CTA INCORPORATED

TROPICAL RAINFALL MEASURING MISSION (TRMM)
PHASE B
DATA CAPTURE FACILITY
DEFINITION STUDY

FINAL REPORT

Prepared for

National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland 20771

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ACRONYMS AND ABBREVIATIONS

JDRN	Japanese Data Reception Node
JPL	Jet Propulsion Laboratory
kbps	Kilobits Per Second
LAN	Local Area Network
LOR	Line Outage Recorder
LZP	Level Zero Processing
Mbps	Megabits Per Second
MB	Megabytes
MO&DSD	Mission Operations and Data Systems Directorate
MODLAN	Mission Operations Division Local Area Network
MODNET	MO&DSD Operational/Developmental Network
MTBF	Mean Time Between Failures
MTTR	Mean Time to Restore
N/A	Not Applicable
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency
Nascom	NASA Communications (Network)
Nascom II	Augmented Nascom (Network)
NCC	Network Control Center
NCDS	NASA Climate Data System
NMCC	Network Management Control Center
NSGW	Nascom Service Gateway
NSSDC	National Space Science Data Center
OSI	Open System Interconnect
OSL	Orbiting Solar Laboratory
Pacor	Packet Processor
PMSS	Pacor Matrix Switch Subsystem
POCC	Payload Operations Control Center
PR	Precipitation Radar
Prod	Production
Q	Quadrature
Q/A	Quality and Accounting
QL	Quick Look
QLP	Quick Look Processing

ACRONYMS AND ABBREVIATIONS

Retx Msg	Retransmission Message
Retx Req	Retransmission Request
RFP	Request for Proposal
RIU	Remote Interface Unit
RMA	Reliability, Maintainability, Availability
ROM	Rough Order of Magnitude
RPP	Recorder Processor Packetizer
R-S	Reed-Solomon
RT	Real Time
RTP	Real-Time Processing
SDAC	Science Data Analysis Center
SIRT	Synchronous Intelligent Remote Terminal
SMEX	Small Explorers
SN	Space Network
SOCC	Science Operations and Control Center
SOHO	Solar and Heliospheric Observatory
SOW	Statement of Work
SSA	S-Band Single Access
SSM/I	Special Sensor Microwave Imager
STDN	Spaceflight Tracking and Data Network
STGT	Second TDRS Ground Terminal
TBD	To Be Determined
TBR	To Be Resolved
TDCF	TRMM Data Capture Facility
TDM	Time-Division Multiplexed
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
TRMM	Tropical Rainfall Measuring Mission
TSDIS	TRMM Science Data and Information System
VCID	Virtual Channel Identifier
VIS/IR	Visible/Infrared
WSC	White Sands Complex
WSGT	White Sands Ground Terminal
XTE	X-Ray Timing Experiment

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SSM/I	Special Sensor Microwave Imager
STDN	Spaceflight Tracking and Data Network
STGT	Second TDRS Ground Terminal
TBD	To Be Determined
TBR	To Be Resolved
TDCF	TRMM Data Capture Facility
TDM	Time-Division Multiplexed
TDRS	Tracking and Data Relay Satellite
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TSDIS	TRMM Science Data and Information System
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VIS/IR	Visible/Infrared
WSC	White Sands Complex
WSGT	White Sands Ground Terminal
XTE	X-Ray Timing Experiment

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1.0 INTRODUCTION

The National Aeronautics and Space Administration (NASA) and the National Space Development Agency of Japan (NASDA) initiated the Tropical Rainfall Measuring Mission (TRMM) to obtain more accurate measurements of tropical rainfall than ever before. These measurements will be used to improve scientific understanding and knowledge of the mechanisms effecting the intra-annual and interannual variability of the Earth's climate. The success of the TRMM is largely dependent upon the handling and processing of the measurement data by the TRMM Ground System supporting the mission.

The TRMM Ground System is a multiple-facility system that encompasses many existing NASA institutional facilities. TRMM Ground System elements include the Payload Operations Control Center (POCC) and Command Management System (CMS); the TRMM Data Capture Facility (TDCF); the TRMM Science Data and Information System (TSDIS), which includes the Science Data Analysis Center (SDAC) and the Science Operations and Control Center (SOCC); the Flight Dynamics Facility (FDF); the Japanese data reception node (JDRN); the National Space Science Data Center (NSSDC); ground truth stations and other non-TRMM data sources. These facilities communicate using NASA institutional services such as the NASA Communications Network (Nascom), augmented Nascom Network (Nascom II) or, for geographically-proximate facilities, Local Area Networks (LANs). Space-to-ground communications between the TRMM spacecraft and the TDCF (return link) and the POCC (forward link) are provided by the Space Network (SN), with the Deep Space Network (DSN) providing backup communications in the event of an SN failure.

1.1 OBJECTIVE AND SCOPE OF STUDY

The objectives of this study are to define the data capture and processing requirements for the TRMM Data Capture Facility and to use those requirements to design and evaluate two independent TDCF implementations. The first implementation is based on the existing Packet Processor (Pacor) at Goddard Space Flight Center (GSFC). The second implementation is based on the Customer Data Operations System (CDOS). The Pacor-based implementation results in a local TDCF at GSFC; the CDOS-based implementation results in a remote TDCF at the White Sands Complex (WSC) in Las Cruces, New Mexico.

The scope of this study is limited to the functions performed by the TDCF. These functions include capturing the TRMM spacecraft return link data stream; processing the data in the real-time, quick-look, and routine production modes, as appropriate; and distributing the resulting real time, quick-look, and production data products to users. Higher-level processing (beyond Level Zero) and analysis are handled by other TRMM Ground System elements and are beyond the scope of this study.

1.2 TRMM MISSION OVERVIEW

The principal objective of the TRMM is to obtain three years of climatological determinations of rainfall in the tropics, culminating in data sets of 30-day average rainfall over 5-degree square areas, and associated estimates of vertical distribution of latent heat release. The rainfall data are needed to enhance existing atmospheric general circulation models for both research and large-scale weather prediction. The vertical latent heat profile data are needed to enhance models of the 30-to-60-day tropical oscillation in rainfall and wind fluctuations and other models concerning the effects of tropical atmosphere on distant air motion.

The TRMM spacecraft will be placed in low-Earth circular orbit at an altitude of 350 kilometers and an inclination of 35 degrees. This orbit will permit documentation of the diurnal rainfall cycle. The projected spacecraft operational life is three years.

The TRMM scientific instrument complement currently envisioned consists of four instruments: a Precipitation Radar (PR); two passive microwave radiometers -- the single-frequency Electronically Scanning Microwave Radiometer (ESMR) and the multiple-frequency Special Sensor Microwave Imager (SSM/I); and a visible/infrared (VIS/IR) radiometer -- a modified version of the Advanced Very High Resolution Radiometer (AVHRR). All of these instruments except the PR have been flown on previous space meteorological missions. The PR, a Japanese instrument, will be the first quantitative precipitation radar flown in space and will provide good measurements of rain rates over both land and ocean. The passive microwave radiometers will provide good measurements of rainfall rates over oceans; rainfall rate measurements over land are less reliable due to surface inhomogeneities.

