The Radiation Assessment Detector (RAD) for Mars

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Abstract

The Radiation Assessment Detector (RAD) is a simple, 1 kg energetic particle spectrometer proposed for the Mars Science Laboratory (MSL) to detect and analyze ALL relevant energetic particle species (p, n, He, CNO, Fe, etc.) incident on the Martian surface, including direct and indirect radiation created both in the atmosphere and the regolith. Fully characterizing and understanding the radiation environment on Mars is fundamental to quantitatively assessing the habitability of the planet, and essential for future manned Mars missions.

The RAD instrument consists of a solid-state detector stack and CsI calorimeter with active coincidence logic to identify charged energetic particles using the dE/dx vs E method. RAD also uses a separate plastic scintillator and anti-coincidence shell to detect neutrons and gamma rays. Each of these techniques and components have been used for radiation detection in space since the 1960s, but combined in this way for the first time with RAD. Finally, RAD's simple, compact, and lightweight design makes it ideally suited for other future space missions (both manned and unmanned) as well, where full characterization of the local radiation environment is required.

Science Objectives

RAD completely fulfills its primary goal and MSL AO Science Investigation D (*to characterize fully the radiation environment at the surface of Mars*), as well as addresses several important questions related to Science Investigations A-C. Within this investigation RAD addresses five specific science objectives:

1. *Characterize the energetic particle spectrum at the surface of Mars, including direct and indirect radiation created both in the atmosphere and regolith.*
2. *Determine the radiation dose rate and equivalent dose rates for humans on the surface of Mars.*
3. *Validate Mars atmospheric transmission models and radiation transport codes.*
4. *Determine the radiation hazard and mutagenic influences to life, past and present, at and beneath the Martian surface.*
5. *Determine the chemical and isotopic effects of energetic particles on the Martian surface and atmosphere.*

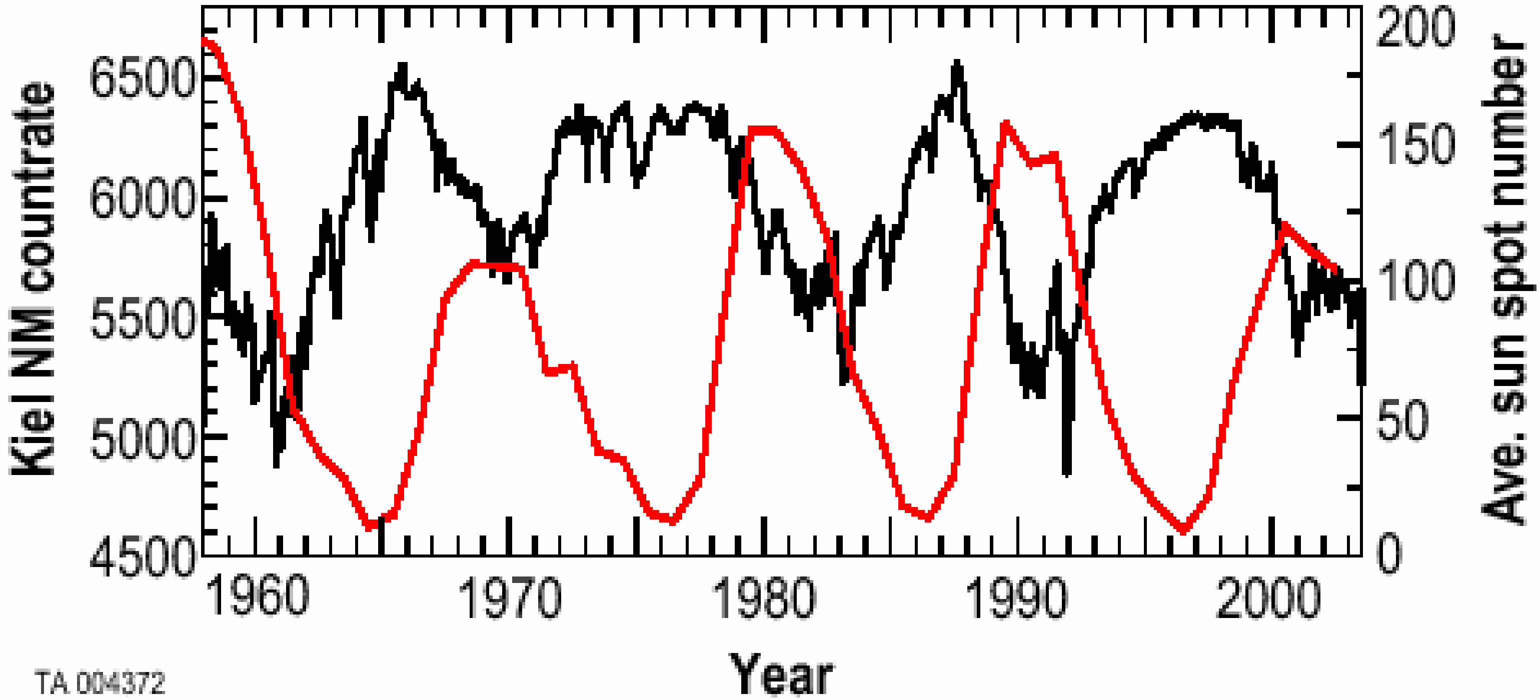


Figure FO1-1. Ground-based neutron monitor observations (black) provide a proxy for GCR flux. (Sunspot number is in red). GCRs are modulated by solar activity with a 15-30% reduction at solar maximum.

Figure FO1-2. Massive SEP events from October/November 2003 created havoc on satellites and spacecraft throughout the heliosphere. Earlier in the month, a similar SEP knocked out the MARIE instrument on Mars Odyssey after recording radiation dose rates in excess of 1200 mrad/day. Shown are GOES proton fluxes and ACE/SWEPAM solar wind data superposed on SOHO/EIT images.

