Space Research Institute
Russian Academy of Sciences

FREND Experiment Archive Interface Control Document (EAICD)

EXM-FR-ICD-IKI-0086

version 2.0 of 27.11.2020

Moscow, 2020

Table of Contents

Changelog

Document changes are described below

Date	Description	Ver	Signature
20.01.2016	TOC populated	1.0	A. Malakhov
18.03.2016	Initial Release	1.1	A. Malakhov
22.03.2016	Table 2-1 updated with correct SCI Dosimeter data rate	1.2	A. Malakhov
28.10.2017	§§ 3.2.2, 3.2.3, 3.2.4, 3.2.5, 3.4 added to describe PDS data types, labels metadata and delivery schedule.	1.3	A. Malakhov
20.12.2017	§2.3.1 – Detectors subsystem description updated §2.3.2 – collimator design expanded	1.4	A. Malakhov
25.01.2018	§3.2 update to explain no geometry in metadata	1.5	A. Malakhov
12.02.2018	Updates in reply to the RID: §3.3 – paragraph added with file naming conventions §3.4.1 – RAW data created by SOC §3.4.2, 3.4.3 – description of FREND/SOC interaction for data retrieval and products PDS4 validation	1.6	A. Malakhov
14.06.2018	§3.2.2 – Table 3.15, edited Science calibrated definition	1.7	A. Malakhov
15.08.2019	§3.4.2.1 with Dosimeter Raw to Calibrated algorithm added §3.4.3.1 with Dosimeter Calibrated to Derived algorithm added §3.5 Delivery schedule updated	1.8	A. Malakhov
07.11.2019	Edits in reply to ESAC comments: §1.2 Reference Documents paragraph added §3.2.1 frd_par_hk label definition added §3.2.2 Table 3.15 correction of ERROR_* parameter names to match the actual label files §3.2.5 Update of Calibrated Dosimeter Products to correctly define gaps metadata fields §3.4 Product generation algorithms for neutron science added §3.5 delivery schedule harmonized with current dates	1.9	A. Malakhov
27.11.2020	Edits in reply to Dosimeter product review §2.3.3 – dosimeter description expanded §3.1.1 – dosimeter data format description expanded §3.1.2 Limits to cal curves introduced §3.2 – edits re partially processed HK product, highlighting it is the only one for HK processing, deleting earlier mentions of calibrated HK §3.3. Updating links to tables in Table 3-20 and product names to match PSA convention §3.4.3.3 – update of dosimeter algorithm §3.2.2, 3.2.3, 3.4.4.2 – update of Dosimeter detector names in algorithm §4 – added with references	2.0	A. Malakhov

1 Introduction

The Experiment Archive Interface Control Document aims at describing the contents of the Fine Resolution Epithermal Neutrons Detector (FREND) instrument archive as stored in Planetary Science Archive (PSA). This comprises both logical structures of the data stored and physical meaning of all data products.

1.1 Document Scope

To thoroughly describe FREND instrument data stored in the PSA, this document first contains reference sections that outline the basic operating principles of the instrument and physical processes involved in measurements. Next, different possible operational scenarios are explained along with measurement modes that can be used for data accumulation. Finally, PSA contents descriptions are given – different data product levels are explained in detail (with structures and physical meaning), as well as algorithms used to generate them.

1.2 Reference Documents

#	Document Reference
[RD1]	EXM-GS-PLN-ESC-20001 Flight Operations Plan iss 7 ver 2
[RD2]	
[RD3]	
[RD4]	
[RD5]	

2 Instrument description

FREND stands for Fine Resolution Epithermal Neutron Detector. This is an instrument installed onboard the Trace Gas Orbiter (TGO) of the joint Roscosmos-ESA ExoMars mission.

2.1 Science objectives

There are 3 major scientific goals:

- Measure epithermal and fast neutron fluxes from the Martian surface with high spatial resolution of about 40 km (linear pixel size);
- Create maps of Hydrogen concentration in the Martial soil with 40 km spatial resolution;
- Monitoring of neutrons and charged particles fluxes at broad energy ranges during periods of quiet Sun and during Solar Particle Events;
- Measure fluxes and fluences of neutrons and charged particles at broad energy ranges and equivalent radiation doses during periods of quiet Sun and during Solar Particle Events; update radiation environment data in interplanetary space and on the surface of Mars to be used for spacecraft radiation analysis and manned flight radiation safety analysis.

2.2 Physical principles

The instrument is aimed to collect data on the flux of neutrons from Martian soil. This allows estimation of hydrogen content in the soil at up to 1 meter depth. The unique feature of the instrument is its neutron collimator that narrows significantly the detectors' field of view, thus enabling creation of high resolution maps. The instrument's basic functionality principles are explained below

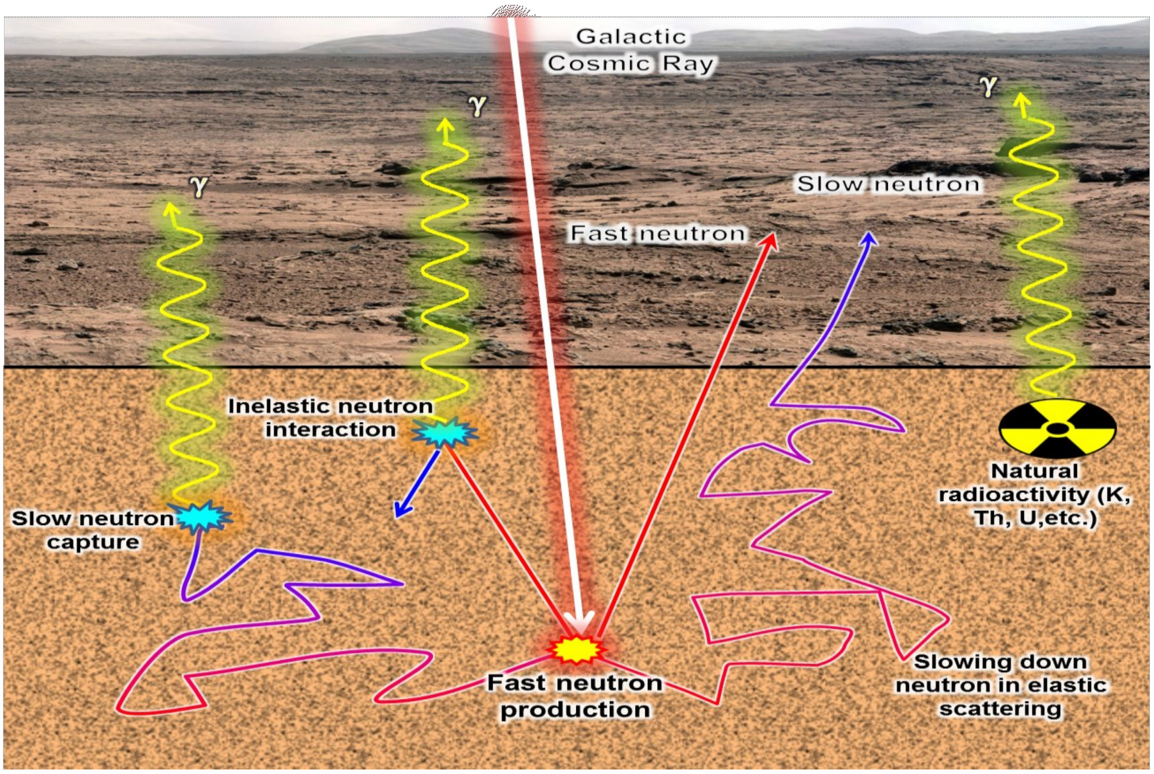

Figure 2-1 FREND measurement physical principle

The figure above shows physical processes involved in measurements of FREND. Once a Galactic Cosmic Ray (GCR) reaches Martian soil, it penetrates through and produces fast neutrons that scatter through the soil. These neutrons in turn start interacting with different materials of the soil triggering different nuclear reactions: some produce gamma-rays, and some simply thermalize (slow down) the neutron. Some particles escape from the soil back to the atmosphere and then the space, some get caught by the soil. As a result, the flux of particles that escaped from the soil can be registered on orbit. Since the GCR flux is rather constant (or at least well-known), the resulting flux is only influenced by the type and composition of soil it interacted with. Hydrogen is one of the most effective moderators of neutrons. Thus well-thermalized neutrons (with low energy) detected on orbit are a signature of rich H content in the soil, and vice versa, high-energetic flux is signature of low H concentration.

The described method works well on depths of up to 1 meter, since neutrons that penetrate below that level almost never escape back to the atmosphere and get caught by the mass of soil.

Collimator module is a unique feature of FREND that significantly narrows the field of view of the instrument by blocking all the neutrons coming from directions other than the field of view, thus enabling measurements with high spatial resolution. The collimator is explained more in section 2.3.2.

FREND also contains a dosimetry module that performs radiation dose measurements onboard the spacecraft. Parameters of these measurements are described in section 2.3.3.

2.3 Instrument and Subsystems

The Figure below shows the overall design of the instrument and explains its different subsystems' locations:

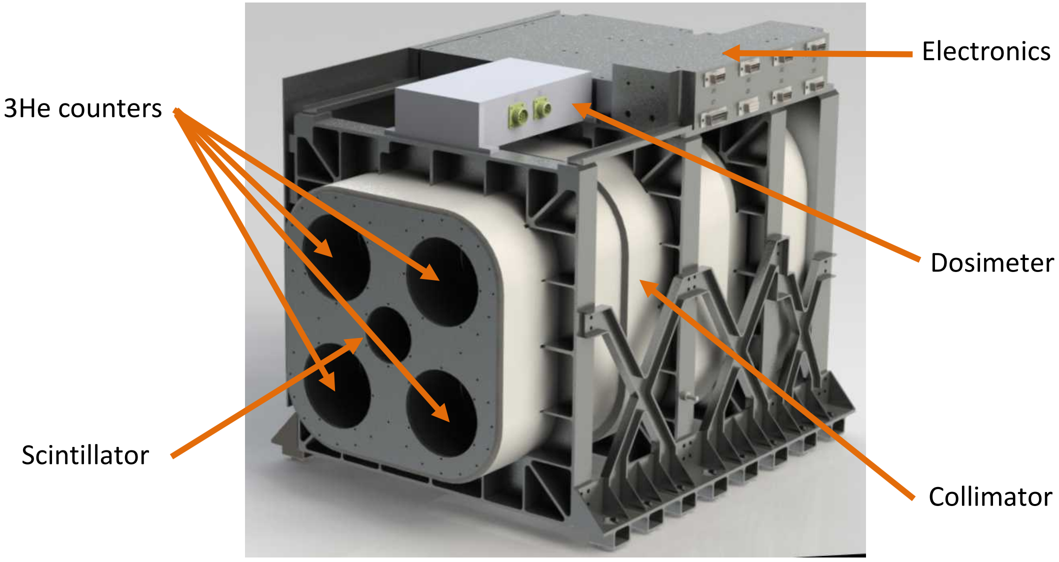

Figure 2-2 FREND Subsystems

- Detectors. Comprises four ^{3}He and one scintillator detectors that perform measurements of neutron flux;
- Collimator. A passive (unpowered) module that absorbs all signal coming from out of field of view, thus providing measurements with high spatial resolution;
- "Liulin-MO" dosimeter. A separate measurement unit that performs radiation dose measurements;
- Digital electronics. A model performing control over the instrument and provides digital interfaces to the spacecraft;
- Thermal subsystem. A separate and uncontrolled subsystem that does thermal control of the instrument.

Further details of these subsystems are given in sections that follow.

2.3.1 Detectors

FREND instrument detectors subsystem contains 5 detectors: 4 identical proportional counters and 1 scintillation detector. Each proportional counter detects neutrons in the 0.4 eV – 500 keV energy range, the scintillator detects neutrons of 0.5 – 10 MeV. The locations are shown on the figure below:

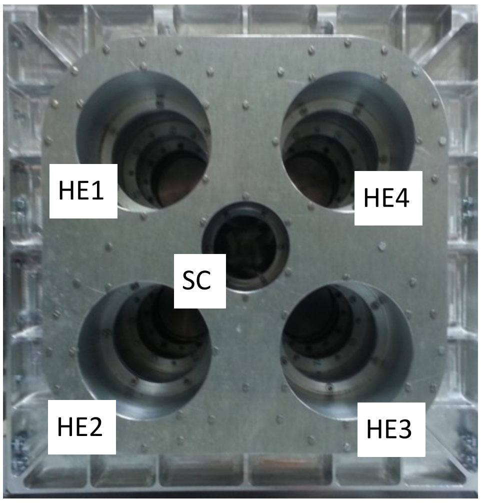

Figure 2-3 FREND Detectors scheme

Each detector is located deep inside the openings of the collimator that provide for a/the narrow field of view.

FREND measurement principle is to register each neutron coming through the volumes of its detectors together with its energy. This is essentially what is done within this subsystem. When a neutron is detected, the impulse is emitted by the sensor that is then digitized and sent to the Electronics module. This impulse amplitude is characteristic of the particle's energy.

^{3}He detectors are cylindrical gas-filled proportional counters covered by 1 mm Cd shield. All 4 detectors are identical. The 4 detectors all measure the same signal (i.e. particles of the same energy range), to increase the instrument's statistical capabilities: when the 4 measurements are acquired, they are summed up together allowing for lower exposition time of the map. Their geometrical dimensions are 78mm along the cylinder axis and 50.8 mm in diameter. They are filled with ^{3}He gas with addition of CO_2. Gas pressure inside the cylinder is 4560 Torr (6 atm). The signal from these detectors is processed and digitalized into 16 energy bins available in the instrument data.

Scintillation detector consists of a cylindrical stilbene crystal surrounded by a plastic anti-coincidence shield both mated to a photomultiplier tube. Stilbene crystal dimensions are 36 mm in diameter and 36 mm along the cylinder axis. Plastic shield is 5 mm thick. The signal from the scintillator is processed by an anti-coincidence scheme and divided into two channels – "neutrons" (SCN) and "particles" (SCG, the latter containing signal captured in plastic from gamma-rays and charged particles). These two channels are also processed and digitalized into 16 energy bins each available in the instrument data.

Signal from both types of detectors is digitalized as 16 energy bins, i.e. during the accumulation time of every scientific frame (default is 5 seconds), every particle's energy level is measured and then the particle "event" is recorded into the corresponding energy bin. That way, every science frame of FREND contains a spectra for all 5 detectors accumulated (by default, during the 5 seconds).

Two images below are measured during calibrations of the flight unit of FREND to characterize the energy bins:

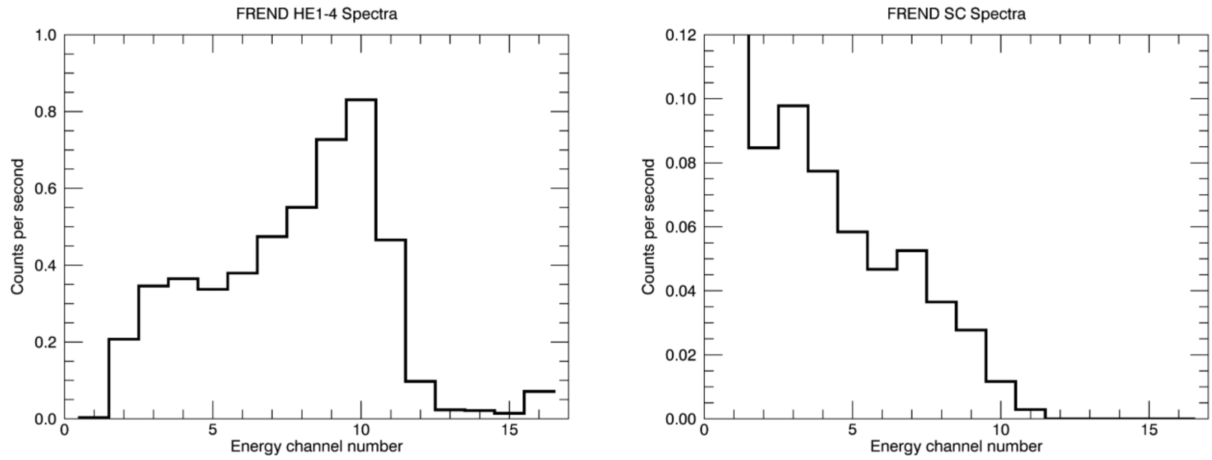

Figure 2-4 Detectors spectra

Left: pulse height spectrum measured by HE1-4 detector system with ^{252}Cf located directly in front of the sensors. The 2nd peak in channel 10 correspond to full energy deposition of 764 keV by proton and triton originated from the reaction of thermal and low energy epithermal neutron capture by ^{3}He. Low energy channels of this spectrum correspond to wall effects tail when either a proton or triton escapes the detector volume. **Right:** spectra measurements of the SC detector measured with ^{252}Cf located directly in front of the sensors.

