MSL-RAD Cruise Operations Concept

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The Mars Science Laboratory (MSL) payload includes the Radiation Assessment Detector (RAD) instrument, intended to fully characterize the radiation environment for the MSL mission. The RAD instrument operations concept is intended to reduce impact to spacecraft resources and effort for the MSL operations team. By design, RAD autonomously performs regular science observations without the need for frequent commanding from the Rover Compute Element (RCE). RAD operates with pre-defined "sleep" and "observe" periods, with an adjustable duty cycle for meeting power and data volume constraints during the mission. At the start of a new science observation, RAD performs a pre-observation activity to assess count rates for selected RAD detector elements. Based on this assessment, RAD can enter "solar event" mode, in which instrument parameters (including observation duration) are selected to more effectively characterize the environment. At the end of each observation period, RAD stores a time-tagged, fixed length science data packet in its non-volatile mass memory storage. The operating cadence is defined by adjustable parameters, also stored in non-volatile memory within the instrument. Periodically, the RCE executes an on-board sequence to transfer RAD science data packets from the instrument mass storage to the MSL downlink buffer. Infrequently, the RAD instrument operating configuration is modified by updating internal parameter tables and configuration entries.

RAD cruise operations were conducted at JPL through the MSL Mission Operations Team. RAD activities were fully reviewed and approved according to procedures consistent with a NASA flagship mission. No formal mission requirements were in place for conducting a long-term science investigation with instruments in cruise. Yet the RAD instrument characterized the radiation environment *inside* an interplanetary spacecraft for over seven months in transit to Mars. This paper describes operations concept for the RAD instrument during the cruise phase of the MSL mission.

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I. Introduction

The Radiation Assessment Detector (RAD) flight instrument aboard Mars Science Laboratory (MSL) is designed to measure a broad spectrum of energetic particle radiation. It will make the first-ever direct radiation measurements on the surface of Mars, detecting galactic cosmic rays, solar energetic particles, secondary neutrons, and other secondary particles created both in the atmosphere and in the Martian regolith. The radiation environment on Mars, both past and present, may have implications for habitability, a key science objective for the MSL mission. Radiation exposure is also a major concern for future human missions to Mars or other destinations beyond Earth orbit. In fact, the MSL/RAD investigation is an Advanced Exploration Systems project in NASA's Human Exploration and Operations (HEO) Mission Directorate. Unlike other MSL science instruments, RAD operated throughout most of the cruise phase of the MSL mission. Extended cruise operations for RAD provides a unique dataset for assessing the radiation environment within an interplanetary spacecraft. This paper describes the cruise-phase operations concept for the MSL/RAD instrument.

II. RAD Instrument Overview

A. RAD Instrument Hardware

The Radiation Assessment Detector (RAD) instrument[1] aboard the Mars Science Laboratory (MSL) is a very compact, low-power science instrument capable of characterizing a broad spectrum of radiation. RAD is designed to minimize critical mission resources (mass, power, data volume and operations overhead) while returning detailed information regarding the complex radiation environment encountered in a shield spacecraft and on the surface of Mars.

RAD consists of the RAD Sensor Head (RSH) and the RAD Electronics Box (REB) integrated together in a small, compact volume. The RSH contains a charged-particle telescope with three silicon PIN diode solid-state detector assemblies (SSDs A, B, & C), a thallium-doped Cesium Iodide (CsI) scintillator, plastic scintillators for neutron detection and anti-coincidence shielding, and the front-end electronics. The REB contains the RAD Analog Electronics (RAE), the RAD Digital Electronics (RDE) and RAD Sleep Electronics (RSE). The RAE features a novel mixed-signal Application-Specfic Integrated Circuit (ASIC) for analog signal processing, the Voltage-Input Readout Electronics for Nuclear Applications (VIRENA). This ASIC is controlled by the Electronics for VIRENA Interface Logic (EVIL) Field-Programmable Gate-Array (FPGA). The RDE includes a second FPGA to communicate with the rover and perform onboard analysis of science data. The RSE includes sleep-timer circuits to control internal instrument power supplies. The sleep-circuit enables autonomous operation, independent of commands from the rover. RAD is a highly capable and highly configurable instrument that can operate in a variety of spacecraft, including the International Space Station and future human spaceflight vehicles in development. The entire package, including all electronics needed for signal processing and communication with the rover, is contained in a package with a mass of 1.56 kg. Power consumption while acquiring science data is 4.2 W.

