Maintaining Continuous Operation of Complex Instruments at the SGP CART Site

D. L. Sisterson
Argonne National Laboratory
Argonne, Illinois

J. J. Teske and D. K. Breedlove
ERC, Incorporated
Billings, Oklahoma

R. A. Peppler and C. P. Bahrmann
Cooperative Institute for Meoscale Meteorological Studies
The University of Oklahoma
Norman, Oklahoma

Introduction

In support of the scientific goals of the U.S. Department of Energy's (DOE's) Atmospheric Radiation Measurement (ARM) Program, the Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) site provides continuous data streams from unattended, complex instruments at remote field sites. The 31 SGP CART site facilities are distributed in a study area covering 55,000 mi^2, which contains 168 instruments with 837 sensors. The generation of continuous data streams is made possible by a tightly controlled process that ensures successful instrument maintenance. This maintenance process incorporates documentation, training, experienced maintenance personnel, and real-time coordination with the Site Scientist Team (SST), instrument mentors, and the site program manager's office to achieve high levels of data capture and data quality.

Instrument Maintenance Process

The instrument maintenance process at the SGP CART site consists of a cycle of structured activities that result in a continuous maintenance effort with the primary goals of 1) improving instrument reliability, performance, and data quality and 2) achieving cost efficiency. The six primary activities in the instrument maintenance process at the SGP CART site are depicted in Figure 1.

Instrument Maintenance Capability

Most of the instruments fielded at the SGP CART site use commercial sensors placed in stands and mounts of unique configurations for deployment at remote sites. Many of the instruments were

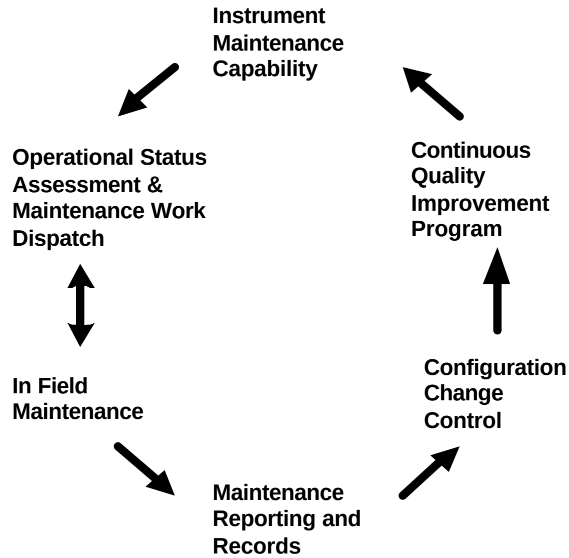

Figure 1. Instrument maintenance process.

developed uniquely and specifically for the ARM Program. A few instruments remain in a laboratory (developmental) configuration and are housed in environmentally controlled trailers or shelters at the SGP CART site.

Building a maintenance capability to service a wide variety of instrument types requires many support elements. Fundamental to this task is recruiting experienced local technicians. Instrument mentors and vendors have provided operations and maintenance training, as well as continued troubleshooting coordination and support, for the on-site technicians. These interactions have resulted in the transfer of the fundamental knowledge to perform field maintenance on the various instrument types. Operations and maintenance activities require a consistent, repeatable maintenance effort. Although technical documentation is provided with the instrument mentor/vendor training, most of the documentation at the appropriate skill level has been developed by site operations personnel in coordination with instrument mentors. This maintenance documentation has evolved into a substantial library of both paper and electronic procedures.

A reliable instrument maintenance capability requires efficient, timely methods for procuring parts and services to repair failed components. For the SGP CART site, these capabilities have been provided by the site program manager and staff at Argonne National Laboratory. They have established basic ordering agreements with several local vendors and support contracts with instrument vendors to allow parts, supplies, tools, test equipment, instrument sensor repairs, and spare components and assemblies to be obtained quickly. The implementation in 1998 of the SGP CART site's electronics repair laboratory (which serves all three CART sites) has enabled more on-site repairs of equipment and has resulted in reduced instrument down time related to off-site shipping and repair, as well as substantial cost savings to the ARM Program.

