Fire Fighting Technology Equipment and Testing Guide

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Willie May, Under Secretary of Commerce for Standards and Technology and Acting Director

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List of Acronyms

BDP	Bi-Directional Probe
DVR	Digital Video Recorder
NI	National Instruments
NIST	National Institute of Standards and Technology
TC	Thermocouple

Chapter 1

Data Acquisition System

1.1 Hardware

Data acquisition systems are constructed using National Instruments (NI) hardware. The systems starts with the chassis - NI SCXI-1000/NI SCXI-1001. The 1000 is a 4-slot chassis while the 1001 is a 12-slot chassis. The max scan rate of the chassis is (5 μs $\times$ # of channels used)$^{-1}$. A 200 kS/s 16-bit digitizer, NI SCXI-1600, connects the chassis to the computer (via USB). The remaining chassis slots are filled with the NI SCXI-1102. The SCXI-1102 is a 32-channel thermocouple amplifier/voltage input module. Each SCXI-1102 is connected to a TC-2095; a shielded, 32-channel, rack-mountable terminal accessory. All of the measurement devices connect to the TC-2095 using either chromel-alumel connectors (temperature) or copper-copper connectors (voltage). A schematic of the hardware configuration is shown in Fig. (1.1).

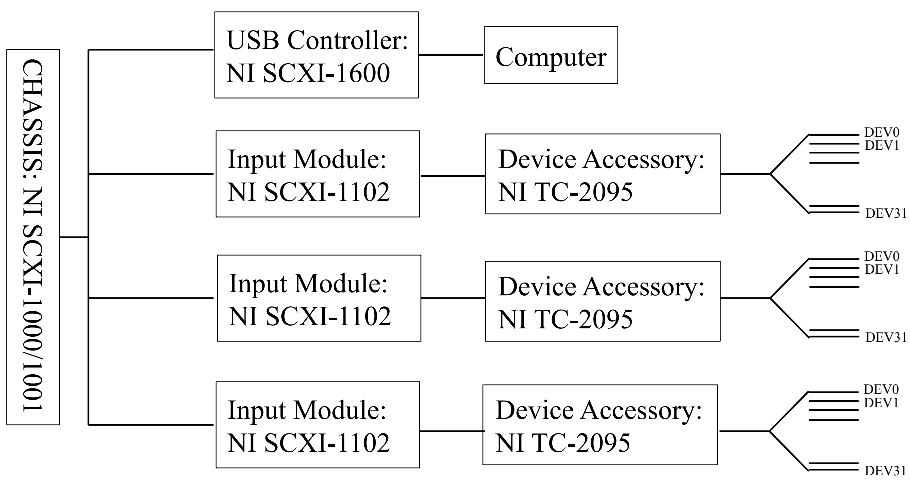

Figure 1.1: Schematic of data acquisition hardware.

1.2 Software

Channel lists are built using NI-MAX and fed into 32-bit NI LabVIEW as a task using NI-DAQmx. Note that in the current configuration, the computer must also have a 32-bit operating system on it.

Chapter 2

Thermocouples

Two types of type K thermocouples (TCs) are used: bare bead and metal sheathed. The bare bead TCs are made from 30 gauge glass braid insulated solid wire. The bare bead thermocouples are used in the TC trees and single point measurements. The metal sheathed TCs (#125-KSL-600-U from Furnace Parts) have a 1/8 in diameter Inconel 600 sheath and an ungrounded junction. These TCs are moisture proof and are typically used in conjunction with bi-directional probes. The sheathed TCs are typically ordered with a 48 in TC and 120 in type K lead wire (NIST01A from Furnace Parts) or a 144 in TC and 120 in type K lead wire (NIST01B from Furnace Parts).

2.1 Uncertainty

2.2 Thermocouple Welders

Two different welders are used to construct the bare bead TCs. The Miyachi Unitek TC Welder (01-0196-02) is a manual feed thermocouple welder designed to weld thermocouple wires together without oxide layers by using argon cover gas. The welder can handle wires from 38 gauge to 20 gauge.