FREND detectors can have the following settings:

- High voltage level: Low or High. Default level is low. This selects one of the 2 preset high voltage levels that power the ^{3}He and stilbene detectors. High level can be used in case a decay in sensitivity of detector is observed.
- Discriminator level: On or Off. Default level is Off. Discriminator is a setting that digitally cuts off 3 (out of 16) lower energy bins from the detector's channels. This setting is only applicable to ^{3}He detectors.
- Accumulation time: number of seconds during which a single data frame is collected. During this time all registered particle events in all the detectors are added up to the spectra. Once the new frame is opened, an empty set of spectra (one spectra per detector) begins accumulation. This means that the accumulation time drives the instrument's spatial resolution. Default is 5 seconds.

2.3.2 Collimator

Collimator is a module that shields FREND's detectors fields of view to a narrow spot below the spacecraft. This allows creating maps of neutron flux with high spatial resolution, opposed to those created by omnidirectional instruments that collect signal from one horizon to another.

The figure below explains the main collimation principle. Every detector is surrounded by 2 layers of shielding: first a polyethylene layer that is rich with H and moderates (slows) the neutrons quite effectively and then a layer of ^{10}B that is a good absorber of neutrons. The cadmium shield in front of the detector is only there to cut off neutrons with energies lower than 0.4 eV.

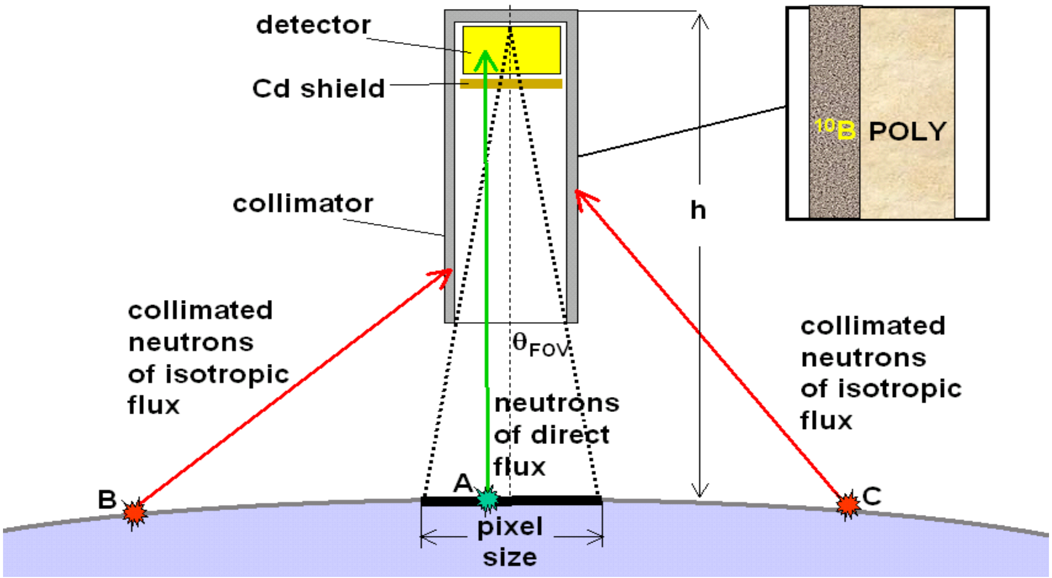

Figure 2-5 Collimation principle diagram

As one can see, only neutrons coming from inside the pixel will be registered by a detector. Neutrons coming from points B or C will not be detected, thus allowing the instrument to only collect data from the pixel below the spacecraft.

FREND's pixel size on Mars surface is estimated to be 40 km, considering the spacecraft orbit is 400 km.

The following image provides a schematic cross-section of the collimator and detectors located inside.

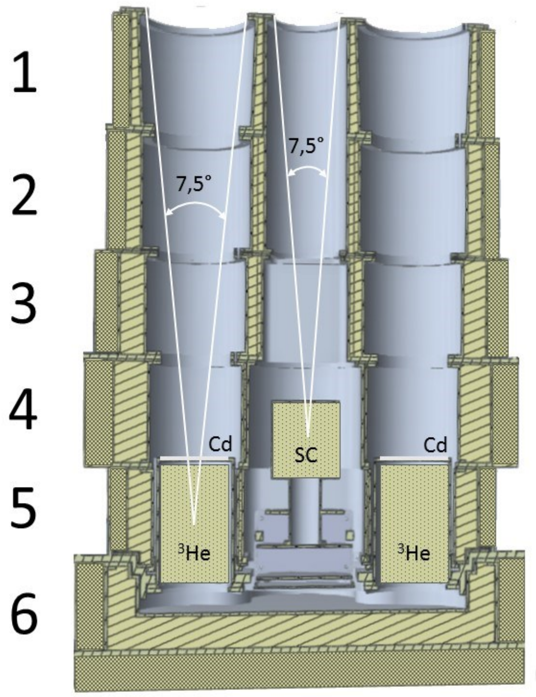

Figure 2-6 Collimator cross-section

The collimator is comprised of 6 sections, each containing a layer of polyethylene (outside, in solid color) and of ^{10}B powder (inside, straight lining). ^{3}He and Scintillator detectors are also shown with their field of view cones. This structure enables good protection from out of field of view neutrons. The exact schematics (width and height) of sections is a tradeoff between the "ideal" collimator model that was calculated for Martian conditions and the structure that can be manufactured and withstand the space environment.

2.3.3 Dosimeter

FREND's "Liulin-MO" Dosimeter is a separate module that performs monitoring of radioactive doses in the vicinity of the spacecraft. It measures the energy deposition spectra, flux, and absorbed dose rate of the charged and Galactic Cosmic Rays (GCR) gamma particles, Solar Energetic Particles (SEP) and secondary particles, that allow the calculation of the absorbed dose *D* in the dosimeter's detectors. It also measures the linear energy transfer (LET) spectra in silicon, that allow the assessment of LET in water LET(H_2O) and then the calculation of the radiation quality factor *Q* according to the *Q(L)* relationship given in ICRP – 60, where *L* stays for LET:

$$Q = \int Q(L)D(L)dL \,/D \qquad (1)$$

Q(L) is related functionally to the unrestricted LET or LET(H_2O) of a given radiation. The quality factor *(Q)* describes the different biological effectiveness of the various radiation types. The biologically significant dose equivalent *H* is equal to the absorbed dose weighted by the corresponding quality factor *H=DxQ*.

The dosimeter module measures the following parameters:

- Absorbed dose rate – 10^{-7} Gy/hr – 10^{-1} Gy/hr;
- Flux density – 0.01 – 10000 particles/($cm^2 \cdot s$);
- Energy deposition spectra in dosimeter's detectors –80 keV – 190 MeV;
- LET(H_20) in the range 0.13-177 keV μm^{-1}.

Liulin-MO contains two dosimetric telescopes - BA, and DC arranged at perpendicular directions. A schematic view of the location of the detectors inside the box of Liulin-MO is presented in Fig. 2-7(a). Each pair of the dosimetric telescopes consists of two 300 µm thick, 20x10 mm area rectangular Si PIN photodiodes. The distance between the parallel Si PIN photodiodes is 20.8 mm. The geometry factor of the telescope for isotropic radiation is ~ 1.38 cm^2 sr. The geometry factor of a single detector is ~ 12.56 cm^2 sr.

The primary measured parameters are the amplitudes of the voltage pulses at the outputs of the charge-sensitive preamplifiers - shaping amplifiers CSA1 to CSA4, connected to the detectors (Fig. 2-7(b)). The amplitude of a voltage pulse is proportional to the energy deposited in the corresponding detector by a charged particle or a photon crossing the detector. By an 8-bit ADC these amplitudes are digitized and organized in a deposited 256 channel's energy deposition spectrum for every one of the detectors.

The gains of preamplifiers CSA1 to CSA4 are a compromise between the conflicting goals of measuring gamma rays, electrons and high - energy protons (which have very low LET and hence requires high gains) and covering the HZE spectrum (which requires low gains to measure highly ionizing particles such as iron). As a result of the compromise one of detectors in each pair of parallel detectors and its corresponding CSA measures and provides the energy deposition spectrum in the range ~ 0.08 -18 MeV. Those are detectors – preamplifiers B - CSA2 and D - CSA3. The gains of CSA2 and CSA3 are ~ 240 mV MeV^{-1}. CSA2 and CSA3 are powered by + 5V. This leads to a maximum energy deposition of ~ 18 MeV that can be registered in these channels without electronic saturation. The other detector in each pair of parallel detectors and its corresponding CSA measures the energy deposition spectrum in the range ~ 0.3 - 190 MeV. Those are detectors – preamplifiers A - CSA1 and C – CSA4. The gains of CSA1 and CSA4 are ~ 60 mV MeV^{-1}. CSA1 and CSA4 are powered by + 12 V. This leads to a maximum energy deposition in silicon of ~ 190 MeV that can be registered in these channels without electronic saturation. The energy resolution is not worse than 100 keV in the 100 keV – 18MeV range and not worse than 800 keV in the 18 MeV – 190 MeV range. A coincidence technique for the associated with every dosimetric telescope electric signals from its CSAs is applied to obtain the LET. The energy deposition spectra

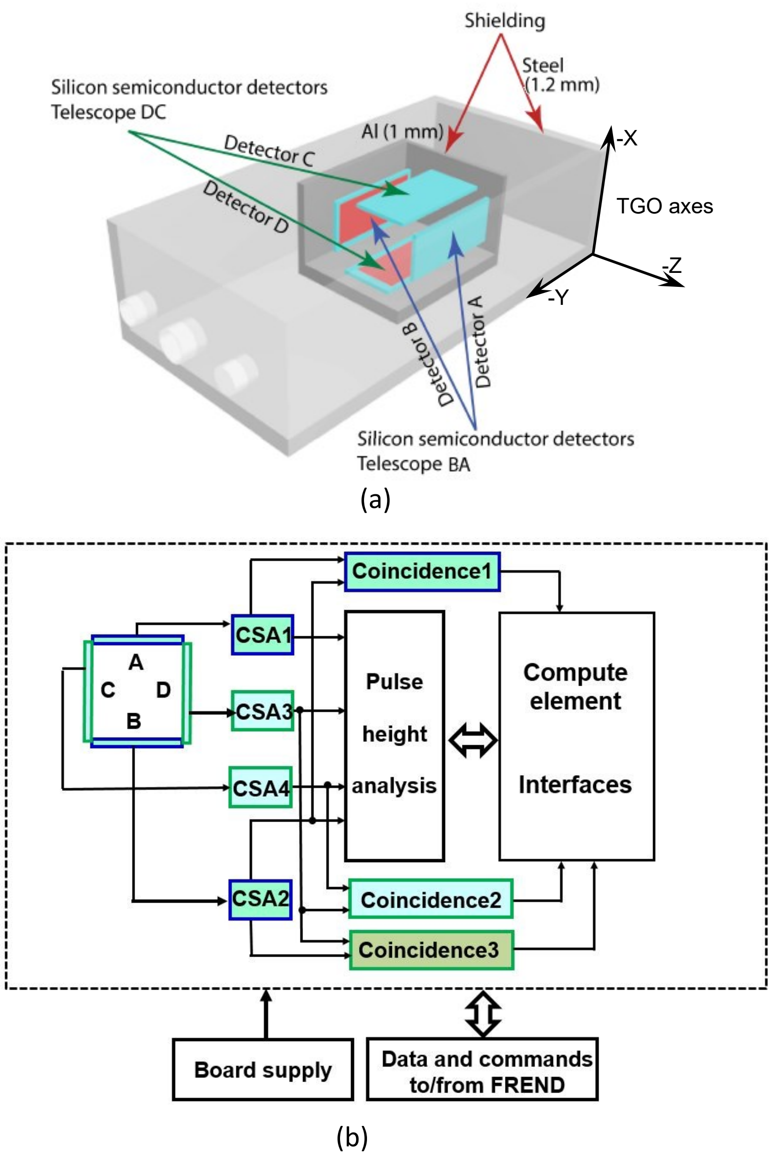

Fig.2-7. (a) A schematic view of Liulin-MO detectors' location in the dosimeter box and TGO s/c axes; (b) Dosimeter functional diagram

measured in each pair of parallel detectors in coincidence mode are recorded separately and used to obtain the LET spectrum in that direction

The energy deposition spectrum in the single detector named further B(A) (alternatively called also in direction BA) is obtained by combining the energy deposition spectrum measured by B - CSA2 in the range ~ 0.08 - 15.9 MeV with the energy deposition spectrum measured by A - CSA1 in the range ~ 16 - 190 MeV. The same procedure is used to obtain the energy deposition spectrum in the single detector D(C) (alternatively called also in direction DC). In that way each pair of two parallel detectors and their corresponding CSAs provide data in the energy deposition range ~ 0.08 - 190 MeV. All events with energy deposition > 190 MeV are registered in the last spectral channels of A and C detectors and are considered as events with 190 MeV energy deposition in the subsequent calculations.

The dosimeter module is located on top of the FREND structure and outside the collimator (see Figure 2-2), thus having an omnidirectional field of view.

Dosimeter module possesses 2 redundant circuits (digital electronics, detectors have no redundancy) and 2 redundant memory arrays that can be operated in any combinations. It receives power directly from TGO, but sends all its data acquired to FREND Electronics module. FREND will then retransmit it together with its own scientific data. Similarly, Dosimeter is commanded through FREND that retransmits all incoming Dosimeter commands from TGO to FREND.

The front-end electronics of Liulin –MO allows registration of no more than 20000 counts s^{-1} or 10000 counts s^{-1} cm^{-2}. This is the limit for registration of powerful SEP fluxes. It was confirmed by electronic calibrations and calibrations with gamma sources of the instrument. The death time from applying of coincidence techniques is ⍰ 0.05% of the total accumulation time. For registration of GCR and SEP this death time has no practical significance. The processing of the data and the data transfer to FREND are conducted in parallel by different electronics. There is no death time from these two processes

Totally 9 energy deposition spectra in anti-coincidence and coincidence modes are measured and provided in Liulin-MO output data:

- B0 and D0 – spectra measured by detectors B and D in anti-coincidence (0 denotes the lower energy part of the full spectrum);
- BA0, BD0, DC0 – spectra measured by B or D in coincidence with detectors A, D or C respectively;
- A1 and C1 - spectra measured by detectors A and C in anti-coincidence (1 denotes the higher energy part of the spectrum);
- AB1 and CD1 – spectra measured by detectors A or C in coincidence with B or D.

Quantities for the particle flux are denoted by F, those for the dose – by D. For example the flux measured by detector B in anti-coincidence is FB0, the corresponding dose – DB0. The full quantity of the flux (dose) measured by a single detector is obtained by summarizing the corresponding parts:

FBA=FB0+FBA0+FBD0+FA1+FAB1; DBA= DB0+DBA0+DBD0+DA1+DAB1

FDC=FD0+FDC0+FBD0+FC1+FCD1; DCD=DD0+DDC0+DBD0+DC1+DCD1

The dose rates and the fluxes are resolved every minute and recorded in the output data – further called “minute quantities”, while the energy deposition spectra and the LET spectra are resolved every hour.

For more details about Dosimeter Liulin-MO see Semkova et al., 2018

2.3.4 Digital Electronics

The electronics module of FREND is the core module performing the following functionality:

- TGO 1553 communication (commands and scientific/housekeeping data generation)
- Low-voltage power conversion
- Monitoring of FREND state, including FDIR (Fault Detection Isolation and Response algorithms) functions
- Commands acceptance and execution (i.e. control over other subsystems)
- Power provision to the Neutron detection subsystem
- Signal acquisition from the neutron detectors
- Data acquisition from the Dosimeter module

FREND electronics are based on the use of a FPGA chip that performs all the logical operations within the instrument.

