IMPORTANT NOTICE: The current official version of this document is available via the Sandia National Laboratories WIPP Online Documents web site. A printed copy of this document may not be the version currently in effect.

ACTIVITY/PROJECT SPECIFIC PROCEDURE

SP 12-15
CALIBRATION OF WATER QUALITY MEASUREMENT INSTRUMENTATION
Revision 2

Effective Date: March 29, 2017

Author:	Owen Lofton	*Original signed by Owen W. Lofton*	*3/29/2017*
	(printed name)	(signature)	(date)

1.0 Purpose and Scope

This document describes the Sandia National Laboratories (SNL) Waste Isolation Pilot Plant (WIPP) procedure for calibration of pH, conductivity and analytical water quality measurement instruments. Calibration and operation guidelines are included in the procedure. This SP is in support of activities described in several WIPP Test Plans (TPs). Both SNL and contractor personnel will use this SP.

Acronyms and definitions for terms used in this procedure may be found in the Glossary located at the Sandia National Laboratories (SNL) WIPP Online Documents web site.

2.0 Implementation Actions

Several different models and brands of water quality measurement instruments will be used for the experimental work in support of the WIPP-related studies. This document is not meant to substitute for the manufacturer instruction manuals for these instruments. The user is responsible for reading and understanding the appropriate manuals. Guidelines for implementing and documenting quality assurance (QA) procedures are presented in this document, and follow the general guidelines given in Nuclear Waste Management Procedure (NP) 12-1 “Control of Measuring and Test Equipment.”

2.1 Safety and Training

The activities described in this SP shall conform to SNL Environmental Health and Safety Programs (ES&H). All activities described in this SP are subject to ES&H requirements governed by the WIPP Industrial Safety Program and the WIPP Industrial Hygiene Program.

Disposal of the pH and conductivity solutions used during the performance of this procedure will adhere to the SNL/Carlsbad lab practices.

As defined in the SNL ES&H manual, personnel will not be exposed to hazardous voltages. The voltage levels expected in the performance of this procedure should be 24 VDC or less.

© 2017 Sandia Corporation

2.2 Responsibility

The Person in Charge (PIC), whose activities warrant the use of this procedure, is responsible for implementing the requirements of this procedure. The PIC is responsible for directing or performing the calibrations and measurements following the requirements of this procedure, documenting calibrations, and assuring that the latest revision of this document is followed. All calibrations performed in support of instruments that will be used on a WIPP testing program shall be documented in the applicable Scientific Notebook or Scientific Notebook Supplement. In this procedure the term 'record' or 'recorded' will imply that the results/information are documented in the applicable Scientific Notebook or Scientific Notebook Supplement.

2.3 Water Quality Measurement Instrument Selection

The PIC will ensure that the water quality measurement instruments are of the proper type, design, range, accuracy, and tolerance to accomplish their required function.

2.4 Identification

The water quality measurement instruments are identified by manufacturer, model number, and serial number, if applicable. When not supplied with a serial number, the instruments will each be assigned a permanent number that will be recorded when that instrument is used.

2.5 Instrument Preparation

Prior to calibration of any instrument, inspect the instrument for damage, wear or excess dirt. If the instrument is damaged or in disrepair, notify the PIC and implement corrective actions following their direction. Prior to the calibration of all instruments and following manufacturer's recommendations, clean the instrument and any sensor electrodes.

2.6 Calibration

2.6.1 Standards

Calibration will be performed using commercially obtained solutions that are traceable to NIST or other nationally recognized standards. The use of room air as a zero value conductance standard is a normal, acceptable, and manufacturer recommended practice for GLI Conductivity Instruments. The identity, manufacturer, lot number and expiration date of the standards used shall be recorded (N/A for room air). A calibration solution will not be used past its expiration date listed on the container by the manufacturer.

As a general guideline, the solution(s) to be used during a calibration should be close to or bracket the expected measurement ranges for that instrument. During Calibration Adjustments or As-Left Calibrations the upper value solution should match or exceed 50% of the full range of the instrument.

