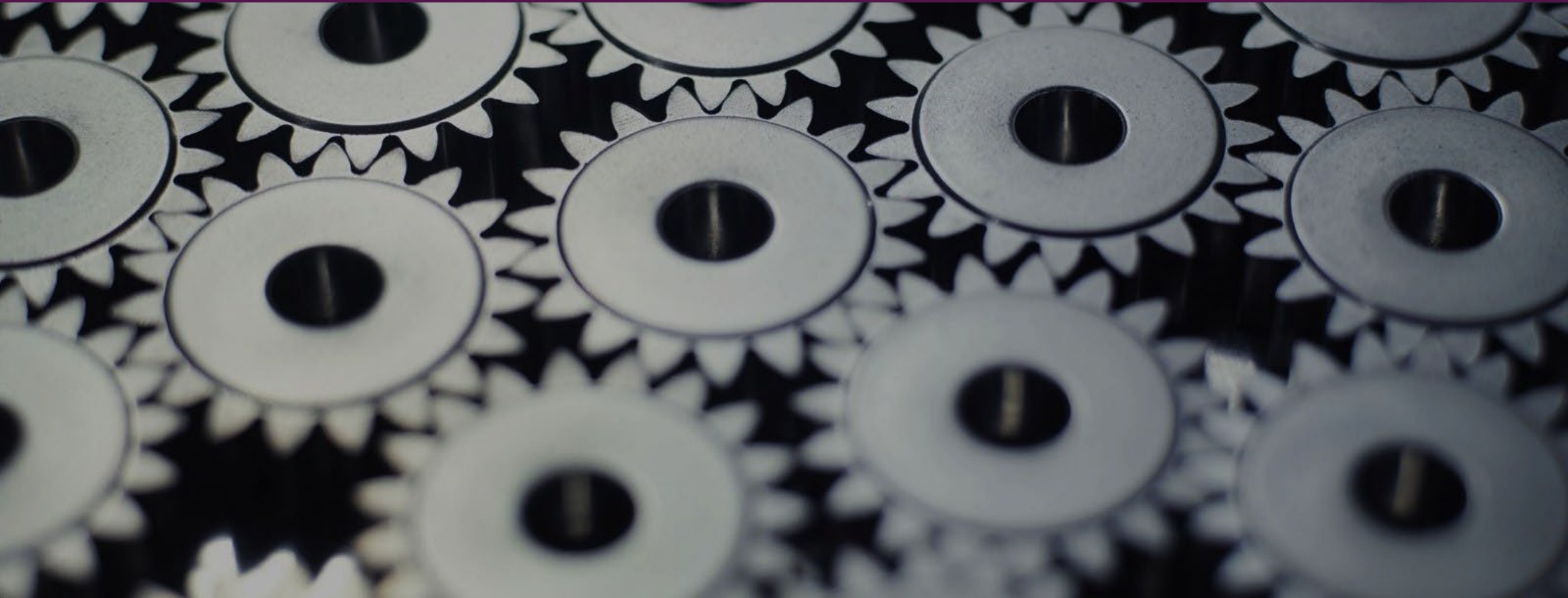


Software Verification and Validation



What is Software Verification & Validation



Verification

“Was it built right?”



- **Verification** is about ensuring that the program is built correctly and meets design specifications.
 - Are all requirements met;
 - Is the design clear and understandable;
 - Does the design match the requirements;
 - Ensure all features are properly specified;
 - Confirm the flow is logical;

“Is it working correctly?”

- Does the software work as intended?
- Does the program notify of errors during use? (i.e. missing values)
- Do all calculations return the correct result?

$$\text{effective density} = \frac{M_1 + M_2 + M_3}{\left(\frac{M_1}{\rho_1}\right) + \left(\frac{M_2}{\rho_2}\right) + \left(\frac{M_3}{\rho_3}\right)}$$

$$\text{effective density} = \frac{0.2 \text{ g}}{0.027554663 \text{ cm}^3}$$

$$\text{effective density} = 7.25894595 \text{ g/cm}^3$$

A	B	C	D	E	F	G	H	I
1	Effective Density - used for when weights are used together as a summation.				SOP 2 (also SOP 28)			
2	Fill in the yellow cells with values/equations as appropriate.							
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16	0.2		0.027554663		SUMS			
17	7.258299555				Effective Density			
18								

3.5. Effective density values standards:

$$\text{Effective Density} = \frac{\sum \rho_i}{\sum V_i}$$

Why is Software Verification & Validation Important?



Reduces the risk of implementing software with errors.



Ensure that the software satisfies the requirements and meets the needs of the user.



Ensures that the reported results are accurate.



Meets compliance with adopted documentary standards.

Documentary Standards:

ISO/IEC 17025



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6.4 Equipment

- Equipment used for laboratory activities that influence results must perform correctly, including software files.
- Equipment must be verified prior to implementation.

Documentary Standards:

ISO/IEC 17025



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7.5 Technical Records

- The lab must maintain records generated during the verification and validation process, including:
 - Original and new software files
 - Checklists (Ex. GLP 15 checklist)
 - Calculations conducted to validate formulas
 - Revisions made during the development process
 - Dates of revisions and personnel responsible

Documentary Standards:

ISO/IEC 17025



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7.11 Control of Data and Information Management

- Software used to generate data to report must be validated prior to implementation.
- All changes to software files must be authorized, documented, and validated prior to release.
- The lab is responsible for ensuring that documents are stored in a manner to prevent unauthorized changes to the software and to prevent loss of files.

Documentary Standards:

ISO/IEC 17025



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8.3 Control of Management System Documents

- The lab is responsible for ensuring documents are:
 - Adequate for use prior to implementation;
 - Documents are reviewed and updated as needed;
 - All revisions are documented, and the current revision status is identified; and
 - Obsolete software is stored in a manner to prevent use.

Documentary Standards:

ISO/IEC 17025



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8.4 Control of Records

- The lab is responsible for ensuring that all records (current and obsolete) are accessible.
- All records must be stored in a manner to prevent loss. Backups may be maintained in physical or electronic forms.
- Retention time for records should follow the lab's stated retention policy.
 - Software files should be maintained for the life of the file, and not less than the stated retention policy.

Documentary Standards:

ISO/IEC 17025



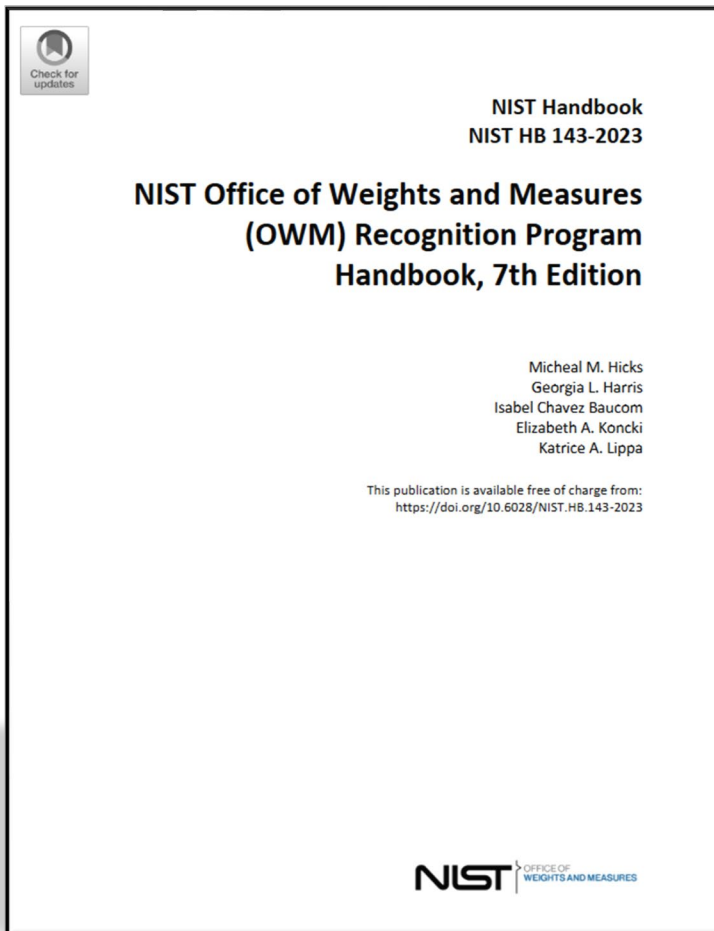
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8.5 Actions to Address Risks and Opportunities

- The lab shall consider risks and opportunities for improvement with software updates.
 - What are current risks in established software that can be reduced?
 - What are potential risks that may occur during the development process?
- Opportunities for improvement can
 - Improve the user interface;
 - Reduce redundancies in data entry;
 - Add in look up tables that look up needed data for the user

Documentary Standards:

NIST HB 143-2023



4.10 Software Requirements

- As spreadsheets are a frequently used software tool to produce reportable data, validation and verification of the software file is a requirement.
- NIST GLP 15, Software Quality Assurance (NISTIR 8250) may be adopted by the lab for their software assurance program.
 - The lab may develop their own software assurance procedure as long as it is equivalent or better than GLP 15.