The FREND electronics module contains low voltage conversion elements that convert the TGO-supplied +22-+36V power to standard levels of +/-5V, +/-12V etc. This power is used to operate the electronics module itself as well as other subsystems of the instrument.

The FREND Electronics module acquires digital signal from the Scintillator detector and all four ^{3}He detectors. Data from these signals are processed and put into scientific data packets.

Commands to and from the dosimeter module are handled within FREND electronics module. Dosimeter transmits its measurements data through RS-422 interface in packetized form ready for retransmission to TGO. Commands are, in the same way, retransmitted through FREND to the Dosimeter module.

All interactions with TGO (data exchange, commanding, power provision) are handled by the Digital Electronics module. The high-level block diagram is on Figure 2-8 below:

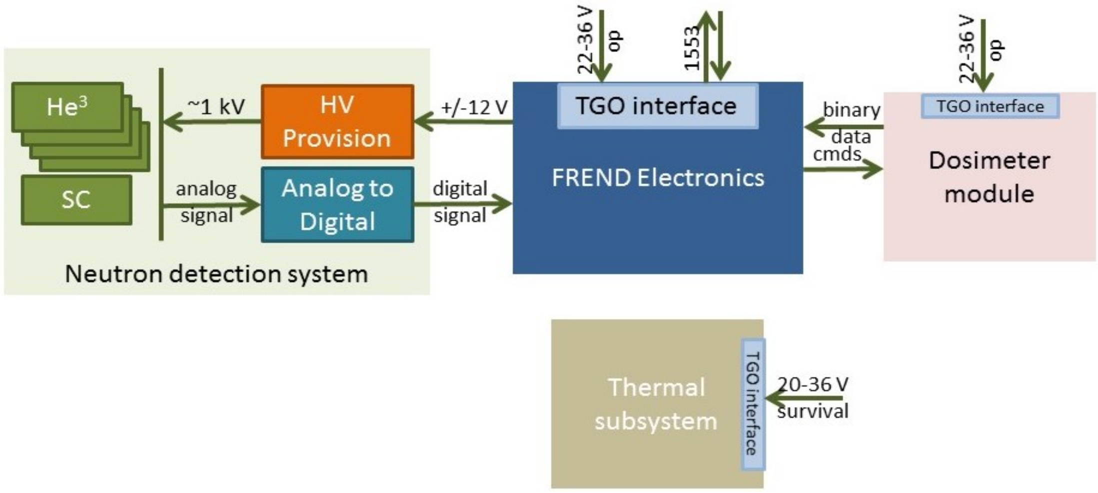

Figure 2-7 FREND Digital Electronics block diagram

2.3.5 Thermal control subsystem

The Thermal Control Subsystem is only powered on (by TGO) when FREND is powered OFF, i.e. in survival mode. This is foreseen because when powered off, the instrument cannot heat itself and thus can get too cold during some of the mission phases.

FREND thermal subsystem is totally isolated from the instrument and is completely controlled by TGO (by switching on/off survival heater power lines). Its design is very simple as it consists of 2 thermostats (for nominal and redundant survival heater lines) and a set of passive resistors located at key locations within the instrument. Thermostats control the temperature levels at which the resistors are powered on or off.

The Thermal Control Subsystem is hard-coded for the following temperature setpoints:

- Turn ON if T < -20 °C
- Turn OFF if T > 0 °C

These levels cannot be changed by command.

2.4 Operations

This chapter describes FREND operations, explaining possible measurement modes of the instrument and how they are related to scientific observations that are performed by the instrument.

2.4.1 Modes

The diagram in Figure 2-9 below shows possible FREND Mode Transitions:

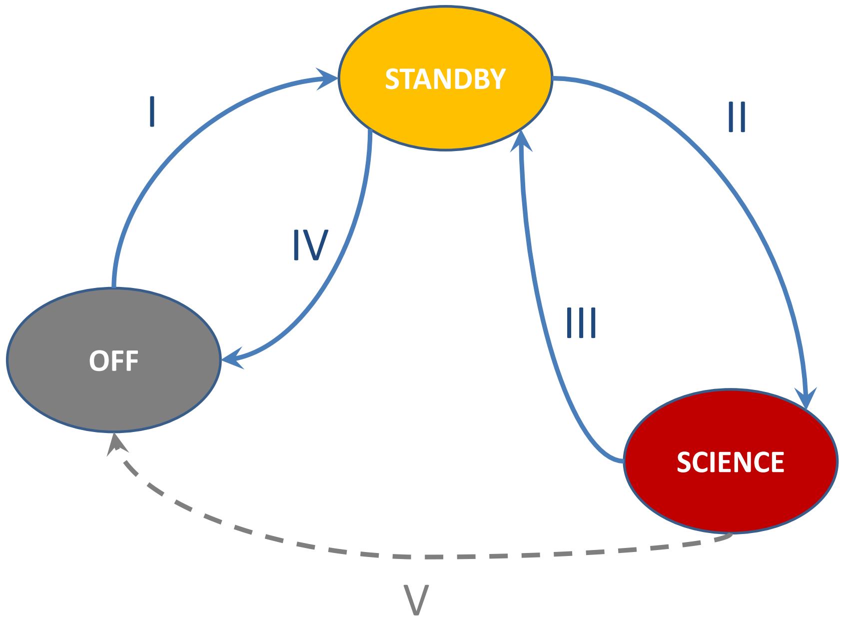

Figure 2-8 FREND Mode Transitions

This diagram demonstrates 2 major ideas: the preferred way of mode transitions and all possible mode transitions.

The preferred way to operate the instrument is from OFF to STANDBY to SCIENCE to STANDY to OFF, i.e. I – II – III – IV path.

The transition path from SCIENCE to OFF (by powering off the 2 power lines) is possible, will not result in major harm to the instrument, but is not nominal, may result in partial loss of data, and is not recommended for operations.

It is not possible to go from OFF to SCIENCE directly.

It should be noted that FREND instrument has no "mode definitions" within it, i.e. no housekeeping data or flag will show that the instrument is currently in this or that mode. Operational modes are only defined for operational simplicity. The instrument is considered to be in this or that state if it is configured correspondingly. These differences are explained below.

2.4.1.1 Survival Mode (OFF)

Definition. This mode refers to the instrument when it is powered OFF, i.e. both operational power lines (FREND and Dosimeter) are disabled. It should be noted that Survival Heater Lines **must** be activated at all times when the instrument is OFF. This will make sure the Thermal Control Subsystem is operational and keeps instrument temperatures within limits (see Section 2.3.5).

Power. Instrument consumption depends on thermostats activation/deactivation cycles, but will not exceed 6.7W at 28V ±10% (thermostats are ON 100% of time case).

Data. No data is transferred in this mode.

2.4.1.2 Standby Mode

Definition. This mode is defined as "detectors OFF mode", i.e. when all FREND detectors are OFF with the exception of dosimetry module that has no standby mode and begins measurements immediately after power on. All FREND digital electronics are operating, providing housekeeping data and “null” science packets (there is no possibility to turn off science packets generation). Dosimetry module is operating nominally, performing measurements. As soon as any of the 5 FREND detectors (4 proportional counters or scintillator) is enabled, this assumes transition to Science mode.

Power. Instrument consumption is 5W (FREND) + 2.6W (Dosimeter) = 7.6W total @28V.

Data. Housekeeping data is generated (default @0.1Hz, or 1 packet per 10 seconds). FREND Neutron Science is generated (default @0.2Hz or 1 packet per 5 seconds). FREND Dosimeter Science is generated (default @0.00(5)Hz, or 1 packet per 180 seconds). The resulting data rate is provided in table 2-1 below:

Data type	Bytes per s/a	S/a num	Msgs per min	Bits per day	Mbits per day
HK	64	2	2	2949120	2,81
SCI Neutrons	54	6	12	44789760	42,71
SCI Dosimeter	64	10	0,33	2433024	2,32
Total				**50171904**	**47,847656**

Table 2-1 FREND Data Rate

In this table “s/a” means “subaddress”, which refers to 1553 protocol message size. Each data type thus comprises N chunks as reported in column “s/a num”. That way [Bits per day] = [Bytes per s/a] · [s/a num] · [Messages per min] · 60 · 24 · 8.

HK and SCI Dosimeter data types contain meaningful data, SCI Neutron data type is generated, but contains no measurements since FREND detectors are OFF.

2.4.1.3 Science Mode

Definition. This mode is defined as “any detector is ON”, i.e. any of the 5 FREND detectors (4 proportional counters or scintillator) is turned ON. Dosimetry module has no “standby” mode, thus it always performs measurements when powered. All FREND subsystems are operating as defined in Standby Mode above, and at least one of the FREND detectors is powered. All data types (Housekeeping, Neutron Science and Dosimeter Science) are being generated with meaningful data.

Power. Consumption depends on the number of FREND detectors operating. Default value (when all 5 detectors are ON) is 8.8W (FREND) + 2.6W (Dosimeter) = 11.4 W @28V. In case any of the FREND detectors are OFF, power consumption will decrease by ~0.75W per detector (@28V).

Data. Data is generated exactly as described in Standby Mode sect 2.4.1.2 above. The only difference is that in Science Mode Neutron Science packets contain meaningful data.

2.4.2 Observation scenarios

2.4.2.1 FREND Neutron Science

During nominal science observations the main goal for FREND is to be turned on all the time and stay in the same configuration for as long as possible, pointing to nadir for as long as possible: FREND is a statistical instrument, and thus the more data it accumulates within the same configuration, the more statistically accurate its data will be.

FREND main science goal is constructing maps of neutron flux from the surface of Mars. To do so, FREND registers all particles within its field of view from the orbit as TGO flies by a certain region of the planet. Mars is split into a number of pixels for mapping purposes, and all particles registered over a pixel will later be summed up and averaged over time. That way every new measurement over the pixel adds up to the number of particles detected in that pixel during all earlier flybys and thus adds up statistical certainty.

From the observational point of view, this drives following FREND observations requirements:

- the instrument must **stay on for as long as possible** to accumulate enough data so that each pixel becomes statistically certain. Another reason for that is that every power cycle of collimated detectors has a warm-up period of several hours, when detection efficiency reaches maximum level;
- the instrument must **measure in the same configuration** over time: if the configuration is changed, then the map accumulation process must start over for the new configuration. The configuration most appropriate for measurements will be pre-selected based on cruise calibration data;
- the instrument must **point to nadir** most of the time. In case TGO is pointing off-nadir, the data acquired during this maneuver cannot be used for mapping, since FREND is performing measurements from regions far away from the pixel below TGO. It must be noted that the instrument will not be turned off during maneuvers for safekeeping reasons, but rather data accumulated in off-nadir will be discarded from mapping process.

To accomplish these, FREND's standard observational scenario during science phase will be to turn ON in Standby, transition to Science Mode immediately after that and stay in this mode for indefinitely long, until spacecraft conditions and resources allow. In case the instrument is switched off for whatever reason, upon power-up the same scenario will be used.

2.4.2.2 FREND Dosimetry Science

FREND Dosimeter is an omnidirectional detector that performs radiation environment monitoring. Its observational scenario is similar to that of FREND Neutron Science part of the instrument, except that it does not depend on pointing. FREND Dosimetry Module will be turned on together with the instrument as a whole and start its monitoring measurements for indefinite time, until turned off. Its measurement cycle is one hour, after which the accumulated data is transferred to TGO.

Due to data exchange protocol restrictions, one cycle of dosimetry data is split into 20 chunks and transferred to TGO every 3 minutes. That is why while N^{th} cycle measurement is performed, $N\text{-}1^{st}$ cycle data is transferred to TGO. During the first hour of operations, dummy dosimetry data (incremental counter) is transferred.

2.4.3 Possible configurations

As defined in 2.4.1, FREND has a number of high-level modes (Standby, Science, Survival). Within each mode a number of other configurable parameters exist that influence the way the instrument accumulates data and these are explained in this section. Current values for these settings are always reported within instrument data and in PSA products, as a consequence, but exact parameter names and their meanings are defined further in section 3. This section explains the meaning of FREND configurable parameters.

Housekeeping Accumulation time. This configuration affects the generation period for FREND housekeeping telemetry. Default is 10 seconds, valid range is 1 – 655535 seconds.

Neutron Science Accumulation Time. This configuration affects the measurement cycle for FREND Neutron Science detectors (collimated data). During the cycle all particles registered are saved within single spectra. 5 spectra are generated during each measurement cycle – one for each collimated detector.

High Voltage Level. Sets the level of high voltage used. The setting can be set for all five collimated detectors separately. There are two predefined levels – "LOW" and "HIGH", the latter used to increase detectors efficiency in case a decay is observed. Default is "LOW".

Discriminators level. Turns ON or OFF discriminators, separately for all five collimated detectors. Discriminator is a setting that cuts off low energy particles from being registered, useful in case noise is observed in the lower energy channels. Lower 3 (out of 16) energy channels are affected. Default is OFF.

Counters Limits. FREND Housekeeping data contains a number of counts detected by each detector within the Housekeeping Frame accumulation period – this data is only used for health checks, since housekeeping data is transmitted online.

FDIR Setpoint. Temperature level for Fault Detection Isolation and Response algorithms. If set (not equal to 0), FREND compares its mounting point temperature to the setting level and will autonomously turn off high voltages in case the actual temperature is higher than the setpoint.

Dosimeter side. FREND Dosimeter contains two separate compute elements that can be switched over for redundancy purposes.

Dosimeter memory side. Dosimeter module contains two redundant memory arrays that can be switched over. This setting is independent from the Dosimetry Side setting defined above.

2.4.4 Sequences

FREND Sequences are described in detail in the TGO Flight Operations Plan [RD1] and are not reported within this document. Their basic outlines and purpose are defined below:

Procedure Name		**Description**
FR-FCP-001	Power-On (NOM)	Powers ON FREND Electronics and Dosimeter Nominal power lines, switches OFF Survival Heater lines, configures data readout by TGO.
FR-FCP-002	Power OFF	Turns OFF FREND Electronics and Dosimeter Nominal and Redundant power lines, switches ON Survival Heater lines, shuts down data readout by TGO.
FR-FCP-003	Standby to Science A	*(obsolete)* Configures to Science A or B Modes from any other mode. These modes were used for ground testing mainly.
FR-FCP-004	Standby to Science B	
FR-FCP-005	Parameterized Sequences	Configures FREND and Dosimeter to desired state, depending on Sequence Parameters. This sets all the configurable instrument parameters as described in sect. 2.4.3 to desired states.
FR-FCP-010	Science to Standby	Configures FREND and Dosimeter to Standby Mode from any other mode.
FR-FCP-011	Power-ON (RED)	Powers ON FREND Electronics and Dosimeter Redundant power lines, switches OFF Survival Heater lines, configures data readout by TGO.

Table 2-2 FREND Sequences list

Parameterized Sequences FR-FCP-005 are of course the ones mostly used for instrument control since they allow to transition FREND to any mode. They take as parameters all the possible configuration values and issue a set of instrument commands to tune the instrument.

Standby to Science A and B sequences FR-FCP-003 and FR-FCP-004 are now obsolete since they were mainly developed for onground testing. They configured FREND to a pre-defined state (mode “Science A” or “Science B”) and have no flexibility in parameters, which was useful for testing, but will not be used in flight.

3 Instrument data

3.1 Raw data types

FREND generates 3 major data types: FREND Housekeeping, FREND Neutron Science and FREND Dosimeter Science. This section lists all the relevant structures. These structures, however, are not archived into the Planetary Science Archive (PSA). They are processed from binary data as generated by FREND into PSA formatted files, as described in 3.2. This section describes data formats as generated by FREND for completeness of this ICD.

FREND is connected via Mil1553 protocol that uses subaddresses, max 64 bytes each, to send or receive data. The spacecraft, being the initiator of exchange, reads FREND data from these subaddresses, each of which contain different data types, according to Table 3-1

Subaddress	Telemetry type
2	Housekeeping1
3	Housekeeping2
4	Science He1
5	Science He2
6	Science He3
7	Science He4
8	
9	Science SCN
10	Science SCG
11	Science Dosimeter1
12	Science Dosimeter2
13	Science Dosimeter3
14	Science Dosimeter4
15	Science Dosimeter5
16	Science Dosimeter6
17	Science Dosimeter7
18	Science Dosimeter8
19	Science Dosimeter9
20	Science Dosimeter10

Table 3-1 FREND Subaddress usage

Tables 3-2 to 3-5 below represent structures that are written to each of the above mentioned subaddresses.

