

# **MetroVal**

## **Advanced Calibration Software With Real Time Uncertainty and Prediction analysis**

# Outline

- ✚ MetroVal overview
- ✚ Procedure
- ✚ Uncertainty
- ✚ Prediction
- ✚ Math capabilities
- ✚ Operating
- ✚ Reporting
- ✚ Running as command line by another program

## **MetroVal**

is a general purpose flexible  
**calibration** and **analysis** program  
that can fit many situations and requirements  
and is utilized in many fields of calibration.

It complies with international metrology standards and  
recommendations such as

**ISO GUM (& supplement 1+2)** = for uncertainty

**ISO 17025** = for accreditation

**ILAC G8, clause 2.3** = for compliance with specification

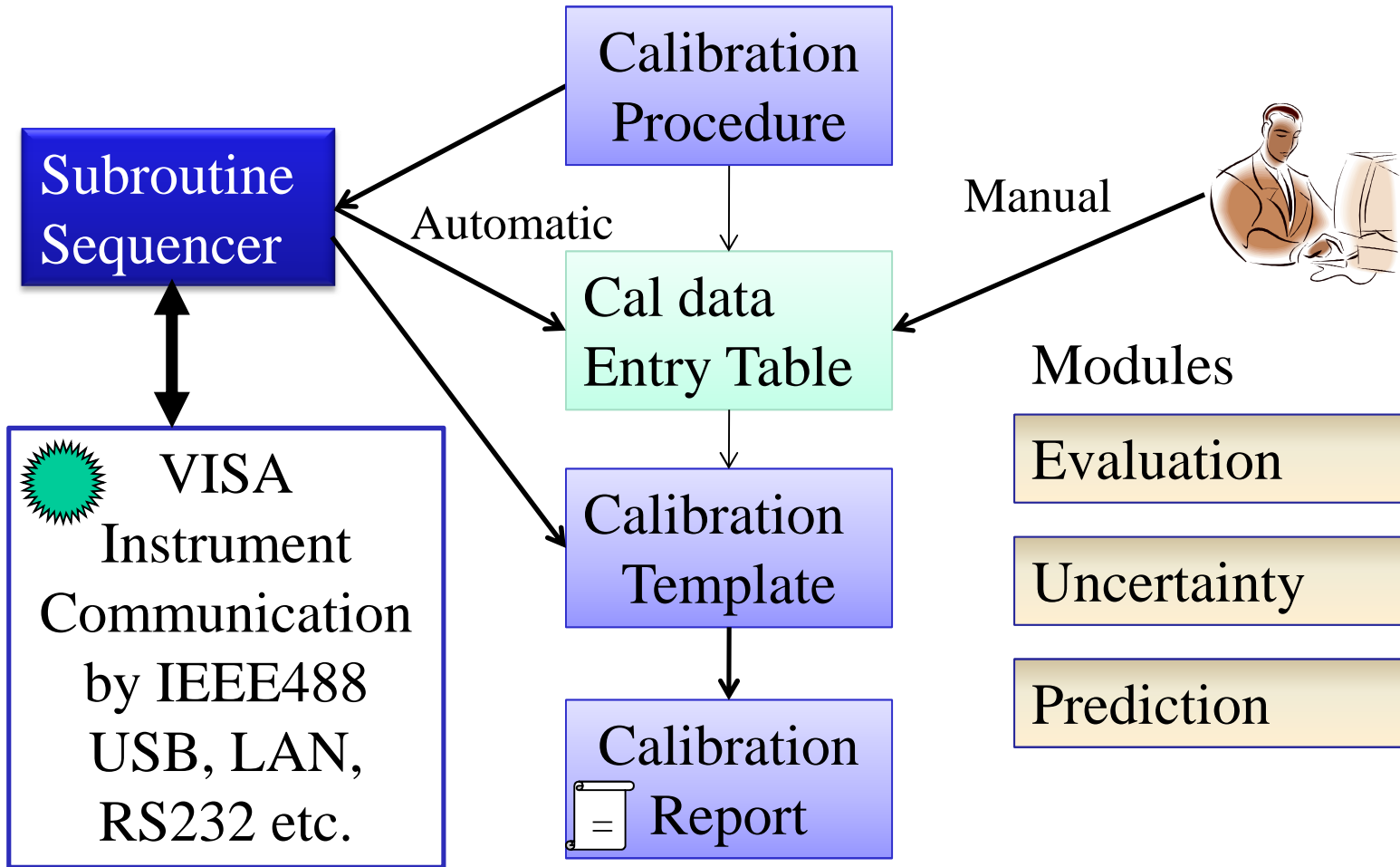
**ILAC G24 / OIML D 10** = for recalibration intervals

and has many capabilities beyond these standards.

MetroVal's features were fine tuned and continue to be, based  
on users feedback.



## MetroVal Block Diagram



**The calibration procedure** is a table written by non-programmers. Each cell contains a parameter, an instruction or a link. The table is executed line by line.