GLP 15 (NISTIR 8250)

GLP 15 **Good Laboratory Practice** **for** **Software Quality Assurance**

1 Introduction

This is the metrology laboratory procedure for protecting, validating, and approving the accuracy of computer software and systems. All software and systems that affect reported measurement results, reported corrections, or uncertainties must be evaluated to comply with this document. All supporting software used in the laboratory to monitor the validity of measurement results must be validated as well.

Types of Software:

Commercial-off-the-Shelf (COTS)

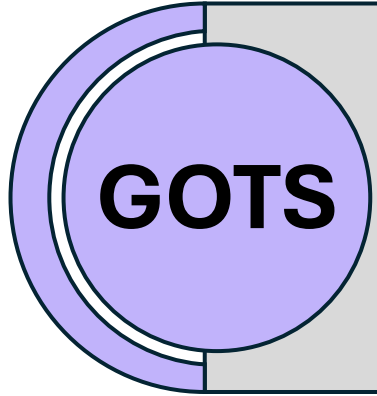


- Software product that is commercially available for purchase and use.
- Can be modified to fit the needs of the user.
- Ex:
 - Windows Office (e.g. Excel, Word)
 - Google apps
 - Productivity apps (e.g. Adobe)

COTS are the most likely used software type utilized

- The program's software codes have been designed and validated by the publisher prior to release.
 - Updates to these codes may be pushed out by the software developer.
- User created files modifying the program to work as the user needs must be validated by the user who developed the file prior to implementation.
 - Example: Calibration data worksheets developed using Excel must be validated to ensure that the design meets requirements and that formulas entered in the worksheet work as intended.
- When a software publisher updates the software version, the user should verify that updates to the software have not introduced errors into pre-existing software files.

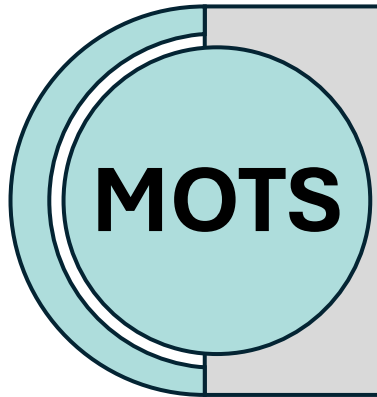
Additional Types of Software



Government-off-the-Shelf

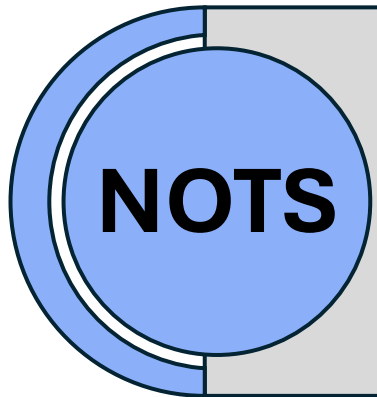
Software developed by a government agency or developed by a third party with funding by the agency.

***Not commercially available to the public.**



Modified-off-the-Shelf

COTS products that include accessible source code, allowing users to customize the software code to meet specified needs. This allows the users the ability to customize software beyond basic COTS solutions, without needing to build the code from scratch.



Niche-off-the-Shelf

Software developed to meet the needs of a specific industry, such as manufacturing, engineering, aviation, or medical.

Software Failures



What are the impacts of software failures

Inaccurate results

Recall of customer items

Financial loss

Noncompliance to industry standards

Software Failures

- Failures in software can lead to inaccurate results reported to the customer;
- Customer items may need to be recalled to resolve errors reported by the lab, and could impact consumer confidence with the lab and could lead to potential loss of business;
- Failures are a non-compliance to industry standard that must be addressed through documented corrective actions;
- Calibration work to be conducted using the designated software will need to be halted until the failures are resolved.

NASA's Mars Climate Orbiter

A \$327.6 Million Conversion Error

- In 1999, NASA launched the Mars Climate Orbiter (MCO) to Mars, losing contact with the spacecraft during final approach.
- The cause of the error was due to NASA systems using metric SI units, while ground software provided by Lockheed Martin used US customary units.
- This resulted in the orbiter entering Mar's atmosphere at a lower than intended orbit, causing the orbiter to burn up in Mar's atmosphere.
- Improper verification and validation of all systems on the orbiter did not catch the conversion errors in the software system prior to launch or during its transit to Mars.





Equifax Data Breach

A failure in software updates

- In 2017, vulnerabilities in Equifax software allowed hackers to access sensitive information of an estimated 147 million individuals.
- Investigations revealed that Equifax was aware of the software vulnerabilities prior to the incident but had not properly implemented software patches to address these vulnerabilities.
- The data breach cost the company \$700 Million in fines and settlements.

Vulnerabilities impacting software should be addressed immediately.



Excel: 15 Significant Digit Limit

C8			
fx			
A	B	C	D
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			

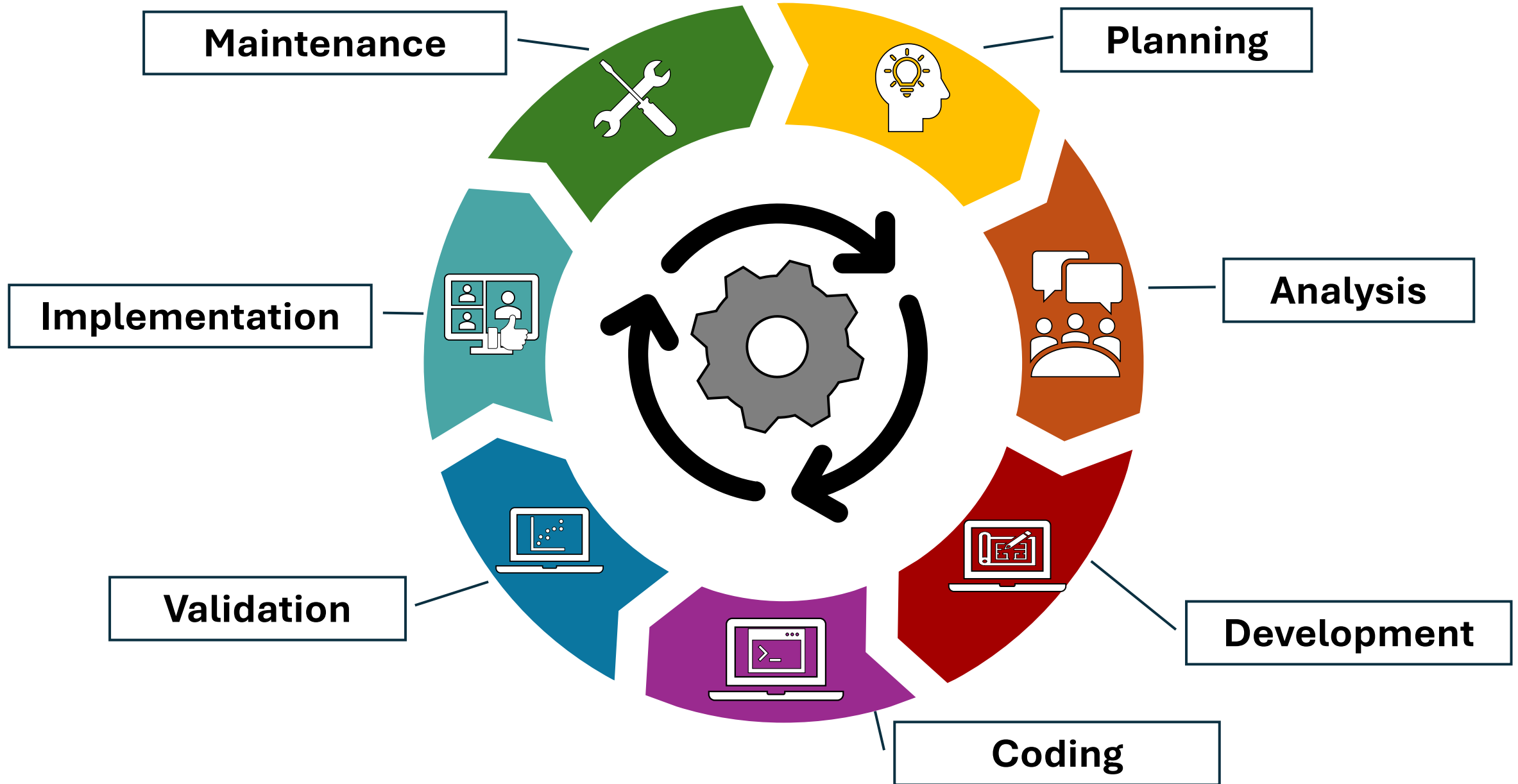
$\pi =$
 $\frac{3.1415926535}{8979323846}$
 $\frac{2643383279}{50288419716}$
 $\frac{939937510}{}$

$\pi =$	3.14159265358979000000
---------	------------------------

- Excel has a limitation on storage of numbers to 15 significant digits.
 - Exceeding this limit, additional number are truncated with a zero replacement.
- This limit can cause calculation errors, giving inconsistent results.
- Errors can be minimized using:
 - rounding functions (=ROUND; =ROUNDUP), or
 - breaking formulas down into separate steps to minimize accumulation of calculation errors.