A minimum of one standard shall be used for calibration of water quality measurement instruments. The use of two or more standards is recommended when a wide range of measurement values may be encountered. The following table summarizes the recommendations for each type of instrument. The basis for this table is the manufacturers' recommendations combined with previous calibration history and experience with these instruments. These recommendations are subject to adjustment by the PIC.

Instrument / Calib. Type	GLI pH	YSI Model 60 pH	GLI Conductivity	YSI Conductivity
As-found / As-left Calib.	2	1	2	1
Calibration Adjustments	2	2	1	1

Table 1. Minimum Number of Standards Required During Calibrations

2.6.2 Temperature & Stability of Readings

During the calibration, the temperature of the area and solutions will be monitored and recorded. Prior to the start of the calibration, all solutions shall be given sufficient time to equilibrate to room temperature. The temperature of a solution will be measured and recorded.

When an instrument is placed into a calibration solution, rapid changes in values will be observed while the instrument acclimatizes (temperature equalization is a significant part of this process). This process cannot be rushed and requires sufficient time to allow completion (recommended times are specified within the procedure section for each instrument). Stable readings will indicate that full equalization of the solution and instrument has occurred. A change of less than 1% in subsequent readings demonstrates that stability has been achieved.

2.6.3 Frequency

The instrument will be calibrated prior to initial use in the collection of qualified data and on a frequency identified by the PIC and the manufacturer's recommendations. After being used in a testing activity for the collection of WIPP QA-type data, the instruments will undergo an As-Found calibration check to establish their accuracy.. If the user of the instrument observes any irregularities in the instrument, tag the instrument documenting the concern and return for immediate recalibration.

2.6.4 Acceptance Criteria

The water quality measurement instruments calibration results are acceptable when they meet or exceed (better than) the uncertainty specifications identified by the manufacturer or the PIC. The acceptance criteria used to approve or reject the calibration results will be listed in the applicable Scientific Notebook or supplement to the Scientific Notebook.

2.6.5 Troubleshooting

If the water quality measurement instrument cannot meet the acceptance criteria (see section above), the calibration solution should be replaced and a subsequent re-calibration attempted. If the instrument still does not meet the acceptance criteria, the instrument will be removed from service, labeled with an 'Out of Service' tag and returned for repair or removed from permanent service.

2.7 pH Meter Calibration As-Found or As-Left Check

For all pH measuring instruments that have been used to collect data in support of a WIPP program activity, perform an As-Found calibration check to determine the accuracy of the device prior to performing any adjustments. If the pH instrument has been adjusted, perform an As-Left calibration check to document the instrument's accuracy. The steps are the same whether it's an As-Found or As-Left calibration check.

2.7.1 For all As-Found or As-Left Calibrations, a minimum single point solution check shall be performed. Additional buffer solutions may also be incorporated into the check as directed by the PIC.

2.7.2 For all pH buffer solutions, following placement on the instrument probe, allow sufficient time for the instrument to equilibrate to the applied solution. The manufacturer recommends a 5-10 minute acclimation time for the YSI Model 60 instrument; the GLI instruments may require 60 minutes or more. Stable pH readings indicate that the pH instrument and solution have equilibrated.

2.7.3 Place the pH instrument being calibrated into the first and lowest value pH buffer solution. Once the value being measured by the pH instrument has stabilized, record the value of the buffer solution and the value displayed by the pH instrument.

2.7.4 Rinse the probe with deionized water and dry it with clean wipes and lab-grade compressed air or equivalent. If this is a single-point calibration, proceed to step 2.7.6, otherwise place the pH instrument into the next pH buffer solution. Once the value being measured by the pH instrument has stabilized, record the value of the buffer solution and the value displayed by the pH instrument.

2.7.5 Repeat step 2.7.4 for any additional pH buffer solutions being used for the applicable calibration.

2.7.6 For the pH instrument being calibrated, the results of the calibration check shall be compared against the expected uncertainty or accuracy requirement of the instrument.

2.7.7 If the calibration check is an As-Found calibration and the results do not fall within the expected uncertainty or accuracy requirements, a Corrective Action Request (CAR) will be issued to document the results and impacts related to the change in pH instrument's performance.