2.3 Thermocouple Extension Wire

Two sets of type K extension wire are used: single pair (EXPP-K-24-S-1000) or 20 pair (20KX24SPP). Both wires are 24 gauge, 7-32 stranded, polyvinyl coated wire.

2.4 Thermocouple Connectors

Thermocouple miniature connectors are high temperature liquid crystal polymer (HMPW-K-M/F). Thermocouple miniature panel jacks are used with the BDP boxes (MPJ-K-F).

Table 2.1: Thermocouple Connections

Use	Connection End 1	Connection End 2
TC Tree/Single TC	TC Bead	Male
Inconel sheathed	TC Bead	Male
Single Extension	Female	Male
BDP TC Extension	Male	Male
BDP Box	Female Panel Jack	Female Panel Jack
20 Pair Extension	Female Panel Jack	Male

Chapter 3

Bi-Directional Probes

Bi-directional probes are order from ... size specs. Pressure measurements are made using a XX Setra.

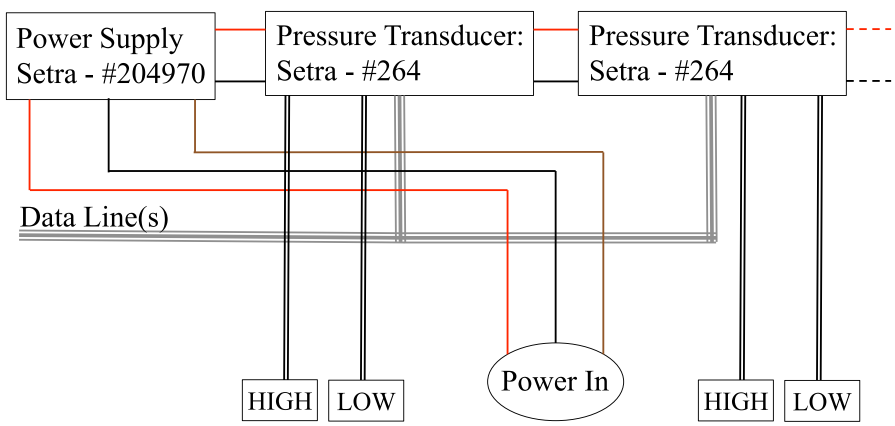

Figure 3.1: Schematic of pressure measurement setup for use with BDPs.

3.1 Uncertainty

Uncertainty

Chapter 4

Heat Flux Gauges

Medtherm Corporation Schmidt-Boelter total heat flux gages and radiometers are used with full scale outputs that range from 20 kW/m^2 to 100 kW/m^2. Each transducer outputs millivolts. Voltage is converted to heat flux using a conversion factor provided on each device's unique data sheet.

4.1 Uncertainty

Calibration is performed in compliance with ISO/IEC 17025, ANSI/NCSL Z540-1, and MIL-STD-45662A to Medtherm PI-20 with traceability to the National Institute of Standards and Technology. The total expanded uncertainty is $\pm 3\%$ with a coverage factor = 2 (95 % confidence level).

Chapter 5

Gas Analyzer

The CAI 602P Gas Analyzer can detect gas concentrations for CO_2, CO, and O_2 and output a voltage from 0 V to 5 V, which corresponds to 0 % gas concentration to a programmable full-scale concentration.