NB: For all tables, smaller bit or byte number means most significant bit. I.e, within one word bit 0 is most significant bit, bit 15 is least significant. Within one word, byte 0 is most significant byte, byte 1 is least significant byte. Within a DWORD, byte 0 is most significant byte, byte 3 is least significant byte, etc.

Table 3-2 Housekeeping 1, Subaddress 2

z	Parameter	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Comment
0	HK_SYNCRO1	0	1	1	1	1	1	0	0	0	1	1	0	1	1	1	0	Always 0x7C6EA12C
1		1	0	1	0	0	0	0	1	0	0	1	0	1	1	0	0	
2	SID_HK1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	Always 0x02
3	HK_FRAME_NUM1																	Running counter 0-65535
4	HK_FREND_TIME1	MSbit																Frame transmit time
5																	LSbit	1 tick = 1ms
6	HK_SC_TIME	MSBit																Copy of TGO time received
7																		This time received at
8																	LSBit	HK_SC_TIME_TS moment
9	HK_TEMP1 (PSU Red)																	
10	HK_TEMP2 (PSU Main)																	
11	HK_TEMP3 (HV HE1)																	
12	HK_TEMP4 (HV HE2)																	
13	HK_TEMP5 (HV HE3)																	
14	HK_TEMP6 (HV HE4)																	
15	HK_TEMP7 (HV SC)																	
16	HK_TEMP8 (MntPt FDIR)																	
17	HK_TEMP9 (Actel)																	
18	HK_TEMP10 (PSU +3.3V)																	
19	HK_TEMP11 (PSU +1.5V)																	
20	HK_TEMP12 (Dosimeter)																	
21	HK_VOLT1 (5V)																	
22	HK_VOLT2 (1.5V)																	
23	HK_VOLT3 (3.3V)																	
24	HK_VOLT4 (6V)																	
25	HK_HV_STATE	0	SCF	He4F	He3F	He2F	He1F	SCLVL		HV4LVL		HV3LVL		HV2LVL		HeV1LVL		HVxLVL: 0 = off, 3 = low, 2 = high HV Failures: 0 = OK, 1 = FAIL
26	HK_DISC_LEV	0	0	0	0	0	0	0	0	0	0	0	SC	HE4	HE3	HE2	HE1	Discriminator levels: 0 = off 1 = on
27	HK_DATA_COLLECT_TIME																	HK Accumulation time in sec
28	HK_SC_TIME_TS	MSBit																FREND time of last SC clock
29																	LSBit	received
30	SCI_DATA_COLLECT_TIME																	SCI Accumulation time in sec
31	HK_CHSUM1																	Sum of words above, no overflow

Table 3-3 Housekeeping 2, Subaddress 3

Word	Parameter	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Comment
0	HK_SYNCRO2	0	1	1	1	1	1	0	0	0	1	1	0	1	1	1	0	Always 0x7C6EA12C
1		1	0	1	0	0	0	0	1	0	0	1	0	1	1	0	0	
2	SID_HK2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	Always 0x03
3	HK_FRAME_NUM2																	Running counter 0-65535
4	HK_FREND_TIME2	MSbit																Frame transmit time
5																	LSbit	1 tick = 1ms
6	HK_LIM	HE1_High				HE1_Low				HE2_High				HE2_Low				Counter Limits
7		HE3_High				HE3_Low				HE4_High				HE4_Low				
8		SCN_High				SCN_Low				SCC_High				SCC_Low				
9	HK_FDIR																	Temperature FDIR limit. 0 = Disabled, temperature limit otherwise. Use HK_TEMP8 cal curve
10	STATUS_BITS	FD	AC	DS														FDIR (0 = Off, 1 = On), Active Clock (0 = Main, 1 = Red), Dosi Side (0 = Red, 1 = Main) bits
11	RESERVED																	
12																		
13	HK_HE1CNT																	Sums of counts with respect of Counter Limits settings
14	HK_HE2CNT																	
15	HK_HE3CNT																	
16	HK_HE4CNT																	
17	HK_SCCCNT																	
18	HK_SCGCNT																	
19	HK_CMD1_ECHO	MSBit																Copy of CMD1 in Command history
20																	LSBit	
21	HK_CMD1_TIME	MSBit																Time of CMD1 in Command history
22																	LSBit	(FREND time format, 1 tick = 1us)
23	HK_CMD2_ECHO	MSBit																Copy of CMD2 in Command history
24																	LSBit	
25	HK_CMD2_TIME	MSBit																Time of CMD2 in Command history
26																	LSBit	(FREND time format, 1 tick = 1us)
27	HK_CMD3_ECHO	MSBit																Copy of CMD3 in Command history
28																	LSBit	
29	HK_CMD3_TIME	MSBit																Time of CMD3 in Command history
30																	LSBit	(FREND time format, 1 tick = 1us)
31	HK_CHSUM2																	Sum of words above, no overflow

Table 3-4 Neutron Science (HE1...HE4, SCN and SCG), Subaddresses 4, 5, 6, 7, 9, 10

Word	Parameter	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Comment
0	SCN_SYNCRO	0	1	1	1	1	1	0	0	0	1	1	0	1	1	1	0	Always 0x7C6EA12C
1		1	0	1	0	0	0	0	1	0	0	1	0	1	1	0	0	
2	SID_SCN																	Equals to subaddress number
3	SCN_FRAME_NUM																	Running counter 0-65535
4	SCN_FREND_TIME	MSbit																Frame transmit time
5																	LSbit	1 tick = 1ms
6	SCI_SC_TIME	MSbit																Copy of TGO time received
7																		
8																	LSbit	
9	SCI_ACC_TIME																	SCI Accumulation time in sec
10	Data_SCN[0]																	Neutron data array. Each WORD element contains the number of counts (as UINT) in the n-th channel.
11	Data_SCN[1]																	
12	Data_SCN[2]																	
13	Data_SCN[3]																	
14	Data_SCN[4]																	
15	Data_SCN[5]																	
16	Data_SCN[6]																	
17	Data_SCN[7]																	
18	Data_SCN[8]																	
19	Data_SCN[9]																	
20	Data_SCN[10]																	
21	Data_SCN[11]																	
22	Data_SCN[12]																	
23	Data_SCN[13]																	
24	Data_SCN[14]																	
25	Data_SCN[15]																	
26	SCN_CHSUM																	Sum of words above, no overflow

Table 3-5 Science Dosimeter, Subaddresses 11-20

Word	Parameter	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Comment
0	SCD_SYNCRO	0	1	1	1	1	1	0	0	0	1	1	0	1	1	1	0	Always 0x7C6EA12C
1		1	0	1	0	0	0	0	1	0	0	1	0	1	1	0	0	
2	SID_SCD																	Equals to subaddress number
3	SCD_FRAME_NUM																	Running counter 0-65535
4	SCD_FREND_TIME																	Frame transmit time 1 tick = ms
5	Data_SCD[0]																	Dosimeter data array. Description of contents is given below.
6	Data_SCD[1]																	
7	Data_SCD[2]																	
8	Data_SCD[3]																	
9	Data_SCD[4]																	
10	Data_SCD[5]																	
11	Data_SCD[6]																	
12	Data_SCD[7]																	
13	Data_SCD[8]																	
14	Data_SCD[9]																	
15	Data_SCD[10]																	
16	Data_SCD[11]																	
17	Data_SCD[12]																	
18	Data_SCD[13]																	
19	Data_SCD[14]																	
20	Data_SCD[15]																	
21	Data_SCD[16]																	
22	Data_SCD[17]																	
23	Data_SCD[18]																	
24	Data_SCD[19]																	
25	Data_SCD[20]																	
26	Data_SCD[21]																	
27	Data_SCD[22]																	
28	Data_SCD[23]																	
29	Data_SCD[24]																	
30	Data_SCD[25]																	
31	SCD_CHSUM																	Sum of words above, no overflow

3.1.1 Dosimeter Data Format

Dosimeter data format consists of several layers of data and headers due to large data sizes of its minimal measurement. Below are thus some definitions.

Dosimeter data consists of **Measurement Frames** (see 3.1.1.1) that are generated every 1 hour. These Measurement Frames are then split into 20 **Packets** (see 3.1.1.2) generated every 3 minutes. The Packets are then split into 10 **Subaddress Messages** (see 3.1.1.3 and 3.1) and sent to TGO via subaddresses 11-20.

> **NB:** for dosimeter data format described in this paragraph, little-endian byte ordering is used, e.g. most significant byte always goes last. This is different from FREND neutron frames as described in tables above.

3.1.1.1 Measurement Frames

Measurement Frames contain scientific data of the dosimeter. These are the top-level data structures of the Dosimeter. Measurement Frames are generated once per hour. Their contents are below:

Data	Comment	Size	Size total
	Spectra Data with one hour resolution		**5888**
	3-Byte spectra x 256 channels		3840
SpB0	Number of particles in each channel of detector B in anticoincidence	768	
SpBA0	Number of particles in each channel of detector B in coincidence with A	768	
SpBD0	Number of particles in each channel of detector B in coincidence with D	768	
SpD0	Number of particles in each channel of detector D in anticoincidence	768	
SpDC0	Number of particles in each channel of detector D in coincidence with C	768	
	2-Byte spectra x 256 channels		2048
SpA1	Number of particles in each channel of detector A in anticoincidence	512	
SpAB1	Number of particles in each channel of detector A in coincidence with B	512	
SpC1	Number of particles in each channel of detector C in anticoincidence	512	
SpCD1	Number of particles in each channel of detector C in coincidence with D	512	
	Fluxes and Doses Data with one minute resolution		**70**
	4-Byte Dose Data		24
DB0	Dose accumulated in detector B in anticoincidence	4	
DBA0	Dose accumulated in detector B in coincidence with A	4	
DD0	Dose accumulated in detector D in anticoincidence	4	
DDC0	Dose accumulated in detector D in coincidence with C	4	
DA0	Dose accumulated in detector A in anticoincidence in spectral channels 1-255	4	
DC0	Dose accumulated in detector C in anticoincidence in spectral channels 1-255	4	
	2-Byte Flux Data		8
FA1	Flux accumulated in detector A in anticoincidence	2	
FAB1	Flux accumulated in detector A in coincidence with B	2	
FC1	Flux accumulated in detector C in anticoincidence	2	
FCD1	Flux accumulated in detector C in coincidence with D	2	
	3-Byte Doses and Fluxes		33

DA1	Dose accumulated in detector A in anticoincidence in spectral channels 21-255	3	
DAB1	Dose accumulated in detector A in coincidence with B in spectral channels 21-255	3	
DC1	Dose accumulated in detector C in anticoincidence in spectral channels 21-255	3	
DCD1	Dose accumulated in detector C in coincidence with D in spectral channels 21-255	3	
FB0	Flux accumulated in detector B in anticoincidence	3	
FBA0	Flux accumulated in detector B in coincidence with A	3	
FDB0	Flux accumulated in detector B in coincidence with D	3	
FD0	Flux accumulated in detector D in anticoincidence	3	
FDC0	Dose accumulated in detector D in coincidence with C	3	
FA0	Flux accumulated in detector A in anticoincidence in spectral channels 1-255	3	
FC0	Flux accumulated in detector C in anticoincidence in spectral channels 1-255	3	
Fluxes and Doses dummy (0xFF)			5
… Fluxes and Doses repeats 59 more times …			
Fluxes and Doses repeated 60 times			**4200**
Measurement Frame dummy (0x00)			**41**
Measurement Frame Total			10129

Table 3-6 Dosimeter Measurement Frame Contents

Note: One "Fluxes and Doses" measurement takes 70 bytes. This measurement is repeated once per minute, thus the 70 bytes are repeated sequentially 60 times in the Measurement Frame.

N.B. In dosimeter frames the little-endian system is employed. Within one word, byte 0 is least significant byte, byte 1 is most significant byte. Within a DWORD, byte 0 is least significant byte, byte 3 is most significant byte, etc.

3.1.1.2 Packets

Dosimeter packets contain scientific data from Measurement Frame (see above), split into 20 packets. Bytes from Measurement Frames are put into "Data" fields (see below) inside Packets sequentially. Packets thus contain, in total, 10129 bytes allocated for "Data". Packets contain some headers that make them 512 bytes long each. These packets are transmitted to FREND every 3 minutes. The additional headers structure is described below:

Packet 1		
#	**Name**	**Description**
1	Active MSU	'5A/5B for first (main) MCU board or '6A/6B' for second (reserve) MCU board
2	Counter LO	low byte of the packet's counter of 512 bytes from the start (reset by a command or power on) (zero based count, equal 0)
3	Counter HI	high byte of the packet's counter of 512 bytes from the start (reset by a command or power on)

4	Status	Status byte: bit 1: flash check 0x0000 - 0x1FFF; 0 - ERR or 1 - OK bit 2: flash check 0x2000 - 0x4000; 0 - ERR or 1 - OK bit 3: UART 2 err; 0 = NO ERR or 1 = ERR bit 4: No receive time every sec from FREND; 1 = NO TIME; 0 = TIME OK bit 5: TRAP address = 1 RCON.14 bit 6: Watchdog timer = 1 RCON.3 bit 7: Brown out = 1 RCON.2 bit 8: Power on Reset = 1 RCON.0
5	Time (LSB)	Board Time (start of accumulation)
6	Time	
7	Time	
8	Time (MSB)	
9 … 510	Data	Chunks of Measurement Frame
511	CRC LO	
512	CRC HI	
Packet 2…19		
#	**Name**	**Description**
1	Active MSU	'5A/5B for first (main) MCU board or '6A/6B' for second (reserve) MCU board
2	Counter LO	low byte of the packet's counter of 512 bytes from the start (reset by a command or power on) (zero based count, equal 0)
3	Counter HI	high byte of the packet's counter of 512 bytes from the start (reset by a command or power on)
4 … 510	Data	Chunks of Measurement Frame
511	CRC LO	
512	CRC HI	
Packet 20		
#	**Name**	**Description**
1	Active MSU	'5A/5B for first (main) MCU board or '6A/6B' for second (reserve) MCU board
2	Counter LO	low byte of the packet's counter of 512 bytes from the start (reset by a command or power on) (zero based count, equal 0)
3	Counter HI	high byte of the packet's counter of 512 bytes from the start (reset by a command or power on)
4 … 504	Data	Chunks of Measurement Frame
505	MCU Temp LO	
506	MCU Temp HI	
507	All CRC (LSB)	
508	All CRC	
509	All CRC	
510	All CRC (MSB)	
511	CRC LO	
512	CRC HI	

Table 3-7 Dosimeter Packet Format

3.1.1.3 Subaddress Messages

FREND Subaddress Messages correspond to subaddress 11…20 structures as described in 3.1. They have additional headers, whereas the "Dosimeter Data Array" fields contain one Packet (see 3.1.1.2), split into 10 Subaddress Messages sequentially. These 10 Subaddress Messages are generated by FREND and read by TGO every 3 minutes.

3.1.2 Calibration Curves

This section describes different calibration curves that enable the conversion from raw to engineering values. The calibrations in these sections only relate to Flight Spare FREND model that is flying onboard TGO.

Temperature conversions. The conversion formulae is

degC = a*rawX+b

where a and b are coefficients from the table below, X is the raw value from FREND frames, degC is the engineering value in degrees celsius.

Parameter	a	b
HK_TEMP1 (PSU Red)	0,081555834	-288,8080301
HK_TEMP2 (PSU Main)	0,082174463	-289,8609355
HK_TEMP3 (HV HE1)	0,08186398	-288,7594458
HK_TEMP4 (HV HE2)	0,08186398	-287,7770781
HK_TEMP5 (HV HE3)	0,081555834	-290,0313676
HK_TEMP6 (HV HE4)	0,081148564	-288,3583021
HK_TEMP7 (HV SC)	0,082070707	-289,3560606
HK_TEMP8 (MntPt FDIR)	0,081761006	-289,0754717
HK_TEMP9 (Actel)	0,081555834	-289,2158093
HK_TEMP10 (PSU +3.3V)	0,082174463	-289,4500632
HK_TEMP11 (PSU +1.5V)	0,081453634	-291,0776942
HK_TEMP12 (Dosimeter)	0,08186398	-290,1511335

Table 3-8 FREND FSp Temperature calibration curves

NB: For temperature conversions valid engineering unit range is 1000 to 6000 for all 12 temperatures. Values outside of this range are considered meaningless and marked as NaN in partially processed data.

