ARM Climate Research Facility

C-band Scanning ARM Precipitation Radar 2 (CSAPR-2) System Specification for ARM Mobile Facility 3

Revision 2.2

Pacific Northwest National Laboratory

October 16, 2012

1. Introduction

The U.S. Department of Energy's Atmospheric Radiation Measurement (ARM) Program has been operating zenith pointing cloud radars at its ARM Climate Research Facilities (ACRF) for over a decade. These radars, operating in the Ka and W bands, have provided years of invaluable data pertaining to cloud structure and dynamics. However, vertically pointing radars have their limitations in that only a two dimensional view of the cloud is obtained. Millimeter wave radars are also poor precipitation radars since they saturate in light rain and experience excessive atmospheric loss due to atmospheric liquid water.

As part of the 2009 American Recovery and Reinvestment Act, ARM procured four C-band Scanning ARM Precipitation Radars (CSAPRs). Three are located at ARM's SGP site in Oklahoma and a fourth is located at ARM's site in Barrow, Alaska. To differentiate between the previously delivered CSAPRs and the new CSAPRs being procured by this specification, the new radars are referred to as CSAPR-2.

This specification outlines the minimum requirements necessary to meet ARM's science goals with the transportable CSAPR-2.

2. Overview

The CSAPR-2 is a dual polarization Doppler radar mounted on an elevation-over-azimuth antenna positioner. A key difference with the CSAPR-2 over the original CSAPRs is that this radar shall be more readily transportable. The CSAPR-2 shall consist of two trailers with one trailer containing the radar pedestal/antenna and the other the operations shelter and diesel generator. A concept of this is shown in Figure 1.

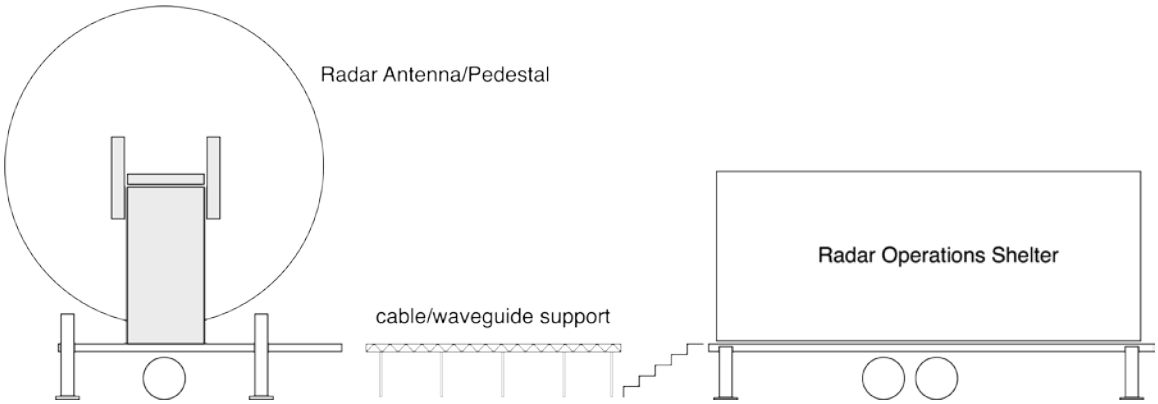

Figure 1 CSAPR-2 Concept

The CSAPR-2 shall be set up to function in various operational modes by either a local or remote operator via the Internet. When operating, the CSAPR-2 shall record data in files that are pulled via ftp by the ACRF site data system.

3. Overall Design Requirements/Guidelines

3.1. To the maximum extent possible, all components and major subsystems shall be commercial-off-the-shelf (COTS) that are certified by a Nationally Recognized Testing Laboratory (NRTL), such as UL or CSA.

3.2. All parts and components shall be new and less than one year old from the time the contract is placed. Exceptions to this require written authorization of the PNNL Technical Oversight Representative (TOR).

3.3. No parts or components shall be purchased from non-authorized merchants or auction sites. Exceptions to this require written authorization of the PNNL Technical Oversight Representative (TOR).

3.4. All electrical service wiring shall be completed by a licensed electrician to the applicable code in the state that the system is wired. Adherence to NFPA-70 (NEC) 2008 is considered the minimum standard for electrical service wiring.

4. Radar Operations Shelter Requirements

4.1. The shelter shall be based on a new 20’ x 8.5’ ISO shipping container (ISO 6346) with double doors on each end. A plan view concept of the shelter is shown in Figure 2. Note that door and wall placement is to be determined during the design process.