Within the constraints of the passive microwave measurements of the ESMR and the SSM/I, the PR measurements will be used to determine the height profile of the precipitation content, from which the desired latent heat release profile can be estimated. The AVHRR measurements will be analyzed in conjunction with the PR and passive microwave rainfall measurements to allow better interpretation of other VIS/IR measurements from past and future operational satellites.

Instrument and spacecraft data will be transmitted to the Tracking and Data Relay Satellite System (TDRSS) once per orbit to be relayed to the White Sands Ground Terminal (WSGT) or Second TDRS Ground Terminal (STGT) at the WSC. The WSGT or STGT will transmit the data to the TDCF for processing in a real-time, quick-look, or production mode. The appropriate resulting data products will then be distributed to other elements of the TRMM Ground System, including the JDRN located on the west coast of the United States, the FDF, and the TSDIS at GSFC. The TSDIS SOCC is responsible for science planning and instrument monitoring and coordination; the TSDIS SDAC is responsible for higher-level processing of production data products. Ancillary ground truth data and data from supporting field experiments required for data processing and validation will be stored at the TSDIS. Data products generated by the TSDIS will be available to TRMM scientists via electronic or non-electronic transport mechanisms. Upon approval by the TRMM Science Team, data products will be released to the NSSDC at GSFC for archiving and distribution to general users.

1.3 TRMM END-TO-END SYSTEM DESCRIPTION

The current concept of the TRMM end-to-end data system is illustrated in Figure 1-1. The arrows appearing in the figure are intended to convey primary data flows only; control interfaces such as post-event reports and requests for retransmission of data or data products are not shown. The broad, striped arrows indicate interfaces that will be supported by Nascom, Nascom II or an alternate communications link, depending on the TDCF implementation considered. The narrow, solid arrows indicate interfaces that will be supported by communications links or media other than Nascom or Nascom II, such as LANs or magnetic tape. The dashed arrows indicate potential interfaces that are not now baselined but that may eventually be implemented subject to on-going negotiations.

A brief overview of the return link end-to-end system concept, from the generation of data on-board the TRMM spacecraft to the archiving of higher-level data products at the

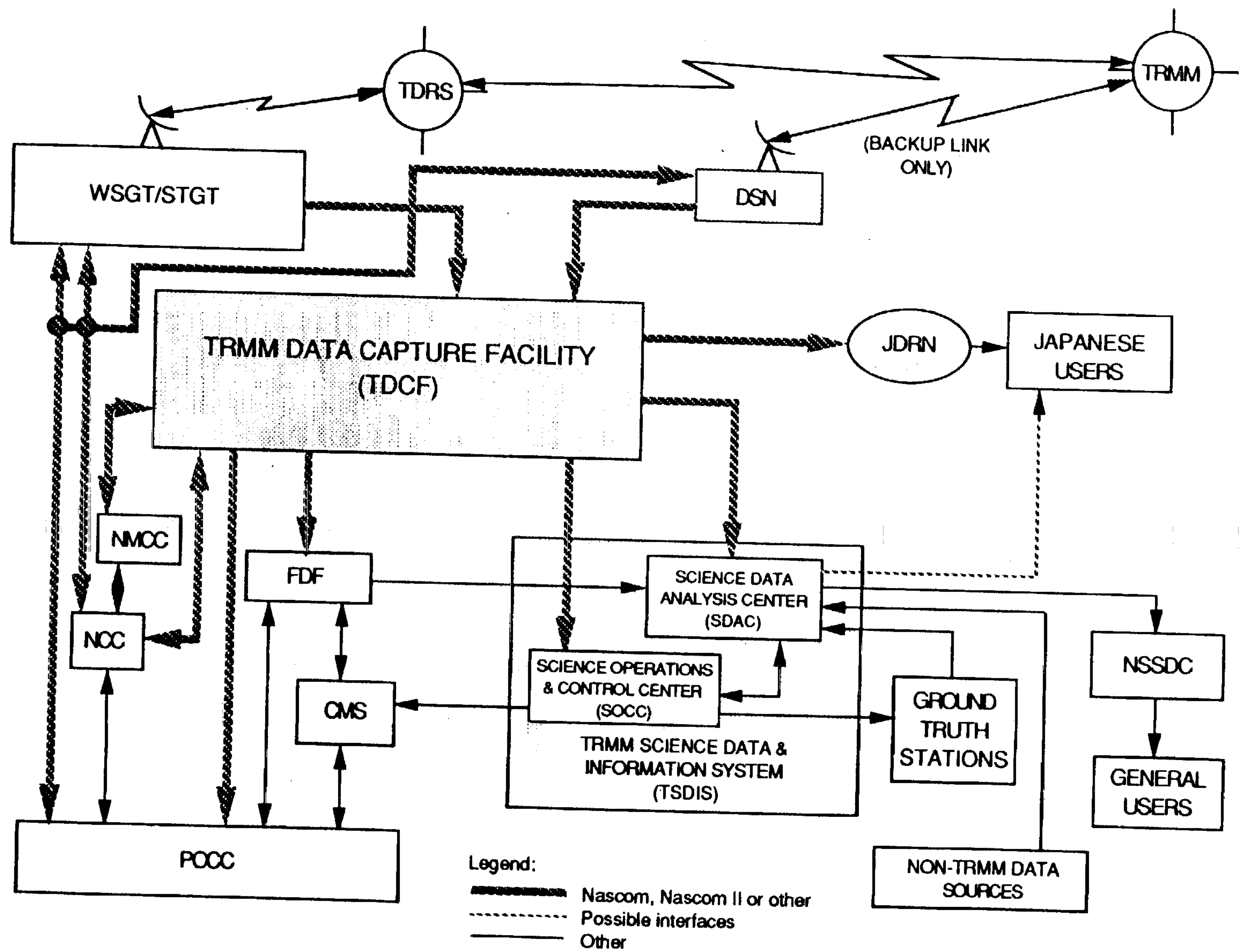

Figure 1-1. TRMM End-to-End System Concept

NSSDC, was presented in Section 1.2. Subsections 1.3.1, 1.3.2, and 1.3.3 address the elements comprising the spacecraft data system, the SN, and the TRMM Ground System, respectively, in terms of their functions in the end-to-end system concept. A more detailed concept of mission operations from data generation on-board the spacecraft through the distribution of Level Zero products by the TDCF is presented in Section 2 and will not be discussed here.

1.3.1 Spacecraft Data System

Instrument and spacecraft data are input to the on-board Communications and Data Handling (C&DH) subsystem to be formatted and transmitted to the TRMM Ground System via the TDRSS and other elements of the SN. The C&DH subsystem is composed of four primary components: the Synchronous Intelligent Remote Terminal (SIRT), the RIU-to-1773 Adapter, the Recorder Processor Packetizer (RPP), and the Command Telemetry Terminal (CTT). These components communicate using a MIL-STD 1773 fiber optic data bus. With the exception of the SIRT, these C&DH components are adaptations of the C&DH components being developed for the Small Explorers (SMEX). The SIRT will be a new component developed specifically for the TRMM C&DH. The RIU-to-1773 Adapter maps a standard RIU interface to the 1773 data bus and is used primarily for the spacecraft power subsystem interface. The RIU-to-1773 adapter is not applicable to the remainder of this discussion and will not be addressed further. An overview of the applicable TRMM C&DH components and the TRMM instrument complement is illustrated in Figure 1-2.

