13.5	Insert Unit Dialog	91
13.6	Unit Validation Dialog	92
13.7	Syntax Rules for Units	94
13.8	Validation of the Model Equation	95
13.9	Supported Units by the Unit Validation Tool	96
13.10	Physical and Value Model Equations	96
13.11	Non SI Units	97
13.12	Error Messages and Warnings	98
13.13	Compatibility with Older Versions	100

14 Working with Diagrams	101
14.1 Diagram View	102
14.2 Diagram Details	103
14.3 Diagram Menu Commands	108
14.4 Diagram Printing and Export	108
14.5 Multiple Diagrams	108
15 Configuration	110
15.1 General Tab	110
15.2 Language Tab	111
15.3 Budget Tab	111
15.4 Result Tab	112
15.5 Number Representation Tab	113
15.6 Appearance Tab	114
15.7 Directory Tab	114
16 Online Help	115
16.1 Version Information	115
17 Expert Modules	116
17.1 Export to Excel Expert	116
17.2 Save as Version 3 Expert	117
18 Monte Carlo Simulation	118
18.1 Open Monte Carlo Engine	118
18.2 Theory of Operation	118
18.3 System Requirements	119
18.4 Installation	119
18.5 Using the Monte Carlo Simulation Expert Module	120
18.6 Configuration of the Monte Carlo Simulation	122
18.7 Limitations	123
18.8 Presentation of the Monte Carlo Simulation Results	123
18.9 Using Graphs and Markers in Histograms	125
19 Correlation Matrix Test Expert	127
19.1 Test for Positive Semi-definite	127
19.2 Eigenvalue Decomposition	128
19.3 Not positive semi definite correlation matrix	128
19.4 Interface to Python	129
20 Working with Templates	130
20.1 Using Template Files	130
20.2 Writing Template Files	130

20.3	Template Options	131
20.4	National Language Support	132
21	Tips and Tricks	133
21.1	Entering relative Uncertainty Parameters and in Percent	133
21.2	Value Calculations in Parameter Fields	133
21.3	Using Multiple Program Windows	134
21.4	Working With Large Equation Systems	134
21.5	Write Access to the Installation Directory	134
	Appendix A Glossary of Some Relevant Terms	135
	Appendix B Menu Structure	137
	Appendix C List of Input and Output Fields	139
	Appendix D Greek Letters and Special Characters	142
	Appendix E Functional Matrix	144
	Appendix F Error and Warning Messages	145
	Appendix G OLE Automation Interface	154
	Appendix H Calculation of the Sensitivity Coefficients	154
H.1	Linearity Check	155
	Appendix I Equations Used with GUM Workbench	156
I.1	Type A Evaluation	156
I.2	Type B Evaluation	157
I.3	Uncertainty Propagation (Budget)	159
I.4	Effective Degrees of Freedom	160
I.5	Expanded Uncertainty and Correlation Between Results	160
	Appendix J Example Report Pages	161
	Appendix K License terms	165
	Appendix L References	167
	Appendix M Index	168

1 Introduction

GUM Workbench® is software used to analyze the uncertainty of any measurement, test or analysis, including calibrations, physical testing and chemical analyses. The statistical and mathematical analysis and computations follow the rules of the *ISO Guide to the Expression of Uncertainty in Measurement* [1] and the requirement document *EA 4/02* of the European Cooperation for Accreditation [3]. (The document was previously called *EAL-R2*). The evaluation is compatible with other GUM based documents e.g. the NIST Technical Note 1297 [4], the Eurachem/CITAC Guide [5] and the UKAS M3003 [6].

GUM Workbench® is distributed in three different versions. The versions use a very similar user interface and the same internal calculation modules. The standard version 1.3 supports all functions to evaluate the value and measurement uncertainty for single result. The professional version 2.3 supports multiple results and OLE automation. The professional version 2.4 is based on version 2.3 and adds graphics, plotting and Monte Carlo simulation support. See Appendix E for the details about the different versions. All versions share the same file format.

The computation examples given in *EA 4/02* can be analyzed with the help of GUM Workbench. They are included in the software package as examples.

The program supports a systematic procedure for building uncertainty analyses as recommended in the *EA* document. Starting with the mathematical equation which models the physical relationship between quantities in the respective measurement, the user is prompted for the data required for the analysis, such as the standard uncertainty or the distribution of values.

The analysis process is controlled by a standardized classification of the input quantities according to the information available.

The result of the analysis is a transparent table of the uncertainty budget. This table holds all used quantities with their quantity names and values, the associated standard uncertainty and effective degrees of freedom, the sensitivity coefficient automatically derived from the model equation and the contribution to the standard uncertainty of the result of the measurement.

Finally the complete result of the examination is presented as a value with associated expanded uncertainty and automatically or manually selected coverage factor. All values are rounded to a useful number of decimal places.

For documentation purposes, the result of the uncertainty analysis together with all input data can be printed as a report. All entered text is included in the printout and is used to produce a clear and structured documentation. Before the actual printing process is initiated, the user can check the result in a preview window.

Each analysis together with all the input (the model equation, the values and all the text) can be saved in a file. In this way the analysis is available for later modification or checking.

Each saved analysis may be used as a starting point for new uncertainty analyses utilizing the same model but using new or changed data.

The program is especially suited to examination of the influence of various values and their associated uncertainties on the complete result of measurement.

This is the users manual for the Software GUM Workbench® Version 1.3, 2.3 and 2.4. See Appendix E for the functionality of the different versions. This manual mainly concentrates on the aspects of the program usage. It is not intended to be guidance for developing an uncertainty budget. Any discussion and advice in the manual is given without any warranty and for the sole purpose to illustrate the usage of the program. It is in the full responsibility of the user to understand the details of the uncertainty evaluation and to ensure that the use of the software is appropriate for a certain measurement result.

2 Installation and Setup Procedure

To install GUM Workbench® the setup program should be run. The setup program (Setup.exe) is usually started from the CD and will automatically copy all files and configurations necessary to run GUM Workbench® to the computer. The setup procedures for all versions are very similar. All steps must be followed to install the software. For a fully functioning version, an authenticity certificate with a valid serial number and key-code is necessary. The standard installation of GUM Workbench does not require administrative privileges. In situations where the program directory is write protected, the user may choose to install GUM Workbench somewhere else.

GUM Workbench® cannot be installed when any version of it is running. The warning message in Figure 1 will be shown. Close all running GUM Workbench® applications and press OK.

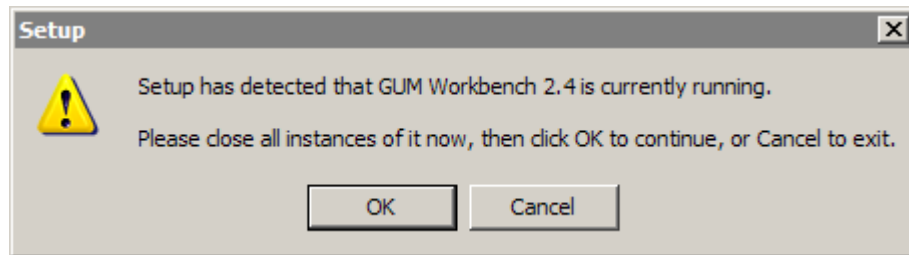


Figure 1: A running GUM Workbench® version has been detected and must be terminated
The welcome message with the detailed version information is shown below in Figure 2.

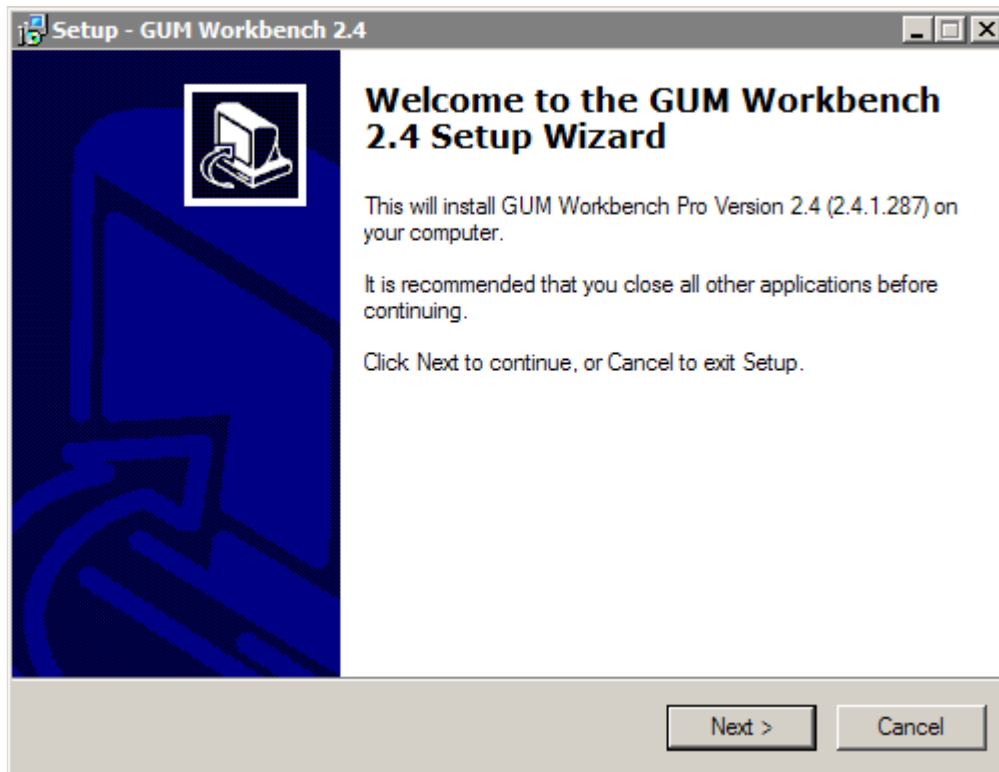


Figure 2: Welcome message - press *Next* to continue

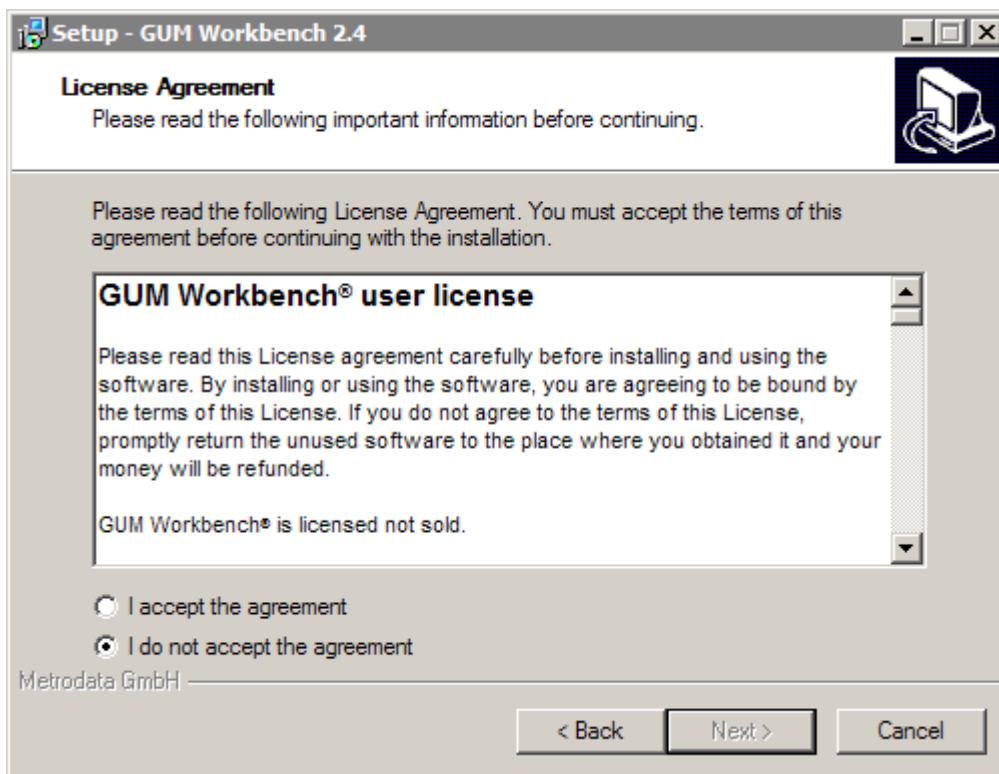
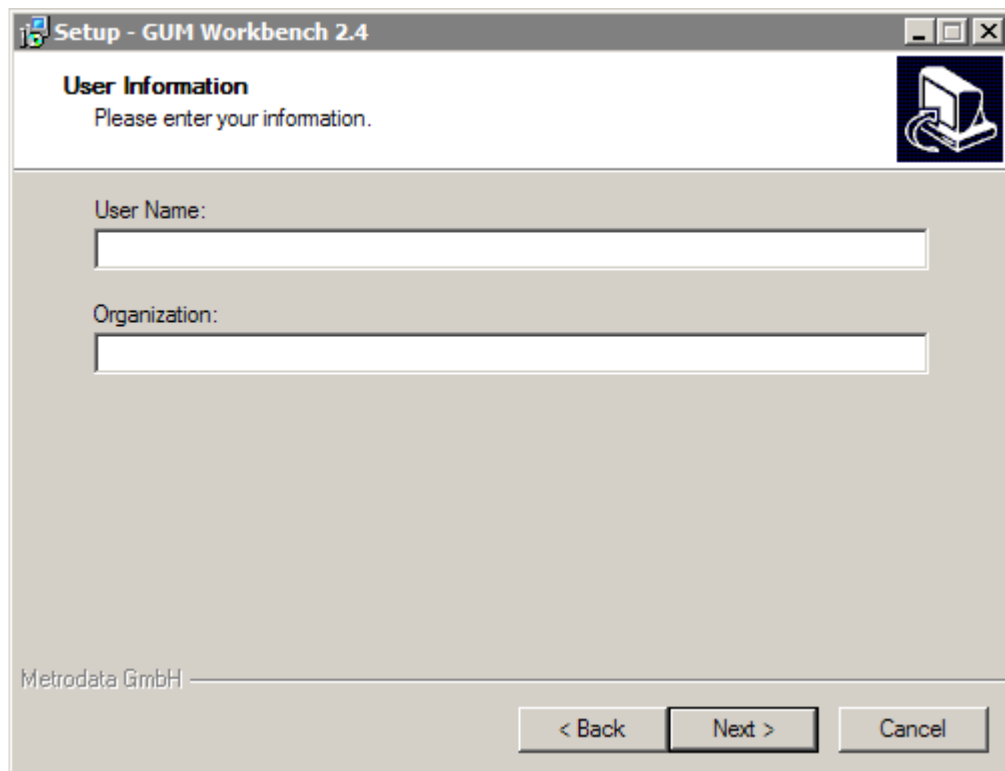


Figure 3: License Agreement – select accept and press *Next*

Please read the license agreement (Figure 3) carefully and choose *accept* to be able to continue. In case you do not accept the agreement, press *Cancel* and quit the setup.



Setup - GUM Workbench 2.4

User Information
Please enter your information.

User Name:

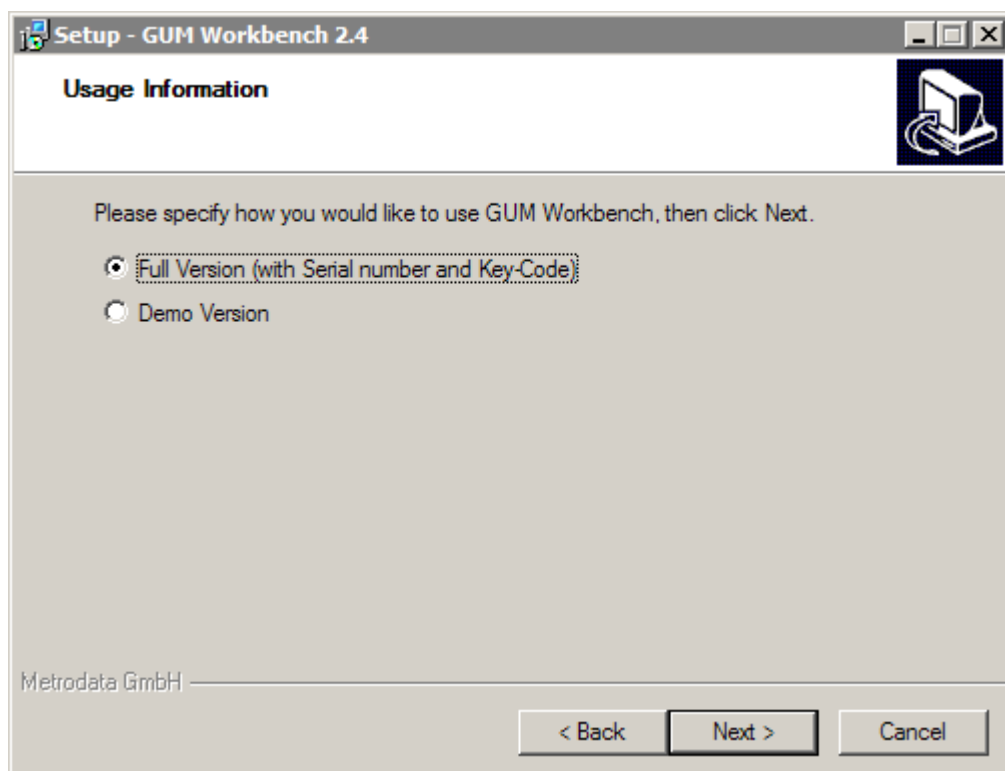
Organization:

Metrodata GmbH

< Back Next > Cancel

Figure 4: User Information – enter information and press *Next*

A valid user name and organization (Figure 4) needs to be entered to be able to continue.



Setup - GUM Workbench 2.4

Usage Information
Please specify how you would like to use GUM Workbench, then click Next.

☒ Full Version (with Serial number and Key-Code)

☐ Demo Version

Metrodata GmbH

< Back Next > Cancel

Figure 5: Usage Information – Select *Full* or *Demo* version and press *Next*

The demo version is a limited installation which cannot save any data to a file. For a fully functional version, a valid serial number and key-code are necessary and must be entered (Figure 6).

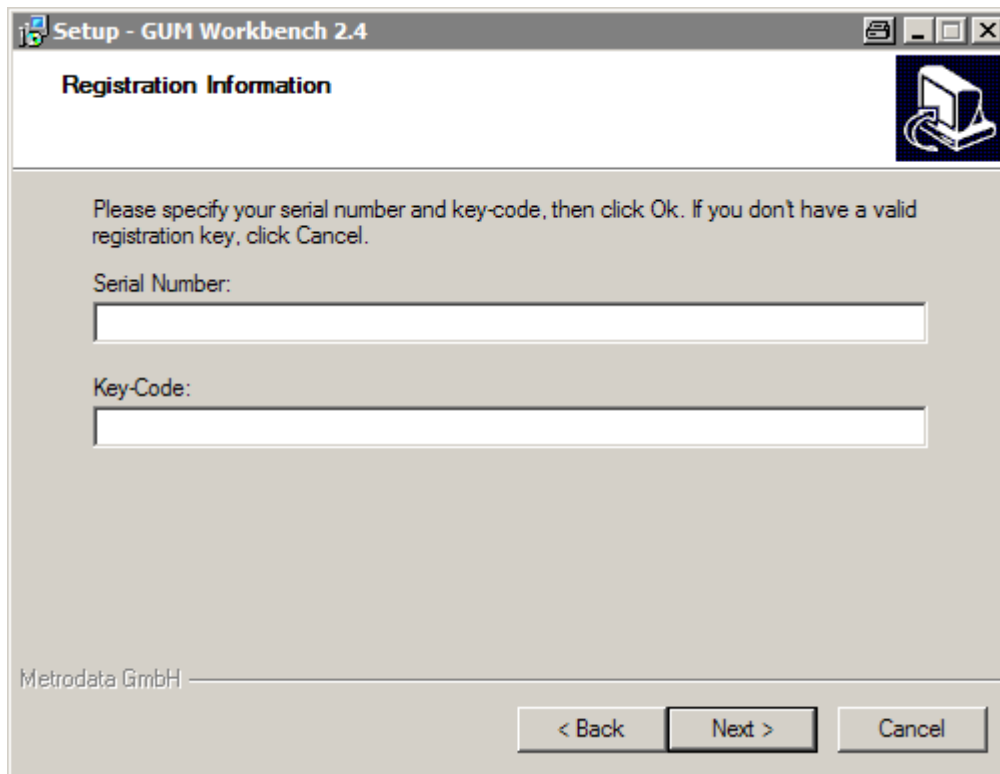


Figure 6: Registration Information - enter your serial number and key-code. Press *Next*.

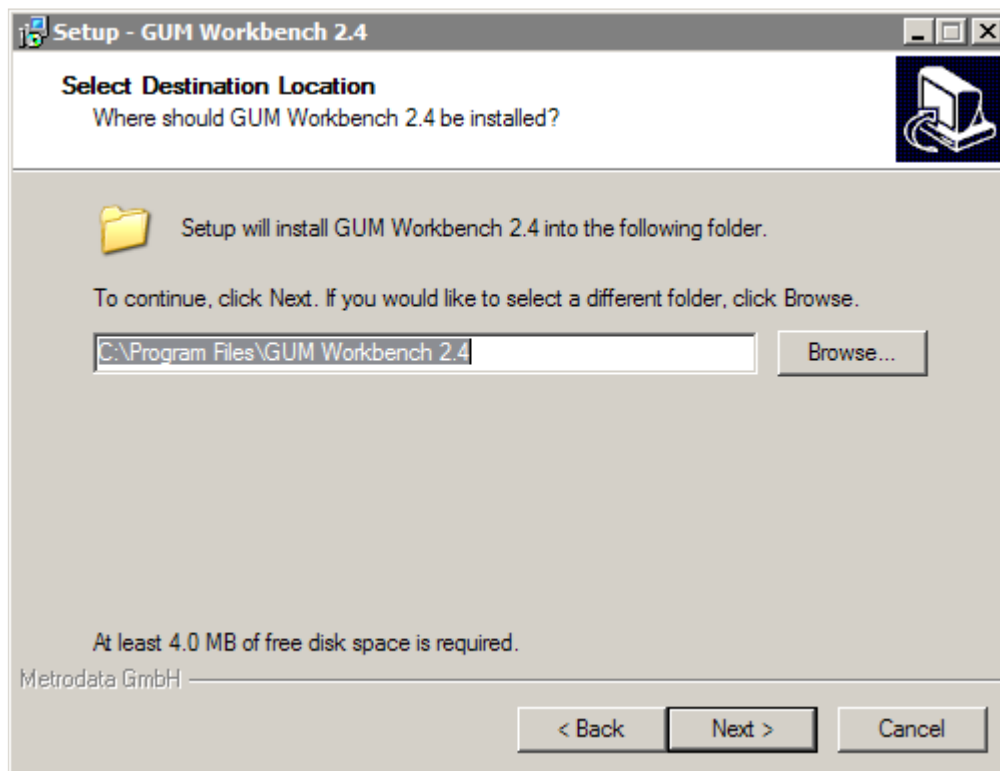


Figure 7: Select Destination Location – choose a directory and press *Next*

Usually GUM Workbench® is installed in the Windows® program files directory. In some cases, it might be useful to select another directory if this directory is write-protected.

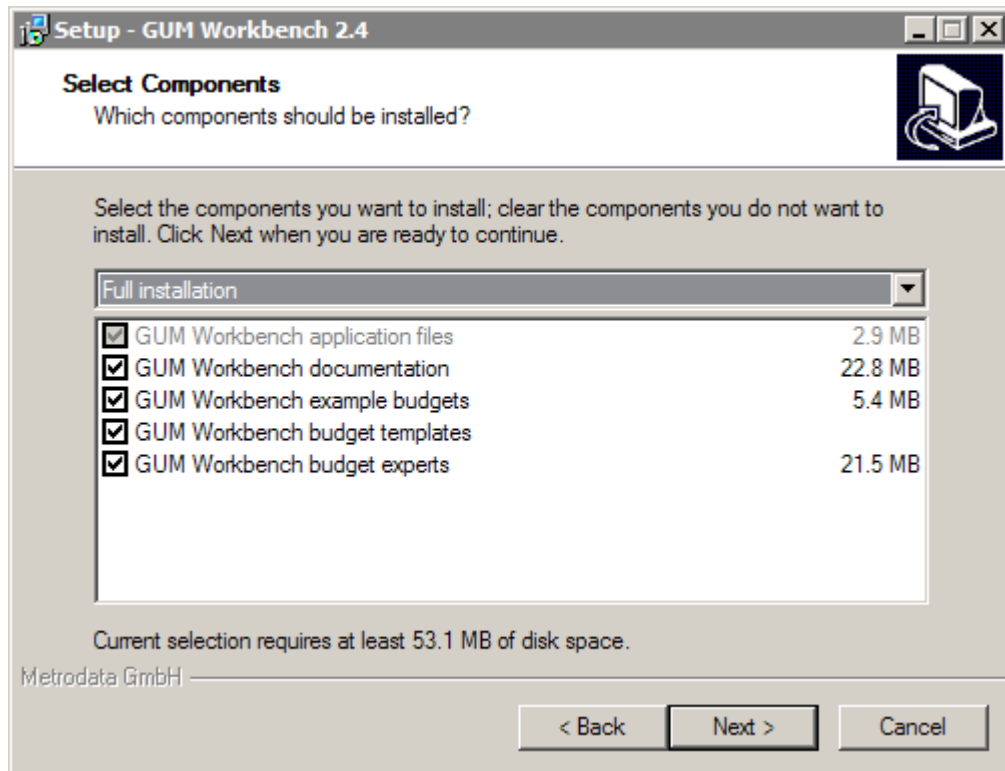


Figure 8: Select Components – select the components to install and press *Next*

For a fully operational installation all components (Figure 8) should be installed.

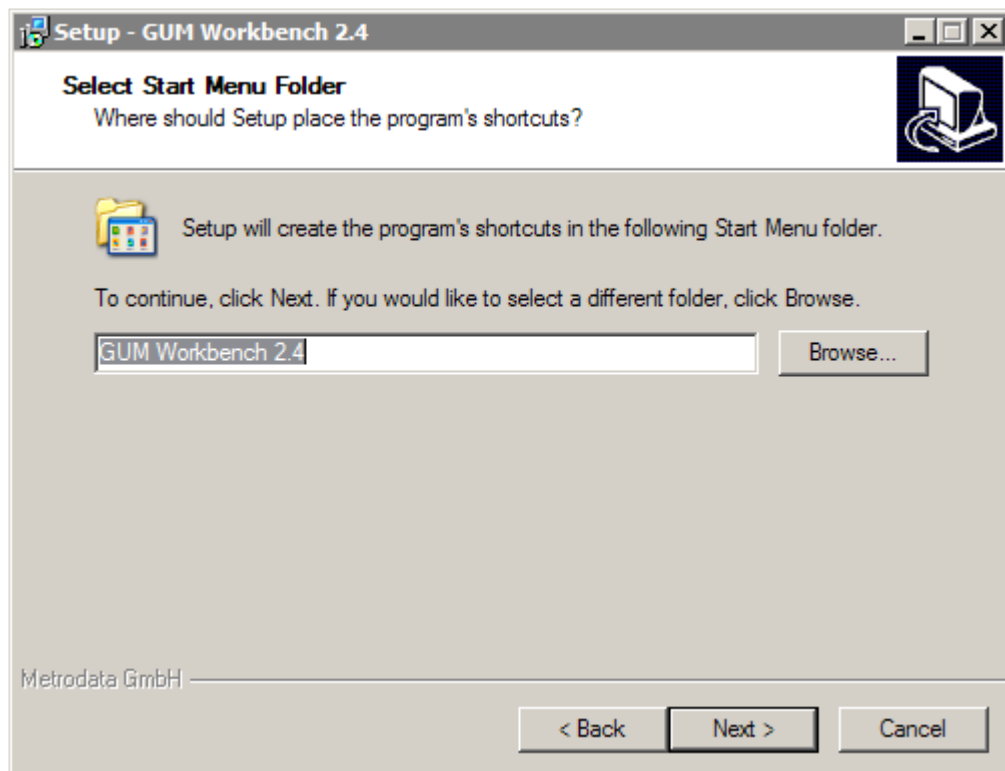


Figure 9: Select Start Menu Folder – choose a name and press *Next*

Choose a name for the start menu shortcut in Figure 9.

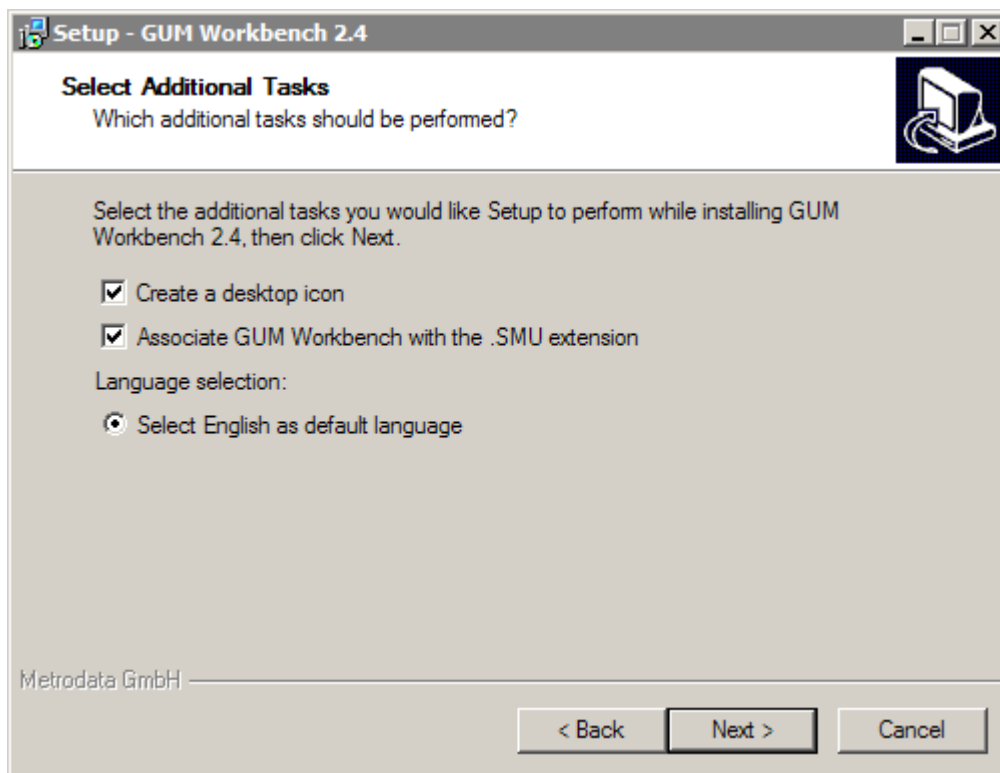


Figure 10: Select Additional Tasks – choose the tasks and press *Next*

GUM Workbench® can create an icon and can register the application as the default editor for SMU files. The language option can also be changed at a later time (Section 15.2).

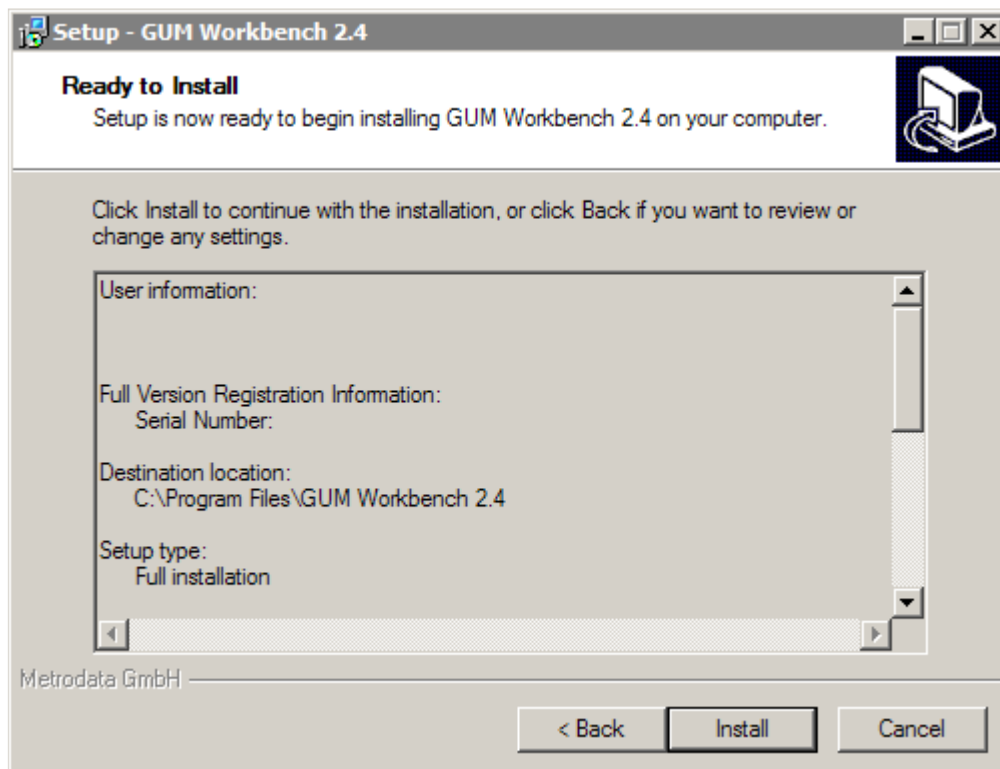


Figure 11: Ready to Install – verify the installation settings and press *Install*

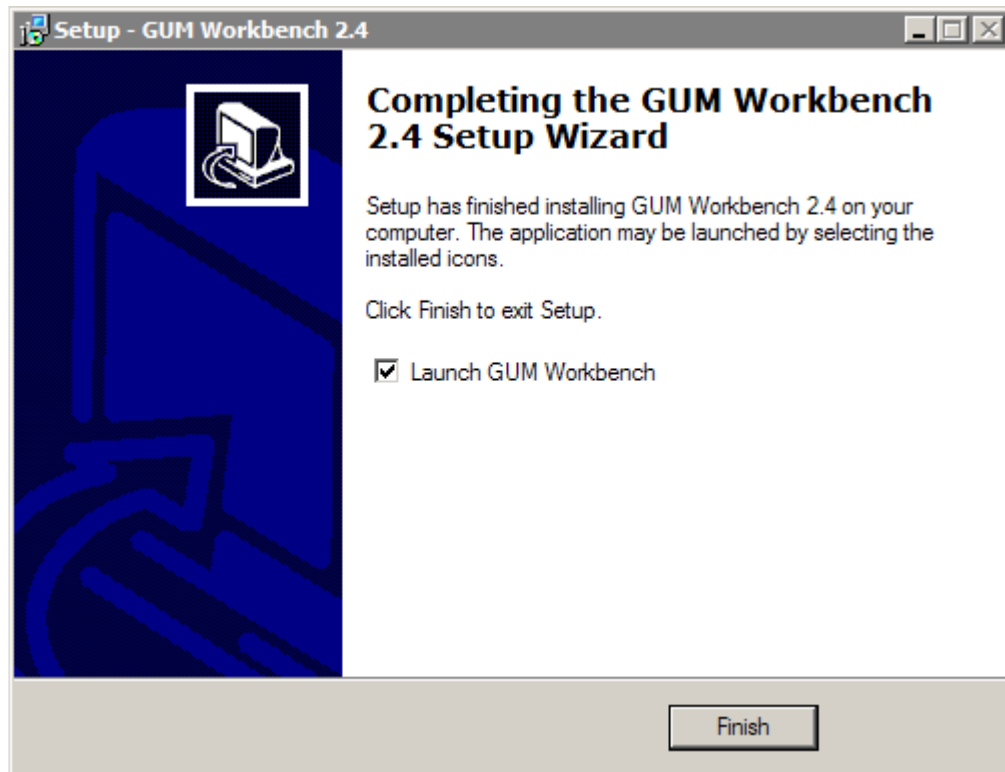


Figure 12: The installation is complete, press *Finish*

The setup procedure installs an uninstall icon in the start menu folder. To uninstall GUM Workbench®, run the uninstall program. It will remove all installed components from your computer.

2.1 Network Installation

In addition to the standard installation of GUM Workbench®, a network installation setup procedure is available for all versions. A network installation requires a multi-user license and a network setup installation CD. The network version is file server based and needs a single installation on one server. Please consult the network installation manual for details.

3 Running GUM Workbench

GUM Workbench® needs to be installed on your computer before you can use it. Please consult the section on the setup procedure for details about installation. If GUM Workbench® is installed correctly on your computer, you should have a program group called GUM Workbench x.y (x.y is your version of GUM Workbench® 1.3, 2.3 or 2.4) in your start menu. You either can start GUM Workbench® without a file, with one of the examples loaded automatically or with any other existing GUM Workbench file (.SMU) if you double click on it.

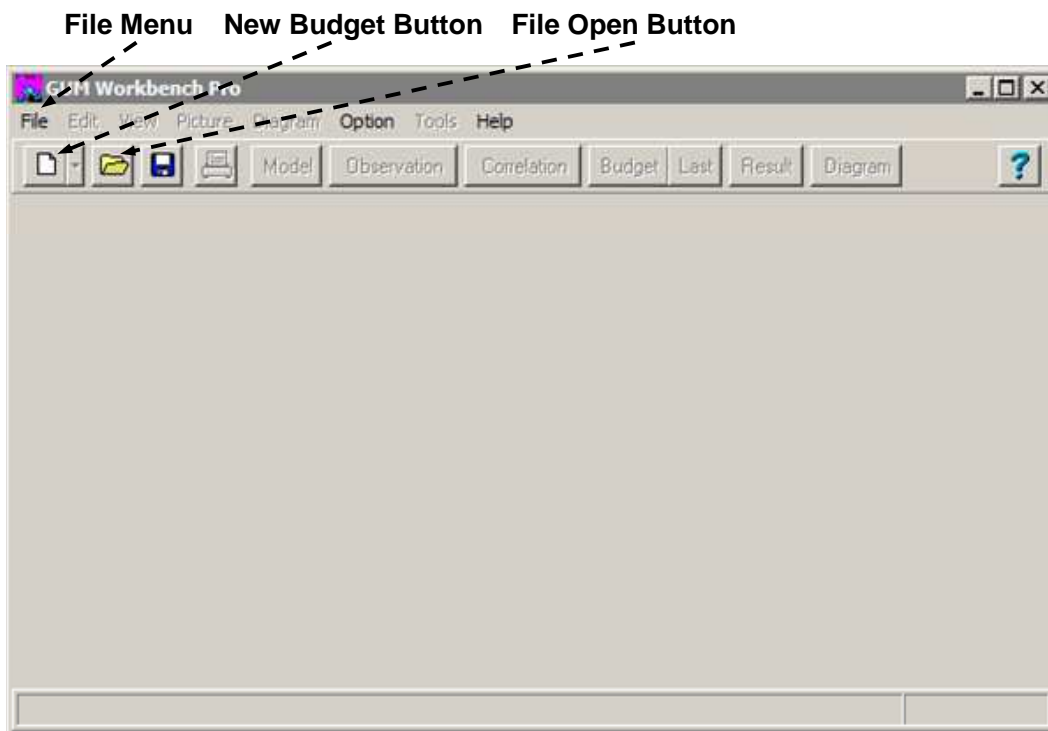


Figure 13: Main window after start-up

After GUM Workbench® is launched it will present you with a window similar to Figure 13 if no file is loaded automatically. You can either start a new evaluation with the new budget button or the *New Budget* command in the *File / New* menu or you can load an existing file with the *Open...* dialog in the *File* menu.

Another way to launch GUM Workbench® is to double click on an SMU file (if the SMU file association was activated during setup). This will start GUM Workbench® and automatically load the chosen file.

If an existing SMU file name is given as a parameter in the command line, GUM Workbench® will load that file after startup.

4 Performing an Uncertainty Analysis

This is a quick guide on how to perform an uncertainty analysis . Details of the different steps will be given in the following sections.

1. A new analysis is started with the *New* command from the *File* menu.
2. The *Title* register from the *Model* is selected. A title and a general description for the measurement procedure may be entered in the appropriate fields.
3. The *Model Equation* register holds the model equation in the *Equation* field. The program will then analyze the model equation and produce a list of quantities¹.
4. The quantity type and other necessary details are entered in the *Quantity Data* register for each quantity name.
5. Observation data is input in the screen view *Observation*.
6. Correlation coefficients between input values can be entered in the screen view *Correlation Matrix*.
7. The program then produces a detailed result that is shown in the screen view *Budget*.
8. The final result is displayed with an automatically selected coverage factor.
9. The Report-Generator prints a structured report which follows the rules given by the EA and ISO-guides.
10. To save an uncertainty analysis, select *Save* or *Save as* from the *File* menu.

¹ A note to those who are new to the GUM method:

GUM Workbench[®] requires a model equation be specified. This should not be difficult to fulfill. The model equations encountered in direct measurements or many calibrations are simple. Try to write:

`Result = Observation;`

or

`Error = Observation - Reference;`

Next, express the reasons for “metrological doubt“ in simple statements like:

`Observation = Display + x_1 + x_2;`

`Reference = Certified + x_3 + x_4;`

If one has a measurement in which a number of uncertainty contributions should simply be calculated as the square root of the sum of squares, this may be achieved by entering a model equation of this type:

`A = b + c + d + e`

As long as the model equation is not specified and the model equation field is left empty, the measuring situation is undefined and GUM Workbench[®] will not run.

5 Using GUM Workbench

The principle idea behind the graphical user interface (GUI) for GUM Workbench® is that an uncertainty evaluation is a multi-faceted object with different facets to be viewed. It is possible to look on the same object from different points of view which are related to the different tasks in the development of an uncertainty evaluation.

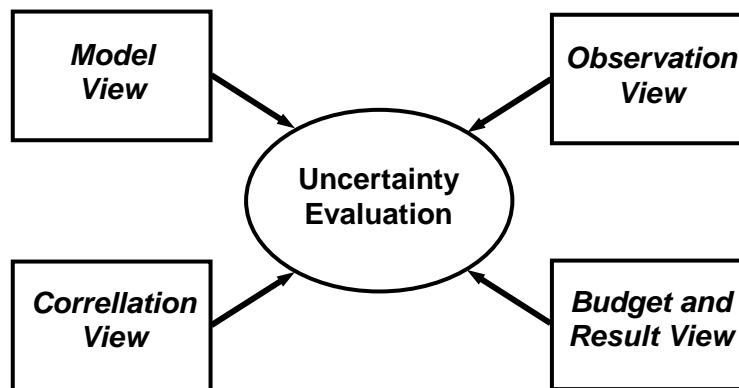


Figure 14: Different views of an uncertainty evaluation

Figure 14 shows the possible views for an uncertainty evaluation. During the design phase of a measurement evaluation, the model will be constructed in the *Model View*. During the measurement phase, the readings of the instruments will be entered in the *Observation View*. Known correlations can be edited in the *Correlation View* and the results can be inspected in the *Budget/Result View*. The current view can be freely chosen at any time. Table 1 lists the general tool bar buttons used to navigate between the views.

Table 1: General tool bar

Button	Command	Description	Section
	New	Open New or Open Template	3, 20
	Open	Open a file (.SMU)	11.4
	Save	Save file	11.1
	Print Report	Print a report	10.3
	View Model	Select Model View	5.1
	View Observation	Select Observation View	5.2
	View Correlation Matrix	Select Correlation Matrix View	5.3
	View Uncertainty Budget	Select Uncertainty Budget View	5.4
	View Last Budget	Select Last Budget View	5.4.4
	View Result	Select Result View	5.5
	View Diagrams	Select Diagram View*	14.1
	Help	Open Online Help	16

* Diagrams are only available in version 2.4

The main window of GUM Workbench® is shown in Figure 15. The program window is constructed in four parts: the standard *Main menu* with various commands, a toolbar with the *View selection*, the *Working area* which is dependant on the view and the *Status line* at the bottom. The different views are further structured as necessary by dialog pages. A specific view can be chosen either via the tool bar or the *View* menu.

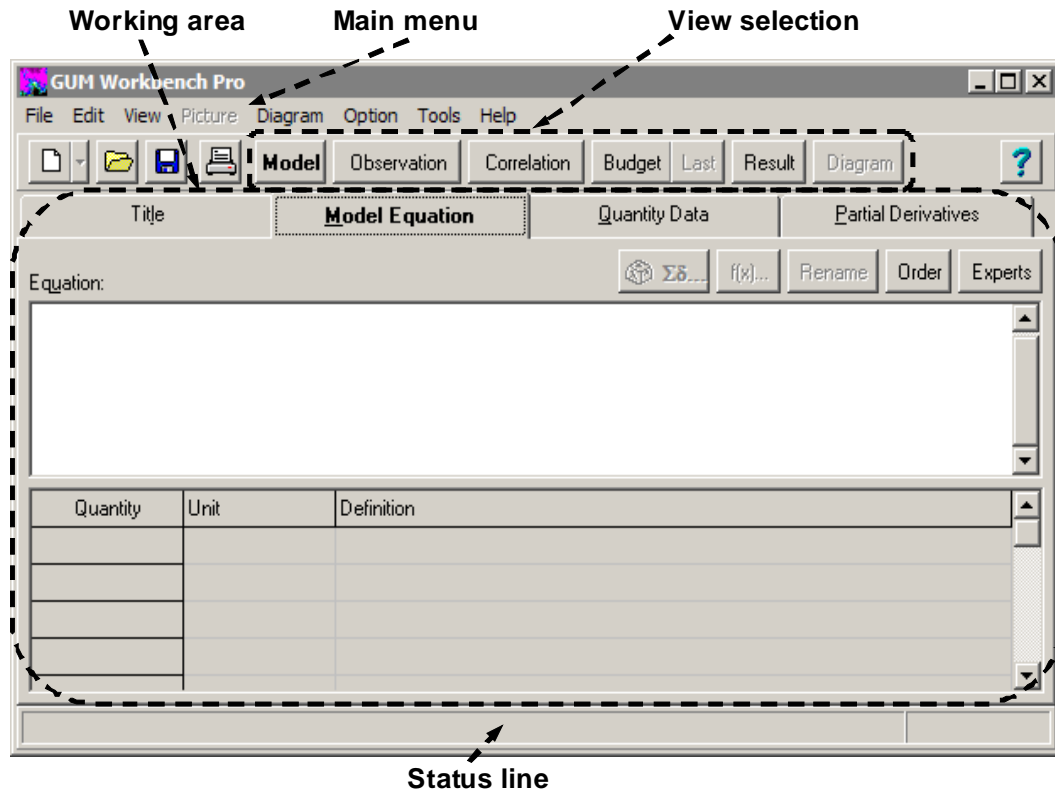


Figure 15: The main window of GUM Workbench®

5.1 The *Model* View

In the *Model* view, the data for a model can be examined and edited. The registers *Title*, *Model Equation*, *Quantity Data* and *Partial Derivatives* (only Version 2.4) are available. By selecting the different register pages, the corresponding data can be viewed or edited.

5.1.1 The *Title* Register

The register *Title* contains the title of the measurement task, a general description and optional pictures to illustrate the measurement task (see Section 12). These data are used for informational purposes and are part of the printout. They do not play any role in the quantitative analysis.

5.1.2 The *Model Equation* Register

The model equation is the central component of the uncertainty evaluation. The mathematical relationship between observed data and influence quantities is described in the

model equation. It can be entered in the *Equation* field². The model equation then leads to the generation of the list of quantities. The *Unit* and the *Definition* of the quantities can be edited in the table below the model equation.

5.1.3 The *Quantity Data Register*

The data of the different quantities can be viewed and edited in the *Quantity Data* register. The quantity type is chosen here and all data except the observation series will entered in this register. It also provides a separate *Description* field for every quantity.

5.1.4 The *Partial Derivative Register*

The *Partial Derivative* register is only supported in GUM Workbench® Version 2.4. It provides a view of the algebraic form of the partial derivatives. The algebraic equations are provided for information only and they are not used for the calculation. They must be copied to a description field if they are needed in the printed report. The generation of the partial derivatives is limited to 1024 lines.