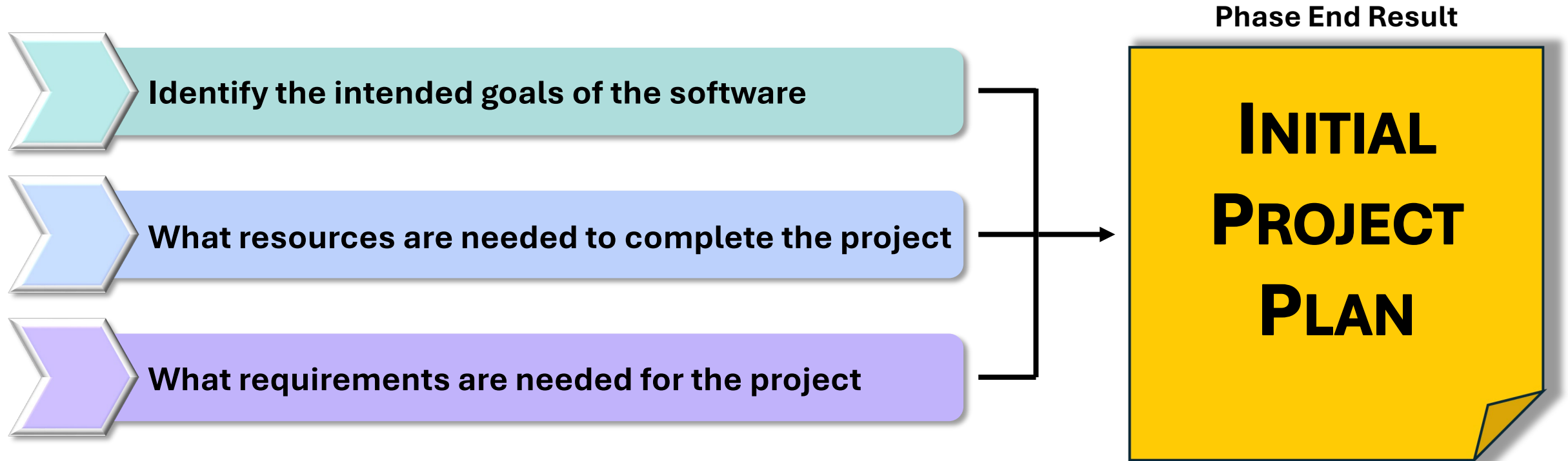
I	J	K
	Result	
1/1000	0.0010000000000000000000	
1 + 1/1000	1.0010000000000000000000	
(1 + 1/1000) - 1	0.0009999999999999890000	

Software Lifecycle





Planning



Software needs will vary based on the intended use.

Ex. A program developed to provide calculations for SOP 4 mass calibrations will have different requirements and goals from a program developed for SOP 19 volume calibrations.



Analysis

Evaluate the goals and requirements

- Are they achievable?
- Identify unrealistic goals.
- Are there available programs to develop the software?
- What are the financial needs to complete the project?

Complete a risk assessment on the project

- Does existing software have bugs/issues that should be addressed?
- Will the new software improve upon existing software?
- What potential risks or challenges could impact software development?
- Is the project worth pursuing?

Phase End Result

**PROJECT
APPROVAL**



Development

Begin design of the software program

- Create the blueprint for how the program will be laid out for use.
- Where will data need to be entered into the program?
- What data will the user be responsible for entering?

Data requirements

- What information will need to be prepopulated into the software for it to function correctly? (i.e., reference tables; standards data)

Phase End Result

**SOFTWARE
BLUEPRINT**



Development

Spreadsheets should:

- Be clear and make sense;
- Must provide instructions for use;
- If multiple tabs are present, each tab should be labeled to properly identify the purpose of the tab;
- The correct procedure should be used and must be specified;
- Formulas and methods related to the specified procedure should be referenced;

SOP 5 - 3-1 Weighing Design NISTIR 5672 (2019 Version)									
SC Test Number:		WO#:		Customer Name:					
Date:				Kit Manufacturer:					
Observer:				Serial Number:					
Page #:				Weight Class:					
Nominal:				Air Density:		#DIV/0!	g/cm ³		
Density:	#N/A	g		Humidity (% RH):	Start	End	Average		
Weight ID:		g/cm ³		BP (mmHg):			#DIV/0!		
Balance:				Temp (°C):			#DIV/0!		
Standards Information									
Standard(s)	(g)	Check Standard(s)	(g)	Sens. Wt:			0.000000		
S1:	0.000000	S _c 1:	0.000000	ck std SD (s _p):			mg		
S2:	0.000000	S _c 2:	0.000000				mg		
S3:	0.000000	S _c 3:	0.000000	pooled s _w :			mg		
S4:	0.000000	S _c 4:	0.000000	df:					
S5:	0.000000	S _c 5:	0.000000	Measurand:					
S6:	0.000000	S _c 6:	0.000000	Tare Weights					
S7:	0.000000	S _c 7:	0.000000	t _s :			0.000000		
S8:	0.000000	S _c 8:	0.000000	t _x :			0.000000		
S9:	0.000000	S _c 9:	0.000000	t _{s(x)} :			0.000000		
S10:	0.000000	S _c 10:	0.000000						
Standards Updated 4/9/2026									
S - X = a ₁			S - S _c = a ₂			X - S _c = a ₃			
S			S			X			
X			S _c			S _c			
X+sw			S _c +sw			S _c +sw			
S+sw			S+sw			X+sw			
Revisions Log Standards Instructions SOP 5 TolTab +									



Development

Spreadsheets should:

- Files should open to blank data entry cells;
- Data entry fields and calculations should be properly labeled;
- Data entry fields should be color coded, avoiding the use of conditional formatting colors (such as red and green);

In the provided example, different shading is used to indicate cells crucial for calculations (defaults to the yellow once filled)

SOP 5 - 3-1 Weighing Design
NISTIR 5672 (2019 Version)

SC Test Number:		WO#:		Customer Name:	
Date:				Kit Manufacturer:	
Observer:				Serial Number:	
Page #:				Weight Class:	
Nominal:				Air Density:	#DIV/0! g/cm ³
Density:	#N/A g			Humidity (% RH):	Start End Average
Weight ID:	g/cm ³			BP (mmHg):	#DIV/0!
Balance:				Temp (°C):	#DIV/0!

Standards Information			
Standard(s)	(g)	Check Standard(s)	(g)
S1:	0.000000	S _c 1:	0.000000
S2:	0.000000	S _c 2:	0.000000
S3:	0.000000	S _c 3:	0.000000
S4:	0.000000	S _c 4:	0.000000
S5:	0.000000	S _c 5:	0.000000
S6:	0.000000	S _c 6:	0.000000
S7:	0.000000	S _c 7:	0.000000
S8:	0.000000	S _c 8:	0.000000
S9:	0.000000	S _c 9:	0.000000
S10:	0.000000	S _c 10:	0.000000

Standards Updated 4/9/2026

Sens. Wt:	0.000000
ck std SD (s _p):	mg
pooled s _w :	mg
df:	
Measurand:	
Tare Weights	
t _s :	0.000000
t _x :	0.000000
t _{s(x)} :	0.000000

S - X = a ₁	S - S _c = a ₂	X - S _c = a ₃
S	S	X
X	S _c	S _c
X+sw	S _c +sw	S _c +sw
S+sw	S+sw	X+sw

Revisions Log Standards Instructions SOP 5 TolTab +



Development

Spreadsheets should:

- Results are apparent and labeled;
- Embedded data (i.e. reference values, look-up tables) should be dated to ensure the most current values are being used;

Embedded Data

Standard(s)		(g)	Standards Information	
			Check Standard(s)	(g)
S1:		0.000000	S _c 1:	0.000000
S2:		0.000000	S _c 2:	0.000000
S3:		0.000000	S _c 3:	0.000000
S4:		0.000000	S _c 4:	0.000000
S5:		0.000000	S _c 5:	0.000000
S6:		0.000000	S _c 6:	0.000000
S7:		0.000000	S _c 7:	0.000000
S8:		0.000000	S _c 8:	0.000000
S9:		0.000000	S _c 9:	0.000000
S10:		0.000000	S _c 10:	0.000000
Standards Updated 4/9/2026				