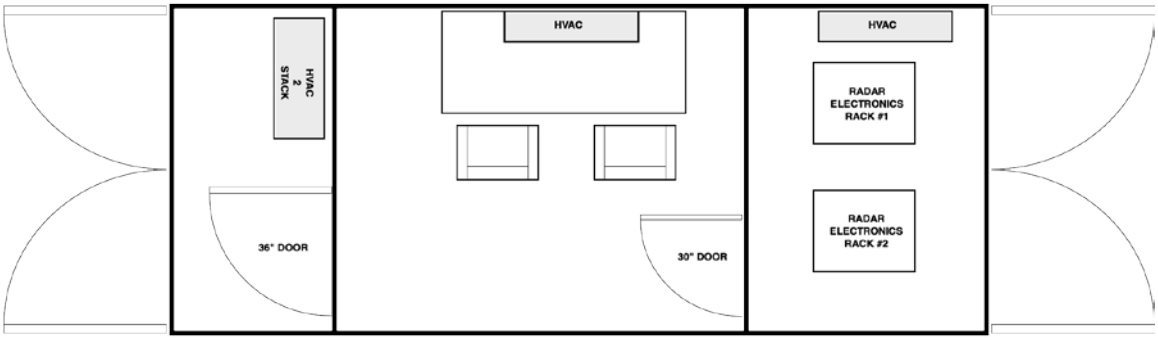

Figure 2 CSAPR-2 Operations Shelter Plan View Concept

4.2. The shelter’s double doors shall have a method to mechanically restrain them fully open (270°) and partially open (180°).

4.3. An alcove shall be established by building a wall no less than 24” in from the shelter’s double doors.

4.4. The wall between the electronics room and the operations room shall be determined during the design phase. The design goal should be to facilitate access to the electronics mounted in the racks yet maximizing the size of the operations room.

4.5. The 36” entry door shall be made of a non-corrosive metal, have metal framing, and have an automatic door closer. This door shall be UL-listed, Commercial-Grade Class A or B Fire Door.

4.6. The shelter shall have no exposed wood surfaces.

4.7. The sidewalls shall have tie-downs for securing loads during transport. These tie-downs shall be spaced approximately 48” apart. We recommend Horizontal Galvanized E-Track (http://www.uscargocontrol.com/Van-Trailer-Products/E-Track-Straps-Tie-Downs) or equivalent.

4.8. The floors shall have flush-mounted D-ring tie-downs spaced approximately 24” from each sidewall and 48” apart.

4.9. The shelter shall have a wall with interior door that separates the radar electronics racks from the operations. This wall/door shall be sound insulated to minimize sound transfer to the maximum extent practical.

4.10. The shelter shall have three split-type air conditioners. One shall handle the full heat load at 40 C ambient outside temperature inside the operations room. Another shall handle the full heat load at 40 C ambient outside temperature inside the electronics room. The other shall be installed as a hot (i.e. powered) spare.

4.11. The shelter shall include an electric heat system that will heat the inside of the shelter from -40 C to 20 C within one hour.

4.12. The shelter walls, floor, ceiling, and rear external doors shall be insulated and have a minimum R-value of R8.

4.13. The shelter shall meet ASHRAE 62.2 for fresh air ventilation inside the shelter.

4.14. The shelter floor shall be non-skid, non-corrosive metal flooring such as diamond deck or equivalent.

4.15. The shelter shall sustain 58 m/s (130 mph) wind loads.

4.16. The shelter shall have weatherproof cable feedthoughs.

4.17. The shelter shall be maintenance free as much as possible.

4.18. Two adjustable office chairs shall be provided.

4.19. A 5-pound UL-listed Class ABC fire extinguisher shall be provided for the operations room and the electronics room. They shall be mounted to a shelter wall.

4.20. A smoke alarm wired into the shelter’s electrical system with battery backup shall be provided. Sensors shall be placed in both the electronics and operations rooms per NFPA-70 guidelines.

4.21. A CO_2 monitor shall be installed in both the operations room and the electronics room per NFPA-70 guidelines.

4.22. The CSAPR-2 data acquisition system and electronics not required to be mounted on the antenna positioner shall be housed in a shock-mounted 19”, fully enclosed electronics rack(s). The rack(s) shall have removable sides and doors to facilitate service of installed equipment.

4.23. Instrument racks shall be fastened to both the floor and walls with helical wire rope vibration isolators to prevent tipping and movement during transport.