5.1 Usage

- Turn on the gas analyzers. The gas analyzers should warm up for about one hour before usage. Keep them powered on as long as possible during testing.
- Plug the voltage output wires into the DAQ.
- Perform zero and span calibration on all analyzers. Use the left and right arrows to switch gas channels. Use shortcut keys to jump from the home measurement screen to the zero screen (F5) and span screen (F6).
  - Flow N_2 and zero the CO_2, CO, and O_2 channels.
  - Flow CO_2/CO calibration gas and span the CO_2 and CO channels.
  - Use ambient air to span the O_2 channel.
- Use the arrow keys to set the upper ranges to the appropriate setting, which corresponds to 5 V on the output to the DAQ.
- Measure the delay time for the sample gas to travel through all of the plumbing (from the sample port to the analyzer). You can do this by holding a gas source near the sample port and measuring the time from exposing the sample port until the gas analyzer reads an increased value. Record this time so that the gas concentration data can be offset during data post-processing.
- You are ready to record gas concentration data to the DAQ.

5.2 External Plumbing

Important note: The optimal pressure at the sample inlets or calibration gas inlets is 0 psi! The internal pump will pull the gas sample as needed. The internal gas analyzer components should never be exposed to a pressure in excess of 2 psi at the sample inlet. Pressures to the gas analyzer in excess of 2 psi may damage or dislodge the internal plumbing or pump diaphragm. For the gas sample inlets, be sure to use in-line pressure regulators (max. 2 psi) combined with bypass valves to stop and relieve any incoming excess pressure. For the calibration gas inlets, be sure to use bypass tees to relieve any incoming excess pressure.

5.2.1 Calibration Gas Plumbing

Calibration (span) gas (CO_2 and CO) $\rightarrow$ Bypass tee $\rightarrow$ Span gas inlet.

5.2.2 Sample Gas Plumbing

Sample tubes $\rightarrow$ Filter in dry ice (for scrubbing and cooling) $\rightarrow$ Sample pump (bypass value is on) $\rightarrow$ Sample inlet on gas analyzer $\rightarrow$ Outlet tube directed away from operator.

5.3 Uncertainty

The uncertainty of the gas concentrations is XX.

5.4 Internals

An overview of the internal components of the gas analyzer is shown in Fig. 5.1. The internal pump is located in the center of the chassis towards the front of the analyzer, as shown in Fig. 5.2. The O_2 sensor is located on the right side of the analyzer under the foam cover. The CO sensor is located on the left side of the analyzer towards the front panel, and the CO_2 sensor is located on the left side of the analyzer towards the rear panel.