2.7.8 If the As-Found results are out of tolerance or if improved performance is desired, perform the complete calibration adjustment section related to the type instrument being calibrated.

2.7.9 If the calibration check was an As-Left calibration and the results are out of tolerance, repeat the applicable calibration adjustment section related to the type instrument being calibrated. Remove the instrument from service if the calibration adjustment has been performed more than two times, and the instrument still does not meet the expected uncertainty or accuracy requirements. Tag and label the pH instrument accordingly, and if practical, return it to the manufacturer for repair.

2.8 GLI pH Meter Calibration Adjustment

NOTE: An in-progress calibration can always be aborted by pressing the **ESC key**. After the "ABORT: YES?" screen appears, do one of the following:

1. Press **ENTER key** to abort. After the "CONFIRM ACTIVE?" screen appears,
2. Press **ENTER key** again to return the analog output to its active state
3. Use ⇑ **or** ⇓ **key** to choose "ABORT: NO?" screen, and press **ENTER key** to continue calibration.

NOTE: If at any time during calibration, the "2 POINT BUFFER: CONFIRM FAILURE?" screen appears, press **ENTER key** to confirm. Then, use the ⇑ **or** ⇓ **key** to select between "CAL: EXIT" or "CAL: REPEAT" and do one of the following: **ENTER key** to return the analog output to its active state. With the "2 POINT BUFFER? (CAL: REPEAT)" screen selected, press **ENTER key** to repeat calibration of this point.

2.8.1 Immerse the sensor in the first buffer (preferably pH 7). Important: Allow the sensor and buffer temperatures to equalize. Depending on their temperature differences, this may take 60 minutes or more. Stable pH readings indicate equalization of temperatures.

2.8.2 Press MENU key to display a "MAIN MENU" screen. If the screen is not showing, use the ⇑ or the ⇓ key to display it.

2.8.3 Press ENTER key to display CALIBRATE | SENSOR screen.
2.8.4 Press ENTER key again to display SENSOR | 2 POINT BUFFER screen.
2.8.5 Press ENTER key again to display 2 POINT BUFFER | IN 1st SOLUTION screen. With the sensor in the first buffer, press ENTER key again to confirm this.

NOTE: During calibration, the analog output is automatically "held" at the last measured value.

2.8.6 While the "2 POINT BUFFER: | PLEASE WAIT" screen is displayed, the transmitter waits for the pH and temperature signals to stabilize, measures the buffer value, and automatically calibrates this point. Thereafter, the "2 POINT BUFFER: | PT1=7.00 pH" screen appears for 5 seconds to confirm calibration of this point.

NOTE: Any time the "PLEASE WAIT" screen appears during calibration you can manually complete calibration of the point by pressing the ENTER key. However, this is not recommended because the pH and temperature signals may not be fully stabilized, resulting in a less accurate calibration.

2.8.7 After the screen appears, remove the sensor from the first buffer, rinse it with deionized water and dry it with clean wipes and lab-grade compressed air or equivalent, and immerse it in the second buffer (typically pH 10). Wait for a minimum of 60 minutes, then press ENTER key to confirm this.
2.8.8 While the screen is displayed, the transmitter waits for the pH and temperature signals to stabilize, measures the buffer value, and automatically calibrates this point. Thereafter, the "2 POINT BUFFER: | PT2=10.00 pH" screen appears for 5 seconds to confirm calibration of this point.
2.8.9 A "pH SLOPE XX.X mV/pH" screen appears, indicating a slope value to gauge sensor performance. The slope should be between 54 and 62 mV/pH for optimal sensor performance. Record this value. in the applicable Scientific Notebook or supplement to the Scientific Notebook.
2.8.10 Press ENTER key to end calibration ("2 POINT BUFFER: CONFIRM CAL OK?" screen appears).
2.8.11 This completes the two point buffer solution calibration adjustment. The transmitter is now ready for a pH As-Left calibration check; perform section 2.7 of the procedure.