4.24. The shelter’s exterior and interior paint color shall be white or off-white.

4.25. The shelter's internal lighting shall be by dimmable LED to include general illumination in the shelter (500 LUX) along with task lighting (1000 LUX) over the workbench.
4.26. The shelter shall have an exterior LED light at the entry.
4.27. The shelter shall be fitted with emergency lights in the electronics room and the operations room. Emergency lighting shall comply with OSHA regulations.
4.28. Removable stairs that can be leveled to accommodate uneven terrain shall be provided.
4.29. A method of rigidly supporting the cables and waveguide between the radar operations shelter and the antenna/pedestal trailer shall be provided. This system shall be designed:
- To keep the cables/waveguide a minimum of 36" off the ground.
- Stable to prevent tipping over in winds.
- Leveling supports for uneven ground.
- In 8 sections of 5' length each for a total of 40'.

5. Trailer Specifications

5.1. There shall be separate trailers for the radar pedestal and the radar operations shelter. These trailers shall meet US DOT standards for commercial trailers.
5.2. The radar operations trailer shall be a minimum of 20' long and 8' wide.
5.3. The pedestal trailer shall have hand-actuated outriggers for stabilizing the CSAPR-2 antenna/pedestal.
5.4. The trailers shall have welded tie-downs to allow securing the trailer in the event of hurricane force winds.
5.5. The radar operations trailer shall include mounting points (i.e. Tandemloc Fastmount) for each of the shelter's four corners to attach the shelter to the trailer.

6. Radar System Requirements

6.1. Operating frequency shall be tunable from 5600 to 5800 MHz.
6.2. PRF shall be adjustable from 200 Hz to 1200 kHz.
6.3. Pulse width shall be adjustable from 100 ns to 2.0 μs.
6.4. The transmitter phase noise shall be no greater than 0.25 degrees.
6.5. The radar shall be dual polarization radar.
6.6. The radar shall simultaneously transmit horizontally and vertically polarized signals.
6.7. The radar shall simultaneously receive horizontally and vertically polarized signals.
6.8. The transmitter shall be able to radiate with a staggered pulse repetition time.
6.9. The transmitter shall be able to radiate with multiple pulse repetition frequency.
6.10. The radar shall use a receiver with digital IF with reprogrammable digital filters.
6.11. The radar shall use two identical receivers for the horizontally polarized channel and vertically polarized channel.

6.12. The gains of the receiver for horizontally polarized channel and vertically polarized channel shall be matched to each other.
6.13. A digital receiver shall have a linear dynamic range no less than 100 dB.
6.14. The resolution of the digital receiver shall have be no less than 16-bit ADC resolution.
6.15. Receiver noise figure shall be no greater than 2.0 dB.
6.16. The minimum observable equivalent reflectivity factor with a single pulse shall be no greater than -10 dBz at 20 km with a transmit pulse range resolution no greater than 100 m. A detailed engineering analysis shall be supplied to document this performance requirement.
6.17. The radar shall include a signal generator as a built-in test equipment to automate the calibration of the receiver in the horizontal and vertical polarization channel.
6.18. The automated receiver calibration shall provide the gain and noise figures of horizontal and vertical polarization channels.
6.19. The automated receiver calibration shall characterize the receiver over the full dynamic range of the digital receiver.
6.20. The radar shall be capable adaptive clutter suppression for both the polarization channels. The clutter suppression capability shall be no less than 50 dB.
6.21. The radar system shall provide a velocity de-aliasing using dual pulse repetition frequency technique.
6.22. The radar system shall provide a velocity de-aliasing using staggered pulse repetition time technique.

7. Antenna/Pedestal

7.1. The radar system shall use a prime focus parabolic reflector antenna for dual polarization operation.
7.2. Antenna beamwidth shall be no greater than 1.0° (giving an antenna diameter of approximately 5 meters).
7.3. Antenna gain shall be no less than 45 dB.
7.4. The antenna peak side-lobe level shall be no greater than -28 dB relative to the peak main lobe gain of both horizontal and vertical polarization pattern.
7.5. Integrated cross-polarization isolation shall be no less than 32 dB.
7.6. The absolute difference between the antenna gains of the horizontal and vertical polarization channels within the main lobe shall be no greater than 1 dB. The main lobe is defined as the 20 dB contours below the peak gain.
7.7. The pedestal shall be capable of continuous scanning in azimuth from 0° to 360° in both clockwise and counter clockwise direction.
7.8. The pedestal shall be capable of scanning continuously from elevation angle no less than -5.0 degrees and elevation angle no greater than 185.0 degrees at any fixed azimuth angle.
7.9. The pedestal shall have its maximum scan speed no less than 6 rpm.
7.10. The elevation and azimuth pointing accuracy of the pedestal shall be 0.1 degree or better.