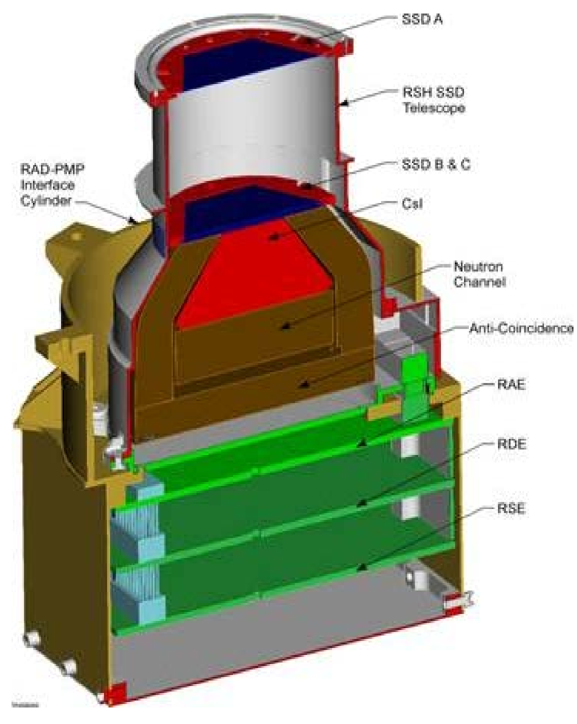

Figure 1. Cut-away view of the RAD instrument.

The RAD instrument is mounted internally within MSL, with the SSD telescope field-of-view extending through the top deck of the rover. A thin window, consisting of a 25-micron Kapton outer film bonded to a 25-micron thick aluminum foil, provides a light-tight protective cover for RAD within MSL.

B. RAD Instrument Operations

RAD, as initially conceived, was to operate continuously on the surface of Mars with data being stored to internal memory every hour. However, due to energy constraints of the MSL rover power system (which became apparent during the early design phase of the project), RAD was subsequently designed to operate autonomously for arbitrarily long observing periods, alternating with intervals of a low-power sleep state. This approach maintains a regular observing cadence necessary to meet the science objective of characterizing the onset of SEP events, while reducing the overall energy requirements on the rover. While awake, RAD collects, bins, and formats its measurements, and saves the data to Non-Volatile Random Access Memory (NVRAM). The science data (up to 1023 packets) will remain in NVRAM until the Rover Compute Element (RCE) is ready to transfer them to the Rover telemetry storage.

The RAD operational concept is also intended to reduce impact to spacecraft resources and effort for the MSL operations team. By design, RAD autonomously performs synoptic science observations without the need for frequent commanding from the RCE. RAD operates with pre-defined “sleep” and “observe” periods, allowing its duty cycle to be adjusted for power and data volume constraints during the mission. During the start of a new science observation, RAD performs a brief pre-observation activity to determine whether a Solar Particle Event (SPE) is in progress, based on count rates for selected RAD detector elements. If count rates exceed a specified threshold, RAD will configure for “solar event” mode, in which instrument parameters (including observation duration) are selected to more effectively characterize the environment. At the end of each observation period, RAD stores a time-tagged, fixed length science data packet in its non-volatile mass memory storage. The operating cadence is defined by adjustable parameters, also stored in non-volatile memory within the instrument. Periodically, the RCE will execute an on-board sequence to transfer RAD science data packets from the instrument mass storage to the MSL downlink buffer. (This sequence was built into the daily operations sequence.) The RAD instrument’s internal configuration can be modified by updating parameter tables; these modifications are performed infrequently during cruise.