Because of the large total numbers of instruments and instrument maintenance records at the SGP CART site, the most efficient way to document maintenance was to implement a full office automation capability on-site. In 1996, a personal computer (PC) network using servers running Microsoft NT was designed and implemented. With the establishment of this network, site operations staff were able to expand and fully automate instrument maintenance reports by using weather-hardened laptop computers that could be taken into the field. All instrument maintenance reports were converted from paper forms to data base records, yielding a cost-efficient method for capturing and manipulating maintenance information. Other infrastructure data management processes were also transformed to data bases maintained on the PC network. During 1997, most archived paper records were converted to electronic format, and the fully implemented integrated system was dubbed the Operations Management Information System (OMIS). This system provides an on-site capability for rapid exchange of all aspects of operations data and information. By early 1998, OMIS was expanded with a World Wide Web interface, giving the site program manager's office access to operations and budget information.

Instrument Operational Status Assessment and Maintenance Work Dispatch

A key element in performing efficient maintenance is having a capability to assess the operational status of instruments. At the SGP CART site, this is done through daily interaction between site operations maintenance personnel, the on-site data system computer operator (hereinafter called the on-site operator), the on-site scientist, and instrument mentors.

During weekday operations, the on-site operator uses the Site Data System (SDS) instrument status Web site to determine whether the SDS is collecting and processing data from the SGP CART site's individual instruments. Error conditions in the status displays denote problems in the communications path between the SDS and instruments in the field. Typical problems concern modems, automatic switching devices, and telephone lines. Upon observation of a problem, the on-site operator notifies the maintenance manager, who analyzes the information and checks other sources. The maintenance manager initiates work orders for troubleshooting and repair of the failed communications components. Communication is initiated with the SGP Data and Science Integration Team developers for software and hardware problems related to the actual SDS and the integrated data processing circuit, which is the complete electronic pathway of data collected from the instruments for delivery to the ARM Experiment Center at Pacific Northwest National Laboratory and to the ARM Data Archive at Oak Ridge National Laboratory.

During weekday operations, the on-site scientist also performs instrument data quality assessment through the use of automated quality metrics. If the on-site scientist identifies preliminary data quality problems, he notifies the maintenance manager, and additional instrument maintenance work orders are initiated. More complete weekly data quality reports are submitted to the maintenance manager by SST members at the Cooperative Institute for Mesoscale Meteorological Studies (University of Oklahoma) or at the University of Utah and by instrument mentors. The maintenance manager reviews these reports and initiates work orders where applicable.

Other instrument operational status assessments come from the field maintenance technicians themselves. Their assessments consist of observed failures in the field that cannot be repaired during the technician's visit and are scheduled for maintenance when replacement parts become available.

The on-site manager, in concert with the SST and the site program manager, can dispatch nonroutine (e.g., triage) visits to any of the 31 site facilities when an interrupted data stream from a particular instrument or suite of instruments has been identified as critical, as in association with an intensive observation period (IOP) or a campaign. A triage team of field maintenance technicians is dispatched to each site to provide corrective maintenance (CM), usually within 24 hours.

In-Field Maintenance

Routinely scheduled instrument preventive maintenance (PM) is performed at the SGP CART site's central facility (CF) and at the 23 extended facilities (EFs), 4 boundary facilities (BFs), and 3 intermediate facilities (IFs). Most of the CF instruments receive PM daily, five days per week, except for holidays. Some CF instruments, such as the energy balance Bowen ratio station, surface meteorological observation station, soil water and temperature system, and eddy correlation equipment, receive PM biweekly, as do all instruments at the EFs, BFs, and IFs.

The SGP CART site is divided into four quadrants: two in the northern half and two in the southern half. Each week, two field maintenance technician teams leave the CF on a multi-site road trip. The first week, the two teams service EFs at the northern sites, with one team traveling the northwest quadrant route and the other team the northeast quadrant route. The second week, the two teams service the EFs at the southern sites, with one team traveling the southwest quadrant route and the other team the southeast quadrant route. Figure 2 shows the biweekly EF maintenance travel routes for the SGP CART site.

Maintenance at Extended Facilities

Preparation for the EF maintenance trip consists of completing a detailed predeparture inspection checklist for PM, loading spare parts and test equipment, and receiving a briefing on the work orders to be completed during the week's trip. In addition, the field maintenance technician team receives money for lodging, meals, and other expenses for the week's trip.