**Sequencer**

Row	Cal Point	Unc. file	Page	Symbol(s)	Instruction/Ima	Repea	Histor	Param	ID string	Filter	Unc Meth	Toler	BM	Unit
1	DC Voltag													
2		C:\Docu												
3	100 mV		1	Predict570(&DC01set			F:\FLUtest		DC VOL					
4				&DCV		10								
5				UUTres		0								
6									ISO		ISO			mV
7	1 V		2	Predict570(&DC1set			F:\FLUtest		DC VO					
8				&DCV		10								
9				UUTres		0								
10									MC					
									Eq					
									EqD					
									OK					
									Txt					
11	10 V		3	Predict570(&DC10set			F:\FLUtest		DC VOL					1e-6V

**Data for prediction**

**Available uncertainty methods**

**Accredited capability**

**Unc. Page & components**

**Subroutine**

Sequencer: C:\MetroVal Files\DMM calibration using 5700.prc

File Edit Update-Sequencer Cal-Procedure Data-Table Graph Help

Enable Edit/Save  Simulate

visa32.dll found in C:\WINDOWS\system32

Configuration Sequencer Variables

Test From row 1 to bottom Now on row 3 Step Variables: 0 Stop

Row	&Symbol/F	Instrument	Command	Parameter	Value	Additional param	User
1	DC Volta						
2	100 mV						
3	&DC01set	1061A	Prompt	Short the input wit			
4			Send	F3;C1;R0			F3:DC
5			Wait	1000			
			Send	Z			zero,
			Wait	10000			
			Send	R2			R2: 1
9		5700	Send	OUT 100 MV			
10			Prompt	Connect the UUT			
11			Send	OPER			
12			Wait	3000			
13	&DCV	1061A	Receive		13041.9:		
14			Wait	3000			
15	1 V						

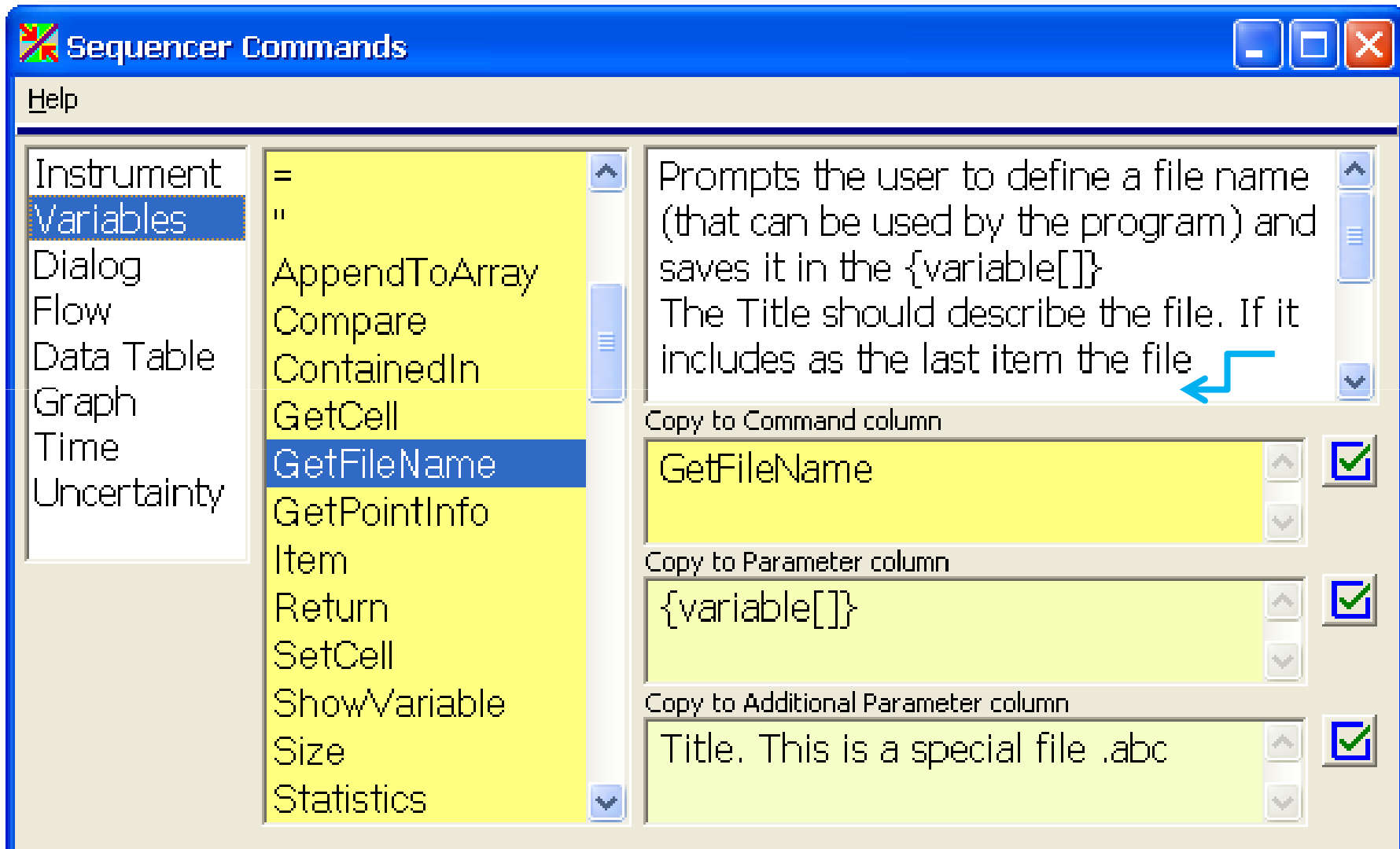
The Sequencer

Subroutine starts here

VISA sends an instrument command

... and the instrument responds

Right clicking on a Command field in the Sequencer opens a command editor which allows editing commands and variables.