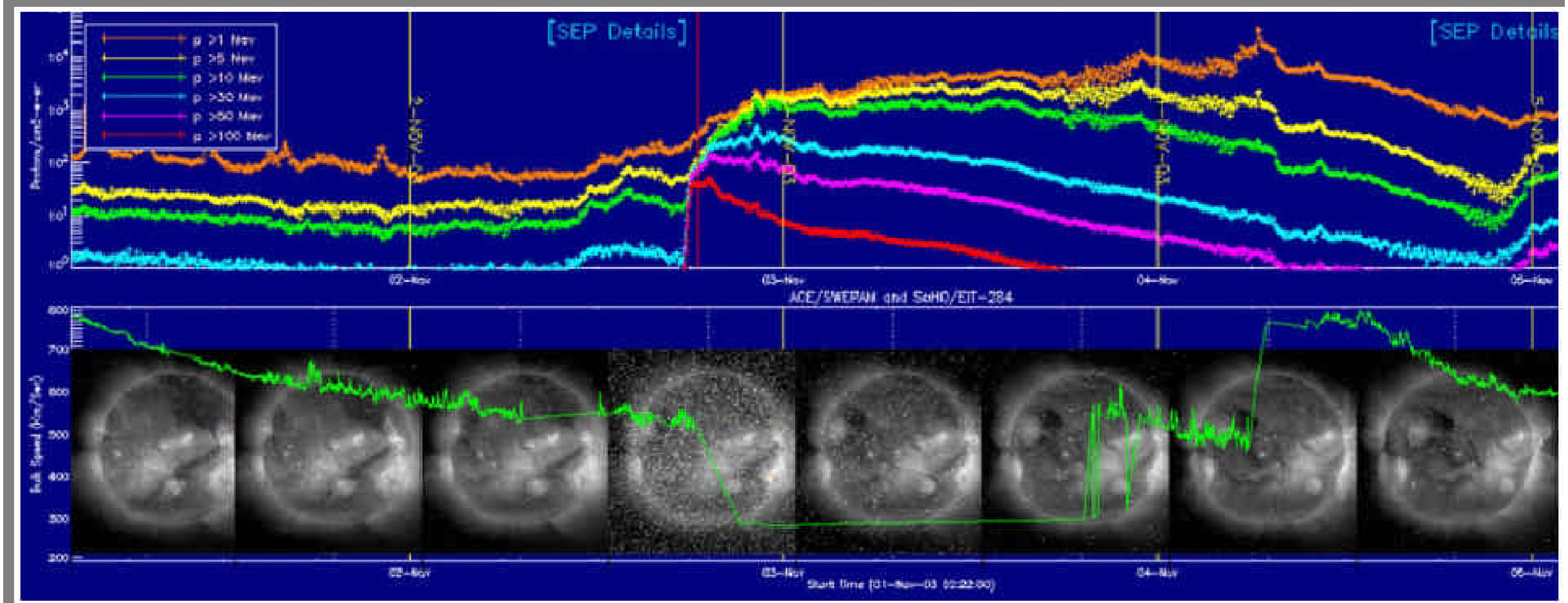


Figure F01-3. Energetic particle spectrograms (e.g. SOHO/COSTEP) provide complete spectral information necessary to evaluate potential astronaut risk. Three particle species show the intensity of flare associated particles over several days (Posner, 2004). Quality-factors (Q) for the type of radiation are shown to the left.

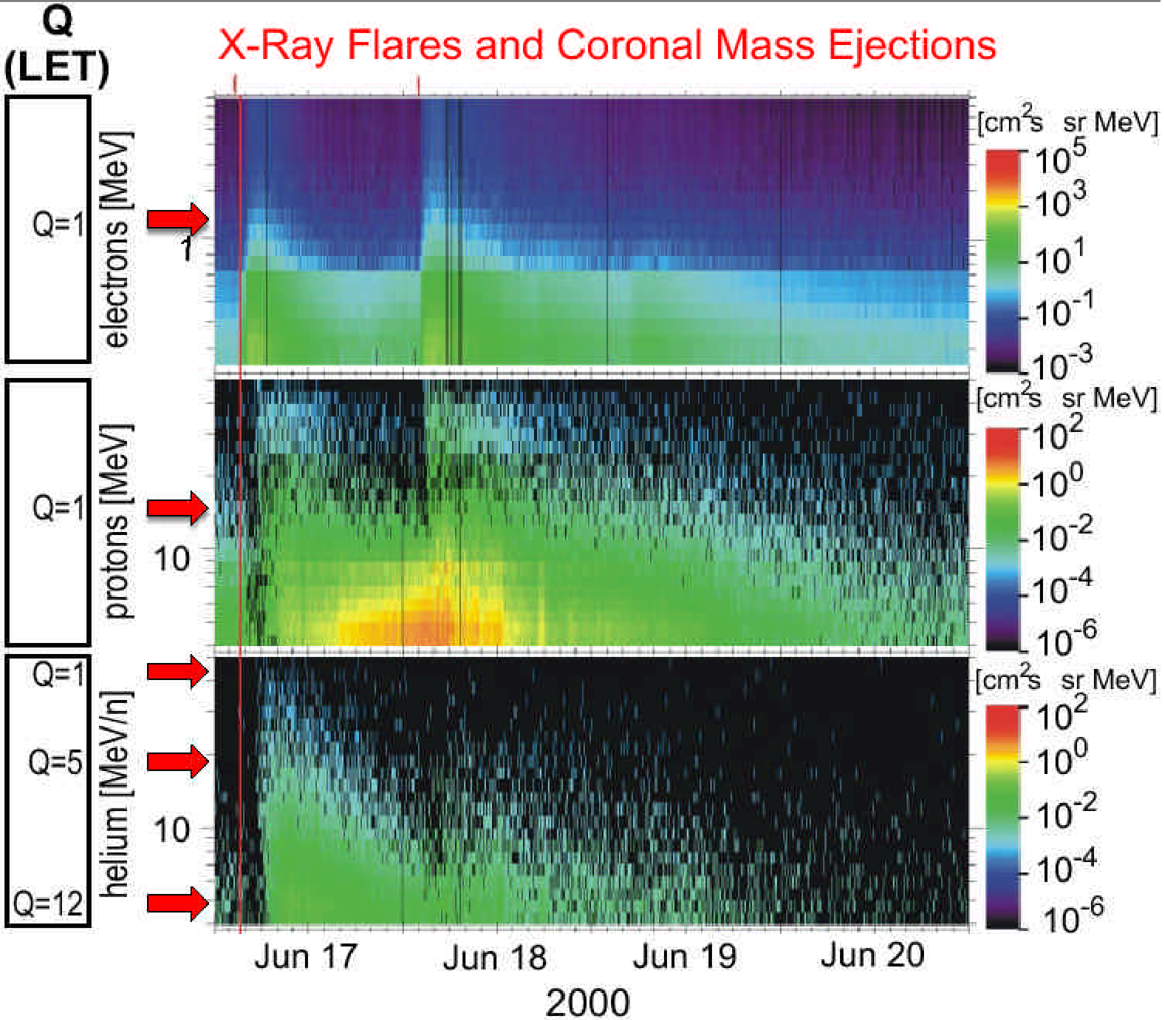
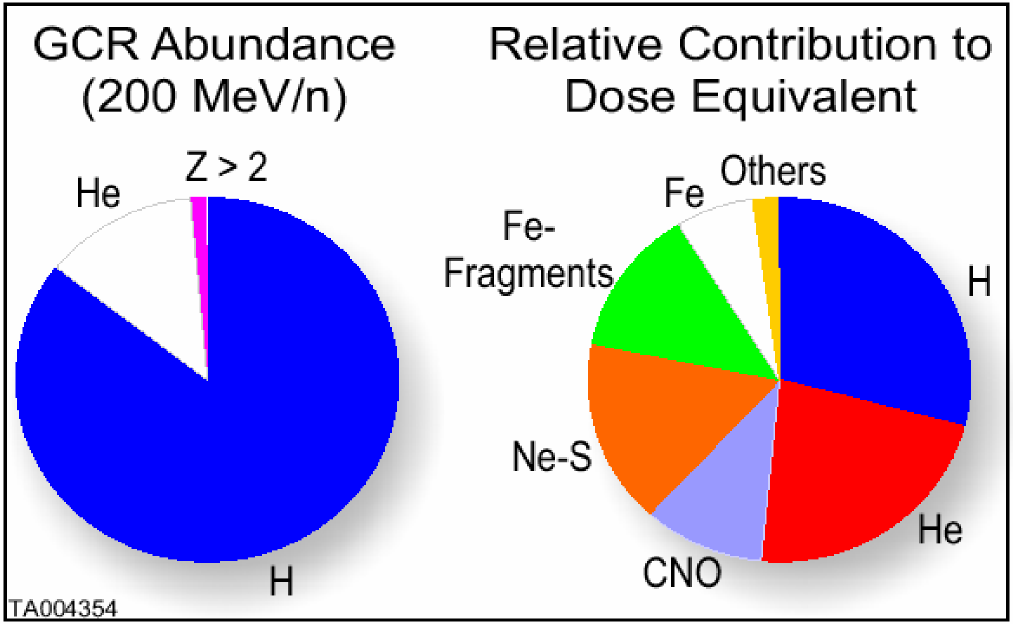
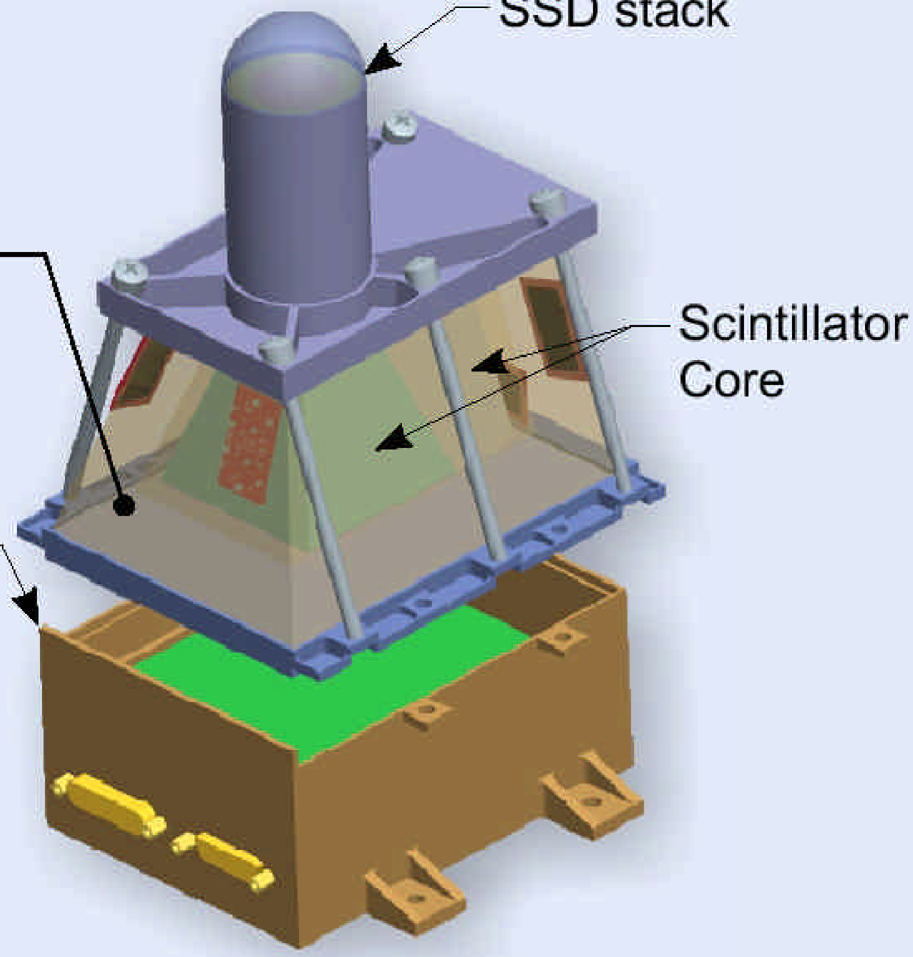