Upon arrival at the first EF site, the team asks the on-site operator at the CF to turn off the SDS automated collection and ingest processes, to prevent the collection and processing of instrument data during maintenance. The team then performs PM checks on all of the EF's instruments and communications equipment.

A detailed, instrument-specific PM checklist for each of the EF's instruments is completed by using a field-hardened laptop computer. The electronic record forms are menu driven, with drop-down, preformatted responses for each instrument checklist item. For some instruments, the laptop computers are connected to the instrument data loggers, and real-time sensor voltages, meteorological values, or both are observed. If the observed values fall outside the expected range, the applicable data base field is marked as an observed problem, and troubleshooting begins. All instrument problems that are observed at an EF or are worked on as a result of a work order are fully documented in a CM report on the laptop computer as a data base record. These reports document the date and time of the problem, the location, the instrument, a problem description, the problem resolution or action taken, whether the action fixed the problem, the date and time the instrument was returned to operational status, the suspected root cause of the failure, and the name of the specific component that failed or was the cause of the problem.

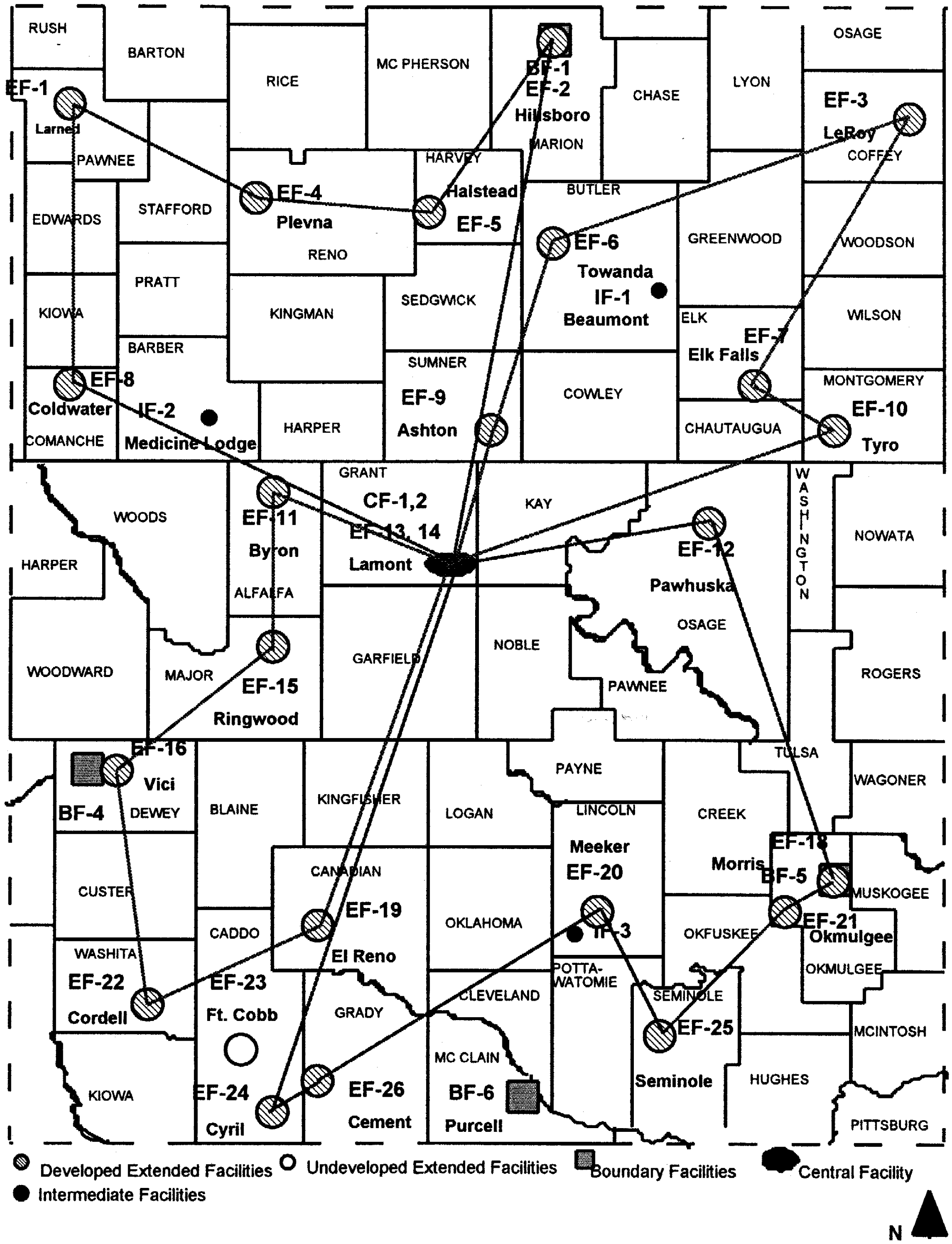

Figure 2. EF service routes (NE, NW, SE, SW) for the ARM SGP CART site. Approximate scale: 50 kilometers (31 miles) per inch.

Other activities performed at the EF by the field maintenance technician team include observing and recording the surface conditions of vegetation types, vegetation heights, and other relevant information. The teams also inspect and document the EF's grounds and safety equipment and download instrument data stored on individual instrument loggers over the past two weeks. This "sneakernet" data is the backup data set used to fill gaps when data were not successfully collected remotely by the SDS. When all of the scheduled PM work, scheduled or unscheduled CM work, grounds reports, and the sneakernet data gathering are complete at the EF, the team notifies the on-site operator at the CF to initiate remote testing to verify communication between the CF and the EF. When communications are in place, the on-site operator turns the remote collection and ingest processes back on at the CF, and the field team departs the EF for the next site on the maintenance route.