# Available Uncertainty Methods



- # **GUM** (first order Taylor expansion). Expanded uncertainty computation is extended to include correlations. C-sensitivities and result uncertainties may be complex numbers.
- # **Simplified Monte Carlo** (assuming Root-Sum-Squares equation). May use complex numbers as with the GUM method.
- # **Monte-Carlo simulation directly from the measurement equation.** The equation may include complex numbers. Distributions and reference values are given in the budget table. It can compute c-sensitivities. Produces the **most correct results.**



# Uncertainty Budget (1)

The screenshot displays the MetroVal software interface with the following components:

- Components Table:**

Symbol	Description of the component	Value of	Unit of u	Distribution	Confid	Divisor	c Sensit	Unit of c	u - Stan	c*u contr	d.f.	Mean (or me	Deviation - t	Referenc
U1	Predicted value for today	0.003	V	Normal	2	1			0.0015	0.0015	999	0.11	0.01	0.1
U2	UUT resolution	0.001	V	Rectangle		$=1/\sqrt{1+2}$			0.003464	0.003464	999			
U3	Repeatability	4.787135	V	Normal	1	1			4.787135	4.787135	3	0.001075	-0.098925	0.1
U4	Voltage Controller	0.0005	V	Triangle		$=1/\sqrt{6}$			0.001224	0.001224	999			0
- Correlations Table:**

Ui	Uj	r(i,j)	correlation
r1			
- Measured Data Table (repeatability):**

Line	U3
1	0.001
2	0.0011
3	0.0012
4	0.001
5	
- Results Table:**

Uncertainty	Value	Unit	confid	k factor	d.f.
uc Combined	0.004	V			
U Expanded (ISO)	0.0078	V	0.95	1.96	1.64E
MC Expanded (MC)	0.0073	V	0.95	1.8	
Val Deviation	-0.0889	V			

c-sensitivity can be complex

Deviation

Methods: GUM and Monte-Carlo can be complex and correlated

Each budget page contains one cal point

# Uncertainty Budget (2)

Links to Procedure

Graphic analysis

The screenshot shows a software window with the following components:

- Components Table:** A table listing uncertainty components with columns for Symbol, Description, Value, Unit, Distribution, Confid, Divisor, c, Sensit, Unit of c, u - Stan, c\*u contr, d.f., Mean or me, Deviation - t, and Refe.
- Correlations Table:** A table for correlation coefficients with columns for Ui, Uj, and r(i,j).
- Measured Data Table (repeatability):** A table with columns for Line U2, Ui->, RefData, and H11T.
- Results Table:** A table showing uncertainty results with columns for Uncertainty, Value, Unit, confid, k factor, and d.f.

Callouts in the image point to:

- Links to Procedure:** Points to the 'Description' column in the Components Table.
- Graphic analysis:** Points to the 'Distribution' column in the Components Table.
- Computed field:** Points to the formula '=col(RefData)' in the Measured Data Table.
- Measured, imported and computed columns:** Points to the 'RefData' and 'H11T' columns in the Measured Data Table.

# Uncertainty Budget (3)

The screenshot shows the 'Uncertainty Spreadsheet' software interface. The main window displays a 'Components Table' and a 'Results Table'. The 'Components Table' lists two components, U1 and U2. U1 has a value of 1, a rectangular distribution, a confidence interval of 1, and a divisor of 1.73205. The 'Results Table' shows the uncertainty budget results, including the standard uncertainty (uc), expanded uncertainty (U), and Monte-Carlo (MC) results. The MC results show a mean of 9.3 and a standard deviation of 3.48, which is significantly lower than the GUM result of 6.8. The GUM result is labeled as 'GUM fails'.