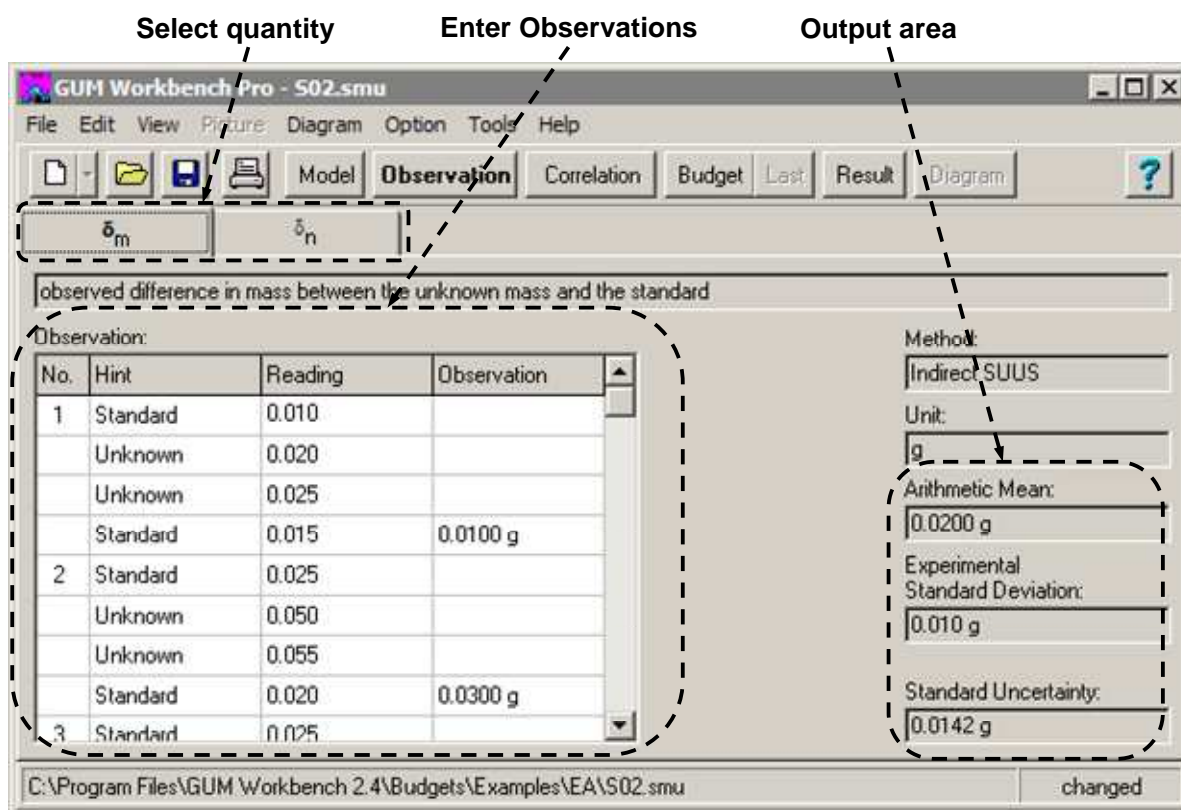


Figure 16: *Observation View*

² Note: The correct way of entering a model equation will be familiar to users with previous experience in programming languages such as Pascal or C, since the syntax is very similar.

5.2 The *Observation* View

The *Observation* View processes the values of repeatedly observed quantities. The data is typed into a table (see Figure 16). The structure of this table depends on the method of observation chosen. If an uncertainty evaluation contains more than one quantity of Type A the different quantities can be selected with the register tabs.

When valid data for all observations (or readings) have been typed in, the output area will display the mean value, the experimental standard deviation and the standard uncertainty of the data.

All observation data must be stated in the same units that were entered in the list of quantities in the field *Unit*.

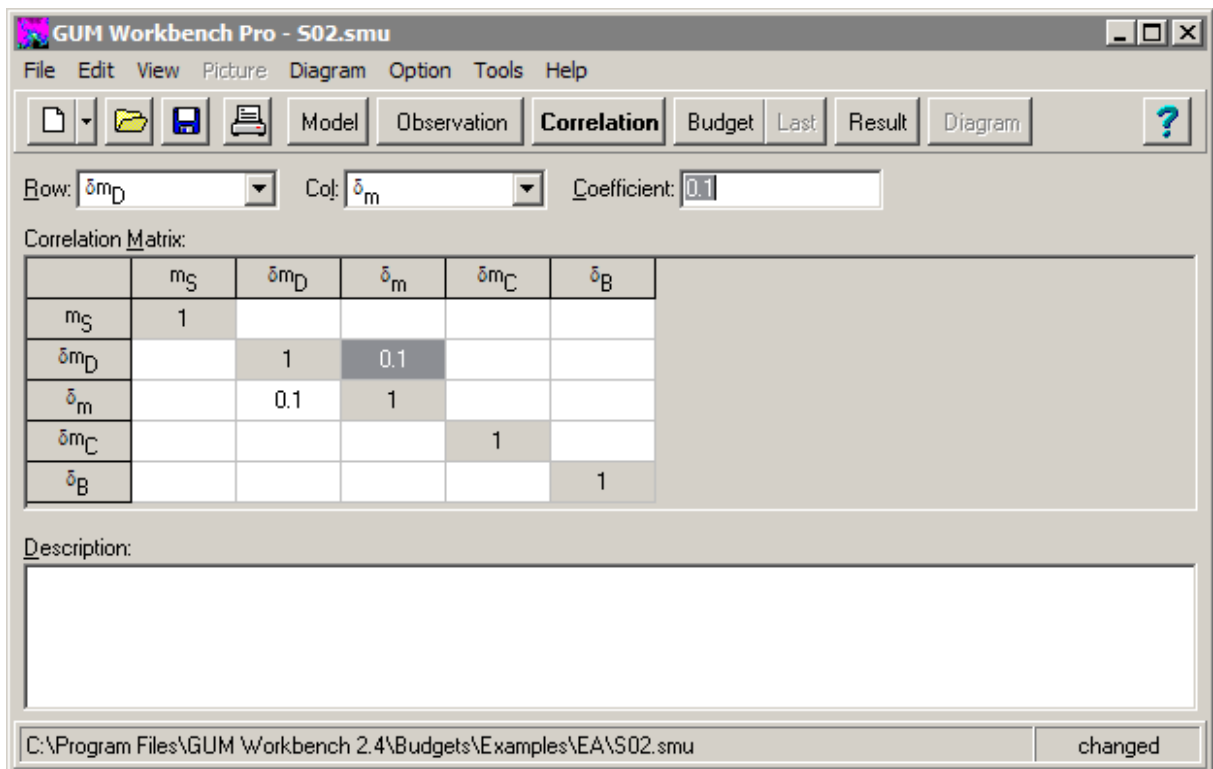


Figure 17: *Correlation* View

5.3 The *Correlation Matrix* View

The screen view *Correlation Matrix* allows known correlations between input data be entered in a matrix of correlation coefficients. Each matrix element contains the correlation coefficient for the accompanying column and row quantities.

The value of the coefficients must be between -1 and +1, inclusively. For clarity, only non-zero values are shown.

To change the correlation coefficient between two input quantities, the corresponding row and column fields are selected. The matrix cell that belongs to the two values is marked

(dark background and white numbers if any). In the *Coefficient* field, the value can be edited. The matrix value is updated as soon as change is committed by pressing enter or tab or by selecting a different matrix cell.

There are always two values in the matrix that are changed, the chosen coefficient and the value symmetrical to it.

When correlations between input values are taken into account, it is advisable to use the *Description* field to document the reasoning and decisions associated with the introduction of the correlation into the analysis, and to document from which sources the correlation coefficients came.

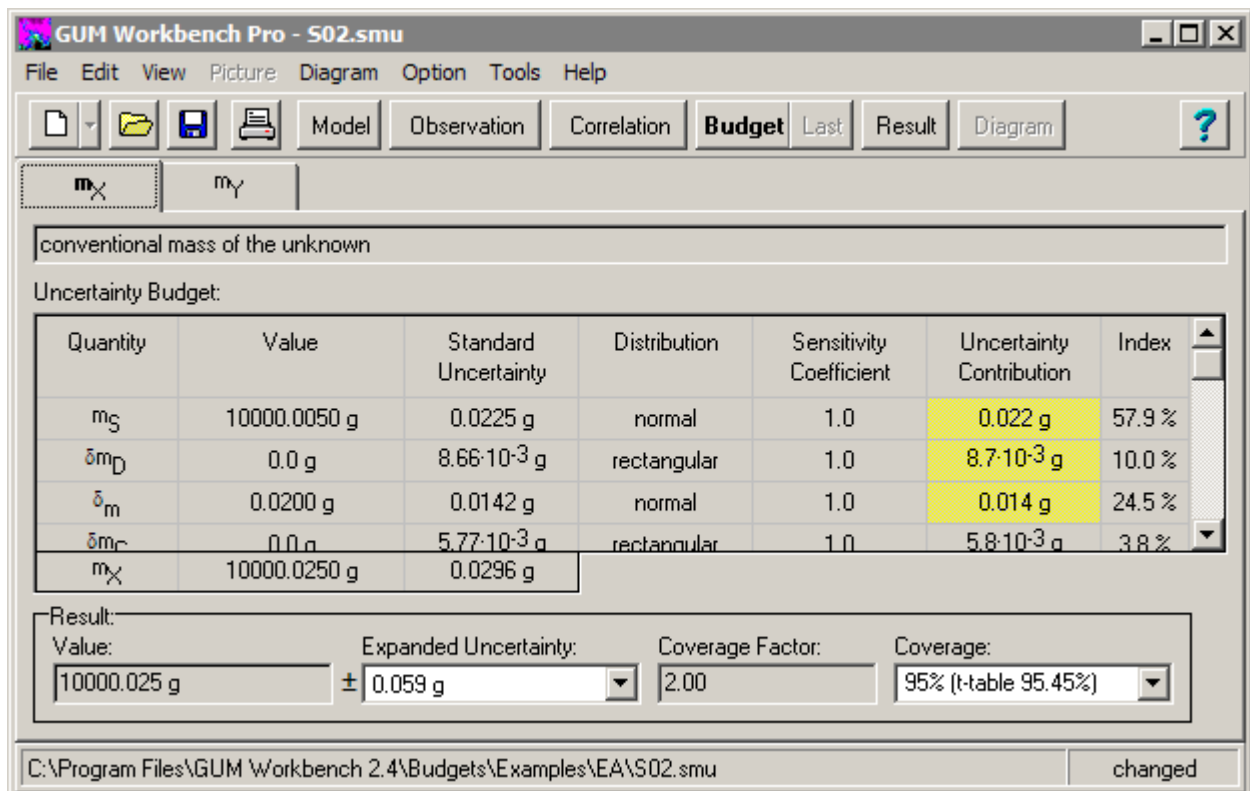


Figure 18: Budget View

5.4 The Uncertainty Budget View

The *Uncertainty Budget* view shows the result of the analysis. The name (in the quantity column) and value of each symbol are shown in a tabular form. All other columns can be activated or deactivated in the *Config* dialog (see Section 15).

For all input values which are not constants or interim results, the following columns are displayed when activated: the *Standard Uncertainty*, the *Degrees of Freedom*, the *Sensitivity Coefficients*, the *Uncertainty Contribution*, the *Correlation* between input and result and the *Uncertainty Index*. The *Standard Uncertainty* and the *Uncertainty Contribution* can be

expressed in absolute or relative forms. The selection is made with the *Config* dialog in the *Option* menu.

The *Index* column indicates the percentage of the variance that stems from the given input quantity in the budget. The values in the *Index* column might be negative in case of negative correlation effects. Negative values indicate that the quantity is reducing the total uncertainty in the budget.

Interim results are only shown with the value and the standard uncertainty if the budget display option is not activated for the interim result (only version 2.3 and 2.4).

The result is displayed in the bottom line. The *Value*, the corresponding *Standard Uncertainty* and the *Degrees of Freedom* of the result are shown, if activated.

If a value is invalid because of incomplete data for a quantity, the phrase *not valid!* is displayed in the table.

All sensitivity coefficients are shown without units. The correct unit is the unit of the result quantity divided by the unit of the input quantity.

The program automatically evaluates all uncertainty contributions. All important contributions in the uncertainty contribution column are highlighted (yellow background color)³. The percentage of uncertainty contributions which will be highlighted can be chosen in the *Config* dialog in the *Option* menu. In printed reports, the highlight color is gray, while yellow is used when exporting a budget table in HTML Format.

The results are automatically rounded and printed in E-Format if necessary (see also the *Config* dialog in the *Option* menu in Section 15.5).

The uncertainty in the budget may be stated in one of the following three ways:

- Absolute.
- Relative, as a fraction of the value.
- Relative, as a percentage of the value.

The optional column *Corr.-Coeff.* shows the correlation coefficient between the result and the given input quantity.

³Which cells are shown in yellow?

GUM Workbench[®] selects cells for highlighting in yellow according to the following scheme: All quantities are ranked according to the size of their uncertainty contribution. The quantity with the greatest contribution is shown automatically in yellow. Next the software continues by highlighting the cells with second greatest, third greatest etc. This goes on until a calculation based on the highlighted uncertainty exceed the percentage of the total resulting uncertainty specified in the *Config* dialog.

5.4.1 Selecting the Coverage

Below the budget table, the *Value* of the result is stated with its *Expanded Uncertainty* and the *Coverage Factor* that was used to calculate it. The selected *Coverage* determines the way the coverage factor is calculated (see Figure 19). It can either be done manually or calculated from a t-table by using the effective degree of freedom calculus or an assumed distribution of the result can be used.



Result:	Expanded Uncertainty:	Coverage Factor:	Coverage:
Value: 10000.025 g	± 0.058 g	2.00	95% (normal)

Figure 19: Result display and *Coverage* selection

For situations in which the distribution of the result can be described with a t-distribution based on the established degrees of freedom, the *Coverage* should be set to 95% (t-table 95.45%). The value of the coverage factor is then taken from a *t*-table with a coverage probability of 95.45% as prescribed by the GUM.

Note: The probability shown in the field *Coverage* is a description of the probability interval and not an exact number. If for example *95% (normal)* is selected then a coverage factor of 2.0 is used although this value leads for a normal distribution to an interval with a probability of 95.45%.

Warning: Care must be taken to choose an appropriate method to establish the coverage factor if the expanded uncertainty is of importance. Choosing the wrong *Coverage* method might lead to a significant underestimation (or overestimation) of the expanded uncertainty.

5.4.2 Rounding Rules

For numbers in the uncertainty budget, the following rules of rounding are used:

- For the standard uncertainty, the degrees of freedom, the sensitivity coefficient and the uncertainty contribution, the values are rounded to three significant digits.
- In the value column, numbers are rounded to the last significant digit of their standard uncertainty.
- In the result group, the expanded uncertainty is rounded to two significant digits. The result value is rounded to the last significant digit of the expanded uncertainty. The coverage factor is given with three significant digits.
- If any uncertainty value is zero or the quantity is a constant, the number displayed in the value column will be rounded to a maximum of fifteen significant digits.

Note: The screen view *Budget* may be configured to show or hide different elements of the above data. There is more information on this in section 15.3.

5.4.3 Warning: *not valid!*

GUM Workbench® performs an automatic validation of every input quantity, interim result and the result. An analysis is possible only if all data for a quantity have been correctly entered. Missing values of input quantities are marked with *not valid!* in the budget. If an invalid quantity exists, any interim results which depend on such a quantity and the result also have a status of *not valid!*.

Missing data entries can quickly be found by inspecting the value, standard uncertainty or degrees of Freedom of quantities which are marked as *not valid!* or by using the command *Find Missing Data* in the *Edit* menu (shortcut Ctrl-F).

For situations where sensitivity coefficients are marked as *not valid!* see section 5.4.5.

5.4.4 Last Budget

Two buttons give access to the uncertainty budget: *Budget* and *Last*. When the *Budget* button is selected, a recalculation of the entire budget will be performed. This is necessary only when the model equation or data for quantities have been changed. The button *Last* gives access to the uncertainty budget without recalculation. The use of this button in uncertainty analyses with many quantities can save time and give the user a way to directly evaluate the effect of any changes made to either the model equation or the data for the quantities.

When activating the screen *Budget*, errors messages may appear initially. This is because the uncertainty budget is calculated when the button *Budget* is pressed. Out of range error messages may be displayed, or a *not valid!* may appear in the column *Sensitivity Coefficient* or other columns.

When errors of this type are present, the standard uncertainty cannot be calculated. To correct these errors, changes must be made to either the model equation or to the data for one or more of the quantities.

When pressing the button *Budget*, only the data for the quantities are evaluated. The model equation is checked when leaving the model equation field. Note that the model equation field can not be left as long as the model equation is mathematically not correct. This however does not guarantee that the quantity data will give a correct evaluation of the standard uncertainty or an error free calculation of the standard deviation. For example a

division by zero may only occur during the calculation with zero data which is done when the budget is calculated.

5.4.5 Sensitivity Coefficient Marked as *not valid!*

If the sensitivity coefficient of a quantity is marked *not valid!*, but the uncertainty contribution is correctly defined, then a mathematical problem exists. The reason for that problem can be an extremum (minimum or maximum) or a strongly nonlinear relation between the result and that input quantity. Such nonlinearity should be seen in relation to the magnitude of the standard uncertainty associated with the quantity.

In such cases, the mathematical equation must be investigated in more detail. It is likely that the model equation does not correctly represent the measurement situation.

Even though a sensitivity coefficient has been identified as *not valid!* by GUM Workbench®, an uncertainty budget is usually calculated nevertheless. The column for sensitivity coefficients should be checked for any occurrences of *not valid!* in order to ensure that the budget does not have the above problem.

5.4.6 Multiple Budget View

The multiple result versions 2.3 and 2.4 of GUM Workbench® support a multiple budget view. At the top of the *Budget View*, a register tab is displayed which allows the user to switch to the different budget tables. All budget tables have the same structure and the columns are controlled by the *Config* dialog. Only results for which the *Calculate Budget* option is activated are visible in the *Budget View* (see Section 9.1). All budget tables which are visible in the *Budget View* are printed in the report. The order of the result quantities in the *Budget View* and the result view is controlled by the *Change Quantity Order* dialog.

The *Coverage* is chosen separately for every result and the expanded uncertainty is calculated from the standard uncertainty and the coverage factor. All results are treated independently in this calculation. It is in the responsibility of the user to choose an adequate method to select the coverage. In some cases it might be wise to state only a standard uncertainty with a set of correlated results. The user might consult the correlation matrix given in the *Result View* to support this decision.

Result		Correlation-Matrix		
Quantity	Value	Expanded Uncertainty	Coverage-factor	Coverage
Y_1	3.3	1.3	2.00	95% (normal)
Y_2	2.5	1.6	2.00	95% (normal)

Figure 20: *Result View*

5.5 The *Result View*

The multiple result versions 2.3 and 2.4 of GUM Workbench® support a *Result View*. The *Result View* contains a register tab for the result table and optionally, a tab for the correlation matrix (Figure 20). The correlation-matrix tab will be visible if the *Calculate Correlation* option is activated for any result. The result table will list all results where the *in Resultlist* option is activated together with their value, expanded uncertainty, coverage factor and the selected coverage. The order of the results is controlled by the *Change Quantity Order* dialog.

Result		Correlation-Matrix	
		Y_1	Y_2
Y_1		1	0.66
Y_2		0.66	1

Figure 21: *Correlation-Matrix* between results showing the correlation coefficients






The *Correlation-Matrix* will show the correlation coefficient between all results for which the *Calculate Correlation* option is activated (see Figure 21).

6 The Model Equation

The field *Equation* in the register *Model Equation* holds the mathematical model of the uncertainty analysis. This is the starting point for all subsequent calculations by the program.

The quantities in the equation can be added, deleted or renamed at any time. Some operations are available as tool buttons. Table 2 shows the buttons in the equation tool bar. When the user leaves the equation field, the syntax of the model equation is checked and the table of quantities will be created or updated.

Table 2: Equation tool bar

Button	Command	Description	Section
	Insert Character	Opens Insert Character dialog	6.5.3
	Insert Function	Opens Insert Function dialog	6.5.2
	Renaming a Quantity	Opens the Renaming dialog	6.5.1
	Change Quantity Order	Opens the Change Order dialog	7.10
	Call Expert Support	Opens the Call Experts dialog	17

Note that individual equations in the equation field will not wrap around when their length exceeds the visible area. By using the navigation arrows which appear below the equation field, the right hand side of long entries may be inspected. Upon printing, any line from the equation field will be wrapped around only if there are blank spaces in appropriate places. Thus, it is good practice to use spaces on both sides of mathematical operators and in other places where it may help the legibility of the equation.

The *Equation* field and other editing fields support two different modes. The display mode shows the content of the field similar to the printed version. In the edit mode, the text is shown and can be modified. The edit mode is activated by entering the field with the tab key or by clicking on it and the display mode is activated when exiting the field with the tab key or by clicking somewhere else. In the display mode, text following an underscore () is turned into an index, while text enclosed in backslashes (\) is looked up in a special characters table in order to provide a display of special characters.

6.1 The *Equation* Field

There are two states of the equation field (and any other text field in GUM Workbench®). The display mode shows the equation using indices and special characters, including Greek letters and other mathematical symbols. The display mode is active when the cursor is not positioned inside the *Equation* field.

The edit mode shows any underscore and backslash entries in ASCII format. The edit mode is active when the cursor is positioned inside the *Equation* field.

The use of elaborate formatting is optional. It does not add to the mathematical rigor of GUM Workbench®, only to the appearance of text, quantity names and mathematical symbols. When no underscores or backslashes are used, display mode and edit mode are identical.

New users of GUM Workbench® are advised to first acquaint themselves with the basic principles of building an uncertainty budget. For presenting quality reports, the concepts and rules for text and quantity name formatting should be revisited.

The equation field can be resized. When placing the cursor right below the equation field, it will change into a divider symbol. By pressing and dragging the proportion of the screen used for the equation field and the list of quantities can be adjusted. For viewing convenience, the display mode of the equation field will show the equation in 20% oversize as compared with edit mode. The font size of the display and edit modes can be changed in the *Config* dialog in the *Option* menu (see Section 15.6).

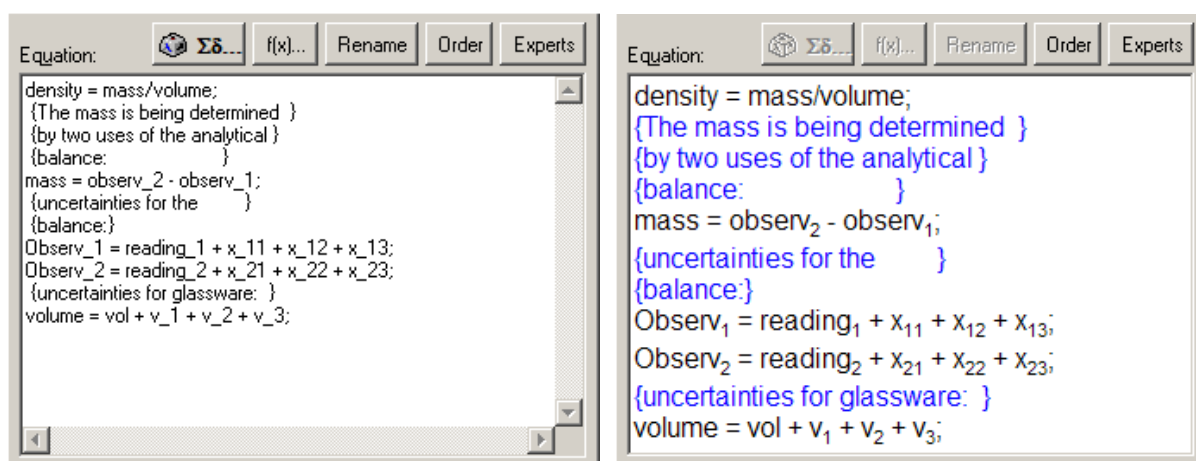


Figure 22: Equation field in edit mode (left) and display mode (right)

The two equation field representations in Figure 22 show how edit mode (left) differs from display mode (right) and how the slight enlargement of screen fonts in the display mode of the equation fields increases the readability of the equation.

6.2 Structure of the Model Equation

The model equation is entered in the screen view *Model* in the register *Model Equation* where the *Equation* field resides. The general form of a model equation is:

$$\text{output_quantity} = \text{expression};$$

The right hand side represents an algebraic expression derived from a suitable combination of mathematical operators and functions as well as numbers and input quantities. If exact

values of mathematical constants such as π or e are needed, predefined values will be offered as defaults by creating quantities with names `pi`, `\pi\` and `e` respectively.

The algebraic expression on the right hand side of the model equation is evaluated according to common mathematical rules of operation when the uncertainty analysis is performed.

When a model equation is more complex and contains a large number of input quantities, it is advisable to split it into smaller parts, thereby making it easier to understand. This is done by introducing interim results.

6.2.1 Comments in the Model Equation

Placing comments inside of the model equation field is possible through the use of curly brackets⁴. Any text contained in curly brackets is regarded as a comment and will be disregarded in the interpretation of the mathematical contents of the equation field. For example, one might enter:

```
density = mass/volume;
  {The mass is being determined  }
  {by two uses of the analytical }
  {balance:                      }
mass = observ_2 - observ_1;
  {uncertainties for the         }
  {balance:}
Observ_1 = reading_1 + x_11 + x_12 + x_13;
Observ_2 = reading_2 + x_21 + x_22 + x_23;
  {uncertainties for glassware:  }
volume = vol + v_1 + v_2 + v_3;
```

6.2.2 Mathematical Operators

Table 3 lists the possible mathematical operators in the model equation. Operations with high priority are executed before those with a lower priority. In case of equal priority, execution proceeds from left to right, except when raising a number to a given power, in which case execution moves from right to left.

⁴ Comments { ... } »Curly brackets«

These are entered with most keyboards using the Alt-Gr key. In GUM Workbench® they may also be entered using the *Insert Character* dialog

The sequence of operations can be controlled by putting certain parts in parentheses⁵ ‘(’, ‘)’ and thereby giving them higher priority. GUM Workbench[®] follows common mathematical rules of operation in that execution starts with the innermost pair of parentheses and works its way to the outermost pair.

Table 3: Mathematical operators

Priority	Symbol	Operation
3	^	Raise to the power of
2	* × ·	Multiplication ⁶
2	/ ÷	Division ⁷
1	+	Addition
1	–	Subtraction

6.2.3 Mathematical Functions

Table 4 lists the possible mathematical functions in the model equation. Function names are reserved names and should not be used as quantity names. Attempting to do so will generate an error message. The arguments for the built-in trigonometric functions should be expressed in radians. Likewise, the result of calling any arc-function will be in radians. Two functions are provided for easy conversion between degrees and radians. The function $\text{rad}(x)$ multiplies x by $\pi/180$ while $\text{deg}(x)$ divides x by this factor.

$$\text{deg}(\text{acos}(1/2)) = 60$$

$$\text{sin}(\text{rad}(30)) = 0.5$$

⁵ The practical limit to the number of nested parentheses in any one expression is 32.

⁶ There are three alternative ways to enter the multiplication operator. The operators \cdot and \times can be entered using the *Insert Character* dialog. Note that the operator \times is different from the letter x .

⁷ There are two alternative ways to enter the division operator.

Table 4: Mathematical functions

Symbol	Mathematical function ⁸
	Absolute value, Modulus
<code>sqr()</code>	Square
<code>sqrt()</code>	Square root
<code>root3()</code>	Cubic root
<code>exp()</code>	Natural exponential function (base e)
<code>ln()</code>	Natural logarithm (base e)
<code>log()</code>	Common logarithm (base 10)
<code>sin()</code>	Sine
<code>cos()</code>	Cosine
<code>tan()</code>	Tangent
<code>cot()</code>	Cotangent
<code>asin()</code>	Arc sine
<code>acos()</code>	Arc cosine
<code>atan()</code>	Arc tangent
<code>acot()</code>	Arc cotangent
<code>sinh()</code>	Hyperbolic sine
<code>cosh()</code>	Hyperbolic cosine
<code>tanh()</code>	Hyperbolic tangent
<code>coth()</code>	Hyperbolic cotangent
<code>asinh()</code>	Arc-hyperbolic sine
<code>acosh()</code>	Arc-hyperbolic cosine
<code>atanh()</code>	Arc-hyperbolic tangent
<code>acoth()</code>	Arc-hyperbolic cotangent
<code>const()</code>	Conversion to a constant
<code>deg()</code>	Conversion to degrees
<code>rad()</code>	Conversion to radian
<code>average()</code>	Average of multiple arguments

6.2.4 Conversion to Constant

With the function `const()`, the uncertainty of an expression can be removed for the calculation. If x is a quantity with the uncertainty $u(x)$, then `const(x)` has the value of x without any uncertainty associated to it (the standard uncertainty is set to zero).

This function can be used for example if only the uncertainty of a quantity is needed.

1. Uncertainty: $u_x = x - \text{const}(x)$

⁸ Function names are all lower case and will only work if written exactly as shown here.

2. Relative uncertainty: $w_x = x / \text{const}(x)$, presuming $x \neq 0$

Note: The program does not check whether the `const()` function is used properly. The user is responsible for the correct usage of this function.

6.2.5 Average Function

With the function `average()`, the arithmetic mean of multiple arguments separated by comma can be evaluated. The function operates like a macro and the function call is substituted by the addition of the arguments and dividing the sum by the number or arguments.

6.2.6 Numbers

Numbers start with a digit and can be prefixed by an optional + or -. Integer numbers (e.g. 12, 256 or 10000), floating point numbers (1.25, -0.05 or 12000.8) and floating point numbers in exponential format (1.20008E4 or -5.0E-2) are allowed.

Integers: 12, 256 or 10000

Floating point numbers: 1.25, -0.05 or 12000.8

Exponential format: 1.20008E4 or -5.0E-2.

Floating point numbers entered into GUM Workbench[®] may use either a comma "," or a period "." as the decimal separator. The only exception is when entering a number directly into the equation field. Inside the equation field, the decimal separator must be a period ".".

Using commas to separate groups, such as in 1,000.85, is not supported by GUM Workbench[®]. Such entries will be rejected by the equation field as well as data fields throughout the program.

Numbers entered in exponential format will be displayed in a typographically more appealing manner in many parts of the program for example -5.0E-2 is displayed as $-5.0 \cdot 10^{-2}$.

6.2.7 User Defined Functions

The equation field is in effect a miniature programming environment. By setting up user defined functions, extra capabilities can be put into GUM Workbench^{®9}.

⁹ Defining functions is an option which adds elegance and clarity to mathematical expressions. It is an aid to the handling of long equation fields. Checking and entering a mathematical model is often easier using a function. However there is nothing which can be done with functions that cannot be described using standard expressions. Readers who do not presently see a specific purpose for user defined functions in their work are advised to just note the concept and to go on reading more about GUM Workbench[®] basic features continuing with section 6.3.

A user defined function is defined with statements in the equation field of the form:

```
function_name(a,b,c,...) = expression;
```

where (a,b,c,...) is the parameter list. The function name and parameter names follow the same rules as quantity names. There may be none, one or more parameters in the function. The expression of a function definition is subject to the same rules as expressions in the model equation itself. The expression may use the parameters, which are contained in the parentheses following the function name, it may use other quantities of the equation system or it may define its own quantities.

Subsequently, the function can be used in later parts of the equation field in a fashion similar to the built-in mathematical functions.

User defined functions are useful when the measuring situation involves calculations with significant aspects of repetition of the same mathematical structure. It also serves as a means for the user to "paste in new functionality". For this purpose, user defined functions may be kept in SMU files from which they can be copied to other SMU files as required. User defined functions may also be seen as an alternative to using interim results.

The name of a user defined function cannot be used for naming quantities or other functions later in the same equation field. Names already used for quantity names cannot be used as function names. However, while the parameter names used in a function definition may be used for other purposes, this is not recommended since this could be confusing to some readers of the uncertainty analysis.

Function names can make use of backslash as well as underscore notation. The same is true for the parameters.

Functions must be defined before they can be used. Otherwise the function call will not be recognized as a legal action, and an error message will be displayed

Function names will not appear in the list of quantities. Thus, in a simple interpretation, functions with parameters may also be viewed as a means of working with interim results without having them appear in the list of quantities.

Parameter names will not appear in the list of quantities either. If a function definition makes use of parameters not included in the parameter list, these will be interpreted as input quantities of the uncertainty analysis.

It is possible to keep functions in the equation field without using them via a call.

If a function is expressed using both symbolic parameters and input quantities, and even though the same function is not called, it is still necessary to set the input quantities to some type

and value. They need to be valid quantities of an uncertainty analysis. However, their uncertainties and values will not enter the analysis since the sensitivity coefficients are zero as long as the function is not called.

6.2.7.1 Example of a User Defined Function

This example shows the application of a user defined function for linear regression in connection with a calibration curve involving six points. The actual values of the six calibration points are labeled a, b, c, d, e and f. The corresponding six indications from the instrument are labeled A, B, C, D, E and F respectively.

Two functions need to be defined, each with 12 parameters. The following two lines need to be entered in the top of the equation field.

```
Slope(a,b,c,d,e,f,A,B,C,D,E,F) = ((a*A+b*B+c*C+d*D+e*E+f*F)
- (a+b+c+d+e+f) * (A+B+C+D+E+F)/6) / (a^2+b^2+c^2+d^2+e^2+f^2
- (a+b+c+d+e+f)^2/6);

intcpt(a,b,c,d,e,f,A,B,C,D,E,F) = (A+B+C+D+E+F)/6
- slope(a,b,c,d,e,f,A,B,C,D,E,F)*(a+b+c+d+e+f)/6;
```

These user defined functions may be used to facilitate the handling of linear regression, for instance in models of chemical analysis.

An example of calling these functions will typically involve the definition of the twelve input parameters. Here, for the sake of the example, let us just assume that the following calibration data is available:

(a,A)	=	(-1,2)
(b,B)	=	(1,-1)
(c,C)	=	(5,5)
(d,D)	=	(7,4)
(e,E)	=	(9,6)
(f,F)	=	(10,6.5)

The call:

```
SLOPE=slope(-1,1,5,7,9,10,2,-1,5,4,6,6.5);
```

will return a value of

```
SLOPE = 0.544750430292599
```

and the call:

```
INTERCEPT = intcpt(-1,1,5,7,9,10,2,-1,5,4,6,6.5)
```

will return a value of

```
INTERCEPT = 0.935456110154905
```

6.3 Independent Quantities

GUM Workbench dynamically manages the list of quantities which is generated from the *Equation* field in the *Model View* (register *Model Equation*). Usually the quantities are generated from equations separated by semicolons. The left side of an equation defines a result or interim result and the right side of an equation defines the input quantities (or interim results). Additionally GUM Workbench supports a simple declaration mechanism to declare independent quantities which may or may not be used in any of the equations. The declaration must be written in the equation field before the quantity is used in any equation. The declaration consists of a quantity name followed by a semicolon e.g. $x;$. If a quantity is no longer used in the model equation, its data will be deleted. Therefore the declaration of quantities may be used to protect the data of quantities being deleted during the development of a model.

6.4 The Name of a Quantity

The name of a quantity can consist of any combination of letters, digits, the underscore (`_`) and pairs of backslashes (`\ \`) containing predefined names of special characters. A numeric digit, however, may not appear as the first character in a quantity name. A full table of what is acceptable to write between backslashes and which special character it represents is available in Appendix D of this manual. Backslashes complete with coding may be conveniently entered using the *Insert Character* dialog (see Section 6.5.3).

Table 5: Reserved characters for mathematical control

	!	"	#	\$	%	&	,	()	*	+	,	-	.	/
0	1	2	3	4	5	6	7	8	9	:	;	<	=	>	?
@	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
P	Q	R	S	T	U	V	W	X	Y	Z	[\]	^	_
`	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
p	q	r	s	t	u	v	w	x	y	z	{		}	~	
	ı	ç	£	¤	¥	ı	§	¨	©	ª	«	¬	-	®	-
°	±	²	³	´	µ	¶	·	,	¹	º	»	¼	½	¾	¿
À	Á	Â	Ã	Ä	Å	Æ	Ç	È	É	Ê	Ë	Ì	Í	Î	Ï
Ð	Ñ	Ò	Ó	Ô	Õ	Ö	×	Ø	Ù	Ú	Û	Ü	Ý	Þ	ß
à	á	â	ã	ä	å	æ	ç	è	é	ê	ë	ì	í	î	ï
ð	ñ	ò	ó	ô	õ	ö	÷	ø	ù	ú	û	ü	ý	þ	ÿ

In Table 5, the 17 characters highlighted in gray together with the reserved function names in Table 4 constitute the means for mathematical control over the equation field. Note the character within the circle. It is not a minus sign, and entering it into the model equation will bring up error message 100.

Table 6: Characters available for writing quantity names

	!	"	#	\$	%	&	,	()	*	+	,	-	.	/
0	1	2	3	4	5	6	7	8	9	:	;	<	=	>	?
@	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
P	Q	R	S	T	U	V	W	X	Y	Z	[\]	^	_
`	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
p	q	r	s	t	u	v	w	x	y	z	{		}	~	
	ı	ø	£	¤	¥	¦	§	¨	©	ª	«	¬	-	®	¯
°	±	²	³	´	µ	¶	·	¸	¹	º	»	¼	½	¾	¿
À	Á	Â	Ã	Ä	Å	Æ	Ç	È	É	Ê	Ë	Ì	Í	Î	Ï
Ð	Ñ	Ò	Ó	Ô	Õ	Ö	×	Ø	Ù	Ú	Û	Ü	Ý	Þ	ß
à	á	â	ã	ä	å	æ	ç	è	é	ê	ë	ì	í	î	ï
ð	ñ	ò	ó	ô	õ	ö	÷	ø	ù	ú	û	ü	ý	þ	ÿ

In Table 6, the characters highlighted in gray can be used to define a quantity name. Additionally, the backslash and the underscore are highlighted by black frames. These characters play a key role for formatting quantity names using special characters. Backslash entries are used to display Greek letters and other symbols, while the underscore marks the beginning and end of characters of a subscript of a quantity name. The use of backslash or underscore for any purposes other than that described in this manual is not recommended.

Quantity names are case sensitive, thus a is different from A. The names of the built-in functions are not legal quantity names.

Parentheses, (...) and curly brackets, {...} each have their own specific meaning when entered into the equation field. Thus, they cannot be used as parts of a quantity name.

Even though quantity names can be long, the use of very long names is not recommended because of space restrictions. Some views will display only a limited portion of a long quantity name, depending on the window size in which GUM Workbench® is executed. In all instances where there is restricted space for showing a quantity name, however, display mode will be used. Quantity names which are long in edit mode because of one or several backslash entries may prove to be much shorter when displayed.

The selection of an appropriate name is up to the user but care should be taken when choosing names for quantities in order to maintain readability of the uncertainty model.

In many cases, the quantity name can be derived from the name of a physical quantity. It is also recommended to follow the notation of scientific literature and technical practice for a given quantity.

6.5 Editing the Model Equation

The model equation can be changed at any time. To do this, select the screen view *Model* and then select the register *Model Equation*. The *Equation* field holds the equation, which may now be expanded or edited.

When exiting the field, the model equation is analyzed and the quantity table is adjusted depending on the changes made to the equation. The *Equation* field can only be left if the equation is mathematically correct. If this is not the case, an error message will be displayed and the cursor is positioned at the point where the error was detected.

An error in the model equation locks the software until the error is corrected. The user must return to the equation field to correct the equation because it is not possible to activate any other parts of the software until the format of the equation is correct (e.g. save the file or to open a different SMU file are not possible).

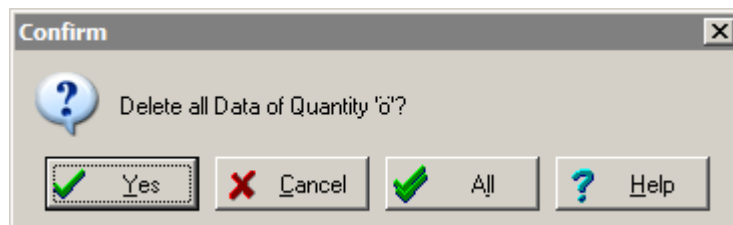


Figure 23: Confirmation message for deleting Quantities

In GUM Workbench® there are two distinctly different situations for changing the name of an input quantity:

1. If any changes to a quantity name have been introduced, the new name will replace the old name in the quantity table. After user-confirmation (see Figure 23), all data connected with the old quantity will be deleted. Selecting *All* will delete all quantities without further confirmation.
2. If a quantity should be given a new name without losing the assigned data, use the command *Renaming a Quantity* from the *Edit* menu. (Or use the keyboard shortcut Ctrl-R). Here the names of quantities introduced in the model equation and displayed in the quantity list can be renamed. It should be noted that this option is only available

in the *Edit* menu when the cursor has been placed somewhere inside of the *Equation* field.

The program cannot distinguish between a quantity name that was changed or newly added.

After renaming, the quantity appears with its new name throughout the software. Changing the name of a quantity, however, does not change it where it has been used in description or definition fields. Thus renaming is not the same as a total find-and-replace operation throughout the entire SMU file.

Text formatting in description, definition and unit fields can make use of superscripts and subscripts, through the use of the caret character (^) which acts analogously to the underscore character (_) in that it switches on and off superscripts.

In quantity names – i.e. in the equation field – however, superscripts are not possible and the caret character (^) is a reserved symbol for the mathematical operator indicating raise to a power.

6.5.1 The Command *Renaming a Quantity*

A quantity can be given a new name with the *Renaming a Quantity* command from the *Edit* menu. This command is only available when the cursor is placed in the equation field (edit mode). The name of the quantity is changed without changing any of the existing data associated with it.

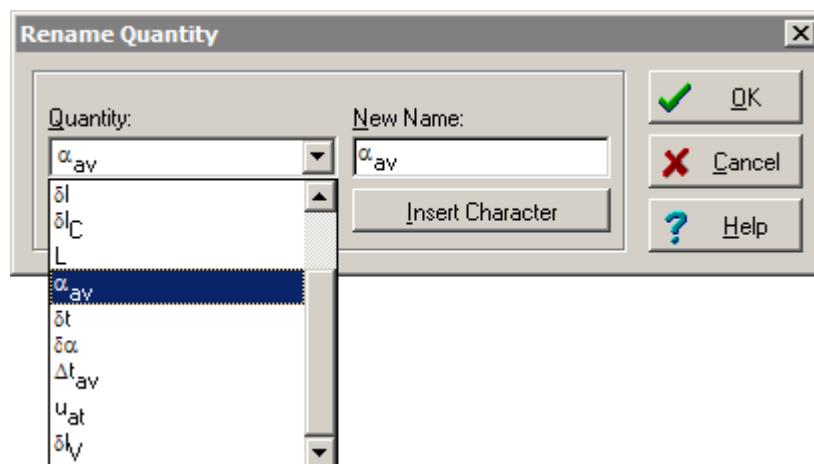


Figure 24: *Rename Quantity* dialog

To rename a quantity, select the register *Model Equation* in the screen view *Model* and place the cursor in the equation field (edit mode). Now choose *Renaming a Quantity* from the *Edit* menu or use the shortcut Ctrl-R. In the field *Quantity*, select the quantity you want to change. The field *New Name* is where the new name of the quantity should be entered. After confirming the change with OK, the quantity is renamed in the model equation and the list of quantities.


If another quantity already carries the new name, an error message will be displayed.

In the *Renaming a Quantity* dialog, an *Insert Character* button is available which provides the functionality of picking special characters in backslash entry for the new name.

Renaming a quantity with a name which is also used intrinsically in a function definition as a symbolic parameter will lead to renaming all occurrences of the name independently of whether it is a quantity or a parameter.

If the new name is so long that it extends over the edge of the field, place the cursor in the field and use the End-key to scroll to the far end of the display.

6.5.2 Insert Function Dialog

The *Insert Function* dialog can be used if the equation field is in edit mode. The dialog is available in the equation tool bar with the  button (Figure 25).

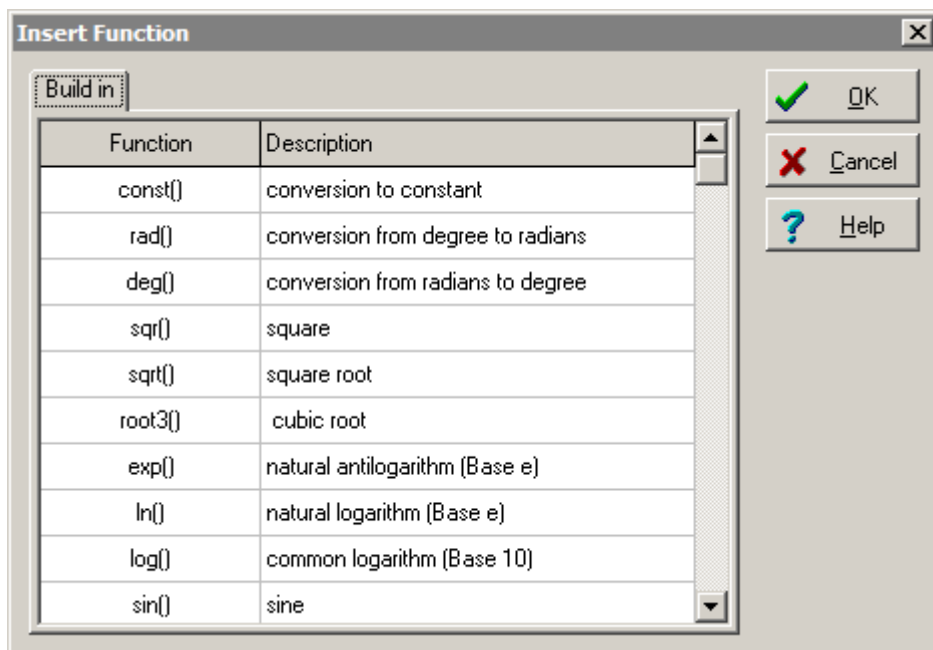


Figure 25: *Insert Function* dialog

All available build-in functions are listed. Select a function and press *OK* (or double click the function row) and the function string will be inserted in the equation field at the cursor position.

6.5.3 Insert Character Dialog


The Windows® System font contains characters that cannot be entered via the keyboard. The *Insert Character* command allows these characters to be used in a description or text field.

To insert a character, place the cursor in the text where the character should be inserted. Select the *Insert Character* command from the *Edit* menu (keyboard shortcut: ctrl-A). Choose

a character from the table and confirm the selection with OK. The selected character will then be inserted into the text.

Characters may be selected by clicking on them and then pressing OK. They may also be double-clicked or selected by using the arrow keys of the keyboard to move horizontally or vertically within the table. A double-click directly selects and inserts the character.

6.5.4 Greek and Other Special Character

Greek letters are entered in the text and equation fields by using the backslash notation. The user may optionally enter these letters via the keyboard or by opening the *Insert Character* window using the menu, the control-A shortcut, or by pressing the  button which appears above the model equation field.

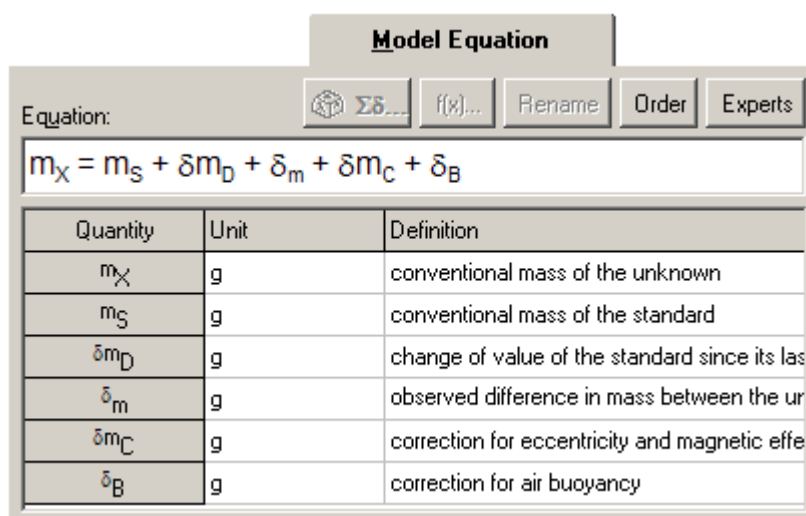
The names of Greek letters are spelt differently in languages other than English. For compatibility reasons between international editions of GUM Workbench®, however, it is necessary that all users use the codes provided in Appendix D. Changing the language of the interface will not change the codes.