During any given week of EF maintenance, each field team typically completes about 75 PM checklists for instruments and site equipment and 25 individual CM actions at the EFs. On average, field maintenance technician teams are at each EF for 1-2 hours. The need to complete their route sometimes prevents teams from making all the appropriate repairs before they move on to the next EF. In such cases, a field team can be dispatched for emergency repairs, or repairs can be completed during the next regular visit. Emergency repairs are authorized by the on-site manager, the SST, and the site program manager.

Maintenance at Boundary and Intermediate Facilities

Scheduled PM and scheduled or unscheduled CM are performed biweekly at the BFs and IFs. Only one field maintenance technician team is dispatched for this work. The first week, the team services the northern BFs and IFs. The second week, the team services the southern BFs and IFs. Because the instruments at these sites (radar wind profilers, atmospherically emitted radiance interferometers, etc.) are relatively complex, this maintenance is performed by more senior field maintenance technicians. Preparation for the BF/IF maintenance trips is the same as that for the EF trips. The routes for BF/IF maintenance are shown in Figure 3.

The field maintenance technician team departs the CF and drives to the first BF/IF and completes PM checklists, as well as scheduled and unscheduled CM, on the BF/IF instruments and equipment. All checklists are completed on a laptop computer. Sneakernet data are collected from applicable BF/IF instruments. When the maintenance work is complete, the team departs and drives to the next site scheduled. During a typical week, the team completes 12 PM checklists and 2-4 CM actions at each BF or IF, spending 2 hours at each facility.

Maintenance at the Central Facility

For the CF instruments (excluding the EF instruments collocated at the CF), PM is performed every weekday, except for holidays, again by using checklists on a laptop computer. A more frequent PM schedule has been implemented at the CF because of the ease of access and the greater complexity of the instruments. Some instruments require minimal effort, such as daily liquid nitrogen coolant filling, dome cleaning, and minor adjustments for alignment or shading. Complex systems requiring daily