Equation:  $u(1)^2 \text{ EQ}$

Components Table

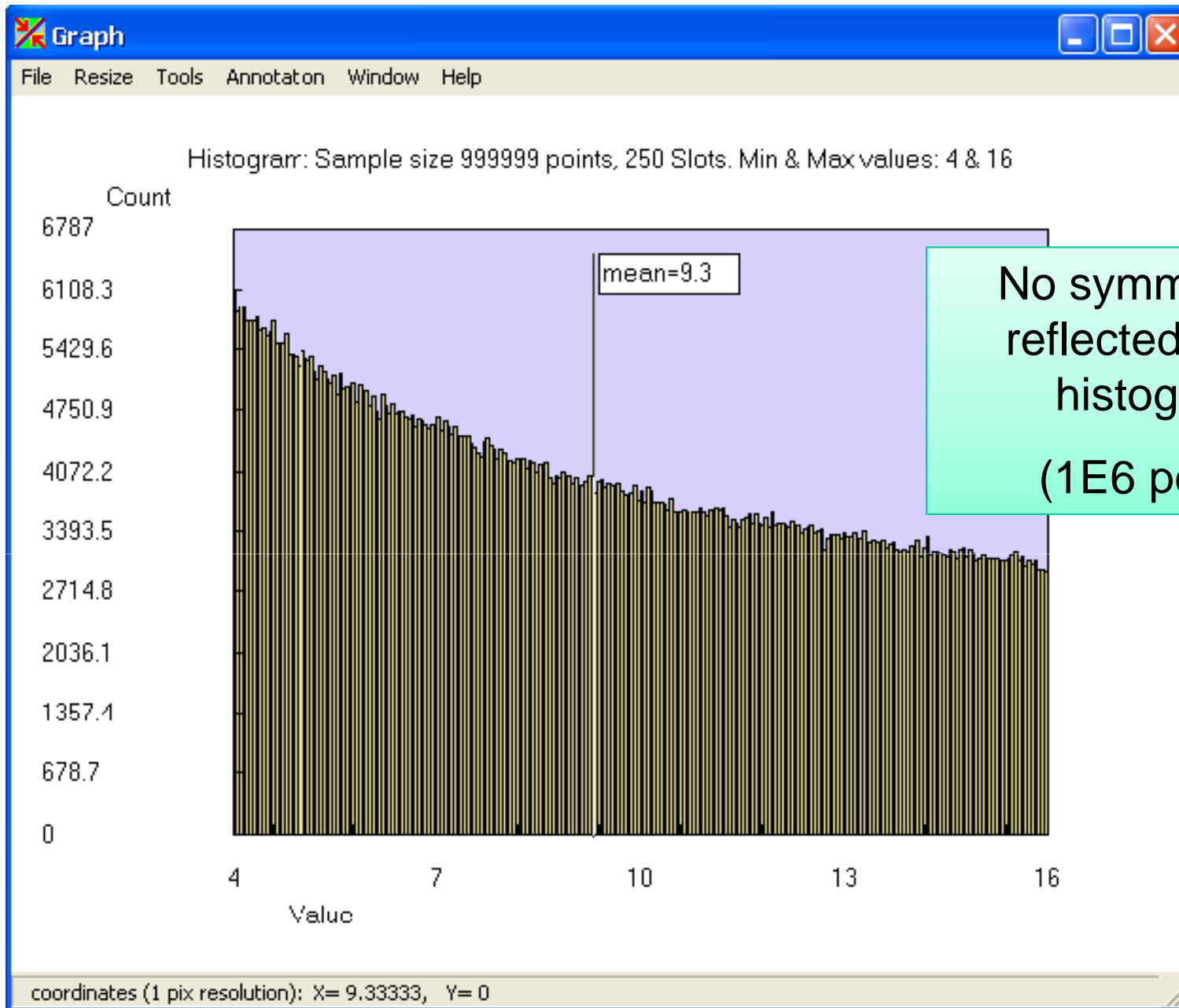
	Value of	Unit of u	Distribution	Confid	Divisor	c	Sensit	Unit of c	u - Stan	c*u contr	d.f.	Mean
U1	1		Rectangle	1	1.73205	0.6			0.577350	3.4641	999	3
U2												

Results Table

Uncertainty	Value	Unit	confid	k factor	d.f.	Low	High
uc	Sigma (MC)	3.48					
U	Expanded (GUM)	6.8	0.95	1.96	999		
MC	Expanded (MC)	5.7	0.95	1.6		5.1	6.3
Val	Mean (MC)	9.3				4.2	15.6

Annotations:

- Unsymmetrical measurement equation
- Difference with GUM [4.1.4] = 9
- GUM fails
- With M-C from equation, high and low endpoints are computed



# Uncertainty from Measurement Equation by Monte-Carlo simulation

**Compute derivatives**

**j is Imaginary unit**

Symbol	Description
U1	S11m Re S11m
U2	S11m Im S11m
U3	Edf Re Directi
U4	Edf Im Directiv