The SIRT is a 8086 processor-based terminal that provides the instrument interface to the 1773 bus. The SIRT serves as the C&DH gateway to each instrument for the receipt of instrument science and engineering data and the transmission of commands back to the instrument. The SIRT performs the necessary packetization functions for instrument science and engineering data transport on-board the spacecraft and over the space-ground link. It also performs any required depacketization functions for command and ancillary data transfer to the instruments. A design option currently under consideration may transfer some of the packetization functions to the RPP for the data to be stored on the solid state recorder for playback to the return link. Under this option, the SIRT will continue to provide the instrument interface to the bus.

The RPP is based on the 80386 32-bit microprocessor and contains a number of communications interfaces, including the MIL-STD 1773 data bus, a RS-449-like serial twisted wire channel, and a differential RS-232 interface for asynchronous communications. The RPP also contains an 82380 Direct Memory Access (DMA) controller for data transfers, such as dumps to memory, that do not require processor intervention. Two RPPs are among the C&DH components. Each RPP provides an interface to 2 (TBR) gigabits (Gb) of solid state memory which will permit the storage of nearly two orbits of data. The RPP is the primary C&DH computer that performs on-board processing and command and telemetry packetization as required. The RPP sequentially identifies the return link data packets with an application process identifier (APID), generates the real time and playback virtual channels, and generates the fill virtual channel as necessary to meet the return link transmission rate of 2 Mbps.

The CTT provides the prime interface from the C&DH subsystem to the TDRS transponder and performs low-rate I/O and time-distribution functions. The CTT is 8086 processor-based and provides a backup capability for command and control of the data system. It also provides the hardware for encoding telemetry to, and decoding commands from, the transponder. Encoding and decoding functions include cyclic redundancy code (CRC)

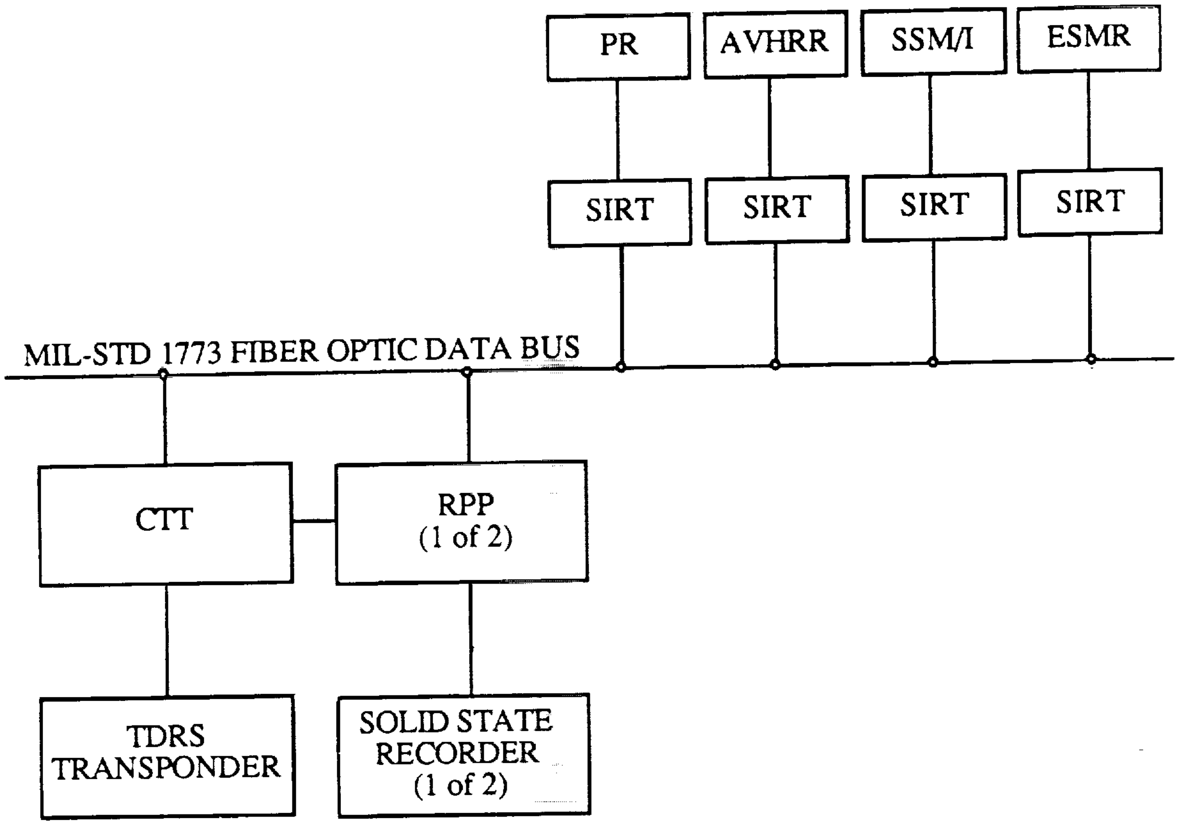

Figure 1-2. C&DH Component Overview

checks and convolutional encoding. Hooks for the addition of Reed-Solomon (R-S) encoding are present. Commands are received from the transponder and forwarded via the 1773 link to the bus controller. Telemetry is transferred using either the 1773 bus (low rate) or a dedicated serial channel from the RPP (high rate).

1.3.2 Space Network

The SN relays return link and forward link data between the TRMM spacecraft and the TRMM Ground System. The elements of the SN include the TDRSS, WSGT, STGT, and Network Control Center (NCC). As illustrated in Figure 1-1, the TDRSS relays the data between the TRMM spacecraft and the WSGT or STGT under control of the NCC; the WSGT or STGT relays the data between the TDCF (return link) or POCC (forward link) and the TDRS.

1.3.3 TRMM Ground System

The TRMM Ground System contains many diverse supporting elements. These include the POCC, CMS, TDCF, FDF, TSDIS, JDRN, ground truth stations, other non-TRMM data sources, and the NSSDC. TRMM Ground System elements communicate using Nascom, Nascom II, or LANs. Nascom resources are coordinated with the NCC; Nascom II resources are coordinated with the Network Management Control Center (NMCC).

The POCC is the operations and control center for the TRMM spacecraft. The POCC is responsible for monitoring and maintaining the health and safety of the TRMM spacecraft and its instrument complement. It manages and controls the core systems, including data management, power, thermal, and control systems, and monitors the payload usage of spacecraft resources. The POCC analyzes spacecraft and instrument telemetry data received from the WSGT or STGT and generates instrument and spacecraft commands necessary to ensure mission health and safety. These commands, along with instrument commands generated by the TSDIS, are uplinked to the spacecraft via the POCC interface with the SN WSGT and STGT. Additional details regarding the forward link operations concept are presented in Section 2.4.