7.11. The pedestal shall include a hand-held operational control unit to move the pedestal without the radar data system being set up.

7.12. For transport, the pedestal (with the antenna removed) shall embody a self-contained system which allows the pedestal to be folded down to the trailer deck without the use of a crane or other rented/leased supplemental lifting device. The pedestal shall be secured from movement while in the transport position.

7.13. The antenna, pedestal, and trailer shall fit into a vendor supplied standard 20' x 8.5' ISO shipping container.

8. Data Acquisition Requirements

8.1. The radar data system's operating system shall be Linux.

8.2. Radar Calibration - In this mode, the system must prompt the operator (or retrieve from a file in remote mode) for the required actions (i.e. signal injection, antenna pointing, etc.) required to calibrate the radar. The system must step through test signal powers over the full dynamic range of the receiver and record the radar return signal at a fixed range gate. The calibration data shall be written to disk with a time stamped file header.

8.3. Data Acquisition - This mode shall collect data. The data shall be time tagged and written to disk as it is taken.

8.4. Data Range Correction - This is a post trial data analysis mode that shall provide range correction to the raw data.

8.5. Data Calibration - This mode shall process the range corrected data with the calibration data to provide the final output data files. The reflectivity data shall be converted to dBZ units.

8.6. Doppler Moments – The radar data system shall use both pulse pair and DFT techniques to estimate the first three Doppler moments, i.e. reflectivity, radial Doppler velocity, and spectral width. The DFT size shall be user selectable whose value is no less than 32 and no greater than 1024

8.7. Spectra Data – The radar shall have the provision to record spectra data for each range gate.

8.8. I/Q Data – The radar shall have the provision to record raw I/Q data for short durations (typically less than 2 hours).

8.9. Data File Generation –They shall be placed in a directory that will allow them to be transferred via Internet by ftp. The user shall be able to select the file collection directory so that data can be written to a large capacity external disk in the event the radar is operating in a stand-alone configuration. A ftp server shall be installed on the radar computer.

8.10. Data Storage – The data acquisition system shall have enough disk storage to store the following:

- Two weeks of moments data
- Four days of spectral data

8.11. Output file format – The following data files shall be generated at a minimum:

- Moments data files
- System health and monitoring data files

8.12. Moments data minimum requirements – the following variables shall be stored in the moments data file:

- Base time (time measurement began)
- Offset from base time (seconds)
- Number of FFT points used in moment estimation
- Range – distance for each radar range gate measured at the center of the range gate
- Modulation method
- Pulse width
- Pulse repetition frequency
- Transmit power
- Transmitter temperature
- Antenna gain
- Electronics rack temperature
- Environment control temperatures (if used)
- Calibration data
- Co-polarization reflectivity
- Differential reflectivity (ZDR)
- Co-polar correlation coefficient
- Differential phase (ΦDP)
- Specific differential phase (KDP)
- Cross-polarization reflectivity
- Mean Doppler velocity
- Spectral Width
- Noise level for each ray profile.
- Signal to noise ratio
- Antenna positioner elevation as a function of time; and,
- Antenna positioner azimuth as a function of time.

8.13. Spectra/Moments data file minimum requirements:

- Requirements are the same as the Moments file requirements with the addition of the radar spectra as a function of range and time.
- Operator shall be able to select a different directory/folder for storage of Spectra/Moments data. This shall be used at installations where we do not have enough Internet bandwidth to transfer spectra data in which case these data shall be written to an external disk.

8.14. System Monitoring and Health data file minimum requirements:

- Shall be daily files with ten minute mean, maximum, minimum, and standard deviation of the following variables:
    - Transmit power
    - Transmitter temperature
    - Antenna temperature
    - Electronics rack temperature
    - Key voltages
    - Disk usage
- This file shall be stored in two locations:

- The same directory as the Moments data file so that it can be collected by the ACRF site data system; and,
- An Archive directory on the data acquisition system that holds the last 90 days of the System Monitoring and Health data.

8.15. The radar application software shall allow for the provision to email a list of addresses in the event any of the monitored conditions is in an alarm condition.

9. Operator Interface

9.1. Local control - The system shall be designed so that a person using the data acquisition/control computer may operate it.

9.2. Remote control - The system shall be operable by remote control via an Ethernet network link. All operating functions shall be made available while operating in remote mode.