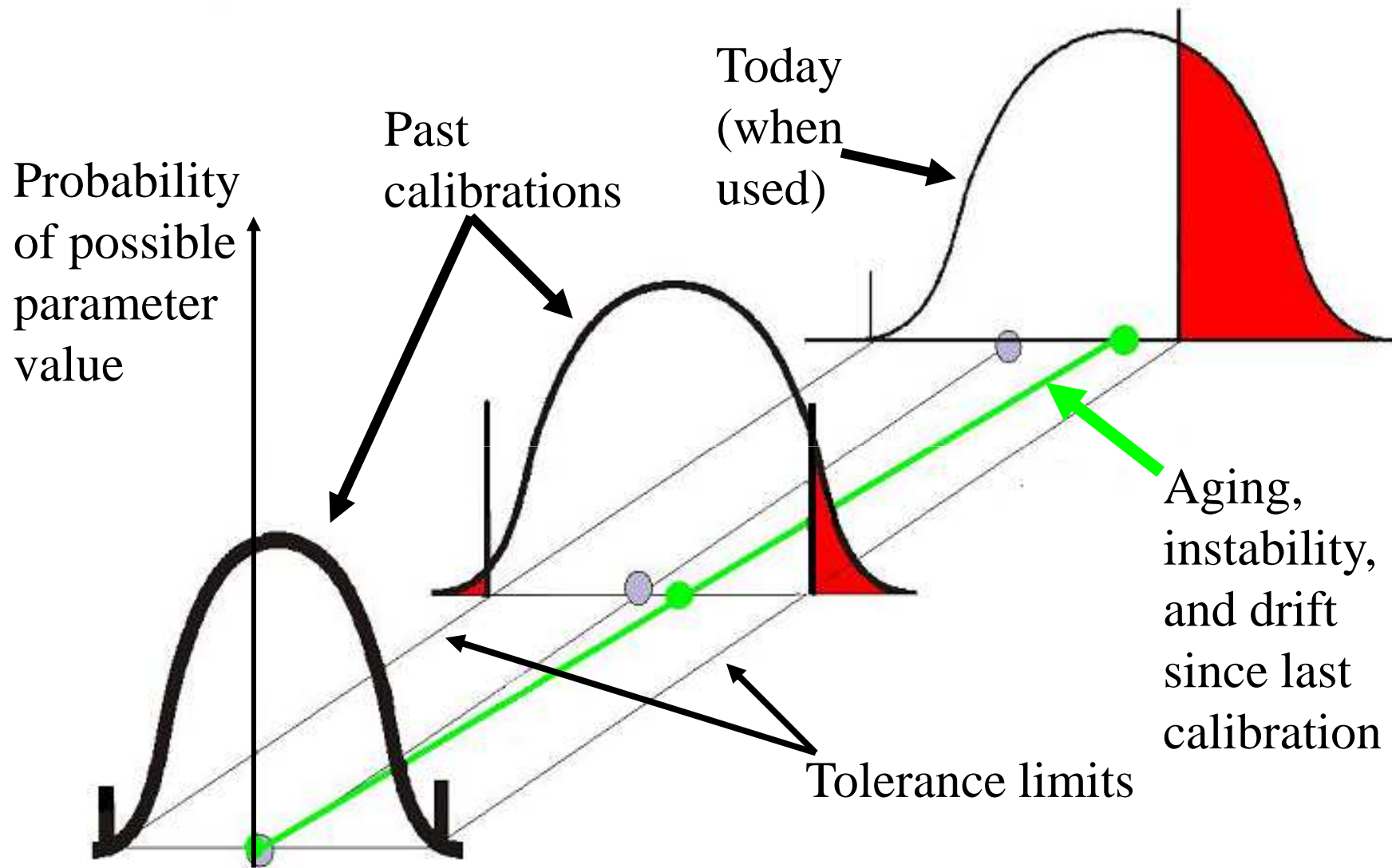
Uncertainty	Value
uc	Sigma (MC) 0.0
U	Expanded (ISO) 0.0
MC	Expanded (MC) 0.0
Val	Mean (MC) 0.0801

Measurement Equation Editor  
Use U(i) for the component in line i

(((u(1)+u(2)j)-(u(3)+u(4)j))/(u(5)+u(6)j))(1+((u(7)+u(8)j)-(u(9)+u(10)j))(u(13)+u(14)j)/(u(11)+u(12)j))-((u(17)+u(18)j)-(u(19)+u(20)j))/(u(21)+u(22)j))(((u(23)+u(24)j)-(u(25)+u(26)j))/(u(27)+u(28)j)))/((u(3)+u(4)j)(U(29)+u(30)j)/(u(5)+u(6)j))(1+((u(7)+u(8)j)-(u(9)+u(10)j))(u(13)+u(14)j)/(u(11)+u(12)j))-((u(17)+u(18)j)-(u(19)+u(20)j))/(u(21)+u(22)j))(((u(23)+u(24)j)-(u(25)+u(26)j))/(u(27)+u(28)j)))



# Why use prediction as an uncertainty component?



The contribution of reference instrument's aging, drift and instability to the total measurement uncertainty is important. It is especially significant when

- ✚ Doing proficiency testing
- ✚ Calibrating or comparing reference instruments of similar quality
- ✚ Comparing instruments over a long period of time
- ✚ Monitoring the quality of reference instruments
- ✚ Verifying aging and other instability specifications
- ✚ Estimating recalibration intervals



# Past Calibrations used for Prediction and Interval Analysis

Predictor - History File: C:\Documents and Settings\... MetroVal files\4808hisa.his

File Edit Search Characters Schedule Predict Graph Report Help

Reload this file  
C:\Documents and Settings\MetroVal files\4808hisa.his

An Example History (4808)

Line	Day	Month	Year	Unit1	Input Value	Output Value	Unit2	Deviation	Uncertainty	Parameter	Status	id String	k	df	Con
17	6	5	2000	V	-1	-0.9999999	ppm	0	2.6	DCV	OK	008, Gain -ve, 1V,	2		
18	6	5	2000	V	0	0	Same	0	1E-06	DCV	OK	009, Offset +ve, 10V,	2		
19	6	5	2000	V	10	10.000002	ppm	0.2	2.1	DCV	OK	010, Gain +ve, 10V,	2		
20	6	5	2000	V	19	18.999998	ppm	-0.1	2.3	DCV	OK	011, 19V Gain, 10V,	2		
21	6	5	2000	V	0	1E-06	Same	1E-06	1E-06	DCV	OK	012, Offset -ve, 10V,	2		
22	6	5	2000	V	-10	-10.000001	ppm	-0.1	2.1	DCV	OK	013, Gain -ve, 10V,	2		
23	6	5	2000	V	-19	-18.999999	ppm	0	2.3	DCV	OK	014, -19V Gain, 10V,	2		
24	6	5	2000	V	0	0	Same	0	1E-05	DCV	OK	015, Offset +ve, 100V,	2		