The CMS checks instrument commands and software updates generated by the TSDIS SOCC to ensure that the commands and updates are valid and that existing instrument resource allocations are not exceeded. Ancillary data generated by the FDF are also verified and validated. Valid data, software updates, and commands are transmitted to the POCC for subsequent uplink to the spacecraft.

The TDCF receives return link data from the WSGT or STGT, performs error checking and correction, provides data quality and accounting information at the frame and packet APID level, and separates packets by APID. The TDCF provides real-time, quick-look, and production processing, maintains a short-term data store, and formats data products for distribution to the TRMM data users by electronic or physical media. Section 2.3 provides a detailed operations concept for the TDCF.

The FDF provides orbit, attitude, and navigation computational services in support of flight projects and science customers. Prelaunch services include mission design analysis, trajectory analysis, sensor analysis, and operations planning. Operational support services include orbit and attitude determination, anomaly resolution, maneuver planning and support, sensor calibration, post-delta velocity analysis, and generation of planning and scheduling data products. TRMM orbit and attitude parameters are verified and, if necessary, repaired by the FDF using engineering data from the spacecraft. The repaired orbit and attitude results are transmitted to the TSDIS for use in instrument operations and science data processing (Levels 1 through 4), and to the CMS for eventual uplink to the TRMM spacecraft. The FDF also plans and schedules TRMM orbital maneuvers in coordination with the TSDIS, and provides orbital maneuver parameters to the POCC via the CMS.

The TSDIS is responsible for science planning and instrument monitoring and coordination, as well as the higher-level processing of Level Zero data products provided by the TDCF. Since instrument control options are limited, the POCC will perform instrument commanding using the CMS, based upon TSDIS SOCC-provided science plans. Instrument failures will be addressed by the SOCC providing functional command requirements to the POCC for execution using predefined command sequences. Software repair will be done off-line and transmitted to the CMS for validation and verification and subsequent uplink to the spacecraft via the POCC. Level 1 through 4 data products are distributed to TRMM scientists and, after release approval by the TRMM Science Team, to the NSSDC for archiving and subsequent distribution to general users.

The Japanese data reception node is the location within the continental United States (CONUS) where Japanese users may pick up their production data products.

The ground truth stations provide remote and *in situ* measurements from the Earth's surface supplemented by special experiments with instrumented aircraft. These data are used to validate TRMM measurements, aid mission sampling analysis studies, and develop key regional climatologies. Data are currently being gathered both on-shore and off-shore near Cape Canaveral, Florida, at a monsoon site near Darwin, Australia, and at an ocean site in Kawajalein Atoll, Marshall Islands.

Other non-TRMM data sources include, among others, meteorological satellites such as the Geostationary Operational Environmental Satellite (GOES) and Geostationary Meteorology Satellite (GMS). The imagery data from these satellites will be received electronically and compared to the TRMM radar imagery.

The NSSDC is the permanent archive and distribution center for all TRMM data. The data are transferred to the NSSDC on durable media after certification by the TRMM Science Team at the TSDIS. In addition to direct distribution, a number of services will be available to participating science users through the NASA Climate Data System (NCDS). The NCDS functions as an interactive scientific information management system that provides an integrated set of tools for locating, manipulating, and displaying climate research data. TRMM products will be included in the NCDS as rapidly as the data products are approved for release by the TRMM Science Team.

1.4 REFERENCE DOCUMENTS

The following reference documents were used throughout the course of this study:

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Simpson, Joanne, et al., "A Proposed Tropical Rainfall Measuring Mission (TRMM) Satellite", Bulletin American Meteorological Society, Vol. 69, No. 3, March 1989.

"Telecommand, Part 1: Channel Service, Architectural Specification", Recommendation CCSDS 201.0-B-1, Blue Book, Issue 1, Consultative Committee for Space Data Systems, January 1987 or later issue.

"Telecommand, Part 2: Data Routing Service, Architectural Specification", Recommendation CCSDS 202.0-B-1, Blue Book, Issue 1, Consultative Committee for Space Data Systems, January 1987 or later issue.

"Telecommand, Part 3: Data Management Service, Architectural Definition," Recommendation CCSDS 203.0-B-1, Blue Book, Issue 1, Consultative Committee for Space Data Systems, January 1987 or later issue.

1.5 REPORT ORGANIZATION

Section 2 describes the TRMM operations concepts for instrument operations, spacecraft operations, return link data processing and forward link data handling. The return link data processing concept addresses real time telemetry, quick-look and production processing. Concepts subsequent to Level Zero processing and distribution by the TDCF are beyond the scope of this document and are not discussed.

Section 3 defines the baseline requirements that must be satisfied by the selected TDCF implementation, including system capabilities, communications and data standards, external interfaces, and system functional, performance, and operations requirements.

Section 4 identifies the mission assumptions and issues that may impact the TDCF implementation. These assumptions and issues should be validated prior to the final selection of the TDCF implementation.

Section 5 defines the logical and physical interfaces between the TDCF and external entities and communication networks.

Section 6 presents the two TDCF architecture and design options that are the primary focus of this study. The two options are described in terms of the system configuration, operations concepts, development and operating costs, and advantages and disadvantages.

Section 7 provides an analysis of the critical issues and trade-offs resulting from the architecture and design options presented in Section 6.

Section 8 provides recommendations for the final TDCF implementation selection process.

Appendix A provides a Glossary of Terms that defines the terminology used in the context of this study.

2.0 TRMM MISSION OPERATIONS CONCEPT

This section presents the general operations concept envisioned for the Tropical Rainfall Measuring Mission. In order to understand the overall TRMM operations concept, it is necessary to have a broad understanding of the operations occurring on-board the spacecraft, such as data formatting and transmission to ground facilities, as well as the operations occurring on the ground. Instrument and spacecraft operations concepts are assumed to remain constant for all TRMM ground data handling scenarios. Return link processing and forward link handling are specific to each TDCF implementation scenario. Instrument operations, spacecraft operations, return link processing, and forward link handling are addressed in the subsections that follow.

2.1 INSTRUMENT OPERATIONS

There are four instruments comprising the TRMM complement: the Advanced Very High Resolution Radiometer (AVHRR), the Electronically Scanning Microwave Radiometer (ESMR), the Special Sensor Microwave Imager (SSM/I), and the Precipitation Radar (PR). These instruments operate continuously, 24 hours a day, 7 days a week. Functional descriptions of each of these instruments were presented in Section 1.3.1.

The AVHRR generates data at an average rate of 50 kilobits per second (kbps), including housekeeping data. The data are transmitted as a bit stream to a SIRT component of the TRMM platform C&DH subsystem. In the initial design configuration, the SIRT provides the packetization necessary for further data transport within the C&DH (1773 data bus) and to the ground (Consultative Committee for Space Data Systems (CCSDS) Packet Telemetry Recommendation, January 1987).