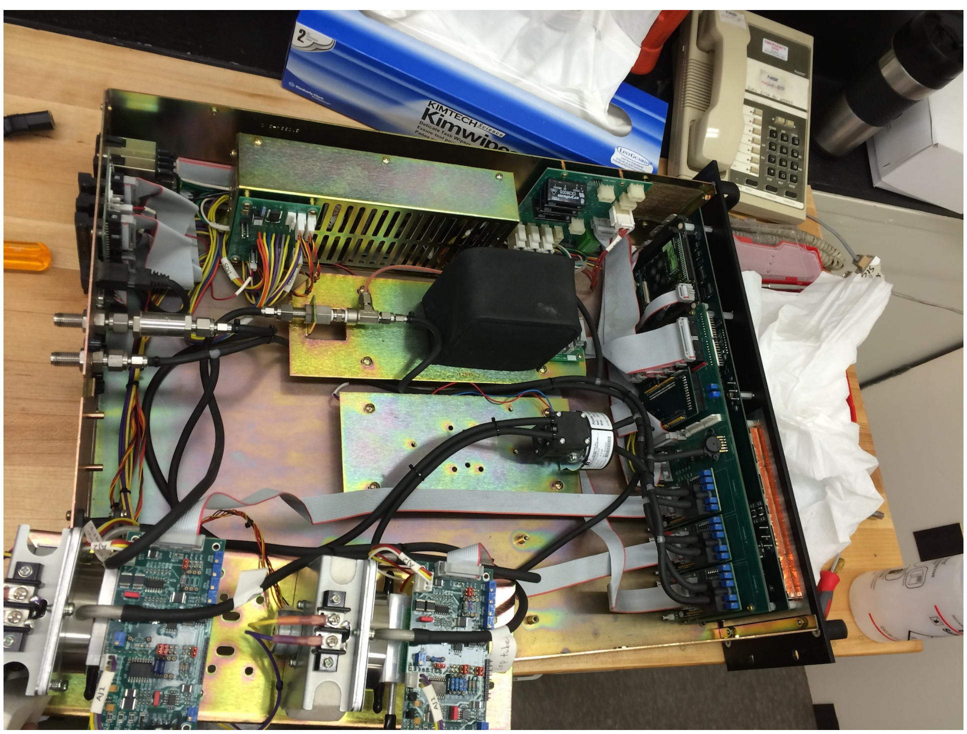

Figure 5.1: Internal components of the gas analyzer.

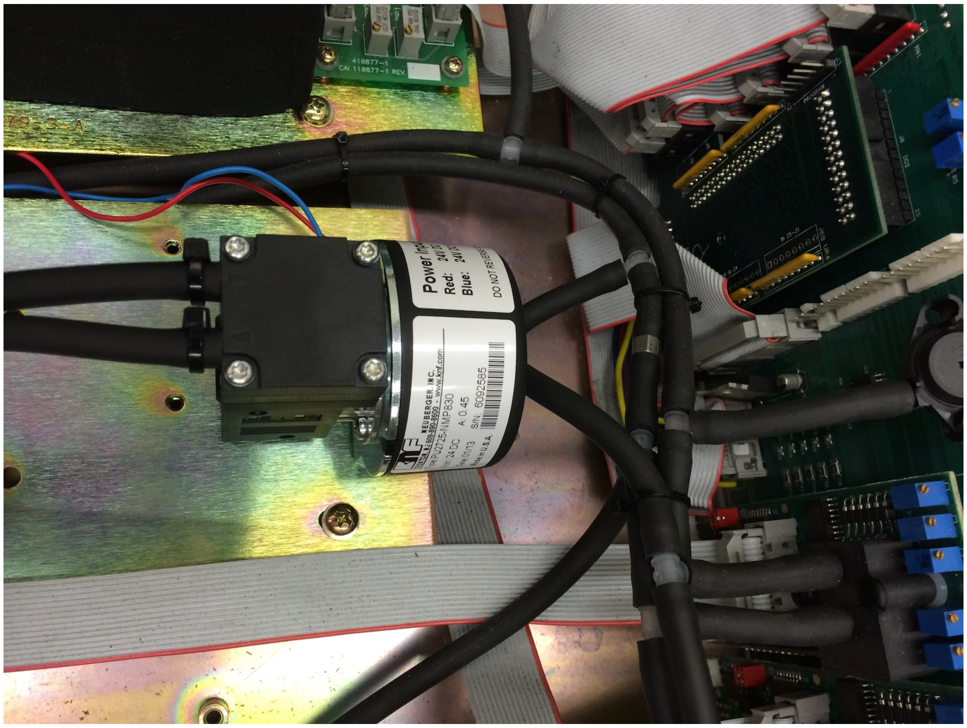

Figure 5.2: Internal pump within the gas analyzer.

5.5 Diagnostics

5.5.1 No Internal Flow

If the flow drops to zero, then display the flow diagnostics by pressing Main → F3. Check the internal flow value for the three gases. If it is zero, then there might be a issue with the internal plumbing if the upstream pressure (from sample or calibration gases) exceeded 2 psi. An internal gas line might have been disonnected or the pump might have been damaged. Check power to the internal pump and ensure that it is operating, and check the internal plumbing connections.

5.5.2 Bad Gas Concentration Readings

If the channel is reading gas concentration values out of range or sporadic values, you may need to clean the internal sensor cell windows. Check the raw voltages in the analyzer setup by pressing Main → F5 → F6 → F2, then cycle through each gas using the left/right arrows. The raw voltages should be around 1.0 V at 0 % concentration, and 9 V at full-scale concentration. Refer to Section 10 of the CAI 600P User Manual for more information.

