PRECISION RADIAL VELOCITY SPECTROMETER

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CHANGE RECORD

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0.1	8th August 2006	All	Red Team Review draft
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APPLICABLE DOCUMENTS

Reference	Document Title	Document Number & Issue
AD01	PRVS Science Case	PRVS-SPEC-00004-0001 Issue 1.0

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1 INTRODUCTION

1.1 PURPOSE OF THE DOCUMENT

Precision Radial Velocity Spectrometer (PRVS) is a high resolution spectrometer which shall be built for use on either of the Gemini 8 meter telescopes. Gemini North, located at Mauna Kea or Gemini South, located at Cerro Pachon. The instrument shall primarily be used to measure the radial velocity of M dwarf stars and the instrument shall be compatible with either location. By measuring the radial velocity of M dwarf stars very accurately the science community hope to detect the presence of orbiting planets. In the science case it is recommended that a larger number of targets can be surveyed with Gemini North and that the location will have slightly improved atmospheric conditions.

This document formally records the Science Requirements of the PRVS instrument. The requirements are derived from the instrument science case [AD01] and simulated data obtained from a system model that was developed as part of the concept design study. This document records and controls the key science requirements and will be used to derive the main technical requirements.

1.2 PRVS GENERAL CAPABILITIES

a. Supports high precision radial velocity measurements

b. Enables high resolution spectroscopy across the Y, J and H infrared atmospheric windows.

2 REQUIREMENTS

In the remainder of this document, we detail the requirements placed on the PRVS instrument by the scientific users, including instrument capabilities that must be present in order to support the studies detailed in Science Case.

The high level science requirements are captured in this document as well as the top level technical requirements applied to the instrument. The continued identification and definition of the derived requirements will be carried out during the preliminary design phase.

In each case, a unique number is assigned to the requirement so that traceability may be maintained and assumptions used in the preparation of the requirements are listed.

2.1 FUNCTIONAL REQUIREMENTS

2.1.1 High Resolution Spectroscopy

PRVS shall enable High Resolution Spectroscopy of objects in the focal plane of the Gemini telescope.

2.1.2 Radial Velocity [FR_01]

PRVS shall enable the radial velocity of objects imaged by the Gemini telescope to be calculated.

2.1.3 Quick Look [FR_02]

PRVS shall provide a quick look function to enable the progress of observations to be viewed.

2.1.4 Data Product [FR_03]

The instrument shall produce data files suitable for the calculation of the velocity of the source of illumination from the Doppler shift of spectral lines.

2.1.5 Observation Preparation [FR_04]

PRVS shall allow observations to be prepared remotely from the telescope

2.1.6 Alignment [FR_05]

PRVS shall maintain alignment on the science target during the observation.

2.2 PERFORMANCE REQUIREMENTS [RF_06]

A detailed definition of the fields used in the performance requirements template is given in Appendix A.

2.2.1 Primary Science Requirements

2.2.1.1 Radial Velocity Precision

Title	Radial Velocity Repeatability	**Reference**	SR_1
Description			
PRVS shall enable the measurement of radial velocity precision of (1) ≤3 m/s rms (2) ≤2 m/s rms (3) ≤1 m/s rms The radial velocity measurement shall be stable over a period of 5 years.			
Priority	(1) Essential (2) Optimal (3) Desirable		
Source	Science Case		
Maturity	Firm		
Proof of Compliance	Demonstrate that requirement is met through lab testing prior to delivery. This may be performed by observation of solar spectra. Full acceptance based on known stable stars (from optical observations) during commissioning.		
Related requirements	SR_4 Spectral resolving power SR_5 Sampling SR_6 Simultaneous wavelength range SR_7 Spectral Response Function (SRF) stability		
Assumptions	Dependent upon the amount of Doppler information contained in the science target spectrum. This is modelled in the Science Case.		
Comment	This repeatability follows all defined calibration and maintenance activities.		