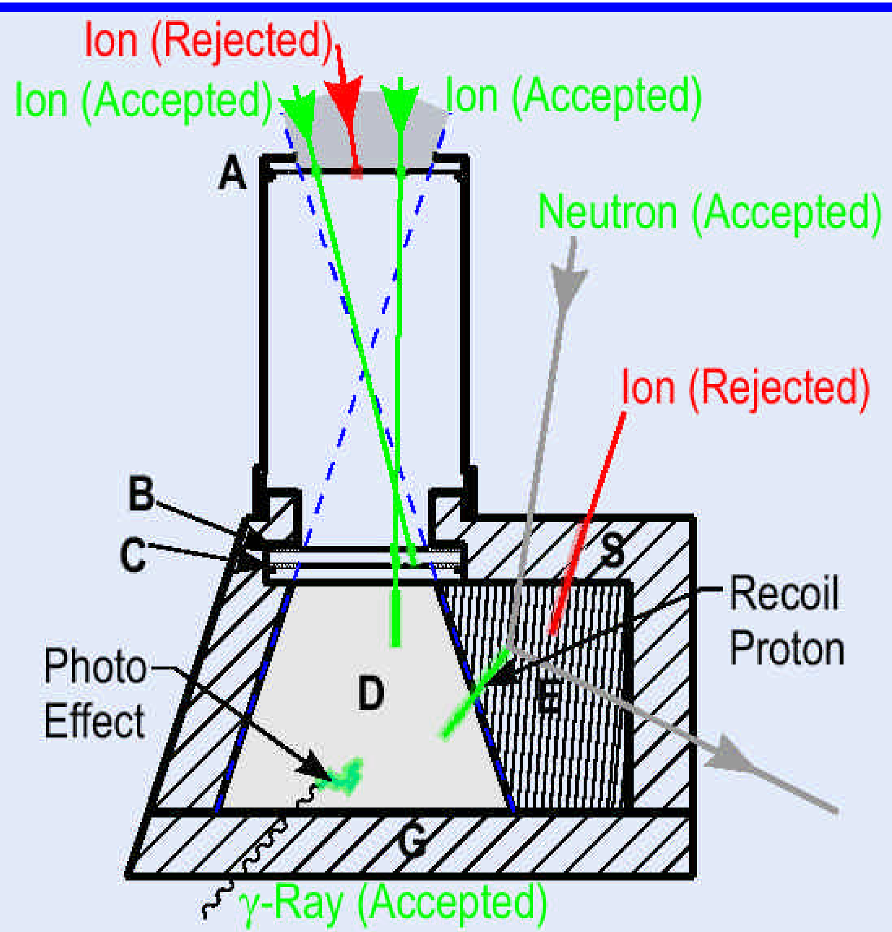
Figure F01-4. Relative abundances of protons, helium ions and heavy ions that contribute to the GCR flux in the inner heliosphere. Due to the high quality factors of heavy ions, the dose equivalent of GCRs (i.e. the radiation hazard to humans in space), is dominated by heavy ions that only contribute < 1% of the GCR flux. (Wilson et al. 1997).



RAD Instrument



3-D view of the compact, weight-saving design of the RAD instrument. The electronics box provides a base for the sensor unit and the lightweight Ni housing provides sufficient stability for the sensor without obstructing the neutron and gamma radiation environment.



Schematic of the RAD sensor with sample paths of energetic ions, neutrons, and γ-rays. The SSDs A-C define the aperture for charged particles. The scintillators D and E are surrounded by anti-coincidence elements (S, G) and provide stopping power for charged particles as well as detection capabilities for neutral (neutrons, γ-rays) ionizing radiation.