6.6 Examples of Model Equations

The following examples demonstrate how the equation field should be used. Please consult the SMU files in the examples directory for additional examples.

6.6.1 Example 1

Figure 26 shows the model equation from the file S02.SMU "Calibration of a weight of nominal value 10 kg".



The screenshot shows a dialog box titled "Model Equation". It contains an "Equation:" field with the text $m_X = m_S + \delta m_D + \delta m + \delta m_C + \delta B$. Below the equation field is a table with three columns: Quantity, Unit, and Definition.

Quantity	Unit	Definition
m_X	g	conventional mass of the unknown
m_S	g	conventional mass of the standard
δm_D	g	change of value of the standard since its last
δm	g	observed difference in mass between the ur
δm_C	g	correction for eccentricity and magnetic effe
δB	g	correction for air buoyancy

Figure 26: Model equation example 1 (EA-4/02-S02)

The equation when seen in the edit mode is:

$$m_X = m_S + \backslash\delta\backslash m_D + \backslash\delta\backslash m + \backslash\delta\backslash m_C + \backslash\delta\backslash m_B$$

Names starting with the letter "m" represents mass values. Indices provide the means to differentiate between the different mass quantities. Names for mass correction quantities, i.e. mass values that are small compared to the nominal value or main value, starts with "\delta\m". A name starting with "\Delta\" would represent a measured difference in mass. The name starting with "\delta\" represents correction for a factor not directly related to mass.

6.6.2 Example 2

Figure 27 shows the model equation from the file S03.SMU "Calibration of a nominal 10 kW standard resistor".

Model Equation		
Equation: Σδ... f(x)... Rename Order Experts		
$R_X = (R_S + \delta R_D + \delta R_{TS}) \times r_C \times r - \delta R_{TX}$		
Quantity	Unit	Definition
R_X	Ω	resistance of the unknown resistor
R_S	Ω	resistance of the reference
δR_D	Ω	change of the resistance of the reference si
δR_{TS}	Ω	temperature related resistance deviation of t
r_C		correction factor for parasitic voltages and in
r		= R_X/R_S ratio of the indicated resistance fc
δR_{TX}	Ω	temperature-related resistance deviation of t

Figure 27: Model equation example 2 (EA-4/02-S03)

The equation when seen in the edit mode is:

$$R_X = (R_S + \backslash\delta\backslash R_D + \backslash\delta\backslash R_{TS}) \times r_C \times r - \backslash\delta\backslash R_{TX}$$

Names starting with the letter R represent electrical resistance. Indices differentiate between the different resistances. Names starting with the letter r indicate a relation between two resistances.

6.7 Interim Results

The equations for interim results have the same structure as the equations for results. They are entered in the field *Equation* in the screen view *Model* in the Register *Model Equation*. The order of the equations in the *Equation* field is arbitrary. All equations must be separated by a semicolon (;).

Although not required, it is considered good practice to insert a line-break by inserting a carriage return (enter key) after each semicolon in the equation field.

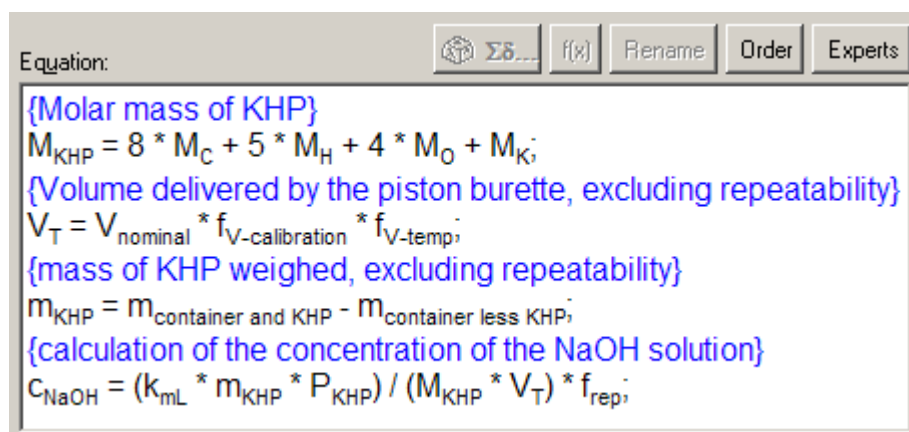
For interim results the following rules must be followed:

1. In Version 1.3 only one quantity of the type *Result* can exist. Every interim result must be used on the right hand side of at least one equation. Version 2.3 and 2.4 can have any number of results.
2. Every interim result must be calculable without any direct or indirect use of its own value. Mathematical loops or recursion are not allowed. A linear calculation order for the equation system should exist.
3. The number of interim results is limited only by the maximum number of quantities (512) and the amount of system memory (This means that there is no limit in practice).
4. An interim result may be used multiple times on the right hand side of other equations.

For interim results, GUM Workbench® Version 1.3 does not perform a separate uncertainty calculation. The value, however, is listed in the budget for transparency and traceability reasons.

6.7.1 Example of Interim Results

The example for a calculation of the concentration of a sodium hydroxide solution (EURACHEM A2.SMU) illustrates the use of quantities as interim results.



The screenshot shows a software window titled 'Equation:' with a toolbar containing icons for a globe, a summation symbol, a function symbol f(x), and buttons for 'Rename', 'Order', and 'Experts'. The main text area contains the following model equation with interim results in blue text:

$$M_{\text{KHP}} = 8 * M_{\text{C}} + 5 * M_{\text{H}} + 4 * M_{\text{O}} + M_{\text{K}};$$

$$V_{\text{T}} = V_{\text{nominal}} * f_{\text{V-calibration}} * f_{\text{V-temp}};$$

$$m_{\text{KHP}} = m_{\text{container and KHP}} - m_{\text{container less KHP}};$$

$$C_{\text{NaOH}} = (k_{\text{mL}} * m_{\text{KHP}} * P_{\text{KHP}}) / (M_{\text{KHP}} * V_{\text{T}}) * f_{\text{rep}};$$

Figure 28: Model equation with interim results

The following equations have been entered by the user into the equation field:

```
{Molar mass of KHP}
M_KHP = 8 * M_C + 5 * M_H + 4 * M_O + M_K;
{Volume delivered by the piston burette, excluding
repeatability}
V_T = V_nominal * f_V\minus\calibration * f_V\minus\temp;
```

```

{mass of KHP weighed, excluding repeatability}
m_KHP = m_container\sp\and\sp\KHP - m_container\sp\less\sp\KHP;
{calculation of the concentration of the NaOH solution}
c_NaOH = (k_mL * m_KHP * P_KHP) / (M_KHP * V_T) * f_rep;

```

The quantity c_{NaOH} is the result. The quantities M_{KHP} , V_T and m_{KHP} are interim results. All other names represent input quantities or constants.

By splitting the model equation into four algebraic equations, the legibility of the equation has been improved. Interim results can be used more than once in other equations which can lead to a more compact equation system. The physical, or in this case, chemical motivation that led to the equations has also become easier to follow.

6.8 List of Quantities

The list of quantities is displayed below the equation field. It contains a *Unit* field and a *Definition* field for every quantity. The entries of the quantity names are generated automatically when the equation field is left. The *Unit* and the *Definition* columns can be edited freely and may contain a maximum of 255 characters each.

Double-clicking in the list of quantities will bring up the data-screen for the quantity in the double-clicked line.

The units are included for the convenience of the user. It is the responsibility of the user to handle measurement units correctly.

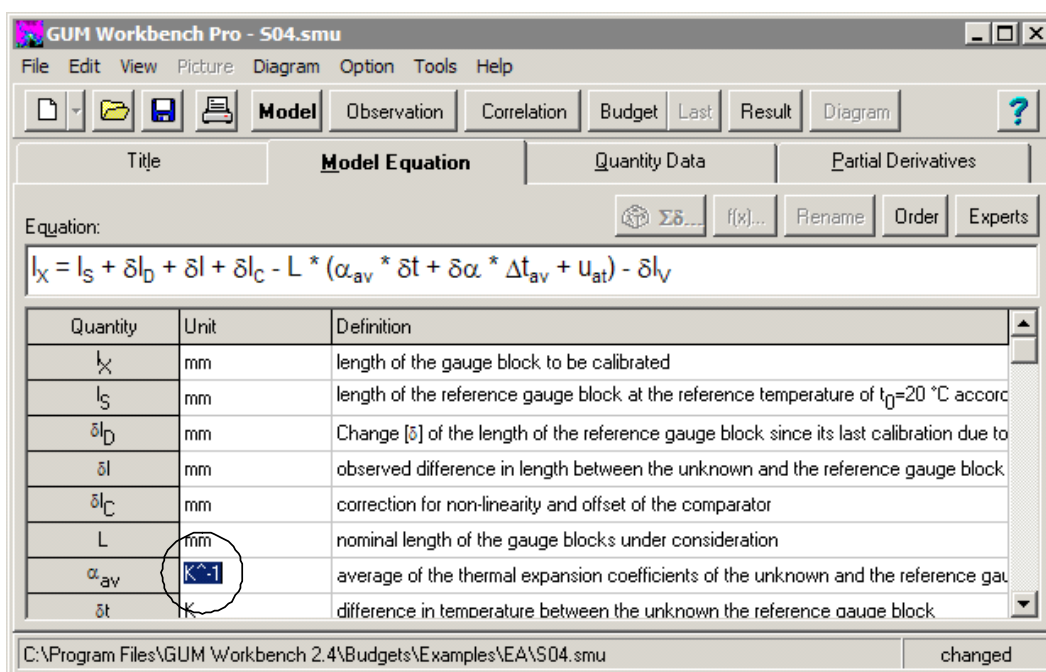


Figure 29: List of quantities with unit field in edit mode

The definition field is intended for a short characterization of the quantity. It is displayed in conjunction with the quantity data (register *Quantity Data*) and during the editing of observations (screen view *Observation*), where it acts as a heading to the data for the quantity.

Note that in the preceding screenshot (Figure 29), a unit field (circle) is in edit mode, while the definition fields are in display mode. Notice the δ character in the *Definition* field of the third row. In the unit field, the circumflex symbol is used to indicate a superscript value.

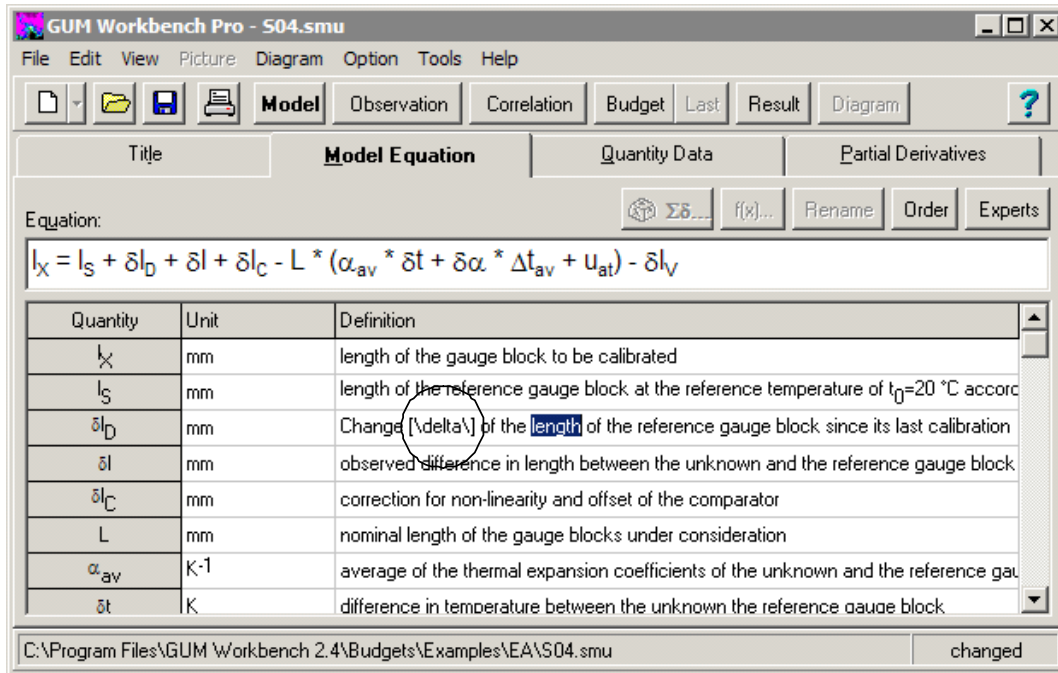


Figure 30: List of quantities with definition field in edit mode

In Figure 30 the unit field is now in display mode showing the inverse Kelvin in typographical display, while the definition field at the circle is in edit mode. Here the Greek letter now appears as a backslash entry.

6.9 Use of Units

A unit may be associated with every quantity in the model equation. This unit may be entered in the table of quantities. The unit entry is a text field with a maximum of 255 characters. By default all units are empty. The chosen units are printed or displayed with any input and output of values in the GUM Workbench®. Underscore and backslash entries are available for defining unit names. In the case of importing a quantity from another SMU file, GUM Workbench® does check whether units are used correctly. In addition version 2.4 supports SI unit validation (see Section 13).

7 Quantities

Figure 31 shows a graphical overview of the different types of quantities, each with their own options which will be explained in detail in the following pages.

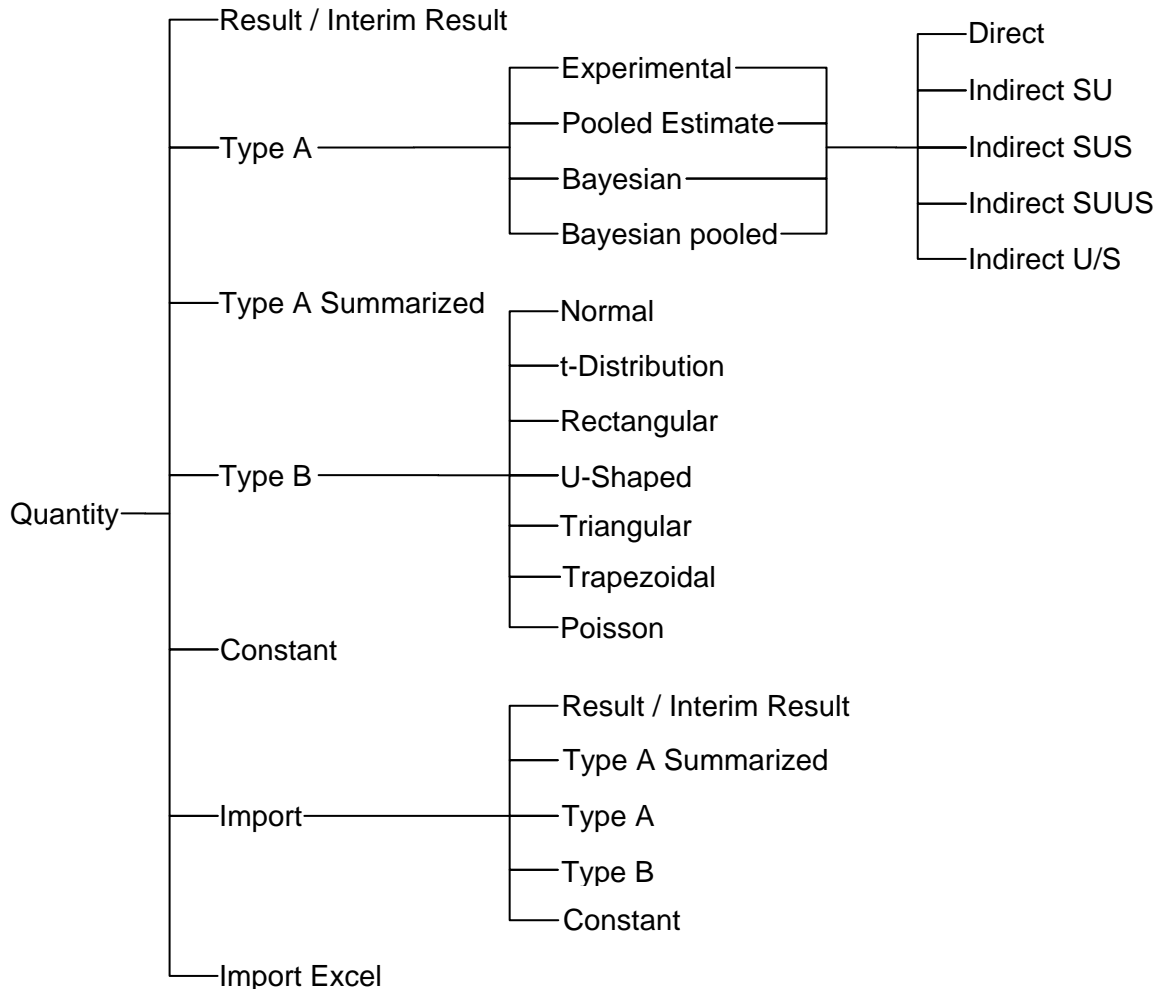


Figure 31: Quantity type tree

Predefined rules for defaulting in the decision tree are built into GUM Workbench®.

1. Results and Interim results will be unambiguously determined by the equation and will take the appropriate type.
2. The constants π and e will be defaulted to their values.
3. All other quantities will be defaulted to *Type B, Rectangular*.
4. When a quantity is changed to *Type A* the *Uncertainty Evaluation* will default to *Experimental* and the *Method of Observation* field will default to *Direct*.

The user may override these defaults except for results and interim results.

7.1 Quantity Data View

The screen *Quantity Data* in the screen view *Model* holds the relevant data for every quantity of the analysis. To edit the data of a quantity, it should first be selected at this register. The current data is displayed and may be edited.

Figure 32: *Quantity Data* register

Figure 32 shows the *Quantity Data* register. The quantity is selected by clicking on the left hand side tab of the screen (*Select Quantity*). The right hand side now displays the data associated with this quantity.

The top gray field of the register shows the short definition of the quantity taken from the list of quantities. The evaluation type of the quantity can be chosen from a list in the *Type* field.

There is room for entering a description of the incomplete knowledge of the quantity and extracted mathematical information in the *Description* field. In addition version 2.4 supports pictures which will be printed in the report.

The displayed fields, including the *Type* field, depend on the selected quantity type. These fields will be explained in the following pages.

7.1.1 Selection of a Quantity

A quantity is selected using the tabs in the *Quantity Data* register in the *Model* screen view. Once selected, the data of this quantity can be edited. Quantities can be selected with a mouse click or the Cursor-UP- and Cursor-DOWN keys. If there are more quantities than the screen can show at one time, a scrollbar will appear on the left side of the tabs.

7.1.2 Description Field for Quantities

In the *Quantity Data* register, a description field is present for each quantity. These fields may be used to enter information on and explanations for each quantity, e.g. where the quantity originates and how the data have been derived.

The purpose of the *Description* field is to provide a place where the user may store comments, describing the incomplete knowledge of the current quantity and the resulting mathematical information, and supply further explanations which should be made available for documentation.

- For evaluation of Type A uncertainty contributions, a description of the measurements may be entered.
- For evaluation of Type B uncertainty contributions, the choice of distribution may be justified.

The descriptive texts will be printed along with the data for the quantity in the report. Upon printing, the text is automatically justified to match the width of the printer. To force a new paragraph in the printout, the description field should contain an empty line (see Section 10.1).

7.1.3 Selection of a Quantity Type

Within the *Type* field (screen view *Model*, register *Quantity Data*), every quantity is assigned to an evaluation type. The evaluation type controls the processing of the data.

Table 7: Quantity Data Types

Quantity Type	Description	Comment
Result	The measurand	The evaluation type of the result (or output) quantity is set automatically by the program. No other quantity can be set to this evaluation type.
Interim result	Additional measurand	Complex model equations can be simplified with interim results. This evaluation type is set automatically. In version 2.3 and 2.4 Interim results may have a budget and can be included in the results list.
Type A	Repeatedly observed quantity determined by means of a statistical analysis	The value of the quantity is evaluated by a statistical analysis of a series of observations. For quantities of this evaluation type, the method of pre-calculation and the number of observations must be entered. Optionally the standard deviation can be predetermined.

Quantity Type	Description	Comment
Type A summarized	For quantities which are repeatedly observed, but where the current data does not include the details of a statistical analysis, but rather a summary of the analysis performed elsewhere	For Type A Summary, GUM Workbench® does not perform the statistical analysis. Only three numbers need to be entered.
Type B	A quantity which is not being repeatedly observed and not determined using a statistical analysis (known uncertainty or uncertainty evaluation directly from incomplete knowledge)	For these quantities, a known or assumed distribution must be selected. The parameters of the distribution must be entered.
Constant	Mathematical constant	For mathematical constants (no uncertainty), the value must be entered.
Import	Imported quantity (when using the result or an input quantity of an existing uncertainty analysis as an input quantity in the current file)	The filename of an existing uncertainty analysis is required, and the name of the imported quantity must be selected.
Import Excel	Imported quantity data from MS Excel	The filename of an existing Excel-file is required. The cells in the Excel file which contain the data should be specified.

Note: The field *Type* always displays the same options. Although included in the list, the presence of *Result* and *Interim result* does not mean that quantities which are not a result or an interim result can be given such status using this command. It is also impossible to change the type of quantities which in the sense of the model equation are a result or an interim result. It is the logic of the model equation which determines – at all times – which quantity is the result and which quantities – if any – are interim results.

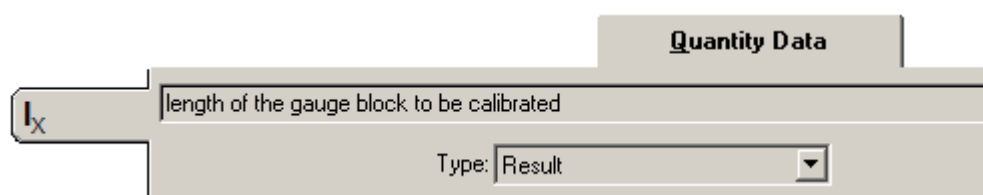


Figure 33: *Quantity Data* for a result quantity

7.2 Result

Figure 33 shows the *Quantity Data* for a result quantity. Apart from the description field, there are no associated data to enter with the result.

The result is equal to the output quantity. The numerical value and uncertainty of the result can be seen in the view *Budget*. Several display options are additionally supported in version 2.3 and 2.4. See Section 9.1 for the details.

7.3 Interim Result

Figure 34 shows the Quantity Data for a *Interim Result* quantity. These quantities are displayed in a fashion similar to that for the *Result*.

Figure 34: *Quantity Data* for an interim result

Again only the description field can be edited. The numerical value and uncertainty of interim results can be seen in the *Budget View*. For additional result display options in version 2.3 and 2.4, see Section 9.1.

7.4 Type A Quantities Determined by Statistical Methods

For repeated observations evaluated by statistical methods, the following data are necessary in order to define the details of the evaluation (see Figure 35).

Figure 35: *Quantity Data* for a quantity of type A

1. The field *Method of Observation* selects the relevant variety of pre-calculation. The default value is *Direct* observation with no pre-calculation.
2. The field *Number of Observations* contains the number of observations used for evaluation. The actual number of readings is determined by combining the number of observations with the method of observation.
3. The field *Uncertainty Evaluation* determines the method used for evaluating the uncertainty. In this field the user may select whether experimental determination of the standard deviation or entry of a pooled estimate from a prior evaluation should be used for the given Type A quantity.

4. If *Pooled Estimate* is selected in the field *Uncertainty Evaluation*, the values from a prior evaluation must be entered the fields *Standard Deviation* and *Degrees of Freedom*.

The field *Number of observations* can take values ranging from 2 to 9999, if the field *Uncertainty Evaluation* has been set to *Experimental*.

If, however, *Pooled Estimate* is selected, the valid range for the number of observations is from 1 to 9999.

7.4.1 Type A Pooled Estimate

GUM Workbench® supports the uncertainty evaluation option *Pooled Estimate* to combine a pre-known experimental standard deviation with a data series from an experiment.

Figure 36: *Type A* evaluation with option *Pooled Estimate*

To use the pooled estimate option, the *Type* of the quantity needs to be *Type A* and the *Uncertainty Evaluation* field must be set to *Pooled Estimate* (see Figure 36). Two additional fields will be provided to input the already known experimental standard deviation and the degrees of freedom for this standard deviation. The degrees of freedom will be used as a weighting factor to combine the already known standard deviation with the standard deviation of the actual data series

$$s_{\text{pooled}} = \sqrt{\frac{s_{\text{exp}}^2 \cdot (n - 1) + s_{\text{pre}}^2 \cdot \nu_{\text{pre}}}{\nu_{\text{pooled}}}} \quad \text{with } \nu_{\text{pooled}} = n - 1 + \nu_{\text{pre}} \quad (1)$$

Where s_{pooled} is the pooled standard deviation, s_{exp} is the experimental standard deviation of the current data series of n observations, s_{pre} is the given experimental standard deviation with the degrees of freedom ν_{pre} known before the measurement and ν_{pooled} are the degrees of freedom of the pooled standard deviation s_{pooled} . The standard uncertainty of the mean is s_{pooled} divided by the square root of n .

7.4.2 Type A Bayesian Extension

GUM Workbench® supports an extension of the *Type A* evaluation to include the Bayesian evaluation method as described in the Supplement 1 to the Guide to Expression of Uncertainty in Measurement. The Bayesian evaluation is a useful extension of the *Type A* for small numbers of observations (usually smaller than 10). It is possible with the Bayesian evaluation to completely avoid using of the effective degrees of freedom calculus in the uncertainty evaluation.

Figure 37: *Type A Bayesian* evaluation with 4 observed values

7.4.2.1 How to use the Bayesian Evaluation?

The Bayesian evaluation is available for quantities with the *Type A* and *Type A summarized* type. To use the Bayesian evaluation, choose either *Type A* or *Type A summarized* in the *Type* selection box in the quantity data of the quantity (*Model View*, *Quantity Data* page).

When *Type A* is selected, two additional options become available in the *Uncertainty Evaluation* selection box (see Figure 37). To activate the Bayesian evaluation, choose either *Bayesian* or *Bayesian pooled* for *Uncertainty Evaluation*. An additional selection box will be visible which allows the user to select an *Assumed Distribution*. Currently only the *Normal* distribution is supported. The Bayesian evaluation is based on an assumed distribution. The standard uncertainty will be extended by an additional factor (for details see Supplement 1 to the GUM [2])

$$s_{\text{Bay}} = s_{\text{exp}} \cdot \sqrt{\frac{n-1}{n-3}}, \quad (2)$$

where s_{Bay} is the Bayesian standard deviation and s_{exp} is the experimental standard deviation of the current data series and n is the number of values in the data series. The number of degrees of freedom of the quantity will be assumed to be infinite. The *Number of Observations* n must be greater than 3 for the Bayesian evaluation. The standard uncertainty of the mean is s_{Bay} divided by the square root of n .

7.4.2.2 Type A Bayesian Pooled

If *Bayesian pooled* is selected in the *Uncertainty Evaluation* selection box, two additional input fields become available (see Figure 38). The user needs to enter an experimental standard deviation and the degrees of freedom associated with it. The degrees of freedom must be greater than 2.

Figure 38: *Type A Bayesian pooled* evaluation with 2 observed values

The given experimental standard deviation and the observed experimental standard deviation from the data series are combined (pooled) and the standard deviation value is calculated based on the Bayesian extension

$$s_{\text{Bay,pooled}} = \sqrt{\frac{s_{\text{exp}}^2 \cdot (n - 1) + s_{\text{pre}}^2 \cdot \nu_{\text{pre}}}{n + \nu_{\text{pre}} - 3}}, \quad (3)$$

where $s_{\text{Bay,pooled}}$ is the pooled Bayesian standard deviation, s_{exp} is the experimental standard deviation of the current data series of observations, n is the number of observations and s_{pre} is the given experimental standard deviation with the degrees of freedom ν_{pre} known before the measurement.

The standard uncertainty of the mean is $s_{\text{Bay,pooled}}$ divided by the square root of n .

Note: The Bayesian uncertainty evaluation for Type A is not part of the original GUM published in 1993. The user has the responsibility for using this option correctly. The option should not be used in cases when a full formal GUM (1993) compliance is required.

7.4.3 Type A Summarized

The *Type A summarized* option should be used in situations where the uncertainty of the quantity is estimated using statistical methods, but where the same statistical calculation has been performed outside of GUM Workbench®.

The screenshot shows the 'Quantity Data' dialog box. At the top, it says 'observed difference in length between the unknown and the reference gauge block'. Below this, there are several fields:

- Type: Type A summarized (dropdown menu)
- Uncertainty Evaluation: Standard (dropdown menu)
- Mean Value: -94E-6 mm
- Standard Uncertainty: 4.75E-6 mm
- Degrees of Freedom: 13

Figure 39: *Type A summarized* with standard uncertainty input

The option *Uncertainty Evaluation* controls which data need to be entered. With the selection *Standard*, the *Mean Value*, the *Standard Uncertainty*, and the *Degrees of Freedom* should be specified (see Figure 39). There are no observations to be entered, and unlike other Type A quantities, a quantity of this type will not appear on a tab in the screen view *Observation*.

The screenshot shows the 'Quantity Data' dialog box. At the top, it says 'observed difference in length between the unknown and the reference gauge block'. Below this, there are several fields:

- Type: Type A summarized (dropdown menu)
- Uncertainty Evaluation: Experimental (dropdown menu)
- Mean Value: -94E-6 mm
- Experimental Standard Deviation: 10.6E-6 mm
- Number of Observations: 5

Figure 40: *Type A summarized* with experimental standard deviation input

With *Uncertainty Evaluation* set to *Experimental*, the *Mean Value*, the *Experimental Standard Deviation*, and the *Number of Observations* should be entered in the appropriate fields (see Figure 40).

Quantity Data

observed difference in length between the unknown and the reference gauge block

Type: Type A summarized

Uncertainty Evaluation: Bayesian

Assumed Distribution: Normal

Mean Value: -94E-6 mm

Experimental Standard Deviation: 7.51E-6 mm

Number of Observations: 5

Figure 41: *Type A summarized Bayesian evaluation*

If the *Uncertainty Evaluation* is set to *Bayesian*, the Bayesian extension is supported. The Bayesian extension is based on an *Assumed Distribution*. Currently only a *Normal* distribution is supported. The *Mean Value*, the *Experimental Standard Deviation*, and the *Number of Observations* should be entered (see Figure 41) and the calculation is done as discussed in section 7.4.2.

7.4.4 Method of Observation

Observations needed for an analysis are not always taken directly. In laboratories calibrating weights, it is common practice to alternate between weighing the unknown mass and the reference mass. The observation is then defined as the difference between the values for each of two observations taken one after the other. Therefore preprocessing for repeated observations is possible.

GUM Workbench[®] allows for four different preprocessing situations.

7.4.4.1 Direct

This option should be used when there is no need for preprocessing. Observations are taken directly as they are. The number of readings is equal to the number of observations.

7.4.4.2 Indirect SU

This option should be used when each observation requires measurements to be performed in cycles. The reference value and the unknown value are measured alternately. The observation is calculated as the unknown value (U) minus the standard value (S)). The number of readings is two times the number of observations.

7.4.4.3 Indirect SUS

This option should be used when each observation requires measurements to be performed in cycles. First the reference value is measured, next the unknown value is measured and finally the reference value is measured again. The observation is calculated as the unknown value (U) minus the mean of the two standard values (S...S). The number of readings is three times the number of observations.

7.4.4.4 Indirect SUUS

This option should be used when each observation requires measurements to be performed in cycles. First the reference value is measured, next the unknown value is measured twice and finally the reference value is measured again. The observation is calculated as the mean of the two unknown values (UU) minus the mean of the two standard values (S...S). The number of readings is four times the number of observations.

7.4.4.5 Indirect U/S

This option should be used when each observation requires measurements to be performed in cycles. The reference value and the unknown value are measured alternately. The observation is calculated as the unknown measurand (U) divided by the standard value (S). The number of readings is two times the number of observations.

There is more information on entering observations in Section 8.

7.5 Type B: Quantities Determined by Other Than Statistical Methods.

For quantities, which are not determined by means of statistical methods, a known or assumed distribution must be given. Additional parameters of the selected distribution will be requested.

Table 8: Summary of the supported distributions for type B

Distribution	Description
Normal	The Quantity can be described by a normal distribution. Value, expanded uncertainty and coverage factor are needed. The degrees of freedom are set to a value to >100 by default.
t-Distribution	Similar to normal distribution. Value, standard uncertainty and degrees of freedom are needed.
Rectangular	The Quantity can be described by a rectangular distribution. The mean value and the half-width of the distribution are needed. The degrees of freedom are infinite by definition.
U-shaped	The Quantity can be described by a U-shaped distribution. The mean value and the half-width of the distribution are needed. The degrees of freedom are infinite by definition.
Triangular	The Quantity can be described by a triangular distribution. The mean value

Distribution	Description
	and the half-width of the distribution are needed. The degrees of freedom are infinite by definition.
Trapezoidal	The Quantity can be described by a trapezoidal distribution. The mean value, the half-width of the distribution and the uniformly distributed fraction (shape factor) are needed. The degrees of freedom are infinite by definition.
Poisson	The standard uncertainty is equal to the square root of the expectation value.

In the following sections, additional explanations may be found on the use of GUM Workbench® with the seven distributions listed above.

7.5.1 Normal Distribution

This option is used in situations where the data for the input quantity come from an uncertainty analysis, a certificate or an estimation based on scientific facts, when data assigned to the quantity is normally distributed, and when the mean value and mean variation is known with sufficient statistical certainty.

The screenshot shows the 'Quantity Data' dialog box. At the top, there is a title bar 'Quantity Data'. Below it, a text field contains the description: 'length of the reference gauge block at the reference temperature of $t_0=20\text{ °C}$ according to'. To the left of the dialog is a small icon with the letter 'S'. The main area of the dialog contains several input fields: 'Type' is a dropdown menu set to 'Type B'; 'Distribution' is a dropdown menu set to 'Normal'; 'Value' is a text field with '50.000020' and a unit 'mm' to its right; 'Expanded Uncertainty' is a text field with '30E-6' and a unit 'mm' to its right; and 'Coverage Factor' is a text field with '2.0'.

Figure 42: *Quantity Data* for *Type B Normal* distribution

The fields *Value*, *Expanded Uncertainty* and *Coverage Factor* should be filled in with the relevant data. The degrees of freedom are automatically set to >100 . If, for a normally distributed value, only the standard uncertainty is stated, the *Coverage Factor* should be given as 1.0.

7.5.1.1 The Fifty-Fifty-Technique

Even when rather vague knowledge concerning an uncertainty component is available, it may be transformed into a standard uncertainty. To do so, the method known as the fifty-fifty technique is often quite useful. In GUM Workbench®, this can be done by defining the relevant quantity as a *Type B* and *Normal*.

Let us say that this knowledge could be best expressed as: "There is a fifty-fifty probability that the value of the quantity is between A and B ". This would enter the uncertainty analysis in the following manner:

- Calculate $(A + B)/2$ and enter into the field *Value*.
- Calculate $(B - A)/2$ and enter into the field *Expanded Uncertainty*.
- Enter 0.676 in the field *Coverage Factor*.

7.5.1.2 Note on the Fifty-Fifty-Technique

Let the input quantity be denoted by X with the best estimate of X being x . Now consider a case where one wishes to express available knowledge based on qualified guessing. If there is a fifty-fifty probability that the value of the quantity is between A and B , the probability is 50% for the quantity to be contained in the interval.

If there are no obvious indications that the quantity should not be normally distributed, the best estimate of the value of the quantity is the center of the interval, $(A + B)/2$.

In the uncertainty analysis one enters a standard uncertainty of $U(x) = 1.48 \times a$, where $a = (B - A)/2$. This is correct, since for a normal distribution with expectation value x and standard deviation s , approximately 50% of the distribution is contained within the limits $x \pm s / 1.48 = x \pm s \times 0.676$

In case – in a related situation – the qualified guessing can be expressed in the form that "there is about a two out of three chance that the value of X lies in the interval A between and B ", the same values for *Value* and *Expanded Uncertainty* as above are used, but the field *Coverage Factor* should be filled in by the number 1.0.

(In the GUM-method, this technique is introduced in clauses 4.3.5 and 4.3.6).

7.5.2 t-Distribution

This option is used in situations, where the data for the input values comes from an uncertainty analysis, a certificate or an estimate based on scientific facts.

Figure 43: *Quantity Data* for *Type B t-Distribution*

If we assume that the input values are distributed normally, but we do not know the mean value or the standard distribution with enough statistical certainty (because the number of observations is too small), we can assume a t-distribution (or Student-distribution) for the distribution of values with the stated degrees of freedom. To do this, data for *Value*, *Standard Uncertainty* and *Degrees of Freedom* are needed.

7.5.3 Distributions with an Upper and Lower Limit

This option is used in situations, where the data for the input values comes from an uncertainty analysis, a certificate or estimation based on scientific facts. The distribution of data assigned to input values is rectangular, triangular or U-shaped.

Figure 44: *Quantity Data* for distributions with an upper and lower limit

The mean value (*Value* field) and the half span between limits of the variability of the quantity (*Halfwidth of Limits* field) are needed.

7.5.4 Trapezoidal Distribution

In situations where an input value is distributed equally over a certain range but where the limits of that range are not well known, the trapezoidal distribution may be used.

The screenshot shows the 'Quantity Data' dialog box with the 'Trapezoidal distribution' selected. The fields are as follows:

Field	Value
Type	Type B
Distribution	Trapezoidal
Value	2.5
Halfwidth of Limits	1
Shapefactor	0.7

Figure 45: *Quantity Data* for *Trapezoidal* distribution

The shape factor β (ranges from 0 to 1) determines the width of the section over which the distribution is even, compared to the total width. All distributions between rectangular ($\beta = 1$) and triangular distribution ($\beta = 0$) are possible (see Figure 46).

To use the trapezoidal distribution, the following data should be entered into GUM Workbench® (see Figure 45): The *Value* x_i , the half-width of the distribution of the quantity (*Halfwidth of Limits*) a , and the *Shapefactor* β .

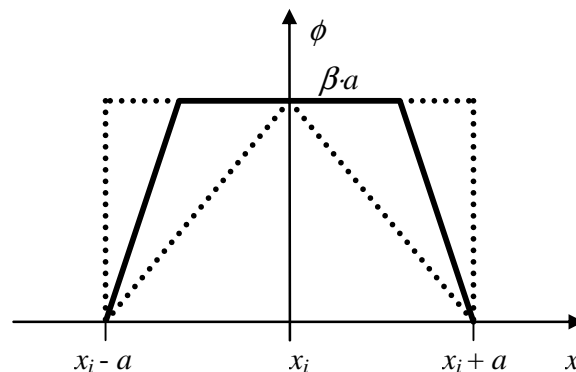


Figure 46: Trapezoidal distribution

It is possible to enter the extreme values of the shape factor as 0 and 1, whereby the distribution becomes rectangular and triangular respectively. However in these extreme cases it is advisable to use the triangular or rectangular distribution directly.

7.5.5 Poisson Distribution

Only the expectation value needs to be entered with the Poisson distribution (see Figure 47).

Figure 47: *Quantity Data* for *Poisson* distribution

The standard uncertainty is equal to the square root of the expectation value.

7.6 Constant

Quantities of type *Constant* are used for named constants in the model equation. Quantities of this type are not associated with any uncertainty and by definition they have infinite degrees of freedom. In practice these are often reference or calibration values the definition of which does not contribute any uncertainties.

Figure 48: *Quantity Data* for *Constant*

The constant given in the *Value* field must be expressed in the correct unit.

In the model equation, it is also possible to enter constants without unit directly as numbers entered in the equation. For constants entered directly into the equation field, the decimal separator must be the point ('.').

7.7 Working with Imported Quantities

GUM Workbench® allows the user to reuse input values and the results of other uncertainty analyses previously saved as SMU files for the current analysis.

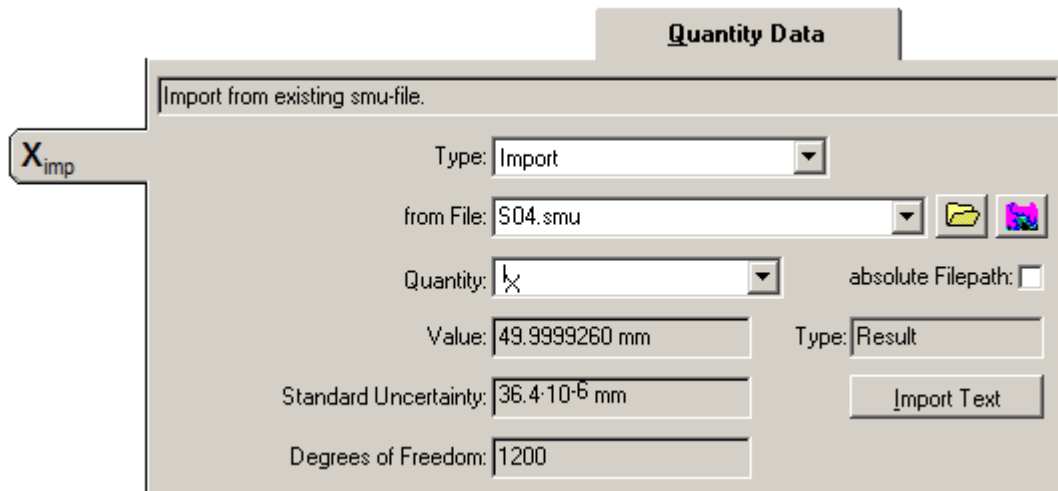


Figure 49: Quantity Data for Import

This is done at the register *Quantity Data* by selecting *Import* in the *Type* field. Next the filename of the SMU file should be typed in the *from File* field. The *Quantity* select box below it now contains all those quantities from the SMU file which are available for import, and the relevant quantity should be selected. Only those quantities which are imported quantities themselves will not be available for import.

The unit of the imported value must match the unit given in the list of quantities for the quantity which should use the data.

- To use values from another uncertainty analysis, the data must be available in a saved file.
- Select *Import* at the *Type* field for the quantity that should use the imported values.
- The name of the import file is given in the *from File* field. Clicking on the folder icon brings up an *Open* dialog to help locate the file.
- Select the quantity you want to import from the *Quantity* field. The type of the selected quantity will be stated next to that field.
- The fields *Value*, *Standard Uncertainty* and *Degrees of Freedom* now display the current data for the imported quantity. If the saved uncertainty analysis is changed, the data will be updated automatically upon opening.

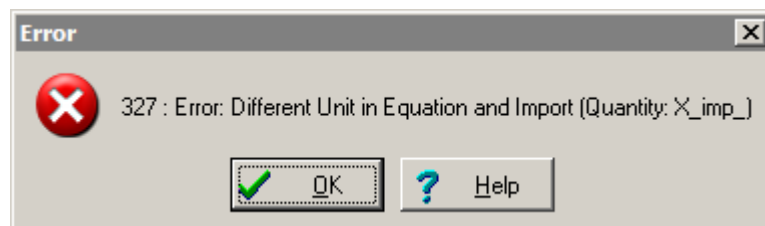




Figure 50: Error message for unit mismatch

GUM Workbench® performs a limited check on units, when a quantity is imported. If there is a mismatch, the error message in Figure 50 will be displayed.

The relative position of the source file and the importing file should be maintained if the *absolute Filepath* option is not activated. The folder structure in which they are placed may be moved as a whole, or overlying folder names may be changed, but they should not be moved relative to each other. Otherwise GUM Workbench® will no longer know where to find the source field when the importing file is opened, which leads to error 319. Source files should not be moved at all if the *absolute Filepath* option is activated.

7.7.1 Search for an Uncertainty Analysis

The  button helps to find the file. In the open dialog select the saved analysis you want and confirm your choice with *OK*. A quantity which is an imported quantity in its file cannot be imported from that file, but should be grabbed from the file in which it resides. The imported analysis can be opened in another GUM Workbench® window by clicking on the  button.

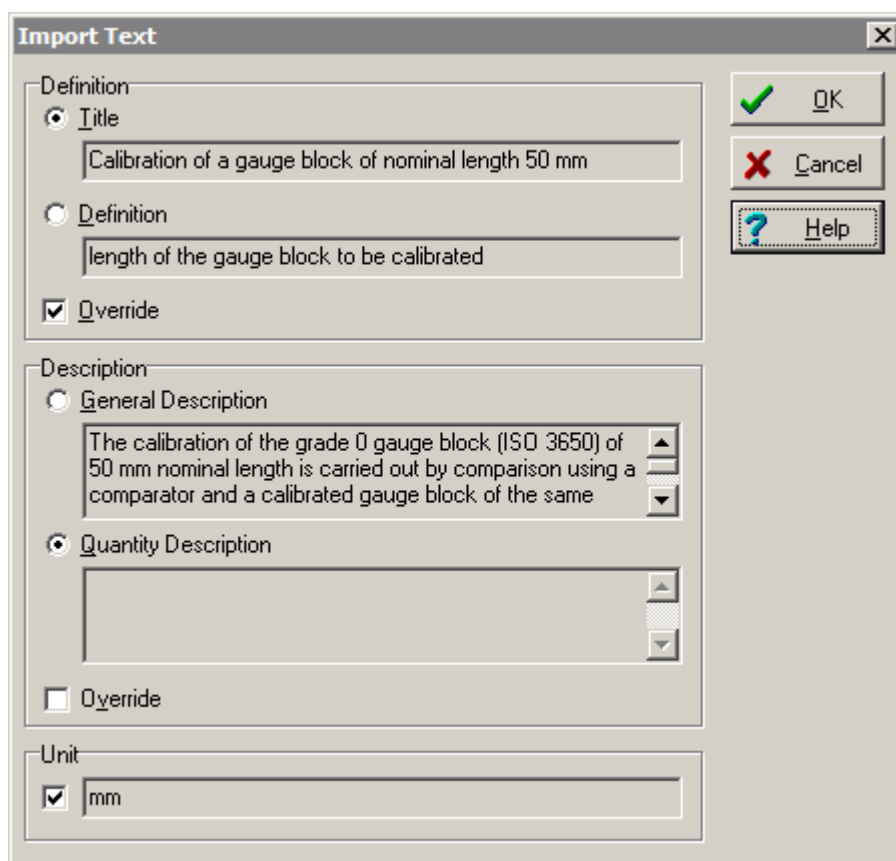


Figure 51: *Import Text* dialog

7.7.2 Importing Texts Associated With a Quantity

While GUM Workbench® automatically imports the data required for uncertainty analysis, importing of the texts associated with the source quantity is optional and takes place only

upon user interaction. The *Import Text* button in Figure 49 opens the *Import Text* dialog in Figure 51.

Which texts are available for import depends on the type of the quantity the data should be imported from.


- When importing a result quantity, it is possible to import the title, the general description, the definition and the description for the quantity.
- When importing an input quantity, the definition and the description for the quantity are available for import.

Each text may be picked separately and can even be combined with an existing text for the receiving quantity.

After text has been imported it will not – as is the case with other imported data – be automatically updated in case modifications are made to the source file

The options *Override* controls whether the imported text should be appended to any text already present, or whether the content of the text fields in the receiving fields should be entirely replaced by the selected texts from the source file.

7.8 Import from Microsoft Excel®

GUM Workbench® can dynamically import data from MS Excel® into an uncertainty analysis. To import data from XLS files the MS Excel® application should be installed correctly. The import from MS Excel® is based on the OLE automation interface provided by MS Excel®. MS Excel® will be started automatically as soon as an analysis imports data from an XLS file. The MS Excel® startup can cause a delay if a file with Excel imports is loaded. MS Excel® is started invisibly in the background if it was not already running before. Use the  button to make MS Excel® visible.

The import from MS Excel® is a dynamic import. Any changes in MS Excel® are immediately (within one second) visible inside GUM Workbench®. GUM Workbench® can not access any cells in MS Excel® which are in edit mode. Therefore it is important to leave the edit mode in MS Excel® when data is changed to allow GUM Workbench® to read the data. The edit mode in MS Excel® is left by pressing enter or by leaving the cell.

The screenshot shows the 'Quantity Data' dialog box with the 'Import from Excel' tab selected. On the left, there is a tab labeled 'X_{imp}'. The main area contains the following fields and controls:

- Type:** A dropdown menu set to 'Import Excel'.
- File:** A text field containing 'S02 data.xls', followed by a folder icon and a blue 'X' icon.
- Worksheet:** A dropdown menu set to 'Tabelle1', with an 'absolute Filepath:' checkbox to its right.
- Value Cell:** A text field with 'E21' and a numeric field with '0.0200', accompanied by an eye icon.
- Standard Uncertainty Cell:** A text field with 'E25' and a numeric field with '0.0142', accompanied by an eye icon.
- Degrees of Freedom Cell:** A text field with 'E28' and a numeric field with '52', accompanied by an eye icon.