2.2.1.2 Sensitivity

Title	Sensitivity	**Reference**	SR_2
Description			
PRVS shall have a sensitivity of (1) Y ≥ 11.75, J ≥ 11.25, H ≥ 10.75 for S/N = 300 in 3600 s (2) Y ≥ 12.25, J ≥ 11.75, H ≥ 11.15 for S/N = 300 in 3600 s			
Priority	(1) Essential (2) Optimal		
Source	Science Case		
Maturity	Open		
Proof of Compliance	Sensitivity will be verified during on-sky commissioning using observations of flux standards. Contributing factors (throughput, read–noise, image quality) will be verified in the lab during Integration and Test phase.		
Related requirements	SR_4 Spectral Resolving Power SR_8 Throughput SR_10 Instrument Background		
Assumptions	The sensitivity estimates are based on models that include the following assumptions: 0.1 average throughput (which includes telescope, optics, and detector); 0.6 arc seconds median seeing at J 10 e RMS read noise (with multiple non-destructive reads); 0.1 e/s instrument background (instrument thermal background, scattered light background, and sky background); 0.1 e/s dark current (including persistence) S/N = 200 in flat field spectral resolving power R = 70000; sampling of 2.5 pixels per spectral resolution element. science case is based on our 'essential' sensitivity figure		
Comment	The sensitivity is dependent on parameters outside of the instrument. Assumptions must be made about these.		

2.2.1.3 Observational Efficiency

Title	Observational efficiency	**Reference**	SR_3
Description			
PRVS shall have "open shutter" efficiencies (1) (a) ≥50% for 10 min observation (b) ≥70% for a one-hour observing block			
Priority	(1) Essential		
Source	Science Case and OCDD - Survey Efficiency		
Maturity	Firm		
Proof of Compliance	Related functional requirements will be demonstrated in the lab with modelling to confirm that this requirement is met. Final acceptance is on the telescope during Commissioning.		
Related requirements	SR_11 Acquisition		
Assumptions	o Overheads taken to include: telescope offsetting, instrument configuration and acquisition. o That the overheads do not include calibration (wavelength, flat-fielding, etc.) and observations of standard stars. o Efficiency = total exposure times/total elapsed time.		
Comment	The typical exposure times are going to be between 10 and 60 mins.		

2.2.2 Derived Requirements

2.2.2.1 Spectral Resolving Power

Title	Spectral resolving power	**Reference**	SR_4
Description			
Spectral resolving power is the defined as $R = \lambda/\Delta\lambda$ where: λ = wavelength $\Delta\lambda$ = the smallest resolved wavelength interval. The spectral resolving power at the centre of the waveband shall be (1) $R \geq 50000$ (2) $R \geq 70000$			
Priority	(1) Essential (2) Optimal		
Source	SR_1 Radial Velocity Precision SR_2 Sensitivity		
Maturity	Firm		
Proof of Compliance	Demonstrate compliance via lab observations of arc spectra prior to delivery		
Related requirements	SR_5 Sampling SR_6 Simultaneous Wavelength Range		
Assumptions	A 1x2 2048x2048 array format. Spectral lines are considered to be resolved if they satisfy the Rayleigh criterion.		
Comment	The spectral resolving power varies slightly with wavelength hence the specification applies at the centre of a spectral order.		

2.2.2.2 Sampling

Title	Sampling	**Reference**	SR_5
Description			
(1) Each spectral resolution element shall be sampled by ≥ 2.5 pixels			
Priority	(1) Essential		
Source	SR_1 Radial Velocity Precision		
Maturity	Stable		
Proof of Compliance	Demonstrate compliance via lab observations of arc spectra prior to delivery		
Related requirements	SR_4 Spectral Resolving Power SR_6 Simultaneous Wavelength Range		
Assumptions	A 1x2 2048x2048 array format. Intra-pixel response function (see Science Case).		
Comment			

2.2.2.3 Simultaneous Wavelength Range

Title	Total wavelength coverage	**Reference**	SR_6
Description			
The instrument shall be capable of single shot spectroscopic wavelength coverage of (1) ≥ 80 % of the Y + J + H bands (MKO filter wavelengths) Telluric lines within these bands may be masked out.			
Priority	(1) Essential		
Source	SR_1 Radial Velocity Precision SR_2 Sensitivity		
Maturity	Stable.		
Proof of Compliance	Acceptability to be demonstrated in the lab, during module testing and subsequently at integration and test, by confirmation of throughput at all wavelengths.		
Related requirements	SR_4 Spectral Resolving Power SR_5 Sampling		
Assumptions	A 1x2 2048x2048 array format. Models of the achievable radial velocity precision assume that wavelengths within ± 30 km/s of telluric features deeper than 2% are masked out. Standard MKO filters (which are matched to 'good' telluric regions).		
Comment	Y + J + H assumed to cover 0.99 to 1.75 μm.		