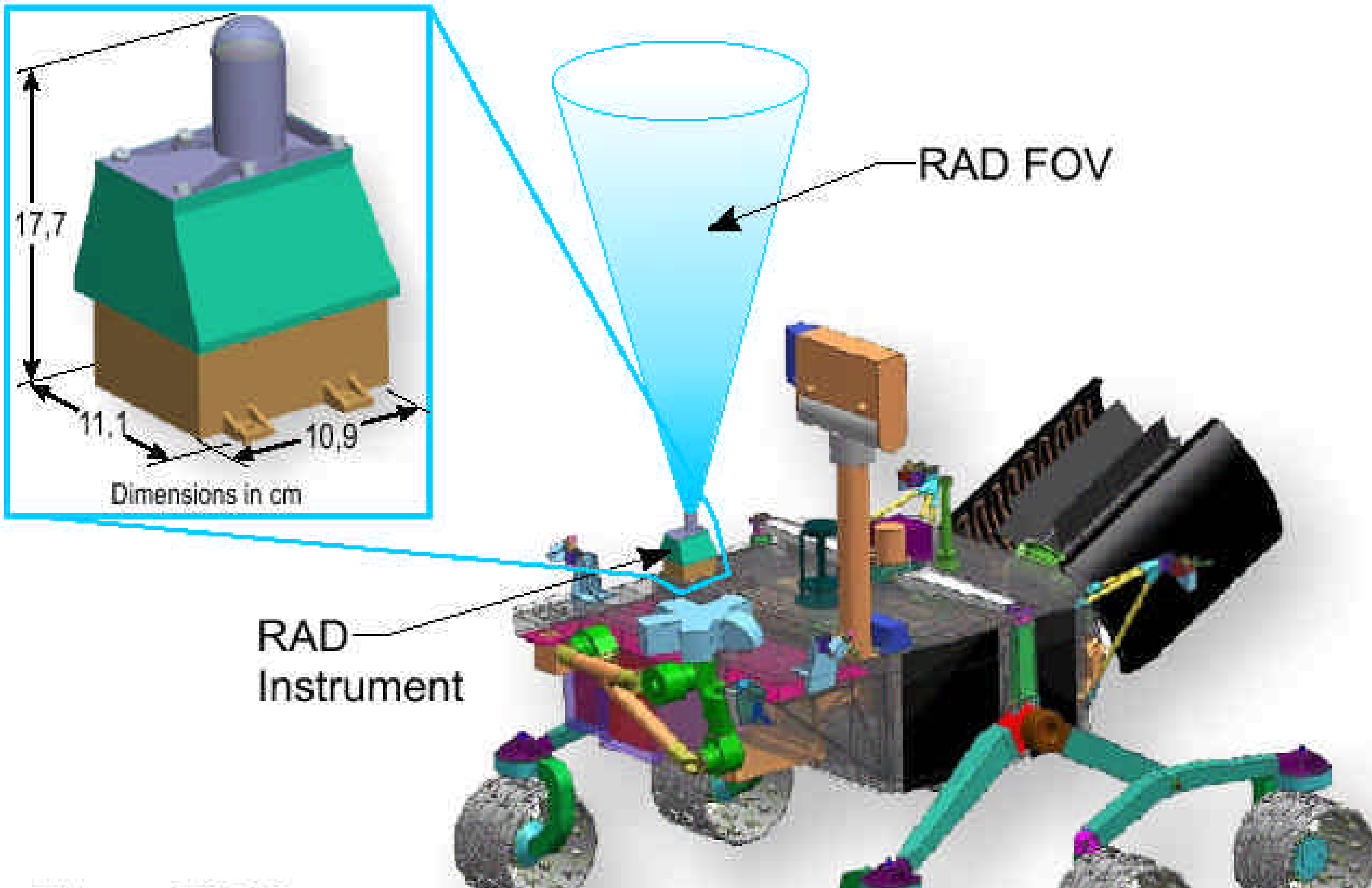


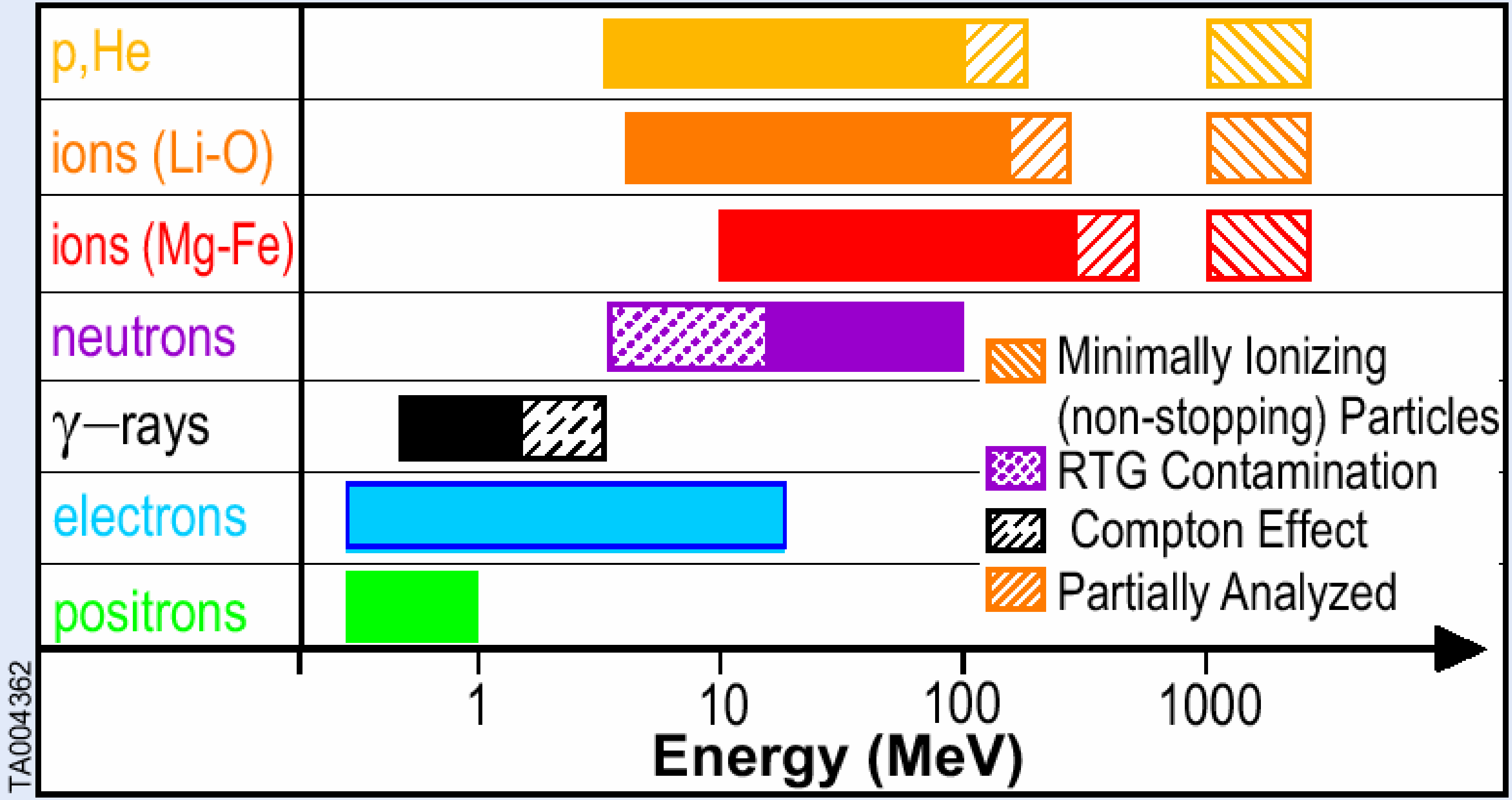
Figure F02-6
The RAD instrument has minimal accommodation requirements on the MSL rover.