The ESMR generates data at a rate of 1 kbps. Housekeeping data are also generated at a very low rate. Science and housekeeping data are transmitted as a bit stream to a C&DH SIRT for packetization and data transport.

The SSM/I generates data at an average rate of approximately 4.3 kbps, including housekeeping data. The data are transmitted as a bit stream to a C&DH SIRT for packetization and data transport.

The PR generates data at a continuous rate of 85 kbps, including housekeeping data. The PR will utilize a NASA provided SIRT to perform the necessary CCSDS and 1773 bus packetization.

Each instrument receives commands, ancillary data, and software updates via the C&DH subsystem and the instrument's associated SIRT. Commands may be forward-linked in real time from the ground during a TDRS contact or retrieved from on-board storage. Commands forward-linked in real time from the ground may result from the presence of new targets of opportunity, the need for instrument recalibration or realignment as evidenced by scientific interpretation of the instrument science data, or the need for instrument safing to protect the health and safety of the instrument, the spacecraft, or both. Commands stored on-board the spacecraft are limited to commands that can be readily and accurately predetermined and defined, such as safing sequences or periodic orbit and attitude adjustments.

2.2 SPACECRAFT OPERATIONS

The TRMM spacecraft generates housekeeping data specific to the spacecraft (as opposed to the instruments) at a rate of 1-2 kbps. These data are used by the POCC to monitor the health and safety of the TRMM spacecraft and its instrument complement.

Instrument and spacecraft return link data are input to the on-board C&DH subsystem and formatted into source packets in accordance with the CCSDS Packet Telemetry (Version 1) Recommendation (CCSDS 102.0-B-2, January 1987). Each packet is assigned an APID which identifies the packet's ground processing and routing requirements. As a minimum, each instrument's packets are assigned an APID unique to the instrument; other APIDs are assigned as necessary (e.g., ancillary data). The resulting CCSDS packets are recorded on the primary solid state recorder on-board the spacecraft for playback during scheduled TDRS contacts. The baseline spacecraft configuration utilizes an interface that will make the recorder look like a large circular buffer. After recording data from the first orbit it will continue to record the next orbit subject to the constraint that an orbit pass buffer may not be overwritten until a ground command is sent to release that buffer. The second solid state recorder acts as a flight spare and is activated upon failure of the primary recorder or upon receipt of an activation request from the POCC. Both recorders are capable of simultaneously recording and replaying data. The data are replayed over a maximum of eight virtual channels. It is assumed that one virtual channel identifier (VCID) will be assigned to the real-time data transmitted to the ground, one VCID will be assigned to fill frames, and up to six VCIDs will be assigned to playback data. These assignments have not been finalized.

During TDRS contacts, the recorded packets are played back in forward order (the order in which they were recorded), multiplexed and placed into the data field of the CCSDS Version 1 Transfer Frame, which is the data structure within the packet telemetry system that transports CCSDS packets across the space-to-ground link in a standardized manner. Version 2 packet telemetry segmentation, as defined in the CCSDS Packet Telemetry Recommendation (CCSDS 102.0-B-2, January 1987), is not supported, nor is any use of segmentation flags in Version 1 source packets. Transfer Frames are then assigned, by means of a VCID, to any one of up to six virtual channels available for the transmission of playback data over the physical channel.

Real-time data, i.e., instrument and spacecraft data generated during the TDRS contact, are packetized and multiplexed into Transfer Frames by the C&DH in the manner described for the recorded data. These Transfer Frames are assigned to a single virtual channel which has been reserved exclusively for real-time data transfer. Real-time packets are also recorded on one of the spacecraft recorders in order to ensure against the loss of any data generated during the TDRS contact.

Transfer Frames are encoded by the C&DH to provide error protection and a means of assessing data quality on the ground. The R-S encoding scheme specified in CCSDS 102.0-B-2 (Packet Telemetry, January 1987) is currently baselined to be implemented on-board the TRMM spacecraft.

The return link rate is assumed to be a constant 2 Megabits per second (Mbps). The C&DH generates fill Transfer Frames as necessary to maintain the 2 Mbps rate; these Transfer Frames are assigned to a single virtual channel reserved for that purpose. The real-time and fill virtual channels are then interleaved with the playback virtual channel(s) to produce a single physical channel.

2.3 RETURN LINK PROCESSING

A general overview of the return link processing operations concept is presented in this subsection. This scenario differs slightly for each of the TDCF implementations considered. The return link processing operations concepts specific to each TDCF implementation are presented in Section 6.

Return link of the physical channel is accomplished using the SN. The TDCF receives the TDRS acquisition session schedule from the NCC. In accordance with the established schedule, the TDRS relays the data to the WSGT or the STGT located at the WSC in New Mexico. The WSC then forwards the data to the TDCF using the Nascom II* Network, which consists of a number of gateways connected by long-distance communications links. The data are transferred to the Nascom II Network at the return link rate of 2 Mbps.

Return link data are processed as real-time telemetry, quick-look data, or routine production data. The type(s) of processing to be performed are initially determined on the basis of virtual channel assignment. Real-time data may be processed in real-time and production modes; playback data may be processed in quick-look and production modes. The Nascom II Network does not have the capability to separate the virtual channels comprising the physical channel, and so routes the entire physical data stream to both the POCC and the TDCF. The POCC performs the necessary error checking and correction functions and then separates the data stream into its component virtual channels to identify the real-time telemetry data; the playback and fill virtual channels are discarded. The TDCF also performs error checking and correction functions, separates the data stream into its component virtual channels, captures the real-time and playback virtual channels on a nonvolatile physical medium, and, depending on the TDCF implementation, either stores or discards the fill virtual channel. Real-time and playback virtual channels are stored by the TDCF for a period of 2 years. In addition, quality and accounting information are generated by the TDCF for each real-time and playback virtual channel. Real-time, quick-look, and production processing are then performed by the TDCF on the basis of the APID and user requirements.

2.3.1 Real-Time Processing

As noted in the previous paragraph, the return link data stream is routed to the POCC for use in monitoring spacecraft and instrument health and safety. The data are transmitted at a rate of 2 Mbps, the rate at which they are received by Nascom II, in order to minimize the delay incurred in delivering and analyzing the data. Under this concept, the POCC is required to perform the virtual channel separation and any packet processing necessary to support health and safety monitoring.

Real-time telemetry processing performed by the TDCF is limited to packet demultiplexing and, on the basis of APID, data quality and accounting. Each real-time packet is transmitted to the TSDIS SOCC for use in science planning and instrument monitoring and coordination upon completion of the demultiplexing and quality and accounting procedures; summary session-level quality and accounting information is transmitted following the last packet comprising the real-time primary data set. Real-time primary data sets are bounded by a single APID and a single TDRS contact. The real-time data transmission rate from the TDCF to the TSDIS is assumed to be 200 kbps or less.

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*It is assumed throughout this document that Nascom II has the capability to interface directly to the WSGT or STGT at the WSC. If this assumption is incorrect, existing Nascom facilities will be used to transfer the data from the WSC to the TDCF.