Year: 2000, Month: 5, Day: 6

Relative Filter: 0.015

Unit 1 --> V, Unit 2 --> ppm

Parameter: DCV, Status: OK, id String: 011, 19V Gain, 10V, Confidence: 95.45

When calculating:  Allow Exp. in output,  Don't format number of digits

Buttons: New Year, Schedule Line, Reset, -Schedule, +Schedule

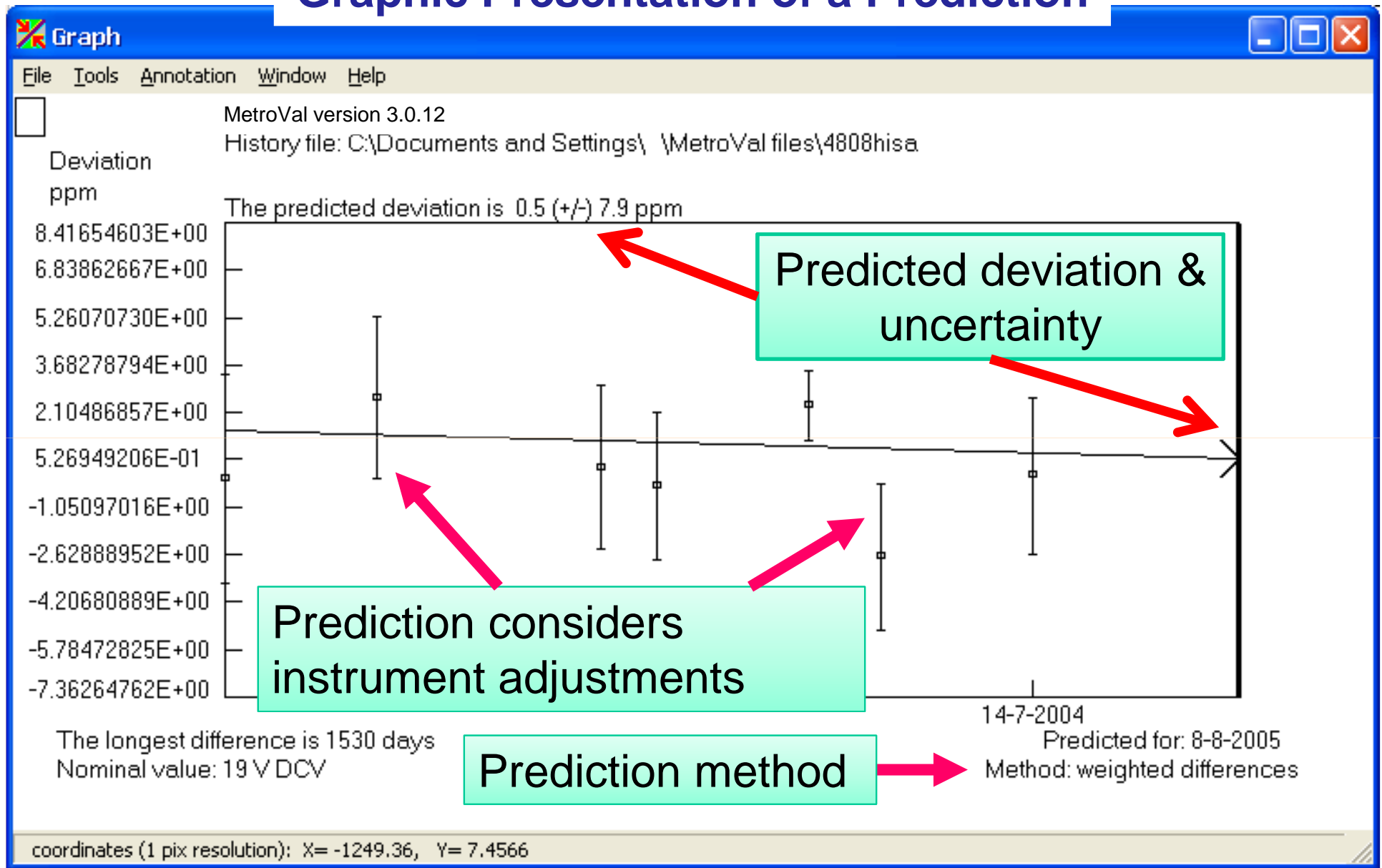
Adjustment info, spec etc.

Run predictions and graphics

k, df, confidence

Each row is one calibration point

# Graphic Presentation of a Prediction



## Available Prediction Methods



- ✚ **Weighted Linear Regression.** Takes into consideration both **regression statistics** and **measurement uncertainties**. Best for white noise instabilities.
- ✚ **Weighted Linear Regression of Differences.** Advantage when instrument passes occasional **adjustments** (“as received” and “as left”). Best for random walk instabilities.
- ✚ MetroVal program can chose the best method and use it when in automatic mode.

# Uncertainty & Procedure Linker (in function view)

Linker - Function View (Beta)

Procedure Description: Calibration of  
 Tolerance Version: Automatic  
 Procedure version

Function: 1, DC Voltage  
 Function Comment:

1. Procedure | 2. Functions | 3. Points | 4. Uncertainty Components | 5. Points for a Component

Component U2  Accept

#	U1	U2	U3	U4
Description	certificate	non-linearity 90 day Sp	drift taken as specificat	UU
Symbol (Link)				
Rpt'd Meas. Header	ktubloyino			
Unc Distribution	Normal	Rectangle	Rectangl	
Divisor (k)	2	=sqrt(3)	=sqrt(3)	
Sensitivity: value unit	1	1	1	
Repetitions	1	0	0	
Prediction File				
Prediction Filter				

U2 Data Source

- Repeated measurements
- Unc & Mean
- Unc only (ignore mean)
- Mean only
- Reference (true) value
- Unc mean Ref predefined

U2 Input Method

- By Sequencer
- Manual at run-time
- From this table
- From Prediction

non-linearity 90 day Spec

The Linker is used to make the Procedure, Uncertainty & Prediction in one step

# What is Visible to the Operator?



The procedure tree with calibration points to choose for the present job.