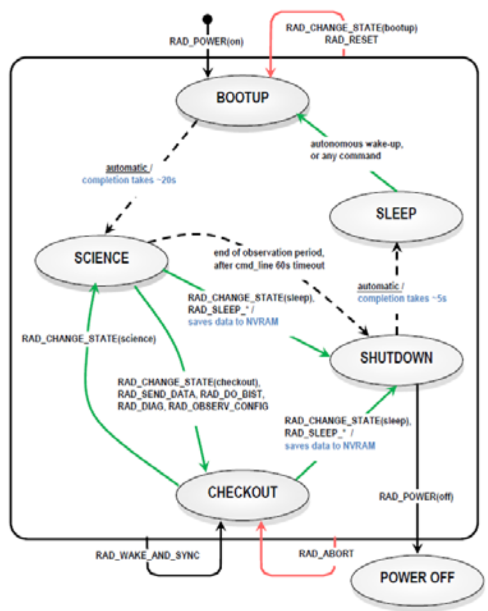

Figure 2. RAD instrument state-diagram.

RAD operates as a state-machine (Fig. 2), with the six states described in Table 1. In the power-off state, no operations or communications are performed by the RAD instrument. Upon the rover RAD_POWER(ON) command, RAD immediately enters BOOTUP state in which a specified image of operating software is loaded, verified and executed. RAD configures itself for science observations during BOOTUP, doing a pre-observation sampling of event rates to determine whether a solar event in in progress. RAD then transitions into SCIENCE mode, observing and recording radiation events for the prescribed observation period. At the end of the observation, RAD enters the SHUTDOWN state where it compresses the observation data into a fixed-sized data packet, stores the science data to flash non-volatile memory, then writes status information in preparation for the next science observation. RAD then loads the sleep timer and goes to SLEEP. RAD remains asleep until the sleep timer expires at which point RAD powers itself on, enters BOOTUP state and repeats the cycle. The need for the RCE to command RAD may occur at any point in the autonomous cycle. The RAD instrument is designed to “wake-up” from SLEEP state should command-line activity be detected. The rover FSW is designed to gracefully wake RAD up, regardless of current state, to permit interactive commanding to occur. In these commanding sessions, RAD is transitioned into CHECKOUT state, in which no science processing is performed. Rather, RAD is fully responsive to spacecraft commands which may request data transfers, modify RAD operating parameters or even update RAD instrument software.

Table 1. RAD Instrument State Descriptions

RAD State	Description	RCE State	Commanding	Data Produced
OFF	The power to the RAD is off	N/A	None	None
BOOTUP	Checks PROM and EEPROM integrity. Configures Sensor Head for expected radiation environment. Transitions to the SCIENCE state.	On or Off	None	None
SCIENCE	Radiation science data is collected.	On or Off	All commands except memory commands	Science data, housekeeping, messages
CHECKOUT	Can perform memory loads, dumps, RAM checkout, self-diagnostics and data transfer to RCE.	On	All commands	Engineering, housekeeping, messages
SHUTDOWN	Processes and stores science data in RAD NVRAM, saves internal parameters for next observation, loads sleep timer and initiates sleep state	On or Off	None	None
SLEEP	Main 28VDC supply is on, RAD secondary supplies are off. RDE is not powered. RAD monitors Rx line for activity, or waits prescribed sleep duration to complete.	On or Off	Any toggle on the command line will wake-up RAD	None

C. RAD Commanding (MSL Rover FSW interface)

The RAD instrument operates on MSL via sequenced activities built from a small set of spacecraft commands required to meet the instrument needs. The RAD_POWER commands control the power-state of RAD. RAD_POWER(ON), not only applies spacecraft power to the instrument, but also initiates communications between the RCE and instrument. The RAD instrument is also provided current spacecraft clock (SCLK) time during RAD_POWER(ON). The RAD_POWER(OFF) command gracefully turns the RAD instrument off by commanding the instrument to SHUTDOWN then SLEEP state before removing spacecraft power. As designed, RAD can operate autonomously for hours, or even days without command from the RCE. Periodically (usually daily), RAD science data are transferred to the RCE to be downlinked to the ground. The RAD operating cadence is interrupted by the RAD_WAKE_AND_SYNC command. This command is designed to transition RAD to CHECKOUT state from any of the possible states of RAD: SLEEP, BOOT, SCIENCE and SHUTDOWN. As such, the RCE will make up to three attempts to command RAD into the responsive CHECKOUT state before either proceeding with time synchronization or declaring an instrument fault. With RAD in CHECKOUT state, other commands can be issued to retrieve health/status information (RAD_DIAG), transfer the entire store of science observations (RAD_SEND_DATA), change RAD observation characteristics (RAD_OBSERV_CONFIG), modify internal signal and/or data processing parameters (RAD_MEM_LOAD_TABLE), or load a new code image into electronically erasable/programmable read-only memory (RAD_MEM_LOAD_CODE). After the desired transactions between the rover and RAD instrument are completed, the autonomous observation cycles are resumed by commanding RAD to sleep (RAD_SLEEP_FOR_TIME). Nominal RAD operations consists of regular science data transfer activities with infrequent changes to RAD configurations or internal processing parameters. There are additional commands for off-nominal operations (RAD_ABORT, RAD_RESET), but these commands were not utilized in flight operations.