2.3.2 Quick-Look Processing

Data requiring quick-look processing represent a small fraction of the data return-linked by the TRMM spacecraft. In TRMM's case no more than 3 TDRS contacts per day will be provided quick-look processing. Data are identified as requiring quick-look processing on the basis of the VCID, the APID, and the TDRS acquisition session previously specified by the user.

Quick-look processing reconstructs data sets to approximate the form of data generated by the TRMM instruments or by the TRMM spacecraft. Only playback data are used in quick-look processing; no merging of real-time data with playback data or redundant data deletion is performed. Quick-look processing demultiplexes the source packets from the designated playback virtual channel(s), sorts the packets by APID, time-orders (sequences) the packets in accordance with the packet sequence control fields in the packet primary header and annotates the data with indicators describing data quality. The source packet time code in the packet secondary header may be used to resolve any ambiguities in the packet sequence control field. The primary data set and quality indicators are then formatted as a quick-look data product for distribution to users. Quick-look primary data sets are bounded by a single VCID, single APID, and a single TDRS contact.

Quick-look data products containing science, engineering, and ancillary data are distributed to the TSDIS SDAC for science coordination. Quick-look data products containing ancillary data are distributed upon request to the FDF for refinement or repair of the orbit and attitude data or calibration of the attitude sensors. Distribution occurs within 2 hours of receipt of the last bit of data comprising the quick-look data set by the TDCF. The data transmission rate from the TDCF to the TSDIS is assumed to be 1 Mbps, although a higher rate is being discussed. The transmission rate from the TDCF to the FDF is TBD.

2.3.3 Production Processing

All real-time and playback data, including the playback data designated to receive quick-look processing, are processed to Level Zero by the TDCF. The production primary data set comprises all packets with the same APID whose time codes lie between the defined start and stop time for the data set.

In routine production processing, packets are first demultiplexed from the virtual channels. On the basis of the APID, the TDCF reconstructs data sets to exactly match the form of the data generated by the TRMM instruments and the TRMM spacecraft. Reconstruction of these data sets requires time-ordering the data, including merging real-time and playback data as necessary, removing redundant packets resulting from the merging process, and identifying gaps (missing packets) in the data in addition to the functions of data quality annotation and data set formatting described for quick-look processing in Section 2.3.2.

Production primary data sets are bound in 24-hour periods and must be delivered to the user within 24 hours after the receipt of the last bit of data defining the primary data set. The oldest data in the production data product is never more than 48 hours old. Production data products containing science, engineering and ancillary data are distributed to the TSDIS SDAC for higher-level processing (Levels 1 through 4) and to the JDRN via Nascom II facilities. Production data products containing ancillary data are distributed to the FDF for refinement and calibration, and to calculate definitive orbit and altitude. The data transmission rate from the TDCF to the TSDIS and to the JDRN is assumed to be 1 Mbps; the transmission rate from the TDCF to the FDF is TBD.

2.3.4 Return Link Data Recovery and Retransmission

The TDCF performs quality and accounting checks on the incoming return link data stream. If the quality of the data falls below specified performance criteria and is deemed unacceptable (too many uncorrectable errors, too many missing Transfer Frames, etc.), the TDCF alerts the POCC. The current data are processed by the TDCF as if the data were of acceptable quality. The POCC examines the quality of its received data and, if appropriate, requests retransmission from the NCC. If the NCC is unable to effect the retransmission, the POCC may request retransmission of the data from the TRMM spacecraft. The capacity of each of the dual on-board recorders provides the capability to recover data for a period of up to 2 orbits, or approximately 3 hours, after the initial dump. The retransmission request must be sent to the spacecraft within 1.5 hours of the initial dump to effect activation of the spare recorder and prevent loss of new data or overwriting of the requested data on the primary recorder. The data are retransmitted to the ground via the SN and are reprocessed in accordance with the real-time processing, quick-look processing, and production processing scenarios described in Sections 2.3.1, 2.3.2, and 2.3.3, respectively.

If Nascom II experiences a line outage or the TDCF experiences a catastrophic failure that otherwise impacts the TDCFs capability to receive the return link data stream, the data may be retransmitted from the WSGT or STGT line outage recorder (LOR). Data recovery from the LOR is permitted only in the event of a line outage or a catastrophic facility failure. The LOR data recovery period is limited to 5 hours after acquisition of the data by the WSGT or STGT.

On occasion, it may be necessary for a TDCF user to request retransmission of raw (captured) data or processed (production) data sets. Raw data may be recovered at any time within the 2-year storage period from the TDCF long-term data store and retransmitted to users by line replay, if an electronic interface between the user and the TDCF exists, or by magnetic tape if no electronic interface exists. The user must specify the date and time(s) of the desired TDRS acquisition session(s), as well as the appropriate VCID(s) and APID(s). Routine production data products are stored for 72 hours. Within this designated storage period, production data products may be retransmitted by line replay over the electronic interface to the user. Subsequent to the designated storage period, routine production data products must be recovered from the Level 1A data stored by the TSDIS.

2.4 FORWARD LINK HANDLING

Several types of data are forward linked to the TRMM spacecraft by TRMM ground facilities. These data types include commands to both the instruments and the TRMM spacecraft, ancillary data such as orbit and attitude parameters, and software updates.

Instrument commands are generated by TRMM instrument scientists in response to the results of analyses performed on their instrument data, targets of opportunity identified in the observation area, or instrument health and safety issues. These commands are forwarded from the TSDIS SOCC to the CMS for validation and verification and then to the POCC for uplink to the spacecraft via the SN.

Spacecraft commands are generated by the POCC in response to spacecraft health and safety issues, required orbit and attitude adjustments, or other necessary calibrations. The POCC may also issue instrument or spacecraft safing commands if required to ensure spacecraft health and safety. These commands are uplinked to the spacecraft by the POCC via the SN.

Ancillary data are generated by the FDF or the TSDIS SOCC and uplinked to the spacecraft and individual instruments via the CMS, the POCC, and the SN. These data include parameters related to spacecraft orbit and attitude, among others, and are necessary for the proper interpretation and analysis of the data generated on-board the spacecraft. The ancillary data are assigned an APID unique to ancillary data on-board the spacecraft and retransmitted to the ground with the science and engineering data for analysis via the SN.

Updates to on-board software may be generated by either the TRMM instrument scientists or the POCC. Software updates may be necessary to correct a previously-undetected error in the instrument software or to enhance instrument or spacecraft operations. Updates generated by TRMM scientists are validated and verified by the CMS; all updates are uplinked to the spacecraft via the POCC and the SN.

The POCC uplinks all forward link data generated by TRMM ground facilities to the TRMM spacecraft. The forward link data are assumed to be formatted in accordance with the Command Operation Procedure 1 (COP-1) specified in the CCSDS Telecommand Recommendation, Part 2, Data Routing Service (CCSDS 202.0-B-1, January 1987). COP-1 is a closed-loop telecommanding protocol that utilizes ("go-back-n") retransmission techniques to correct telecommand frames which were rejected by the spacecraft because of error. The uplink is accomplished by means of a secure data link from the POCC to the SN WSGT/STGT. The data are transmitted to the TDRS spacecraft and relayed to the TRMM spacecraft.