Figure 52: *Quantity Data* for *Import Excel*

Data can be imported from MS Excel® by selecting *Import Excel* in the *Type* field on the register *Quantity Data*. Next the filename of the XLS file should be typed in the *from File* field. The *Worksheet* select box below it contains the names of the worksheets available in the XLS file and the worksheet which contains the data should be chosen. In the three *Cell* fields the cell names containing the relevant data should be entered. GUM Workbench® always imports summarized data (value, standard uncertainty and degrees of freedom) from MS Excel®. The mean value and its uncertainty should be calculated in MS Excel® spreadsheet before they can be imported. If no cell name for the *Degrees of Freedom Cell* is given, GUM Workbench® will assume a value of >100.

Note: It is possible to use cut and paste to provide GUM Workbench® with the link information to a cell in a XLS file. One needs to mark one cell on a sheet in MS Excel® which contains the data and copy it to the clipboard. If one then selects the *Cell* field in GUM Workbench® and activates the *Paste* command then GUM Workbench® will set the correct filename worksheet and cell name.


The relative positions of the source file and the importing file should be maintained if the *absolute Filepath* option is not activated. The folder structure in which they are placed may be moved as a whole, or overlying folder names may be changed, but they should not be moved relative to each other. Otherwise GUM Workbench® will no longer know where to find the source field when the importing file is opened. Source files should not be moved if the *absolute Filepath* option is activated.

The button helps to find the XLS file. In the open dialog select the MS Excel® file and confirm your choice with *OK*. The source Excel file can be opened by clicking on the button.

To view the cell from which the data is imported click on the button.

7.9 Multiple File Import

GUM Workbench® can import multiple quantities from one or multiple SMU files. If more than one quantity is imported from the same file the correlation coefficient is automatically imported with the quantity. Therefore GUM Workbench® automatically maintains a correlation table between all quantities in an evaluation. The imported correlation coefficients are visible in the correlation view, but the fields are gray and can not be edited.

Multiple file imports should be managed with the *Imported Files* dialog. The dialog shows a register tab for imports from SMU files and a register tab for imports from XLS files, if any are used in the present evaluation. On the register tab a list of files is shown together with the names of the quantities which import data from these files. The name of the source file can be changed by providing a new file name in the *New Filename* field. Use the  button to search for the new file. All quantities which imported data from the old file will be changed to import data from the new file. The new file should have a similar data structure or the same

quantity names to avoid import errors.

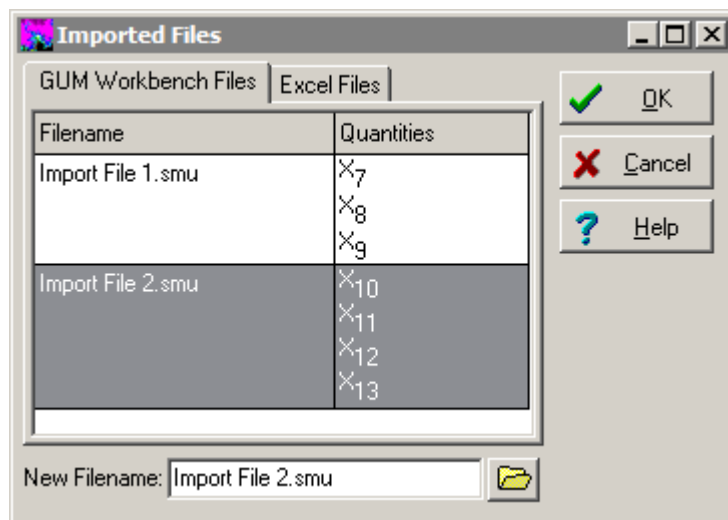


Figure 53: *Imported Files* dialog

7.10 Change Order of quantities

When an uncertainty model is created, the quantity names are placed by default in the order in which they are first met when stepping through the equation field.

When there are many quantities, the default order may not give the best view of the quantities. The sort order can be changed with the menu command *Change Quantity Order* which is located in the *Edit menu*. This may make the position of each quantity in the list more logical thus simplifying the use of the program.

To manually arrange the individual quantities, use the following steps:

1. From anywhere in the program, bring up the *Change Quantity Order* dialog.
2. Select the quantity which should be moved.
3. Click on *Move Up* or *Move Down* to bring it to the new position.
4. When completed, click *OK* to close the dialog.

After a sort has been completed and the SMU file is saved to disk, the sort order becomes part of that file. When the file is opened at a later time, the quantities will appear in the order they were last sorted. The sort order controls all lists in GUM Workbench® where the quantities appear. It also affects reports, be they printed or exported.

7.10.1 Sorting Options

Three options are available for sorting the full list of quantities in one operation.

Alphabetic: This option sorts in alphabetical order. Any Greek letter is alphabetized after Z following the Greek alphabet.

By Type: This option sorts by type in this order:

Type A, Type A Summarized, Type B Normal, Type B t-distribution, Type B Rectangular, Type B U-shaped, Type B Triangular, Type B Trapezoidal, Constant, Imported, Interim results, Result.

Default: This returns the sort order to the order in which quantities are first met when stepping through the equation field

7.10.2 Moving a Block of Quantities

To move adjacent quantities in the list up or down simultaneously, select them by dragging with the mouse. Then press *Move Up* or *Move Down* to move the selected block of quantities.

Note: In the sorting window, arrow keys control which quantity is highlighted. To change its position in the list, the mouse should be used to click either of the buttons *Move Up* or *Move Down*.

7.10.3 Two-Step Sorting

It is often the case, that several quantities in an analysis have the same type. There may e.g. be several Type B, Rectangular quantities. For the sort the feature *By Type*, such quantities will remain in the same mutual order as before the sort.

For sorting quantities according to the type and making quantities with identical type appear in alphabetical order: First click *Alphabetic* and next click *By Type*.

7.10.4 New Quantities

When adding quantities to a model equation, the previous selected sort order will be maintained. If the sort order has been modified by hand (no sort option was selected) then any new quantities will be added at the bottom of the list in the order in which they appear in the equation field. In this case the quantity order needs to be maintained manually or a sort option needs to be selected.

8 Readings and Observations

The screen view *Observation* processes the values of repeatedly observed quantities.

observed difference in length between the unknown and the reference gauge block

Observation:

No.	Observation
1	-100E-6
2	-90E-6
3	-85E-6
4	-95E-6
5	-100E-6

Method: Direct

Unit: mm

Arithmetic Mean: -94.00·10⁻⁶ mm

Experimental Standard Deviation: 6.5·10⁻⁶ mm

Standard Uncertainty: 4.75·10⁻⁶ mm

Edit Observations Choose Quantity Statistical Information

Figure 54: *Observation* view

The data is typed into a table. The structure of the table depends on the method of observation chosen. When valid data for all observations (or readings) have been typed in, the statistical information area will display the mean value, the standard deviation and the standard uncertainty of the data. All observations must be stated in the same unit as that entered in the list of quantities in the field *Unit*.

Multiple quantities can be of Type A. If more than one quantity is of Type A in an analysis, all such quantities show up as tabs in the observation view and one can freely navigate between them.

8.1 Import Observations Dialog

The command *Import Observation* in the *Tools* menu will open the *Import Observations* dialog (see Figure 55). The data for an observed quantity (Type A) can either be read from a text file in the correct format or from the clipboard. After confirmation, the data are read in, checked and put in the observation table. Any existing data will be replaced by the imported data.

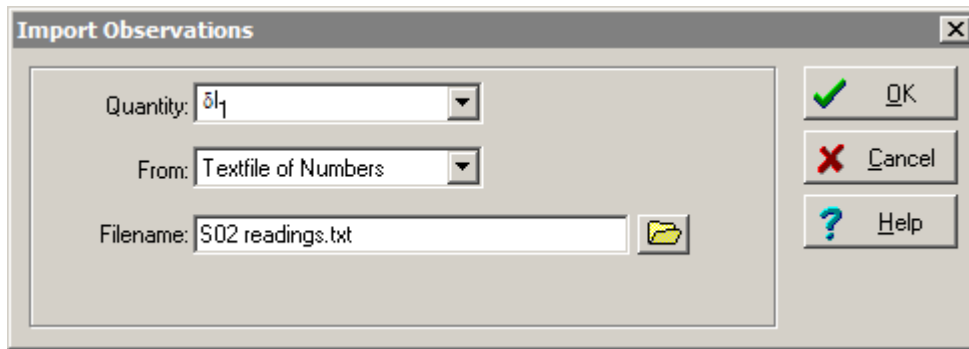



Figure 55: *Import Observations* dialog

To import the data, choose the *Import Observation* command from the *Tools* menu. Now select the quantity from the *Quantity* field for which data import should take place. Only quantities of Type A are available. In the field *From*, the source of the data is given. This can either be a text file containing numbers or the clipboard.

If *Textfile of Numbers* is used, the name should be entered in the *Filename* field. Choose a text file containing the values for a repeated observation. Start the import by pressing *OK*.

Use the  button to open a browser which helps to locate the desired file. If the file does not exist, an error message '950 Error: file not found' appears.

8.1.1 Structure of Text Files Containing Numbers

Repeated observation data can be imported from a file which uses the following format:

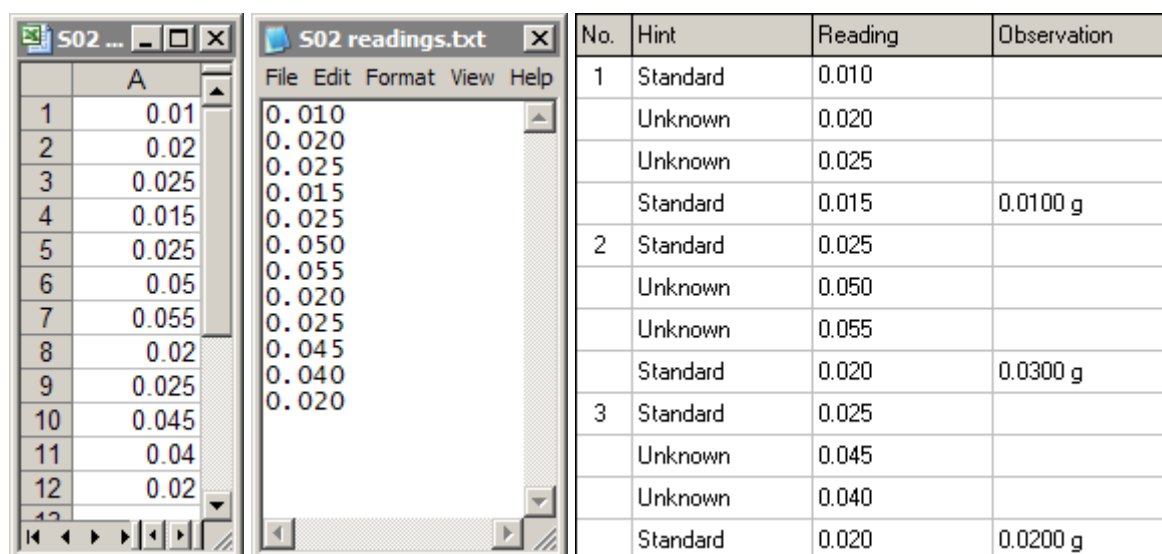
Every line contains a number written according to the rules numbers should follow.

- Spaces before and after numbers are allowed.
- The maximum length of a line is 255 characters.
- Every line ends with a carriage return.
- Empty lines are not allowed.

The maximum number of imported data is the number of observations that were selected earlier. Extra data are ignored. If the amount of data in the text file is smaller than the selected number of observations, just those values that are in the file will be imported, leaving the observation screen incomplete.

8.1.2 Pasting Observation Data

The data shown in Figure 56 should be copied from a column of cells in a Microsoft Excel® spreadsheet (left) or a text editor (middle) to the observation view (right). Three observations were taken with the method *SUUS*.



The figure shows three windows from the GUM Workbench software. On the left is an Excel spreadsheet titled 'S02 ...' with a column 'A' containing 12 rows of data: 0.01, 0.02, 0.025, 0.015, 0.025, 0.05, 0.055, 0.02, 0.025, 0.045, 0.04, and 0.02. In the middle is a text file window titled 'S02 readings.txt' showing the same 12 values listed vertically. On the right is the 'Observation view' table, which organizes these readings into three groups (No. 1, 2, and 3), each with a 'Hint' (Standard or Unknown), a 'Reading', and an 'Observation' (e.g., 0.0100 g, 0.0300 g, 0.0200 g).

No.	Hint	Reading	Observation
1	Standard	0.010	
	Unknown	0.020	
	Unknown	0.025	
2	Standard	0.015	0.0100 g
	Standard	0.025	
	Unknown	0.050	
3	Unknown	0.055	
	Standard	0.020	0.0300 g
	Standard	0.025	
4	Unknown	0.045	
	Unknown	0.040	
	Standard	0.020	0.0200 g

Figure 56: Observed data in Excel, in a text file and in the *Observation* view

From MS Excel® spreadsheets, the data can be copied via the clipboard. Use the *Edit|Copy* command in Excel to copy the data to the clipboard and use the *Import Observation* command in GUM Workbench® to read the data from the clipboard. The data must be in one column. The data from the text file can be either copied via clipboard or read directly from the text file.

8.2 Correlation Analysis for Type A

The command *Correlation Analysis for Type A* from the menu *Tools* will start an analysis for possible correlation between measurands. Calculation of the pair-wise correlation coefficients is performed using the formula

$$r(q_i, q_j) = \frac{1}{(n-1) \cdot s(q_i) \cdot s(q_j)} \cdot \sum_{k=1}^n (q_{i,k} - \bar{q}_i) \cdot (q_{j,k} - \bar{q}_j) \quad (4)$$

with q_i and q_j being two observation series with the data $q_{i,k}$ and $q_{j,k}$ for $k = 1 \dots n$. The total table is produced by calculating all possible pairs.

A correlation analysis can only be carried out for measurements for which the standard deviation is determined through experiment, and the data of those experiments must be available to GUM Workbench®. This implies that quantities of either *Type A, pooled estimate* or *Type A summarized* do not qualify for such an analysis. Only quantities which are *Type A, experimental* can undergo a correlation analysis.

A further prerequisite for a correlation analysis is that the number of observations of the two quantities must be equal and that all of the observations are filled in and valid. If there are for example five quantities, A, B, C, D and E in an analysis which are *Type A, experimental*, no correlation will be calculated if they all have different numbers of observations. If A and B

have the same number of observations, but for C, D and E they are different, then only one coefficient will be calculated. If A and B each have four observations and C and D each have five observations, while E has six observations, then only two coefficients will be calculated. If all five had the same number of observations, ten coefficients would be calculated.

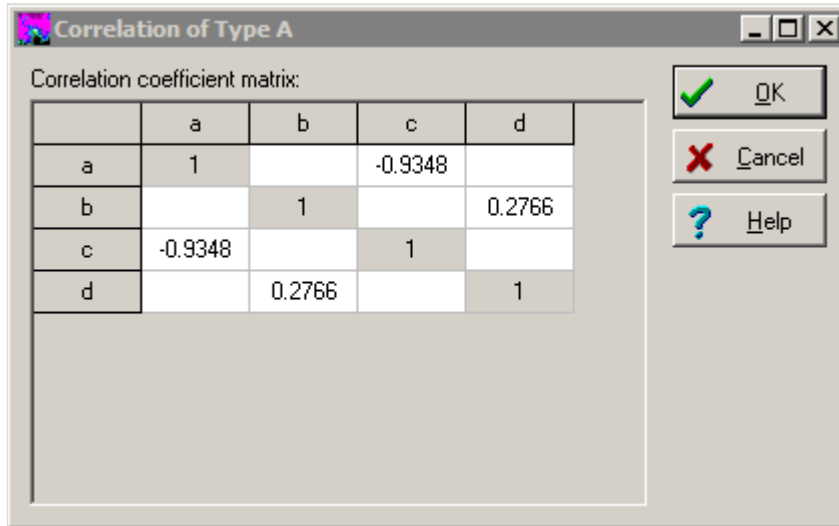


Figure 57: Correlation analysis of Type A of the data in Table 9

The sub-matrix displayed in the screenshot in Figure 57 resulted from the data set in Table 9.

Table 9: Example for correlated observations

a	b	c	d
23.31	0.03678	0.3456	67.5
23.24	0.03681	0.3457	67.5
23.20	0.03685	0.3458	67.4
23.17	0.03684	0.3460	67.5
	0.03688		67.6

Warning: This analysis should be used only if there is convincing evidence that the observed quantities are correlated. If this analysis is used for data that is not suitable, it may lead to false results.

Whether a correlation analysis of this form makes sense depends on the manner in which the measurements are performed. One important prerequisite is that the observations of the various quantities have taken place simultaneously.

8.2.1 Analyze

Select the command *Correlation Analysis for Type A* in the menu *Tools*, to perform an analysis. The program now analyses all measurements of Type A and displays the computed possible correlation coefficients in matrix form. The correlation coefficients will be rounded to four decimal places.

The default window can display a full four by four matrix. When there are more than four quantities which qualify for the analysis, scroll bars will appear so that all the cells of the result matrix may be inspected. Alternatively the window size may be adjusted.

The resulting correlation coefficients are empty if either the two quantities have different number of observations or if the correlation found was close to zero, i.e. $-0.005 < r < 0.005$).

Cells are labeled *not valid!* if observations (readings) have been omitted. Even if just one cell in the sub-matrix is not valid, the OK button will be grayed out and the only option available is to cancel the analysis and enter the missing data before restarting the analysis.

8.2.2 Transfer Correlation of Type A

After clicking *OK* in the *Correlation for Type A* window, the dialog shown in Figure 58 is brought up.

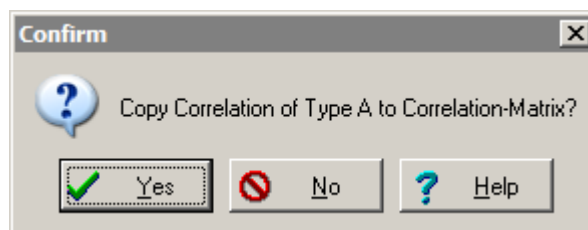


Figure 58: Confirmation to transfer the correlation table

Press *Yes* to accept the data from the correlation analysis which will be transferred as input to the relevant cells of the input correlation matrix of the model.

Upon transfer, any data which was already present in the cells in the total matrix will be replaced without warning by the new data. Note that those cells which are empty in the calculated sub-matrix will remain unchanged. This is true even for a coefficient which is empty because the correlation is close to zero.

All of the coefficients will be transferred. If the user decides that only a certain selection of the coefficients are relevant and required in the main correlation matrix, this should be handled by manually transferring those coefficients.

8.2.3 Subsequent Updating

The correlation coefficients are derived from the actual observed data which are present in the tables under *Observation*. The function which copies the values from the analysis to correlation matrix works on a snap shot of the observation values. If new data is entered for quantities of *Type A*, *experimental* at a later time, a new *Correlation Analysis for Type A* should be considered. GUM Workbench® will not automatically adjust the data originally

copied to the main matrix. Doing so requires the user to run a new *Correlation Analysis for Type A* and then copy the new coefficients.

8.2.4 Issues with Zero Standard-Deviation

As may be seen by inspecting equation 4, a correlation coefficient is undefined if the standard deviation of one of the sets of observations is zero.

GUM Workbench® will bring up error message 700 when the standard deviation is zero for a quantity which qualifies for the calculation of experimentally indicated correlation.

In most cases, a sensible workaround would be to just add an infinitesimally small number to one of the observation in that series.

9 Multiple Results

Versions 2.3 and 2.4 support multiple result evaluations. Any evaluation which includes multiple partially independent equations is a multiple result evaluation.

GUM Workbench® supports three additional user interface elements to handle multiple results. In the *Model* view, tab register *Quantity Data*, display options are supported for all results and interim results (the type of these quantities is automatically selected and can not be changed). The *Budget* view supports multiple budgets and an additional *Result* view shows a summary of all results in the evaluation and an optional correlation matrix.

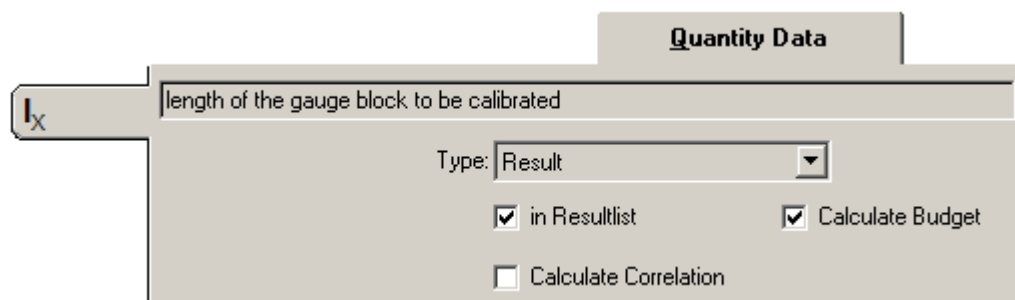


Figure 59: Result display options

9.1 Result Display Options

The multiple result versions of GUM Workbench® support options for results and interim results to control the display of the results in the budget view and in the result view (see Figure 59). In larger evaluations with several results and interim results, it might be useful to display only a limited number of these results in the budget or the result view.

- The option *in Result List* controls the visibility of the result in the *Result View*. Only results with the option turned on will be visible in this view.
- The option *Calculate Budget* controls the visibility of the result in the *Budget View*. A budget table will be visible in the *Budget View* for every result with the option activated.
- The option *Calculate Correlation* controls the inclusion of the result in the *Correlation-Matrix* between results in the *Result* view. This option is available only if the *in Result List* option is activated.

When the *in Resultlist* option is activated but the *Calculate Budget* option is not, two additional selection boxes are visible allowing the user to control how the expanded uncertainty of the result will be calculated (see Figure 60).

The figure shows a software dialog box titled "Quantity Data". Inside, there is a text field containing "length of the gauge block to be calibrated". Below this, there are several controls: a "Type:" dropdown menu with "Result" selected; a checked checkbox labeled "in Resultlist"; an unchecked checkbox labeled "Calculate Budget"; an unchecked checkbox labeled "Calculate Correlation"; an "Uncertainty:" dropdown menu with "expanded Uncertainty" selected; and a "Coverage:" dropdown menu with "95% (t-table 95.45%)" selected.

Figure 60: Result display options if *Calculate Budget* is turned off

With the *Uncertainty* box, the user chooses the format of the expanded uncertainty which can either be absolute, relative or relative in percent (%). With the *Coverage* box the user selects the way the coverage is calculated. If *manual* is selected, an additional edit field will be visible to enter the *Coverage Factor*.

9.2 Multiple Budget View

The multiple result version of GUM Workbench® supports a multiple budget view. At the top of the budget view, a register tab is displayed which allows the user to switch to the different budget tables. All budget tables have the same structure and the columns are controlled by the configuration dialog. Only results where the *Calculate Budget option* is activated are visible in the *Budget View*. All budget tables which are visible in the *Budget View* are printed in the report. The order of the results in the *Budget View* and the result view is controlled by the *Change Quantity Order* dialog.

The *Coverage* is chosen separately for every result and the expanded uncertainty is calculated based on the standard uncertainty and the coverage factor only. All results are treated independently in this calculation.

Note: It is the responsibility of the user to choose an appropriate method to select the coverage. It might be wise to state only a standard uncertainty with a set of correlated results. The user might consult the correlation matrix given in the result view to support his judgment.

9.3 Limitations and Performance

The number of results is only limited by the memory resources of the computer. The calculation of a large number of results (more than 20) will take some time depending on the processing power of the computer. Therefore it is useful to use the *Last Budget View* to avoid a recalculation of the budget if this is not necessary.

10 Printing and Export

GUM Workbench® is capable of generating qualified documentation to support decisions based on measurements. The standard report is a structured document which lists all sources of information together with the calculations performed. Additionally the content can be exported to a file in as an html or rtf-format so that a customized version can be generated.

10.1 Automatic Documentation

GUM Workbench® supports description fields in many places. They should be used to comment on the experiment and the different decisions made during the evaluation. All description fields will be printed in a report or exported to a html/rtf file (see section 1). The contents of the description fields will be formatted to fit the paper size. Table 10 lists the formatting conventions for the description fields.

Table 10: Formatting conventions for description fields

Sequence	Description
Single line break	Single line breaks will be treated as white space and substituted by a single space character.
Multiple spaces	Multiple spaces will be replaced by one space.
Double line break	Double line break (empty line) will be interpreted as an end of paragraph.
\n\	The character string '\n\' will be interpreted as a line break.
\t\	The character string '\t\' will be interpreted as a tab character allowing simple table support.
\b+\ ... \b-\	The text between '\b+\'' and '\b-\'' will be printed in bold.
\i+\ ... \i-\	The text between '\i+\'' and '\i-\'' will be printed in italic.
\u+\ ... \u-\	The text between '\u+\'' and '\u-\'' will be printed underlined.
\rm+\ ... \rm-\	The text between '\rm+\'' and '\rm-\'' will be printed in Times New Roman font.
\ss+\ ... \ss-\	The text between '\ss+\'' and '\ss-\'' will be printed in Arial font.

10.2 Document Information Fields

The document information fields are accessible in the *Model* view under the *Title* register. Four edit fields are located below the *Title* field (see Figure 61). These fields should be used to improve the documentation of the uncertainty evaluations.

The image shows a form with five input fields arranged horizontally. The first field is labeled 'Title:'. The second is 'Reference:', the third is 'Date:', the fourth is 'Version:', and the fifth is 'Author:'. Each label is followed by a rectangular input box.

Figure 61: Document information fields

The *Reference* field is optional and can contain any text. The content will be printed in the upper left corner on the report (see Figure 62). This field should be used to identify the uncertainty budget in addition to the title.

The *Date* field contains the date for the budget. It can be configured (see section 15.1) so that the field is editable by the user or if it will be updated automatically when the budget is changed. The format needs to be a valid date format.

The diagram shows a rectangular frame representing a report page. The frame is divided into several sections. At the top, there are three columns: the first contains '<Reference>', the second contains '<Title>', and the third contains 'Logo'. Below these, the main body of the page contains '<Title>', 'Author: <Author>', and '<Description>'. At the bottom, there are three columns: the first contains 'Date: <Date>' and 'Ver.: <Version>', the second contains 'File: <Filename>', and the third contains 'Page <i> of <n>'. The frame has break symbols (two parallel diagonal lines) on the left and right sides, indicating that the content can span multiple pages.

Figure 62: Structure of the report page

The *Version* field is optional and can contain any text. The content will be printed together with a prefix ('Ver.:') in the lower left corner on every page of the report (see Figure 62). It can be used to distinguish different versions of uncertainty budgets.

The *Author* field is optional and can contain any text. If it contains text, it will be printed in an additional author line below the title in the report preceded by a prefix ('Author: '). If the field is empty, no author line is inserted in the report.

10.3 Print Report Command

The *Print Report* command from the *File* menu creates a report. It contains all data and descriptions as well as the uncertainty budget. The preview shown in Figure 63 lets the user check the report before printing.

The format and language of the report can be selected using the *Config* command from the *Option* menu (see Section 15.2 for details).

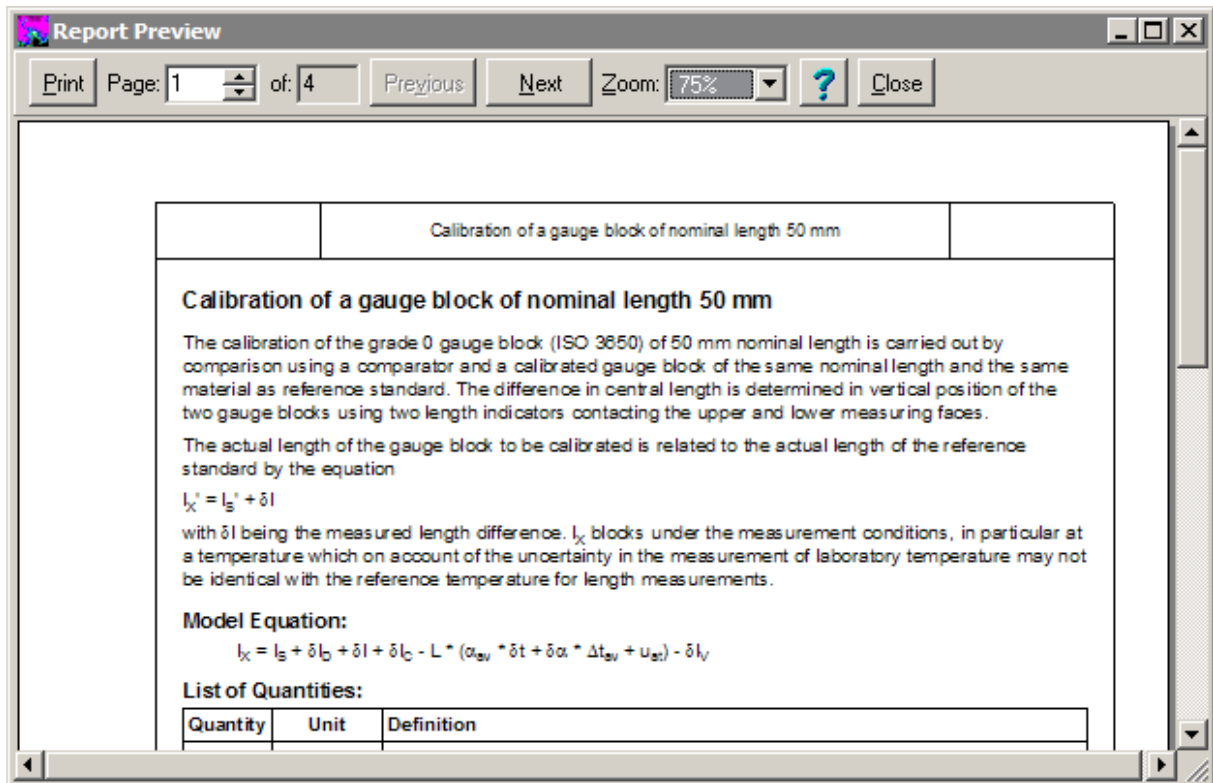


Figure 63: Report Preview

By pressing *Print* the report is sent to the printer and the preview is closed.

The page counter shows the number of the page being displayed as well as the total number of pages in the report. The buttons *Previous* and *Next* are used to scroll through the report page by page. The magnification of the report image may be changed using the *Zoom* field.

Pressing *Close* ends the preview without printing a report.

Appendix J shows an example of a full uncertainty analysis report as it is printed by GUM Workbench®.

Paper formats and orientation: Please note that GUM Workbench® allows the user to choose between printing in the Din A4 or US letter formats. Printing may also be in portrait or landscape orientation (see Section 15.2 for details). When other paper sizes are required, the export option in rtf-format should be used so that the printing can be done by an external word processor.

10.3.1 Printer Setup Command

The destination printer can be chosen with the *Printer Setup* command. After startup, GUM Workbench® automatically chooses the system default printer. Use the *Printer Setup* to change the default. The standard Windows printer setup dialog will be shown. Other options like paper source can be configured, too. Please make sure that the chosen paper is consistent with the paper defined in the *Config* dialog (see Section 15.2).

For further details, please refer to the documentation for the individual printer as well as Windows® documentation.

10.3.2 Selection of Printing Range

To print a report on the currently selected printer, press the *Print* button in the *Preview* window. The *Printing* window contains fields in which the range of pages to be printed is set (see Figure 64).

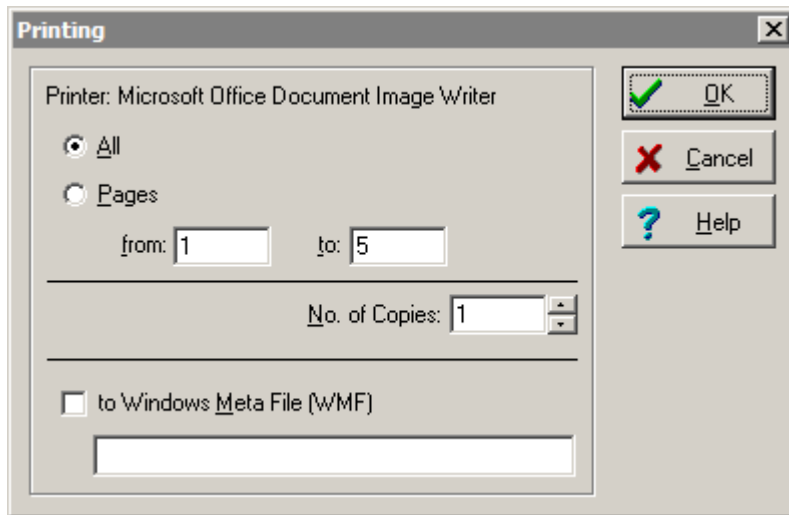


Figure 64: Select printing range dialog

The following options are available:

- The *All* option prints all pages of the report.
- The *Pages* option prints only the pages selected in the *from* and *to* fields.
- The *to Windows Meta File (WMF)* option writes the report contents to a Windows Meta File (WMF or EMF) instead to a printer. A file name must be given in the field below the option. The file name will have the extension EMF or WMF. For each page, a file is created with the given name and the string ‘_p<i>’ added to it before the extension (<i> is replaced by a number 0,1,...,n-1 for n pages).

Pressing *OK* starts the printing process.

10.3.3 Report Options

The number and order of the paragraphs in the reports cannot be altered. The paper format Din A4 or US Letter in portrait or landscape orientation can be used for printing reports. In the *Config* dialog, the contents of the table containing the uncertainty budget can be configured by the user (see Section 15.2).

10.3.4 Insert a Logo on the Report Pages

GUM Workbench® supports a simple method to insert a logo on all report pages.

10.3.4.1 Requirements

- The logo should be available as a bitmap-file (BMP) or as a JPEG-file (JPG).
- The logo should fit in the designated area of 30 mm width and 10 mm height in the upper right corner of the report.

10.3.4.2 Insert Logo

Please follow the following steps to insert a logo to the report pages:

1. The logo-file (either BMP or JPG) should be copied to the subdirectory `.\etc\` below the GUM Workbench® installation directory.

`(C:\Programme\GUM Workbench x.y\etc\)`

The default name is either `LOGO.BMP` or `LOGO.JPG`.

2. The file `.\etc\LOGO.TXT` should be edited. This file contains important information about the size of the logo and where to find it. All lines starting with semicolon are ignored. Section `[Logo]` contains the relevant lines.

```
[Logo]
width=250
height=50
filename='etc\LOGO.bmp'
```

The size of the area where the logo is printed should be given in units of 1/10 mm (width=250 is equal to 25.0 mm width, height=50 is equal to 5.0 mm height). The filename should be given relative to the GUM Workbench® installation directory (filename='etc\LOGO.bmp' means that the bitmap-file `LOGO.bmp` in the subdirectory `.\etc\` will be used). If the file is in JPEG format the filename should be changed to `LOGO.JPG`. No logo will be printed if the file does not exist.

If the logo-file exists and the file `.\etc\LOGO.TXT` is changed according to the actual logo size, the logo is printed on every report page in the upper right corner centred to the point 185.0 mm from the left and 20.0 mm from the top of the page. The frame around the logo area is 30 mm by 10 mm.

10.3.4.3 Possible Problems

Please consider the following if a logo does not appear on a report as expected:

- Check the version of GUM Workbench®. It needs to be at least 1.3.7, 2.3.7 or 2.4.1.

- The logo-file (LOGO.BMP or LOGO.JPG) may not exist at the location specified in LOGO.TXT, or the format is not correct. The format is given by the file extension and should be either BMP or JPG.
- The entry 'filename=' in the file LOGO.TXT is not correct or either the width or the height is zero.
- The file LOGO.TXT does not exist or the file has a wrong format.

10.4 Export Command

The data used for the uncertainty analysis, the budget, and the result can be exported to the clipboard or a file for further editing. It is easy to export the data for use by a word processor (for example Microsoft Word®) to generate specially formatted reports or to achieve greater flexibility in printing.

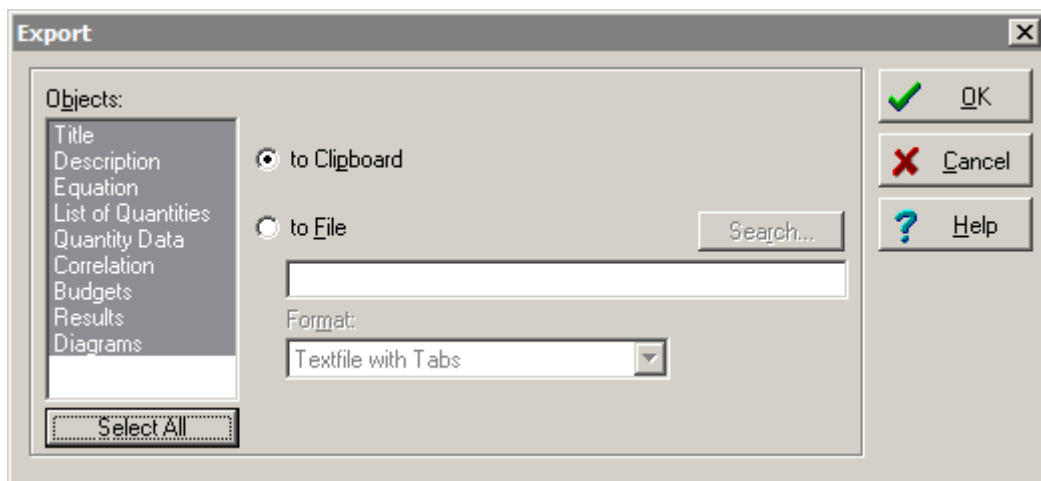


Figure 65: *Export* dialog with all objects selected

The language for the export process can be selected using the *Config* command in the *Option* menu. To export data, run the *Export* command in the *Tools* menu to open the *Export* dialog (Figure 65). The list *Objects* allows the user to select the parts of the uncertainty assessment that should be exported (see Table 11).

Table 11: List of items which may be exported

Item	Description
Title	Title of the uncertainty analysis
Description	Content of the General Description field
Equation	Contents of the Equation field
List of Quantities	List of all quantities together with their unit and definition
Quantity Data	All available data together with a description
Correlation	The correlation coefficients in a matrix table together with a description

Item	Description
Budgets	Budgets in the form of tables
Results	Results of the analysis together with their expanded uncertainties and coverage factors. Optionally, this item includes the correlation coefficients between the results in for of a matrix table.
Diagrams	Version 2.4 can export diagrams in rtf-format as metafile objects.

Multiple selections can be done by pressing the shift- or control-key. The *Select All* button marks all available objects.

Select the *to Clipboard* option to perform export via the clipboard.

If the *to File* option is activated, a filename must be given in the field beneath this switch. The *Format* field offers several possible formats for the export file. The *Search* function can help in finding the desired file. The *OK* button activates the export process to the selected destination.

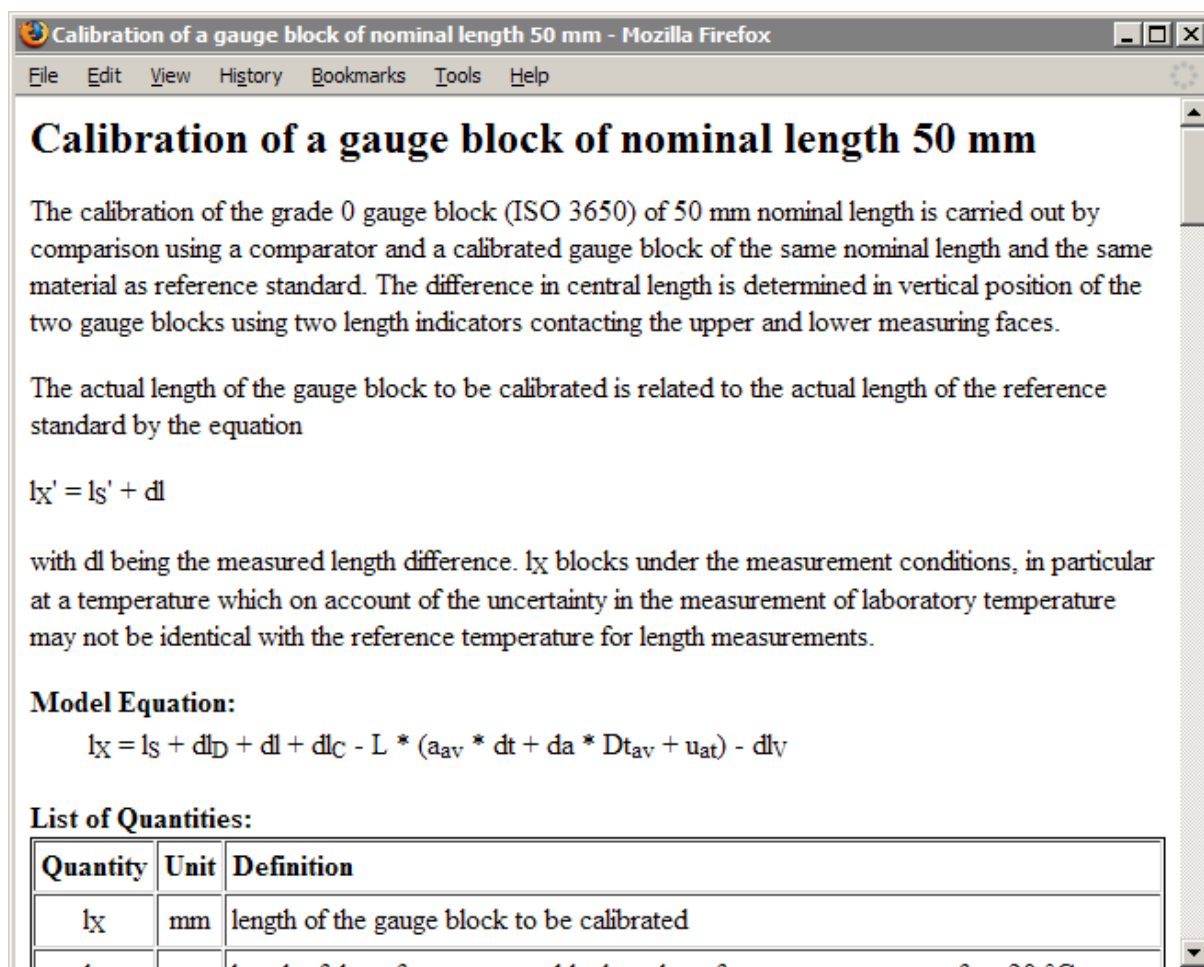


Figure 66: Exported html-file shown with an internet browser

Figure 66 shows an html-formatted file generated with the *Export* dialog and opened with an Internet browser.

Figure 67 shows the same content exported to a file in rtf-format and opened with Microsoft Word.

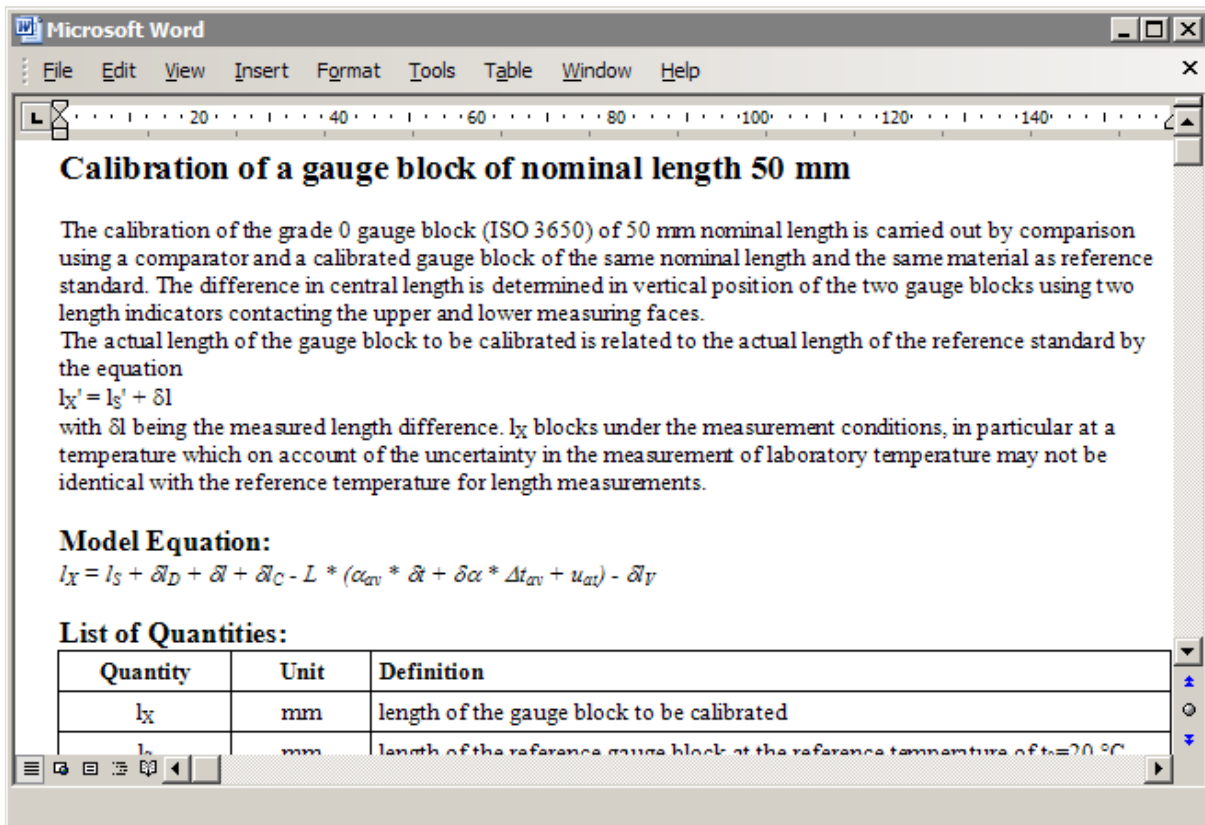


Figure 67: Exported rtf-file shown inside Microsoft Word

10.4.1 Exporting via Clipboard

When exporting via the clipboard, the best format will be automatically chosen by the receiving application program. The clipboard always contains all format versions. If one exports to an application that can import rtf-format, then the rtf-format is usually chosen.

Text processing applications like Microsoft Word® usually support a ‘paste special’ command which gives the user the full control over the format that is pasted into the document.

When exporting to a spread-sheet application like Microsoft Excel®, one should be aware that in GUM Workbench® numbers are formatted together with a unit. The spread-sheet application usually does not recognize the number as a number in the presence of a unit string. When exporting to MS Excel® the *Export2Excel* expert can be used as described in Section 17.1.

11 Loading and Saving Files

GUM Workbench® saves uncertainty budgets as text files with the extension ".SMU". The text files have an internal structure based on the Windows INI-file format. There exist different versions of the file structure (1 – 4) which are upwards compatible. Version 1.3 and 2.3 will read all file structures up to version 3 and version 2.4 will read all structures up to version 4. The difference between the version 3 and the version 4 structure is that version 4 files contain pictures and diagrams while version 3 files do not.

11.1 Save Command

To be able to return to an uncertainty analysis, it must be saved as a file. When saving, all the data which have been entered are saved. To initiate saving, select *Save* or *Save as* from the *File* menu.

Click on the  button in the tool bar to save a file under its current name and path.

If the analysis has not been saved previously (i.e. the filename field in the status line is empty), the *Save as* procedure is called and the standard Windows save dialog will be used. All valid Windows filenames with the file extension .SMU are allowed. If the extension is omitted .SMU will be added to the filename automatically.

If an analysis was loaded earlier, the *Save* command saves all data to this file. Before the newer file replaces the original file, the extension of the original file is changed to BAK. If a backup version of the file already exists it is deleted.

If a file is write-protected, it can not be replaced by another file. Any attempt to overwrite a protected file will result in cancellation of the writing process, and an error message will be displayed.

GUM Workbench® displays *changed* in a right field of the status line as soon as any open SMU file has been edited.

Note that an invalid equation field will disable the save command. When the cursor is placed in the model equation field and that field is not valid in a strictly mathematical sense, the SMU file cannot be saved.