III. Cruise Operations Processes

MSL flight operations were conducted at JPL, utilizing the MSL Ground Data System (GDS) and Deep Space Network (DSN) infrastructure. The architecture of the MSL GDS[2] provides elements for activity planning and sequencing, downlink pipeline processing of engineering and science telemetry, uplink processing, support for navigation and trajectory design, spacecraft engineering assessment and science product tools (including planning and visualization). RAD operations relied heavily on the capabilities provided by the MSL GDS to conduct the successful cruise campaign. Fig. 3 below illustrates the tactical data flow for instruments through the MSL GDS.

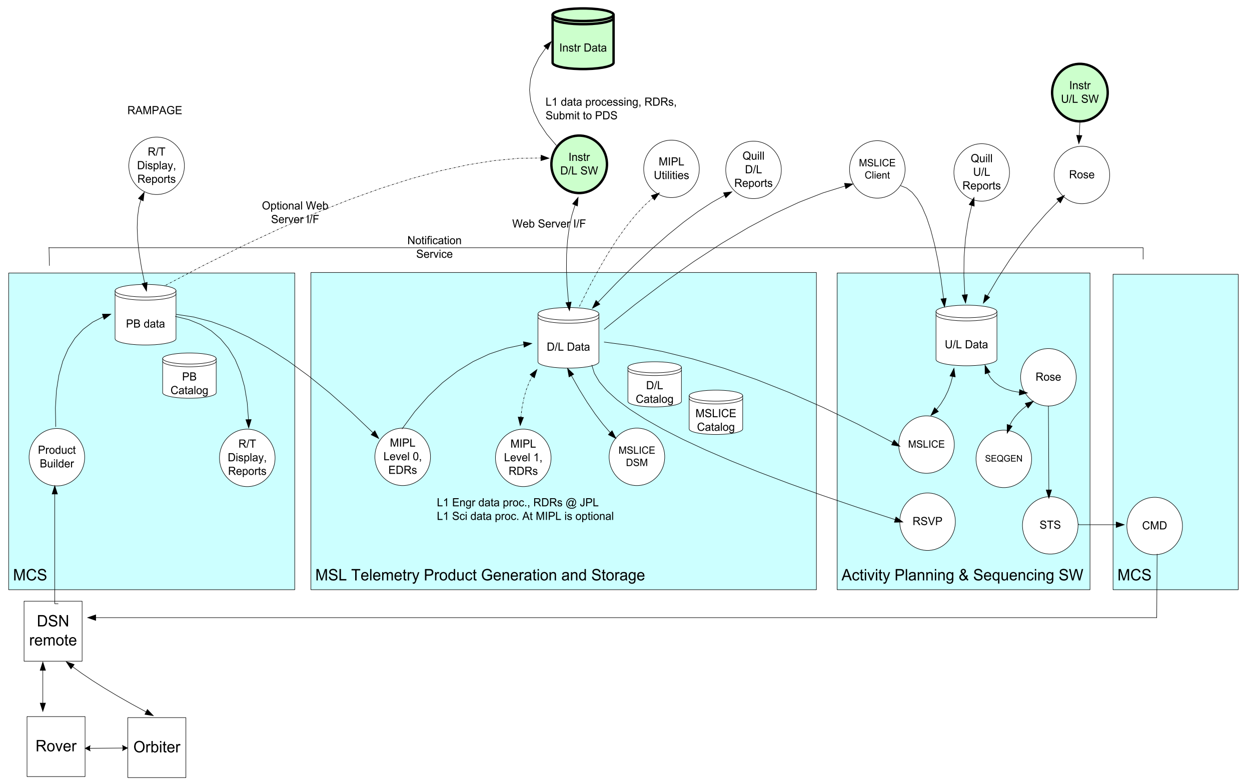

Figure 3. MSL GDS Tactical Data Flow

Key Acronyms: MIPL – Multi-mission Image Processing Laboratory, D/L –Downlink, U/L – Uplink, MCS – Mission Control System, MSLICE – MSL Interface, SEQGEN –Sequence Generation /Validation, STS – Sequence Translation System, RSVP – Rover Surface Visualization and Planning tool

Mission operations functions via a set of rigorously controlled processes, developed to avoid unintended activities that can lead to problems, failures, even loss of mission. There is a strong driver to minimize commanding during flight, since problems can arise from several factors: from errors in commands and associated parameters, to loss of commandability (telecommunications link failure) during a pass. As a result, all commanded activities are thoroughly reviewed, with sequence testing and multiple checks of accuracy of the uplink products performed. Cruise operations for the RAD instrument were not a mission requirement, so it was even more important to demonstrate RAD activities and commanding were benign; posing virtually zero risk to the mission. Ground processing of data products from science instruments is geared to surface operations, so the pipeline for handling science data was still in development throughout much of the cruise phase of the mission. The RAD instrument provided a modest datastream which permitted realistic checkout of the ground data pipeline prior to landing. The following sections outline the processes and sequences employed for RAD operations throughout cruise.

A. Overview MSL cruise uplink processes:

Throughout cruise, the mission plan consisted of "cruise segments" which generally were one-week in duration. The planning, sequencing, approval for uplink cycle for cruise activities was two-weeks in duration, thus there were generally two cruise segments in development simultaneously for the operations team. Througout the cruise phase, there were mission critical acitivities planned. Trajectory correction maneuvers, attitude maintenance turns, flight software uploads, subsystem checkouts and characterizations, navigation activities, and science instrument checkouts were required to be performed to deliver the rover to Mars in a reliable manner. The mission operations team entered cruise with a detailed, approved mission plan and there was little margin for extraneous activities.The RAD investigation approached the MSL mission operation team with a “minimalist” plan to allow science to be gathered and incremental adjustments be made to the instrument in cruise.

A timeline for MSL uplink builds is provided in Fig. 4. An Activity Lead (AL) shepherds each activity through the uplink process. For a RAD activity to be incorporated into the uplink build process, a Cruise Activity Design (CAD) document is first reviewed and approved at the the Activity Plan Approval Meeting (APAM) for formal inclusion in the Mission Plan (MP). Once approved, RAD sequences were built using the MSL Sequencing (MSEQ) tool and tested prior to delivery to the Sequence Integration Engineer (SIE). The integrated sequences are executed in a workstation testset (WSTS) or full engineering testbed environment with the products and execution timing compared with modeled results. Test results, flight rule compliance and associated ground operations procedures for the activities are reviewed before the uplink products are built. The final uplink products (sequences and file loads) are compiled, then subjected to final review prior to the Command Approval Meeting (CAM) where final approval for uplink is reached. Some sequence uplink products are uplinked in a bundle associated with activities in the cruise segment, where others products (such as file loads or contingency sequences) may not be uplinked until the time of execution. At the time of execution, the AL supports the activity from the Cruise Mission Support Area (CMSA), following a detailed on-console procedure.

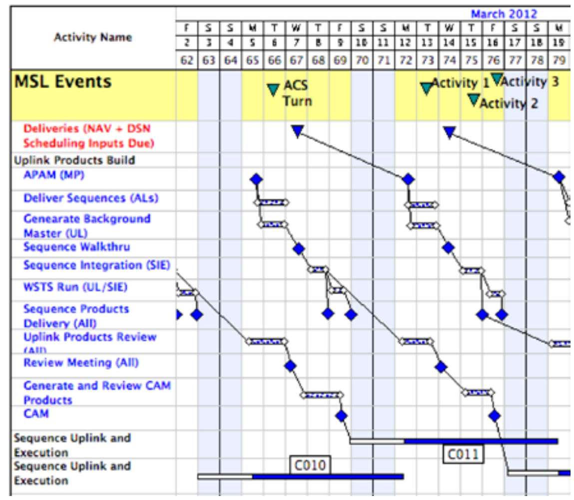

Figure 4. MSL uplink build process timeline.