Voltage conversions. The conversion formulae is

volts = a*rawX

where a and b are coefficients from the table below, X is the raw value from FREND frames, volts is the engineering value in volts.

Parameter	a
HK_VOLT1 (5V)	0,00079
HK_VOLT2 (1.5V)	0,000354
HK_VOLT3 (3.3V)	0,001713
HK_VOLT4 (6V)	0,000789

Table 3-9 FREND FSp Voltage calibration curves

NB: for voltage conversions valid engineering unit range is 500 to 15000 for all voltages except HK_VOLT3 (3.3V) – its range is 500 to 7000. Values outside of this range are considered meaningless and marked as NaN in partially processed data.

3.2 PSA Data types

The table below lists different levels of data processing that FREND delivers to the PSA.

Primary Data	
Processing Level	***Description***
Raw	Raw data as read from the instrument. Consists of housekeeping telemetry (engineering data), FREND Neutron Science data (counts in detectors), FREND Dosimeter Science data (radiation environment measurements). All 3 types of data are time series. This data product is produced automatically by ESAC.
Partially Processed	Only Housekeeping telemetry is processed to this level – all engineering units converted to physical units (temperatures, voltages, instrument time etc). This is the last data level for FREND Housekeeping.
Calibrated	For all 2 science types of data defined above: all engineering units converted to physical units (temperatures, voltages, instrument time etc). Instrument engineering effects are removed from scientific data (temperature drifts, detector on/off efficiency curves, effects based on SC altitude corrected etc). These are time series.
Derived	Maps of counts are created. Several maps may be created (per detector, per energy range etc., TBD) per data delivery cycle. These are table data. These maps may be updated (newer versions created) that accumulate new data with previously delivered in order to provide maps with higher statistical evidence. FREND dosimeter data recalculated for the conditions in the interplanetary space at distance of 1.5 AU. These are time series of cosmic rays fluence rates and dose rates corrected for the shielding effects of Mars. This is the last data level for FREND Neutron and Dosimeter Science data.
Supplementary Data	
Type	***Description***
Calibration	Data from calibration measurements of the instrument are delivered. These are time-series, having the same format (PSA labels) as Calibrated FREND Science data type. They are delivered once only. Calibration data are from on-ground and in-flight calibration measurements.
Special	Hydrogen maps, based on Maps of Counts as described in Derived data type section. These maps are computationally complex and model-dependent, so will not be produced on a regular basis. Might be overwritten (new version created) as more data is accumulated by the instrument. Generally, these may be delivered once or twice per mission.

Table 3-10 FREND PSA Data Types

The sections that follow describe in more details the PDS labels used in each of the data products identified above, together with their meanings.

3.2.1 Raw and Partially Processed Product

Raw product contains all instrument data converted from binary stream to tabbed files and their labels, according to PDS formats. There are three Raw products generated:

- **frd_raw_hk** corresponds to FREND Housekeeping data, containing instrument engineering telemetry. This product corresponds to source binary frames as described in Table 3-2 and Table 3-3.

- **frd_par_hk** corresponds to FREND partially calibrated Housekeeping data, which is processed, compared to frd_par_hk only in terms of converting of all parameters to engineering units. It is described in Table *3-12*

- **frd_raw_sc_n** corresponds to FREND Science Neutron data containing measurements of ^{3}HE and Scintillation detectors. The product corresponds to source binary frames as described in Table 3-4.

- **frd_raw_sc_d** corresponds to FREND Science Dosimetry data containing measurements of the dosimeter module. This corresponds to source binary frames as described in Table 3-5.

The three tables that follow contain labels and description of data contained within them.

Label	**Type**	**Description**
EFRN1000 HK_SYNCHRO_1	ASCII_NonNegative_Integer	Always 0x7C6EA12C
EFRN1020 SID_HK1	ASCII_NonNegative_Integer	Always 2, as per Table 3-1
EFRN1030 HK_FRAME_NUM_1	ASCII_NonNegative_Integer	Running counter, 0…65535
EFRN1040 HK_FREND_TIME_1	ASCII_NonNegative_Integer	Time since FREND Power ON, ms
EFRN1060 HK_SC_TIME	ASCII_Integer	TGO Timestamp
EFRN1090 HK_TEMP_1 PSU RED	ASCII_NonNegative_Integer	FREND temperatures in engineering units. Cal curves see Table 3-8.
EFRN1100 HK_TEMP_2 PSU MAIN	ASCII_NonNegative_Integer	
EFRN1110 HK_TEMP_3 HV HE1	ASCII_NonNegative_Integer	
EFRN1120 HK_TEMP_4 HV HE2	ASCII_NonNegative_Integer	
EFRN1130 HK_TEMP_5 HV HE3	ASCII_NonNegative_Integer	
EFRN1140 HK_TEMP_6 HV HE4	ASCII_NonNegative_Integer	
EFRN1150 HK_TEMP_7 HV SC	ASCII_NonNegative_Integer	
EFRN1160 HK_TEMP_8 MNTPT FDIR	ASCII_NonNegative_Integer	
EFRN1170 HK_TEMP_9 ACTEL	ASCII_NonNegative_Integer	
EFRN1180 HK_TEMP_10 PSU +3.3V	ASCII_NonNegative_Integer	
EFRN1190 HK_TEMP_11 PSU +1.5V	ASCII_NonNegative_Integer	
EFRN1200 HK_TEMP_12 Dosimeter	ASCII_NonNegative_Integer	
EFRN1210 HK_VOLT_1 5V	ASCII_NonNegative_Integer	Secondary voltage levels in engineering units. Cal curves see Table 3-9
EFRN1220 HK_VOLT_2 1.5V	ASCII_NonNegative_Integer	
EFRN1230 HK_VOLT_3 3.3V	ASCII_NonNegative_Integer	
EFRN1240 HK_VOLT_4 6V	ASCII_NonNegative_Integer	
EFRN1250 HK_HV_STATE UNUSED	ASCII_Integer	Always 0
EFRN1251 HK_HV_STATE SCF	ASCII_Integer	High Voltage Failure flag for neutron detectors. 0 = HV nominal 1 = failure detected
EFRN1252 HK_HV_STATE HE4F	ASCII_Integer	
EFRN1253 HK_HV_STATE HE3F	ASCII_Integer	
EFRN1254 HK_HV_STATE HE2F	ASCII_Integer	
EFRN1255 HK_HV_STATE HE1F	ASCII_Integer	
EFRN1256 HK_HV_STATE SCLVL	ASCII_NonNegative_Integer	High Voltage levels for neutron detectors. 0 = HV off 3 = HV Low level 2 = HV High level
EFRN1258 HK_HV_STATE HE4LVL	ASCII_NonNegative_Integer	
EFRN125A HK_HV_STATE HE3LVL	ASCII_NonNegative_Integer	
EFRN125C HK_HV_STATE HE2LVL	ASCII_NonNegative_Integer	
EFRN125E HK_HV_STATE HE1LVL	ASCII_NonNegative_Integer	
EFRN1260 HK_DISC_LEV UNUSED 8	ASCII_NonNegative_Integer	Always 0
EFRN1268 HK_DISC_LEV UNUSED 3	ASCII_NonNegative_Integer	
EFRN126B HK_DISC_LEV SC	ASCII_Integer	Neutron detectors discriminators levels:

Label	Type	Description
EFRN126C HK_DISC_LEV HE4	ASCII_Integer	0 = discriminator OFF 1 = Discriminator ON
EFRN126D HK_DISC_LEV HE3	ASCII_Integer	
EFRN126E HK_DISC_LEV HE2	ASCII_Integer	
EFRN126F HK_DISC_LEV HE1	ASCII_Integer	
EFRN1270 HK_DATA_COLLECTION_TIME	ASCII_NonNegative_Integer	FREND Housekeeping frames generation time, s
EFRN1280 HK_SC_TIME_TS	ASCII_NonNegative_Integer	FREND time of last SC clock update, ms
EFRN1300 SCI_DATA_COLLECT_TIME	ASCII_NonNegative_Integer	FREND neutron science frames generation time, s
EFRN1310 HK_CHSUM1	ASCII_NonNegative_Integer	Frame checksum
EFRN2000 HK_SYNCHRO_2	ASCII_NonNegative_Integer	Always 0x7C6EA12C
EFRN2020 SID_HK2	ASCII_NonNegative_Integer	Always 3, as per Table 3-3
EFRN2030 HK_FRAME_NUM_2	ASCII_NonNegative_Integer	Running counter, 0…65535
EFRN2040 HK_FREND_TIME_2	ASCII_NonNegative_Integer	Time since FREND Power ON, us
EFRN2060 HK_LIM_HE1_HIGH	ASCII_NonNegative_Integer	Counter limits refer to low and high channel numbers of neutron science data that are summed up and then included into housekeeping counters (below). LOW and HIGH are values 0…15 representing lower and upper bound of the sum. Defaults are 0…15
EFRN2064 HK_LIM_HE1_LOW	ASCII_NonNegative_Integer	
EFRN2068 HK_LIM_HE2_HIGH	ASCII_NonNegative_Integer	
EFRN206C HK_LIM_HE2_LOW	ASCII_NonNegative_Integer	
EFRN2070 HK_LIM_HE3_HIGH	ASCII_NonNegative_Integer	
EFRN2074 HK_LIM_HE3_LOW	ASCII_NonNegative_Integer	
EFRN2078 HK_LIM_HE4_HIGH	ASCII_NonNegative_Integer	
EFRN207C HK_LIM_HE4_LOW	ASCII_NonNegative_Integer	
EFRN2080 HK_LIM_SCN_HIGH	ASCII_NonNegative_Integer	
EFRN2084 HK_LIM_SCN_LOW	ASCII_NonNegative_Integer	
EFRN2088 HK_LIM_SCC_HIGH	ASCII_NonNegative_Integer	
EFRN208C HK_LIM_SCC_LOW	ASCII_NonNegative_Integer	
EFRN2090 HK FDIR	ASCII_NonNegative_Integer	Fault detection, investigation and response temperature limit, in engineering units. In case HK_TEMP_8 MNTPT FDIR is higher than this value, all FREND HVs will be turned off.
EFRN2100 STATUS_BIT FDIR	ASCII_Integer	0 = no FDIR triggered, 1 = FDIR was triggered
EFRN2101 STATUS_BIT Active Clock	ASCII_Integer	0 = Main quarz used, 1 = redundant quarz used
EFRN2102 STATUS_BIT DosimeterSide	ASCII_Integer	0 = main Dosimeter side used, 1 = redundant dosimeter side used
EFRN2110 RESERVED	ASCII_NonNegative_Integer	Always 0
EFRN2130 HK_HE1CNT	ASCII_NonNegative_Integer	Sum of counts in neutron detectors in channels selected by counter limits values above.
EFRN2140 HK_HE2CNT	ASCII_NonNegative_Integer	
EFRN2150 HK_HE3CNT	ASCII_NonNegative_Integer	
EFRN2160 HK_HE4CNT	ASCII_NonNegative_Integer	
EFRN2170 HK_SCCCNT	ASCII_NonNegative_Integer	
EFRN2180 HK_SCGCNT	ASCII_NonNegative_Integer	
EFRN2190 HK_CMD1_ECHO	ASCII_NonNegative_Integer	Command echoes and times of command receipt (FREND time, us since power on)
EFRN2210 HK_CMD1_TIME	ASCII_NonNegative_Integer	
EFRN2230 HK_CMD2_ECHO	ASCII_NonNegative_Integer	
EFRN2250 HK_CMD2_TIME	ASCII_NonNegative_Integer	

Label	Type	Description
EFRN2270 HK_CMD3_ECHO	ASCII_NonNegative_Integer	
EFRN2290 HK_CMD3_TIME	ASCII_NonNegative_Integer	
EFRN2310 HK_CHSUM1	ASCII_NonNegative_Integer	Frame checksum

Table 3-11 FREND Raw Housekeeping Product (frd_raw_hk) label definitions

Label	Type	Description
PUS_TIME_UTC	UTF8_String	
PUS_TIME	UTF8_String	
EFRN1000 HK_SYNCHRO_1	ASCII_NonNegative_Integer	Always 0x7C6EA12C
EFRN1020 SID_HK1	ASCII_NonNegative_Integer	Always 2, as per Table 3-2
EFRN1030 HK_FRAME_NUM_1	ASCII_NonNegative_Integer	Running counter, 0…65535
EFRN1040 HK_FREND_TIME_1	ASCII_NonNegative_Integer	Time since FREND Power ON, ms
EFRN1060 HK_SC_TIME	ASCII_Integer	TGO Timestamp
EFRN1090 HK_TEMP_1 PSU RED	ASCII_Real	FREND temperatures in physical units after application of cal curves in Table 3-8.
EFRN1100 HK_TEMP_2 PSU MAIN	ASCII_Real	
EFRN1110 HK_TEMP_3 HV HE1	ASCII_Real	
EFRN1120 HK_TEMP_4 HV HE2	ASCII_Real	
EFRN1130 HK_TEMP_5 HV HE3	ASCII_Real	
EFRN1140 HK_TEMP_6 HV HE4	ASCII_Real	
EFRN1150 HK_TEMP_7 HV SC	ASCII_Real	
EFRN1160 HK_TEMP_8 MNTPT FDIR	ASCII_Real	
EFRN1170 HK_TEMP_9 ACTEL	ASCII_Real	
EFRN1180 HK_TEMP_10 PSU +3.3V	ASCII_Real	
EFRN1190 HK_TEMP_11 PSU +1.5V	ASCII_Real	
EFRN1200 HK_TEMP_12 Dosimeter	ASCII_Real	
EFRN1210 HK_VOLT_1 5V	ASCII_Real	Secondary voltage levels in physical units after application of cal curves in Table 3-9
EFRN1220 HK_VOLT_2 1.5V	ASCII_Real	
EFRN1230 HK_VOLT_3 3.3V	ASCII_Real	
EFRN1240 HK_VOLT_4 6V	ASCII_Real	
EFRN1250 HK_HV_STATE UNUSED	ASCII_Integer	Always 0
EFRN1251 HK_HV_STATE SCF	ASCII_Integer	High Voltage Failure flag for neutron detectors. 0 = HV nominal 1 = failure detected
EFRN1252 HK_HV_STATE HE4F	ASCII_Integer	
EFRN1253 HK_HV_STATE HE3F	ASCII_Integer	
EFRN1254 HK_HV_STATE HE2F	ASCII_Integer	
EFRN1255 HK_HV_STATE HE1F	ASCII_Integer	
EFRN1256 HK_HV_STATE SCLVL	ASCII_NonNegative_Integer	High Voltage levels for neutron detectors. 0 = HV off 3 = HV Low level 2 = HV High level
EFRN1258 HK_HV_STATE HE4LVL	ASCII_NonNegative_Integer	
EFRN125A HK_HV_STATE HE3LVL	ASCII_NonNegative_Integer	
EFRN125C HK_HV_STATE HE2LVL	ASCII_NonNegative_Integer	
EFRN125E HK_HV_STATE HE1LVL	ASCII_NonNegative_Integer	
EFRN1260 HK_DISC_LEV UNUSED 8	ASCII_NonNegative_Integer	Always 0
EFRN1268 HK_DISC_LEV UNUSED 3	ASCII_NonNegative_Integer	
EFRN126B HK_DISC_LEV SC	ASCII_Integer	Neutron detectors discriminators levels: 0 = discriminator OFF 1 = Discriminator ON
EFRN126C HK_DISC_LEV HE4	ASCII_Integer	
EFRN126D HK_DISC_LEV HE3	ASCII_Integer	
EFRN126E HK_DISC_LEV HE2	ASCII_Integer	
EFRN126F HK_DISC_LEV HE1	ASCII_Integer	