11.2 Read Only Option

If a saved analysis needs to be protected against accidental change or deletion, this can be achieved by activating the *Read Only* option in the *Option* menu. After confirming the choice, the read only attribute of the file is set. It is not possible to modify a file which is flagged as

read only. By selecting the option again, the attribute can be reset (after user confirmation) to read and write.

This option is useful for protecting template analyses from alterations especially if they are intended to be a permanent starting point for subsequent analyses. An alternative is to use special template files (see section 20).

11.3 Save as Command

By selecting *Save as* from the *File* menu, the *Save as* dialog will be shown. The user can navigate to a sub-directory and type in the name for the current uncertainty analysis. A warning message will be shown if an existing file name is selected.

If a file is write-protected, it cannot be overwritten. Any attempt to replace a protected file causes the process to be cancelled and an error message to be displayed.

11.3.1 File Name


To save a model under a different name or path, select a new filename. To save a model under an already existing filename, select the name from the list or type in the name. After clicking on *OK*, a confirmation dialog will appear before overwriting the existing document.

The Filename can be any valid file name for Windows and it can have an extension of up to three characters.

11.3.2 Save as Type

Select the format that should be used to save the model. The default format is SMU. Alternatively the file can be saved in template format (SMT, see Section 20).

11.4 The Open Command

The *Open* command opens the standard Windows open dialog to select a file. When the user presses *OK*, an existing uncertainty analysis is read from a file into the memory. Select the command from the *File* menu or click on the  open button in the tool bar to open a document.

11.4.1 File Name

The name of the required analysis should be entered or selected from the list of files. Only files matching the selection from the *Files of type* field are displayed.

11.4.2 Files of Type

The field *Files of type* defines the format of the files which should be displayed for selection. The default format is SMU. Alternatively, template files (.SMT) can be loaded to edit them (see Section 20). This is different from using templates as a starting point of an analysis. Templates should be used as a starting point by opening them via *File|New|Templates*.

12 Working with Graphics and Pictures

GUM Workbench® version 2.4 supports the inclusion of graphics and pictures in the report.

12.1 Requirements

- The picture should be present either as a file or in the clipboard in the following format:
Bitmap-file (BMP), JPEG-file (JPG), PNG-file (PNG) or Metafile (WMF, EMF).
- The PC should have sufficient memory to handle graphics (> 1GB RAM).

12.2 User Interface

Figure 68 shows the additional register tab page to handle a picture. The description fields support picture tab pages next to them.

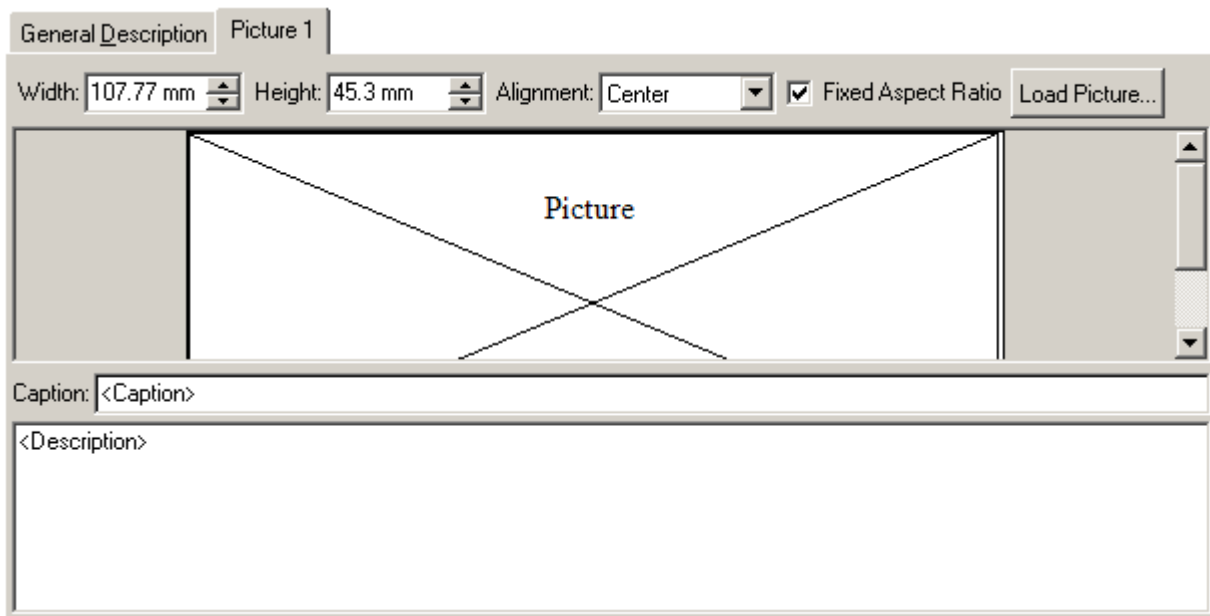


Figure 68: A register tab page to handle a picture.

The picture is loaded with the *Load Picture* button. The *Load Picture* Dialog will open to load the picture from a file or the clipboard.

After a picture is loaded, its size can be manipulated to fit it on the report page. The size of the preview on the screen is nearly the same size as that printed in the report.

Below the picture area is the picture *Caption* and another description field. This description is printed in the report after the picture. If a figure *Caption* is entered it will be printed in bold below the picture.

It is possible to add and delete picture tab pages as necessary with the picture menu.

12.2.1 Load Picture Dialog

Figure 69 shows the *Load Picture* dialog. The dialog has a picture preview. The picture can be either loaded from the clipboard with the *Paste* button or it can be loaded from file with the *Load* button. Any picture can be deleted with the *Delete* button. Press the *OK* button when the correct picture is loaded or leave the picture unchanged with the *Cancel* button.

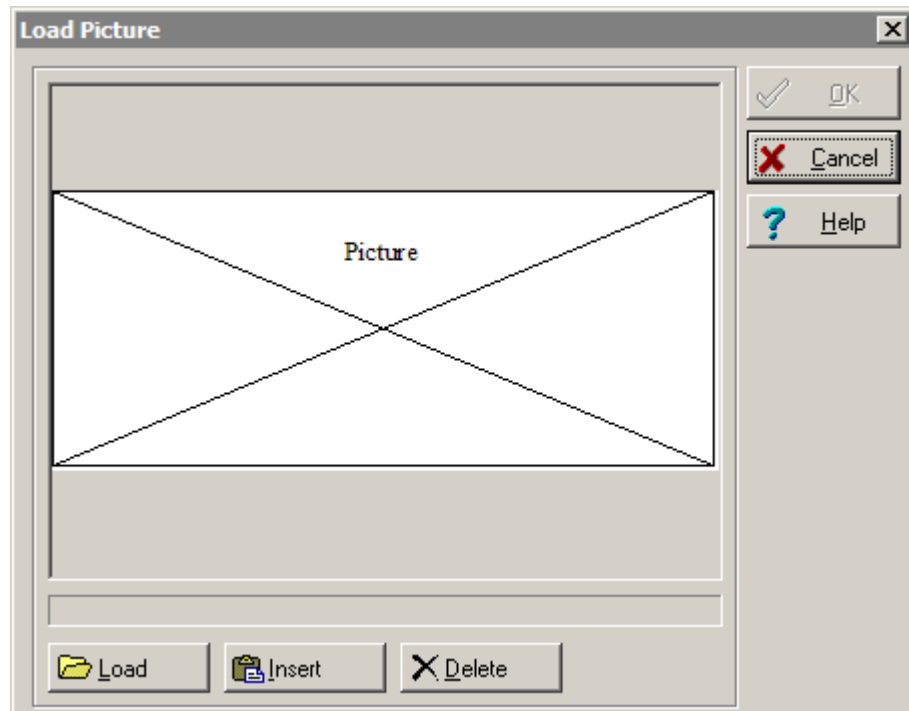


Figure 69: *Load Picture* dialog with a simple picture loaded

The supported graphics formats for pictures are shown in Table 12.

Table 12: Supported graphics formats for the loaded pictures

Format	Description	Extension
JPEG	Compressed graphics format from Joint Photographic Experts Group. Useful for photos and diagrams.	*.jpg, *.jpeg
Bitmap	Bitmap graphics format. Useful for small graphics.	*.bmp
PNG	Portable Network Graphics format	*.png
Metafile	Windows metafile format. Usually used with the clipboard.	*.wmf
Ext. Metafile	Extended version of the Windows meta format.	*.emf

12.3 Picture menu commands

The pictures can be managed with the Picture Menu. The supported commands are listed in Table 13.

Table 13: Picture menu commands

Menu Command	Description
Add Picture	Adds an additional picture tab page to the end of the list.
Delete Picture	Deletes the currently visible picture tab page.
Insert Picture	Inserts an additional picture tab page at the position of the currently visible picture tab page.
Swap Picture	Exchanges the currently visible picture with the picture next to it on the right side.
Load Picture...	Opens the Picture Load dialog.

12.4 Picture Printing

Pictures are printed in the report below the text from the main *Description* field. A picture may contain text in the picture description field which is printed below the picture. This allows embedding the picture in the text in the report.

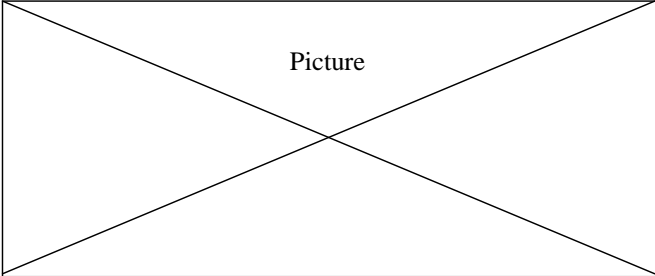
<Ref>	<Title>	<Logo>						
<p><Title> Author: <Author> <Description></p> <div style="text-align: center;">  <p>Picture</p> <p><Caption></p> </div> <p><Picture Description></p> <p>Model Equation: X;</p> <p>List of Quantities:</p> <table border="1"> <thead> <tr> <th>Quantity</th><th>Unit</th><th>Definition</th></tr> </thead> <tbody> <tr> <td>X</td><td>mm</td><td><Definition></td></tr> </tbody> </table> <p>X: Type B rectangular distribution Value: 0 mm Halfwidth of Limits: 0.1 mm</p> <p><Description></p>			Quantity	Unit	Definition	X	mm	<Definition>
Quantity	Unit	Definition						
X	mm	<Definition>						
Date: <Date> Ver.: <Ver>	File: <Filename>.SMU	Page <i> of <n>						

Figure 70: Structure of the report page with pictures

Figure 70 shows the structure of the report page. The first page starts with the title and the author line. The general description follows. If a picture is loaded it will be printed after the general description followed by an optional caption. Below the picture, the contents of an additional description field connected with the picture may be printed (see picture register tab page). The rest of the uncertainty discussion then follows: model equation, list of quantities, quantity data with descriptions and other pictures, uncertainty budgets with descriptions and the list of results.

12.5 Multiple Pictures

The *General Description* area and the symbol *Description* areas support multiple picture tab pages. Every picture tab page includes an additional description field. In the report the *Description* of the first tab page will be printed first followed by the first picture and the optional caption. The description on the picture tab page will then be printed below the picture. Additional pictures and descriptions can follow. In principle, the number of pictures and description blocks (pages) is not limited. The power of the computer will in practice limit the number of pictures to less than 10 in any GUM Workbench® file.

12.6 Picture Storage

When a picture is loaded into GUM Workbench® (see Figure 68), it becomes part of the uncertainty evaluation and is saved with the rest of the data in a SMU file. The SMU file is a text file and the picture will be encoded in text. The base64 (MIME) coding scheme is used. It converts the binary picture data to a block of characters when the SMU file is saved and back to a binary picture when the SMU file is loaded. The size overhead is about 137%. So the data block in the SMU file is 37% larger than the binary file.

A SMU file with pictures is defined as a format version 4. It is not backwardly compatible with older GUM Workbench® versions prior to 2.4 which only support the file format 3. To make an uncertainty budget compatible with older GUM Workbench® versions, all pictures, picture captions and the descriptions below the pictures must be deleted.

GUM Workbench® will save the data as SMU version 3, as long as no diagram is present and no information is added in the picture register tabs.

Under *Tools|Experts*, the expert *SaveAsVer3* is available to save any budget with pictures as Version 3 (see Section 17.2). This will delete all pictures, picture captions and any text entered in the description fields below the pictures.

12.7 Performance Considerations

High resolution pictures usually need a lot of memory and processing time. GUM Workbench® is not optimized for graphics processing and may slow down as it handles large picture files. In addition, high resolution graphics create large SMU files which require extra time to load and save.

The use of high resolution pictures is only recommended if the high resolution is necessary for the final report. The resolution of pictures should be adjusted to the needs before the picture is loaded into the evaluation. In addition a memory upgrade might help to improve the performance of the computer.

13 Unit Validation

GUM Workbench® Version 2.4 supports a SI unit validation tool. The SI unit validation support is implemented with two additional dialogs. An Insert Unit Dialog provides a list of supported units which can be inserted in the unit fields. The Unit Validation Tool Dialog will verify the correct usage of the units together with an inspection of the equations.

Warning: The automatic unit validation does *not* guarantee that a model equation is appropriate for the intended use or that the calculated values are correct. It only verifies that the entered units and the model equation are formally consistent. Consistency is one precondition for meaningful results and it is useful to check the usage of units, however unit validation is not sufficient for model validation. The unit validation can not replace expertise and knowledge about the measurements which are necessary to judge if a model is appropriate for the evaluation of a measurement.

13.1 The SI System of Units

This section provides an overview on the SI unit system as far as it is implemented in GUM Workbench®. The SI unit system is the internationally agreed metric system of units. It defines two classes of units: base units and derived units. The 7 named base units are fundamental because they cannot be expressed in terms of the other base units. The other classes of units are the derived units, which may or may not have a name, but can always be expressed as a combination of the base units. The named units defined by the SI system are listed in Table 14 and Table 15.

Table 14: SI base units

Symbol	Unit	Quantity
m	meter	length
kg	kilogram	mass
s	second	time
A	ampere	electric current
K	kelvin	thermodynamic temperature
mol	mole	amount of substance
cd	candela	luminous intensity

Table 15: Derived SI units with a name

Symbol	Name	Quantity	In SI base units
Hz	hertz	frequency	s^{-1}
N	newton	force, weight	$m \cdot kg \cdot s^{-2}$
J	joule	energy, work, heat	$m^2 \cdot kg \cdot s^{-2}$
W	watt	power, radiant flux	$m^2 \cdot kg \cdot s^{-3}$
Pa	pascal	pressure, stress	$m^{-1} \cdot kg \cdot s^{-2}$
lm	lumen	luminous flux	cd
lx	lux	illuminance	$m^{-2} \cdot cd$
C	coulomb	electric charge or electric flux	$s \cdot A$
V	volt	voltage, electrical potential difference, electromotive force	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-1}$
Ω	ohm	electric resistance, impedance, reactance	$m^2 \cdot kg \cdot s^{-3} \cdot A^{-2}$
F	farad	electric capacitance	$m^{-2} \cdot kg^{-1} \cdot s^4 \cdot A^2$
Wb	weber	magnetic flux	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-1}$
T	tesla	magnetic field	$kg \cdot s^{-2} \cdot A^{-1}$
H	henry	inductance	$m^2 \cdot kg \cdot s^{-2} \cdot A^{-2}$
S	siemens	electrical conductance	$m^{-2} \cdot kg^{-1} \cdot s^3 \cdot A^2$
Bq	becquerel	radioactivity (decays per unit time)	s^{-1}
Gy	gray	absorbed dose (of ionizing radiation)	$m^2 \cdot s^{-2}$
Sv	sievert	equivalent dose (of ionizing radiation)	$m^2 \cdot s^{-2}$
Kat	katal	catalytic activity	$s^{-1} \cdot mol$
$^{\circ}C$	celsius	thermodynamic temperature ⁽¹⁾ $T_{^{\circ}C} = T_K - 273.15$	$K^{(1)}$

13.2 Prefix Notation

For all named units, the SI system supports a prefix notation. The prefix consists of a one or two letter combination to scale the unit to the user's needs. The prefixes are listed in Table 16.

For example, the prefix kilo denotes a multiple of one thousand, so 1 kilometer equals 1000 meters, 1 kilogram equals 1000 grams and 1 kilowatt equals 1000 watts, and so on. Each SI prefix name has an associated symbol which can be used in combination with the unit symbols. Thus, the "kilo" symbol, k, can be used to produce km, kg, and kW, (kilometer, kilogram, and kilowatt).

Table 16: Prefixes defined by the SI system

Prefix	Name	Factor	Short Scale
Y	yotta-	10^{24}	Septillion
Z	zetta-	10^{21}	Sextillion
E	exa-	10^{18}	Quintillion
P	peta-	10^{15}	Quadrillion
T	tera-	10^{12}	Trillion
G	giga-	10^9	Billion
M	mega-	10^6	Million
k	kilo-	10^3	Thousand
h	hecto-	10^2	Hundred
da	deca-	10^1	Ten
d	deci-	10^{-1}	Tenth
c	centi-	10^{-2}	Hundredth
m	milli-	10^{-3}	Thousandth
μ	micro-	10^{-6}	Millionth
n	nano-	10^{-9}	Billionth
p	pico-	10^{-12}	Trillionth
f	femto-	10^{-15}	Quadrillionth
a	atto-	10^{-18}	Quintillionth
z	zepto-	10^{-21}	Sextillionth
y	yocto-	10^{-24}	Septillionth

Although all combinations of prefix and named unit are legal, some units are not prefixed in practice. E.g. $^{\circ}\text{C}$ is not prefixed, K is used instead (mK).

13.3 Other Derived Units

Other derived SI units without a separate name are listed in Table 17.

Table 17: Other derived units

Symbol	Name	Quantity	In SI base units
m^2	square meter	area	m^2
m^3	cubic meter	volume	m^3
m/s	meter per second	speed, velocity	$\text{m}\cdot\text{s}^{-1}$
m/s^2	meter per second squared	acceleration	$\text{m}\cdot\text{s}^{-2}$
m/s^3	meter per second cubed	jerk	$\text{m}\cdot\text{s}^{-3}$
rad/s	radian per second	angular velocity	s^{-1}
$\text{N}\cdot\text{s}$	newton second	momentum, impulse	$\text{kg}\cdot\text{m}\cdot\text{s}^{-1}$
$\text{N}\cdot\text{m}\cdot\text{s}$	newton meter second	angular momentum	$\text{kg}\cdot\text{m}^2\cdot\text{s}^{-1}$
$\text{N}\cdot\text{m}$	newton meter	torque, moment of force	$\text{kg}\cdot\text{m}^2\cdot\text{s}^{-2}$
m^{-1}	reciprocal meter	wave number	m^{-1}
kg/m^3	kilogram per cubic meter	density, mass density	$\text{kg}\cdot\text{m}^{-3}$
m^3/kg	cubic meter per kilogram	specific volume	$\text{kg}^{-1}\cdot\text{m}^3$
mol/m^3	mole per cubic meter	amount (-of-substance) concentration	$\text{m}^{-3}\cdot\text{mol}$
m^3/mol	cubic meter per mole	molar volume	$\text{m}^3\cdot\text{mol}^{-1}$
J/K	joule per Kelvin	heat capacity, entropy	$\text{kg}\cdot\text{m}^2\cdot\text{s}^{-2}\cdot\text{K}^{-1}$
$\text{J}/(\text{K}\cdot\text{mol})$	joule per Kelvin mole	molar heat capacity, molar entropy	$\text{kg}\cdot\text{m}^2\cdot\text{s}^{-2}\cdot\text{K}^{-1}\cdot\text{mol}^{-1}$
$\text{J}/(\text{K}\cdot\text{kg})$	joule per kilogram Kelvin	specific heat capacity, specific entropy	$\text{m}^2\cdot\text{s}^{-2}\cdot\text{K}^{-1}$
J/mol	joule per mole	molar energy	$\text{kg}\cdot\text{m}^2\cdot\text{s}^{-2}\cdot\text{mol}^{-1}$
J/kg	joule per kilogram	specific energy	$\text{m}^2\cdot\text{s}^{-2}$
J/m^3	joule per cubic meter	energy density	$\text{kg}\cdot\text{m}^{-1}\cdot\text{s}^{-2}$
N/m	newton per meter	surface tension	$\text{kg}\cdot\text{s}^{-2}$
J/m^2	joule per square meter	surface tension	$\text{kg}\cdot\text{s}^{-2}$
W/m^2	watt per square meter	heat flux density, irradiance	$\text{kg}\cdot\text{s}^{-3}$
$\text{W}/(\text{m}\cdot\text{K})$	watt per meter kelvin	thermal conductivity	$\text{kg}\cdot\text{m}\cdot\text{s}^{-3}\cdot\text{K}^{-1}$
m^2/s	square meter per second	kinematic viscosity, diffusion coefficient	$\text{m}^2\cdot\text{s}^{-1}$
$\text{Pa}\cdot\text{s}$	pascal second	dynamic viscosity	$\text{kg}\cdot\text{m}^{-1}\cdot\text{s}^{-1}$
$\text{N}\cdot\text{s}/\text{m}^2$	Newton second per square meter	dynamic viscosity	$\text{kg}\cdot\text{m}^{-1}\cdot\text{s}^{-1}$
C/m^3	coulomb per cubic meter	electric charge density	$\text{m}^{-3}\cdot\text{s}\cdot\text{A}$
A/m^2	ampere per square meter	electric current density	$\text{A}\cdot\text{m}^{-2}$
S/m	siemens per meter	conductivity	$\text{kg}^{-1}\cdot\text{m}^{-3}\cdot\text{s}^3\cdot\text{A}^2$
$\text{S}\cdot\text{m}^2/\text{mol}$	siemens square meter per mole	molar conductivity	$\text{kg}^{-1}\cdot\text{s}^3\cdot\text{mol}^{-1}\cdot\text{A}^2$
F/m	farad per meter	permittivity	$\text{kg}^{-1}\cdot\text{m}^{-3}\cdot\text{s}^4\cdot\text{A}^2$
H/m	henry per meter	permeability	$\text{kg}\cdot\text{m}\cdot\text{s}^{-2}\cdot\text{A}^{-2}$

Symbol	Name	Quantity	In SI base units
V/m	volt per meter	electric field strength	$\text{kg}\cdot\text{m}\cdot\text{s}^{-3}\cdot\text{A}^{-1}$
A/m	ampere per meter	magnetic field strength	$\text{A}\cdot\text{m}^{-1}$
cd/m^2	candela per square meter	luminance	$\text{cd}\cdot\text{m}^{-2}$
C/kg	coulomb per kilogram	exposure (X and gamma rays)	$\text{kg}^{-1}\cdot\text{s}\cdot\text{A}$
Gy/s	gray per second	absorbed dose rate	$\text{m}^2\cdot\text{s}^{-3}$

13.4 Non SI Units

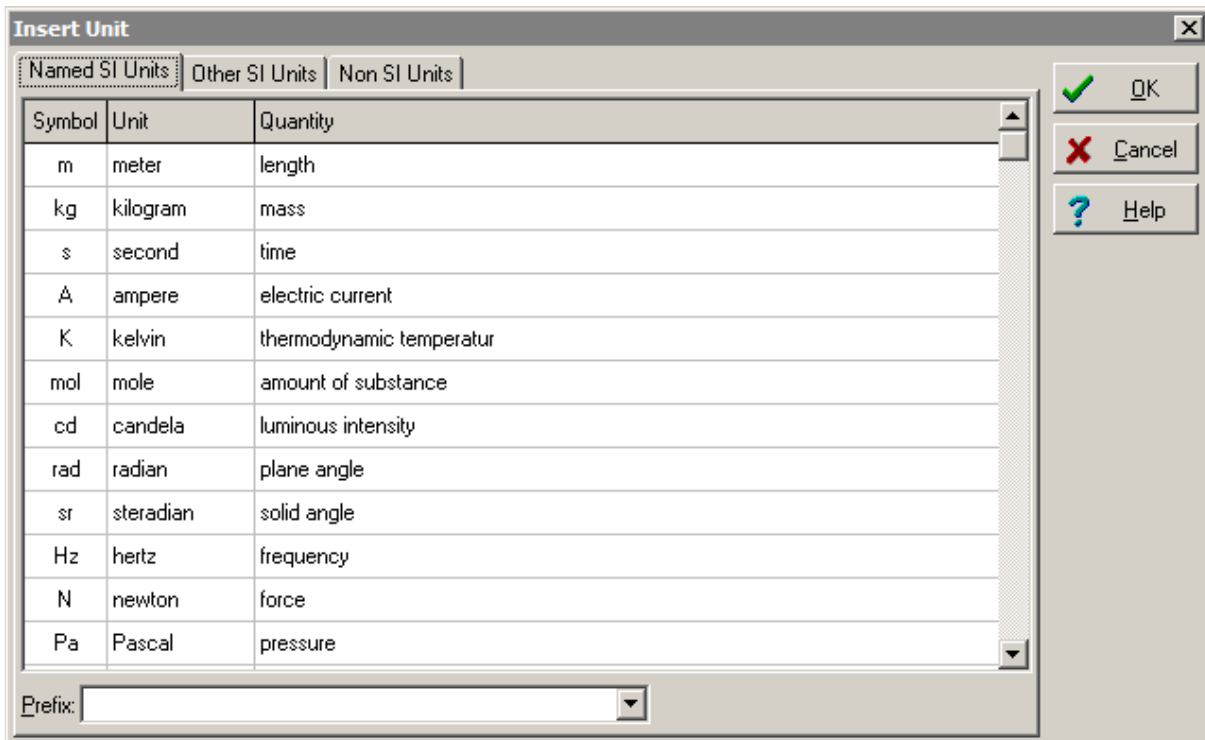
Although the SI unit system is widely used for many measurements, other units are used as well. In the context of SI, the use of non SI units is strongly discouraged whenever a SI unit is available. Some non-SI units which may be used together with SI units are listed in Table 18. The usage of these units will not raise a warning message in GUM Workbench®.

Table 18: Non SI units which may be used together with SI units

Symbol	Definition	Unit	Quantity
bar	10^5 Pa	bar	pressure
l, L	10^{-3} m^3	liter	Volume
t	10^3 kg	tonne	mass
min	60 s	minute	time
h	60 min	hour	time
d	24 h	day	time
eV		Electron volt	energy
u		atomic mass unit	atomic mass
dB		decibel	logarithmic ratio (base 10)
Np		neper	logarithmic ratio (base e)
%	10^{-2}	percent	percentage
°		degree	plane angle
Å	10^{-10} m	ångström	length (atomic scale)

13.5 Insert Unit Dialog

GUM Workbench® directly supports all named SI units, other SI units and some non-SI units. With the *Edit | Insert Unit* dialog the user has access to the built-in units (Figure 71).

Figure 71: *Insert Unit* dialog

The *Insert Unit* dialog is most useful in the Symbol List in the *Model Equation* tab. To enter a unit in the *Symbol List*, the User opens the *Insert Unit* dialog (shortcut ctrl-U). Now the unit should be selected from the table and in case of *Named SI Units* a Prefix can be selected (see Table 16). When the user presses *OK*, the selected unit will be combined with the selected prefix and inserted as text at the present cursor position.

13.6 Unit Validation Dialog

After the units for all quantities have been entered in the *Symbol List* (below the *Equation* field), the usage of units can be validated. This validation is done with the *Tools|Unit Validation* dialog.

The usage of units is validated in three steps.

1. The units of all quantities are scanned and the syntax is checked. This ensures that all unit fields contain legal unit strings.
2. The units of all quantities are translated into base units. If a unit can not be translated into SI base units or to the predefined non SI units, a warning will be issued.
3. The units of the quantities will be substituted into the equations and the equations will be checked. For all equations, the combination of units of the right side and the combination of units of the result will be evaluated and compared. If the units do not match exactly then the difference will be shown in an error message.

A summary of the three steps will be shown on a *Summary* tab. The equation and the units are consistent if all three steps are passed successfully.

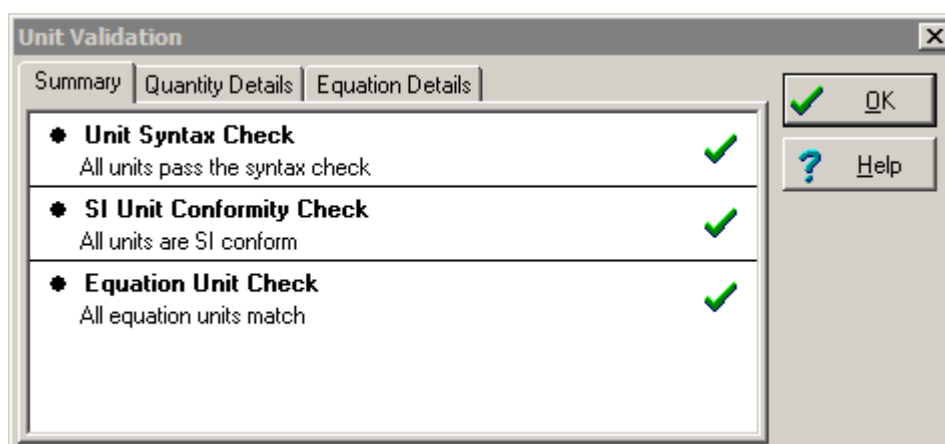


Figure 72: Unit Validation Dialog – Summary

The result of each validation step can either be successful (✓), a warning issued (!) or an error occurred (✗). If there is an error, the units are not consistent and need to be changed. If there are warnings, the details of the warning should be inspected. A warning means that no clear decision can be made as to whether the units are consistent or not. The user should understand the reason for the warning and he needs to decide if the warning can be ignored or if the unit or the equation should be changed.

On the *Quantity Details* tab (see Figure 73), the details of the unit translation to the base units can be inspected. Warning and error messages are also shown here.

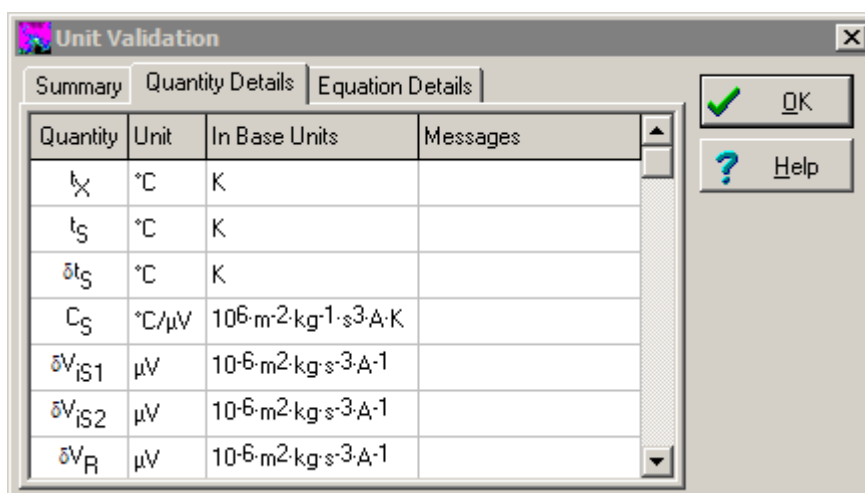


Figure 73: Unit Validation Dialog – Quantity Details

The results of the evaluation of the equations can be inspected on the *Equation Details* tab. Warnings and error messages are provided there as well.

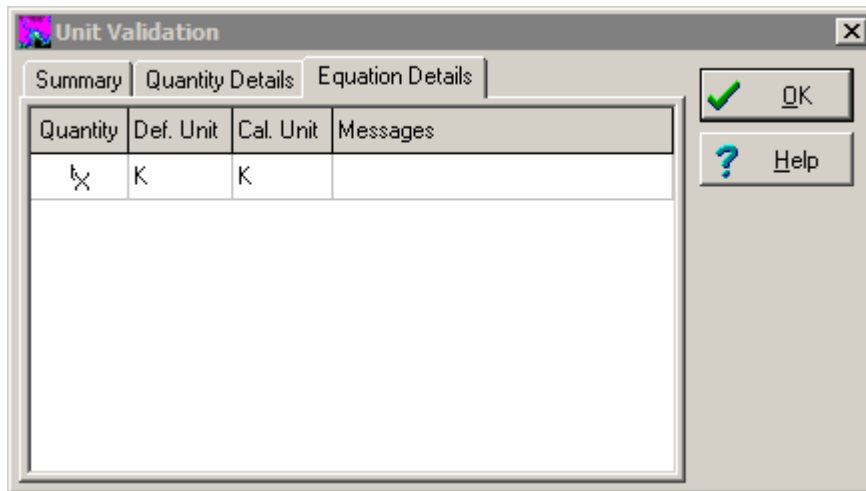


Figure 74: Unit Validation Dialog – Equation Details

13.7 Syntax Rules for Units

All unit strings should follow strict syntax rules. These rules need to be followed by SI units as well as non-SI units. They are basically linked to the concept of a unit system. Any unit is a factor which will be combined with a number. Thus, a unit needs to be either a base unit or it can be expressed as a product or quotient of base units.

All SI units can be expressed by the following general product:

$$\text{SI unit} = f_{\text{prefix}} \cdot \text{m}^{i1} \cdot \text{kg}^{i2} \cdot \text{s}^{i3} \cdot \text{A}^{i4} \cdot \text{K}^{i5} \cdot \text{mol}^{i6} \cdot \text{cd}^{i7}$$

The exponents $i1$ to $i7$ are usually integer numbers between -4 and 4 and f_{prefix} is the prefix factor. In the context of noise voltage however the unit $\text{Hz}^{-0.5}$ ($\text{s}^{0.5}$) is used. In general, the exponents can be any real number.

In GUM Workbench® the following syntax rules are implemented:

1. A unit string is either one unit name or a product (*) or quotient (/) of unit names or a number. Addition (+) and subtraction (–) are not allowed.
2. The factors of the products or quotients are either other products or quotients or named units or numbers.
3. The ^-Symbol is used to indicate the exponentiation of the factors of the product/quotients. Example: m^2 has the meaning of m^2 .
4. No functions can be used in the unit strings. Square root should be written as exponentiation to 0.5.
5. Prefixes may be used in conjunction with named Units. The prefixes are translated into scaling factors.

All unit strings given in the *Insert Unit* dialog are syntactically correct and serve as examples for valid unit strings. Table 19 lists some examples of valid unit strings which do not conform to the SI system of units.

Table 19: Examples of valid unit strings which do not conform to SI

Unit String	In Base Units	Comment
psi	psi	non SI unit name (no further translation)
psi/Pa	$\text{m}\cdot\text{kg}^{-1}\cdot\text{s}^2\cdot\text{psi}$	combination of SI and non-SI, psi is a non-SI unit and cannot be translated any further
$10^{-3}\cdot^{\circ}\text{F}\cdot\text{L}$	$10^{-6}\cdot\text{m}^3\cdot^{\circ}\text{F}$	combination of factor and units, $^{\circ}\text{F}$ is a non-SI unit and can not be translated any further
$\mu\text{in}\cdot\text{Gkat}$	$10^9\cdot\text{s}^{-1}\cdot\text{mol}\cdot\mu\text{in}$	Gkat is translated to $10^9\cdot\text{s}^{-1}\cdot\text{mol}$, but μin is not translated to $10^{-6}\cdot\text{in}$ since prefixes are not supported for non-SI units

13.8 Validation of the Model Equation

The units are factors and can be evaluated independently of the values. Therefore the equation can be validated without knowledge of the actual values. This is called unit calculus.

When all units are syntactically correct, they are translated to base units. With the base unit representation, the equations are evaluated by the following rules:

1. If two quantities are added (+) or subtracted (–) they must have exactly the same unit. The unit of the result of the operation is equal to this unit.
2. If two quantities are multiplied (*) or divided (/) they may have any unit. The unit of the result of the operation is the product or quotient of the units of the two quantities.
3. The power operator (^) supports two cases.
 - a. If the exponent is a given fixed number, the basis expression can have any unit and the unit of the result of the operation is calculated according to the power law.
 - b. If the exponent is a variable expression, the unit of the basis and the exponent should be unity (1) and the unit of the result of the operation is unity as well.
4. The argument of the `sqr()`, `sqrt()` and `root3()` functions can have any unit and the unit of the result is calculated based on the function (e.g. `sqrt(m2) = m`).
5. The argument of the `rad()` function should be '°' and the unit of the result is unity (1).
6. The argument of the `deg()` function should be unity (1) and the unit of the result is '°'.

7. The argument of the `const()` and the absolute function (`|` `|`) may have any unit and the unit of the result is the same as the argument.
8. All arguments of the `average()` function should be the same and the result of the function has the same unit. Internally, the `average()` function is replaced by the sum of the arguments divided by the number of arguments. Therefore error messages referring to an addition may occur.
9. The argument of all other functions should be unity (1) and the unit of the result is unity (1) as well.

13.9 Supported Units by the Unit Validation Tool

The *Unit Validation* tool supports all named SI units together with all the defined prefixes (see table 14, 15 and 16). Also the allowed non-SI units (see table 18) are supported. All these units will be translated into base units.

13.9.1 Kelvin and Degree Celsius

The SI unit system defines the K as the base unit for the thermodynamic temperature. However, the °C is also defined as an official SI unit and, by definition, a temperature difference of 1 °C is exactly equal to 1 K. The GUM Workbench® *Unit Validation* tool uses this equivalence to express °C as K when comparing units. But since 0 °C is equivalent to 273.15 K, this assumption is not correct for absolute temperatures and GUM Workbench® will issue a warning if °C and K are used in the same equation, because absolute and relative temperatures may be used incorrectly. The user should either avoid the mixed usage of °C and K or carefully check that the usage is correct.

13.10 Physical and Value Model Equations

If only non-prefixed unit names are used in the unit strings of the quantities, the model equation represents the physical relation between the quantities (kg is in this respect the named unit of mass despite the fact that it contains a prefix). These equations are universal and can be used independently of the actual scale of the quantities involved.

The disadvantage of a physical model equation is that all values need to be converted to non-prefixed units before they can be entered into the evaluation. Therefore, in practice, value equations are often used instead. Value equations are model equations where the entered values are based on defined prefixed units. For example, in a chemical value equation, a volume is entered as ml instead of m³. In an electrical evaluation, a small voltage may be entered as mV instead of Volt.

Value model equations often need to convert units by magnitude like the conversion from ml to litre or mV to Volt, etc. Thus, numbers such as 1000 or 1E-6 need to be entered in the model equation. Although these equations now produce the correct result values, they are not correct from the unit point of view. As a consequence, the Unit Validation Tool will issue an error message that the calculated and the defined units are not equal. In addition, a warning will be issued that numbers are used in the model equation.

The reason for this problem is that the conversion factors between different scales of a unit have also a unit assigned. For example the conversion factor from l to ml is 1000 ml/l, which is equal to $1000 \cdot 10^{-3}$. The equation is formally correct when the correct unit for the conversion factor is used.

In GUM Workbench®, the conversion factors in value equations need to be quantities of type constant with the correct unit assigned to them.

The following example illustrates the usage of a conversion factor. The concentration of a prepared solution may be evaluated with the following model:

$$c = k_{\text{mL}} \cdot m / V$$

The result c should be in mg/L. For the convenience of the user, the mass m should be entered in mg and the volume V should be entered in ml. Therefore a conversion factor $k_{\text{mL}} = 1000 \text{ ml/L}$ is necessary to convert the values from mg/ml to mg/L.

13.11 Non SI Units

The GUM Workbench® unit validation concept also supports any non-SI units as long as they are well constructed and follow the basic syntax rules.

Any unit name which is not defined, either as an existing unit or as a prefix plus an existing unit, will be treated as new non-SI unit and warnings will be issued. No prefixing is supported for this new unit. The Unit Validation Tool verifies if the non-SI units are used correctly together with the SI units.

Although GUM Workbench® does not intentionally support any automatic conversion between non-SI units and SI units, this can be easily added to the model equation. The following examples show the conversion of temperature and pressure between SI and non-SI units. The conversions use user-defined functions. The conversion factors need to be quantities of the type constant.

13.11.1 Example Temperature °F and °C

For the conversion between a temperature in °F to a temperature in °C and back, two user functions can be defined:

$$f_C(t_F) = k_F \cdot (t_F - t_{F0}); \text{ \{conversion from } ^\circ\text{F to } ^\circ\text{C}\}}$$

$$f_F(t_C) = t_C/k_F + t_{F0}; \text{ \{conversion from } ^\circ\text{C to } ^\circ\text{F}\}}$$

The conversion constants k_F and t_{F0} have the following values:

$$k_F: \text{ constant} = 5/9, \text{ unit: } ^\circ\text{C}/^\circ\text{F}$$

$$t_{F0}: \text{ constant} = 32, \text{ unit: } ^\circ\text{F}$$

The conversion functions can be applied to the following values:

Model Equation	Input Quantities	Result
$t_{C1} = f_C(t_{F1})$	$t_{F1} = 0 \text{ } ^\circ\text{F} \pm 0.1 \text{ } ^\circ\text{F} \text{ (k=2)}$	$t_{C1} = -17.778 \text{ } ^\circ\text{C} \pm 0.056 \text{ } ^\circ\text{C} \text{ (k=2)}$
$t_{F2} = f_F(t_{C2})$	$t_{C2} = 50 \text{ } ^\circ\text{C} \pm 0.1 \text{ } ^\circ\text{C} \text{ (k=2)}$	$t_{F2} = 122.00 \text{ } ^\circ\text{F} \pm 0.18 \text{ } ^\circ\text{F} \text{ (k=2)}$

13.11.2 Example Pressure psi and Pa

The conversion between psi and Pa is based on an agreed gravity constant of 9.80665 m/s^2 , the defined value for the pound (lb) and the inch (in). Two user functions do the conversion:

$$f_{\text{Pa}}(p_{\text{psi}}) = k_{\text{psi}} \cdot p_{\text{psi}};$$

$$f_{\text{psi}}(p_{\text{Pa}}) = p_{\text{Pa}}/k_{\text{psi}};$$

The conversion constant k_{psi} has the following value:

$$k_{\text{psi}}: \text{ constant} = 0.45359237 \cdot 9.80665 / (25.4 \cdot 10^{-3})^2, \text{ unit: Pa/psi}$$

The conversion functions can be applied to the following values:

Model Equation	Input Quantities	Result
$f_{\text{Pa}}(p_{\text{PSI}})$	$p_{\text{PSI}} = 1.00 \text{ psi} \pm 0.01 \text{ psi} \text{ (k=2)}$	$6895 \text{ Pa} \pm 69 \text{ Pa} \text{ (k=2)}$
$f_{\text{PSI}}(p_{\text{Pa}})$	$p_{\text{Pa}} = 10 \text{ kPa} \pm 5.00 \text{ Pa} \text{ (k=2)}$	$1.4504 \text{ psi} \pm 1.5 \cdot 10^{-3} \text{ psi} \text{ (k=2)}$

13.12 Error Messages and Warnings

The following warning messages may be raised by the Unit Validation Tool:

Warning: Numbers are used in the Model equation

This warning is issued if explicit numbers are used in the model equation for which the absolute values are greater than or equal to 10 or less than or equal to 0.1. This warning can be avoided by introducing a constant quantity instead (see the section on value equations).

Warning: °C and K are used in the model equation

This warning is issued if K and °C are used as units in the same sub-equation. This warning cannot be avoided if K and °C need to be used in the same evaluation. The user should carefully check the equation to insure that the temperature quantities are used correctly.

Warning: Non-SI units used (<names>)

This warning is issued if any non-SI units are used in the unit strings. The user should check whether not an SI unit was misspelled or whether the use of the non-SI unit was intended. This warning cannot be avoided.

Warning: The unit contains only a number string

Although a number string as a unit is syntactically correct, this could lead to a misinterpretation of the value reported together with this unit. Therefore it should be avoided by using an empty unit string for unity.

The following syntax error messages may be raised by the Unit Validation Tool. They are related to the syntax check of the unit strings:

Error: '<character>' is not allowed in units!

Error: '<character>' is not valid here!

Error: '<character>' is not a valid unit name!

Error: abs-operator not allowed in units!

Error: comma is not allowed in units!

Error: '+' and '-' are not allowed in units!

The error messages listed above indicate that a non-valid character has been found in the unit string. One reason might be that a multiplication or division operator is missing.

Error: functions are not allowed in units!

This error message indicates that a function call has been found in the unit string. Functions cannot be used within unit strings.

Error: missing ')!'

Error: multiplication is not complete!

Error: missing exponent!

The error messages above indicate that the unit string is not complete.

Error: exponents must be constant numbers!

The usage of the ^-operator is limited in unit strings. The ^-operator must be directly followed by an optional + or – sign and a number using a period for the decimal separator. A comma is not supported.

The following error messages may be raised by the Unit Validation Tool. They are related to the equation unit check:

Error: units must be equal with '+' and '-'!

It is only possible to add the values of two quantities if the units are exactly the same including any prefix factor. This error message may also occur if the average function is used.

Error: unit must be 1 with <function>() function!

The unit of arguments of most of the built-in functions must be unity. The trigonometric functions like $\sin()$ and $\cos()$ expect the argument be in radians.

Error: rad-function expects unit equal '°'!

The conversion function from degrees to radians expects the argument to be in degrees ('°').

Error: units with the ^-operator must be 1!

If the exponent is not a constant number the basis and the exponent should have the unit 1.

13.13 Compatibility with Older Versions

The unit support is fully compatible with older versions of GUM Workbench®. No changes to the file structure were necessary because of the unit validation support.

14 Working with Diagrams

GUM Workbench® version 2.4 supports an additional Diagram view. Diagrams can be viewed on screen, printed in a report and exported to RTF files.

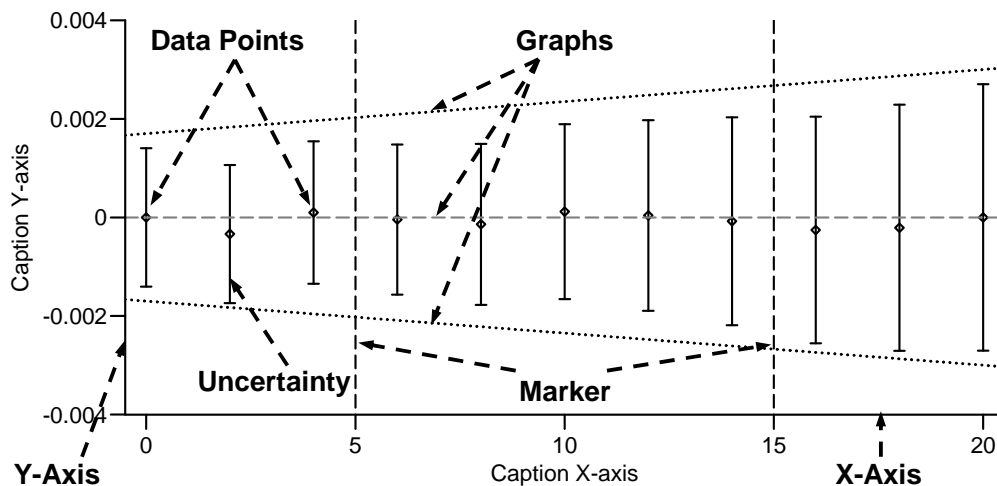


Figure 75: Structure of a diagram

Diagrams can be used to present results of the uncertainty evaluation in graphical form. Figure 75 shows the structure of such a diagram. A diagram is a 2-D plot of data points with uncertainty together with graphs (or curves) of arbitrary functions, and markers (vertical lines). The horizontal axis is referred to as the x-axis while the vertical axis is the y-axis. An axis can be scaled with labelled ticks and has a descriptive caption. Different types of diagrams are supported. They differ in the nature of the data and how the data is presented.

The *Scatter Diagram* ($X|Y$) shows data points in a 2-D x/y diagram. The x and the y coordinates of the points are controlled by separate quantities. Uncertainty bars are plotted if an uncertainty is given for the quantities.

The *Uncertainty Diagram* ($Y|U$) shows uncertainty bars in the y-direction for a given set of data represented by different quantities. The data values are the x-positions of the bars. This diagram is useful if the uncertainty has been evaluated for different points in a working range of a measurement process and a plot of the uncertainty over the range is needed.

The *Value Diagram* (Y) is a diagram to plot and compare different values. The selected quantities are plotted next to each other in the same scale (y-axis) together with uncertainty bars. The x-axis is labelled with the quantity names.