2.9 YSI Model 60 pH meter

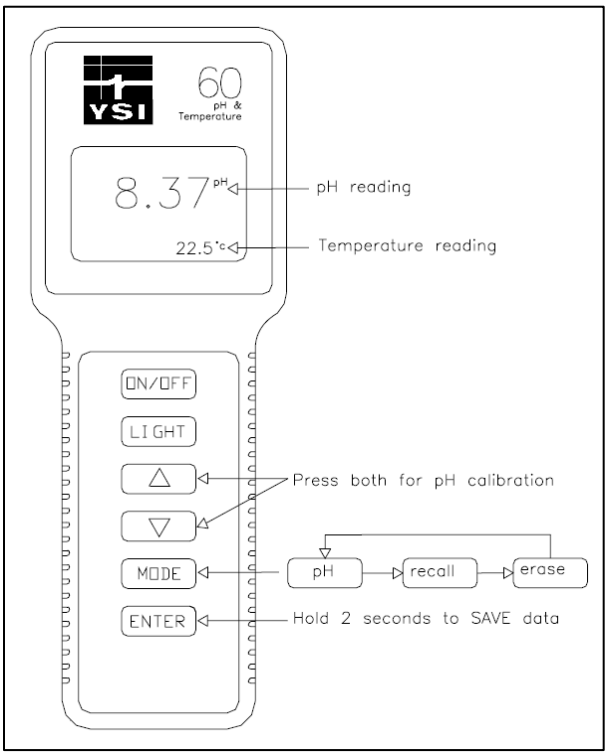

Figure 1

2.9.1 Turn the instrument on by pressing the **ON/OFF** key. If the instrument was already on, press the **MODE** key until pH is displayed.

2.9.2 Remove the pH meter probe from its 4 pH storage buffer, rinse the probe with deionized water, then carefully dry the probe.

2.9.3 Using a 100 mL graduated cylinder, place 30 to 35 mL of the 7 pH buffer solution in the cylinder and place the pH sensor in the buffer and allow a 10 minute dwell time to acclimate before calibrating. Be sure to immerse the probe so that both the pH and temperature sensors are covered by the solution (see Figure 2).

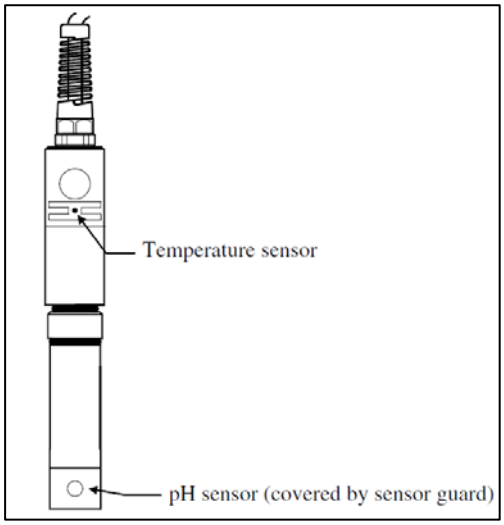

Figure 2

NOTE: Refer to Sec. 2.6.2 of this procedure for guidance on temperature and stability readings.

2.9.4 To enter the calibration menu, use two fingers to press and release both the **UP ARROW** and **DOWN ARROW** keys at the same time. As shown in Figure 3, the Model 60 display will show **CAL** at the bottom, **STAND** will be flashing and the main display will show **7.00** (the buffer to be used to adjust the offset).

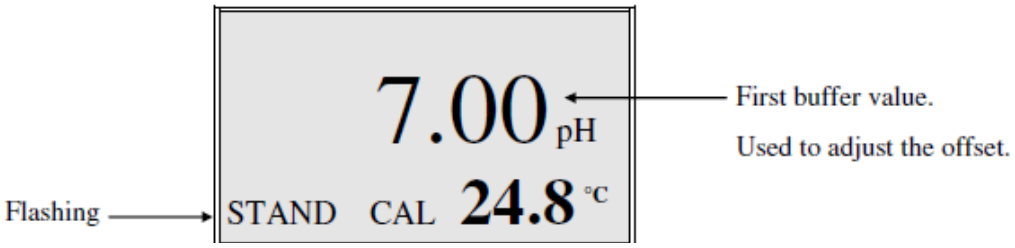

Figure 3

2.9.5 Press the **ENTER** key. The Model 60 display will show **CAL** at the bottom, **STAND** will stop flashing and the pH calibration value is shown with the middle decimal point flashing.