5.5.3 Diagnostic Information

The following screens provide useful diagnostic information that can be sent to technical support:

- To display the version and serial number, press Main → F5 → F10.
- To display flow diagnostics, press Main → F3.

- To display raw voltage/channel values, press Main $\rightarrow$ F5 $\rightarrow$ F6 $\rightarrow$ F2, then cycle through each gas using the left/right arrows.

Refer to Section 10 of the CAI 600P User Manual for more information on maintenance and troubleshooting.

Chapter 6

Video

6.1 Digital Video Recorder Notes

Model number: Samsung SRD-1680D

Samsung Customer Service: 877-213-1222

When running the “Backup” operation (to export the DVR movies to an external HDD), the DVR splits up files into 2.08 GB .avi movie files. See the video editing workflow section for information on joining multiple split videos into a single video file.

6.1.1 Usage

- Run 12 V power and BNC cables to each camera. Thermal imaging cameras (TICs) need only a BNC cable. Some TICs require powered PAL to NTSC converters.
- Press the record button on the DVR to record all channels.
- Press the record button and confirm to stop recording.
- When finished, use the backup option to retrieve the data to an external USB hard drive. Select the time range, format (.avi), and channels that you want to export, then click the backup button.

FAQ

- Can I dump .avi files directly to an external drive? Quality?
  - Can dump directly to AVI for a given date/time range, retains 1080 HD quality
- How are the internal and external hard disks formatted?
  - Internal: NTFS format. External: FAT32 format. Use the menu to format hard drives.
- How are files stored internally (.avi, proprietary)?
  - Saved internally in DVR format, can export to AVI or to SCC (proprietary format)
- Can the internal drives be configured as RAID?
  - Not internally
- What happens if one drive fails and other internal drives are available while recording?

  - Seamless failover to other available drives

- How should an external drive be formatted?
  - External USB drive should be formatted as FAT32. You can do this using the built in format function.

- Limit on number of connected smartphone viewers or remote viewers?
  - Remote: Search 3, Live unicast 10, Live multicast 20
  - Mobile: 1 Live, 1 CH playback

6.2 Video Editing Workflow

6.2.1 Digital Video Recorder

The process for recording and extracting video from the DVR is as follows:

1. Record video.
2. Backup the video to an external drive to .avi format (H.264 codec and AVI container).
3. Convert the .avi videos to .mp4 format (H.264 codec and MPEG-4 container) for editing. A tool such as Handbrake is recommended.

It is recommended that you maintain the original .avi files and subtitle files, which contain the date/timestamp information for future reference.

6.2.2 Combining Videos

The GoPro cameras and DVR split long videos into multiple files because of the format of the file systems that they write to. If you need to combine multiple .mp4 videos into one file, you can use a tool such as MP4Box or Avidemux. The benefit of these tools over a full video editor is that they can perform simple video operations without reencoding the video, so the processing is much faster.

Multiple video files can also result from the DVR if a video channel temporarily loses signal. If this is the case, be sure to add blank video to pad any time that passed while the video channel signal was lost.

For example, to seamlessly combine two video files (video_1.mp4 and video_2.mp4) into one video file (video_output.mp4), the command line tool MP4Box can be used with the following command

```
MP4Box -cat video_1.mp4 -cat video_2.mp4 -new video_output.mp4
```

6.2.3 Splitting Videos

You can split an .mp4 video into multiple videos (without reencoding) with MP4Box. For example, if you have a 60 s video (video_input.mp4), you can extract video from 30 s to 60 s and save the output to a new file (video_output.mp4) with the following command

```
MP4Box -splitx 30:60 video_input.mp4 -out video_output.mp4
```

6.2.4 Creating Multi-Camera Videos

You can combine multiple videos into a multi-camera video using software such as Adobe Premiere Pro or any other non-linear video editing software.