2.2.2.4 Spectral Response Function (SRF) Stability

Title	Stability	**Reference**	SR_7
Description			
To achieve a radial velocity precision of 0.3 m/s RMS the skewness, defined by the dimensionless third moment μ_3, must be known at all times to within +/- 0.001. This requires: (1) a. that provision shall be made to measure μ_3 to $\pm$ 0.001; b. that μ_3 of the instantaneous optical SRF shall be stable between such measurements (daytime calibration) to this precision or better; c. that μ_3 for the effective SRF, being the combination of the optical SRF in b. and any smearing brought about by image drift during the course of an observation, shall be kept stable to within the same $\pm$ 0.001; this requires the image motion across the face of the detector be $\leq$ 0.1 pixel during an observation			
Priority	(1) Essential		
Source	Radial Velocity SR_1		
Maturity	Under Review		
Proof of Compliance	Demonstrate that requirement is met through lab testing prior to delivery		
Related requirements			
Assumptions	Daytime calibration to measure the SRF will be made at intervals of days to months depending on the change in skewness with time and following maintenance.		
Comment	This requirement sets the spatial and temperature stability of the instrument (see the FPRD).		

2.2.2.5 Throughput

Title	Throughput	**Reference**	SR_8
Description			
Average throughput across the simultaneous wavelength range shall be (1) ≥ 0.05 (2) ≥ 0.10 This includes the telescope and detector QE but excludes the transmission of the atmosphere.			
Priority	(1) Essential, (2) Optimal.		
Source	Sensitivity SR_2		
Maturity	Firm		
Proof of Compliance	Initially, throughputs to be measured on a per module basis during module testing. During integration and test, the throughput including the detector QE will be confirmed with a calibrated point source. A determination of the detector QE is also required, to allow the optical throughputs to be decoupled from the throughput of the whole instrument. Ultimate demonstration of throughput will be carried out at the telescope.		
Related requirements	SR_6 Total wavelength coverage SR_9 Field of View SR_10 Instrument Background		
Assumptions	Simulations of PRVS using 0.1 have been used in defining the Science Case. Field of view 1.4 arc-seconds and seeing 0.6 arc-seconds at J (median at Gemini North).		
Comment	Without specifying the number of nights available to PRVS it is not possible to derive the required throughput from the science case. A pragmatic approach is to estimate the sensitivity of the instrument and confirm that this is sufficient to carry out the observations indicated by the science case. The throughput used in modelling the sensitivity is based on our understanding of what is likely to be possible. Our simulations of PRVS determine the likely sensitivity given realistic atmospheric transmission, optical efficiencies, noise and QE characteristics of a state-of-the art near-infrared array. The overall goal is to maximize throughput.		

2.2.2.6 Fibre Field of View

Title	Field of View	**Reference**	SR_9
Description			
The field of view of the fibre input on the sky shall be (1) ≥1.2 arc-seconds.			
Priority	(1) Essential		
Source	Sensitivity SR_2		
Maturity	Firm		
Proof of Compliance	Acceptability to be demonstrated via opto-mechanical design, confirmation during lab testing.		
Related requirements	SR_8 Throughput SR_11 Acquisition and Guiding		
Assumptions	Median seeing 0.6 arc-seconds at J.		
Comment	Point sources will be within the field of view in the majority of seeing conditions.		

2.2.2.7 Instrument Background

Title	Instrument Background	**Reference**	SR_10
Description			
The instrument background, being the sum of the scattered arc light background, dark current (including persistence), grey moon, instrument thermal background, and sky background, shall be: (1) ≤ 0.20 e/s/pixel (2) ≤ 0.02 e/s/pixel			
Priority	(1) Essential (2) optimum		
Source	Sensitivity SR_2		
Maturity	Firm		
Proof of Compliance	Acceptability to be demonstrated via opto-mechanical design, confirmation during lab testing.		
Related requirements	SR_6 Simultaneous Wavelength Range SR_8 Throughput SR_9 Field of View		
Assumptions			
Comment	The controllable backgrounds are the scattered arc light, dark current (including persistence), and the instrument thermal background.		