The *ζ -Value Diagram* shows the ζ -values of the selected quantities calculated with the following function:

$$\zeta(y) = \frac{|y|}{u(y)}. \quad (5)$$

This diagram is useful for plotting the ζ -values of differences. The ζ -value is a measure of how the significance of a difference compares to the uncertainty of the difference. It might be useful to add a graph of a function to the diagram with a fixed value e.g. $f(x) = 2$ (see section 14.2.5).

A *Histogram* cannot be created directly by the user nor can the data be changed. A histogram is created from the output of a Monte Carlo simulation. The user can only change the axis parameter, edit the graphs and the markers.

14.1 Diagram View

Figure 76 shows the additional *Diagram* view to handle diagrams. The view supports multiple two dimensional (2-D) diagrams. Each diagram may show different data.

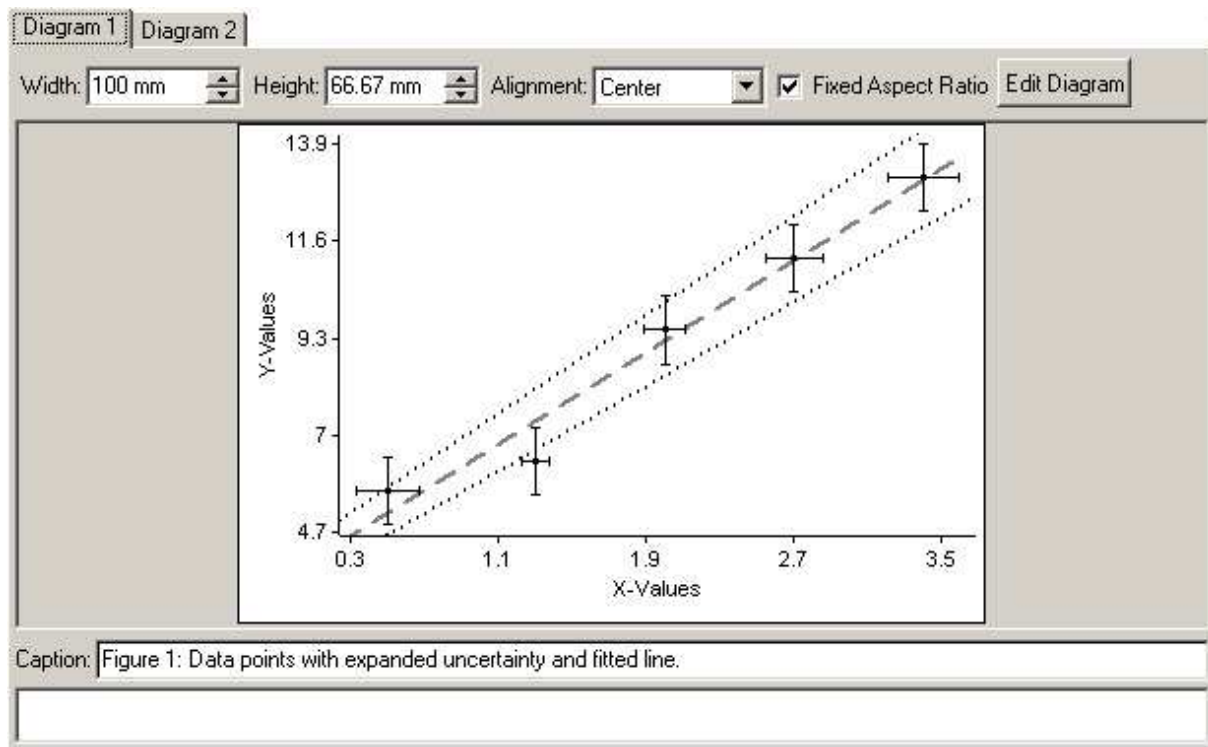


Figure 76: *Diagram View*

A diagram is a 2D plot area whose size can be controlled by the *Width* and *Height* fields. The size of the plot area on the screen is close to the size in the report. The default size is 15 cm x 10 cm.

If *Fixed Aspect Ratio* is selected, the *Width* or the *Height* field will be changed automatically when one or the other is changed.

Alignment controls how the diagram is aligned on the report page. The default is centred.

Note: The diagram will be printed (or exported) with the size given in the *Width* and *Height* fields independent if the diagram fits on the page or not. The user might check the diagram in the preview and correct the size in case it does not fit.

The details of the diagram can be inspected in the *Diagram Details* dialog which can be called by the *Edit Diagram* button, a double click on the diagram or the *Diagram | Edit Diagram...* menu entry.

Below the plot area is the diagram *Caption* and a *Description* field. If a diagram *Caption* is entered it will be printed in the report below the diagram. The optional *Description* is printed in the report after the diagram and the diagram *Caption*.

It is possible to add and delete additional diagrams, if necessary, with commands in the *Diagram* menu.

14.2 Diagram Details

Figure 77 shows the *Diagram Details* dialog. The dialog has different tabs to structure the diagram details.

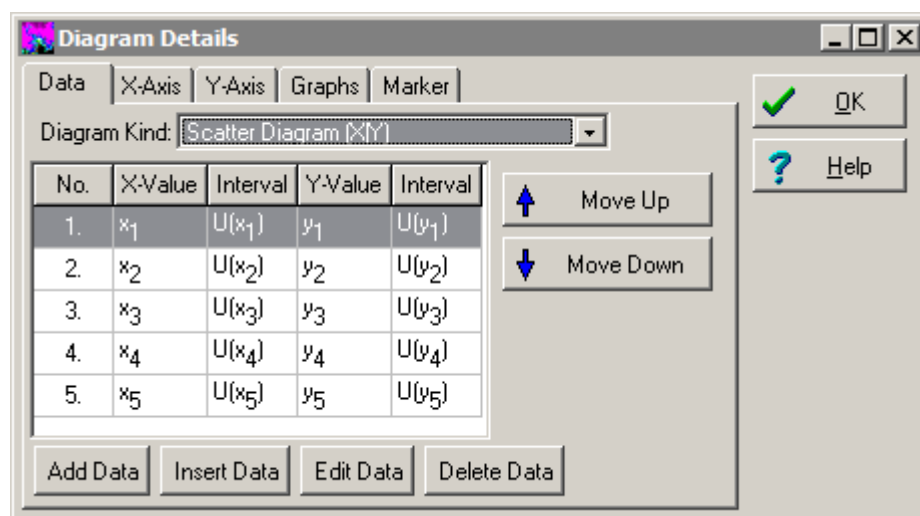


Figure 77: *Diagram Details* Dialog, *Data* tab

The *Data* tab shows the plot data details, the *X-Axis* and the *Y-Axis* tabs show the axis details including the axis *Caption* and the *Graphs* and the *Marker* tabs show the details of the optional *Graphs* and *Markers* plotted on the diagram.

Any changes in the *Diagram Details* dialog will take effect immediately in the diagram.

14.2.1 Data Tab

The *Data* tab controls the *Diagram Kind* (see Table 20) and the plot data matrix.

Table 20: Supported diagram kinds (types)

Diagram Kind	Description	Data
<i>Scatter Diagram (X Y)</i>	Plots data points with separate X and Y values which both may have an uncertainty.	X, U(X), Y, U(Y)
<i>Uncertainty Diagram (Y U)</i>	Plots uncertainty bars for the selected Y values.	Y, U(Y)
<i>Value Diagram (Y)</i>	Plots selected Y values and uncertainties. The X axis is labelled with the quantity names.	Y, U(Y)
<i>ζ-Value Diagram</i>	Plots ζ-values of the selected quantities. The X axis is labelled with a ζ-function call with the quantity names.	Y
<i>Histogram</i>	Plots a histogram. Histogram plots cannot be created by direct user actions. The data of histograms cannot be changed.	

The plot data matrix (table in figure 77) shows the currently selected data. The content is dependent on the currently selected *Diagram Kind*.

The content of the plot data matrix will be deleted if the *Diagram Kind* is changed.

The content of the plot data matrix can be manipulated with the *Move Up* and *Move Down* button to change the order. This is visible on the diagram only if the *Diagram Kind* is *Value Diagram (Y)* or *ζ-Value Diagram*.

The *Add Data* button adds additional data to the end of the plot data matrix. The *Insert Data* button inserts the data at the selected row and the *Delete Data* button will delete the selected data from the plot data matrix.

14.2.2 Adding and Inserting Data

Additional data can be added or inserted with the *Add Data Values* or *Insert Data Values* dialog (see Figure 78). This dialog is called with *Add Data* button or the *Insert Data* button in the *Diagram Details* dialog (see Figure 77).

Add Data Values

X-Value: Y-Value:

Uncertainty: Uncertainty:

☒ Use as Pattern

Select	X-Value	Interval	Y-Value	Interval
<input checked="" type="checkbox"/>	x ₁	U(x ₁)	y ₁	U(y ₁)
<input checked="" type="checkbox"/>	x ₂	U(x ₂)	y ₂	U(y ₂)
<input checked="" type="checkbox"/>	x ₃	U(x ₃)	y ₃	U(y ₃)
<input checked="" type="checkbox"/>	x ₄	U(x ₄)	y ₄	U(y ₄)
<input checked="" type="checkbox"/>	x ₅	U(x ₅)	y ₅	U(y ₅)

OK Cancel Help

Figure 78: *Add Data Values* Dialog for a *Scatter Diagram (X|Y)*

The content of the *Add Data Values* dialog is dependant on the selected *Diagram Kind* (see Table 20). The possible data values can be chosen from the available quantities. Only quantities of certain types (e.g. Result or Interim Result, Type B normal) can be plotted.

With the *Use as Pattern* option, multiple data entries can be added to the plot data matrix. Use the select column to control which data row will be added to the plot data matrix.

The *OK* button will close the dialog and add the data while the *Cancel* button will close the dialog without changing the data.

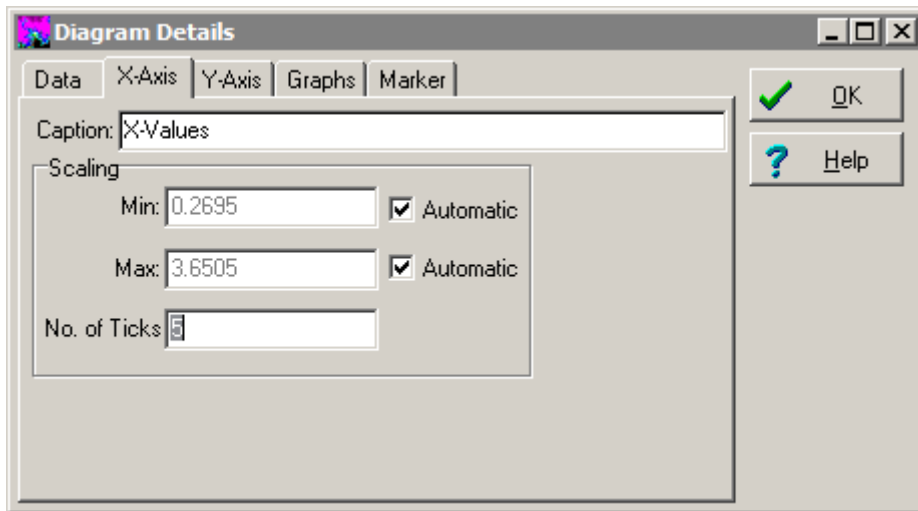
14.2.3 Editing Data

Existing data can be modified with the *Edit Data Value* dialog. This dialog is called with *Edit Data* button in the *Diagram Details* dialog. The dialog is very similar to the *Add Data Values* dialog. The *Use as Pattern* option is not supported.

14.2.4 Axis Control

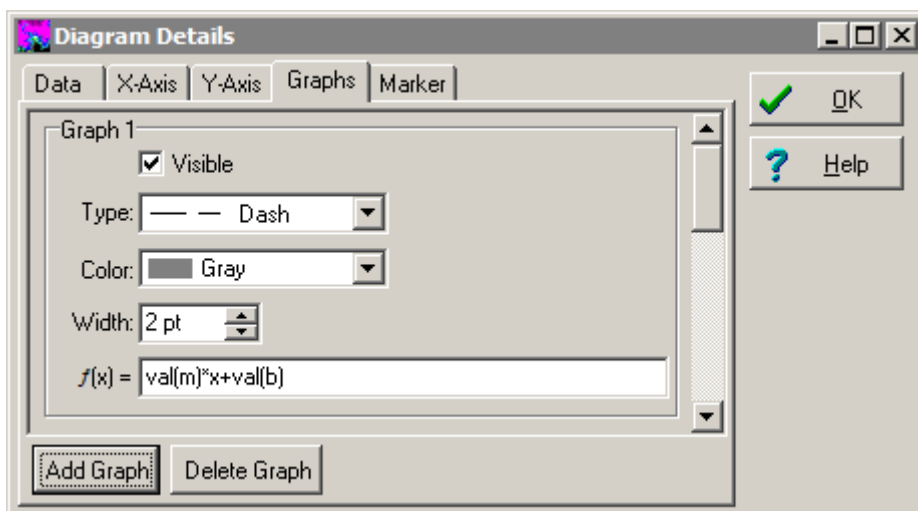
The *X-Axis* and the *Y-Axis* tabs control the details of the axis setting (see Figure 79). The axis *Caption* is printed next to the axis on the plot area. The content can be freely chosen.

The *Scaling* section controls the scaling of the axis. The displayed range is controlled with *Min* and *Max*. The *Automatic* options will calculate the range based on the content of the plot data matrix. The *No. of Ticks* field specifies how many ticks are printed on the axis.

Figure 79: *Diagram Details* Dialog, *X-Axis* tab

14.2.5 Graphs

In addition to the content of the plot data matrix, graphs can be added to the plotting area. Graphs are curves which can be described by a function, such as straight lines, cubic polynomials, exponential functions, etc.

Figure 80: *Diagram Details* dialog, *Graphs* tab

Graphs are controlled by the *Graphs* tab (see Figure 80). They are added and deleted with the *Add Graph* or *Delete Graph* button. For every graph, a *Graph <n>* section is created on the *Graphs* tab. Use the scroll bar to view all graph sections for the current diagram.

A *Graph* is only visible on the diagram if the *Visible* option is selected.

The line type is selected with *Type*. *Solid*, *Dash* and *Dot* are supported.

The *Color* field controls the color of the graph.

The *Width* of the *Graph* is controlled with the *Width* field.

The curve of the *Graph* is controlled by the equation field ($f(x) =$). The content should be a valid equation (no equals sign) which defines the y values of the line as a function of x. Built-in functions like `sin()`, `cos()` and `exp()` can be used. All the quantities of the model equation are accessible with the help of the `val()`, `u()` and `U()` functions (see table 21).

Table 21: Quantity Access Functions

Access Function	Description	Example
<code>val(<name>)</code>	The <code>val()</code> function returns the nominal value of the quantity given by <code><name></code> .	<code>val(x_1)</code>
<code>u(<name>)</code>	The <code>u()</code> function returns the value of the standard uncertainty of the quantity given by <code><name></code> .	<code>u(x_1)</code>
<code>U(<name>)</code>	The <code>U()</code> function returns the value of the expanded uncertainty value of the quantity given by <code><name></code> . This function is only defined for quantities with the type Result or Interim Result.	<code>U(x_1)</code>

The Equation for the graph can be followed by an optional range specification '[<from>...<to>]' for valid x-values. The range specification starts with an open square bracket '[' followed by an optional number <from>, an ellipsis (three dots on the line) and another optional number <to>. The range is open on the side where no number is specified.

Example: [2.5 ... 3.5] will specify that the graph is only plotted for x-values between 2.5 and 3.5. No symbolic limits are allowed.

Graphs are only visible if all data is available and if they can be plotted on the currently selected plotting range (see axis setting). Graphs do not interact with the plotting range selection if automatic is selected.

14.2.6 Marker

Markers are vertical lines in the diagram. They are similar to graphs. Instead of specifying a function to be plotted, the x-position should be given for a marker. See the Section 14.2.5 for the details.

The position of the *Marker* line is controlled by the equation field ($x =$). The content needs to be a valid equation (no equal sign) which defines the x position of the straight line. Built-in functions like `sin()`, `cos()` and `exp()` can be used to calculate the position. All the quantities of the model equation are accessible with the help of the `val()`, `u()` and `U()` function (see Table 21).

Markers are useful together with histogram plots to indicate expectation (mean) values and coverage intervals.

14.3 Diagram Menu Commands

The diagrams can be managed with the *Diagram* menu. The supported commands are listed in Table 22.

Table 22: *Diagram* Menu Commands

Menu Command	Description
<i>Add Diagram</i>	Adds an additional diagram to the end of <i>Diagram</i> view.
<i>Delete Diagram</i>	Deletes the currently visible diagram.
<i>Insert Diagram</i>	Inserts an additional diagram at the position of the currently visible diagram in the <i>Diagram</i> view.
<i>Swap Diagram</i>	Exchanges the currently visible diagram with the diagram next to it on the right side.
<i>Edit Diagram...</i>	Opens the <i>Diagram Details</i> dialog.

14.4 Diagram Printing and Export

The diagrams are printed in the report after the results list and the results correlation table.

Figure 81 shows a typical diagram as it is printed on a report page or in an exported rtf file. In the report and export a diagram is followed by an optional caption and a description.

For export, the diagrams are converted to a metafile format and are embedded in the rtf file. Html and text-format do not support diagram export.

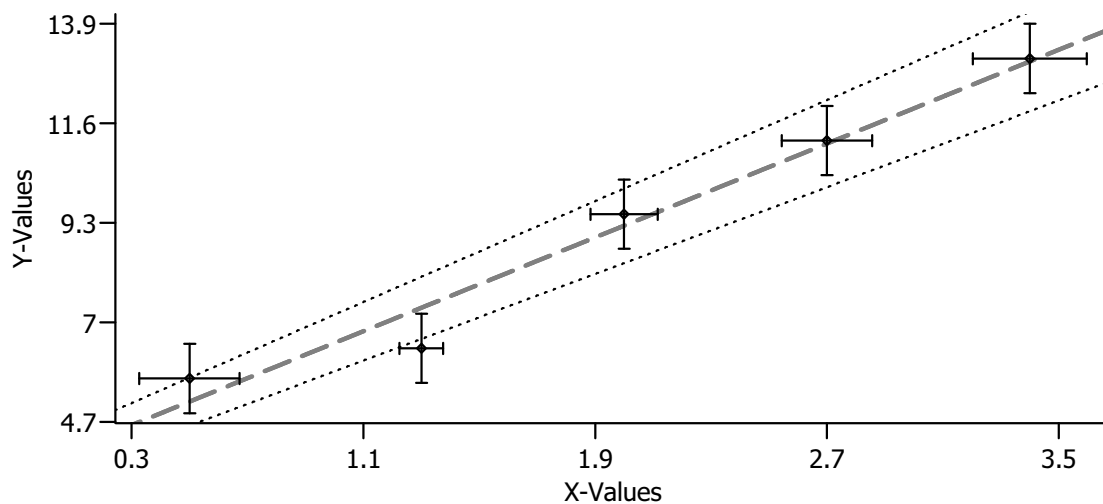


Figure 81: Example Diagram in the Report or in the RTF Export

14.5 Multiple Diagrams

The *Diagram* view supports multiple diagrams. In principle the number of diagrams is not limited. The performance of the computer will in practice limit the number of diagrams to less

than 20 in any GUM Workbench® file. All diagrams will be printed at the end of the report with their Captions and Descriptions.

15 Configuration

The user can configure several aspects of GUM Workbench® via the *Configuration* dialog. The *Configuration* dialog is called via the menu command *Option|Config...* The *Configuration* dialog is structured with several register tabs grouping together different aspects of the configuration. Changes to the configuration are global and persistent. They will be saved when the program is terminated.

15.1 General Tab

The author name and the date format can be configured on the *General* tab (see Figure 82). These are used as defaults for the document information fields.

The *Author* field contains the default author name. The content is copied to the *Author* field in the budget when a new budget is created.

With *Date Order* and *Date Separator*, the date format in the date field is selected. The date format in the report is independent of this selection and is controlled by the language selection of the report.

If *Automatic Date adjustment* is checked, the date field of the budget is not editable and will be automatically updated when the budget is changed.

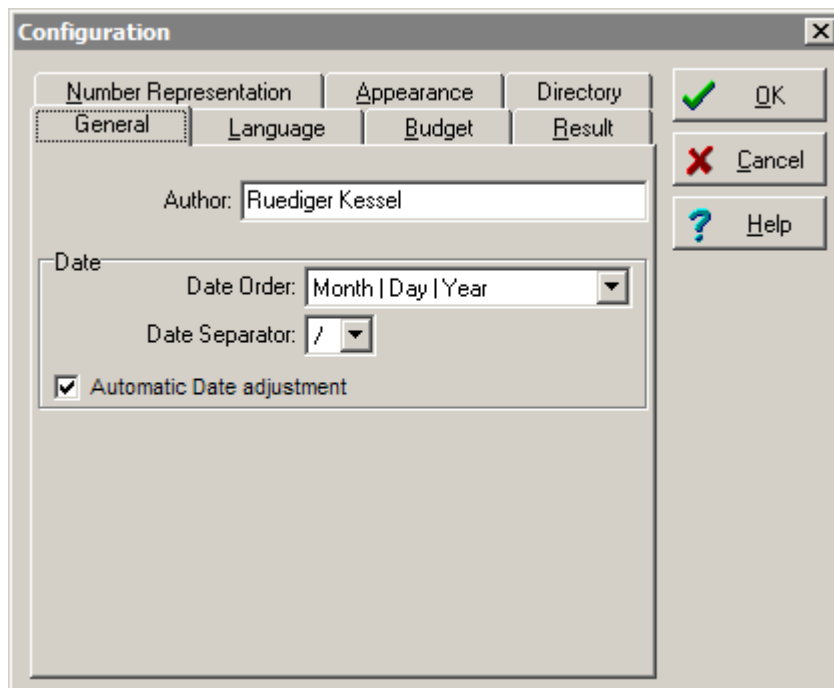


Figure 82: Configuration *General* Tab

15.2 Language Tab

The *Language* tab allows the selection of the language that will be used for the dialogs, the reports and during the export. Additionally the paper format can be specified (see Figure 83).

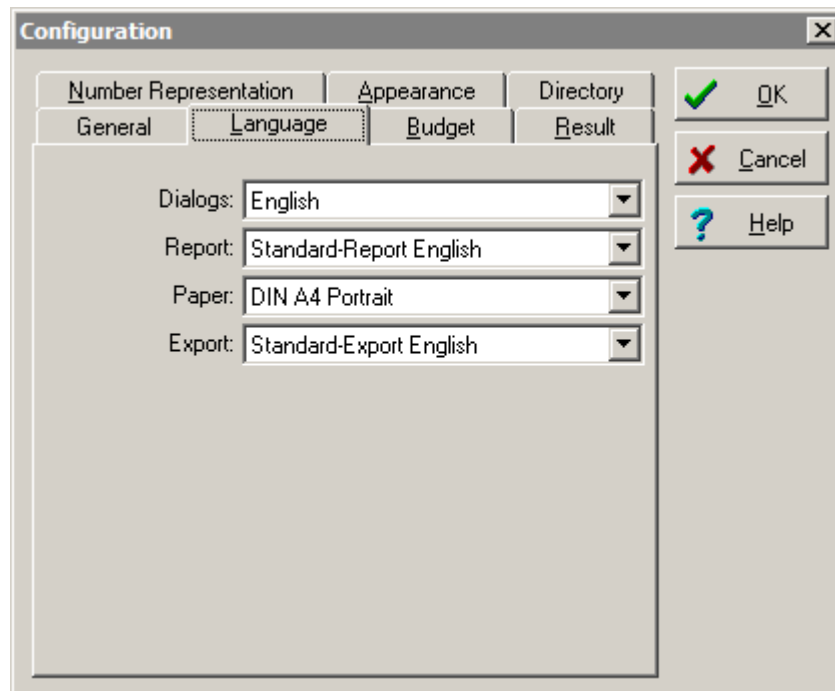


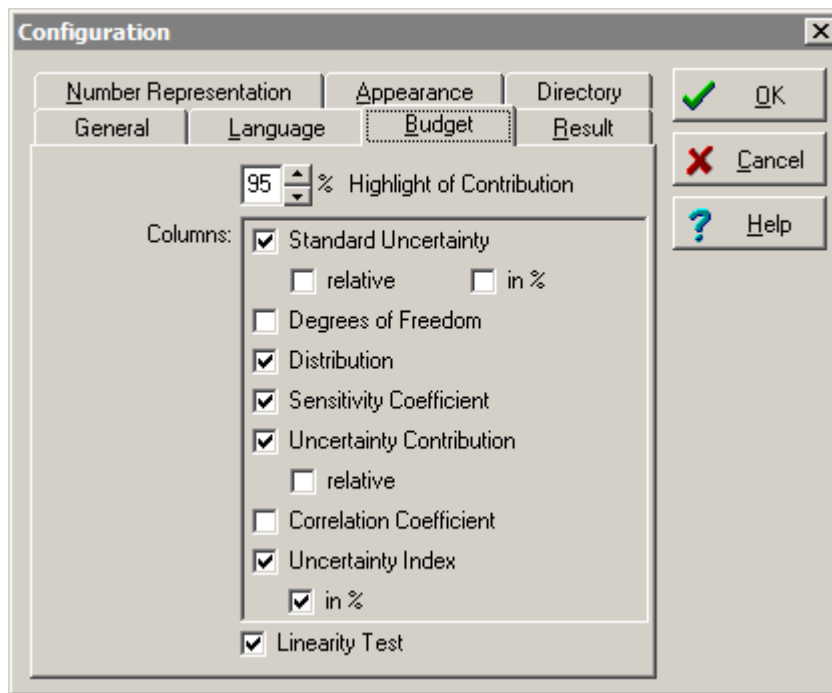
Figure 83: Configuration *Language* Tab

15.3 Budget Tab

Under the *Budget* tab, the user can configure aspects of the *Budget View* (see Figure 84). The *% Highlight of Contribution* field controls the part of the contribution that will be highlighted in the budget. Increasing the level highlights more quantities and decreasing the level will highlight fewer quantities. In the *Columns* section, the budget columns that will be visible in the *Budget View* and in the report are activated.

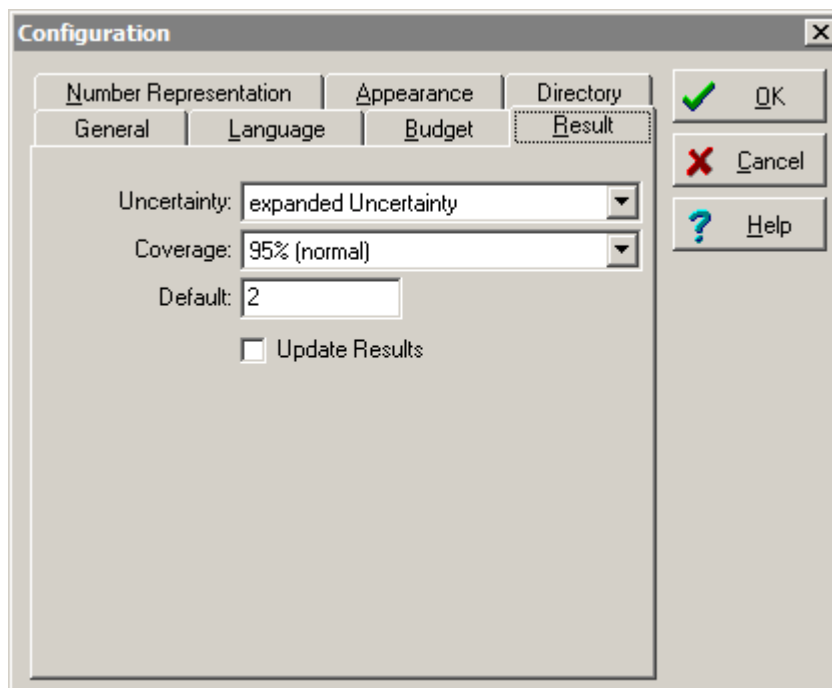
The *Linearity Test* option controls the execution of the linearity check (see section H.1 for details). It needs 5 complete calculations of the model for every input quantity. It can be switched off to avoid long delays during the budget calculation.

Warning: Possibly significant non-linearities of the model might go undetected if the *Linearity Test* option is switched off.

Figure 84: Configuration *Budget* Tab

15.4 Result Tab

Under the *Result* tab, the user has control over the default selection of the uncertainty representation, the coverage and, in the case of manual selection, the default coverage value (see Figure 85). With the *Update Results* option activated, all existing results are changed to the values selected on this tab.

Figure 85: Configuration *Result* Tab

15.5 Number Representation Tab

The *Number Representation* tab controls the number representation for printed numbers and values (see Figure 86). GUM Workbench® will automatically switch to an exponential number representation if the value is smaller or larger than the thresholds selected in this tab.

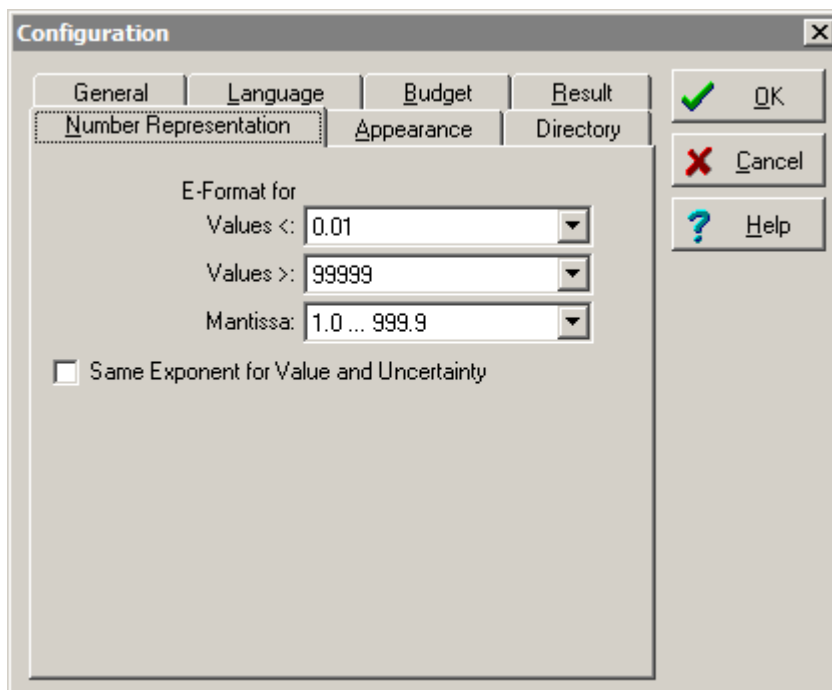


Figure 86: Configuration *Number Representation* Tab

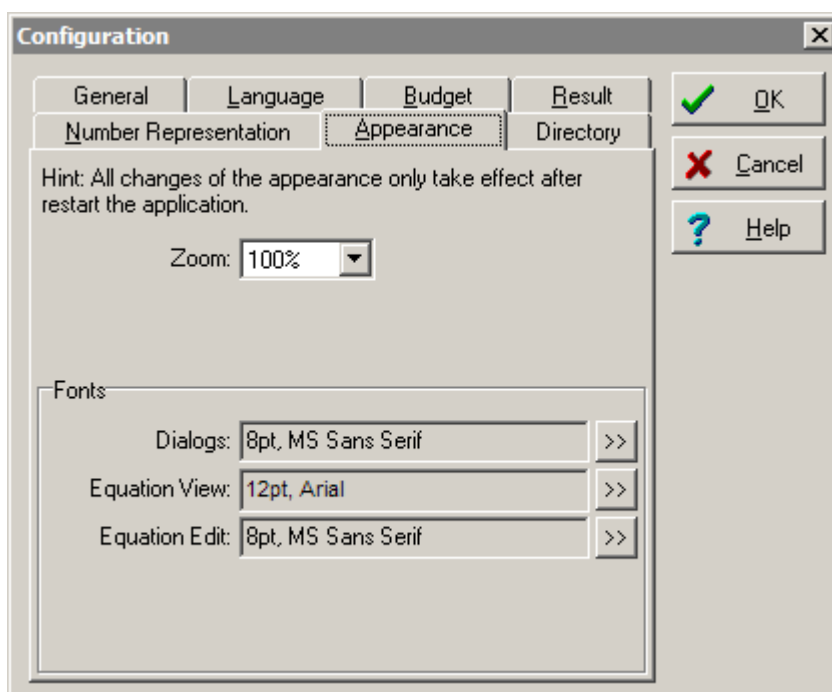


Figure 87: Configuration *Appearance* Tab

The exponent is always a multiple of three and is chosen so that the mantissa is in the range given by the Mantissa field. The *Same Exponent for Value and Uncertainty* option forces the same exponent on the value and the associated uncertainty of a quantity.

15.6 Appearance Tab

Under the *Appearance* tab, the user can select a general *Zoom* factor which will magnify all aspects of the user interface (except the menu) (see Figure 87). Additionally, different fonts can be selected.

15.7 Directory Tab

Under the *Directory* tab, a *Working Directory* can be chosen. This will be the default directory when the application is started.

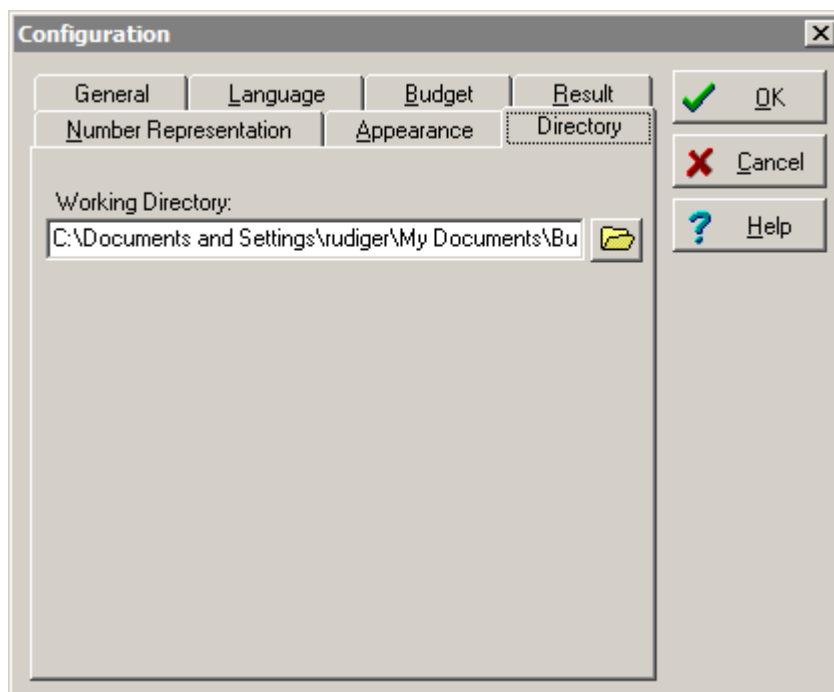


Figure 88: Configuration *Directory* Tab

16 Online Help

GUM Workbench® has extensive on-line help files, which contain important extracts from the present manual.

Help is offered through standard Windows® formatted help files. Help may be called by double-clicking the book icon and using the search facilities. Help can also be called via buttons located on most screens and dialogs of GUM Workbench®. The help buttons will offer context sensitive help, for example information which is relevant for the parts of the program from which help was called.

GUM Workbench® help files are available in several languages. The language to be currently used by the program should be selected using the *Config* dialog. See Section 15.2.

16.1 Version Information

The version information is shown in the *About* dialog called by the *Help | About...* menu. Detailed version information for the internal program modules is available by the *Modules* button in this dialog.

17 Expert Modules

The version 2.3 and 2.4 support an interface to call expert modules from inside GUM Workbench®. Expert modules are separate programs (DLLs) which are stored under the `.\experts\` subdirectory in the GUM Workbench® program directory. The expert DLLs have a special structure and need to be programmed especially for GUM Workbench®.

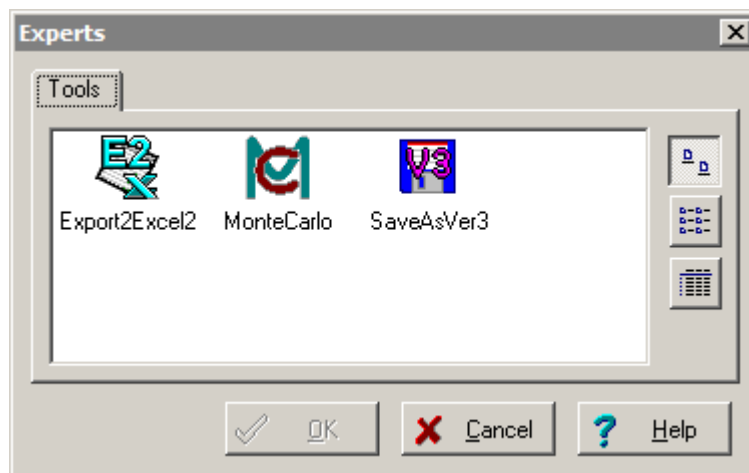


Figure 89: *Experts* dialog with Export2Excel2 expert selected

The experts are called via the *Experts* dialog in the *Tools* menu. Optionally, the experts can be grouped with tabs. The tab names are based on the subdirectory names in the `.\experts\` subdirectory under the GUM Workbench program directory. The *Expert* dialog supports three views for the list of experts. The icon view shows a large icon together with the expert name for every expert module. The list view shows a list of the expert names together with a small icon. The details view shows a list of expert names together with description, producer, version and filename.

After an expert is selected, it is started by double clicking on the icon or pressing the *Ok* button. Further execution depends on the selected expert module. The execution of GUM Workbench® is suspended while the expert module is executed and is resumed when the expert module finishes its operations.

17.1 Export to Excel Expert

The Export to Excel expert (`Export2Excel2.dll`) is a small module which can export the data from GUM Workbench® to MS-Excel®. It uses the OLE automation interface to MS-Excel® to transfer the data. This expert should be started from GUM Workbench® via the *Experts* dialog.

The export expert will present a short dialog in which the user can select the portions of the evaluation to be exported (see Figure 90). The export will start when the *OK* button is

pressed. GUM Workbench® will launch Excel if it is not already running and will create a new workbook in Excel. Based on the user selections several worksheets will be added to the workbook and the data will be transferred. The structure of the worksheets is dependent on the uncertainty evaluation. The main difference between an export to Excel using the built-in export function of GUM Workbench® and using the export expert is that the expert will automatically place values and units in different columns. It will also use some formatting to transfer Greek characters and indexes correctly.

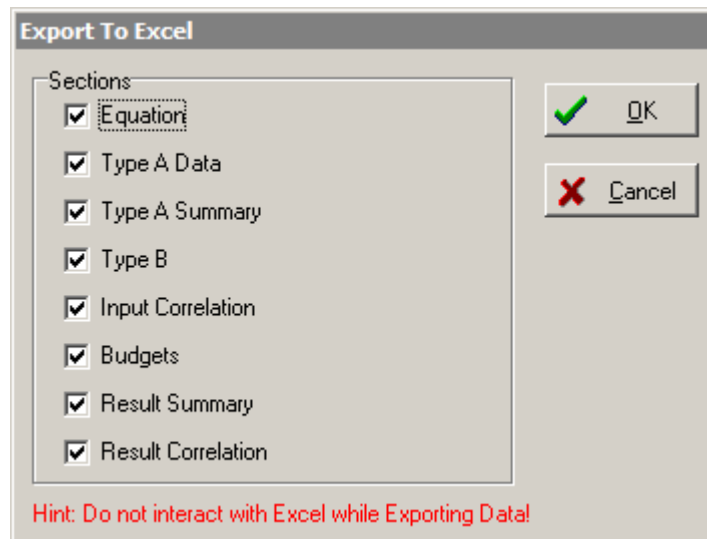


Figure 90: Export2Excel2 expert with all output options selected

Notes:

- It is important not to interact with MS-Excel® as long as the Export to Excel expert is running to guaranty the correct operation. Only interact with MS-Excel® again after the expert has terminated and the control is returned to GUM Workbench.
- Although the data is transferred correctly to MS-Excel®, it is possible that the data is not shown with the correct number of significant digits. To show the correct digits, the user might change the display format in MS-Excel® in these cases.

17.2 Save as Version 3 Expert

The Save as Version 3 expert (SaveAsVer3.dll) is part of the distribution of GUM Workbench version 2.4.

Version 2.4 uses a new version (4) of the file format whenever the user has added a picture or a diagram. In the event that the files need to be read by GUM Workbench version 1.3 or 2.3, the pictures and diagrams need to be deleted because they cannot be loaded by version 1.3 or 2.3. The *Save as Version 3* expert strips of the pictures and diagram and saves the SMU file in format version 3 which can be read by GUM Workbench version 1.3, 2.3 and 2.4. The pictures and diagrams will be stripped without warning.

18 Monte Carlo Simulation

GUM Workbench® versions 2.4.1 and later support an interface to a Monte Carlo simulation engine. The interface is called Monte Carlo Simulation Expert. With the help of this expert, any existing evaluation created with any version of GUM Workbench® can be evaluated using the simulation method as described in GUM Supplement 1 [2].

The actual simulation is done by a Monte Carlo simulation engine. A Monte Carlo simulation engine is a command line program which accepts a model description as a text input file and produces an output file containing the statistical histogram data evaluated during the simulation runs. A configuration file which is part of the Monte Carlo simulation expert describes the details of the interface to a Monte Carlo simulation engine. An engine is only usable if a configuration file is available for that specific engine. Currently the GUM Workbench® supports the interfaces to the Open Monte Carlo Engine (OMCE).

18.1 Open Monte Carlo Engine

The Open Monte Carlo Engine (OMCE) has been developed at the US National Institute of Standards and Technology (NIST). It is an Open Source engine which is automatically installed together with the Monte Carlo Simulation Expert. The OMCE is implemented in Python and the source code is in the public domain. The OMCE source code is part of the GUM Workbench installation (`.\bin\OMCE\`). The OMCE supports all configuration options.

18.2 Theory of Operation

GUM Workbench® manages a detailed description of the result evaluation of a measurement. Based on this description (which is stored in a system of linked internal objects), GUM Workbench® performs uncertainty propagation and the result evaluation. With the Monte Carlo Simulation Expert tool, it is possible to generate the necessary description for a Monte Carlo Simulation Engine to perform a Monte Carlo simulation on the same evaluation model. The Monte Carlo simulation engines currently supported expect the evaluation description in XML format which is based on dictionaries provided with the engines.

A Monte Carlo simulation engine reads the XML file, performs a simulation, and saves the results in several data files. The expert tool, which provides the interface between GUM Workbench® and the simulation engines, reads the data files and generates a diagram from the results provided by the simulation engine. In this way it is possible to compare the results from the uncertainty propagation based on the Budget in GUM Workbench® with the propagation of distributions done by the Monte Carlo simulation. The results are documented in the report and can be exported with the export function.

18.3 System Requirements

A Monte Carlo simulation is an iterative calculation of the model equation 100 000 times or more. This requires a fast CPU with enough computing power. The requirements for system memory are dependent on the Monte Carlo engine used. The minimal and recommended resources for the OMCE are listed in Table 23.

Table 23: System requirements for the Open Monte Carlo Engine

Resource	min. for OMCE	recommended
Operating system	Windows 2000	Windows 2000, XP, VISTA
Memory	500 MB	2 GB
CPU speed	1 GHz	3 GHz
HDD space	25 MB	>1 GB

18.4 Installation

At least three components must be installed to use the Monte Carlo evaluation with GUM Workbench®.

- GUM Workbench® version 2.4.1 or later
- A Monte Carlo simulation engine (e.g. OMCE)
- The Monte Carlo Simulation Expert module `MonteCarlo.dll` version 1.1.0, or later

For the installation of GUM Workbench® 2.4.1, a product CD and a license together with a serial number and key code are needed. Please consult the description for the GUM Workbench® setup in Section 2 for the details.

The Open Monte Carlo Engine and the Monte Carlo Simulation Expert are part of the GUM Workbench® installation for version 2.4.1, and they will be installed if the component 'experts' is activated during the installation. No separate registration is needed for them.

18.5 Using the Monte Carlo Simulation Expert Module

An existing result evaluation in GUM Workbench® can be simulated with a Monte Carlo simulation engine if it is saved to a file and if it does not contain any errors or non valid data. Non-valid sensitivity coefficients and zero uncertainties or sensitivities present no problems to the simulation engine.

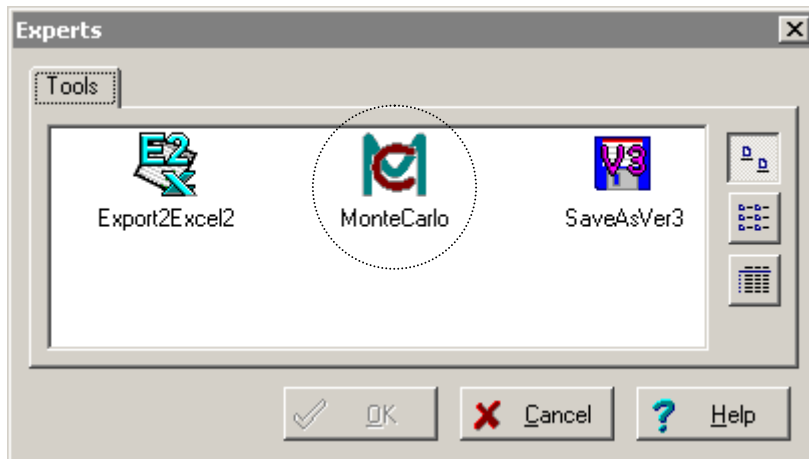


Figure 91: Available experts in the *Tools* category of the *Experts* dialog

The expert is run with the *Tools|Experts* dialog in Figure 91. Choose the *MonteCarlo* expert and press *OK*. The expert module will show an error message and quit if any data are missing or the evaluation is not saved to a file. The expert will then show the dialog window as shown in Figure 92. The user should select the results to be included in the simulation. It is also possible to change the configuration for the Monte Carlo Simulation (MCS) under the *Configuration* tab. The processing is started with the *Run* button.

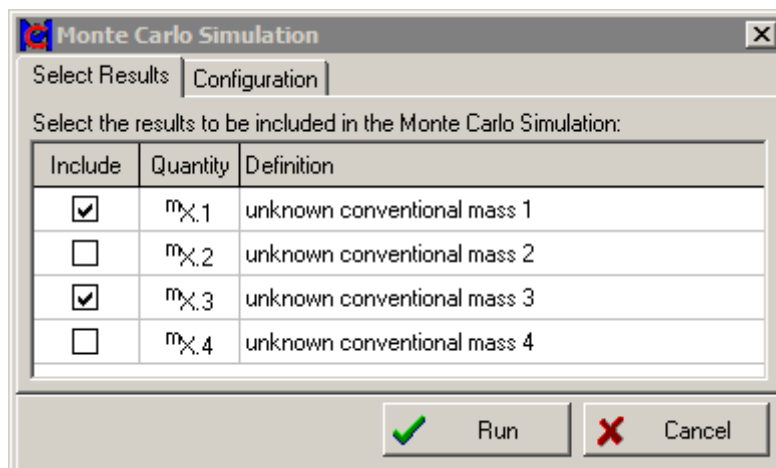


Figure 92: Selection of the results which are evaluated during the Monte Carlo runs

During the first step, an xml input file will be generated automatically. The XML file will have a file name based on the SMU file name, but with a date string added to it and the file

extension OMC, and it will be saved under `My Documents\Budgets\XML\`. A version number might be added to the file name to prevent overwriting of existing files.