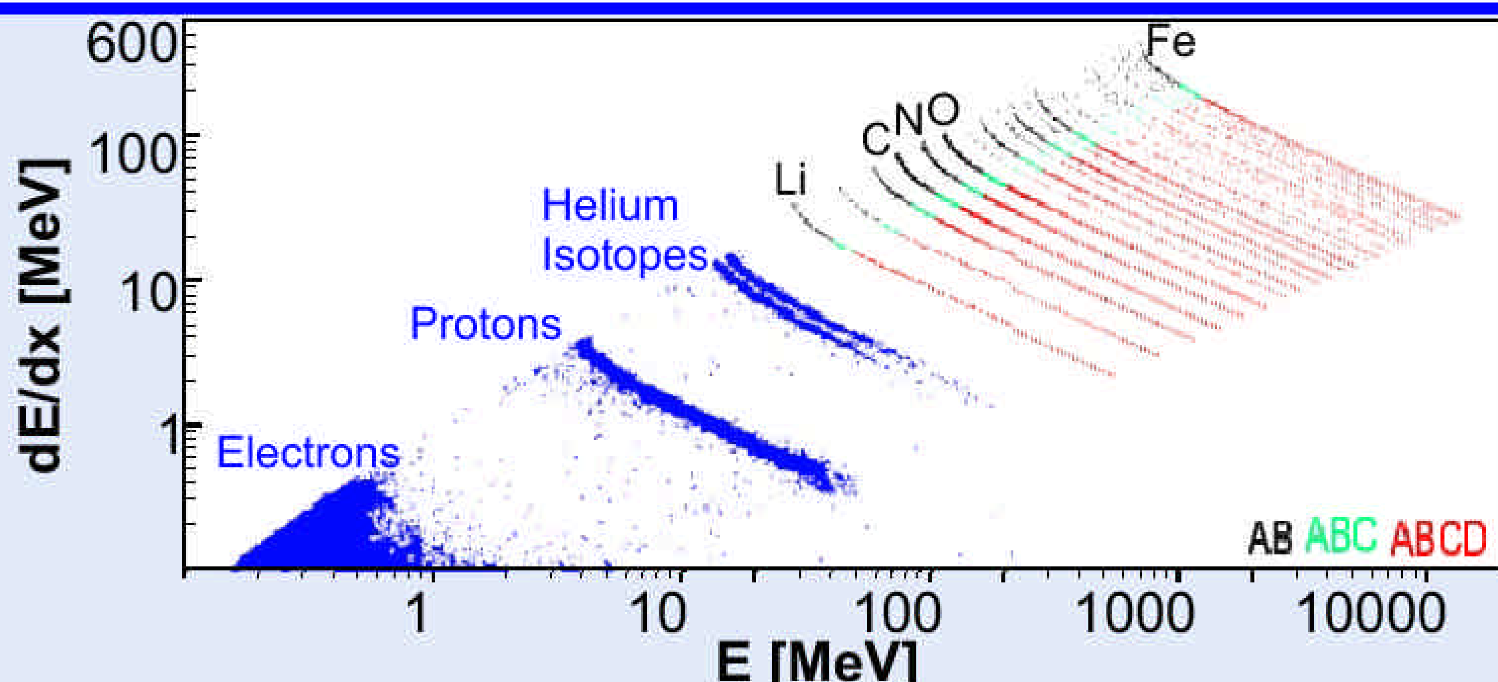
RAD Instrument Summary

RAD is a simple, lightweight yet innovative energetic particle spectrometer consisting of a solid-state detector stack and CsI calorimeter with active coincidence logic to identify charged energetic particles incident on the Martian surface using the dE/dx vs E method. RAD also includes a separate plastic scintillator and anti-coincidence shell to detect secondary neutrons and gamma rays produced in the atmosphere and regolith.

Instrument Parameter	Characteristics
Protons Ions ($2 \leq Z \leq 26$)	5-270 MeV/nucleon
Protons, Helium	4.3-100 MeV/n
Neutrons	2-100 MeV
Electrons	150 keV-15 MeV
X-Rays, Gamma Rays	<1.5 MeV
Geometric Factor (ions)	0.24 $cm^2 sr$
Field of View (FOV)	36.7° (view cone)
Priority Scheme (ions)	[H,He], [C,N,O,], [Mg-Fe]
Time Resolution	1 hr [1 min]
Max Count Rate	5000 events/sec

Energy Coverage





The RAD energy loss matrix spans from electrons to protons to Fe ions. COSTEP observations of e-, p, and He are merged with a RAD heavy-ion simulation, based on actual instrument and data compression parameters, demonstrating RAD's critical capability of resolving energy spectra for low- to high-Q Z=26 ion species individually.