3.0 BASELINE REQUIREMENTS

The requirements contained in this section reflect an analysis of the needs of the TRMM Mission for Level Zero processing as viewed in the context of the current mission implementation concepts. Although the various documents cited in Section 1 were used as a starting point for this analysis, it was found that so much had changed since the Phase A studies that they did not serve as reliable references for the derivation of the requirements presented here. For that reason, specific documents are not cited for each requirement. It is expected that as the mission moves ahead and mission-level requirements are updated and accepted it will be necessary to provide the appropriate review and traceability for these and other element-level requirements.

Within the context of the requirements stated in this section, "and" means that all of the options listed in the requirement must be implemented; "or" means that at least one of the options listed in the requirement must be implemented.

3.1 SCOPE OF LEVEL ZERO FUNCTION WITHIN THE END-TO-END DATA SYSTEM

The TRMM Data Capture Facility will have the primary responsibility for performing all of the initial processing required for the TRMM return link data received from the SN or equivalent backup system. This initial processing encompasses the functions required to receive and capture raw data through the functions required to distribute real-time, quick-look, and production data products to users.

3.2 FUNCTIONAL REQUIREMENTS

3.2.1 System Capabilities

3.2.1.1 The TRMM Data Capture Facility (TDCF) shall provide the basic operational capabilities for reception, capture, real-time, quick-look and production processing, and distribution of TRMM return link digital data transmitted via the SN or other compatible communications networks and Nascom/Nascom II.

3.2.1.2 The TDCF shall provide the basic operational capabilities for handling and storage of all raw return link spacecraft science, engineering, and ancillary data.

3.2.1.3 The TDCF shall provide the capability to perform data quality and accounting functions for all return link data.

3.2.1.4 The TDCF shall provide the capabilities for real-time processing of the real-time virtual channel.

3.2.1.5 The TDCF shall provide the capabilities for quick-look processing of designated packet APID(s) received during a designated TDRS acquisition session.

3.2.1.6 The TDCF shall provide the capabilities for production processing of all TRMM CCSDS-packetized return link data.

3.2.1.7 The TDCF shall provide the timely distribution of real-time, quick-look and routine production data products.

3.2.1.8 The TDCF shall provide the capability to prevent the loss or interruption of services due to abnormal or unexpected data passing through or processed by the system.

3.2.2 Standards

3.2.2.1 Communications

3.2.2.1.1 The TDCF shall provide the capability to support communications standards that are compliant with CCSDS recommendations, as specified in "Packet Telemetry", CCSDS 102.0-B-2, Blue Book, dated January 1987, for the space-ground link.

3.2.2.1.2 The TDCF shall provide the capability to specifically support the subset of the communications standards identified in 3.2.2.1.1 that adhere to the GSFC Aerospace Data Systems Telemetry Standards, Version 3.3, for the space-ground link.

3.2.2.1.3 The TDCF shall support standard telecommunications protocols for ground-to-ground transport as defined by either NASA or International Standards Organization (ISO) accepted standards which, at the appropriate Open System Interconnect (OSI) layer, will permit the transparent transport of the specified CCSDS Transfer Frames and source packets along with other associated elements of information (e.g., space-to ground or ground-to-ground quality information) provided with the data.

3.2.2.1.4 The TDCF should use standard telecommunications interfaces using accepted protocols, as specified in 3.2.2.1.3, that can be supported with commercial-off-the-shelf equipment through the first three layers of the OSI Model to allow the exchange of data as required with other elements of the TRMM Ground System.

3.2.2.1.5 The TDCF shall negotiate and execute Interface Control Documents (ICDs) with each interfacing TRMM Ground System element to specifically define each supported interface.

3.2.2.1.6 The TDCF shall adopt standards, wherever practical, that are consistent with the Government Open System Interconnect Profile (GOSIP).

3.2.2.2 Data Standards

3.2.2.2.1 The TDCF shall adopt standards for data formats and data units consistent with those CCSDS-compatible conventions adopted by the TRMM Project.

3.2.3 External Interfaces

3.2.3.1 Space Network

3.2.3.1.1 The TDCF shall interface with the Space Network (SN) White Sands Ground Terminal (WSGT) and the Second TDRSS Ground Terminal (STGT) located at the White Sands Complex (WSC), either directly or via Nascom/Nascom II, for the receipt of return link data.

3.2.3.1.2 The TDCF shall interface with the SN Network Control Center (NCC) for the receipt of TDRS schedules.

3.2.3.2 Nascom

3.2.3.2.1 The TDCF shall be capable of interfacing with the NASA Communications (Nascom) Network or the augmented Nascom (Nascom II) Network for the receipt of return link data.

3.2.3.2.2 The TDCF shall be capable of interfacing with Nascom or Nascom II for the transmission of production data products to the designated Japanese data reception node.

3.2.3.2.3 The TDCF shall interface with the Network Management Control Center (NMCC) as required to coordinate use of Nascom II facilities and resources.

3.2.3.3 Payload Operations Control Center

3.2.3.3.1 The TDCF shall interface with the Payload Operations Control Center (POCC) located at GSFC for the transmission of selected portions of the recorded unprocessed return link data, selected quick-look data products, and selected production data products, as required, and to request retransmission of return link data when necessary.

3.2.3.3.2 The TDCF shall deliver selected portions of the recorded unprocessed data to the POCC as required.

3.2.3.3.3 The TDCF shall transmit selected quick-look data products to the POCC as required for emergency situations.

3.2.3.3.4 The TDCF shall transmit selected production data products to the POCC for system analysis as required.

3.2.3.4 TRMM Science Data and Information System

3.2.3.4.1 The TDCF shall interface with the TRMM Science Data and Information System (TSDIS) at GSFC for the transmission of real-time, quick-look, and production data products.

3.2.3.4.2 The TDCF shall provide the capability to deliver real-time data products to the TSDIS through a primary electronic interface.

3.2.3.4.3 The TDCF shall provide the capability to deliver quick-look and production data products to the TSDIS through both a normal electronic interface and an appropriate electronic or non-electronic backup interface.

3.2.3.4.4 The TDCF shall deliver real-time, quick-look and production data products to the TSDIS in the form of CCSDS source packets comprising primary data sets and associated quality and accounting information.

3.2.3.4.5 Science Data Analysis Center

3.2.3.4.5.1 The TDCF shall interface with the TSDIS Science Data Analysis Center (SDAC) for the transmission of production data products and selected quick-look data sets.

3.2.3.4.5.2 The TDCF shall transmit selected quick-look data products to the TSDIS SDAC as required.

3.2.3.4.5.3 The TDCF shall transmit production data products to the TSDIS SDAC.

3.2.3.4.6 Science Operations Control Center

3.2.3.4.6.1 The TDCF shall interface with the TSDIS Science Operations Control Center (SOCC) for the transmission of real-time data products.