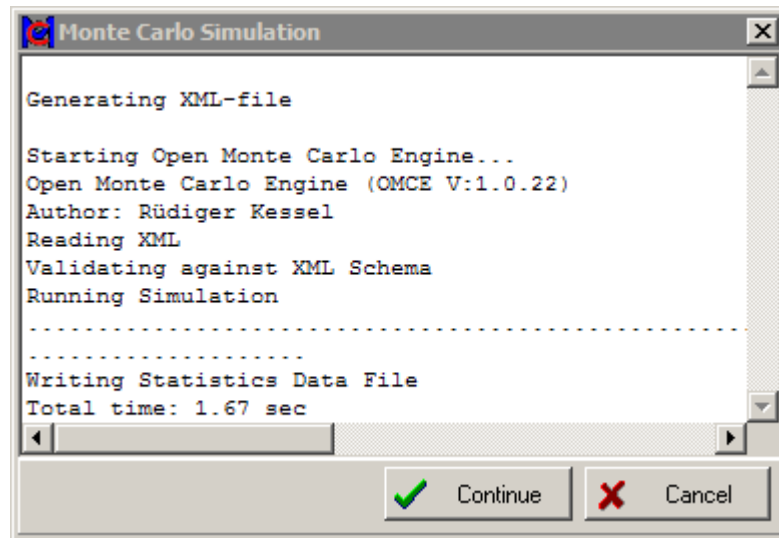


Figure 93: Running the Monte Carlo Simulator

After the xml file is written to a file, the expert will automatically start the selected MCS engine to simulate the model. The simulation will create several data files with the same name as the evaluation but with different extensions (BIN, VAR and CSV). The user can monitor the progress of the simulation in the protocol window (see Figure 93). The user may interrupt the processing at any time by pressing the *Cancel* button.

When the simulation is complete, the *Continue* button will appear. The last step is the transfer of the histogram data back to GUM Workbench® (see Figure 94). The histogram will be displayed prior to data being transferred back to GUM Workbench®.

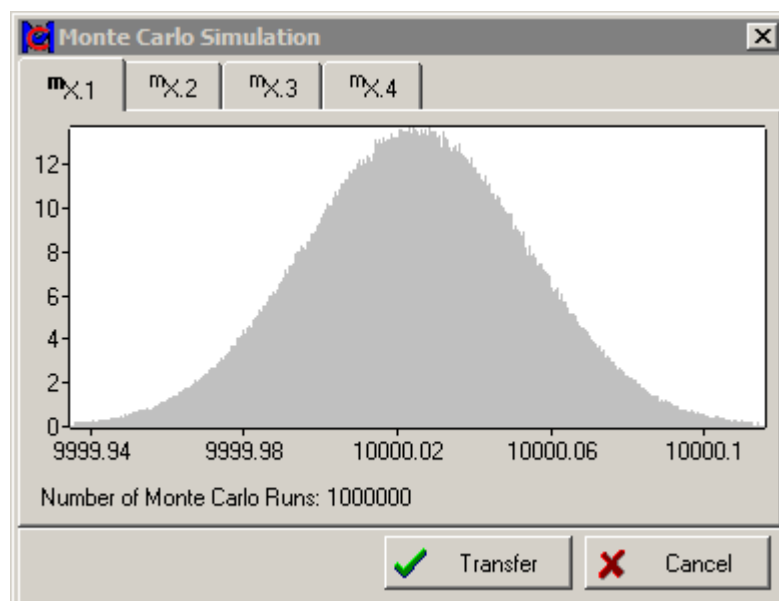


Figure 94: View of the Monte Carlo results and data transfer

By pressing the *Transfer* button, all result data will be transferred into new diagrams in GUM Workbench®. Any existing diagrams from former simulations will not be deleted and should be deleted manually if they are no longer needed.

18.6 Configuration of the Monte Carlo Simulation

The configuration for the Monte Carlo simulation can be changed before it is run. The first choice is the selection of the Monte Carlo engine. Only installed and registered engines can be chosen. The user can freely choose any of the available engines.

The second choice is the control over the number of Monte Carlo runs. The total number of runs can either be specified manually or by an adaptive procedure. The adaptive procedure is controlled by the probability of the interval to be checked and a tolerance divisor. The value of the probability should be between 0.01 and 1 (default value 0.95). The value for the tolerance divisor should be between 1 and 10 (default value 1.0). A larger value for the tolerance divisor will increase the number of MC runs by specifying a tighter tolerance interval checked by the adaptive procedure. The implementation of the adaptive procedure is dependent on the selected MC engine.

The third choice is the number of histogram bars and the width of the histogram. The width of the histogram is based on a probabilistically symmetric coverage (confidence) interval multiplied by an extension factor. The user can chose the probability of the interval and the extension factor to control the histogram.

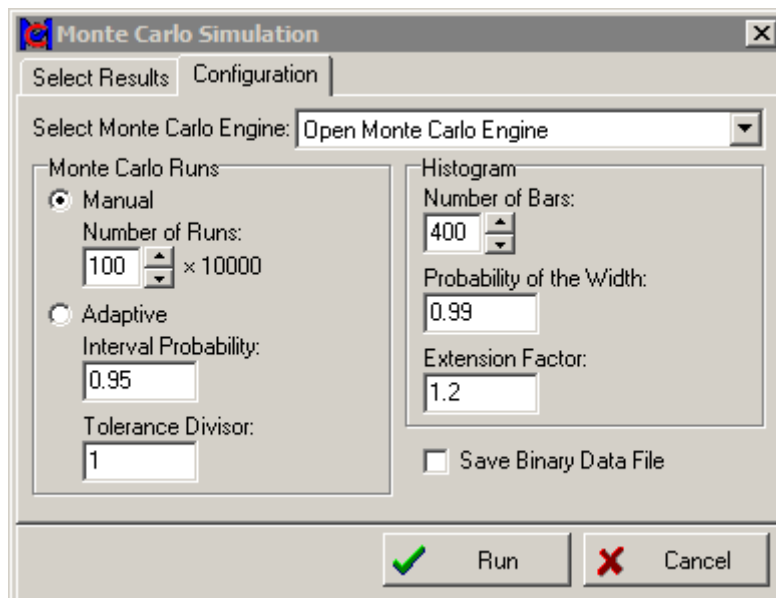


Figure 95: Configuration for the Monte Carlo simulation

Note: Not all options are available for all Monte Carlo Engines and may be implemented differently by different engines. Please consult the documentation of the engine to check if a certain option is available and how it is implemented.

18.7 Limitations

Some Monte Carlo simulation engines might not support all of the features of GUM Workbench®. The simulation cannot run if any feature used in the GUM Workbench® evaluation is not supported by that specific engine. The expert module will not generate an XML file and a Monte Carlo simulation is not possible.

The following features are not supported:

- The `const()`-function does not exist in the context of a Monte Carlo Simulation and it cannot be substituted by other functions. One needs to replace the function call by a number or a quantity of the type constant.
- The OMCE engine only supports correlation coefficients between input quantities which are normally distributed. If the distribution is different from normal, then the user might modify the model equation to avoid the correlation.

18.8 Presentation of the Monte Carlo Simulation Results

The result of a Monte Carlo simulation is histogram data produced by the Monte Carlo engine. During the data transfer, the expert creates a new diagram of type histogram in GUM Workbench® and transfers the histogram data into this diagram. The histogram data cannot be manipulated within GUM Workbench® nor can data be added or deleted. Only the whole diagram can be deleted if it is not needed.

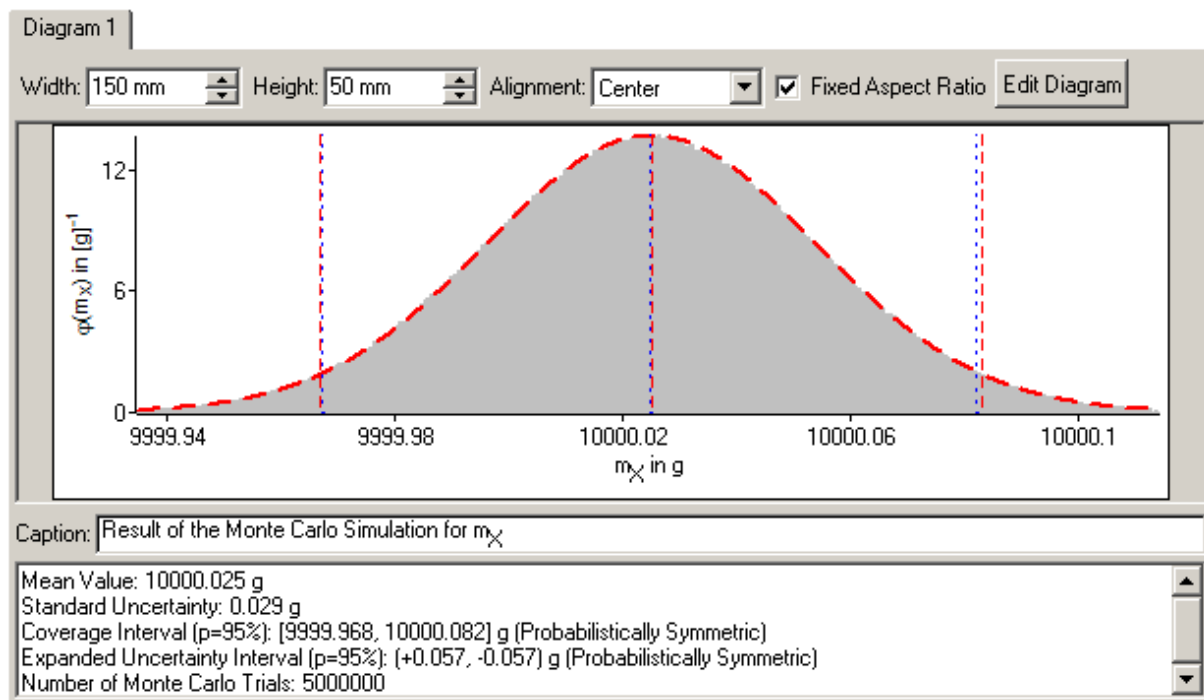


Figure 96: The results of the Monte Carlo Simulation in GUM Workbench®

Figure 96 shows a typical diagram based on a Monte Carlo simulation. The grey data area is the histogram data based on the Monte Carlo runs scaled to be a probability density function (PDF) sampling. The dashed line is a graph of the PDF of a Gaussian (normal) distribution with the mean value and the standard uncertainty calculated with the help of the uncertainty budget. This makes a direct comparison of the results from the Monte Carlo simulation with the results from the standard uncertainty propagation easy.

In addition to the histogram data, the MCS expert creates a description of the diagram which contains the mean value, standard uncertainty and coverage interval which was found during the Monte Carlo simulation together with the total number of Monte Carlo runs.

Figure 97 and Figure 98 show the histogram in the report preview and after an RTF export.

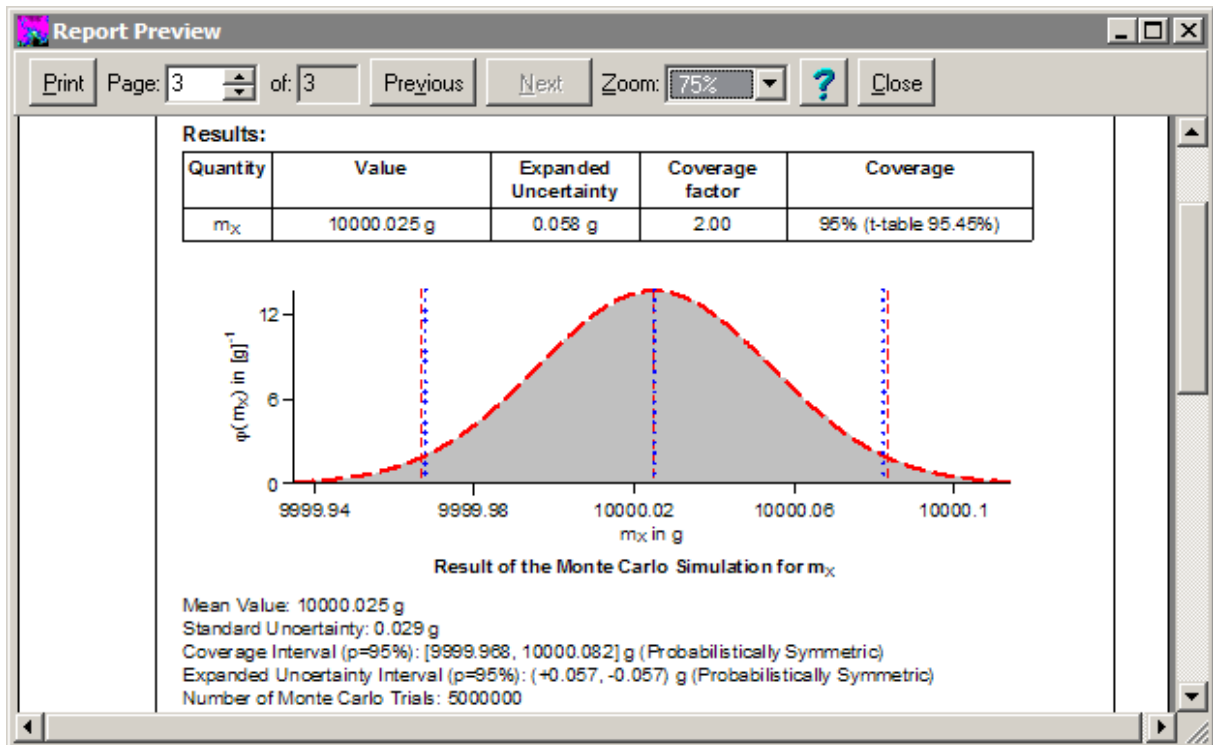


Figure 97: The results of the Monte Carlo Simulation in the printed report

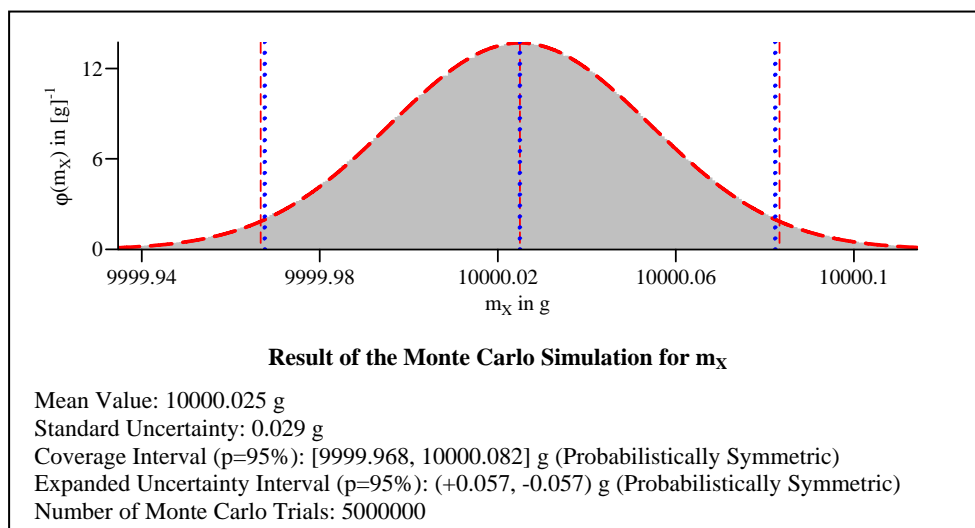


Figure 98: The results of the Monte Carlo Simulation after export as RTF

18.9 Using Graphs and Markers in Histograms

A successful Monte Carlo simulation is a verification of an existing uncertainty budget. Therefore, it is useful to combine information from the uncertainty budget with the histogram data. To show the results from the budget, the calculated values can be shown as vertical markers for the value and the coverage interval (see section 14.2.6). Another possibility is to plot a probability density function (PDF) based on the value and standard uncertainty evaluated in the budget with the help of additional graphs (see section 14.2.5).

By default, the Monte Carlo Simulation expert will add red and blue markers for the expectation value and the 95% coverage interval based on the Monte Carlo simulation (blue) and on the data from the budget (red).

In addition, a red dashed line (graph) of a Gaussian probability density function (PDF) will be added. The equation field for the graphs supports different PDF-functions for the convenience of the user. Table 24 shows the implemented PDFs. The user might change the PDF for a better fit with the histogram data.

Table 24: Probability density functions supported in graphs

PDF	Function	Example
Gaussian	<code>gauss(x,<val>,<u>)</code>	<code>gauss(x,val(Y),u(Y))</code>
Rectangular	<code>rect(x,<val>,<u>)</code>	<code>rect(x,val(Y),u(Y))</code>
Triangular	<code>triang(x,<val>,<u>)</code>	<code>triang(x,val(Y),u(Y))</code>
U-spaped	<code>Ushape(x,<val>,<u>)</code>	<code>Ushape(x,val(Y),u(Y))</code>
Trapezoidal	<code>trapez(x,<val>,<u>,)</code>	<code>trapez(x,val(Y),u(Y),0.5)</code>
Student-t	<code>student(x,<val>,<u>,<dof>)</code>	<code>student(x,val(Y),u(Y),dof(Y))</code>

Notes: The first parameter of the function must be always the symbol x . The spreading parameter (3rd parameter) of all different PDF functions is by definition in this implementation a standard deviation (standard uncertainty).

19 Correlation Matrix Test Expert

The *Correlation Matrix Test* expert is available with version 2.4.1 of GUM Workbench®. It can check if the typed-in correlation matrix is positive semi-definite. The expert uses an interface to Python [7] to run a Python script which does the mathematical calculations. The expert should be started from GUM Workbench® via the *Experts* dialog.

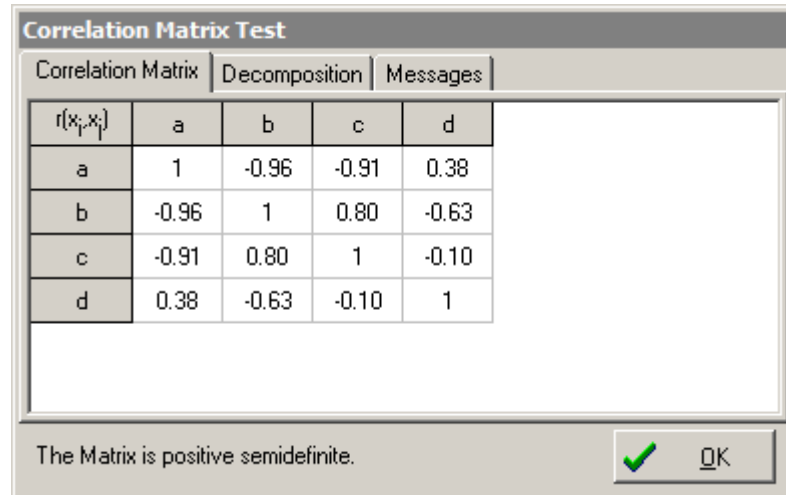


Figure 99: Correlation Matrix Test expert with a matrix which is positive semi-definite

The *Correlation Matrix Test* expert will analyze the correlation matrix and check if the matrix is positive semi-definite. The result will be presented in a dialog shown in Figure 99. The essential part of the correlation matrix will be shown. All quantities which are not correlated with any other quantity will be left out. A judgment statement is printed below the correlation matrix. It is either in black stating that the matrix is positive semi-definite or it is printed in red stating that it is not positive definite. The user can close the dialog with *OK*.

19.1 Test for Positive Semi-definite

The Correlation Matrix Test expert uses a three level strategy to test if a matrix is positive semi-definite. The first step is to try the Cholesky decomposition. If this is possible then the matrix is positive definite and matrix can be used.

In case the Cholesky decomposition fails an eigenvalue decomposition is calculated. If no negative eigenvalues are found then the matrix is positive semi-definite and can be used.

In case some eigenvalues are negative the eigenvalues are compared with a limit (-0.1) and if any eigenvalue is smaller than this limit then the matrix is not positive semi-definite.

If the matrix has negative eigenvalues within the limit then the negative eigenvalues are shifted to a small positive number (10^{-10}) and a new correlation matrix based on the shifted eigenvalues and the original eigenvectors is created. The least maximum norm [9] of the

difference between the original matrix and the corrected matrix is calculated. If the norm of the correction is smaller a limit (0.01) then the original matrix is still close enough to positive semi-definite and can be used. If the correction is too large then the matrix is not positive semi-definite and the matrix should not be used in the evaluation.

19.2 Eigenvalue Decomposition

The eigenvalue and eigenvector structure of the typed-in correlation matrix can be inspected on the *Decomposition* tab.

In the example in Figure 100 the first eigenvalue is slightly negative. Still the overall judgment is that the matrix is close enough to positive semi-definite. The reason is that the typed-in matrix does not deviate much from a correct positive semi-definite matrix and that it is therefore still possible to use the matrix in an uncertainty evaluation.

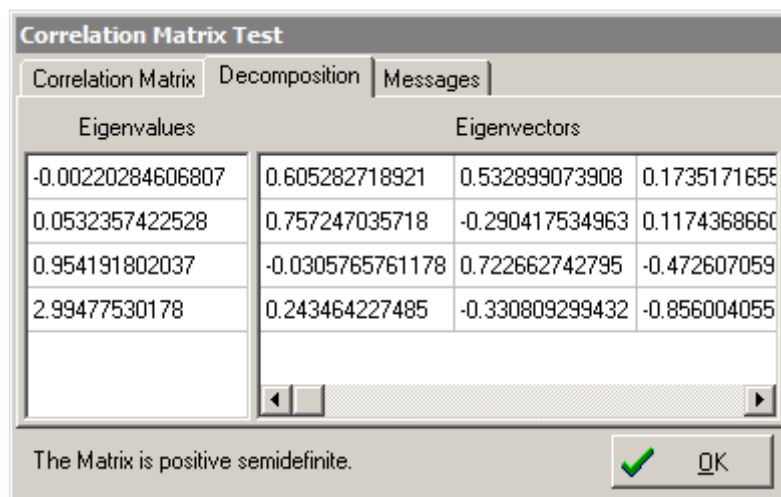


Figure 100: Eigenvalues and eigenvectors of a correlation matrix

19.3 Not positive semi definite correlation matrix

In case the test of the correlation matrix leads to the conclusion that the typed in matrix is not positive semi definite, then the values should be verified. Correlation coefficients which have been calculated on the basis of a physical model are automatically positive semi definite and small negative eigenvalues can only be a result of rounding. Larger negative eigenvalues are in this case usually a result of typos. If the values of a larger correlation matrix are artificially set manually without a physical calculation matrix then the chance is relatively high that the resulting correlation matrix is not positive semi definite.

The eigenvalues (see Figure 100) and the calculated least maximum norm can be used to find the problem in the matrix. In some cases a matrix correction method can be applied [9].

Note: The values of the correlation matrix are directly used in the calculation of the final uncertainty. It is important to bear this in mind when changing the values.

19.4 Interface to Python

The *Correlation Matrix Test* expert uses a Python script to do the calculation. The source code of the script (`CorrMatrixTest.py`) can be found in the `.\Experts\Tools\` directory under the GUM Workbench® installation directory. The script is executed automatically and the output messages can be inspected on the *Messages* tab (see Figure 101).

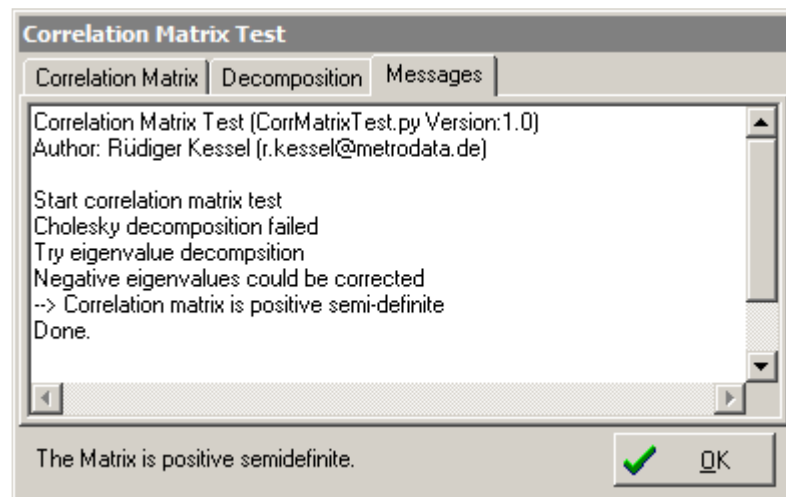


Figure 101: Output from the Python script

The Python script defines two functions listed in Table 25. The names of the functions and the parameter structures must not be changed. The script makes use of the Numpy [8] numerical package for Python.

Table 25: Interface function in the Python script

Function	Description	Parameter	Return type
<code>MatrixTest(DM,DC)</code>	Checks if the matrix DM is positive semi-definite	DM: list of list <code>[[] . . []]</code> DC: number columns and rows	Boolean
<code>Decomposition(DM,DC)</code>	Calculates the eigenvalues and eigenvectors of DM	DM: list of list <code>[[] . . []]</code> DC: number columns and rows	list of 2 arrays <code>[[], []]</code>

Together with GUM Workbench® a version of Python is installed in the GUM Workbench® installation directory which is independent from any other version of Python that might already be installed or is installed later. The expert will only use the private version of Python which is installed together with GUM Workbench®. The Python installation under the GUM Workbench® installation directory should not be changed in any aspect by the user.

20 Working with Templates

GUM Workbench® supports template files. Template files are standard GUM Workbench® files with the extension SMT, which are saved under the sub-directory `.\Templates\EN\` in the GUM Workbench® program directory. Template files can contain complete or partly complete or empty uncertainty models. In addition, they can be used to launch an expert module when they are loaded.

20.1 Using Template Files

The directory and file structure in the `.\Templates\EN\` directory is mapped under the *File|New|Templates* menu when GUM Workbench® is started. All SMT files are converted to menu entries and sub-directories are converted into sub-menus (Figure 102). The extension `.SMT` is left out. Additionally, the file structure is mapped to a popup-menu beside the 'New'-speed-button (Figure 103). If the user selects a template menu entry, the template file is loaded and the view is changed as specified in the template. If the template contains an auto-start expert, the expert will be launched and the evaluation can then be completed and saved under a new file name.

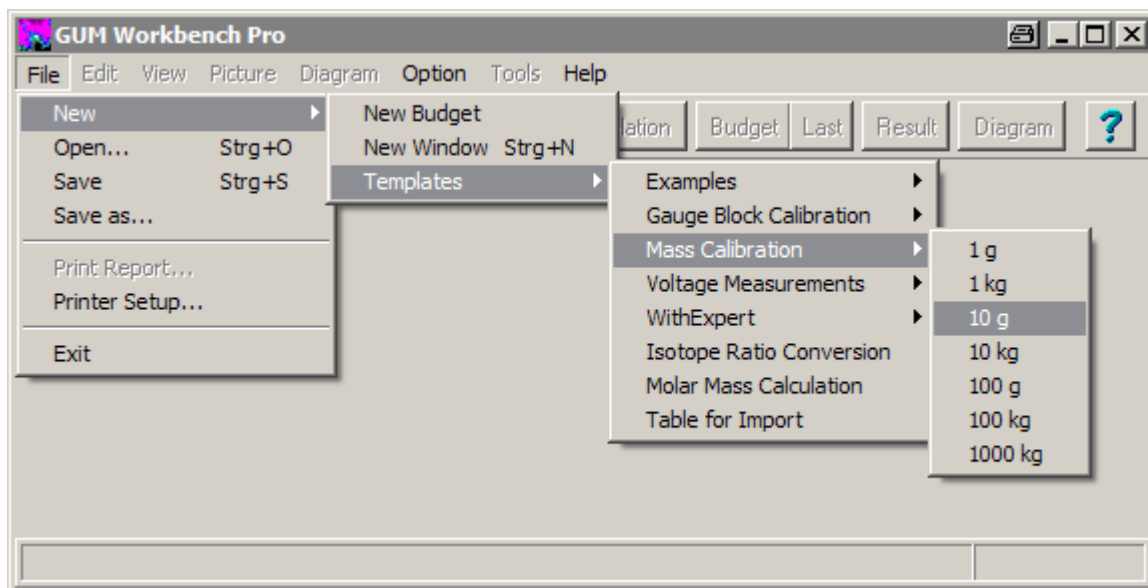


Figure 102: Template selection via *File|New* menu

20.2 Writing Template Files

Template files can be created from scratch or from an existing SMU file. The observations and all data, which would be added later, must be deleted. The evaluation should be saved under a filename with the extension `.SMT` in the `.\Templates\EN\` sub-directory. The filename should be selected carefully because it will be used as a menu entry in the *File|New|Templates* menu later.

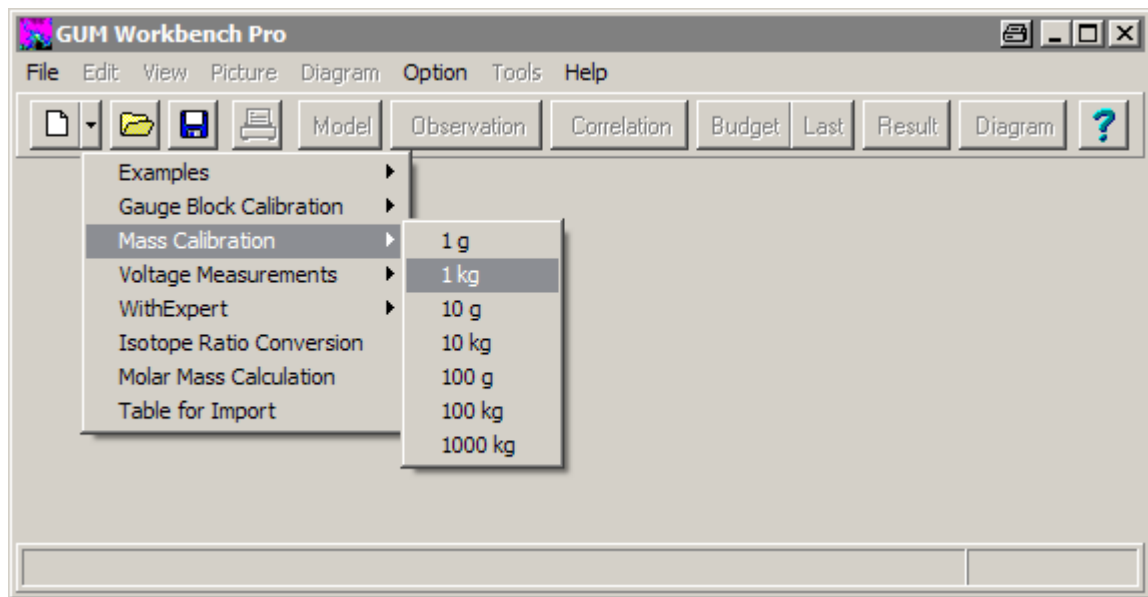


Figure 103: Template selection via popup menu

20.3 Template Options

Template files support some options which cannot be edited within GUM Workbench®. All SMT files are text-files with section structure (like SMU files). To specify the options, the SMU files must be edited by a text-editor (e.g. `notepad.exe`). The following options are available:

- Select the view after loading the template file.
- Select the model page after loading the template file.
- Start an expert module after loading the template file.
- Write-protect the model equation.
- Write-protect the quantity type selection.

The options are controlled by optional entries (lines) in the SMT file under the specific section.

20.3.1 Section [Header]

Entry	Format	Description
SV	number	The view number that will be selected when the template is loaded. (0=Model, 1=Observation, 2=Correlation, 3=Budget, 4=Result)
SP	number	The model page number that will be selected when the template is loaded. (0=Title, 1=Model Equation, 3=Quantity Data).
StartExpert	file name	File name of the expert module (.DLL) that will be launched when the template is loaded. The expert module must be present under the experts-directory.

20.3.2 Section [Model]

Entry	Format	Description
CE	boolean	Enable model equation editing (default is 1).
CTC	boolean	Enable quantity type change (default is 1).

20.3.3 Entry formats

The following formats are used by the entries:

Format	Description
number	<entry>=<n> n: integer 0..32000
boolean	<entry>=<n> n: 0=false, 1=true
file name	<entry>=[<directory>]<filename>.<ext> filename: valid long filename ext: valid extension (3 chars)

20.4 National Language Support

NLS is supported with templates by providing language dependant template directories. The following directories are supported:

Template directory	Language
.\Templates\EN\	English
.\Templates\GE\	German
.\Templates\IT\	Italian
.\Templates\FR\	French
.\Templates\SE\	Swedish
.\Templates\DK\	Danish
.\Templates\ES\	Spanish

The template directory is specified in the NLS configuration file under [Config].TemplDir.

21 Tips and Tricks

This section lists a couple of notes and tricks which might be useful to users and which do not fit into other sections.

21.1 Entering relative Uncertainty Parameters and in Percent

The standard deviation or standard uncertainty may be given relative or as a percent of the nominal value (mean). It is possible to enter this information in GUM Workbench. To use this option, type the percent sign (%) or the string (rel) (parenthesis must be included) after the digits entered into the field for the standard deviation or the standard uncertainty. If for example the mean is 20 g with a standard deviation of 1 g, this can be expressed by typing 0.05(rel) or 5% in the field for the standard deviation.

In the following seven instances, one may enter standard deviations, the half-width of distributions or other uncertainty parameters relative or in percent:

Table 26: Use of percent in parameters

Type	Usage of (rel) or %
Type A summarized	Enter standard deviation (rel) or in % of value.
Type B, Normal	Enter expanded uncertainty (rel) or in % of value.
Type B, t-distribution	Enter standard uncertainty (rel) or in % of value.
Type B, Rectangular	Enter half-width (rel) or in % of value.
Type B, Triangular	Enter half-width (rel) or in % of value.
Type B, U-shaped	Enter half-width (rel) or in % of value.
Type B, Trapezoidal	Enter half-width (rel) or in % of value.

The units will disappear upon leaving a field where the string (rel) or a percent sign "%" has been entered in either of these fields.

In any of these fields, the relevant parameter should be entered without a sign. A + prefix is permitted but adds no new meaning to the contents of the field.

21.2 Value Calculations in Parameter Fields

If the value of a parameter for a quantity of Type B is given as an equation instead of a numerical value, it is possible to enter this equation into the parameter field by preceding it with an equal sign ('='). The same syntax rules apply as for the model equation. The equation must not be terminated by a semicolon. Only built-in functions are supported. It is possible to refer to the mean value of other input quantities by their name. It is advisable to define independent quantities of type constant (see Section 6.3) for the purpose of referring to them in the parameter value calculations of input quantities.

21.3 Using Multiple Program Windows

GUM Workbench® may be run simultaneously in several windows from the same installation on the same computer, although one should not open a SMU file in more than one window. Check the settings in the *Config* dialog because GUM Workbench® will keep some data in resource files, and running simultaneously in more than one window will mean that more than one application will write to these files. This is a useful technique, but it should be used cautiously. There will be no system warnings if the same file is opened in two different windows at the same time and work is carried out in both. Such situation should be avoided, as it could lead to loss of data.

21.4 Working With Large Equation Systems

When building a model equation, it is often a good idea to click away from the equation field at intervals, e.g. after the completion of each line when the semicolon has been entered. That will allow GUM Workbench® to check the syntax for the equation field and any mistakes can be corrected immediately.

21.5 Write Access to the Installation Directory

During the operation of GUM Workbench®, write access is not needed to the installation directory except for saving template files. It is therefore advisable to restrict access to the installation directory after a successful installation to avoid any unintended modification. If templates are to be used, it is necessary to grant write access to the templates subdirectory.

Appendix A Glossary of Some Relevant Terms

arithmetic mean

the sum of values divided by the number of values

correlation

the relationship between two or several random variables within a distribution of two or more random variables

correlation coefficient

the measure of the relative mutual dependence of two random variables, equal to the ratio of their covariance to the positive square root of the product of their variances

covariance

the measure of the mutual dependence of two random variables, equal to the expectation of the product of the deviations of two random variables from their respective expectations

coverage factor

a numerical factor used as a multiplier of the standard uncertainty of measurement in order to obtain an expanded uncertainty of measurement

coverage probability

the fraction, usually large, of the distribution of values that, as a result of a measurement, could reasonably be attributed to the measurand

experimental standard deviation

the positive square root of the experimental variance

expanded uncertainty

a quantity defining an interval about the result of a measurement that may be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurand

experimental variance

the quantity characterizing the dispersion of the results of a series of n observations of the same measurand

input estimate

the estimate of an input quantity used in the evaluation of the result of a measurement

input quantity

a quantity on which the measurand depends, taken into account in the process of evaluating the result of a measurement

measurand

the particular quantity subject to measurement

output estimate

the result of a measurement calculated from the input estimates by the model function

output quantity

the quantity that represents the measurand in the evaluation of a measurement

pooled estimate of variance

an estimate of the experimental variance obtained from a long series of observations of the same measurand in well-characterized measurements under statistical control

probability distribution

a function giving the probability that a random variable takes any given value or belongs to a given set of values

random variable

a variable that may take any of the values from a specified set of values and with which is associated a probability distribution

relative standard uncertainty of measurement

the standard uncertainty of a quantity divided by the estimate of that quantity

sensitivity coefficient associated with an input estimate

the differential change in the output estimate generated by a differential change in an input estimate divided by the change in that input estimate

SMU file

The file format of GUM Workbench[®]

standard deviation

the positive square root of the variance of a random variable

standard uncertainty of measurement

the uncertainty of measurement expressed as the standard deviation

Type A evaluation method

the method of evaluation of uncertainty of measurement by the statistical analysis of series of observations

Type B evaluation method

the method of evaluation of uncertainty of measurement by means other than the statistical analysis of series of observations

uncertainty of measurement

a parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand

variance

the expectation of the square of the deviation of a random variable about its expectation value (or mean value)

Appendix B Menu Structure**File**

New	
New Budget	new uncertainty analysis
New Window	new application window
Open	standard open dialog
Save	save current file
Save as...	standard save dialog
Print Report	see Section 10.3
Printer Setup	see Section 10.3.1
1..9	last opened files, Note 3
Exit	quit GUM Workbench®

Edit

Undo	Note 1, 2
Cut	Note 2
Copy	Note 2, 4
Paste	Note 2
Select All	Note 2
Insert Character	see Section 6.5.3
Insert Unit	Version 2.4 only, see Section 13.5
Renaming a Quantity	see Section 6.5.1
Change Quantity Order	see Section 7.10
Find Missing Data	shows missing data entries
Imported Files...	see Section 7.9

View

Model	see Section 5.1
Observation	see Section 5.2
Correlation Matrix	see Section 5.3
Uncertainty Budget	see Section 5.4
Last Budget	see Section 5.4.4
Result	see Section 5.5
Diagram	Version 2.4 only, see Section 14.1

Picture

	Version 2.4 only
Add Picture	see Section 12.3
Delete Picture	see Section 12.3
Insert Picture	see Section 12.3
Swap Picture	see Section 12.3
Load Picture...	see Section 12.3

Diagram

	Version 2.4 only
Add Diagram	see Section 14.3
Delete Diagram	see Section 14.3
Insert Diagram	see Section 14.3
Swap Diagram	see Section 14.3
Edit Diagram ...	see Section 14.3

Option

Config...	see Section 15
Read Only	see Section 11.2

Tools

Import Observation...	see Section 8.1
Correlation Analysis for Type A...	see Section 8.2
Export	see Section 10.4
Unit Validation...	only version 2.4, see Section 13
Experts...	see Section 17
Monte Carlo Simulation...	only version 2.4, see Section 18
Check Correlation Matrix...	only version 2.4, see Section 19

Help

Contents	
Search...	
How to use	
Documents	
User Manual	
EA-4/02 Document (from Internet)	
Eurachem/CITAG Guide (from Internet)	
About...	see Section 16.1

Notes:

1. Not every action can be undone in GUM Workbench®. The command works when editing texts.
2. GUM Workbench® supports the standard Windows® clipboard functionality.
3. Menu shortcuts to the nine previously opened SMU files are placed here.
4. It is possible to copy from the budget table. Select the part of the budget table that should be copied using the copy menu command.

Appendix C List of Input and Output Fields

This section lists names and brief descriptions and definitions for the GUM Workbench® input and output fields.

Arithmetic Mean

This field shows the arithmetic mean of the observations. It is valid if all observations were valid.

Coefficient

The correlation coefficient which is selected in the matrix can be edited in this field. Numbers in the range $-1.0 \leq \text{value} \leq +1.0$ are valid.

Col

The column of the correlation matrix to be edited can be chosen here. The field presents all possible choices.

Correlation Matrix

The table shows the correlation coefficients between the input values.

Coverage Factor

The coverage factor of the selected measurand is displayed in this field. Only positive values are valid.

Degrees of Freedom

The degrees of freedom for the chosen measurand are given in this field. Only positive integers are valid.

Description

This field is the quantity description in the Quantities register in view Model or the correlation description in view Correlation. This is a multi-line text field.

Distribution

One of the featured distributions can be chosen for the selected Type B measurand.

Equation

This is the model equation in the *Model Equation* register in view *Model*. It is a multi-line text field. The equation must follow the syntax rules for the model equation.

Expanded Uncertainty

This field states the expanded uncertainty of the selected measurand. Only positive values are valid.

From File

The filename and path are shown in this field. Only valid filenames and paths are allowed.

General Description

Can be found in the *Title* register in view *Model* and holds a description of the evaluation. This is a multi-line text field.

Half-width

This field states half of the width between the limits for quantities with rectangular, triangular, trapezoid or U-shaped distributions. Only positive values are valid.

List of Quantities

In this table, each quantity is connected to a unit and a description. The table is located in the Model Equation register in view Model.

Method

This field in view Observation states the method used to gather observations.

Method of Observation

One of several methods of observation can be selected in this field.

Number of Observations

Number of Observations to be used for the calculation of the mean value. Only integers in the range 1 to 9999 are valid.

Observation

This table shows the observed values of Type A measurands. The structure of the table depends on the chosen method of observation.

Quantity

This field states the name of the quantity whose data will be imported from a file. All possible choices are listed in this field.

Row

The row of the correlation matrix to be edited can be chosen here. The field presents all possible choices.

Shape Factor

The shape factor for the trapezoid distribution can be edited in this field. Values in the range 0.0 to 1.0 are valid.

Standard Deviation

This field holds the standard deviation of the chosen measurand. Positive values are valid.

Standard Uncertainty

The standard uncertainty of the selected measurand is given in this field. Positive values are valid.

Title

This one-line text field with a capacity of 255 characters holds the title. It is located at the Title register in view *Model*.

Type

This selects the type for the chosen quantity out of the seven types at the *Quantity Data* register in the screen view *Model*.

Unit

This field displays the unit observations must have.

Uncertainty Budget

This table shows the calculation results: value, standard uncertainty, degrees of freedom, sensitivity coefficient and uncertainty contribution.

Uncertainty Evaluation

The selection of the method used to determine the uncertainty. In this field you are able to switch between experimental determination of the standard deviation or giving a pooled estimate from a prior evaluation.

Value

This field gives the value for the measurand. All numbers are valid. The number of significant digits is determined through the Uncertainty connected with the measurand. In case of constants the maximum number of digits is 15.

Appendix D Greek Letters and Special Characters

Table 27 lists the Greek letters which can be entered using backslash notation. They may be entered directly by typing the codes indicated or by using the command *Insert Character* (Ctrl-A) and double-clicking on the symbol.

Table 27: Greek letters

Symbol	Name	Symbol	Name
α	\alpha\	A	\Alpha\
β	\beta\	B	\Beta\
γ	\gamma\	Γ	\Gamma\
δ	\delta\	Δ	\Delta\
ε	\epsilon\	E	\Epsilon\
ζ	\zeta\	Z	\Zeta\
η	\eta\	H	\Eta\
ϑ	\theta\	Θ	\Theta\
θ	\theta1\		
ι	\iota\	I	\Iota\
κ	\kappa\	K	\Kappa\
λ	\lambda\	Λ	\Lambda\
μ	\mu\	M	\Mu\
ν	\nu\	N	\Nu\
ξ	\xi\	Ξ	\Xi\
\omicron	\omicron\	O	\Omicron\
π	\pi\	Π	\Pi\
ρ	\rho\	P	\Rho\
σ	\sigma\	Σ	\Sigma\
ς	\sigma1\		
τ	\tau\	T	\Tau\
υ	\upsilon\	Y	\Upsilon\
φ	\phi\	Φ	\Phi\
ϕ	\phi1\		
χ	\chi\	X	\Chi\
ψ	\psi\	Ψ	\Psi\
ω	\omega\	Ω	\Omega\

Note that two different typographical versions of the letters theta and sigma (left column) are available. In quantity names they are treated as entirely different characters.

Greek letters are capitalized by placing the first letter of the name in capital.

The list of symbols also contains some additional entries, which are e.g. backslash notation for the underscore, the backslash or the power symbols. These can be used to place the symbols in subscripts and in text fields.

Table 28: Special characters

Symbol	Name
_	\us\
f	\func\
^	\up\
\	\bs\
/	\sl\
.	\dot\
x	\times\
+	\plus\
-	\minus\
,	\comma\
" "	\sp\
½	\N05\
¼	\N025\
¾	\N075\
.	\cdot\

Paste text issue 1:

When text is copied from a word processing document or other resource, certain characters will be improperly displayed when pasted into GUM Workbench®. They will appear as black rectangles. This behavior is due to a certain lack of detail in the Windows® font system which GUM Workbench® uses to display texts. GUM Workbench® does not support Unicode .

Among the characters which have this behavior are the oe-ligature, the diacritical s, the en-dash and em-dash, the dagger, the per-mil, the trade mark, the function, the black dot and certain varieties of quotation marks:

œ Œ - - † ‡ ‰ ™ f • ‘ ” ’ ‹ › …

Two workarounds are suggested:

1. The characters displaying as black rectangles could be manually substituted with other acceptable characters.

2. Do nothing. If the black rectangle characters are left in the texts, they will be printed correctly by GUM Workbench® and will also be correctly exported in .RTF or .HTML formats and appear there exactly as when they were originally copied.

Paste text issue 2:

Separate from the above is the issue of some characters being substituted when pasted into GUM Workbench®. The five characters (four varieties of inverted commas and the approximate sign) will be displayed, but only in an approximate quality.

Appendix E Functional Matrix

Table 29 lists the implemented functions in GUM Workbench® and in which version they are available.

Table 29: Available functions in GUM Workbench®

Function	Version		
	1.3	2.3	2.4
Free model equation	+	+	+
512 quantities	+	+	+
User functions	+	+	+
Report generator	+	+	+
Import Observation dialog	+	+	+
Correlation Analysis for Type A	+	+	+
Insert Character dialog	+	+	+
Insert Function dialog	+	+	+
Change Quantity Order dialog	+	+	+
Import from SMU files	+	+	+
Import from Excel	+	+	+
Imported files dialog	+	+	+
Export to html, rtf, text	+	+	+
Templates	+	+	+
Multiple results		+	+
Export to Excel expert		+	+
Experts interface		+	+
OLE automation interface		+	+
Pictures			+
Symbolic partial derivatives			+
Diagrams			+
Unit Validation dialog			+
Insert Unit dialog			+
Monte Carlo simulation expert			+
Correlation Matrix Test expert			+

Appendix F Error and Warning Messages

Error messages displayed by GUM Workbench® serve to protect against the formulation of uncertainty models which are either not mathematically feasible or not in full accord with the GUM method.

While most error messages are self explanatory, with a software tool as powerful and as versatile as GUM Workbench® there are situations in which the remedy for an error is not intrinsically obvious and will require a closer inspection and an understanding of the situation.

This section lists the error and warning messages which may be displayed during the execution of GUM Workbench®.

Bear in mind, that the value for a Type A quantity is the mean of the observations. An out-of-range arithmetic mean could be the cause of any of the out-of-range error messages. Check the data entered. When the method of observation is not *Direct*, it is relevant to check that data in the "standard" and the "unknown" row have not been interchanged.

GUM Workbench® may, in rare situations, display error messages that are not listed here. This could be a situation where technical support at Metrodata GmbH should be contacted.

We request that the user reinstalls GUM Workbench from the original CD-ROM before contacting the support with such a concern.

Please note that no files in the `.\etc\` folder or the `GUMWBpro.INI` should be changed or moved. Also, remember that SMU files should be created and edited only with a registered and licensed copy of GUM Workbench®. There is no liability on the part of the distributor or developer of GUM Workbench® to perform analyses on a file which has been edited or created by any other means.

Error messages in numerical order:

100: Error: Illegal character.

The character at the cursor position is not allowed in the equation field.

101: Error: Missing '('.

A function name must be followed by an opening parenthesis, '('. GUM Workbench® expects the parentheses at the cursor position.

102: Error: Missing ')', parameter error.

The function parameters must be followed by a closing parenthesis, ')'. GUM Workbench® expects a parenthesis at the cursor position. This error can also occur if the actual number of parameters does not match the expected number of parameters.

103: Error: Missing ‘)’

An opening parenthesis is not being matched by its closing counterpart. The closing parenthesis need to be put at the cursor position or earlier in the equation.

104: Error: Illegal character in factor.

The character at the cursor position is not permitted at this point of the equation. This error can also occur if an operand is missing.