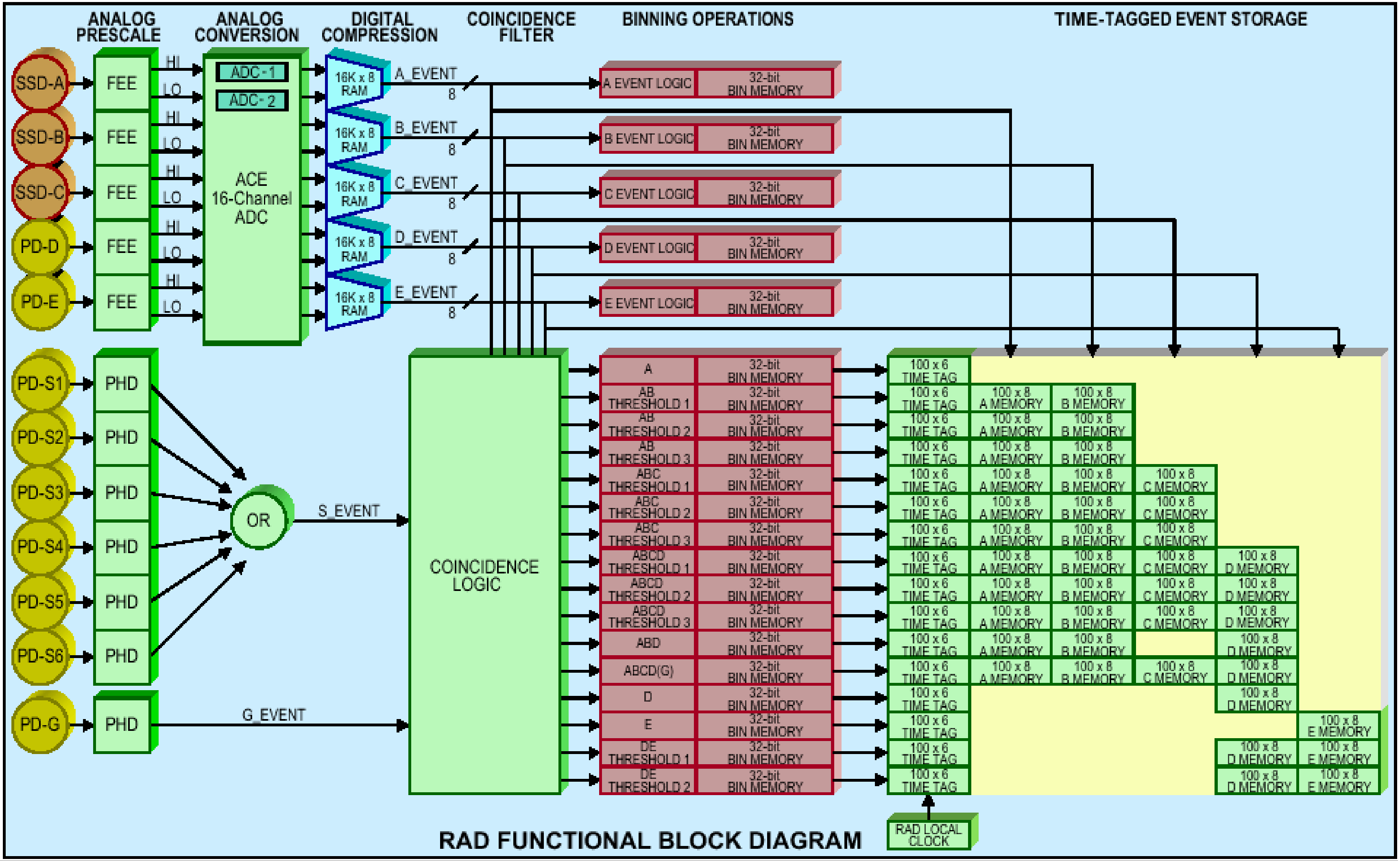


Figure F 02-5 Block diagram illustrating RAD analog and digital signal processing on MSL. The top part shows the analog-digital processing chain for the solid-state detectors and photo-diodes. The fast front-end electronics utilizes two gain stages in order to provide a wide dynamic range for observations of ions with $1 \le Z \le 26$. Analog conversion will be performed in a 16-channel ASIC chip. A coincidence/anticoincidence filter system channels output in two data formats: (a) count rates and (b) pulse-height analyzed data. A sophisticated compression and time-tagging scheme guarantees optimum use of the allocated telemetry.

Resources & Margins

Resource	Current Best Estimate (CBE)	Contingency (%)	CBE + Contingency	Recommended Allocation***	Reserve	% Reserve
Mass (g)	882	21%	1069 (Table FO2-1)	1200	131	12.3%
Power (Ave-W)	4.1	20%	5.0 (Fig. A3-4)	6.0	1.0	20%
Data Rate (Ave-bps)	10.7	20%	12.8 (Sect. A.3)	15.0	2.2	17%
Volume (cm3)	940	20%	1128 (Fig. FO2-5)	1350	222	20%

****The MSL PIP does not suballocate rover payload resources to individual instruments but requests proposers to recommend allocations (MSL PIP p. 31).*

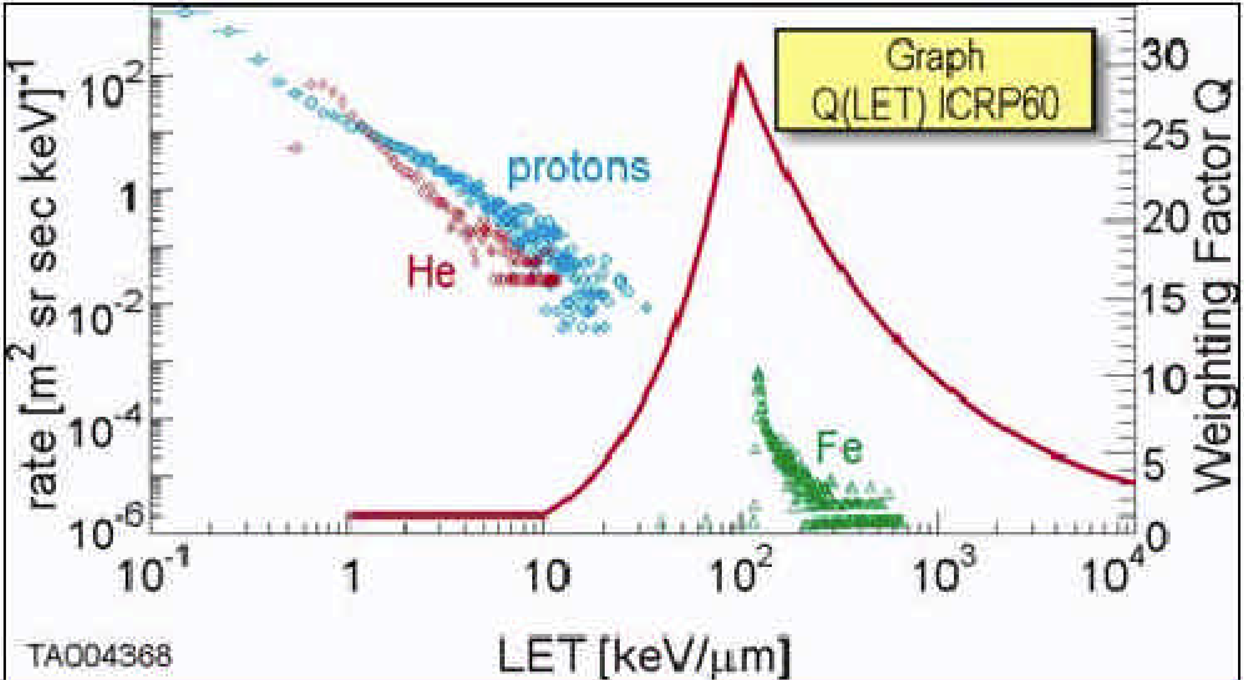


Figure A2-4. *The International Commission on Radiation Protection (ICRP) defines quality factors Q depending on type and LET. A higher Q for humans represents higher risk for the development of severe health problems from exposure. Superposed are simulated LET spectra at the Martian surface due to GCRs using GEANT4 code.*