9.3. Selectable radar parameters - The operator shall be able to graphically select all applicable radar parameters in local mode. The operator shall be able to select all applicable radar parameters with a terminal window. The operator shall be able to select all applicable radar parameters with an ASCII readable configuration file. The system shall maintain a time stamped log file to identify whenever any of these parameters have been changed.

- Graphical display - The system shall provide 3-D graphical data for all the types of scans listed in Section 12. The software application shall display real-time 2D image plots as a plan position indicator display. The software application shall display real-time 2D image plots of range height indicator display. The software application shall display time-height plots (B-scope) of the profiles. The software application shall display an ascope. The parameters that shall be displayed at minimum are:
- SNR
- Received power
- Reflectivity
- Doppler velocity
- Spectra width
- Differential reflectivity
- Correlation coefficient
- Differential phase
- Specific differential phase

10. Scanning Requirements

10.1. The CSAPR-2 shall be mounted on an elevation over azimuth positioner.

10.2. The positioner shall be able to scan at a maximum speed of no less than 36 degrees/second with a positional accuracy of 0.1 degrees or better and peak acceleration of no less than 36 degrees/sec^2.

10.3. To the maximum extent possible, rotary joints/connections shall be used to connect the radar to its data acquisition system.

10.4. The system shall incorporate the following scanning techniques at a minimum:

- Range Height Indication (RHI)
- Plan Position Indication (PPI)
- Velocity Azimuth Display (VAD)
- Sector/Raster scans – the scan is defined by:
    - Starting elevation/azimuth
    - Ending elevation/azimuth
    - Elevation increment angle
    - Number of scans or continuous
    - Sweep speed
- Fixed staring mode – fixed elevation and azimuth with the ability to collect spectra data. This will most often be used for pointing at zenith. It will also be used for calibration to a fixed corner reflector. Operator enters:
    - Elevation
    - Azimuth
    - Dwell time or continuous staring
- Sequencing Staring mode – fixed elevation and azimuth with the ability to collect spectra data. This shall most often be used for pointing at zenith. It shall also be used for calibration to a fixed corner reflector. The system shall have the capability to store at least 5 fixed coordinates and step through these at a set dwell time. Operator enters:
    - Elevation
    - Azimuth
    - Dwell time or continuous staring

11. Operational Requirements

11.1. It is anticipated that some components of the CSAPR-2 shall be located on the positioner while some components shall be located indoors. The umbilical between the positioner and indoor components shall be no less than 7.5 meters long.

11.2. Control and parameter input shall be made via a GUI input, which can be password protected, or through a configuration file. Either way, the configuration history shall be archived.

11.3. The GUI shall display the current position of the positioner, its current scanning mode, its scan speed, and its current configuration of operation.

11.4. The CSAPR-2 shall have a “KILL” switch on both the positioner and indoor control rack, which shall immediately stop all positioner movement.

11.5. The CSAPR-2 shall have a “STOP” button on the client control software to immediately stop scanning.

11.6. The CSAPR-2 shall have an external calibration mode that allows the pointing of the radar at a known radar cross-section calibration target. The CSAPR-2 software shall automatically store data files from this target.

12. Calibration Tower Requirements

12.1. A trailer-mounted crank-up tower shall be included for each radar system. The extended height of the tower shall be roughly 10 m (33')(a Tashjian Towers Model CT33 or equivalent).

12.2. The tower shall also have a 20' composite or fiberglass flagpole that attaches to the top of the crank-up tower, for a total of 53' in combined tower and flagpole length. The means of attaching this flagpole to the tower shall be included. American Flag Store part number FGRES20PKG or equivalent.

13. Maintainability/Reliability Requirements

13.1. Availability greater than 95% for 24/7 operation

13.2. Easily maintainable with Line Replaceable Unit (LRU) design architecture

13.3. The radar system shall access panels to easily access key subsystems for preventive maintenance and testing.

13.4. Built-in test hardware and software shall be provided to adequately test the radar's performance.

13.5. Spare Parts - Each CSAPR-2 installation shall include a spare parts and maintenance support kit that shall support the system for 4 years and include for each radar (at a minimum):

- One transmitter system (transmitter tube, modulator, and power supply)
- One low noise amplifier (LNA)
- A spare computer for each computer used in the system. This shall include all additional boards, including digital receivers, which are installed.
- Receiver protection switches
- Extra waveguide run for a 40' run between the Radar Operations Shelter and the antenna/pedestal.
- Other components that have use/failure rate of less than 2 years to be identified by the Critical Design Review.