106: Error: Missing ‘,’

GUM Workbench® expects a comma (‘,’) and another function parameter at the cursor position.

107: Error: Function name is not allowed here.

The function call at the cursor position is not allowed. This error can occur if a function name is used as a result symbol. In this case select a different name for the result.

108: Error: Missing ‘|’

An absolute function (‘|’) was not closed properly. The matching absolute operator (‘|’) must be put at the cursor position or earlier in the equation.

109: Error: Missing ‘;’

The program expects a semicolon (‘;’) at the cursor position to distinguish between interim results. This error can also occur if an operator is missing at the cursor position or if there is a comma in the equation field.

110: Error: Quantity is not defined.

The quantity name at the cursor position is not defined.

111: Error: Quantity is used twice for output.

The quantity name at the cursor position was already used as a result or interim result. Please select a different name for the symbol.

112: Error: Not a valid number.

The number at the cursor position is not valid. Please check the number and correct it.

113: Error: Too many outputs.

Only one final result can exist in the equation field in Version 1.3. All interim results must be used. During testing unused parts of the equation can be made into a comment with ‘{’ and ‘}’. In case multiple results are needed, it is necessary to upgrade to Version 2.3 or 2.4.

114: Error: Unexpected end, missing factor.

An operator was given without an operand following. Please fill in the missing operand.

115: Error: Illegal character, ';' is not allowed here.

Interim results are not allowed at this point. Please combine all parts into an equation. A semicolon at the end of the equation (';') is not allowed.

116: Error: Missing '='

An equal sign ('=') is expected at the cursor position.

117: Error: Illegal character '=' is not allowed here.

An assignment is not allowed at this point. Please give an expression that should be computed. It should not contain an equal sign ('=').

120: Error: There is no output quantity defined in the equation field.

The program is not able to determine which quantity name is representing the result because all names on the left hand side of the equation are also used on the right hand side. The reason for this is either an invalid mathematical loop or a typing error. Please correct the equation to get an unambiguous name for the result.

121: Error: Missing result quantity.

The program expects a quantity name for a result or interim result at the cursor position.

127: Error: Function not defined

This error occurs if one of the built-in functions was misspelled (e.g. `sqrtrt(x)`). Please check Section 6.2.3 for the correct entry of built-in functions. Also, a call of a user defined function could contain a typing error. The error could also indicate an attempt to use parentheses in a quantity name (Do not write '`p(xx)`', but '`p_xx`'). The error message will also appear if a function is called in the equation field before it is defined. Therefore Function definitions should be placed in the beginning in the equation field.

129: Error: Function is already defined.

Only one function with any given name may be defined. The message also appears if attempts are made to redefine any of the built-in functions. Their names are reserved.

130: Error: Invalid symbolic parameter.

This error appears in various situations with unacceptable contents in the parameter list. It could be two consecutive commas or the presence of a plus sign.

131: Error: Symbolic parameter is already in use.

This error message appears upon leaving an equation field in which resides a function definition with a name used twice in the parameter list.

132: Error: The function name has already been used for a quantity.

This error message indicates an attempt to introduce a user defined function with a function name previously used as a quantity name in the equation field.

133: Error: Number of parameters does not match function definition.

This error message appears if a function is called with a different number of parameters than specified in its definition. All built-in functions take one and just one argument. User defined functions take the number of arguments with which they were defined. Often the reason for this error could be a missing comma in the parameter list of the function call.

135: Error: More than one result

This message appears in cases where more than one quantity could be interpreted as the output quantity. The quantities identified as possible candidates for results will be displayed for reference. There must be one and always just one output quantity for a GUM Workbench® model equation

137: Error: This special character is permitted only in the subscript part of a quantity name

Not all characters are permitted everywhere. To avoid any possibility of misreading the measurement equations, certain special characters have been excluded from becoming a part of the body of a name. They may still, however, be used in the subscript portion of a quantity name. Try to insert an underscore in front of the character at the cursor position. The display of this error could also indicate a rare problem with the resource file convert.ini. A fresh installation of GUM Workbench® might help.

138: Error: Double underscore (_ _) is not valid.

This message is displayed upon leaving the equation field if there is a quantity name with a double underscore. In case this error is displayed while opening an SMU file, Metrodata GmbH should be contacted for help to rescuing such file.

319: Error: SMU file for opening or for import not found.

This error is seen if a wrong file name is entered for opening, or if any of the shortcut features are used in an attempt to open a SMU file which has been deleted or moved since the last time GUM Workbench® worked with it.

Error 319 may also be displayed when opening an SMU file which has not been used for some time. If the file contains imported files from another SMU file, and if the latter has been moved since last use in relation to the file with the error, then the imported file is no longer where GUM Workbench® expects it to be, and error 319 is displayed. Click OK to the error message. The message will appear once for every imported quantity, so go on clicking OK. When the file opens, each imported quantity should be revisited. The file

name field will still display the path and filename where the source file originally resided. Now navigate to the new location of that file and reselect the quantity to import.

327: Error: Units in equation and import do not match.

The unit of the imported quantity and the unit of the quantity representing it must be the same (units, like quantity names are case sensitive, so pH is different from ph). Go to the list of quantities and change the unit of the quantity to be imported.

328: Error: Sum of squares is negative (correlation).

The sum of the squares of the uncertainty contribution is negative. The reason for this can be found in the correlation matrix. The sum of the correlation contributions is negative and the absolute value exceeds the sum of the squared uncertainty contributions. This means that all uncertainty contributions are over-compensated. This is not possible in reality. This error can occur if three or more measurands are mutually correlated.

332: Error: Quantity name not found in imported SMU File.

This error appears upon opening an SMU file which contains imported quantities. While the imported file has been found, it did not contain a quantity with the requested name. This could be simply because the source SMU file has been opened after the import was established and the quantity affected has been renamed or deleted. Click OK to the dialog and then go to the quantity which now appears as *not valid*. The file name will most often still be in the quantity data, so just select or reselect the correct quantity to import.

400: Error: $\log()$ argument out of range.

The argument for the $\log()$ function is outside of the valid range. Only values greater than zero are allowed.

401: Error: $\tan()$ argument out of range.

The argument for the $\tan()$ or $\cot()$ function is outside of the valid range. Only values not equal to $n \cdot \pi + \pi/2$ or $n \cdot \pi$, where n is an integer, are allowed.

402: Error: $\text{asin}()$ argument out of range.

The argument for the $\text{asin}()$ function is outside of the valid range. Only values in the range -1 up to +1 are allowed.

403: Error: $\text{acos}()$ argument out of range.

The argument for the $\text{acos}()$ function is outside of the valid range. Only values in the range -1 up to +1 are allowed.

410: Error: Division by zero.

While processing the equation a division by zero occurred. Please check the equation and the data for the denominator quantities.

411: Error: Mathematical loop is not allowed.

The program detected a mathematical loop that is not allowed. The error indicates that the model equation is constructed in a way that requires the result (directly or indirectly) an interim result to compute this same interim result. Correct the equation so that all interim results can be computed without recursion. Even if the problem is definitely in the equation field, the message is displayed only when activating the *Budget* table and when a calculation actually takes place. As long as some values are not present which are required to calculate the interim result, the phrase '*not valid!*' is displayed in the relevant fields, GUM Workbench® may not react upon the loop. When all fields have been filled in and the budget is activated again, the error will appear. Correct the equation so that all interim results can be computed without recursion.

412: Error: $\ln()$ argument out of range.

The argument for the $\ln()$ function is outside of the valid range. Only values greater than zero are allowed.

413: Error: Exponent must be integer for ^-operator (base is negative).

The base that should be raised to the power ('^') of another value is negative. In this case the exponent must be an integer. Please correct the value of either the base or the exponent or correct the equation to avoid this error.

414: Error: $\sqrt{}$ argument out of range.

The argument for the $\sqrt{}$ function is outside of the valid range. Only values greater than zero are allowed.

415: Error: $\operatorname{acosh}()$ argument out of range.

The argument for the $\operatorname{acosh}()$ function is outside of the valid range. Only values greater or equal to 1 are allowed.

416: Error: $\operatorname{atanh}()$ argument out of range.

The argument for the $\operatorname{atanh}()$ function is outside of the valid range. Only values in the range -1 up to +1 are allowed.

417: Error: $\operatorname{acoth}()$ argument out of range.

The argument for the $\operatorname{acoth}()$ function is outside of the valid range. Only values less than or equal to -1 or greater than or equal to +1 are allowed.

420: Error: The nested level of interim results is too high (max. 32).

GUM Workbench® allows only up to thirty-two nested levels of interim results. The message occurs only during the budget calculation. The equation field may be left without the conflict being identified as an error. Generally there are ways to formulate the model equation so that the limit is not exceeded.

503: Error: Not a valid number.

This appears e.g. if one tries to enter a number into a field using groups notation. "1,000.85" as well as "1.000,85" in any value field would bring up this message. It also appears if a letter is entered into a cell in the *Observation* window or e.g. in a value or half-width field etc.

507: Error: Not a valid number (unit)

This error appears if one has included a measuring unit in e.g. a value or half-width field. Only numbers should be entered. The unit is entered in the list of quantities and will then be displayed behind but outside of the field.

508: Error: Negative value is not permitted.

Negative number not allowed here. This error is displayed e.g. in the screen view *Quantity Data*, when *Type A Summary* is selected, if the number -5 is entered into the field *Degrees of freedom*.

509: Error: No unit allowed here.

This error appears if a unit or other letters have been entered after the digits in the *Reading* field under *Observations*. The unit of a quantity should be entered in the unit field in the list of quantities. For the measuring method of *U/S* of course the units of the reading may not be those of the quantity, but nevertheless it is not correct to enter units in the field.

510: Error: Must be integer.

Number must be an integer. This error is displayed if for example in the screen view *Quantity Data*, *Type A Summary*, the number 9.5 is entered into the field *Degrees of Freedom*.

517: Warning: The Number of Observations must be greater than 3 for Bayesian evaluation

This warning message will be displayed if a value for the *Number of Observations* smaller than 4 is entered. As a consequence, the experimental standard deviation can not be calculated and will be '*not valid!*' and the standard uncertainty of the mean value will also be '*not valid!*'. The uncertainty of any dependent result will not be calculated.

518: Warning: The pooled degrees of freedom must be greater than 2 for Bayesian evaluation

This warning message will be displayed if a value in the *Degrees of Freedom* field (pooled estimate) smaller than 3 is entered. As a consequence the experimental standard deviation can not be calculated and will be 'not valid' and the standard uncertainty of the mean will also be 'not valid'. The uncertainty of any dependent result will not be calculated.

508: Error: negative value is not valid

This error message will be displayed if a negative value for the *Experimental Standard Deviation* or the *Degrees of Freedom* is entered. The value must be changed to leave the edit field.

514: Error: value must be greater than or equal to 1.0

This error message will be displayed if zero is entered in the *Degrees of Freedom* field. The value must be changed to leave the edit field.

510: Error: must be integer

This error message will be displayed if any non-integer value is entered in the *Degrees of Freedom* field. The value must be changed to leave the edit field.

600: Error: New quantity name is not valid.

This error message occurs during the use of the *Rename Quantity* feature. Inspect the small field to the right and make sure that the entry adheres to all rules of naming a quantity.

601: Error: New quantity name already exists.

This error message will be displayed when clicking OK in the *Rename Quantity* dialog if an attempt is made to rename the quantity on the right to a name - entered in the left field - which has already been used in the equation field. Even if - in special situations - it could be sensible and lead to a valid model equation to do so, it is not correct to use the *Rename Quantity* feature in this way. If this is what should be achieved, it must be done by manual editing and filling in quantity data. Otherwise, change the entry in the left hand field to something not previously used in the equation.

602: Error: Number of observations must be set.

This error message occurs in connection with the *Observation* window when the table for entry of readings for a Type A quantity is displayed and the number of observations for that quantity has been left empty in the quantities register. After pressing OK to error 602, entry for all Type A quantities will be blocked. Go to the quantities register and fill in the number of observations. Just give it some value, even it may be changed at any time

later. Important note: While a quantity exists with an undefined number of observations and while in the *Observation* window, a sort operation must not be performed if it would put that quantity first in the list of quantities.

603: Error: Not a valid number of observations (1..9999).

The number of observations is not valid (for Type A uncertainty). Note that there is a slight difference depending on whether the quantity uses a standard deviation which is determined by GUM Workbench® from experimental data entered in the software, or whether a pooled estimate is introduced.

The field *Number of Observations* can take values ranging from 2 to 9999 if the field *Uncertainty Evaluation* is selected to *Experimental*.

It is possible to enter the number 1, and then proceed to the register *Observation*. But it is impossible to estimate an experimental standard deviation from just one observation, so in this situation, 2 is the absolute minimum with which an analysis may be completed.

If, however, 'Pooled estimate' is selected, the valid range for the number of observations is from 1 to 9999.

700: Error: Not a valid number.

Appears e.g. when exceeding ± 1 for a correlation coefficient. Also appears in connection with correlation for Type A quantities in case there is zero standard deviation for a quantity which qualifies for the calculation of experimentally indicated correlation.

Error 700 may also in rare cases appear after editing the equation field upon the first subsequent visit to the budget. Please contact Metrodata GmbH in case error message 700 should appear consistently in the latter situation.

701: Error: Range error ($-1.0 \leq \text{value} \leq 1.0$).

The correlation coefficient must be in the range $-1.0 \leq \text{value} \leq 1.0$. If the data for the correlation is available as a covariant only, the corresponding correlation coefficient should be derived and entered.

804: Error: File is read only.

To save this file, either choose *Save as* and give it a new name or refer to Section 11.2 to learn how to switch off the read-only setting.

805: Error: Cannot create file.

The filename is invalid. Please check the name or select a different one.

903: Error: Page number 'from' > 'to'

In the *Printing* dialog box. Put the smaller page number in the *from* field.

Appendix G OLE Automation Interface

GUM Workbench® version 2.3 and 2.4 supports an OLE automation application interface. A special setup procedure is needed to set up the OLE object registration or the registration needs to be set up manually. By default, the OLE object registration is not activated with the standard setup procedure because administrator privileges are required to register OLE objects.

The following steps are necessary to enable the OLE registration manually:

1. In the configuration file `GUMWBPRO.INI`, section `[Config]` the entry for `InitOLE=1` should be set.
2. `GUMWBPRO.EXE` should be once called with `/REGSERVER` as a parameter (administrator privileges are required for this step) to register the OLE object in the registry. GUM Workbench® will register the OLE object `GUMWBpro.Application` which should be used to access GUM Workbench®.
3. If the OLE object has been registered manually, it should be unregistered manually before GUM Workbench® is uninstalled by calling `GUMWBPRO.EXE` with `/UNREGSERVER` as a parameter (administration privilege is necessary for this step).

GUM Workbench® includes a built-in type library support which can be extracted by the OLE development framework if necessary (see `doc\GUMWBpro_TLB.pdf` for details).

Appendix H Calculation of the Sensitivity Coefficients

GUM Workbench® uses a first order Taylor Series expansion to calculate the sensitivity coefficients of a linear model to propagate the uncertainty. The numerical method which is used to calculate the partial derivatives is described in detail. The calculation is done component by component or input quantity by input quantity. At the beginning, all input quantities are set to the value of their best estimate. The result of the given model equation is calculated. We call the model equation function $f(x_i)$.

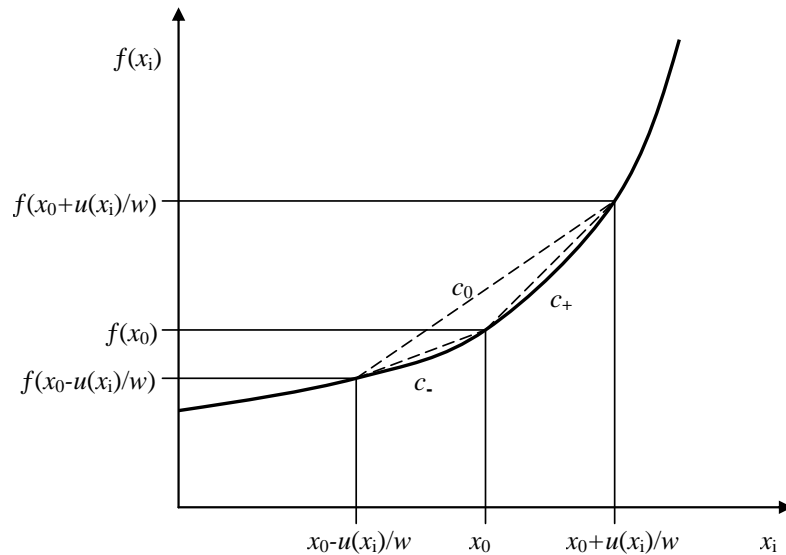


Figure 104: Graphical evaluation of the sensitivity (partial derivative)

Figure 104 shows an example of a possible function around the point x_0 . Graphically the partial derivative is the slope of the tangent of the function in x_0 . If the function is quasi linear around x_0 , the slope of the secant c_0 is a good estimate for the partial derivative in x_0 .

GUM Workbench[®] calculates the slope of a left side secant c_- and a right side secant c_+ and it uses the standard uncertainty of the quantity x_i to scale the interval. A fraction w of the standard uncertainty $u(x_i)$ is used to calculate the slope of the secants

$$c(w) = \frac{f(x_0 + \frac{u(x_i)}{w}) - f(x_0)}{\frac{u(x_i)}{w}}. \quad (6)$$

GUM Workbench[®] uses the average slope c_0 of the left side secant $c(-1)$ and the right side secant $c(+1)$ as the sensitivity for the input quantity.

$$c_0 = \frac{c(-1) + c(+1)}{2} \quad (7)$$

H.1 Linearity Check

GUM Workbench[®] has implemented a robust linearity check. The model equation is sufficiently linear if the difference of the slope of the left side secant $c(-1)$ and the right side secant $c(+1)$ (Equation 6) is smaller than a certain limit (see Figure 104)

$$\left| \frac{c(+1)}{c(-1)} - 1 \right| < \varepsilon_{\text{lin}}, \quad c(-1) \neq 0. \quad (8)$$

Additionally, GUM Workbench[®] calculates secants with a smaller width (tenth of the standard uncertainty). The difference between the slope of a secant with a smaller width and the

secant with the width of the standard uncertainty should also be smaller than a given, defined limit. This test is done for both sides

$$\left| \frac{c(1)}{c(10)} - 1 \right| < \varepsilon_{\text{lin}}, \quad \left| \frac{c(-1)}{c(-10)} - 1 \right| < \varepsilon_{\text{lin}}. \quad (9)$$

GUM Workbench® uses a limit of $\varepsilon_{\text{lin}} = 0.05$ in the linearity test. Applying this limit the usual deviation between the partial derivative and the numerical approximation is smaller than $\pm 0.4\%$ if the test is passed. The maximal deviation is smaller than 5%.

The execution of the linearity test can be switched off to improve performance in the *Configuration* dialog.

Warning: A possibly significant non-linearity of the model may not be detected if the *Linearity Test* option is switched off.

Appendix I Equations Used with GUM Workbench

This section lists the equations which are used inside GUM Workbench® to calculate the elements in the budget table and elsewhere.

I.1 Type A Evaluation

The Type A evaluation is used for the observed data, collected during the measurement. It is a statistical evaluation of the data. A series of n observation values $q_1 \dots q_n$ is given by the user from the experiment. The arithmetic mean value is used as a best estimate

$$x_i = \bar{q} = \frac{q_1 + q_2 + \dots + q_n}{n} = \frac{1}{n} \sum_{j=1}^n q_j. \quad (10)$$

The experimental standard deviation is calculated from the observation series,

$$s^2(q) = \frac{1}{n-1} \sum_{j=1}^n (q_j - \bar{q})^2. \quad (11)$$

The standard deviation of the mean is used for the standard uncertainty of the input quantity

$$u(x_i) = s(\bar{q}) = \frac{s(q)}{\sqrt{n}}. \quad (12)$$

The correlation coefficient between two observation series q_i and q_j is calculated with the following equation:

$$r(q_i, q_j) = \frac{1}{(n-1) \cdot s(q_i) \cdot s(q_j)} \cdot \sum_{k=1}^n (q_{i,k} - \bar{q}_i) \cdot (q_{j,k} - \bar{q}_j). \quad (13)$$

I.2 Type B Evaluation

The type B evaluation is based on a state of knowledge probability distribution. From the distribution the expectation value and the variance are calculated. These values are used for the best estimate and the standard uncertainty.

I.2.1 Rectangular Distribution

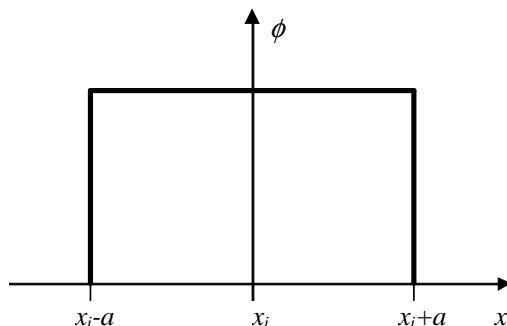


Figure 105: Rectangular distribution

The expectation value of a rectangular distribution is the arithmetic mean and the uncertainty can be calculated with the following formula based on the half width of limits a :

$$u(x_i) = \frac{a}{\sqrt{3}}. \quad (14)$$

I.2.2 Triangular Distribution

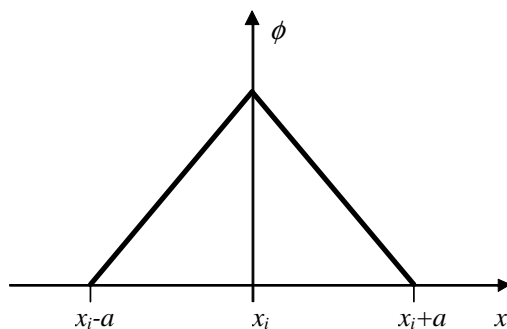


Figure 106: Triangular distribution

The expectation value of a triangular distribution is the arithmetic mean and the uncertainty can be calculated with the following formula based on the half width of limits a :

$$u(x_i) = \frac{a}{\sqrt{6}}. \quad (15)$$

I.2.3 Trapezoidal Distribution

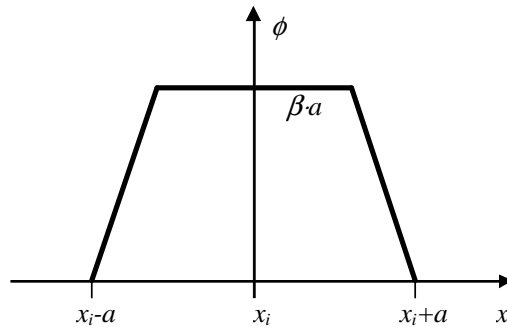


Figure 107: Trapezoidal distribution

The expectation value of a trapezoidal distribution is the arithmetic mean and the uncertainty can be calculated with the following formula based on the half width of limits a and the fraction β of the equally distributed part of the distribution:

$$u(x_i) = a \cdot \sqrt{\frac{1 + \beta^2}{6}}. \quad (16)$$

I.2.4 U-shaped Distribution

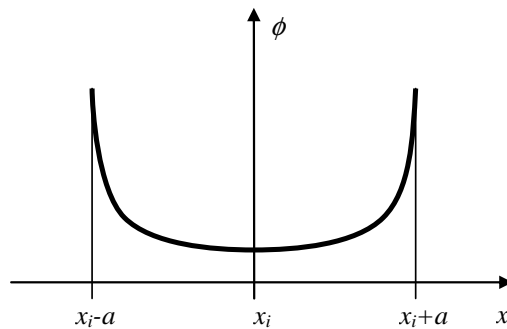


Figure 108: U-shaped distribution

The expectation Value of the U-shaped distribution is the arithmetic mean and the standard uncertainty can be calculated from the half-width with the following equation based on the half-width of limits a :

$$u(x_i) = \frac{a}{\sqrt{2}} \quad (17)$$

I.2.5 Normal Distribution

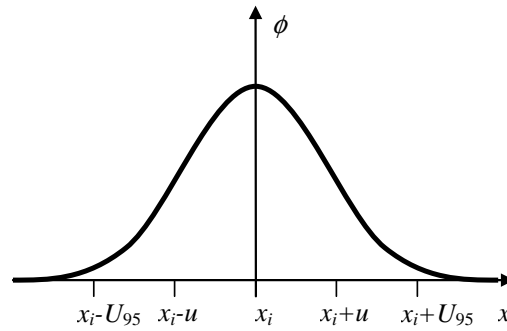


Figure 109: Normal distribution

The best estimate is the arithmetic mean and the standard uncertainty can be calculated from the given spread parameter. This can be any multiple of the standard uncertainty or an expanded uncertainty $U(x_i)$, together with a coverage factor k :

$$u(x_i) = \frac{U(x_i)}{k}. \quad (18)$$

I.3 Uncertainty Propagation (Budget)

The uncertainty propagation is based on the following model equation with n input quantities and m results:

$$y_j = f(x_1, x_2, \dots, x_n), \text{ for } j = 1 \dots m. \quad (19)$$

The sensitivity coefficient is calculated by numerical differentiation (see Appendix H).

$$c_{j,i} = \frac{\Delta y_j}{\Delta x_i} \quad (20)$$

The uncertainty contribution is calculated by multiplication of the standard uncertainty of the input quantities with their sensitivity coefficients. Because the sensitivity can be negative, the uncertainty contributions can be positive or negative (or sometimes zero).

$$u_i(y_j) = c_{j,i} \cdot u(x_i) \quad (21)$$

The law of uncertainty propagation is used to calculate the square of the standard uncertainty of the result,

$$u^2(y_j) = \sum_{i=1}^n u_i^2(y_j) \left[+ 2 \cdot \sum_{i=1}^{n-1} \sum_{k=i+1}^n r(x_i, x_k) \cdot u_i(y_j) \cdot u_k(y_j) \right]. \quad (22)$$

The last term of the equation 22 (the double sum in square brackets) is only calculated for input quantities which are correlated. The correlation coefficient with the following definition is used in the calculation:

$$r(x_i, x_k) = \frac{u(x_i, x_k)}{u(x_i) \cdot u(x_k)}, \quad (23)$$

where $u(x_i, x_k)$ is the covariance between the input quantity x_i and x_k .

The correlation between the result and a contributing input quantity x_i is:

$$r(y_j, x_i) = \sum_{k=1}^N r(x_i, x_k) \cdot \frac{u_k(y_j)}{u(y_j)}. \quad (24)$$

The uncertainty index (coefficient of contribution) $h(y_j, x_i)$ is:

$$h(y_j, x_i) = r(y_j, x_i) \cdot \frac{u_i(y_j)}{u(y_j)}. \quad (25)$$

I.4 Effective Degrees of Freedom

The equation of the degrees of freedom given in the GUM is only valid for non-correlated results. Therefore GUM Workbench® employs the extended equation

$$\begin{aligned} \frac{u^2(y)}{\nu_y} = & \sum_{i=1}^n \frac{u_i^2(y) \cdot r^2(y, x_i)}{\nu_i} \\ & + 2 \cdot \sum_{i=1}^{n-1} \left[\frac{u_i(y) \cdot r(y, x_i)}{\sqrt{\nu_i}} \cdot \sum_{j=i+1}^n r^2(x_i, x_j) \cdot \frac{u_j(y) \cdot r(y, x_j)}{\sqrt{\nu_j}} \right]. \end{aligned} \quad (26)$$

In cases where the input quantities are all uncorrelated Equation (26) simplifies to the well known Welch-Satterthwaite formula.

I.5 Expanded Uncertainty and Correlation Between Results

The expanded uncertainty $U(y_j)$ is calculated by multiplying the standard uncertainty $u(y_j)$ by a coverage factor k_j .

$$U(y_j) = k_j \cdot u(y_j) \quad (27)$$

The correlation coefficient between two results y_k and y_l is:

$$r(y_k, y_l) = \sum_{i=1}^n \sum_{j=1}^n \frac{u_i(y_k)}{u(y_k)} \cdot \frac{u_j(y_l)}{u(y_l)} \cdot r(x_i, x_j) \text{ for } k, l = 1 \dots m. \quad (28)$$

Appendix J Example Report Pages

Calibration of a gauge block of nominal length 50 mm																																									
<p>Calibration of a gauge block of nominal length 50 mm</p> <p>The calibration of the grade 0 gauge block (ISO 3650) of 50 mm nominal length is carried out by comparison using a comparator and a calibrated gauge block of the same nominal length and the same material as reference standard. The difference in central length is determined in vertical position of the two gauge blocks using two length indicators contacting the upper and lower measuring faces.</p> <p>The actual length of the gauge block to be calibrated is related to the actual length of the reference standard by the equation</p> $l_x' = l_s' + \delta l$ <p>with δl being the measured length difference. l_x blocks under the measurement conditions, in particular at a temperature which on account of the uncertainty in the measurement of laboratory temperature may not be identical with the reference temperature for length measurements.</p> <p>Model Equation:</p> $l_x = l_s + \delta l_D + \delta l + \delta l_C - L \cdot (\alpha_{av} \cdot \delta t + \delta \alpha \cdot \Delta t_{av} + u_{at}) - \delta l_v$ <p>List of Quantities:</p> <table border="1"> <thead> <tr> <th>Quantity</th> <th>Unit</th> <th>Definition</th> </tr> </thead> <tbody> <tr> <td>l_x</td> <td>mm</td> <td>length of the gauge block to be calibrated</td> </tr> <tr> <td>l_s</td> <td>mm</td> <td>length of the reference gauge block at the reference temperature of $t_0=20^\circ\text{C}$ according to its calibration certificate</td> </tr> <tr> <td>δl_D</td> <td>mm</td> <td>Change of the length of the reference gauge block since its last calibration due to drift</td> </tr> <tr> <td>δl</td> <td>mm</td> <td>observed difference in length between the unknown and the reference gauge block</td> </tr> <tr> <td>δl_C</td> <td>mm</td> <td>correction for non-linearity and offset of the comparator</td> </tr> <tr> <td>L</td> <td>mm</td> <td>nominal length of the gauge blocks under consideration</td> </tr> <tr> <td>α_{av}</td> <td>K^{-1}</td> <td>average of the thermal expansion coefficients of the unknown and the reference gauge block</td> </tr> <tr> <td>δt</td> <td>K</td> <td>difference in temperature between the unknown the reference gauge block</td> </tr> <tr> <td>$\delta \alpha$</td> <td>K^{-1}</td> <td>difference in the thermal expansion coefficients between the unknown and the reference gauge block</td> </tr> <tr> <td>Δt_{av}</td> <td>K</td> <td>deviation of the average temperature of the unknown and the standard gauge block from the reference temperature</td> </tr> <tr> <td>u_{at}</td> <td></td> <td>coorection for second order terms of $(\delta \alpha \cdot \Delta t_{av})$</td> </tr> <tr> <td>$\delta l_v$</td> <td>mm</td> <td>correction for non-central contacting of the measuring faces of the unknown gauge block</td> </tr> </tbody> </table> <p>l_s:</p> <p>Type B normal distribution Value: 50.000020 mm Expanded Uncertainty: $30 \cdot 10^{-6}$ mm Coverage Factor: 2.0</p> <p>REFERENCE STANDARD: The length of the reference gauge block together with the associated expanded uncertainty of measurement is given in the calibration certificate of a set of gauge blocks as 50,000 02 mm ± 30 nm (coverage factor $k=2$).</p>			Quantity	Unit	Definition	l_x	mm	length of the gauge block to be calibrated	l_s	mm	length of the reference gauge block at the reference temperature of $t_0=20^\circ\text{C}$ according to its calibration certificate	δl_D	mm	Change of the length of the reference gauge block since its last calibration due to drift	δl	mm	observed difference in length between the unknown and the reference gauge block	δl_C	mm	correction for non-linearity and offset of the comparator	L	mm	nominal length of the gauge blocks under consideration	α_{av}	K^{-1}	average of the thermal expansion coefficients of the unknown and the reference gauge block	δt	K	difference in temperature between the unknown the reference gauge block	$\delta \alpha$	K^{-1}	difference in the thermal expansion coefficients between the unknown and the reference gauge block	Δt_{av}	K	deviation of the average temperature of the unknown and the standard gauge block from the reference temperature	u_{at}		coorection for second order terms of $(\delta \alpha \cdot \Delta t_{av})$	δl_v	mm	correction for non-central contacting of the measuring faces of the unknown gauge block
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Date: 01/18/2001	File: S04.smu	Page 1 of 4																																							

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Figure 110: Report EA-4/02 S04 Page 1 (75% of the original size)

	Calibration of a gauge block of nominal length 50 mm													
δl_D: Type B rectangular distribution Value: 0 mm Halfwidth of Limits: $30 \cdot 10^{-6}$ mm DRIFT OF THE STANDARD: The temporal drift of the length of the reference gauge block is estimated from previous calibrations to be zero with limits ± 30 nm. General experience with gauge blocks of this type suggest that the zero drift is the most probable value and that a triangular probability distribution can be assumed.														
δl: Type A Method of observation: Direct Number of observations: 5 <table><tr><td>No.</td><td>Observation</td></tr><tr><td>1</td><td>$-100 \cdot 10^{-6}$ mm</td></tr><tr><td>2</td><td>$-90 \cdot 10^{-6}$ mm</td></tr><tr><td>3</td><td>$-85 \cdot 10^{-6}$ mm</td></tr><tr><td>4</td><td>$-95 \cdot 10^{-6}$ mm</td></tr><tr><td>5</td><td>$-100 \cdot 10^{-6}$ mm</td></tr></table> Arithmetic Mean: $-94.00 \cdot 10^{-6}$ mm Pooled Standard Deviation: $12 \cdot 10^{-6}$ mm Pooled Degrees of Freedom: 9 Standard Uncertainty: $4.75 \cdot 10^{-6}$ mm MEASUREMENTS: A pooled estimate of standard deviation of 15 nm derived from previous measurements is used for the evaluation of the repeatability. The following observations are made for the difference between the unknown gauge block and the reference standard, the comparator being reset using the reference standard before each reading.			No.	Observation	1	$-100 \cdot 10^{-6}$ mm	2	$-90 \cdot 10^{-6}$ mm	3	$-85 \cdot 10^{-6}$ mm	4	$-95 \cdot 10^{-6}$ mm	5	$-100 \cdot 10^{-6}$ mm
No.	Observation													
1	$-100 \cdot 10^{-6}$ mm													
2	$-90 \cdot 10^{-6}$ mm													
3	$-85 \cdot 10^{-6}$ mm													
4	$-95 \cdot 10^{-6}$ mm													
5	$-100 \cdot 10^{-6}$ mm													
δl_C: Type B rectangular distribution Value: 0 mm Halfwidth of Limits: $32 \cdot 10^{-6}$ mm COMPARATOR: The comparator has been verified to meet the specifications stated in EAL-G21. From this it can be ascertained that for length differences D up to ± 10 μ m corrections to the indicated length difference are within the limits $\pm(30 \text{ nm} + 0,02 \cdot \text{abs}(D))$. Taking into account the tolerances of the grade 0 gauge block to be calibrated and the grade K reference gauge block the maximum length difference will be within ± 1 μ m leading to the limits of ± 32 nm for non-linearity and offset corrections of the comparator used.														
L: Constant Value: 50 mm Nominal length of the gauge block to be calibrated.														
α_{av}: Type B rectangular distribution Value: $11.5 \cdot 10^{-6} \text{ K}^{-1}$ Halfwidth of Limits: $1 \cdot 10^{-6} \text{ K}^{-1}$ TEMPERATURE CORRECTION: Based on the calibration certificate of the reference gauge block and the manufacturer's data for the gauge block to be calibrated the linear thermal expansion coefficient of the steel gauge blocks is assumed to be within the interval $(11,5 \pm 1,0) \times 10^{-6} \text{ }^\circ\text{C}^{-1}$.														
δt: Type B rectangular distribution Value: 0 K Halfwidth of Limits: 0.05 K														
Date: 01/18/2001	File: S04.smu	Page 2 of 4												

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Figure 111: Report EA-4/02 S04 Page 2 (75% of the original size)

Calibration of a gauge block of nominal length 50 mm		
<p>TEMPERATURE CORRECTION: Before calibration care is taken to ensure that the gauge blocks assume ambient temperature of the measuring room. The remaining difference in temperature between the standard and the gauge block to be calibrated is estimated to be within $\pm 0,05$ K.</p> <p>$\delta\alpha$: Type B triangular distribution Value: 0.0 K^{-1} Halfwidth of Limits: $2 \cdot 10^{-6} \text{ K}^{-1}$</p> <p>TEMPERATURE CORRECTION: Combining the two rectangular distributions the difference in linear thermal expansion coefficient is triangularly distributed within the limits $\pm 2 \text{ E-6 } ^\circ\text{C}^{-1}$.</p> <p>$\Delta t_{av}$: Type B rectangular distribution Value: 0 K Halfwidth of Limits: 0.5 K</p> <p>TEMPERATURE CORRECTION: The deviation of the mean temperature of measurement from the reference temperature $t_0 = 20 \text{ }^\circ\text{C}$ is estimated to be within $\pm 0,5 \text{ }^\circ\text{C}$.</p> <p>$u_{at}$: Type B normal distribution Value: 0 Expanded Uncertainty: $0.236 \cdot 10^{-6}$ Coverage Factor: 1.0</p> <p>TEMPERATURE CORRECTION: The best estimates of the difference in linear expansion coefficients ($\delta\alpha$) and the deviations of the mean temperature from the reference temperature (Δt_{av}) are zero. Therefore second order terms have to be taken into account in the evaluation of their uncertainty contribution resulting in the product of standard uncertainties associated with the factors of the product term ($\delta\alpha \times \Delta t_{av}$) in the model equation. The final standard uncertainty is $u(\delta\alpha \times \Delta t_{av}) = 0,236 \cdot 10^{-6}$.</p> <p>$\delta l_v$: Type B rectangular distribution Value: 0 mm Halfwidth of Limits: $6.7 \cdot 10^{-6} \text{ mm}$</p> <p>VARATION IN LENGTH: For gauge blocks of grade 0 the variation in length determined from measurements at the centre and the four corners has to be within $\pm 0,12 \text{ mm}$ (ISO 3650). Assuming that this variation occurs on the measuring faces along the short edge of length 9 mm and that the central length is measured inside a circle of radius 0,5 mm the correction due to central misalignment of the contacting point is estimated to be within $\pm 6,7 \text{ nm}$.</p>		
Date: 01/18/2001	File: S04.smu	Page 3 of 4

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Figure 112: Report EA-4/02 S04 Page 3 (75% of the original size)

Calibration of a gauge block of nominal length 50 mm						
Uncertainty Budgets:						
l_x : length of the gauge block to be calibrated						
Quantity	Value	Standard Uncertainty	Distribution	Sensitivity Coefficient	Uncertainty Contribution	Index
l_s	50.0000200 mm	$15.0 \cdot 10^{-6}$ mm	normal	1.0	$15 \cdot 10^{-6}$ mm	17.1 %
δl_D	0.0 mm	$17.3 \cdot 10^{-6}$ mm	rectangular	1.0	$17 \cdot 10^{-6}$ mm	22.8 %
δl	$-94.00 \cdot 10^{-6}$ mm	$4.75 \cdot 10^{-6}$ mm	normal	1.0	$4.7 \cdot 10^{-6}$ mm	1.7 %
δl_C	0.0 mm	$18.5 \cdot 10^{-6}$ mm	rectangular	1.0	$18 \cdot 10^{-6}$ mm	25.9 %
L	50.0 mm					
α_{av}	$11.500 \cdot 10^{-6} \text{ K}^{-1}$	$577 \cdot 10^{-9} \text{ K}^{-1}$	rectangular	0.0	0.0 mm	0.0 %
δt	0.0 K	0.0289 K	rectangular	$-580 \cdot 10^{-6}$	$-17 \cdot 10^{-6}$ mm	20.9 %
$\delta \alpha$	0.0 K^{-1}	$816 \cdot 10^{-9} \text{ K}^{-1}$	triangular	0.0	0.0 mm	0.0 %
Δt_{av}	0.0 K	0.289 K	rectangular	0.0	0.0 mm	0.0 %
u_{at}	0.0	$236 \cdot 10^{-9}$	normal	-50	$-12 \cdot 10^{-6}$ mm	10.6 %
δl_V	0.0 mm	$3.87 \cdot 10^{-6}$ mm	rectangular	-1.0	$-3.9 \cdot 10^{-6}$ mm	1.1 %
l_x	49.9999260 mm	$36.3 \cdot 10^{-6}$ mm				
Results:						
Quantity	Value	Expanded Uncertainty	Coverage factor	Coverage		
l_x	49.999926 mm	$73 \cdot 10^{-6}$ mm	2.00	95% (t-table 95.45%)		
Date: 01/18/2001	File: S04.smu					Page 4 of 4

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Figure 113: Report EA-4/02 S04 Page 4 (75% of the original size)

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Appendix M Index

A

acos(), 26
acosh(), 26
acot(), 26
acoth(), 26
alignment, 102
analysis, 11
arc, 26
Arial, 71
arithmetic mean, 135, 139
asin(), 26
asinh(), 26
atan(), 26
atanh(), 26
author field, 71
average(), 27
axis, 105

B

backslash, 22
Bayesian, 46
bold, 71
budget
 configuration, 111
 multiple, 70
budget table, 16
built-in functions, 25

C

calculate
 budget, 69
 correlation, 69
calculate parameter, 133
caret, 33
change quantity order, 60
Cholesky decomposition, 127
clipboard, 78
coefficient, 139
col, 139
comma, 27
command line, 10
comments, 24
compatibility, 100
configuration, 110
const(), 26
constant, 26, 55
conversion, 26
corr-coeff. column, 17
correlation, 65, 135, 160
correlation analysis, 65
correlation coefficient, 135
correlation matrix, 15, 21, 127, 139, 141
cos(), 26
cosh(), 26

cosine, 26
cot(), 26
cotangent, 26
coth(), 26
covariance, 135
coverage, 18
coverage factor, 18, 135, 139
coverage probability, 135

D

date field, 71
date format, 110
definition, 14
deg(), 25, 26
degrees, 25
degrees of freedom, 139, 160
derived units, 89
description, 14, 16, 33, 41, 42, 139
diagram, 101
 add data, 104
 axis control, 105
 data, 103
 details, 103
 edit data, 105
 graphs, 106
 insert data, 104
 marker, 107
 multiple, 108
 view, 102
direct observation, 49
directory, 114
display mode, 22, 39
display options, 69
distribution, 139
 limited, 53
 normal, 51, 159
 Poisson, 54
 rectangular, 53, 157
 student-t, 52
 trapezoidal, 53, 158
 triangular, 53, 157
 U-shaped, 53, 158
document information, 71
documentation, 71

E

e, 24
edit mode, 23, 39
effective degrees of freedom, 160
E-format, 27
eigenvalue decomposition, 128
equation, 13, 22, 140

comments, 24
 example, 35
 structure, 23
equation field, 22
error, 98, 145
Excel, 116
Excel import, 58
exp(), 26
expanded uncertainty, 18, 135, 140, 160
experimental standard deviation, 135
experimental variance, 135
expert, 116
exponential, 26
exponential format, 27
export, 71, 76
 Excel, 116

F

fifty-fifty, 51
file name, 80
fixed aspect ratio, 102
from file, 140
function
 insert, 34
functions
 built-in, 25
 user defined, 27

G

Gaussian distribution, 51
general description, 140
graph, 125
Graphics, 82
graphs, 106
Greek letters, 35, 142
GUI concept, 12

H

half-width, 140
help, 115
html, 78
hyperbolic, 26

I

import
 Excel, 58
 manager, 60
 multiple, 60
 observation, 63
 SMU, 55
independent quantity, 30
index column, 17
input estimate, 135
input fields, 139

input quantity, 136

insert

logo, 75

unit, 91

installation, 3, 119

interim result, 36, 44

italic, 71

L

language, 111

large equations, 134

last budget, 19

limited distribution, 53

line break, 71

linearity check, 155

list of quantities, 38, 140

ln(), 26

load

picture, 83

SMU, 79

log(), 26

logarithm, 26

logo, 75

M

main menu, 13

main window, 13

marker, 107, 125

mathematical functions, 25

mathematical operators, 24

measurand, 136

measured data, 15, 63

menu structure, 137

method, 140

method of observation, 49, 140

model, 13

model equation, 11, 13, 22

Monte Carlo, 118

multiple

budget, 70

diagram, 108

pictures, 85

program window, 134

multiple results, 20, 69

N

normal distribution, 51

not valid!, 19, 20

number, 27

number of observations, 140

O

observation, 15, 140

method, 49

observation view, 63

OLE, 154

OMCE, 118

online help, 115

open, 79

order of quantities, 60

output estimate, 136

output fields, 139

output quantity, 136

P

paper format, 73

parameter, 28, 133

parentheses, 25

partial derivative, 14

paste, 64, 143

PDF, 126

percent, 133

performance, 70

pictures, 86

period, 27

physical model, 96

pi, 24

picture, 82

storage, 85

Poisson distribution, 54

pooled estimate, 45, 47, 136

positive semi-definite, 127

prefix, 88

preview, 73

print, 71, 72

printer setup, 73

printing range, 74

privileges, 134

probability density function, 126

probability distribution, 136

problems, 75

Python, 129

Q

quantity, 141

name, 30

order, 60

rename, 32, 33

type, 40

quantity data, 14, 41

R

rad(), 25, 26

radian, 25

random variable, 136

read only, 79

reading, 15

readings, 63

reference, 72

register

title, 13

relative in %, 17

relative standard

uncertainty, 136

relative uncertainty, 17

rename, 32, 33

report, 71, 72

report options, 74

requirements

Monte Carlo, 119

pictures, 82

result, 43

configuration, 112

correlation matrix, 21

list, 69

multiple, 69

view, 21

Roman, 71

root3(), 26

rounding, 18, 113

row, 141

rtf, 78

run GUM Workbench, 10

S

save, 79

save as, 80

scatter diagram, 101

select type, 42

semi-definite, 127

sensitivity coefficient, 20, 136, 154

setup, 3

shape factor, 141

SI, 87

sin(), 26

sine, 26

sinh(), 26

SMU, 136

file format, 117

sorting, 61

special character, 34

sqr(), 26

sqrt(), 26

square root, 26

standard deviation, 136, 141

standard uncertainty, 136, 141

start menu, 8, 10

status line, 13

SU, 49

subscript, 33

summarized, 48

superscript, 33

SUS, 50

SUUS, 50

T

tabulator, 71

tan(), 26

tangent, 26

tanh(), 26

t-distribution, 52

template, 130

tips, 133

title, 13

title field, 71

- tittle, 141
- tool bar
 - general, 12
- trapezoidal distribution, 53
- type, 141
 - Bayesian, 46
 - constant, 55
 - import, 55
 - interim, 44
 - pooled estimate, 45
 - result, 43
 - summarized, 48
 - type A, 44
 - type B, 50
- Type
 - Interim Result, 36
- type A, 44, 137, 156
- type B, 137, 157

U

- u(x), 107
- U(x), 107
- U/S, 50
- uncertainty, 137
 - propagation, 159

- uncertainty analysis, 11
- uncertainty budget, 16, 141
- uncertainty diagram, 101
- uncertainty evaluation, 141
- underlined, 71
- underscore, 22, 33
- Unicode, 143
- unit, 14, 87, 141
 - syntax, 94
 - validation, 92
- units, 38, 39

V

- val(x), 107
- validation
 - unit, 87
- value, 142
- value diagram, 101
- value model, 96
- variance, 137
- version, 3, 115
- version field, 71
- view
 - budget, 16
 - diagram, 102

- model, 13
- observation, 15, 63
- quantity data, 41
- result, 21
 - uncertainty budget, 16
- view selection, 13
- views, 12

W

- warning, 98, 145
- working directory, 114

X

- x-axis, 105

Y

- y-axis, 105
- yellow fields, 17

Z

- zeta diagram, 101
- zoom, 73, 114

Metrodata | Datenverarbeitung
GmbH für Messtechnik und
Qualitätssicherung

Im Winkel 15-1
D-79576 Weil am Rhein
Germany

Tel: +49 (0)7621/70 56 813
Fax: +49 (0)7621/70 56 818
web: www.metrodata.de
e-mail: info@metrodata.de

ISBN 978-3-00-032973-9



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