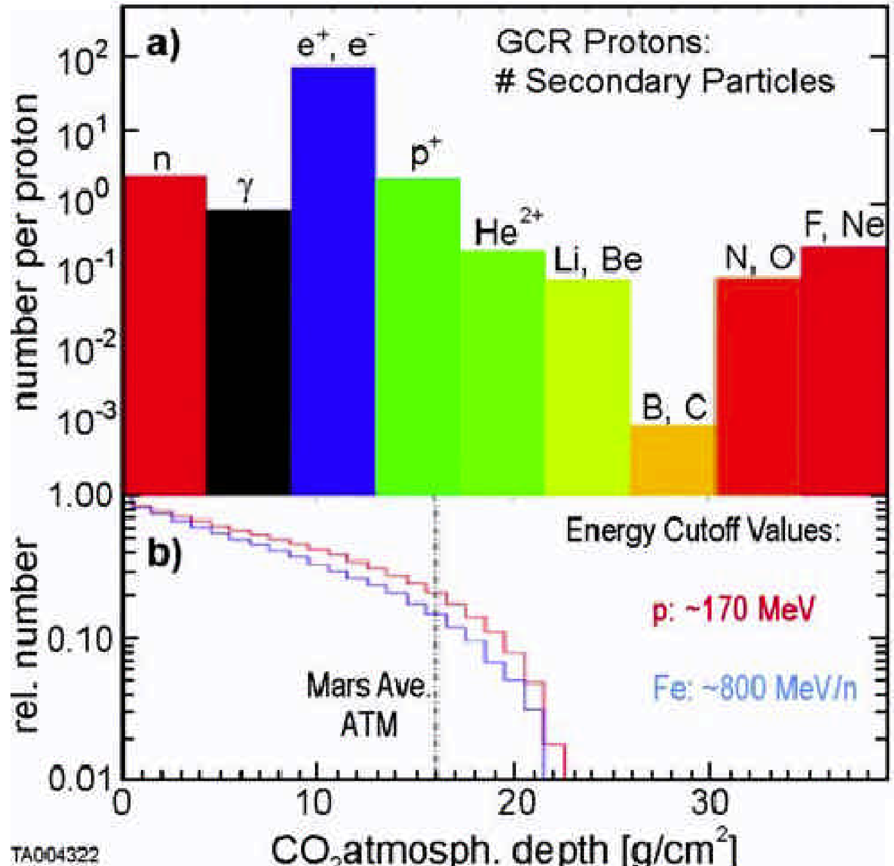
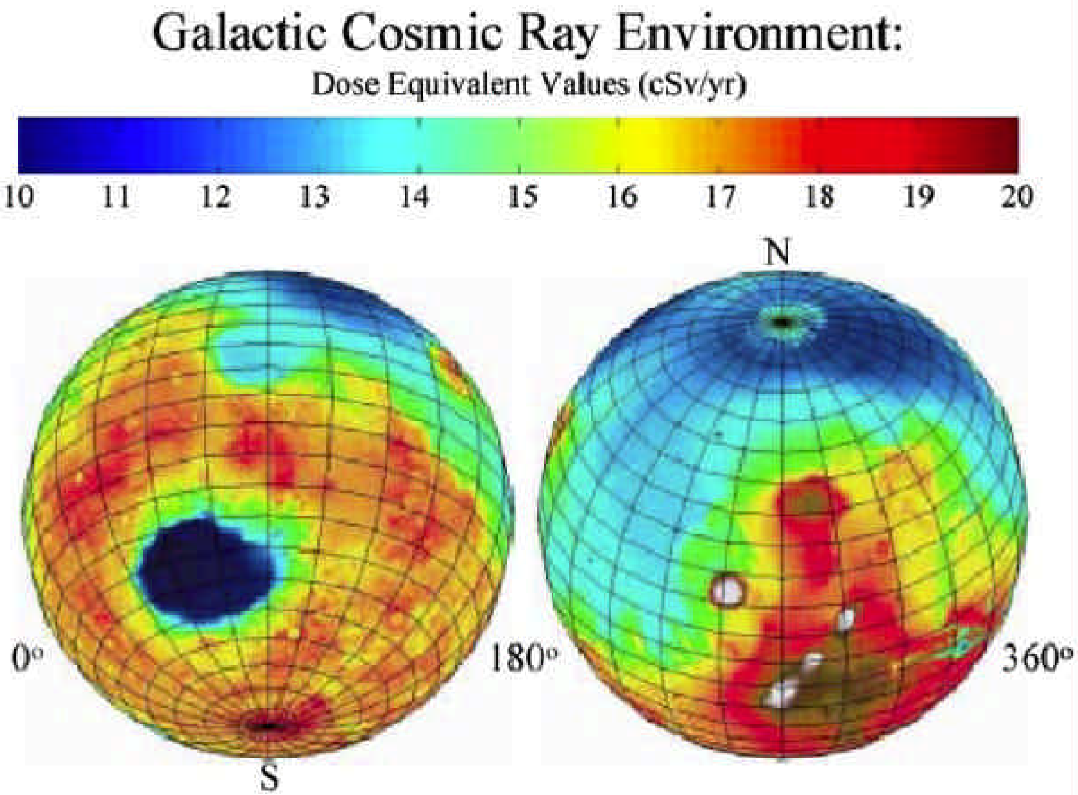


Figure A2-2. ***a)*** *GEANT-4 simulation of secondary particle production rates in the Mars atmosphere for a flat spectrum of incoming protons in the range 0-10 GeV.* ***b)*** *Simulations of the relative number of 170 MeV protons and 800 MeV/n Fe ions that penetrate various depths in the Mars atmosphere.*

Table A1-2: Requirements for Complete Characterization of Radiation Environment.
Full characterization requires measuring ALL of these relevant species.

Particle Species	Quality Factor (Q)	Relevance (Biological Importance and Need for Measurement)
Protons	1-7	Largest flux, large contributor to total dose (>90% of GCR, >98% of SEP)
He (alphas)	2-30	Large flux, high Q at low energies thus large contributor to equivalent dose
C, N, O	5-30	High Q with large probability of reaction in body tissue, significant contributor to equivalent dose, relevance to carbon provenance, carbon cycle from $^{14}C/^{12}C$ ratio
Fe	6-30	High Q factor with largest probability of reaction in body tissue, large contributor to equivalent and effective dose, *primary astronaut safety concern*
Neutrons	3-10	High Q factor, relevant near regolith and within tenuous atmospheres, high probability of reaction in tissue at 10-100 MeV, highly penetrating, *high astronaut safety concern*
γ-rays	1	Solar flare indicator, relevant to Mars geology: saline γ-line (^{40}K) detection
Electrons	1	SEP precursor, highly penetrating, large fluence during SEP events (even with Q=1, large fluence contributes to large equivalent dose)
Positrons	1	GCR cascade by-product, required for radiation transport model validation

Figure FO1-5. Model prediction of Dose Equivalent (health risk) from exposure to GCRs, calculated for solar maximum conditions. Note the strong dependence of radiation exposure on the Martian topography. (Cucinotta et al. 2004)



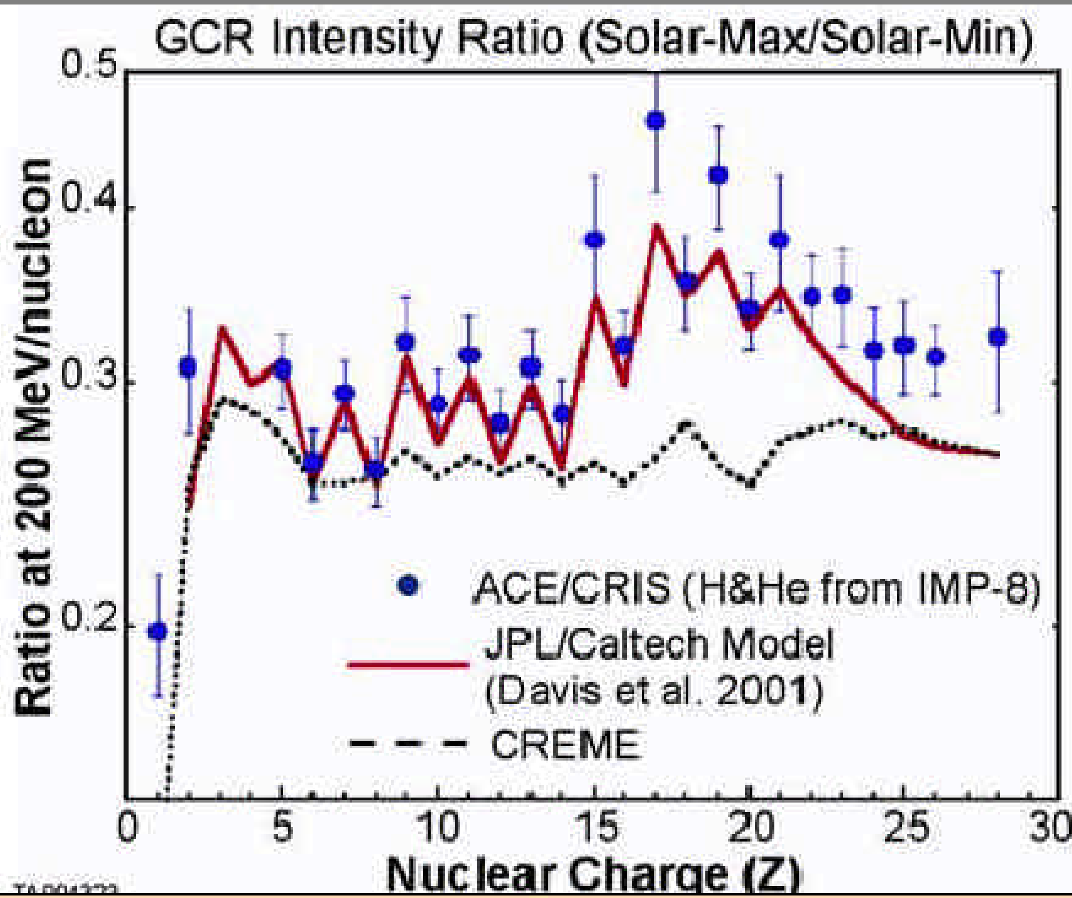


Figure A2-1. *GCR flux at solar maximum is more enriched in heavy nuclei than predicted by the models. Physics-based models agree better than semi-empirical models but both can be improved (Mewaldt, 2004).*