Calculation Results

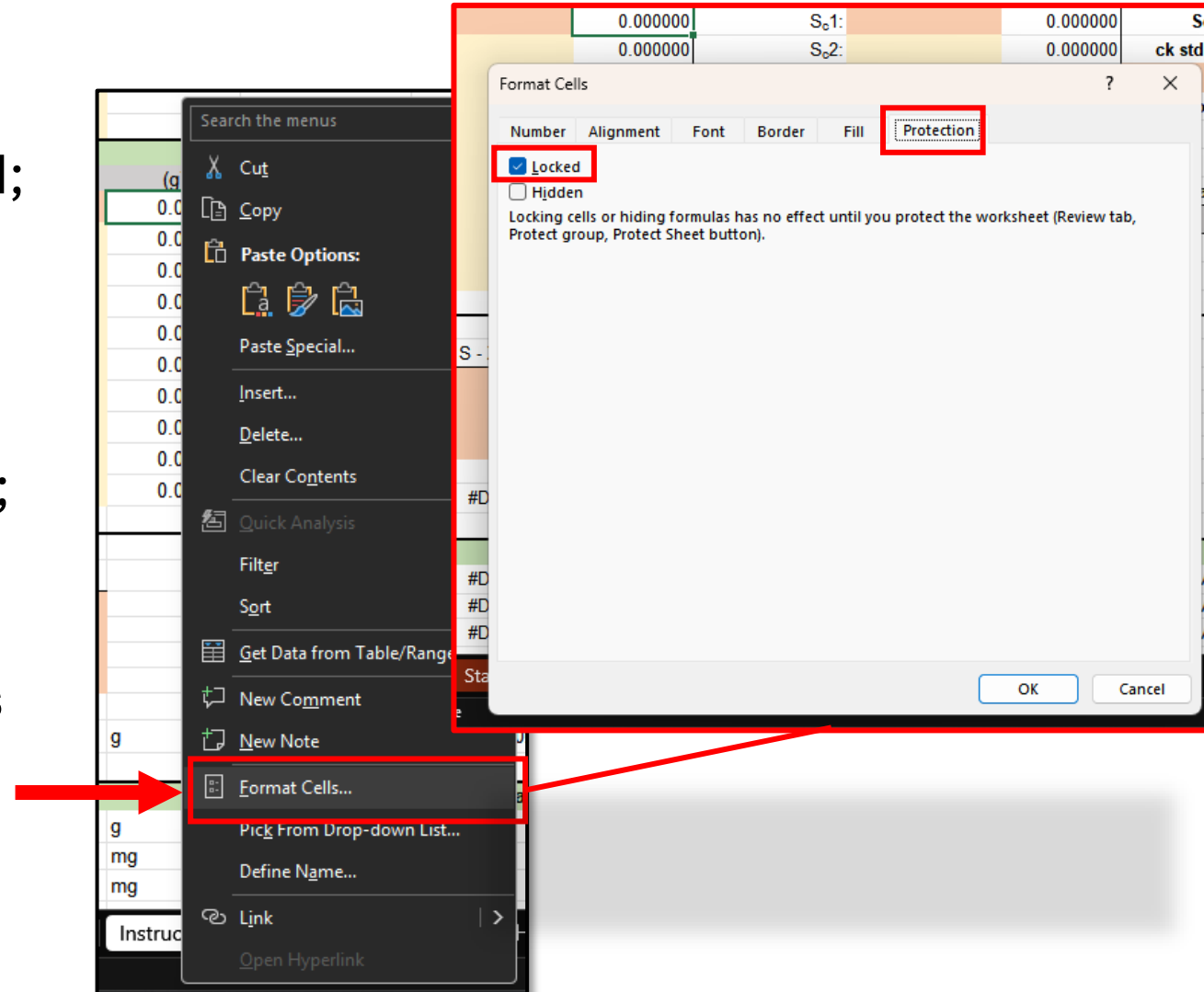
Unknown (X) Calibrated Values							
CM _X =	#DIV/0!	g			TM _X =	#DIV/0!	g
	#DIV/0!	mg				#DIV/0!	mg
CM _{corr(X)} =	#DIV/0!	mg			TM _{corr(X)} =	#DIV/0!	mg
Uncertainty =	#N/A	mg			Tolerance =	#N/A	mg
					Unc + CM _{corr} =	#DIV/0!	mg
						#DIV/0!	#N/A
				Tol Source:			
Check Standard (S _c) Statistical Values							
			t-test		F-test		
0	0.000000	mg	t _{calculated} =	#DIV/0!	s _w =	#DIV/0!	mg
Cal CM _{corr(S_c)} =	#DIV/0!	mg	t _{limit2} =	2	F _{calculated} =	#DIV/0!	
			t _{limit3} =	3	F _{limit} =	#NUM!	
Pooled s _w :	0.000000	mg					
			#DIV/0!		#DIV/0!		
To Report on Calibration Certificate (2 significant digits) :							
Weight ID:	Nominal:	CM _{corr}		Uncertainty (mg)	Tolerance (mg)	Density (g/cm ³)	Pass/Fail
	0	#DIV/0!		#N/A	#N/A	0.00	#DIV/0!
							Air Density (g/cm ³)
							#DIV/0!



Development

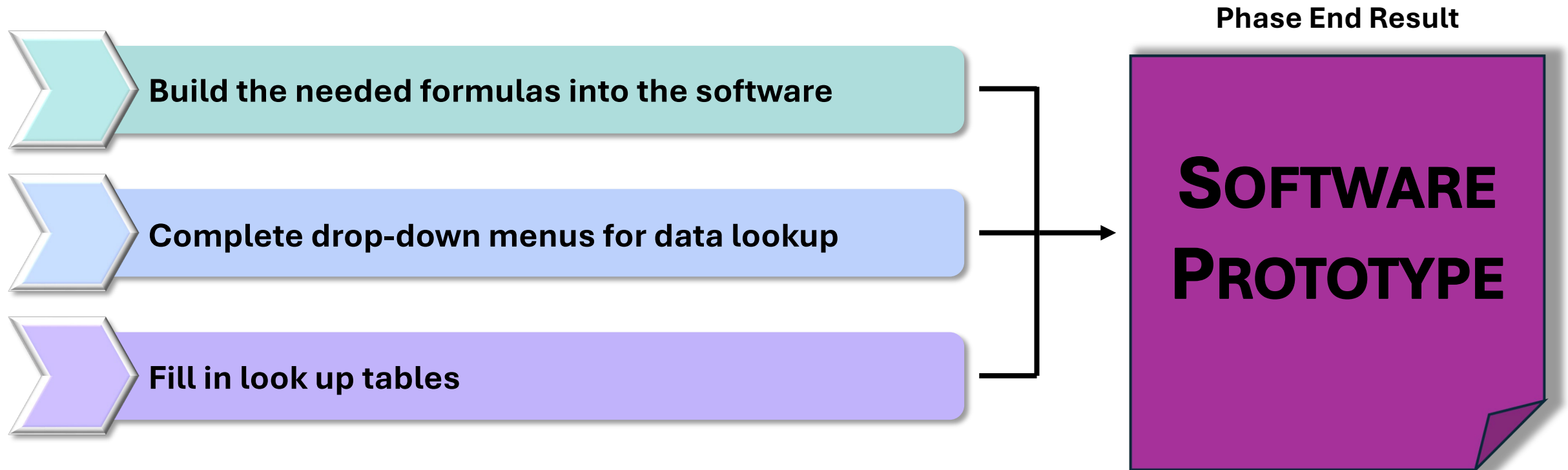
Spreadsheets should:

- If used, graphs must be properly labeled;
- Worksheets should be locked from editing before release.
 - Worksheet passwords should not be shared with unauthorized personnel;
 - All non-data entry fields should be set as locked when protected to prevent the unintentional alterations of calculations.





Coding



The Development and Coding phases may occur together as the software is being developed.