Label	Type	Description
EFRN1270 HK_DATA_COLLECTION_TIME	ASCII_NonNegative_Integer	FREND Housekeeping frames generation time, s
EFRN1280 HK_SC_TIME_TS	ASCII_NonNegative_Integer	FREND time of last SC clock update, ms
EFRN1300 SCI_DATA_COLLECT_TIME	ASCII_NonNegative_Integer	FREND neutron science frames generation time, s
EFRN1310 HK_CHSUM1	ASCII_NonNegative_Integer	Frame checksum
	ASCII_NonNegative_Integer	
EFRN2000 HK_SYNCHRO_2	ASCII_NonNegative_Integer	Always 0x7C6EA12C
EFRN2020 SID_HK2	ASCII_NonNegative_Integer	Always 3, as per Table 3-3
EFRN2030 HK_FRAME_NUM_2	ASCII_NonNegative_Integer	Running counter, 0…65535
EFRN2040 HK_FREND_TIME_2	ASCII_NonNegative_Integer	Time since FREND Power ON, us
EFRN2060 HK_LIM_HE1_HIGH	ASCII_NonNegative_Integer	Counter limits refer to low and high channel numbers of neutron science data that are summed up and then included into housekeeping counters (below). LOW and HIGH are values 0…15 representing lower and upper bound of the sum. Defaults are 0…15
EFRN2064 HK_LIM_HE1_LOW	ASCII_NonNegative_Integer	
EFRN2068 HK_LIM_HE2_HIGH	ASCII_NonNegative_Integer	
EFRN206C HK_LIM_HE2_LOW	ASCII_NonNegative_Integer	
EFRN2070 HK_LIM_HE3_HIGH	ASCII_NonNegative_Integer	
EFRN2074 HK_LIM_HE3_LOW	ASCII_NonNegative_Integer	
EFRN2078 HK_LIM_HE4_HIGH	ASCII_NonNegative_Integer	
EFRN207C HK_LIM_HE4_LOW	ASCII_NonNegative_Integer	
EFRN2080 HK_LIM_SCN_HIGH	ASCII_NonNegative_Integer	
EFRN2084 HK_LIM_SCN_LOW	ASCII_NonNegative_Integer	
EFRN2088 HK_LIM_SCC_HIGH	ASCII_NonNegative_Integer	
EFRN208C HK_LIM_SCC_LOW	ASCII_NonNegative_Integer	
EFRN2090 HK FDIR	ASCII_Integer	Fault detection, investigation and response temperature limit, in engineering units. In case HK_TEMP_8 MNTPT FDIR is higher than this value, all FREND HVs will be turned off.
EFRN2100 STATUS_BIT FDIR	ASCII_Integer	0 = no FDIR triggered, 1 = FDIR was triggered
EFRN2101 STATUS_BIT Active Clock	ASCII_Integer	0 = Main quarz used, 1 = redundant quarz used
EFRN2102 STATUS_BIT DosimeterSide	ASCII_NonNegative_Integer	0 = main Dosimeter side used, 1 = redundant dosimeter side used
EFRN2110 RESERVED	ASCII_NonNegative_Integer	Always 0
EFRN2130 HK_HE1CNT	ASCII_NonNegative_Integer	Sum of counts in neutron detectors in channels selected by counter limits values above.
EFRN2140 HK_HE2CNT	ASCII_NonNegative_Integer	
EFRN2150 HK_HE3CNT	ASCII_NonNegative_Integer	
EFRN2160 HK_HE4CNT	ASCII_NonNegative_Integer	
EFRN2170 HK_SCCCNT	ASCII_NonNegative_Integer	
EFRN2180 HK_SCGCNT	ASCII_NonNegative_Integer	
EFRN2190 HK_CMD1_ECHO	ASCII_NonNegative_Integer	Command echoes and times of command receipt (FREND time, us since power on)
EFRN2210 HK_CMD1_TIME	ASCII_NonNegative_Integer	
EFRN2230 HK_CMD2_ECHO	ASCII_NonNegative_Integer	
EFRN2250 HK_CMD2_TIME	ASCII_NonNegative_Integer	
EFRN2270 HK_CMD3_ECHO	ASCII_NonNegative_Integer	
EFRN2290 HK_CMD3_TIME	ASCII_NonNegative_Integer	
EFRN2310 HK_CHSUM1	ASCII_NonNegative_Integer	Frame checksum

Table 3-12 *FREND Partially Processed Housekeeping Product (frd_par_hk) label definitions*

Label	Type	Description
VFS25RDL FSC:TMRID [3;25]	ASCII_NonNegative_Integer	Always 0x4000 0078
VFS1002L FREND:SC SYNCROG	ASCII_NonNegative_Integer	Always 0x7C6EA12C
VFS1003L FREND:SID SCG	ASCII_NonNegative_Integer	Always 10, as per Table 3-4
VFS1004L FREND:FRAME NUMG	ASCII_NonNegative_Integer	Running counter, 0…65535
VFS1005H FREND:SC TIMEG	ASCII_NonNegative_Integer	Time since FREND Power ON, ms
VFS1007H FREND:SC TIMEG	ASCII_Integer	TGO Timestamp
VFS1010H FREND:COL TIMEG	ASCII_NonNegative_Integer	FREND neutron science frames generation time, s
VFS1011L FREND:SPECTRAG	ASCII_Numeric_Base16	Scintillation detector charged particles spectra (16 channels, 2 bytes each)
VFS1027L FREND:CHSUMG	ASCII_NonNegative_Integer	Frame checksum
VFS0402L FREND:SC SYNCRO1	ASCII_NonNegative_Integer	Always 0x7C6EA12C
VFS0403L FREND:SID SC1	ASCII_NonNegative_Integer	Always 4, as per Table 3-4
VFS0404L FREND:FRAME NUM1	ASCII_NonNegative_Integer	Running counter, 0…65535
VFS0405H FREND:SC TIME1	ASCII_NonNegative_Integer	Time since FREND Power ON, ms
VFS0407H FREND:SC TIME1	ASCII_Integer	TGO Timestamp
VFS0410H FREND:COL TIME1	ASCII_NonNegative_Integer	FREND neutron science frames generation time, s
VFS0411L FREND:SPECTRA1	ASCII_Numeric_Base16	HE1 detector neutron spectra (16 channels, 2 bytes each)
VFS0427L FREND:CHSUM1	ASCII_NonNegative_Integer	Frame checksum
VFS0502L FREND:SC SYNCRO2	ASCII_NonNegative_Integer	Always 0x7C6EA12C
VFS0503L FREND:SID SC2	ASCII_NonNegative_Integer	Always 5, as per Table 3-4
VFS0504L FREND:FRAME NUM2	ASCII_NonNegative_Integer	Running counter, 0…65535
VFS0505H FREND:SC TIME2	ASCII_NonNegative_Integer	Time since FREND Power ON, ms
VFS0507H FREND:SC TIME2	ASCII_Integer	TGO Timestamp
VFS0510H FREND:COL TIME2	ASCII_NonNegative_Integer	FREND neutron science frames generation time, s
VFS0511L FREND:SPECTRA2	ASCII_Numeric_Base16	HE2 detector neutron spectra (16 channels, 2 bytes each)
VFS0527L FREND:CHSUM2	ASCII_NonNegative_Integer	Frame checksum
VFS0602L FREND:SC SYNCRO3	ASCII_NonNegative_Integer	Always 0x7C6EA12C
VFS0603L FREND:SID SC3	ASCII_NonNegative_Integer	Always 6, as per Table 3-4
VFS0604L FREND:FRAME NUM3	ASCII_NonNegative_Integer	Running counter, 0…65535
VFS0605H FREND:SC TIME3	ASCII_NonNegative_Integer	Time since FREND Power ON, ms
VFS0607H FREND:SC TIME3	ASCII_Integer	TGO Timestamp
VFS0610H FREND:COL TIME3	ASCII_NonNegative_Integer	FREND neutron science frames generation time, s
VFS0611L FREND:SPECTRA3	ASCII_Numeric_Base16	HE3 detector neutron spectra (16 channels, 2 bytes each)
VFS0627L FREND:CHSUM3	ASCII_NonNegative_Integer	Frame checksum
VFS0702L FREND:SC SYNCRO4	ASCII_NonNegative_Integer	Always 0x7C6EA12C
VFS0703L FREND:SID SC4	ASCII_NonNegative_Integer	Always 7, as per Table 3-4
VFS0704L FREND:FRAME NUM4	ASCII_NonNegative_Integer	Running counter, 0…65535
VFS0705H FREND:SC TIME4	ASCII_NonNegative_Integer	Time since FREND Power ON, ms

Label	Type	Description
VFS0707H FREND:SC TIME4	ASCII_Integer	TGO Timestamp
VFS0710H FREND:COL TIME4	ASCII_NonNegative_Integer	FREND neutron science frames generation time, s
VFS0711L FREND:SPECTRA4	ASCII_Numeric_Base16	HE4 detector neutron spectra (16 channels, 2 bytes each)
VFS0727L FREND:CHSUM4	ASCII_NonNegative_Integer	Frame checksum
VFS0902L FREND:SC SYNCRON	ASCII_NonNegative_Integer	Always 0x7C6EA12C
VFS0903L FREND:SID SCN	ASCII_NonNegative_Integer	Always 9, as per Table 3-4
VFS0904L FREND:FRAME NUMN	ASCII_NonNegative_Integer	Running counter, 0…65535
VFS0905H FREND:SC TIMEN	ASCII_NonNegative_Integer	Time since FREND Power ON, ms
VFS0907H FREND:SC TIMEN	ASCII_Integer	TGO Timestamp
VFS0910H FREND:COL TIMEN	ASCII_NonNegative_Integer	FREND neutron science frames generation time, s
VFS0911L FREND:SPECTRAN	ASCII_Numeric_Base16	Scintillation detector neutrons spectra (16 channels, 2 bytes each)
VFS0927L FREND:CHSUMN	ASCII_NonNegative_Integer	Frame checksum

Table 3-13 FREND Raw Science Neutrons Product (frd_raw_sc_n) label definitions

Label	Type	Description
PUS_TIME_UTC	UTF8_String	UTC Time of recording YMD_UTC
PUS_TIME	ASCII_NonNegative_Integer	TGO time of recording
VFS25RDL FSC:TMRID [3;25]	ASCII_NonNegative_Integer	Always 0x4000 0079
VFS1111L FREND:DOS SYNC1	ASCII_NonNegative_Integer	Always 0x7C6EA12C
VFS1112L FREND:DOS SID1	ASCII_NonNegative_Integer	Always 11, as per Table 3-5
VFS1102L FREND:FRAM NUMD1	ASCII_NonNegative_Integer	Running counter, 0…65535
VFS1103H FREND:D TIME1	ASCII_NonNegative_Integer	Time since FREND Power ON, ms
VFS1105L FREND:DOS DATA1	ASCII_Numeric_Base16	Dosimeter message, as per 3.1.1.3
VFS1132L FREND:CHSUMD1	ASCII_NonNegative_Integer	Frame checksum
VFS1211L FREND:DOS SYNC2	ASCII_NonNegative_Integer	Always 0x7C6EA12C
VFS1212L FREND:DOS SID2	ASCII_NonNegative_Integer	Always 12, as per Table 3-5
VFS1202L FREND:FRAM NUMD2	ASCII_NonNegative_Integer	Running counter, 0…65535
VFS1203H FREND:D TIME2	ASCII_NonNegative_Integer	Time since FREND Power ON, ms
VFS1205L FREND:DOS DATA2	ASCII_Numeric_Base16	Dosimeter message, as per 3.1.1.3
VFS1232L FREND:CHSUMD2	ASCII_NonNegative_Integer	Frame checksum
VFS1311L FREND:DOS SYNC3	ASCII_NonNegative_Integer	Always 0x7C6EA12C
VFS1312L FREND:DOS SID3	ASCII_NonNegative_Integer	Always 13, as per Table 3-5
VFS1302L FREND:FRAM NUMD3	ASCII_NonNegative_Integer	Running counter, 0…65535
VFS1303H FREND:D TIME3	ASCII_NonNegative_Integer	Time since FREND Power ON, ms
VFS1305L FREND:DOS DATA3	ASCII_Numeric_Base16	Dosimeter message, as per 3.1.1.3
VFS1332L FREND:CHSUMD3	ASCII_NonNegative_Integer	Frame checksum
VFS1411L FREND:DOS SYNC4	ASCII_NonNegative_Integer	Always 0x7C6EA12C
VFS1412L FREND:DOS SID4	ASCII_NonNegative_Integer	Always 14, as per Table 3-5
VFS1402L FREND:FRAM NUMD4	ASCII_NonNegative_Integer	Running counter, 0…65535
VFS1403H FREND:D TIME4	ASCII_NonNegative_Integer	Time since FREND Power ON, ms
VFS1405L FREND:DOS DATA4	ASCII_Numeric_Base16	Dosimeter message, as per 3.1.1.3

VFS1432L FREND:CHSUMD4	ASCII_NonNegative_Integer	Frame checksum
VFS1511L FREND:DOS SYNC5	ASCII_NonNegative_Integer	Always 0x7C6EA12C
VFS1512L FREND:DOS SID5	ASCII_NonNegative_Integer	Always 15, as per Table 3-5
VFS1502L FREND:FRAM NUMD5	ASCII_NonNegative_Integer	Running counter, 0...65535
VFS1503H FREND:D TIME5	ASCII_NonNegative_Integer	Time since FREND Power ON, ms
VFS1505L FREND:DOS DATA5	ASCII_Numeric_Base16	Dosimeter message, as per 3.1.1.3
VFS1532L FREND:CHSUMD5	ASCII_NonNegative_Integer	Frame checksum
VFS1611L FREND:DOS SYNC6	ASCII_NonNegative_Integer	Always 0x7C6EA12C
VFS1612L FREND:DOS SID6	ASCII_NonNegative_Integer	Always 16, as per Table 3-5
VFS1602L FREND:FRAM NUMD6	ASCII_NonNegative_Integer	Running counter, 0...65535
VFS1603H FREND:D TIME6	ASCII_NonNegative_Integer	Time since FREND Power ON, ms
VFS1605L FREND:DOS DATA6	ASCII_Numeric_Base16	Dosimeter message, as per 3.1.1.3
VFS1632L FREND:CHSUMD6	ASCII_NonNegative_Integer	Frame checksum
VFS1711L FREND:DOS SYNC7	ASCII_NonNegative_Integer	Always 0x7C6EA12C
VFS1712L FREND:DOS SID7	ASCII_NonNegative_Integer	Always 17, as per Table 3-5
VFS1702L FREND:FRAM NUMD7	ASCII_NonNegative_Integer	Running counter, 0...65535
VFS1703H FREND:D TIME7	ASCII_NonNegative_Integer	Time since FREND Power ON, ms
VFS1705L FREND:DOS DATA7	ASCII_Numeric_Base16	Dosimeter message, as per 3.1.1.3
VFS1732L FREND:CHSUMD7	ASCII_NonNegative_Integer	Frame checksum
VFS1811L FREND:DOS SYNC8	ASCII_NonNegative_Integer	Always 0x7C6EA12C
VFS1812L FREND:DOS SID8	ASCII_NonNegative_Integer	Always 18, as per Table 3-1
VFS1802L FREND:FRAM NUMD8	ASCII_NonNegative_Integer	Running counter, 0...65535
VFS1803H FREND:D TIME8	ASCII_NonNegative_Integer	Time since FREND Power ON, ms
VFS1805L FREND:DOS DATA8	ASCII_Numeric_Base16	Dosimeter message, as per 3.1.1.3
VFS1832L FREND:CHSUMD8	ASCII_NonNegative_Integer	Frame checksum
VFS1911L FREND:DOS SYNC9	ASCII_NonNegative_Integer	Always 0x7C6EA12C
VFS1912L FREND:DOS SID9	ASCII_NonNegative_Integer	Always 19, as per Table 3-5
VFS1902L FREND:FRAM NUMD9	ASCII_NonNegative_Integer	Running counter, 0...65535
VFS1903H FREND:D TIME9	ASCII_NonNegative_Integer	Time since FREND Power ON, ms
VFS1905L FREND:DOS DATA9	ASCII_Numeric_Base16	Dosimeter message, as per 3.1.1.3
VFS1932L FREND:CHSUMD9	ASCII_NonNegative_Integer	Frame checksum
VFS2011L FREND:DOS SYNC10	ASCII_NonNegative_Integer	Always 0x7C6EA12C
VFS2012L FREND:DOS SID10	ASCII_NonNegative_Integer	Always 20, as per Table 3-5
VFS2002L FREND:FRAM NUMD10	ASCII_NonNegative_Integer	Running counter, 0...65535
VFS2003H FREND:D TIME10	ASCII_NonNegative_Integer	Time since FREND Power ON, ms
VFS2005L FREND:DOS DATA10	ASCII_Numeric_Base16	Dosimeter message, as per 3.1.1.3
VFS2032L FREND:CHSUMD10	ASCII_NonNegative_Integer	Frame checksum

Table 3-14 FREND Raw Science Dosimetry Product (frd_raw_sc_d) label definitions

3.2.2 Calibrated Product

Calibrated products are derived from raw by:

- appending time information;
- converting all measurements to physical units;

- removing instrument-related effects from measured data (specifics described in sect. 3.4.3).