B. RAD Sequences

The cruise activity approval is a time-consuming and detail-driven process. Fortunately, once approved and uplinked sequences remained on-board and were activated multiple times without detailed review. For RAD, the majority of RAD activities were repeated. The RAD instrument was turned off for several critical events, then turned back on following the critical activity. Transfer of RAD science data to the RCE for downlink was almost a daily occurrence. The RAD_TurnON, RAD_TurnOFF, and RAD_GetData sequences were workhorses for RAD operations in cruise. Even these sequences were built, delivered and tested multiple times for the mission: unique sequences were delivered for the RCE-A and RCE-B flight computers, and these sequences were re-compiled for the updated version of rover flight software loaded on both computers mid-cruise. Each of these RAD sequences have similar command constructs imbedded. After either power-on or wake-up commands, a set of RAD engineering products were retrieved and downlinked. In the case of the RAD_GetData sequence, a single command (RAD_SEND_DATA) would transfer all of the previously untransmitted science observations stored since the prior RAD_GetData activity. The RAD_GetData sequence was generally activated from a daily maintenance activity called by the “master sequence” which was uploaded for most cruise segments. RAD_GetData activities frequently occurred during periods when MSL was not in contact with the ground. In this regard, RAD was operated more like an engineering subsystem than a science instrument. RAD instrument operating configurations and/or internal parameters were adjusted four times during cruise (and once at the end of cruise to configure for initial surface operations). A “template” sequence, RAD_TableUpdate, was used to perform such changes to RAD. Updated entries for internal signal processing values, such as offsets, gains, thresholds for detector channels were provided in binary files targeted for specific tables within the RAD instrument. The individual values within these files were determined by the RAD Science Team, based on instrument calibration factors and anaylsis of prior science data. A unique sequence, RAD_Weekend_GetData was used for managing RAD science downlink, when no master sequence was on-board to call RAD_GetData. The last sequence executed, RAD_End_of_Cruise, configured RAD for initial Mars surface operations, downlinked the last cruise data and power off RAD until after MSL landing on Mars.

Table 2. RAD Sequences used during Cruise

Sequenced Activity (# of instances in cruise)	**Activity Description**	**Data Products**
RAD_TurnON (30)	Turn on power to RAD Synchronize with Spacecraft clock Transfer Engineering packets to RCE Initiate Observation cadence (sleep/observe)	RAD Health/Status RAD Memory Test
RAD_TurnOFF (29)	Wake-up RAD and synchronize clock Transfer Engineering, Science packets to RCE Turn off power to RAD	RAD Health/Status RAD Science Packets
RAD_GetData (240)	Wake-up RAD and synchronize clock Transfer Engineering, Science packets to RCE Resume Observation cadence (sleep/observe)	RAD Health/Status RAD Science Packets
RAD_TableUpdate (4)	Wake-up RAD and synchronize clock Transfer Engineering packets to RCE Modify RAD Observation Configurations Load RAD Table entries (from binary files) Resume Observation cadence (sleep/observe)	RAD Health/Status
RAD_Weekend_GetData (4)	Upon activation wait 36 hours Activate RAD_GetData sequence	RAD Health/Status RAD Science Packets
RAD_End_of_Cruise (1)	Wake-up RAD and synchronize clock Transfer Engineering packets to RCE Modify RAD Observation Configurations Initiate surface observation cadence (observe) Wait 50 minutes then activate RAD_TurnOFF	RAD Health/Status RAD Science Packets