2.2.2.8 Acquisition and Guiding

Title	Acquisition	**Reference**	SR_11
Description			
A science target must be acquired and positioned onto the centre of the field of view of the fibre and kept there to an accuracy of (1) ≤± 0.10 arc-seconds on the sky (2) ≤± 0.05 arc-seconds on the sky			
Priority	(1) Essential (2) Optimal		
Source	SR_1 Radial Velocity Precision SR_2 Sensitivity		
Maturity	Firm		
Proof of Compliance	Before delivery, demonstrate compliance via design, analysis and testing of related functional requirements. Full acceptance during commissioning		
Related requirements	SR_3 Observation Efficiency SR_13 Image Quality on Fibre		
Assumptions	Point source.		
Comment	The CCD Fibre Viewer is used for object acquisition and guiding. The FV also improves observational efficiency by speeding the acquisition procedure.		

2.2.2.9 Guiding Sensitivity

Title	Sensitivity	**Reference**	SR_12
Description			
The CCD Fibre Viewer shall have a sensitivity of (1) Z ≥ 14.80 for S/N = 20 in 1 s			
Priority	(1) Essential		
Source	SR_1 Radial Velocity Precision		
Maturity	Open		
Proof of Compliance	Sensitivity will be verified during on-sky commissioning using observations of flux standards. Contributing factors (throughput, read–noise, image quality) will be verified in the lab during Integration and Test phase.		
Related requirements	SR_13 Image Quality on Fibre		
Assumptions	The sensitivity estimates are based on a model that include the following assumptions: 0.01 total throughput in the Z-band (which includes telescope, FV optics, and CCD detector); 5 e RMS read noise; 10 e/s dark current Image scale 0.06 arc-seconds per CCD pixel		
Comment	The radial velocity precision sets the centring requirement on the fibre field of view. Guiding needs to maintain this centring. The sensitivity is set by the requirement to guide on the faintest RV science target.		

2.2.2.10 Image quality on Fibre

Title	Image quality	**Reference**	SR_13
Description			
Spot diameter needs to be small compared to the median seeing (0.6 arc-seconds at J): (1) 50% EED ≤ 0.10 arc-seconds (2 pixels) (2) 50% EED ≤ 0.05 arc-seconds (1 pixel)			
Priority	(1) Essential (2) Optimum		
Source	SR_1 Radial Velocity Precision SR_2 Sensitivity		
Maturity	Firm		
Proof of Compliance	Related functional requirements will be demonstrated in the lab with modelling to confirm that this requirement is met. Final acceptance is on the telescope during Commissioning.		
Related requirements	SR_9 Fibre Field of View		
Assumptions	Median seeing of 0.6 arc seconds at J		
Comment			

2.2.2.11 Image Quality at the Spectrograph Detector

Title	Image quality	**Reference**	SR_14
Description			
The image quality at the detector shall not degrade the diffraction-limited spectral resolving power by more than 5%. This requires: (1) (a) 50% EED ≤ 0.8 pixel (b) 80% EED ≤ 1.6 pixels			
Priority	(1) Essential		
Source	SR_1 Radial Velocity Precision		
Maturity	Under Review		
Proof of Compliance	Related functional requirements will be demonstrated in the lab with modelling to confirm that this requirement is met. Final acceptance is on the telescope during Commissioning.		
Related requirements	SR_4: Spectral Resolving Power		
Assumptions	The detector crosstalk and data reduction will not further degrade this requirement significantly.		
Comment	The spectral resolving power is met by this plus all systematic effects including the detector, detector read-out and data reduction.		

2.2.2.12 Array Cosmetic Quality

Title	Array cosmetic quality	**Reference**	SR_15
Description			
(a) The array shall have a cosmetic quality such that (1) ≤3% of all pixels are hot, cold, or unstable and (2) ≤1% of all pixels are hot, cold, or unstable. (b) there shall be (1) no clusters of hot, cold, or unstable pixels (c) any sub array of 30x30 pixels shall contain no more than (1) 200 hot, cold, or unstable pixels.			
Priority	(1) Essential; (2) Optimal		
Source	Radial Velocity SR_1		
Maturity	Under Review		
Proof of Compliance	Will be confirmed by testing of the array.		
Related requirements			
Assumptions	A hot pixel is defined as one whose dark current is greater than 3e/s above of the average for the array. A cold pixel is defined as one whose response is less than 50% of the average for the array. An unstable pixel is defined as one that deviates (as a function of illumination or time) by more than a few percent of the night sky background in any one exposure. Such pixels are not easily identifiable in the standard dark or flat-field calibration.		
Comment	Dead pixels will cause gaps in the wavelength coverage of the instrument. This may not be a problem but if they lie on regions of interest they will reduce the number of usable spectral lines. This in turn affects the signal to noise in the final measurement of radial velocity.		