2.9.6 When the reading is stable (does not change by 0.01 pH in 10 seconds), the decimal point will stop flashing. Press and hold the **ENTER** key to save the calibration point. The Model 60 will flash **SAVE** on the display along with **OFS** to indicate that the offset value has been saved.

2.9.7 **SLOPE** will now appear on the display and be flashing. This indicates that the slope is ready to be set using a second pH buffer. The system is now calibrated at a single point. If only performing a single point calibration, stop here and press the **MODE** key to return to normal operation and proceed to step 2.9.17. If performing a 2-point (normal) or 3-point calibration, continue on to the next step.

2.9.8 Rinse/dry the probe with deionized water. If performing a 2-point or 3-point calibration, fill the 100 mL graduated cylinder with the next pH buffer and immerse the probe into the solution.

2.9.9 Press the **ENTER** key. The Model 60 display should now show **CAL** at the bottom, **SLOPE** will stop flashing and the pH calibration value (automatically sensed by the instrument) is shown with one of the decimal points flashing.

2.9.10 If the second pH buffer is less than the first buffer (which was used to adjust the offset; (pH 7), the left decimal point will flash. If the second pH buffer is greater than the first, the right decimal point will flash.

2.9.11 When the reading is stable (does not change by 0.01 pH in 10 seconds), the decimal point will stop flashing. Press and hold the **ENTER** key to save the first SLOPE. The Model 60 will flash **SAVE** on the display along with **SLP** to indicate that the first slope value has been saved.

2.9.12 **SLOPE** will start flashing again indicating that the slope is ready to be set using a third pH buffer. If this is a normal two point calibration, press the **MODE** key to return to normal operation and proceed to step 2.9.17. If a three point calibration is desired proceed to step 2.9.13.

2.9.13 If you are performing a 3-point calibration rinse/dry the probe with deionized water. Fill the 100 mL graduated cylinder with the next pH buffer and immerse the probe into the solution.

2.9.14 Press the **ENTER** key. The Model 60 display will now show **CAL** at the bottom, **SLOPE** will stop flashing and the pH calibration value (automatically sensed by the instrument) is shown with one of the decimal points flashing. If the third pH buffer is less than the first buffer (which was used to adjust the offset; usually 7 pH), the left decimal point will flash. If the third pH buffer is greater than the first, the right decimal point will flash.

2.9.15 When the reading is stable (does not change by 0.01 pH in 10 seconds), the decimal point will stop flashing. Press and hold the **ENTER** key to save the second **SLOPE**. The Model 60

will flash **SAVE** on the display along with **SLP** to indicate that the second slope value has been saved. Press the **MODE** key to return to normal operation.

2.9.16 Document the calibration steps in the applicable scientific notebook or supplemental notebook.

2.9.17 This completes the calibration adjustment process. The instrument is now ready for a pH As-left calibration check per Section 2.7 of this procedure.

2.10 Conductivity Sensor As-Found or As-Left Calibration Check

For all Conductivity measuring instruments, perform an As-Found calibration to determine the accuracy of the device prior to performing any adjustments. If the conductivity instrument has been adjusted, perform an As-Left calibration to document the instrument's accuracy. The steps are the same whether it's an As-Found or As-Left calibration.

2.10.1 The minimum requirement for all As-Found or As-Left Calibrations is a single point calibration check. Additional checks with other conductivity solutions may also be performed. The specific number and the solutions used will be identified by the PIC.

2.10.2 For all conductivity solutions, following placement on the instrument probe, allow sufficient time to equilibrate with the applied solution. The YSI instrument requires a minimum dwell time of 1 minute; the GLI instruments may require 60 minutes or more. Stable conductance readings indicate that the conductivity instrument and solution have equilibrated.

2.10.3 Clean the instrument with deionized water and dry it with clean wipes and lab-grade compressed air or equivalent and place it into the first and lowest conductivity solution. Once the value being measured by the conductivity instrument has stabilized, record the solution value and the value displayed by the conductivity instrument.