Coding

- Calculations that repeat should reference the correct cells;
- Calculations should provide accurate results;
- If rounding is done, it should be done at the appropriate locations in the file;

	B	C	D	E	F	
28	Bal SD:		mg			
29				Run 1		
30						
31	(S) O1:		=IF(ISBLANK(\$H\$25),"", \$H\$25			
32	(X) O2:		=IF(ISBLANK(\$H\$25),"", \$H\$25			
33	(X+sw) O3:		=IF(ISBLANK(\$H\$25),"", \$H\$25			
34	(S+sw) O4:		=IF(ISBLANK(\$H\$25),"", \$H\$25			
35						
36	TM =	=F36*1000	mg		=C105	g
37	TM Corr =	=F37*1000	mg		=F36-C10	g
38	CM =	=F38*1000	mg		=C106	g
39	CM Corr =	=F39*1000	mg		=F38-C10	g
40	Uncertainty =	=F40*1000	mg		=M49	g
41						
42				Run 2		
43						
44	(S) O1:		=IF(ISBLANK(\$H\$25),"", \$H\$25			
45	(X) O2:		=IF(ISBLANK(\$H\$25),"", \$H\$25			
46	(X+sw) O3:		=IF(ISBLANK(\$H\$25),"", \$H\$25			
47	(S+sw) O4:		=IF(ISBLANK(\$H\$25),"", \$H\$25			
48						
49	TM =	=F49*1000	mg		=F105	g
50	TM Corr =	=F50*1000	mg		=F49-C10	g
51	CM =	=F51*1000	mg		=F106	g
52	CM Corr =	=F52*1000	mg		=F51-C10	g
53	Uncertainty =	=F53*1000	mg		=M49	g
54						
55				Average		
56						
57	TM =	=AVERAGE(C36,C49)	mg		=AVERAGE(F36,F49)	g
58	TM Corr =	=AVERAGE(C37,C50)	mg		=AVERAGE(F37,F50)	g
59	CM =	=AVERAGE(C38,C51)	mg		=AVERAGE(F38,F51)	g
60	CM Corr =	=AVERAGE(C39,C52)	mg		=AVERAGE(F39,F52)	g
61	Uncertainty =	=F61*1000	mg		=M49	g

< >

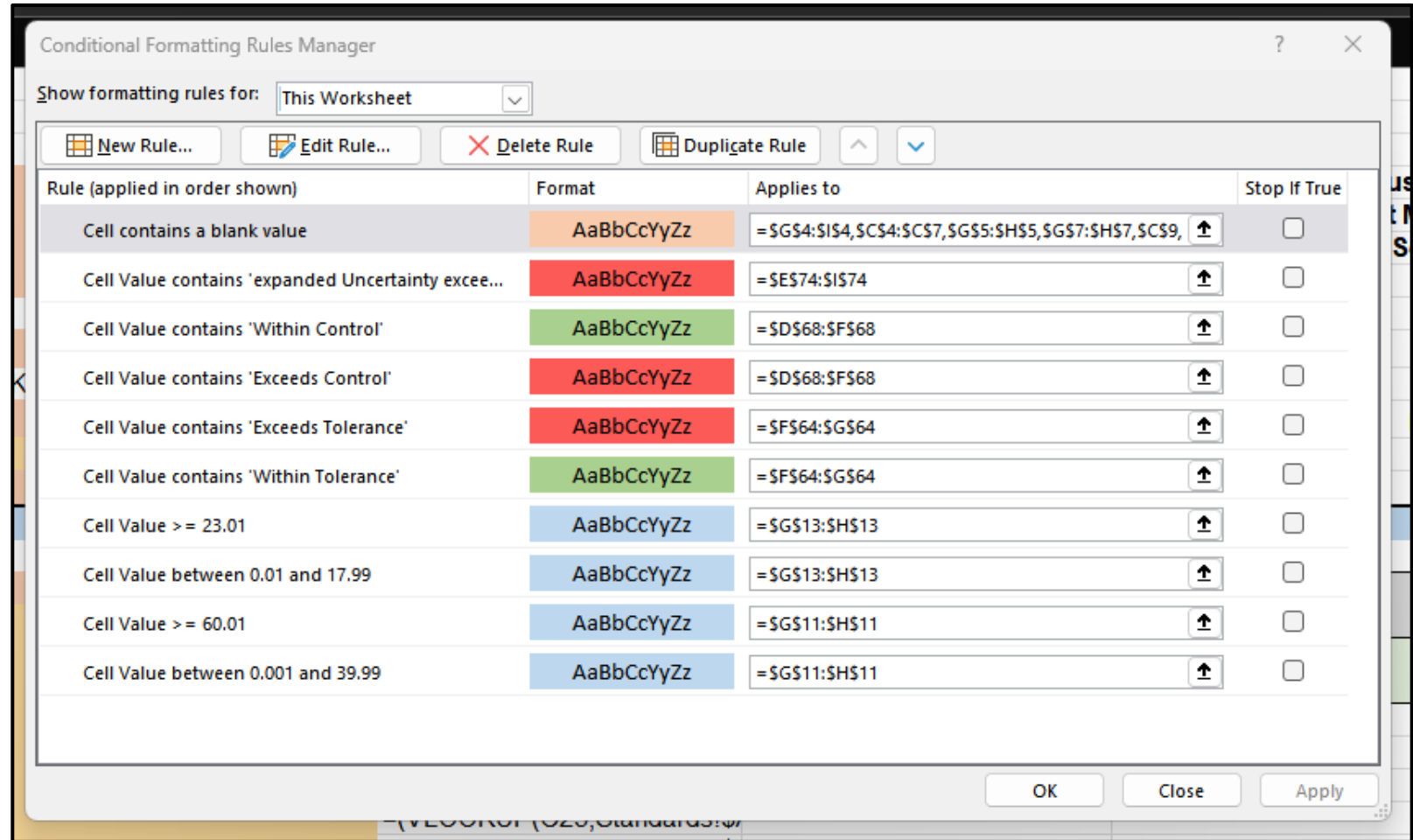
Revisions Log Standards Instructions SOP 4 - Customer SOP 4 - Lab Standards

+



Coding

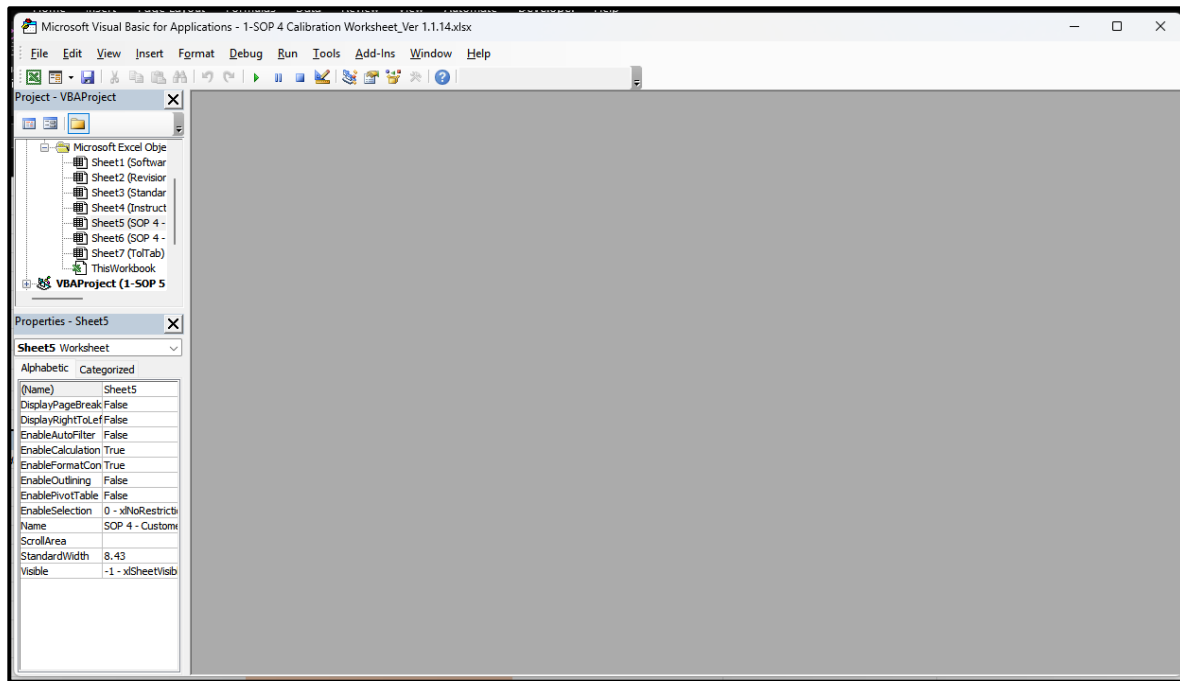
- Conditional logic cells should work as intended;
- Conditional logic cells should withstand boundary tests;