The screenshot shows the 'Cal Procedure Filter' application window. The title bar includes standard window controls and the text 'Cal Procedure Filter'. The menu bar contains 'File', 'Select-all', 'Skip-all', 'Instr.', 'Exapand-all', 'Hide-all', 'Help', 'OK', and 'Stop'. The main area displays a 'Procedure Tree' with the following items:

- 1 Title: DC Voltage (checked)
- 23 Title: AC Voltage (checked)
- 116 Title: DC Current (checked)
  - 117 Point: 100  $\mu$ A (checked)
  - 121 Point: 1 mA (unchecked)
  - 125 Point: 10 mA (checked)
  - 129 Point: 100 mA (checked)
  - 133 Point: 1 A (unchecked, highlighted)
- 137 Title: AC Current (checked)
- 154 Title: DC Resistance (unchecked)

At the bottom of the window is a table with the following data:

Row	Address	Serial	Name	Used as	Message
1		!	1061A	Under Calibrati	
2	GPIB0::4::INS	FLUKE,5700A	5700	Reference	

Instruments used by VISA for the selected cal points

**Title 1**

Name **1V**

Line **2**

**Instructions**

sdm2: sdm, Sample Standard Deviation of the Mean

sdm1: sdm, Sample Standard Deviation of the Mean

Reference->					
Symbol(s)->	sdm2	sdm1			
Units ->	mA	mA			
Ui->	2	1			
1					
2					
3					

## Calibration

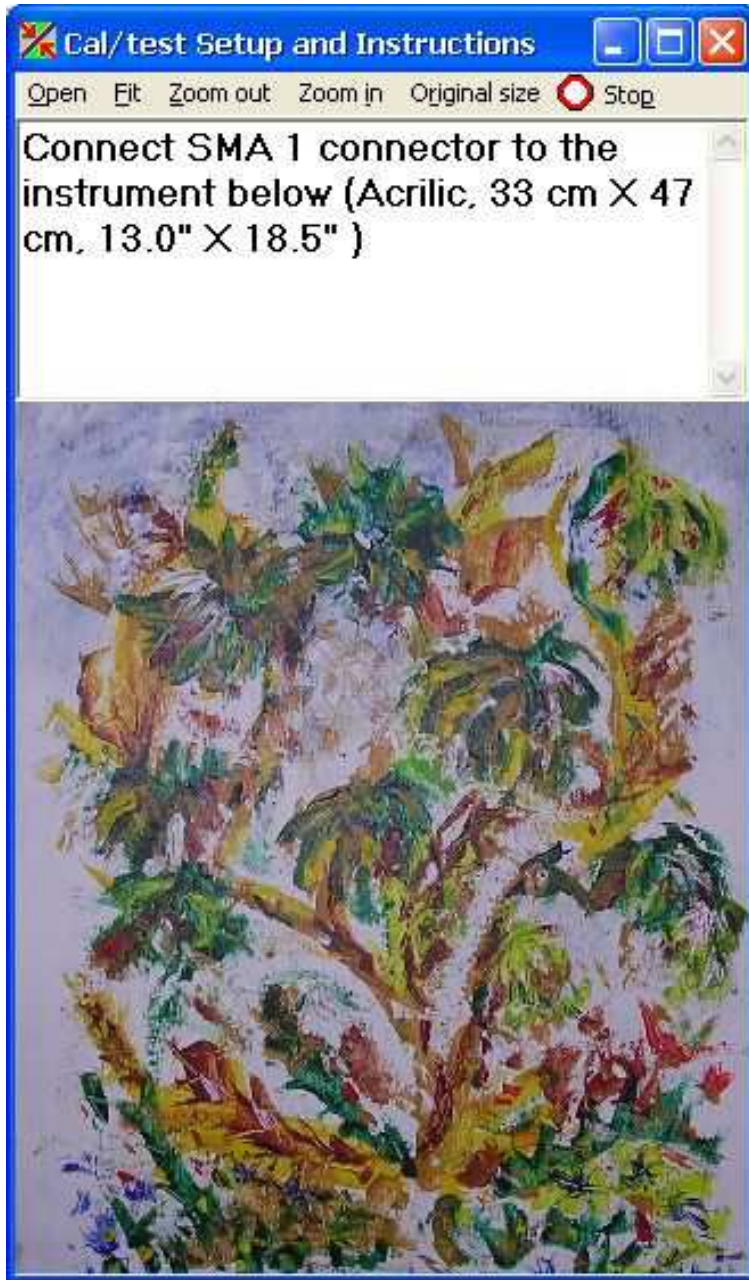
When running calibration manually...

Component description from uncertainty budget

Components reference values

Correlated components measured simultaneously and processed together (e.g. sigma of difference).

Measurements' entry fields. In automatic calibration MetroVal uses VISA for automatic reading & data entry.