2.10.4 Rinse the probe with deionized water and dry it with clean wipes and lab-grade compressed air or equivalent. If this is a single-point calibration proceed to step 2.10.6, otherwise place the conductivity instrument being calibrated into the next conductivity solution. Once the value being measured by the conductivity instrument has stabilized, record the value of the conductivity solution and the value displayed by the conductivity instrument.

2.10.5 Repeat step 2.10.4 for any additional conductivity solutions being used in the calibration.

2.10.6 For the conductivity instrument being calibrated, the results of the calibration check shall be compared against the expected uncertainty or accuracy requirement of the instrument.

2.10.7 If the calibration check is an As-Found calibration and the results do not fall within the expected uncertainty or accuracy requirements, a Corrective Action Request (CAR) will be issued to document the results and impacts related to the change in conductivity instrument's performance.

2.10.8 If the As-Found results are out of tolerance or if improved performance is desired, perform the calibration adjustment section related to the type instrument being calibrated.

2.10.9 If the calibration check was an As-Left calibration and the results are out of tolerance, repeat the applicable calibration adjustment section related to the type instrument being calibrated. Remove the instrument from service, if the calibration adjustment has been performed more than two times and the instrument still does not meet the expected uncertainty or accuracy requirements. Tag and label the conductivity instrument accordingly, and if practical, return it to the manufacturer for repair.

2.11 GLI Conductivity Instrument Calibration Adjustment

NOTE: When using a new sensor, always perform a "RESET CALIBRATE" using the TEST/MAINT menu (PART THREE, Section 5.8) of the GLI Conductivity Instrument Manual before zeroing and calibrating. Steps 2.11.1 through 2.11.8 may be skipped if the sensor has been zeroed previously (an analyzer reading of 0.0 in room air indicates that the sensor has been through these steps previously).

2.11.1 Make sure that the sensor is dry before zeroing. Press **MENU key** to display a "MAIN MENU" screen. If the MAIN MENU | CALIBRATE screen is not showing, use ⇑ **or** ⇓ **key** to display it.

2.11.2 Press the **ENTER key** to display CALIBRATE | SENSOR screen.

2.11.3 Press the **ENTER key** again to display SENSOR | 1 POINT SAMPLE screen.

2.11.4 Press ⇓ **key** once to display SENSOR | ZERO screen.

2.11.5 Press the **ENTER key** to display the "ZERO: IN DRY AIR?" screen.

2.11.6 With the dry sensor held in air, press the **ENTER key** again to start automatic zeroing. (During zeroing, the analog output is automatically "held" at the last measured value.)

2.11.7 After the "ZERO: CONFIRM ZERO OK?" screen appears, press the **ENTER key** to end zeroing.

2.11.8 After the "ZERO: CONFIRM ACTIVE?" screen appears, press the **ENTER key** to return the analog output to its active state (MEASURE screen appears).

2.11.9 Thoroughly rinse the clean sensor in de-ionized water and dry it with clean wipes and lab-grade compressed air or equivalent, and then immerse the sensor into a properly prepared conductivity reference solution of known value. **Important: Allow the sensor and solution temperatures to equalize.** Depending on their temperature differences, this may require 60 minutes or more; a stable conductance reading indicates temperature equalization.

NOTE: Suspend the sensor to prevent its electrodes from touching the container. Remove any bubbles clinging to the outer and center electrodes by gently stirring the sensor in the solution. Sensors with a deeper recessed center electrode require more vigorous stirring.

2.11.10 Press **MENU key** to display a "MAIN MENU" screen. If the MAIN MENU I CALIBRATE screen is not showing, use ⇑ **or** ⇓ **key** to display it.

2.11.11 Press the **ENTER key** to display CALIBRATE | SENSOR screen.

2.11.12 Press the **ENTER key** again to display SENSOR | COND CAL screen.

2.11.13 Press the **ENTER key** again to display SET REF TEMP? I (25°C) screen. The default 25° C reference temperature is suitable for most applications. For another reference, use **arrow** keys to adjust to a different temperature.
NOTE: *During calibration, the analog output is automatically "held" at the last measured value.*

2.11.14 Press **ENTER key** again to display SET SLOPE? I (2.00% / °C) screen. In most cases the default 2.00%/ ° C slope is used, however, use the **arrow keys** to adjust to a different value to match the known slope of the reference solution, if needed.