The following tables describe the format of calibrated data. Values of "Parameter" column correspond to data fields described in FREND data frame formats (see Table 3-4, Table 3-5).

Parameter	Type	Description
UTC_Time	Time	UTC time of this frame, derived from SC time through SPICE.
SCI_ACC_TIME	Unsigned short	Accumulation time of current frame in s.
CAL_HE	Float	Count rate accumulated in all counters during current frame corrected for all instrument and space environment effects, background subtracted, in counts per second. This value ready for mapping.
HE_TOTAL_COUNT	Float	Total counts accumulated in all HE detectors during the period of measurement. This value represents actual measurement before any processing. This value provided for statistical error calculation purposes.

Table 3-15 FREND Calibrated Science Neutron Product label definitions

Parameter	Type	Description
utc_time_d_m	ASCII_Date_Time_YMD	UTC time, beginning of the one minute accumulation interval
flux_min_BA	ASCII_Real	Fluence rate in direction BA, calculated on board from counts accumulated for one minute, [particles/cm^2.s]
flux_min_DC	ASCII_Real	Fluence rate in direction DC, calculated on board from counts accumulated for one minute, [particles/cm^2.s]
dose_min_BA	ASCII_Real	Dose rate in direction BA, calculated on board from the absorbed dose spectrum accumulated for one minute, [μGy/h]
dose_min_DC	ASCII_Real	Dose rate in direction DC, calculated on board from the absorbed dose spectrum accumulated for one minute, [μGy/h]

Table 3-16 FREND Calibrated Science Dosimeter Minute Product label definitions

Parameter	Type	Description
utc_time_d_h	ASCII_Date_Time_YMD	UTC time, beginning of the one hour accumulation interval
flux_hour_BA	ASCII_Real	Fluence rate in direction BA, calculated on ground from the absorbed dose spectrum accumulated for one hour, [particles/cm^2.s]
flux_hour_DC	ASCII_Real	Fluence rate in direction DC, calculated on ground from the absorbed dose spectrum accumulated for one hour [particles/cm^2.s]
dose_hour_BA	ASCII_Real	Dose rate in direction BA, calculated on ground from the absorbed dose spectrum accumulated for one hour [μGy/h]

dose_hour_DC	ASCII_Real	Dose rate in direction DC, calculated on ground from the absorbed dose spectrum accumulated for one hour [μGy/h]

Table 3-17 FREND Calibrated Science Dosimeter Hour Product label definitions

Note, that Calibrated products contain only instrument-related data and no auxiliary information like spacecraft geometry. This is due to the fact that appending any non-instrument information will lead to reprocessing of the whole instrument archive in case, e.g. SPICE mission kernels are updated, which is undesirable. Additionally, SPICE information required to use calibrated dataset for scientific purposes is very basic (only TGO subpoint coordinates and FREND boresight are needed for data processing). It is thus preferable to generate SPICE information at time of use of calibrated product, using the latest SPICE kernels.

3.2.3 Derived Product

Derived products for the Neutron detector are created from calibrated by putting time series data of counts from different detectors and summing these up in each pixel, over a period of time. The structure of derived products is defined below:

Parameter	Type	Description
START_TIME	Time	UTC start and end times of the current map
END_TIME	Time	
MAP	Double[X][Y]	Array of detectors counts per second in current pixel
MAP_EXPOSURE	Double[X][Y]	Array of exposure time in current pixel in seconds
MAP_ERR	Double[X][Y]	Errors of counts in current pixel

Table 3-18 FREND Derived Neutron Science product label definition

X and Y are dimensions of map arrays that define the spatial resolution of the product, to be defined at time of product delivery and will depend on the time span of the product (i.e. longer periods of maps will have better statistics that will allow for higher spatial resolution).

Since geometry information is used during the generation of product, the SPICE version used will be included into product delivery documentation to allow tracebility.

Dosimeter derived product has the same structure as FREND Calibrated Science Dosimeter Minute Product, but accounting for shielding of TGO by Mars in the dose values:**Parameter**

Parameter	Type	Description
ds_utc_time_d	ASCII_Date_Time_YMD	UTC time, beginning of the one minute accumulation interval
ds_flux_min_BA	ASCII_Real	Fluence rate in direction BA, extrapolated for 1.5 AU distance from Sun in deep space, [particles/cm^2.s]
ds_flux_min_DC	ASCII_Real	Fluence rate in direction DC, extrapolated for 1.5 AU distance from Sun in deep space, [particles/cm^2.s]
ds_dose_min_BA	ASCII_Real	Dose rate in direction BA, extrapolated for 1.5 AU distance from Sun in deep space, [μGy/h]

ds_dose_min_DC	ASCII_Real	Dose rate in direction DC, extrapolated for 1.5 AU distance from Sun in deep space, [μGy/h]

Table 3-19 FREND Derived Science Dosimeter Corrected Minute label definitions

3.2.4 Supplementary products

Supplementary products will generally have the same format as Derived products defined in the section above, but will contain data converted to Hydrogen or water equivalent concentrations for each pixel. Product contents to be defined at times of delivery of such supplementary product.

3.2.5 FREND metadata in PSA

This section describes the metadata that is to be added into label files for each delivered product. We only describe FREND-specific metadata, all other project-related or metadata required by PDS standard are to be included by default.

Raw products (as described in 3.2.1):

Raw products do not contain custom FREND metadata.

Calibrated Neutron products (as described in 3.2.2):

- **Time** (UTC, frend:utc_time_n) of data contained in a file. Calibrated data files are split into intervals of 12 orbits (i.e. approximately 1 day).

Calibrated Dosimeter products (as described in 3.2.2):

- **Dosimeter data gaps**, frend:gap class with attributes:
    - **frend:gap_id** a running number of gaps in dosimeter data;
    - **frend:gap_start / frend:gap_end –** UTC times of gap start and end.

Derived Neutron products (as described in 3.2.3):

- **Sequence number and start and end times of data gaps** (UTC, IDs to be defined) – the time intervals with missing or bad data.
- **Map type** (IDs to be defined) of the current product – i.e. HE map, SCN map, summed or averaged map etc. Exact types used will be defined in the notes of the delivery.
- **Description notes** (IDs to be defined)**.** A text field containing free info on specifics of this product.

Derived Dosimeter products (as described in 3.2.3):

- **Start and end times** (UTC, IDs to be defined) of data contained in a file (1 month). Type of data - minute data.
- **Start and end times of data gaps** (UTC, IDs to be defined) – time intervals with missing or bad data.

Supplementary products (as described in 3.2.4):

- **Start and end times** (UTC, IDs to be defined) of data used to generate this map.
- **Map type** (IDs to be defined) of the current product – i.e. H_2 map, water equivalent map, summed or averaged map etc. Exact types used will be defined in the notes of the delivery.

- **Description notes** (IDs to be defined)**.** A text field containing free info on specifics of this product.

3.3 PSA file naming conventions

This section describes file naming conventions of products delivered to PSA as proposed by the FREND team. These are currently TBC and may be updated based on inputs from ESAC/PSA.

Level	Product	Reference	Naming convention
Raw	Housekeeping	Table 3-11	frd_raw_hk_<start_time>-<end_time>
	Science Neutron	Table 3-13	frd_raw_scn_<start_time>-<end_time>
	Science Dosimeter	Table 3-14	frd_raw_scd_<start_time>-<end_time>
Partially Processes	Housekeeping	Table *3-12*	frd_par_hk_<start_time>-<end_time>
Calibrated	Science Neutron	Table 3-15	frd_cal_sc_n_<start_time>-<end_time>
	Science Dosimeter Minute	Table 3-16	frd_cal_sc_dm_<start_time>-<end_time>
	Science Dosimeter Hour	Table 3-17	frd_cal_sc_dh_<start_time>-<end_time>
Derived	Science Neutron	Table 3-18	frd_der_sc_n_<start_time>-<end_time>
	Science Dosimeter	Table 3-19	frd_der_sc_d_<start_time>-<end_time>
Supplementary	Science Neutron		frd_misc_<label>_<start_time>-<end_time>

Table 3-20 PSA Files Naming Convention

In the table above <start_time> and <end_time> are UTC times, e.g. 20180208t180000; <label> is a label describing the supplementary product to be defined at time of delivery of such product (e.g "H" for hydrogen product, "weh" for water equivalent product or other).

3.4 Data processing algorithms

This section contains descriptions of algorithms used to produce different PSA data levels.

3.4.1 Telemetry to Raw

Telemetry is the binary stream that is generated by the instrument and later downlinked to Earth. Raw data product contents are described in section 3.2.1.

Raw product is generated directly from the telemetry streams without applying any processing or cropping. Only conversion from binary data to PSA compatible XML labels and tabbed data files is performed. This product is created by SOC at ESAC.

3.4.2 Raw to Partially Processed

This processing only applies to housekeeping. At this stage, only simple conversions according to calibration curves defined in 3.1.2 from engineering units to physical units is performed. Also, time fields in UTC are added to the data (calculated from spacecraft clock using SPICE). This product is created by SOC at ESAC.

3.4.3 Raw to Calibrated

Calibrated product structure is described in section 3.2.2. The main aim of this product is to perform transition to physical units and remove any instrument-related effects from the data.

To create this dataset, FREND Team retrieves "Telemetry" level data directly from ESOC DDS, ingests these data into the local database and then performs the following steps:

- Retrieve Raw level data from PSA;
- Check that FREND Database and PSA Raw data are identical;

- Assign PSA Raw level filenames to entries in FREND local database (for correct linking of Calibrated level products);

- Process Raw data and create Calibrated level products

This algorithm (involving both, ESOC DDS and PSA Raw level data) is in place, partly, for historical reasons (DDS access was available at time of mission launch), but also allows for cross-check of source DDS “Telemetry” level data with PSA “Raw” level data, which is important at this stage since the Raw data level is source for all higher-level products. PSA Raw level data is retrieved from ESAC PSA directly (via the web or FTP access), or via IKI PSA copy via SCP access.

Delivery of these products is performed, according to the schedule in 3.5 by upload (FTP/SCP) to either IKI or ESAC PSA archives which will then be rsynced with each other.

3.4.3.1 Science Neutron Raw to Calibrated Algorithm

This section describes algorithms applied to data defined in Table 3-13 (raw science neutron) to convert it to calibrated science neutron product defined in Table 3-15. We will describe the steps taken following the parameters enumerated in the target data structure, calibrated product describing how they were obtained from the source data structure, the raw product.

UTC_Time. This field contains time information of the frame. It is converted from source **SC TIME** fields, which are spacecraft time, by applying SPICE library.

SCI_ACC_TIME. This parameter is copied from raw data without conversion and is a number of seconds current measurement lasted.

CAL_HE. This parameter represents a normalized count rates of all four HE counters. In the source raw data these counts are represented by 16-element arrays representing energy spectra in each counter. The resulting parameter provided in calibrated dataset is a result of converting each of the 16-element arrays to a single float number representing neutron count rate in counts per second. These are the steps that are performed for the transition:

1. The efficiency of the detectors is corrected. This is only done for helium counters (**SPECTRA1-4** parameters of the source raw data). For counts in each energy bins 6-15 of each detector a time series curve is created between the moment of power-on and as long as data lasts. The time series are then averaged per-sol so that there is one value per detector per energy bin. The resulting curve is then fitted with an $F = A \cdot [\, 1 - exp(\, B \cdot (t\text{-}C)\,)\,]$ law, where t is time and *A, B, C* – fitting parameters. A fitting coefficient for each sol is defined and then the raw counts are multiplied by this coefficient.

2. Neutrons from Mars are extracted from the signal. HE counters raw data is polluted by charged particles, which detectors also register along with neutrons, which are the signal. This extraction is done based on data obtained from the elliptical orbits, where FREND was operating both in apo- and periapsis of the orbit. In the apoapsis FREND is far away from Mars, and its angular size is negligible, so the only particles detected by helium counters are charged particles of the GCR and background neutrons produced within the spacecraft body. When in periapsis, Mars shields almost half of the sky, together with the GCR particles, so we see the detectors count rate change leaving us with almost half the GCR particles flux, spacecraft background and Martian neutrons. The ratio of count rate for each detector in each channel in apoapsis vs periapsis was calculated and averaged for all elliptical orbits FREND was able to observe. It gave us the calibration values for each detector and each channel to estimate the ratio between Martian neutrons and charged particles in FREND’s data.

3. Count rate is corrected to GCR levels. GCR flux is variable, which yields the charged particles count rate and spacecraft background neutrons count rate change over time. To correct for this effect, we take charged particles time series as measured by FREND’s dosimeter and generate correction

coefficients to bind GCR variations to the moment of FREND's science phase measurements start. These coefficients are applied to all detectors' energy bins.

4. Finally, for each measurement frame we sum up the values of neutrons counts in energy bins 6 to 15 and divide them by **SCI_ACC_TIME** parameter to convert to counts per second. This is the resulting number contained in the product.

Calibrated product also contains a subset of the raw product data frames. Only the measurements that are good enough for mapping purposes are inserted into the calibrated product. Measurements are omitted if:

- Solar particle event pollutes the data and it becomes unusable for mapping of the surface;
- TGO is performing off-nadir measurements, so FREND is not pointed sub-nadir (we exclude all angles above 5° off-nadir).

HE_TOTAL_COUNT. This parameter is a sum of all raw product counts accumulated in all HE counters in channels 6 to 15 during the current measurement frame. This value is pure measurement, prior to any adjustment is done. This value is provided for the purpose of statistical error estimation.

3.4.3.2 Housekeeping Raw to Calibrated Algorithm

This section describes how housekeeping raw parameters, described in Table 3-11 are converted to Calibrated housekeeping parameters described in . We will describe conversions based on the target parameter names:

UTC_Time. This field contains time information of the frame. It is converted from source **SC TIME** field, which are spacecraft time, by applying SPICE library.

TEMP and **VOLT** fields. There is a total of 12 temperatures and 4 voltages present in the dataset. These are converted from the corresponding raw units by applying simple $y = ax + b$ conversion, as described in 3.1.2.

HK_HV_STATE, **HK_HV_FAILURE**, **HK_DISC_LEV** fields. These are status fields that are extracted from the source bit fields and saved as arrays in the calibrated product, for simplicity of access. No conversion is performed.

HK_LIM. Same as above, extracted from source bit fields to an array for simplicity, without conversion.

HK_FDIR field. Essentially this is a temperature that is converted according to a simple $y = ax + b$ conversion, as described in 3.1.2. FDIR temperature is relevant to temperature sensor # 8 (MntPt). We use value -9999 to mimic "NaN", in case FDIR is not used by the instrument.

STATUS* fields. Total of 3 status fields are extracted from relevant bit fields in raw data and converted to byte values for simplicity.

HK_*CNT fields. A total of 6 fields that are copied from raw data (number of counts in each detector, in UINTs, needs no conversion).

HK_CMD*_ECHO fields. A total of 3 4-byte arrays representing copies of 3 last commands received by the instrument, copied from raw data as arrays.

HK_CMD*_TIME fields. A total of 3 integers representing instrument time of last command receipt, copied from source raw data.

3.4.3.3 Dosimeter Raw to Calibrated Algorithm

I. Reconstruct the dosimeter Measurement frame as described in Table 3-6

To receive all calibrated data in the files frd_cal_scdm_<start_time>-<end_time> and frd_cal_scdh_<start_time>-<end_time> one has to use all files frd_raw_sc_d_<start_time>-<end_time> listed in the corresponding files labels. The procedures described in the paragraphs I.1 to I.2.5 work with records of a raw data file of type frd_raw_sc_d_.