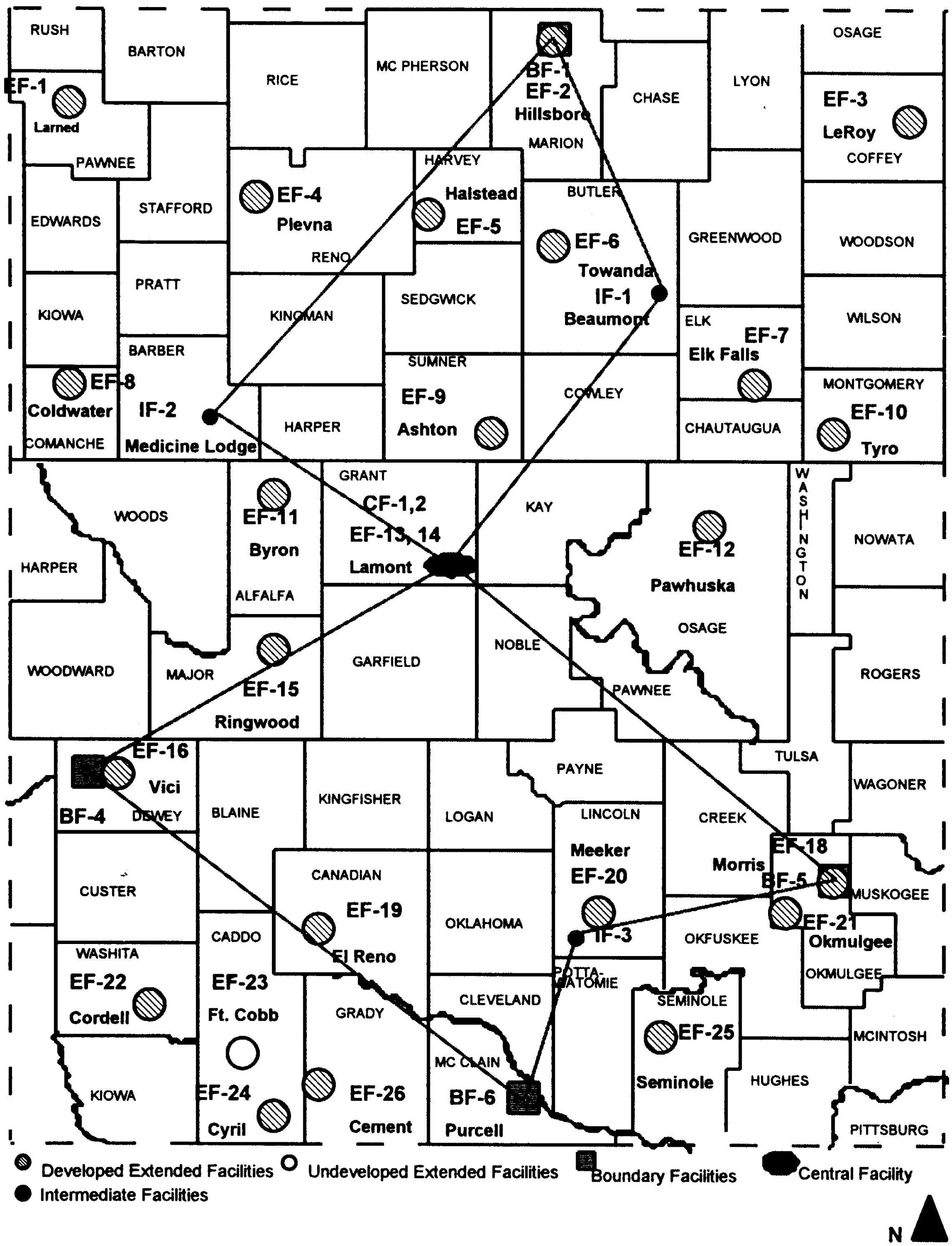

Figure 3. BF and IF service routes (N, S) for the ARM SGP CART site. Approximate scale: 50 kilometers (31 miles) per inch.

inspection (and considerable daily effort) include the aerosol observing facility, the optical trailer instruments, the radar wind profilers, the Millimeter Cloud Radar, the Whole-Sky Imager, the 60-m tower and instruments, and the Radiometer Calibration Facility.

The Raman Lidar is unique in that its operational status is normally checked several times a day during operation. If the instrument is not running, a manual start-up procedure is performed when sky conditions permit laser alignment. A recently installed uninterruptible power supply provides constant power to the system so that it can operate continuously through power bumps or outages lasting nearly 60 minutes.

During a typical 5-day work week, technicians perform 103 PM procedures on CF instruments. Each procedure generates a report. In addition, Instrument Development Program instruments and long-term and short-term guest instruments require PM visits. The CM activities vary from week to week. At the CF, where the instruments are more complex, the weekly time required for CM activities varies from 15 minutes to several days. The on-site manager schedules triage visits to EFs when CM activities are not required at the CF.