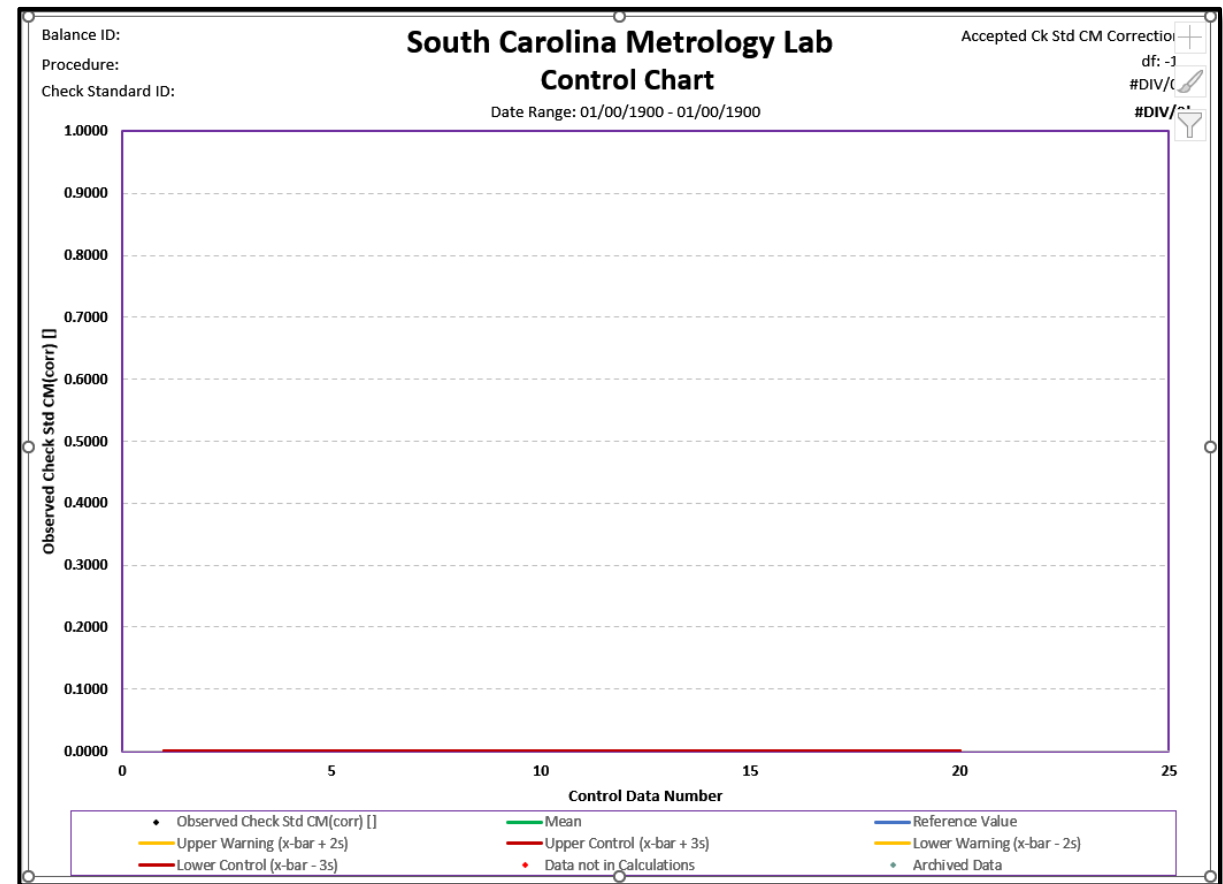


Coding

If used, macros should be functional, and work as intended



Plotted graphs should be accurate





Coding



Complex Formulas

Long, complex formulas can be more error-prone. Break long formulas into smaller parts to improve simplicity and make errors easier to track.

$$\rho_a = \frac{pM_a}{ZRT} \left(1 - x_v \left(1 - \frac{M_v}{M_a} \right) \right)$$

$$x_v = \left(\frac{h}{100} \right) f \frac{p_{sv}}{p}$$

$$Z = 1 - \frac{p}{T} \left[a_0 + a_1 t + a_2 t^2 + (b_0 + b_1 t) x_v + (c_0 + c_1 t) x_v^2 \right] + \frac{p^2}{T^2} (d + e x_v^2)$$

```
=(((M5*101325/760)*0.02896546)/((1-(((M5*101325/760)/(M4+273.15))*(0.00000158123+(-0.00000029331*M4)+(0.0000000011043*M4^2)+((0.000005707+(-0.0000002051*M4))*M6/100*((1.00062+0.0000000314*(M5*101325/760)+0.00000056*M4^2)*(EXP(0.000012378847*(M4+273.15)^2+(-0.019121316*(M4+273.15))+33.93711047+(-6343.1645/(M4+273.15)))/(M5*101325/760)))))+(0.00019898+(-0.000002376*M4))*M6/100*((1.00062+0.0000000314*(M5*101325/760)+0.00000056*M4^2)*(EXP(0.000012378847*(M4+273.15)^2+(-0.019121316*(M4+273.15))+33.93711047+(-6343.1645/(M4+273.15)))/(M5*101325/760))))^2))+((M5*101325/760)^2/((M4+273.15)^2)*(0.0000000000183+(-0.00000000765*(M6/100*((1.00062+0.0000000314*(M5*101325/760)+0.00000056*M4^2)*(EXP(0.000012378847*(M4+273.15)^2+(-0.019121316*(M4+273.15))+33.93711047+(-6343.1645/(M4+273.15)))/(M5*101325/760))))^2))))*(8.314472*(M4+273.15))))*(1-(0.378042616965172*(M6/100*((1.00062+0.0000000314*(M5*101325/760)+0.00000056*M4^2)*(EXP(0.000012378847*(M4+273.15)^2+(-0.019121316*(M4+273.15))+33.93711047+(-6343.1645/(M4+273.15)))/(M5*101325/760)))))))/1000
```



$\rho_a =$	0.001196638 g/cm ³
$x_v =$	0.012574461
$p_{sv} =$	2586.062780974
$f =$	1.004075389
$Z =$	0.999626675

$$=(((C159*C157)/(G156*C161*C160))*(1-(G153*(1-(C158/C157)))))/1000$$

$$=(C162/100)*G155*(G154/C159)$$

$$=(1*(EXP((C164*(C160^2)))+(C165*C160)+C166+(C167/C160))))$$

$$=1.00062+((3.14*10^{-8})*C159)+((5.6*10^{-7})*C163^2)$$

$$=1-((C159/C160)*(C168+(C169*C163)+(C170*C163^2)+((C171+(C172*C163))*G153)+((C173+(C174*C163))*G153^2))+((C159^2/C160^2)*(C175+(C176*G153^2))))$$



Coding



VLOOKUP vs. XLOOKUP

Data Lookup Functions

VLOOKUP

$\rho_{S1} =$

`=VLOOKUP(C16,Standards!$A$4:$M$277,6,)`

S1: 100 gc

$\rho_{S1} =$ 7.95 g/cm³

The VLOOKUP function allows the user to search for a value from the first column and return a value from the designated column number.

VLOOKUP only works right of the first column, and the entirety of the range (including unused columns) must be included in the range formula.

Set C	CM (mg)	TM (mg)	Unc'ty (mg) k=2	Volume (cm ³)	Density (g/cm ³)	Nominal (g)	Last Calibrated	Traceable to NIST Number:	Air Density g/cm ³	Cycle	Calibration Due	SOP
100 GC	0.081434	0.175788	0.037445	12.578638	7.95	100	09/03/25	684/O-0000040074-22	0.0011924	2	9/3/2027	5
50 GC	0.010808	0.057985	0.023132	6.289315	7.95	50	09/03/25	684/O-0000040074-22	0.0011925	2	9/3/2027	5
30 GC	0.029639	0.057945	0.016972	3.773592	7.95	30	09/03/25	684/O-0000040074-22	0.0011912	2	9/3/2027	5
20 GC	0.010944	0.029815	0.009086	2.515727	7.95	20	09/03/25	684/O-0000040074-22	0.0011892	2	9/3/2027	5
10 GC	0.005645	0.015080	0.011057	1.257864	7.95	10	09/03/25	684/O-0000040074-22	0.0011880	2	9/3/2027	5
5 GC	0.019657	0.024375	0.008773	0.628934	7.95	5	09/03/25	684/O-0000040074-22	0.0011877	2	9/3/2027	5
3 GC	0.006443	0.009274	0.003163	0.377360	7.95	3	09/03/25	684/O-0000040074-22	0.0011892	2	9/3/2027	5
2 GC	0.016183	0.018070	0.004113	0.251575	7.95	2	09/03/25	684/O-0000040074-22	0.0011909	2	9/3/2027	5
1 GC	0.015876	0.016820	0.003315	0.125788	7.95	1	09/03/25	684/O-0000040074-22	0.0011920	2	9/3/2027	5
500 MGC	-0.000219	0.000253	0.001691	0.062893	7.95	0.5	09/03/25	684/O-0000040074-22	0.0011860	2	9/3/2027	5
300 MGC	0.000238	0.000521	0.001964	0.037736	7.95	0.3	09/03/25	684/O-0000040074-22	0.0011875	2	9/3/2027	5
200 MGC	-0.007640	-0.007451	0.001617	0.025156	7.95	0.2	09/03/25	684/O-0000040074-22	0.0011855	2	9/3/2027	5
100 MGC	0.003020	0.003115	0.001358	0.012579	7.95	0.1	09/03/25	684/O-0000040074-22	0.0011854	2	9/3/2027	5
50 MGC	0.006285	0.006332	0.001217	0.006290	7.95	0.05	09/03/25	684/O-0000040074-22	0.0011852	2	9/3/2027	5
30 MGC	0.001036	0.001064	0.001245	0.003774	7.95	0.03	09/03/25	684/O-0000040074-22	0.0011836	2	9/3/2027	5
20 MGC	0.003211	0.003230	0.001103	0.002516	7.95	0.02	09/03/25	684/O-0000040074-22	0.0011824	2	9/3/2027	5
10 MGC	-0.000960	-0.000950	0.001365	0.001258	7.95	0.01	09/03/25	684/O-0000040074-22	0.0011815	2	9/3/2027	5
5 MGC	0.004914	0.004918	0.001469	0.000630	7.95	0.005	09/03/25	684/O-0000040074-22	0.0011850	2	9/3/2027	5
3 MGC	0.004616	0.004619	0.001269	0.000378	7.95	0.003	09/03/25	684/O-0000040074-22	0.0011861	2	9/3/2027	5
2 MGC	0.002234	0.002235	0.001299	0.000252	7.95	0.002	09/03/25	684/O-0000040074-22	0.0011861	2	9/3/2027	5
1 MGC	0.005534	0.005535	0.001217	0.000126	7.95	0.001	09/03/25	684/O-0000040074-22	0.0011848	2	9/3/2027	5