C. RAD Data Product Downlink Pipeline

During cruise operations, RAD sequences produced a variety of engineering and science data products which are transferred to the RCE for subsequent downlink. All of the data products aboard MSL are assigned priorities for downlink, depending upon their importance in assessing overall spacecraft health and status. Some real-time telemetry relevant to RAD general health is downlinked for display on consoles in the CMSA. RAD engineering and science data products are downlinked as fixed-format files when their priority level is reached. RAD engineering data products are typically small (less than 2 kbytes) and are intended for detailed investigation should anomalous behavior be observed in RAD performance. RAD science data products can be rather large (up to 3 Mbytes), since a single data product contains all observations transferred to the RCE since the previous instance of RAD_GetData. Early in the mission, RAD observations were recorded at 8-minute intervals, generating up to 180 science packets in a day. Once the science data product is received on the ground, the MSL GDS processes the raw product to generate RAD Experiment Data Records (EDRs). RAD EDR data products consist of the raw instrument dataset that is reformatted to conform to Planetary Data System (PDS) standards. Detailed descriptions of these data are given in the RAD PDS Interface Control Document (ICD) and the EDR Software Interface Specification (SIS) document, available in the PDS archive. EDRs are created with data content spanning a full day-of-year (DOY) based on Universal Coordinated Time (UTC). The RAD EDRs are published and distributed via the File Exchange Interface (FEI) supported by the MSL GDS. A subscription from FEI provided automatic transfer of newly processed RAD EDRs to the RAD Science Operations Center (RAD-SOC) server for incorporation into the RAD data pipeline (see Fig. 5).

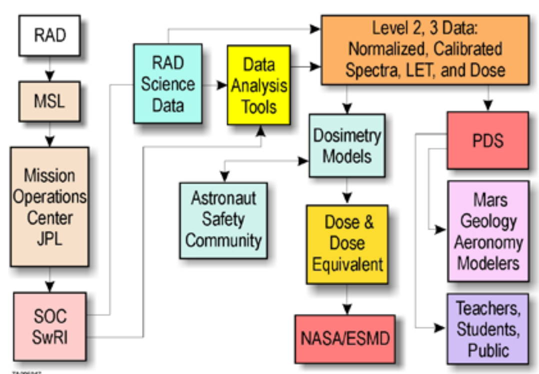

Figure 5. RAD Science Data Pipeline

The received RAD EDR files contain the same compressed binary data as transmitted by RAD to the RCE. Ground RAD data processing software unpacks the RAD science data and applies the appropriate conversion factors to generate a variety of Level 2 and 3 science products for analysis by the science team. For rapid assessment of RAD health/status and science data overview, an automated RAD Daily Report is produced by the RAD-SOC, accessible via RAD Team members on the MSL-RAD website. The website also has restricted-access tools for querying and plotting RAD data throughout the mission.

During cruise operations, there were several occasions where RAD science data downlink extended beyond the planned telecommunications link boundary. The resulting partial data products were received and processed. Later in the mission, these partial RAD science data products were identified and retransmission of these products was performed. These partial product files and retransmission products identified minor issues in the pipeline which were ultimately rectified prior to Mars surface operations.

IV. RAD Operations during MSL Cruise

A. Significant RAD events during MSL Cruise

RAD operations on MSL began with a brief instrument checkout on 6 December 2011, where RAD was operated with a configuration identical to a pre-launch characterization measurement of the Multi-Mission Radioisotope Thermoelectric Generator (MMTRG) on 20 November 2011. Shortly thereafter, RAD was reconfigured to collect science data in frequent, short-duration (~8 minute) observations with 30-second sleep intervals interleaved. This mode of operation allowed the majority of individual particle events to be stored in Pulse Height Analysis (PHA) records within RAD science packets. Internal threshold parameters were adjusted, resulting in a decrease in event count rates. As shown in Fig. 5, RAD characterized 5 distinct solar energetic particle events, starting with a minor event on 23 January 2012. On 28 January 2012, the RAD nominal observation intervals were extended to 16-minutes, with solar event mode remaining at 8-minute duration. This RAD reconfiguration activity was coincident with an on-going solar proton event. The associated RAD_TableUpdate #2 sequence was executed approximately two hours after the flux of this event peaked. The data quality was consistent across this instrument configuration transition. RAD continued to operate with this observation cadence throughout the remainder of RAD cruise operations until three weeks prior to Entry, Descent, and Landing (EDL) preparations. An extreme solar particle event occurred between 7-9 March 2012. RAD transitioned into Solar Event mode on DOY67 at 0815 UTC and reverted to Default Obs mode ~67 hours later (DOY70, 0330 UTC). Another minor energetic partical event occurred a few days after the major event. RAD_TableUpdate #3 was performed on 2 May 2012 to adjust several parameters based on observations for five months in cruise. Another significant solar energetic particle event occurred on 17 May 2012, where RAD entered Solar Event for approximately 13 hours. The peak flux for this event was a factor of ten less than the March event. RAD performed Table Update #4 on 11 June 2012, followed by a Table Update #5 on 29 June 2012 to adjust internal parameters for improved heavy-ion processing. Finally, on 14 July 2012, RAD was configured for initial Mars surface operations and was turned off until after landing on Mars.