Maintenance Reporting and Records

As discussed above, a large number of PM and CM reports are completed each week. Several processes are performed at the CF both during and at the end of each work week to distribute these reports to users.

The site operations PC network is the environment for electronic processing, distribution, and archiving of PM, CM, and other field maintenance reports. When the daily CF PM and CM reports are completed on the laptop computer, the laptop is docked to the network, the data records are downloaded into a clearinghouse holding directory of data base files, and the laptop data base records are cleared. The individual data base records are reviewed for quality and completeness, then exported to a Crystal Reports application for formatting. In Crystal, the reports are processed and exported to an outgoing FTP (file transfer protocol) directory, formatted as tab-separated values or tab-separated text. The files are then sent via FTP to the ARM Meta Data System (MDS) at Brookhaven National Laboratory, where the records are read and inserted into an Empress data base.

The records in the holding directory are also imported into other data bases at the CF that provide user access to the information via the OMIS Web site. When the reports have been distributed to the MDS and OMIS, the records are imported from the holding directory into a master set of data base records for archiving. The holding directories are cleared of records and made ready to import the next day’s or week’s reports. OMIS is a security-protected site to which access is available upon approval by the site program manager.

Data base records for EF, BF, and IF maintenance trips are downloaded weekly from the laptop computers to the CF holding directories. The above process of quality checking, file formatting, FTP transfer, and archiving is also performed on these records. Each of the laptop computers is cleared of report records and prepared for next week’s maintenance trip.

After the PM, CM, and other reports are cleared from the laptop computers, the sneakernet data files collected during the week are extracted and sent to the SDS for transfer to the ARM Data Archive. Each week, reports and sneakernet data are extracted from six laptop computers used for CF, BF, IF, and EF maintenance activities.

Instrument Configuration Change Control

Changes to instrument hardware, software, and maintenance procedures are expected as part of the evolution of ARM measurement needs. A formal process to control, review, and approve these changes has been established as the Baseline Change Request (BCR) system under the management of the site program manager. When a change to an instrument or facility system (hardware, software, or both) is needed, a BCR form is submitted via the Web. Anyone in the ARM Program can submit a BCR. The BCR is reviewed by the site program manager and is assigned a priority, and BCR reviewers are identified. Each of the reviewers is notified via electronic mail that a new BCR has been submitted and is ready for review. The reviewers enter the appropriate security codes to obtain access to the Web-based BCR system and consider the BCR for approval.

The site program manager prioritizes BCRs as follows: emergency (requiring approval in 24 hours or less), critical (1-3 days), very important (3-5 days), important (5-7 days), and routine (7-14 days or longer). The reviewers' comments are captured as follow-up information appended to the BCR data record. Several iterations of comments and reviews are often required to answer questions and address issues associated with the proposed change. When the reviewers are satisfied that all of their comments have been addressed, they submit their approval for the change in a follow-up comment. When the site program manager determines that all issues have been resolved, the BCR is approved, and the change is implemented. Depending on the complexity of the change, an implementation plan might be required to coordinate activities.

Upon successful completion of the change, a final follow-up comment is submitted, denoting that the change has been completed. The site program manager then closes the request, and the BCR is permanently archived. BCRs often require changes to supporting documentation such as procedures and drawings. These changes are made to the appropriate documentation as part of the BCR implementation process.

Continuous Quality Improvement

The SGP CART site has implemented a Continuous Quality Improvement (CQI) program for all site activities. The CQI program consists of a cycle of planning, implementation, proficiency checking, and analysis. For instrument maintenance, CQI activity includes periodic on-site audits by individual site operations managers, the SST, the site program manager, and the site safety officer. The audits include documented inspections and observations of instruments, maintenance procedures, technician proficiency, and other work quality measures. Data collected during the audits are analyzed, and improvements in the work process are developed and inserted into the planning process for implementation.

Continued audits and checks provide feedback to the quality cycle by assessing the effects of the improvements. This continuous assessment provides the mechanism for evolution and improvement in instrument performance.

Acknowledgments

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