Coding



VLOOKUP vs. XLOOKUP

Data Lookup Functions

XLOOKUP

P_{S1} = `=XLOOKUP(C16,Standards!$A$5:$A$277,Standards!$F$5:$F$277)`

S1: 100 gc

P_{S1} = 7.95 g/cm³

Set C	CM (mg)	TM (mg)	Uncty (mg) k=2	Volume (cm ³)	Density (g/cm ³)	Nominal (g)	Last Calibrated	Traceable to NIST Number:	Air Density g/cm ³	Cycle	Calibration Due	SOP
100 GC	0.081434	0.175788	0.037445	12.57863	7.95	100	09/03/25	684/O-0000040074-22	0.0011924	2	9/3/2027	5
50 GC	0.010808	0.057985	0.023132	6.28931	7.95	50	09/03/25	684/O-0000040074-22	0.0011925	2	9/3/2027	5
30 GC	0.029639	0.057945	0.016972	3.77359	7.95	30	09/03/25	684/O-0000040074-22	0.0011912	2	9/3/2027	5
20 GC	0.010944	0.029815	0.009086	2.51572	7.95	20	09/03/25	684/O-0000040074-22	0.0011892	2	9/3/2027	5
10 GC	0.005645	0.015080	0.011057	1.25786	7.95	10	09/03/25	684/O-0000040074-22	0.0011880	2	9/3/2027	5
5 GC	0.019657	0.024375	0.008773	0.62893	7.95	5	09/03/25	684/O-0000040074-22	0.0011877	2	9/3/2027	5
3 GC	0.006443	0.009274	0.003163	0.37736	7.95	3	09/03/25	684/O-0000040074-22	0.0011892	2	9/3/2027	5
2 GC	0.016183	0.018070	0.004113	0.25157	7.95	2	09/03/25	684/O-0000040074-22	0.0011909	2	9/3/2027	5
1 GC	0.015876	0.016820	0.003315	0.12578	7.95	1	09/03/25	684/O-0000040074-22	0.0011920	2	9/3/2027	5
500 MGC	-0.000219	0.000253	0.001691	0.06289	7.95	0.5	09/03/25	684/O-0000040074-22	0.0011860	2	9/3/2027	5
300 MGC	0.000238	0.000521	0.001964	0.03773	7.95	0.3	09/03/25	684/O-0000040074-22	0.0011875	2	9/3/2027	5
200 MGC	-0.007640	-0.007451	0.001617	0.02515	7.95	0.2	09/03/25	684/O-0000040074-22	0.0011855	2	9/3/2027	5
100 MGC	0.003020	0.003115	0.001358	0.01257	7.95	0.1	09/03/25	684/O-0000040074-22	0.0011854	2	9/3/2027	5
50 MGC	0.006285	0.006332	0.001217	0.00629	7.95	0.05	09/03/25	684/O-0000040074-22	0.0011852	2	9/3/2027	5
30 MGC	0.001036	0.001064	0.001245	0.00377	7.95	0.03	09/03/25	684/O-0000040074-22	0.0011836	2	9/3/2027	5
20 MGC	0.003211	0.003230	0.001103	0.00251	7.95	0.02	09/03/25	684/O-0000040074-22	0.0011824	2	9/3/2027	5
10 MGC	-0.000960	-0.000950	0.001365	0.00125	7.95	0.01	09/03/25	684/O-0000040074-22	0.0011815	2	9/3/2027	5
5 MGC	0.004914	0.004918	0.001469	0.00063	7.95	0.005	09/03/25	684/O-0000040074-22	0.0011850	2	9/3/2027	5
3 MGC	0.004616	0.004619	0.001269	0.00037	7.95	0.003	09/03/25	684/O-0000040074-22	0.0011861	2	9/3/2027	5
2 MGC	0.002234	0.002235	0.001299	0.00025	7.95	0.002	09/03/25	684/O-0000040074-22	0.0011861	2	9/3/2027	5
1 MGC	0.005534	0.005535	0.001217	0.00012	7.95	0.001	09/03/25	684/O-0000040074-22	0.0011848	2	9/3/2027	5

The XLOOKUP function is an improved search function that works in any direction, making it more flexible than the VLOOKUP function.

Instead of highlighting the whole table as part of the range, only the needed columns are included in the function.



Coding



Negative Exponents

C.6.3.6 The variance of the air density is:

$$u^2(\rho_a) = u_F^2 + \left(\frac{\partial \rho_a}{\partial p} u_p \right)^2 + \left(\frac{\partial \rho_a}{\partial t} u_t \right)^2 + \left(\frac{\partial \rho_a}{\partial hr} u_{hr} \right)^2 \quad (C.6.3-3)$$

At relative humidity of $hr = 0.5$ (50 %), a temperature of 20 °C and a pressure of 101 325 Pa, the following numerical values apply approximately:

u_F = [uncertainty of the formula used] (for CIPM formula: $u_F = 10^{-4} \rho_a$)

$$\frac{\partial \rho_a}{\partial p} = 10^{-5} \rho_a \text{ Pa}^{-1}$$

$$\frac{\partial \rho_a}{\partial t} = -3.4 \times 10^{-3} \text{ K}^{-1} \rho_a$$

$$\frac{\partial \rho_a}{\partial hr} = -10^{-2} \rho_a$$

where hr = relative humidity, as a fraction.

Negative Exponents define a negative power as the multiplicative inverse of the base raised to the positive, opposite of the power.

$$\text{Ex. } 10^{-5} = \frac{1}{10^5}$$

OIML R111-1 (2004); uncertainty of air density

$\frac{\partial \rho_a}{\partial t} = -3.4 \times 10^{-3} \text{ K}^{-1} \rho_a \rightarrow$ results in a value of (g/cm³)/°C, where $\rightarrow \left(\frac{\partial \rho_a}{\partial t} u_t \right)^2$ temperature units can now cancel each other out in this section of the equation



Validation

Test the software program to ensure that it operates as intended.

- **Stress test the software!**
 - Evaluate for expected passing performances, and
 - Evaluate for expected failing performances
- Find and correct any errors from development.

Evaluate calculations produced by the software

- Do calculations in the software match with hand calculations?
- Are results from the new software comparable with results from existing software?

Phase End Result

**OPTIMIZED
SOFTWARE**
[ready for use]



Validation

Calculated results between new spreadsheets and old spreadsheets should agree

Any reasoning as to why old and new spreadsheets do not match should be noted, and it should be determined if the new spreadsheet is improving on pre-existing software.

Look Up Table Updated 2/6/2024									
	S-X=a1			S-Sc=a2			X-Sc=a3		
S	0.0030		S	0.0010		X	0.0320		
X	0.0320		Sc	0.0180		Sc	0.0140		
X+sw	20.0270		Sc+sw	20.0100		Sc+sw	20.0100		
S+sw	19.9960		S+sw	19.9940		X+sw	20.0300		
S1:	100 gb		100.000099			Sc1:	100 gc		100.000118
S2:	0		0.000000			Sc2:	0		0.000000
S3:	0		0.000000			Sc3:	0		0.000000
S4:	0		0.000000			Sc4:	0		0.000000
SW:	20 mgsw		0.019992						
Bal SD:	0.013300 mg								
Bal S _p :	0.000000 mg								
CM =	100.000033 g				TM =	100.000339 g			
CM =	100000.032897 mg				TM =	100000.339066 mg			
(Corr) CM =	0.032897 mg				(Corr) TM =	0.339066 mg			
Uncty =	0.034475 mg				Unc+CM =	0.067372 mg			
							Within Tolerance		
							Tol =	0.250 mg	26.9%