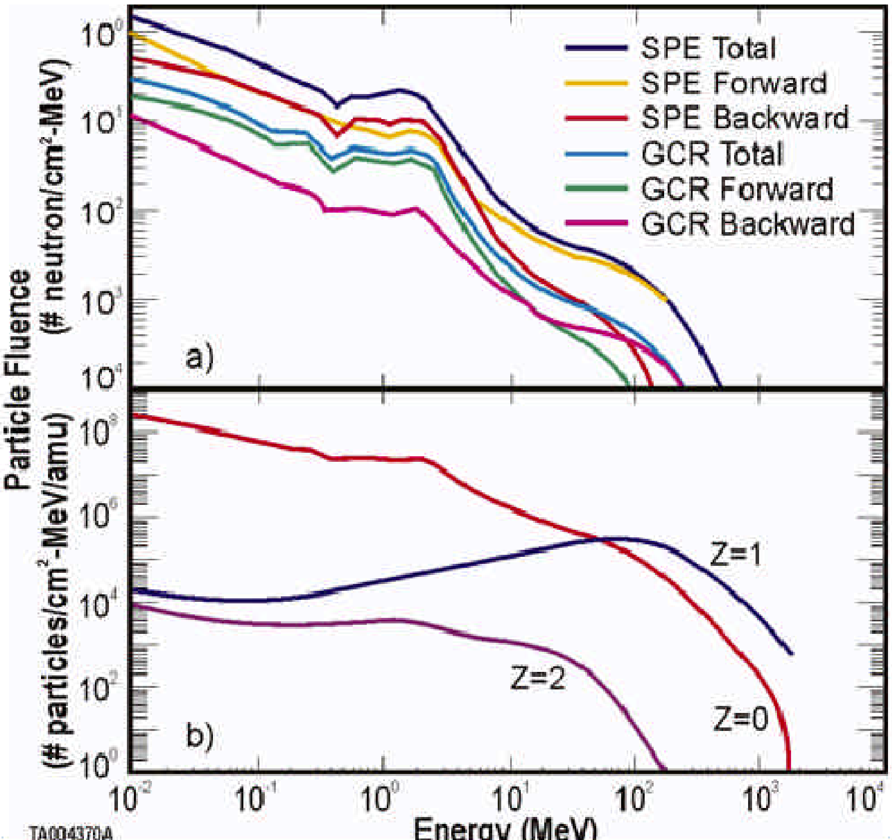


Figure A2-3. ***a).*** *Predictions of secondary neutrons generated in the atmosphere (forward) and regolith (backward) by GCRs and SEPs. Production within the regolith may account for a significant portion of the total neutron flux.* ***b).*** *Worst Case SPE environment at the Martian surface (prior to solar flare events of 2003) (Clowdsley et al., 2003).*

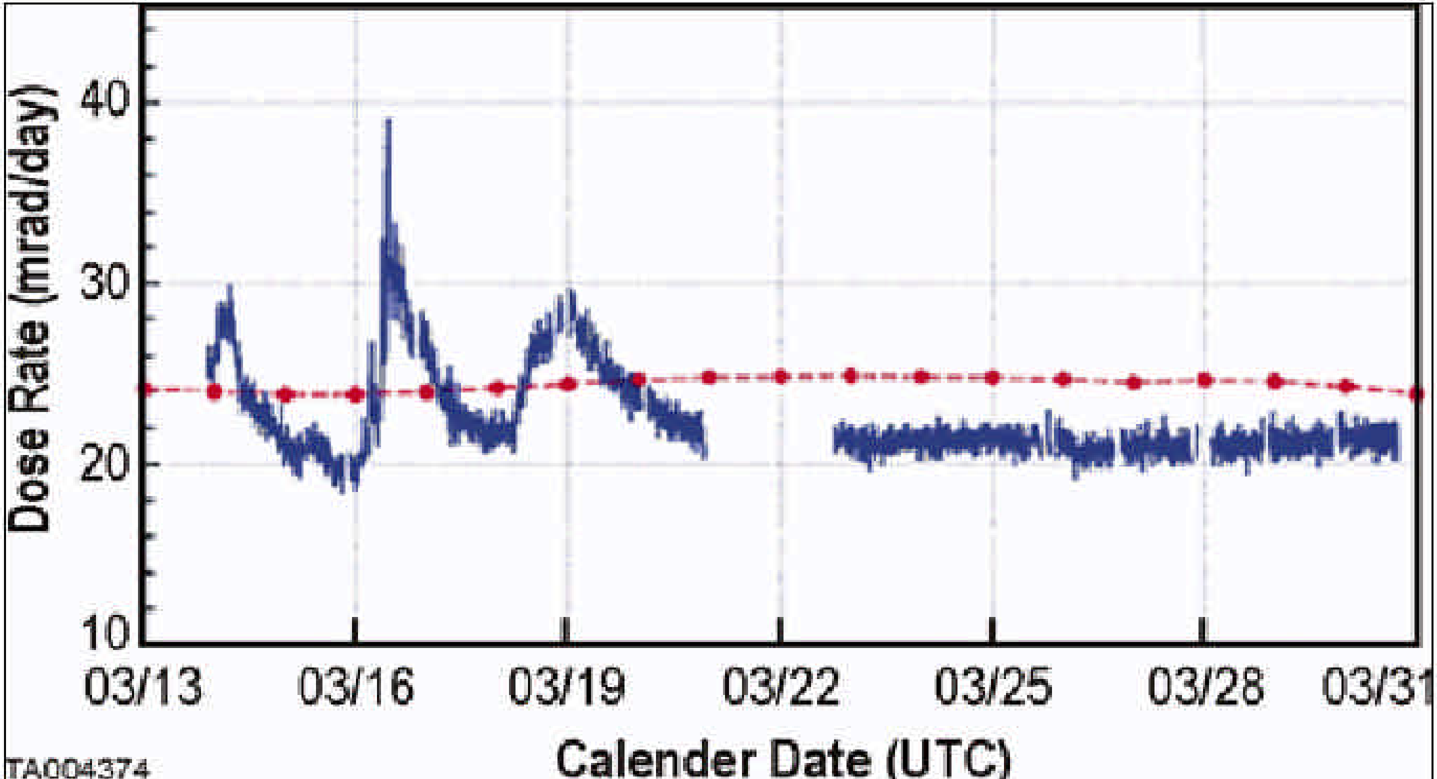


Figure A2-6. *Comparison between MARIE observations and model results from the HZETRN radiation transport code.*

RAD Investigation Summary

RAD is a complete science investigation to *characterize fully the broad spectrum of radiation at the surface of Mars,* measuring ALL of the relevant energetic particle species, including secondary neutrons and other particles created both in the atmosphere and the Martian regolith. RAD's innovative design from heritage components enables us to deliver an extremely low risk, yet powerful experiment, with outstanding science and programmatic value, within the stringent mass and fiscal constraints of the MSL mission.