APPENDIX 1

A1. REQUIREMENT DEFINITION

Requirements are recorded here within a rigid framework, detailed below.

- **Reference**: An unchangeable identification of the form SR_N. To assist in the change control exercise and in the interests of accountability, reference IDs will not be re-used. That is, a deleted requirement may not appear in the released version of a document, but will nevertheless remain recorded within the archive copy and retain its reference ID.

- **Title**: A brief descriptive summary of the function detailed within the requirement

- **Description**: A full textual description of the requirement. Additional ancillary requirements of lower priority may be denoted within this field. However, the authors should consider generating new, "child" requirements in the interests of avoiding confusion in this instance.

- **Priority**: A value for the importance to be attached to the requirement during the analysis, design and test phases. For each requirement, this field will be reflected in a related top-level functional requirement of the instrument. Allowed entries in this field are*: Essential, Optimal, and Desirable*. The characteristics of each denomination are detailed in the proceeding section below.

- **Source**: From where is the requirement derived and what drives it? The needs of the users or the science drivers should be reflected within this list of requirements.

- **Maturity:** We acknowledge, particularly during the conceptual design phase, that the Science Case will be subject to continual evaluation and expansion. We also acknowledge that the project will revisit the requirements capture/analysis/design cycle as is deemed suitable. As such, user requirements will likely be subject to upgrade or expansion but not, we hope, radical change from this point. In this field we indicate any anticipated change to the requirement, or any factors, which will necessitate its re-evaluation. The goal is to evolve a complete set of requirements that can be labelled "firm". Other categories are "under review" which means that the requirement may be altered following further modelling and trade off studies and "open" which means that the requirement is a first estimate and is likely to change following further work.

- **Proof of Compliance:** An adequately specified requirement must, by the definition used here, be specified in such a way that the instrument can be evaluated for conformance. In this field we specify, in detail and with references if necessary, the means by which the requirement will be tested. Not until this field is complete and agreed can a requirement be recorded as "stable". There must be a tight link between this field and the test plan.

- **Assumptions**: Details assumptions that are made in the description of the requirement. Assumptions that relate to fixed external influences or constraints should be noted here. However, those assumptions that prevent the requirement from being considered "stable" suggest that ancillary evaluation of the instrument proposal is required. The numbers of such assumptions should decrease over time, with each release of this document.

- **Related requirements** – Additional, lower-priority requirements (indicating desirable, but non-essential functionality, from instance) may be detailed as being separate requirements if deemed necessary. Such links must be indicated in this field. Inter-dependencies between top-level requirements are undesirable and suggest that a search for overlying, but as-yet unrecorded, requirements is needed. However, such dependencies may be specified in this field.

- **Comment**: This field is to allow clarification of the requirement or additional information of relevance.

A1.1 ASSIGNMENT OF PRIORITIES TO REQUIREMENTS

Three denominations are used to categorise the requirements for the purpose of denoting their importance in the design, optimisation and evaluation processes. Guidelines for assigning a priority rating are given here - one or more of the following characteristics may be sufficient for the requirement to be classed as follows:

Essential: This is a minimum, which exploits the capabilities of the telescope and below which PRVS is no longer scientifically justified. At this level of functionality, PRVS supports science cases that are likely to attract significant interest from the community, and may come to be considered part of the "bread and butter" of the work of the instrument. A design with an essential capability enables a significant number of the science programs to be accomplished that are scientifically very significant.

Optimal: Functionality deemed optimal fully exploits the capabilities of the telescope. Such a categorization implies that it will directly affect the operational efficiency of the instrument and should be optimised at a high priority during design work. At this level, the requirement enables a wide variety of the scientifically interesting programs to be conducted. It supports, or is likely to support, science cases that will be available only using PRVS. Functionality that does not reach the level of optimal should be considered as "de-scoped" or compromised.

Desirable: Design parameters that are desirable reach a level of performance that is not substantially dictated for in the science case or operational concept definitions but may give PRVS significant performance advantage over similar instruments or may enhance efficiency. But given that functionalities in this category are not well justified, although these can be consider worthy or may enhance the capabilities of PRVS, they are not critical to the core functionality of PRVS. Functionalities in this category should not be attempted at the expense of reaching optimal functionality in other areas.

The engineering team will use the Optimal requirements as the baseline for the design but will fall back on the Essential requirements in case of conflict between different requirements. Desirable requirements will only be addressed in the early stages to investigate the feasibility.