Chapter 7

Water Flow Sensor

7.1 Arduino Config, Setup, and Data Logging

The Arduinos record voltage data locally, and they transmit voltage data to the host computer via the AMQP messaging protocol. The host computer uses RabbitMQ to act as a broker. Python scripts and the pika module send and receive AMQP messages. The following steps setup the host computer and Arduinos for this purpose.

7.1.1 Host Computer (RabbitMQ)

Note: the following assumes that the server/host computer's address is 192.168.1.100. It's best to configure the host computer with a static IP address using static DHCP or manually.

1. Install RabbitMQ for your platform and start the RabbitMQ server (./sbin/rabbitmq-server on Mac or Linux). https://www.rabbitmq.com/

2. Create .config file

   - Open *rabbitmq.config.example* (./etc/rabbitmq/ on Mac/Linux; ./etc/ on Windows)
   - Add '[{loopback_users, [] }' after the '{rabbit,' line and save file as 'rabbitmq.config' in the directory containing the example file
     Note: On Windows, may have to save it in the directory
     'C:\Users/%USERNAME%/AppData/Roaming/RabbitMQ/'
     To find such directory, search 'rabbitmq.config.example' on computer and open approriate file location.

3. Copy the receive_data.py script from the NIST-FIRE repository to the data logging computer.

4. Install Python (The Anaconda Python distribution from Continuum Analytics is recommended)

5. Install the pika module for Python using

   ```
   pip install pika
   ```

6. Run the receive_data.py script as

   ```
   python receive_data.py 192.168.1.100 output.csv
   ```

7.1.2 Host Computer (NTP Time Server)

On Windows, download and install the NTP server

http://www.meinbergglobal.com/english/sw/ntp.htm

Note: you might need to disable the Windows Firewall service so that incoming connections will not be blocked.

Mac and Linux use NTP natively.

7.1.3 Arduino Client (Sketch)

1. Install Arduino IDE http://arduino.cc/
2. Plug the Arduino Yun into the USB port of the host computer.
3. Set the Tools > Board to Arduino Yun and the Tools > Port to the /dev/ttyusbmodemXXXXXX setting that matches the plugged-in Arduino.
4. A Sketch is a script that runs on the Arduino microcontroller. Using the Arduino IDE, install the adc_voltage Sketch on the Arduino from the NIST-FIRE repository. This enables the reading and writing of data from the analog-to-digital converter via the REST API on the Arduino. Note: this sketch requires the Adafruit ADS 1X15 library from https://github.com/adafruit/Adafruit_ADS1X15.

7.1.4 Arduino Client (Linux)

1. Unplug the Arduino from the computer, and power on the Arduino from the battery.
2. Connect to the Arduino WiFi network. Access the Arduino web interface (http://arduino.local) with the default password of "arduino". Set the Arduino name (referred to as <arduino_name> in the following steps), time zone, and WiFi network information on the Arduino web config. Also, set the "REST API Access" to be "Open".
3. SSH to the Arduino at root@<arduino_name>.local and install the SFTP server, ntpclient, pip, and pika (for AMQP) on the Arduino

```
opkg update
opkg install openssh-sftp-server ntpclient distribute python-openssl
easy_install pip
pip install pika
```

4. By default, the microSD card on the Arduino is mounted at /mnt/sda1. Copy the send_data.py script from the NIST-FIRE repository to /mnt/sda1 on the Arduino.
5. Go to System > Startup > Local Startup in the Arduino web config and add a startup line to the Local Config section (/etc/rc.local)

```
python /mnt/sda1/send_data.py 192.168.1.100 <arduino_name> /mnt/sda1/output.csv
```

6. The default NTP service is not very robust, so we will replace it with ntpclient and have it sync with the NTP server every 2 minutes. Disable the default NTP service using