2.11.15 With the sensor in the solution, press the **ENTER key** again to display COND CAL I SAMPLE READY? screen, press **ENTER key** to confirm. The screen XXXX mS/cm I READING STABLE? Appears showing the measured reference solution value.

2.11.16 Wait 60 minutes or more; a stable conductance reading indicates temperature equalization. Then press the **ENTER** key. The "PLEASE WAIT" screen may appear if the reading is still too unstable. After the reading has stabilized, the static screen appears showing the last measured value.

2.11.17 Use **arrow keys** to adjust the displayed value to exactly match the known value of the conductivity solution.

2.11.18 Press the **ENTER key** to enter the value and complete calibration ("CONFIRM CAL OK?" screen appears).

2.11.19 This completes the calibration adjustment of the GLI conductivity instrument, return to section 2.10 and perform an As-Left calibration check to verify the performance of the instrument.

2.12 YSI Conductivity Instrument Calibration Adjustment

2.12.1 Turn the instrument on and allow it to complete its self test procedure.
2.12.2 Select a calibration solution which is most similar to the sample you will be measuring.
2.12.3 Place at least 3 inches of solution in a clean sample container.
2.12.4 Insert the probe into the sample container deep enough to completely cover the oval shaped hole on the side of the probe.
2.12.5 Do not rest the probe on the bottom of the container – suspend it above the bottom at least ¼ inch. Press the **MODE** key until the instrument is reading conductivity or specific conductance.
2.12.6 Allow at least 60 seconds for the temperature reading to become stable.
2.12.7 Move the probe vigorously from side to side to dislodge any air bubbles from the electrodes.
2.12.8 Press and release both the **UP ARROW** and **DOWN ARROW** keys at the same time. The **CAL** symbol will appear at the bottom left of the display to indicate that the instrument is now in Calibration mode.
2.12.9 Use the **UP ARROW** or **DOWN ARROW** key to adjust the reading on the display until it matches the value of the calibration solution you are using.
2.12.10 Once the display reads the exact value of the calibration solution being used (the instrument will make the appropriate compensation for temperature variation from 25°C), press the **ENTER** key. The word "**SAVE"** will flash across the display for a second indicating that the calibration has been accepted.
2.12.11 This completes the calibration adjustment of the YSI conductivity instrument, return to section 2.11 and perform an As-Left calibration check to verify the performance of the instrument.

NOTE: If the up or down arrow keys are not pressed during the calibration process, the "SAVE" message will not be displayed since the calibration value has not changed. If an error occurs during calibration, see the YSI Operators Manual, Section 9, *Troubleshooting*.

2.13 References

- Operating Manual, pH/ORP Pro-Series Model P3 Transmitter, GLI International, Inc.
- Operating Manual, Conductivity Pro-Series Model C3 Transmitter, GLI International, Inc.
- Operations Manual, YSI Model 30 Handheld Salinity, Conductivity and Temperature System, YSI Incorporated.
- Operating Manual, YSI Model 60 Handheld pH and Temperature System, YSI Incorporated.

3.0 Records

The following records generated through implementation of this procedure shall be prepared and submitted to the WIPP Records Center in accordance with NP 17-1, “Records”.

QA Record

- Scientific Notebook
- Scientific Notebook Supplement

4.0 Appendices

Not Applicable. There are no appendices associated with this document.

This work of authorship was prepared as an account of work sponsored by an agency of the United States Government. Accordingly, the United States Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so for United States Government purposes. Neither Sandia Corporation, the United States Government, nor any agency thereof, nor any of their employees makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately-owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by Sandia Corporation, the United States Government, or any agency thereof. The views and opinions expressed herein do not necessarily state or reflect those of Sandia Corporation, the United States Government or any agency thereof.

Sandia National Laboratories is a multi-mission program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Parties are allowed to download copies at no cost for internal use within your organization only provided that any copies made are true and accurate. Copies must include a statement acknowledging Sandia Corporation's authorship of the subject matter.