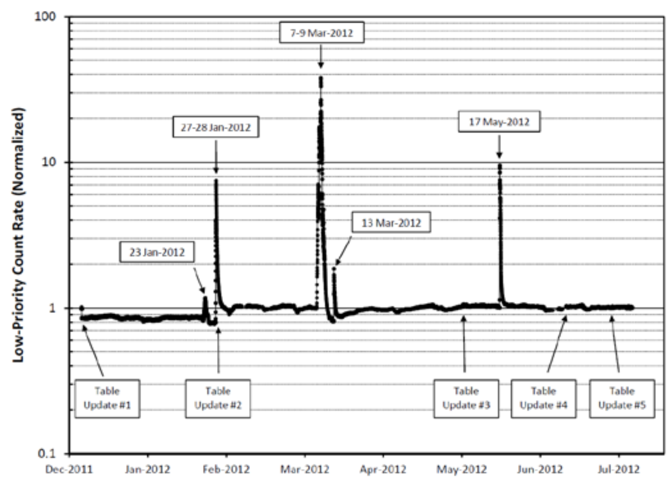

Figure 6. Important RAD events during MSL cruise.

B. RAD Cruise Operating statistics

RAD operated for a substantial portion of the cruise phase of the MSL mission. From initial power-on in December 2011 to pre-EDL turn-off in July 2012, RAD operated for nearly 5000 hours. The instrument was turned off for brief intervals surrounding mission critical events, still maintaining nearly a 95% on-time. Enforcement of the "fly-as-you-test" paradigm resulted in RAD being turned off for trajectory correction maneuvers, rover flight software updates, and engineering subsystem checkouts. Still, RAD collected over 15,000 science observations during cruise. The instrument primary (28V) power was cycled 30 times, but RAD internal instrument power supplies were switched on and off over 15,000 times for autonomous sleep/wake cycles. There were 240 transfers of RAD science data during cruise, with 55 transfers on the RCE-B string. A total RAD science data volume exceeding 240 Mbytes was received on the ground in cruise. Operations for RAD were largely conducted in the background of mainstream commanding. All science data from the cruise phase of MSL was received on the ground and is currently being analyzed by the RAD science team.

V. Conclusion

The RAD instrument collected a substantial volume of radiation data in a period of over seven months of operation inside the MSL spacecraft enroute to Mars. These measurements were not an MSL mission science requirement, but were performed based on availability of resources. The simplicity of the RAD operations concept was a major factor in permitting the extent of coverage afford the instrument during cruise.

Acknowledgments

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References

[1]Hassler, D. M., Zeitlin, C., Wimmer-Schweingruber, R. F., Böttcher, S., Martin, C., Andrews, J., Böhm, E., Brinza, D. E., Bullock, M.A., Burmeister, S., Ehresmann, B., Epperly, M., Grinspoon, D., Köhler, J., Kortmann, O., Neal, K., Peterson, J., Posner, A., Rafkin, S., Seimetz, L., Smith, K. D., Tyler, Y., Weigle, G., Reitz, G., Cucinotta, F. A., "The Radiation Assessment Detector (RAD) Investigation." *Space Sci. Rev.* (Online First), 25 July 2012, doi:10.1007/s11214-012-9913-1 URL: http://www.springerlink.com/content/x5x7610159373213/fulltext.pdf

[2]Dehghani, N., "Building the Ground Data System for the Mars Science Laboratory (MSL) Project – Challenges and Opportunities," *SpaceOps 2008 Conference*, AIAA Paper 2008-3233, Heidelberg, Germany, 2008.