   ```
   /etc/init.d/sysntpd disable
   ```

   Configure the ntpclient service by editing /etc/config/ntpclient to be

   ```
   config ntpserver
           option hostname '192.168.1.100'
           option port     '123'

   config ntpserver
           option hostname '0.pool.ntp.org'
           option port     '123'

   config ntpserver
           option hostname '1.pool.ntp.org'
           option port     '123'

   config ntpserver
           option hostname '2.pool.ntp.org'
           option port     '123'

   config ntpserver
           option hostname '3.pool.ntp.org'
           option port     '123'

   config ntpdrift
           option freq     '0'

   config ntpclient
           option interval 120
   ```

7. Reset power to the Arduino, and then it should start broadcasting data values within about 2 minutes of booting.

7.2 Parts

- Mouser #: 517-929834-02-36-RK
  Mfr. #: 929834-02-36-RK
  Desc.: Headers & Wire Housings FULL STICK HDR/36POS
  $1.13

- Mouser #: 932-MIKROE-197
  Mfr. #: MIKROE-197
  Desc.: Daughter Cards & OEM Boards SMARTPROTO PROTO ADAPTER BOARD
  $4.90

Appendix A

Testing Procedure

A.1 Initial Startup

- Power on the following devices:
  - Generators (check oil and gas levels)
  - Uninterruptible Power Supplies (UPSs)
  - WiFi routers/repeaters
  - Arduino laptop with NTP, RabbitMQ, Python receive_data.py script
  - DAQs and laptops
  - Weather stations
  - Gas analyzers (leave running as long as possible during testing)
  - Digital video recorder (DVR)
  - Bullet cameras and power supplies
  - Thermal imaging cameras (TICs) (check battery levels)
  - Digital video cassette recorders (DVCRs) (check battery levels)
  - GoPros (check battery levels)
  - Video cameras (check battery levels)

A.2 Calibration

- Synchronize clock time on DAQ computers, digital video recorder, etc.
- Verify operation of all:
  - Video channels
  - DAQ channels
  - Check toggle switches on TC-2095s for appropriate measurement device
  - Gas analyzers
- Calibrate gas analyzers with zero and span gases
- Record serial number and probe location of gas analyzers; check and record lag time
- 1 minute calibration run to separate output file (cover BDPs, check TCs, etc.)

A.3 Primary Testing Procedure

- Take GigaPan pictures as needed
- Distribute still cameras
- Verify testing procedure with all personnel
- Safety checks
- Power on gas analyzer pump
- Add dry ice to gas sample traps (or turn on gas dryer)
- Turn on water for heat flux gauges, cool cans, etc.
- Power on Arduino data loggers
- Start recording on:
  - GoPros (Sync GoPro time to DVR screen time)
  - Video cameras
  - Mobile TIC
  - DAQ
  - DVR
- 1 minute pre-test run (with all doors closed)
- Begin test
- Follow testing procedure
- End test
- Stop recording on:
  - DAQ
  - DVR
  - GoPros
  - Video cameras
  - Mobile TIC
- Power off gas analyzer pump
- Power off Arduino data loggers
- Verify successful recording and operation of all DAQ channels in output file
- Take GigaPan pictures as needed
- Prepare for next test

A.4 Data Dump

- Collect and organize data from:
  - DAQ
  - DVR
  - GoPros
  - GigaPan
  - Weather station data logger
  - Mobile TIC
  - Arduinos
  - Video cameras with digital media
  - Still cameras with digital media
- Archive, swap and label tapes from video cameras and DVCRs if needed
- Make copies of all data on external hard drives
- Verify integrity of data
- Format GoPros, video and still camera media, mobile TIC, Arduinos, and GigaPan camera
- On return from trip, extract video from DVCR tapes

A.5 Battery Charging

- Charge all batteries on:
  - Laptops and tablets
  - 12 V batteries
  - TICs
  - GoPros
  - Video cameras
  - Still cameras
  - GigaPan camera
  - DVCRs
  - Radios
  - Arduinos