OLD

Standards Information								
Standard(s)		(g)	Check Standard(s)		(g)			
S1:	100 gb	100.000099	S _c 1:	100 gc	100.000118	Sens. Wt:	20 mgsw	0.019992
S2:		0.000000	S _c 2:		0.000000	ck std SD (s _p):	0.0133	mg
S3:		0.000000	S _c 3:		0.000000	Mean S _c :	0.0404	mg
S4:		0.000000	S _c 4:		0.000000	df for s _p :	247	
S5:		0.000000	S _c 5:		0.000000	pooled s _w :	0.0041	mg
S6:		0.000000	S _c 6:		0.000000	df for s _w :	247	
S7:		0.000000	S _c 7:		0.000000	Measurand:	mg	
S8:		0.000000	S _c 8:		0.000000	Tare Weights		
S9:		0.000000	S _c 9:		0.000000	t _c :		0.000000
S10:		0.000000	S _c 10:		0.000000	t _c :		0.000000
						t _{S(c)} :		0.000000
S - X = a ₁			S - S _c = a ₂			X - S _c = a ₃		
S	0.0030	mg	S	0.0010	mg	X	0.0320	mg
X	0.0320	mg	S _c	0.0180	mg	S _c	0.0140	mg
X+sw	20.0270	mg	S _c +sw	20.0100	mg	S _c +sw	20.0100	mg
S+sw	19.9960	mg	S+sw	19.9940	mg	X+sw	20.0300	mg
a ₁ =	-2.99863E-05	g	a ₂ =	-1.64949E-05	g	a ₃ =	1.89903E-05	g
Unknown (X) Calibrated Values								
CM _X =	100.000033	g			TM _X =	100.000339	g	
	100000.032904	mg				100000.339074	mg	
CM _{corr(X)} =	0.032904	mg			TM _{corr(X)} =	0.339074	mg	
Uncertainty =	0.034686	mg			Tolerance =	0.250	mg	
					Unc + CM _{corr} =	0.067590	mg	
						Within Tolerance		27.04%
						ASTM E617-23		



Validation

- Volume delivered at 60°F: $V_{x60} = \frac{\rho_1 \{ (V_{s60} + \Delta_1) [1 + \alpha (t_1 - 60^\circ\text{F})] \}}{\rho_x [1 + \beta (t_x - 60^\circ\text{F})]}$ $S_{\text{water temp}} = 78.134^\circ\text{F}$

$X_{\text{water temp}} V_{x60}$
 $(25.56^\circ\text{C} \times \frac{9}{5}) + 32 = 78.008^\circ\text{F}$

$$\rho_1 \{ (V_{s60} + \Delta_1) [1 + \alpha (t_1 - 60^\circ\text{F})] \} = \frac{4.986474215}{4.981684007} \text{ g/cm}^3 \cdot \text{gal}$$

$$0.9968816164 \text{ g/cm}^3 \cdot \{ (4.99967 \text{ gal} + 0) \cdot [1 + 0.0000265/^\circ\text{F} (78.134^\circ\text{F} - 60^\circ\text{F})] \}$$

$$\rho_x [1 + \beta (t_x - 60^\circ\text{F})] = \frac{0.9973756946}{0.9964242294} \text{ g/cm}^3$$

$$0.996899962 \text{ g/cm}^3 \cdot [1 + 0.0000265/^\circ\text{F} (78.008^\circ\text{F} - 60^\circ\text{F})]$$

$$V_{x60} = \frac{4.981684007 \text{ g/cm}^3 \cdot \text{gal}}{0.9964242294 \text{ g/cm}^3}$$

$$V_{x60} = \frac{4.986474215 \text{ g/cm}^3 \cdot \text{gal}}{0.9973756946 \text{ g/cm}^3}$$

$$V_{x60} = 4.999561291 \text{ gal}$$

$$V_{x60} = 4.999594678 \text{ gal} \times 231$$

$$\downarrow$$

$$1154.906371 \text{ in}^3$$

- Prover Error:

$$\text{Prover Volume} = V_{x60} - \text{gauge reading}$$

$$\text{gauge reading} = 0.00 \text{ in}^3$$

$$\text{Prover Volume} = 1154.906371 \text{ in}^3 - 0.00 \text{ in}^3$$

$$\text{Prover Volume} = 1154.906371 \text{ in}^3$$

$$\text{Prover Error} = \text{Prover Volume} - V_{\text{nom}}$$

$$\text{Prover Error} = 1154.906371 \text{ in}^3 - 1155 \text{ in}^3$$

$$\text{Prover Error} = -0.093629 \text{ in}^3$$

Hand calculations should agree with results generated by the spreadsheet or are sufficiently small enough to not impact results.

Test Measure Data	
Run 2 Prover Reading:	0.00 in ³
X Water Temp:	25.56 (°C) 78.01 (°F)
Water Density:	0.996900 g/cm ³
Volume Delivered at 60 °F (V _{x60}):	<u>4.999594678 gal</u>
"As Found" Error:	<u>-0.093629 in³</u>
Uncertainty:	0.18 in ³
Error ± Uncertainty:	-0.27 in ³
Tolerance (0.05 %):	0.58 in ³
Adjustment not required	

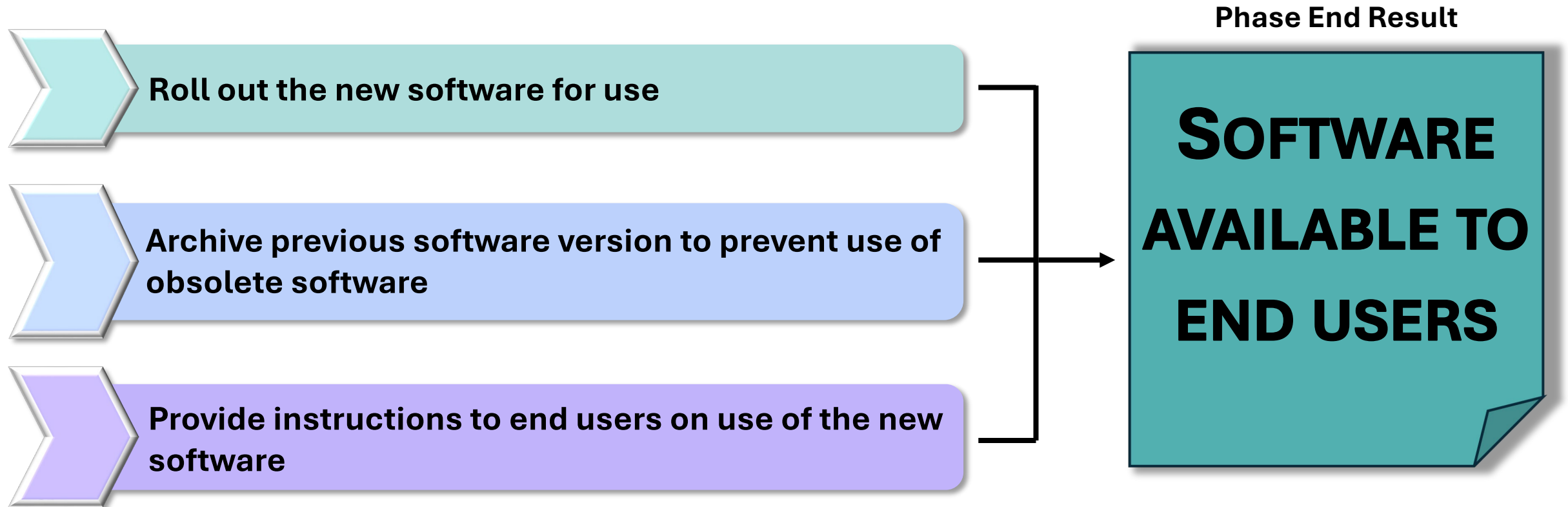


Evaluate for passing and failing values.

Unknown (X) Calibrated Values					
CM _X =	5.000418 g			TM _X =	5.000415 g
	5000.418 mg				5000.415 mg
CM _{corr(X)} =	0.417935 mg			TM _{corr(X)} =	0.415132 mg
Uncertainty =	0.028444 mg			Tolerance =	0.034 mg
				Unc + CM _{corr} =	0.446 mg
				Exceeds Tolerance	
				1312.88%	
			Tol Source:	ASTM E617-23	
Check Standard (S _c) Statistical Values					
Mean S _c :		0.040433 mg	t-test		F-test
Cal CM _{corr(S_c)} =	-0.254988 mg		t _{calculated} =	22.2043	S _w = 0.570739 mg
			t _{limit2} =	2	F _{calculated} = 19063.966367
			t _{limit3} =	3	F _{limit} = 3.88
Pooled s _w :	0.004134 mg		ACTION		FAIL



Implementation





- **Updates to the software;**
- **Review of the software to ensure errors haven't been introduced into the program;**
- **Updates to look up tables and reference values;**
- **Addition of new features or removal of old features**

[illegible]

Ensuring security of your software



- Ensure that all non-data entry cells are locked from editing, and keep the worksheets protected during use.
- When making updates to the software, save edits as a new revision file.
 - Archive previous revision files
- Don't share the worksheet passwords with unauthorized users.

References

- ISO/IEC 17025:2017, “General Requirements for the Competence of Testing and Calibration Laboratories”
- NIST Handbook 143-2023, “NIST Office of Weights and Measures (OWM) Recognition Program Handbook, 7th Edition”
- NIST GLP 15 [2019], “Good Laboratory Practice for Software Quality Assurance”