## Instructions to Operator

← Text

and

← Graphics

Step by step instructions to operator with optional graphic aids, prompts and inputs.



Graphical presentation of uncertainty, result and spec

The screenshot shows a software window titled "Cal Procedure: C:\Users\Alex\Desktop\paris\Balance up to 11 points from INI v1.prc". The interface includes a menu bar (File, Edit, Window, Preview-Instruction, Filter, Control, New-Template, Calibrate, Stop, Help) and a toolbar with icons for "Enable Edit/Save", "U", and "Prompt on". A progress bar at the top displays "Accuracy, up 11.018" with a green bar and a red line, and a "Tol & Ref" label. A red arrow points from the text box above to the "Unc" label in the progress bar. Below the progress bar is a table with the following data:

Row	Function	Point	Unit	Ref.	Read	Meas.	Dev.	Unc.	k	L Limit	H Limit	L Tol	H Tol	Tol.	Pass?
7	Standard Dev	2.018	g		5	0								0.02	Pass
8	Standard Dev	10	kg		5	0								0.02	Pass
12	Eccentricity	Back Left	kg	9		9	0							0.02	Pass
13	Eccentricity	Back Right	kg	9		9	0							0.02	Pass
14	Eccentricity	Front Left	kg	9		9	0							0.02	Pass
15	Eccentricity	Front Right	kg	9		9	0							0.02	Pass
30	Accuracy	up 2.018	g	2.018000		0	-2.01800	0.00011	1.96					0.02	Fail
37	Accuracy	up 3.018	g	3.018000		3.00000	-0.01800	0.00011	1.96					0.02	Pass
44	Accuracy	up 1.018	kg	1.018000		1.00000	-0.01800	0.00011	1.96					0.02	Pass
51	Accuracy	up 10	kg	10.000000		9.99998	-2E-05	0.00011	1.96					0.02	Pass
58	Accuracy	up 11.018	kg											0.02	Pass

An "Input" dialog box is overlaid on the table, containing the text "Enter the resolution (last count) in units kg for this reading of 10 kg". The dialog has a numeric input field with "123" and a text input field with "0.0001". It also features "Ready" and "Stop" buttons.

Progress of calibration

Instruction and input


Report Designer and Viewer

File Front-Pages Data-pages Edit Windows Help

Page\_1  Layout / 3  Only front pages

The Famous Calibration Company

km 34 kvish 6  
make a left turn next to Moshe's budke  
email: FCL@etc.cal



Calibration Certificate

Certificate Number 0

Customer:

Most Important company Ltd.  
10 Main street, Yehupitz

Instrument

Mizin Model:qwe  
1234F 12345678A

A layout (1:3) of the page

A report designer allows you to design your certificate (1:1). It accepts parameters in real time.

# Calibration Results Report

Results Report for Certificate 0

Done for fun only during holidays.

## Frequency accuracy at 3 dBm input power

Fitted number of significant digits

Point/ Param.	Unit	Ref.	Measured	Dev.	Unc.	k
1 MHz	Hz	1000000.000	1000500.00	500.00	0.58	1.65
10 MHz	Hz	10000000.000	10000499.93	499.93	0.51	1.66
100 MHz	Hz	100000000	1.0000045E+08	4.5E+02	1.7E+02	3.10
200 MHz	Hz	200000000.000	200000499.45	499.45	0.67	1.77

k factor computed for every point

## Power step attenuator at 50 MHz

Point/ Param.	Unit	Ref.	Measured	Dev.	Unc.	k	Tolerance	Pass/NC Fail	Not Accredited
60 dB	%	0	14.3	14.3	3.8	2.81	15	NC	*
50 dB	%	0	4.2	4.2	1.3	2.80	10	Pass	*
40 dB	%	0	3.1	3.1	1.7	2.88	10	Pass	*
30 dB	%	0	1.91	1.91	0.42	2.60	1	Fail	*

\*\*\* End Of Report \*\*\*

Possible inclusion of graphs and Data Tables

Pass/Fail per ILAC G8

Automatic indication of not accredited items

If not otherwise stated, the expanded uncertainties are for the confidence probability of about 95% and k=2. Pass/NC/Fail based on deviation from nominal plus uncertainty

# The Famous Metrology Conference

Results Report for Certificate 0 , Cal Date: 19-11-2008

All-in-one-universal-instrument, s/n 0987654321

that never needs calibration or adjustment

Pass/NC/Fail depends on asymmetric uncertainties. Extension of ILAC G8

## Calibration of artifact 1234, function z

Point Name	Unit	Ref.	Measured	Dev.	Unc.	k	Low Tol.	High Tol.	Pass /Fail	Not Acc
20	mm	20.00052	19.9994	-0.0011	-0.0017 +0.0027	2	-0.01	0.01	Pass	*
100	mm	100.00153	100.0017	0.0002	-0.0023 +0.0016	2	-0.01	0.01	Pass	*

\*\*\* End Of Report Data \*\*\*

Accreditation should allow for asymmetric BMC

Reporting asymmetric uncertainties

MetroVal can be started by another program  
(for example MS Access).

The program transfers to MetroVal the name of  
an INI file as a command line parameter.

MetroVal loads the parameters (eg. cal points)  
from the INI and executes the calibration.

When calibration is ended, MetroVal closes and  
the focus is transferred to the calling program.