ATTENTION: Each real byte of the *dosimeter telemetric record* in the raw data file fields of type ASCII_Numeric_Base16 - VFSnn05L, nn=11 to 20 - is represented by 2 ASCII symbols, i.e. by 2 bytes in the file. **Further on 'byte' and 'number of byte' will mean a group of 2 ASCII symbols and the corresponding number of this group**.

I.1. Find the first package of the frame, define the start time of the frame.

I.1.1. In each record, from field number 8 (name VFS1105L, FREND:DOS DATA1):

- from the 3 and 4 bytes define the hex low byte of the packet's number.

- from the 5 and 6 bytes define the hex high byte of the packet's number

- calculate the number of the packet ***NUM***

I.1.2. Find the record for which ***NUM*** is divided by 20 without a residual (***NUM*** mod 20 = 0). This is the record with the first packet of the first measurement frame, contained in the current file with raw data. Denote it as REC1 and ***NUM1***

I.1.3. The first field of the record – PUS_TIME_UTC is the time at which this frame was recorded. Subtract 1 hour *and 3 minutes* from this time and define the start time of the measurements recorded in the frame - TIMEs.

I.2. Construct the measurement frames.

I.2.1. REC1 together with the successive 19 records define the first measurement frame. Check if the packet number of the records in the group is equal to ***NUM1***+i, i=1,2,…19. If this condition is not fulfilled it means that an error has occurred and the measurement frame is invalid. Then find a new record for which (**NUM** mod 20 =0) and proceed in the same manner until a valid frame occurs. .

I.2.2. In REC1 merge field number 8, field number 14, field number 20, field number 26, field number 32, field number 38, field number 44, field number 50, field number 56, bytes from 1 to 88 from field number 62. These 1024 bytes represent Packet 1 of the frame as described in Table 3-7.

I.2.3. Merge in the same manner the corresponding fields of the next 19 records. You obtain the corresponding second, third,…20th packets of the first measurement frame.

2.4. The next 20 records contain data of the second measurements frame.. Define the start time for the frame as in I.1.3. Reconstruct the 20 packets of the second frame as in I.2.2. and I.2.3.

I.2.5. In case the last group in the file contains less than 20 records, check the first several records in the next telemetry file. If their PUS_TIME_UTC (see I.1.3) and packet numbers (I.2.1) connect continuously with those of the group, fill up the last group with these records.

II Reconstruct dosimeter parameters from one Measurement frame.

According to Table 3-7 'Dosimeter Packet Format' construct dosimetric measurements, merging : from packet 1 (REC1) – bytes 9 to 510; from packets 2 to 19 – bytes 4 to 510; from packet 20 – bytes 4 to 504. This structure will be referred to as data set – a one-dimensional matrix with 10129 elements DS(10129). Data are recorded in it as described in Table 3-6 Dosimeter Measurement Frame Contents.

N.B. In dosimeter frames the little-endian system is employed. Within one word, byte 0 is least significant byte.

II.1. Reconstruct the spectral parameters

Define the following one-dimensional matrices each of 256 elements: SpB0(256), SpBA0(256), SpBD0(256), SpD0(256), SpDC0(256), SpA1(256), SpAB1(256), SpC1(256), SpCD1(256). Determine the values of their elements using the following relations:

Index i=0 to 255

k = 0, SpB0(i)= DS(k+i*3)DS(k+i*3+1)DS(k+i*3+2)

k = 768, SpBA0(i)= DS(k+i*3)DS(k+i*3+1)DS(k+i*3+2)

k = 1535, SpBD0(i)= DS(k+i*3)DS(k+i*3+1)DS(k+i*3+2)

k = 2303, SpD0(i)= DS(k+i*3)DS(k+i*3+1)DS(k+i*3+2)

k = 3072, SpDC0(i)= DS(k+i*3)DS(k+i*3+1)DS(k+i*3+2)

k = 3840, SpA1(i)= DS(k+i*2)DS(k+i*2+1)

k = 4352, SpAB1(i)= DS(k+i*2)DS(k+i*2+1)

k = 4864, SpC1(i)= DS(k+i*2)DS(k+i*2+1)

k = 5376, SpCD1(i)= DS(k+i*2)DS(k+i*2+1)

II.2. Reconstruct the flux and dose parameters

Define the following one-dimensional matrices each of 60 elements: DB0(60), DBA0(60), DD0(60), DDC0(60), FA1(60), FAB1(60), FC1(60), FCD1(60), DA1(60), DAB1(60), DC1(60), DCD1(60), FB0(60), FBA0(60), FDB0(60), FD0(60), FDC0(60). Determine the values of their elements using the following relations:

Index i=0 to 255;

j = 5888+i*69

DB0(i) = DS(j+i)DS(j+i+1)DS(j+i+2)DS(j+i+3)

DBA0(i) = DS(j+i+4)DS(j+i+5)DS(j+i+6)DS(j+i+7)

DD0(i) = DS(j+i+8)DS(j+i+9)DS(j+i+10)DS(j+i+11)

DDC0(i) = DS(j+i+12)DS(j+i+13)DS(j+i+14)DS(j+i+15)

FA1(i) = DS(j+i+24)DS(j+i+25)

FAB1(i) = DS(j+i+26)DS(j+i+27)

FC1(i) = DS(j+i+28)DS(j+i+29)

FCD1(i) = DS(j+i+30)DS(j+i+31)

DA1(i) = DS(j+i+32)DS(j+i+33)DS(j+i+34)

DAB1(i) = DS(j+i+35)DS(j+i+36)DS(j+i+37)

DC1(i) = DS(j+i+38)DS(j+i+39)DS(j+i+40)

DCD1(i) = DS(j+i+41)DS(j+i+42)DS(j+i+43)

FB0(i) = DS(j+i+44)DS(j+i+45)DS(j+i+46)

FBA0(i) = DS(j+i+47)DS(j+i+48)DS(j+i+49)

FDB0(i) = DS(j+i+50)DS(j+i+51)DS(j+i+52)

FD0(i) = DS(j+i+53)DS(j+i+54)DS(j+i+55)

FDC0(i) = DS(j+i+56)DS(j+i+57)DS(j+i+58)

III. Calculate the calibrated Science Dosimeter Products

III.1. Calculate hourly flux rates and dose rates from measured spectra - Calibrated Science Dosimeter Hour Product.

The following paragraphs describe how to produce one record of the file frd_cal_scd_h_<start_time>-<end_time>

III.1.1. utc_time_d_h = TIMEs. Round the time to a minute: YYYY-MM-DDThh:mm

III.1.2. The fluence rates in directions BA and DC in units [particles/cm2.s] are calculated by the following formulae:

flux_hour_BA = $\{\sum_{i=0}^{229}[SpB0(i)) + SpBA0(i)) + SpBD0(i)] + \sum_{i=21}^{255}[SpA1(i) + SpAB1(i)]\}/7200$

flux_hour_DC= $\{\sum_{i=0}^{226}[SpD0(i) + SpDC0(i) + SpBD0(i)] + \sum_{i=22}^{255}[SpC1(i) + SpCD1(i)]\}/7200$

III.1.3. The dose rates in directions BA and DC in [μGy/h] are calculated by the following formulae:

dose_hour_BA=

$$\{0.068 * \sum_{i=0}^{229}[SpB0(i) + SpBA0(i) + SpBD0(i)] * i + 0.7427 * \sum_{i=21}^{255}[SpA1(i) + SpAB1(i)] * i\} * 0.1146E-2$$

dose_hour_DC=

$$\{0.070 * \sum_{i=0}^{226}[SpD0(i) + SpDC0(i) + SpBD0(i)] * i + 0.7213 * \sum_{i=22}^{255}[SpC1(i) + SpCD1(i)] * i\} * 0.1146E-2$$

III.2. Calculate the minute fluence rates and dose rate from Fluxes and Doses measurements - Calibrated Science Dosimeter Minute Product

The following paragraphs describe how to produce 60 records of the file frd_cal_scdm_<start_time>-<end_time>, using the reconstructed Measurement frame as described in I.

Each record will be referred to a time following the start time of the measurement frame at **tm** minutes, tm = 0, 1, 2, ……,59. For this record, denoted by index tm:

III.2.1. utc_time_d_m (tm)=TIMEs (rounded to a minute) + tm

III.2.2. The fluence rates in directions BA and DC in units [particles/cm2.s] are calculated by the following formulae:

flux_min_AB(tm) = (FB0(tm) +FBA0(tm) +FDB0(tm) +FA1(tm) +FAB1(tm))/120.

flux_min_CD(tm) = (FD0(tm) +FDC0(tm) +FDB0(tm) +FC1(tm) +FCD1(tm))/120.

III.2.3. The dose rates in directions BA and DC in [μGy/h] are calculated by the following formulae:

$$\mathrm{DBD0} = 0.068 * \sum_{i=0}^{229} \mathrm{SpBD0}(i) * i$$

dose_min_BA(tm) ={DBD0+[(DBA0(tm) +DBD0(tm))*0.068+(DA1(tm) +DAB1(tm))*0.7427]*60}*0.1146E-2

dose_min_DC(tm) ={DBD0+[(DD0(tm) +DDC0(tm))*0.070+(DC1(tm) +DCD1(tm))*0.7213]*60}*0.1146E-2

IV. Reconstruct measured spectra in direction BA and DC (by whish, not included in calibrated products)

Define two 2-dimensional matrices SpBA(465,2) and SpDC(461,2)

Calculate the elements of the matrices, using the following relations.and the matrices defined in II.1.

NB: Indexing starts at 0

<u>Matrix SpBA</u>

a) i =0 to 229 SpBA(i,0) = 0.68*i, SpBA(i,1) = SpB0(i)+SpBA0(i)+SpBD0(i)

b) i = 230 to 464 SpBA(i,0) = 0.7427*(i-209), SpBA(i,1) = SpA1(i-209)+SpAB1(i-209)

<u>Matrix SpDC</u>

a) i=0 to 226 SpDC(i,0) = 0.070*i, SpDC(i,1) = SpD0(i)+SpDC0(i)+SpBD0(i)

b) i=227 to 460 SpDC(I,0) = 0.7213*(i-205), SpDC(i,1) = SpC1(i-205)+SpCD1(i-205)

3.4.4 Calibrated to Derived

Derived product structure is described in section 3.2.2. This product contains neutron science data, plotted on a map instead of time series (as it was in Calibrated product level). Dosimeter data is converted to dose and fluence rates of both telescopes.

Delivery of these products is performed, according to the schedule in 3.5 by upload (FTP/SCP) to either IKI or ESAC PSA archives which will then be rsynced with each other.

3.4.4.1 Neutron Calibrated to Derived algorithm

This section describes algorithms applied to data defined in Table 3-15 (calibrated science neutron) to convert it to derived science neutron product defined in Table 3-18. We will describe the steps taken following the parameters enumerated in the target data structure, derived product describing how they were obtained from the source data structure, the calibrated product.

Derived products are essentially neutron count rate maps, hence they are 2D arrays of pixels. Each pixel contains the number of neutrons accumulated when TGO was flying above it, summed up for all the fly over incidents. Each neutron count is accompanied by the exposition time and statistical error. In case TGO ground track during calibrated product's accumulation frame crosses pixel boundary, then count rate is distributed between pixels proportionally to the track's length.

Derived product will contain epithermal neutrons map (containing counts of all 4 ^{3}HE detectors) and a high energy neutrons map (containing counts of the SCN detector).

START_TIME, END_TIME – start and end UTC times between which this map was accumulated.

MAP [X],[Y] – 2D array of pixels containing neutron count rate of this pixel.

MAP_EXPOSURE [X],[Y] – 2D array of pixels containing exposition time – total number of seconds TGO spent over this pixel.

MAP_ERR [X],[Y] – 2D array of pixels, containing neutron count rate statistical errors. These errors are taken from the calibrated product and propagated to the derived product, considering all the manipulations performed with the neutron count rate.

Array dimensions [X],[Y] will be selected at time of delivery considering statistical certainty level of each pixel: the more the exposure time of each pixel is, the lesser the error of that pixel is, hence it is possible to bin the map into smaller pixels (but with higher spatial resolution). At each delivery, an assessment of adequate binning size will be performed based on the length of period delivered and the statistics accumulated.

3.4.4.2 Dosimeter Calibrated to Derived algorithm

The Derived Science Dosimeter product contains dosimeter minute data – fluence rates and dose rates in two perpendicular directions named AB and CD, but corrected to account for the shielding of cosmic rays fluxes from Mars and for the contribution of Mars albedo particles. To perform this correction TGO orientation towards Mars is necessary. In nominal orientation when TGO –Y axis is directed towards the nadir, the detectors' axes are perpendicular to nadir. Then

ds_utc_time_d = utc_time_d_m

ds_flux_min_BA = flux_min_BA/0.88

ds_flux_min_DC = flux_min_DC/0.88

ds_dose_min_BA = dose_min_BA/0.82

ds_dose_min_DC = dose_min_DC/0.82

Coefficients 0.88 and 0.82 are subjected to precision with the consequent versions of the products.

In the rare cases when TGO has another orientation the correction is more complicated. These intervals can be easily recognized by the short (about 2 hours) depletion of the parameters ***flux_min_AB*** and ***flux_min_CD*** in the calibrated data. The correction algorithm for these cases will be published in a special paper.

3.5 Delivery schedule

This section describes the delivery schedule of FREND products and their public availability through PSA. The main delivery logic is as follows:

- Raw products are created and delivered by ESAC on their own schedule (delivery schedule provided in table Table 3-21 is for example only). Public access to these data for the community is provided 6 months after data receipt and only for science phase data.
- Calibrated FREND Neutron products are created by IKI and delivered to PSA every 6 months for a period of 6 to 12 months before that. Public access to these data for the community is provided at time of delivery.
- Calibrated FREND Dosimeter products are created by SRTI-BAS, Sofia, and delivered to PSA every 6 months for a period of 6 to 12 months before that. Public access to these data for the community is provided at time of delivery.
- Derived FREND Neutron products are created by IKI and delivered to PSA once a year for a period of 9 to 21 months before that. Public access to these data for the community is provided at time of delivery.

- Derived FREND Dosimeter products are created by SRTI-BAS, Sofia, and delivered to PSA once a year for a period of 9 to 21 months before that. Public access to these data for the community is provided at time of delivery.
- Supplementary products are delivered on a case by case basis. Public access to these data for the community is provided at time of delivery.

Dosimeter calibrated products accumulated before March 2018 (i.e. in Cruise and MOI) are planned for delivery in February 2020, as a single delivery.

The following tables gives an example of delivery schedule given that nominal science mission starts in April 2018.

		2016		2017				2018				2019				2020				2021
		III	**IV**	**I**	**II**	**III**	**IV**	**I**	**II**	**III**	**IV**	**I**	**II**	**III**	**IV**	**I**	**II**	**III**	**IV**	**I**
Raw	**D**	Cruise 04-06	Cruise 07-09	MOI 10-12	MOI 01-03	MOI 04-05				Comiss 04-06	Sci 07-09	Sci 10-12	Sci 01-03	Sci 04-06	Sci 07-09	Sci 07-09	Sci 10-12	Sci 01-03	Sci 04-06	Sci 07-09
	P											Sci 07-09	Sci 10-12	Sci 01-03	Sci 04-06	Sci 07-09	Sci 07-09	Sci 10-12	Sci 01-03	Sci 04-06
Calibrated	**D**														Test Sci		Sci 05’18-09’19		Sci 09-03	
	P														Test Sci		Sci 05’18-09’19		Sci 09-03	
Derived	**D**																			Sci 05’18-03’20
	P																			Sci 05’18-03’20

Table 3-21 FREND PSA Product delivery schedule

In this table “D” and “P” keys in the 2nd column mean “Delivery” periods and “Public access” periods. In each cell the first row denotes the mission phase this data belongs to. Numbers below it are months that are delivered or made publicly available. If year is not explicitly shown, then the month is meant to be closest to this cell on the left.

For example, “Sci 09-03” in cell “2020-IV” means a delivery (or public access) of Science phase data between September 2019 and March 2020, including September and March, aimed to be performed on the 1st of October 2020. “Sci 05’18-09’19” in cell “2020-II” means a delivery (or public access) of Science phase data between May 2018 and September 2019 (i.e. all data but the last 6 months), aimed to be performed on the 1st of April 2020.

This schedule is given as example only and can shift in case mission parameters (i.e. start of commissioning and main science phase) change. The delivery logic described above will be followed in this case to update this table

4 References

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