14. Environmental Requirements

14.1. **Temperature**: from -40 C to 60 C for outside components, 20 C to 35 C for indoors components.

14.2. **Relative humidity**: from 0% to 100% humidity.

14.3. **Winds**: the CSAPR-2 shall be designed to withstand sustained winds of 35 m/s and gusts to 45 m/s while operational.

15. Mechanical Requirements

15.1. **Weight**: prior to assembly, no single component of the radar and electronics (with the exception of the positioner and radome) shall weigh more that 90 kg.

15.2. **Size**: when disassembled and packed for shipment, all components shall fit into standard 20' ISO shipping containers.

15.3. **Mounting**: the CSAPR-2 and its supporting infrastructure shall be designed to withstand sustained winds of 35 m/s and gusts to 45 m/s.

16. Electrical Requirements

16.1. **Voltage:** 208/120 3-phase VAC

16.2. **Frequency:** 48 – 62 Hz

16.3. **Uninterruptible Power Supply (UPS):** 20 minutes for all components other than antenna positioner**.** The UPS shall have Internet connectivity with a web-based interface.

16.4. **Remote Power Control:** The power switches to each individual subsystem of the radar such as antenna servo amps, radar control unit, transmitter, digital receiver, signal generator, dehydrator, all computer servers, and any other subsystems shall be remotely (via internet) operable to power cycle the subsystems individually.

16.5. **Electrical Safety:** All non-NRTL certified electrical equipment or subsystems shall meet the requirements set forth in NFPA 70 and NFPA 70E.

17. Safety

Safety at ACFR sites is paramount. Since the CSAPR-2 transmits non-ionizing RF energy with the potential for personnel exposure and rotating portion of the radar weighs in excess of 500 lbs, upfront consideration of safety is required.

RF Exposure: An engineering analysis of RF Safety Hazards shall be provided during the Critical Design Review. IEEE C95.1 IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz shall be the basis for this analysis.

Safety Interlocks: The CSAPR-2 shall incorporate interlocks to prevent exposure to all voltages greater than 50V and to rotating machinery. Kill switches for the pedestal shall be mounted both in the operations shelter and outside the shelter to immediately disable pedestal motion.

18. Documentation

Because this system will be deployed in very remote locations all over the world, accurate and detailed system documentation is required.

- Schematics/Assembly Drawings for all systems and subsystems shall be provided in both paper and electronic format.
- As-built schematics and assembly drawings shall be provided with delivery of the system. Wiring diagrams shall also be provided in both paper and electronic format.
- Software Documentation shall be provided
- Source code shall be provided along with all appropriate make, build, link, etc files. A software maintenance manual shall also be provided that shows the organization of the software modules, data flow, file structure, interfaces, etc.
- Operations & Maintenance Manual
    - An Operations & Maintenance (O&M) Manual shall be delivered with the system. The O&M manual shall have a section that details the concept of operation. An appendix to this manual shall include manufacturer's data sheets for all electronic components in the system.

    - The operations manual shall provide procedures for configuration of any subsystem along with documentation for any subsystem specific software or process.
    - The maintenance manual shall describe the procedures for preventive maintenance associated every applicable subsystem.

19. Deliverables

The following deliverables are required:

- Preliminary Design Review within 6 weeks ARO
- Critical Design Review with 2 months after PDR
- Site Installation Drawings
- List of Export Classification for major components (components identified at CDR, due 2 months before installation)
- Operations/Maintenance Manual
- RF Safety Analysis
- Radar System to be comprised of (at a minimum):
    - Radar Operations Shelter with all associated electronics and data system mounted on a dedicated trailer
    - Antenna/pedestal system with dedicated trailer
    - 20’ x 8.5’ ISO shipping container for antenna, pedestal, and trailer
- Installation of CSAPR-2 at PNNL in Richland, WA
- Acceptance Test Plan prior to operational performance testing
- Two weeks of hands-off operational performance testing after installation at both sites
- Final Acceptance Test at PNNL in Richland, WA
- Operations and maintenance training at PNNL (24 hours minimum)
- Spare parts kits. Functionally tested spare parts shall be delivered. Minimum spare parts are:
    - Low noise amplifier
    - Complete transmitter/modulator/power supply
    - Spare for each installed computer with software installed
    - Spare panels for each type of antenna panel.
    - Extra waveguide run for a 40’ run between the Radar Operations Shelter and the antenna/pedestal.
    - Other components that have use/failure rate of less than 2 years to be identified by the Critical Design Review.