3.2.3.4.6.2 The TDCF shall transmit real-time data products to the SOCC as required.

3.2.3.5 Flight Dynamics Facility

3.2.3.5.1 The TDCF shall interface with the Flight Dynamics Facility (FDF) for the transmission of spacecraft ancillary data products containing such information as attitude sensor data and any appropriate orbit/position data developed through on-board processing.

3.2.3.5.2 The TDCF shall transmit ancillary data products to the FDF in the form of CCSDS source packets comprising primary data sets and associated data quality and accounting information.

3.2.3.5.3 The TDCF shall transmit ancillary data products to the FDF as required.

3.2.3.6 Japanese Data Reception Node

3.2.3.6.1 The TDCF shall interface with a designated Japanese data reception node (JDRN) for the transmission of production data products.

3.2.3.6.2 The TDCF shall provide the capability to transmit production data products to the designated JDRN via Nascom, Nascom II, or other appropriate electronic or non-electronic secondary interfaces.

3.2.3.6.3 The TDCF shall transmit production data products to the JDRN in the form of CCSDS source packets comprising primary data sets and associated quality and accounting information.

3.2.3.6.4 The TDCF shall transmit production data sets to the designated JDRN using a protocol that supports the transparent delivery of the data products.

3.2.3.7 Deep Space Network

3.2.3.7.1 The TDCF shall interface with the Deep Space Network (DSN) via Nascom or Nascom II for the receipt of return link data in the event of a catastrophic failure of the SN.

3.2.4 Data Handling and Data Processing

3.2.4.1 Reception and Capture

3.2.4.1.1 The TDCF shall provide the capability to receive and capture all TRMM return link data (except fill data, which may be excluded from capture at the option of the TDCF) transmitted through the SN either directly or via Nascom or Nascom II.

3.2.4.1.2 The TDCF shall provide the capability to receive and capture all TRMM return link data (except fill data, which may be excluded from capture at the option of the TDCF) transmitted via the Deep Space Network and Nascom or Nascom II.

3.2.4.1.3 The TDCF shall provide data capture and storage for all return link raw data.

3.2.4.1.4 The TDCF shall provide the capability to synchronize on CCSDS Transfer Frames.

3.2.4.1.5 The TDCF shall provide the capability to perform Reed-Solomon (R-S) error decoding and correction.

3.2.4.1.6 The TDCF shall provide the capability to separate the return link physical channel into virtual channels.

3.2.4.1.7 The TDCF shall provide the capability to interpret the Transfer Frame header information in a manner consistent with CCSDS standards.

3.2.4.1.8 The TDCF shall provide the capability to discard fill Transfer Frames from return link data.

3.2.4.1.9 The TDCF shall provide the capability to demultiplex CCSDS packets from Transfer Frames.

3.2.4.1.10 The TDCF shall provide the capability to aggregate non-identifiable data (e.g., packets having unreadable headers) into a separate permanent data set.

3.2.4.1.11 The TDCF shall provide the capability to monitor, store, and report the quality of return link virtual channels. Characteristics monitored and stored shall include, but may not be limited to: total number of Transfer Frames received, number of Transfer Frames with errors, number of detected R-S errors, number of detected R-S errors corrected, number of missing Transfer Frames, and number of times Transfer Frame sync was lost.

3.2.4.1.12 The TDCF shall provide the capability to initiate appropriate and timely retransmission or data recovery procedures in the event that the data quality fails to meet predefined criteria.

3.2.4.2 Production Processing

3.2.4.2.1 The TDCF shall provide the capability to routinely process all TRMM data packets including instrument science, spacecraft and instrument engineering and health and safety data, and ancillary data.

3.2.4.2.2 The TDCF shall provide the capability to construct primary data sets, each of which contains packets identified by a single Application Process Identifier (APID) and a source time code between a predefined start and stop time.

3.2.4.2.3 The TDCF shall provide the capability to merge real-time data with playback data having the same APID in the processing of production data sets.

3.2.4.2.4 The TDCF shall provide the capability to order data packets received during a single TDRS acquisition session using the source packet sequence count contained in the primary packet header.

3.2.4.2.5 The TDCF shall provide the capability to use the source packet time code contained in the secondary packet header to resolve any ambiguities in the source packet sequence count.

3.2.4.2.6 The TDCF shall provide the capability to delete redundant data packets as necessary.

3.2.4.2.7 The TDCF shall calculate the Cyclic Redundancy Code (CRC) for each packet and shall compare the calculated value to the return-linked CRC remainder when provided with the packet.

3.2.4.2.8 The TDCF shall provide the capability to identify and flag, according to specified formats and reports, missing data within each primary data set, or between successive ordered data sets, using information from the packet headers.

3.2.4.2.9 The TDCF shall provide the capability to construct predefined data products reflecting mission needs from data contained in one or more specified APIDs by grouping the specified processed primary data sets into a single data file.

3.2.4.2.10 The TDCF shall provide the capability to generate and include data quality and accounting information with the production data sets forwarded to users.

3.2.4.2.11 The TDCF shall provide the capability to collect identifiable "orphan" packets which have become separated from and were not included in a previously-delivered data product, and combine them into complete blocks of data for transmission to the recipients of the original data product upon request.

3.2.4.2.12 The TDCF shall provide the capability to temporarily store all production data products for a designated period to permit a limited retransmission capability for all scheduled transmissions to users.

3.2.4.2.13 The TDCF shall production process Precipitation Radar data, along with other instrument, engineering and ancillary data packets as required, for delivery to the designated JDRN.

3.2.4.3 Real-Time Processing

3.2.4.3.1 The TDCF shall provide the capability to identify data requiring real-time processing on the basis of the virtual channel identifier (VCID) and APID.

3.2.4.3.2 The TDCF shall provide the capability to perform real-time processing and distribution of real-time data for up to 16 TDRS acquisition sessions per day on an exceptional or emergency basis. Regularly scheduled real-time processing shall be limited to a maximum number of TDRS acquisition sessions per day.

3.2.4.4 Quick-Look Processing

3.2.4.4.1 The TDCF shall provide the capability to identify data requiring quick-look processing on the basis of the VCID and APID.

3.2.4.4.2 The TDCF shall provide the capability to perform quick-look processing and produce primary data sets using appropriately identified playback data. Quick-look processing of playback data shall be available for a limited number of TDRS acquisition sessions per day on either a routine scheduled basis or on an emergency quick-response basis.

3.2.4.5 Data Distribution

3.2.4.5.1 The TDCF shall provide the capability to transmit TRMM data products to their designated destination(s) without alteration of the data contents.

3.2.4.5.2 The TDCF shall provide the capability to group primary data sets and their associated quality and accounting information into predefined data products using prescribed header information and to transmit those data products to designated users.

3.2.4.5.3 The TDCF shall provide the capability to distribute real-time data packets to users immediately upon completion of real-time processing using primary or backup electronic distribution methods.

3.2.4.5.4 The TDCF shall provide the capability to transmit quick-look and production data products containing quality and accounting information on a data set basis.

3.2.4.5.5 The TDCF shall provide the capability to electronically distribute in an expedited mode quick-look data products obtained from processing selected playback data.

3.2.4.5.6 The TDCF shall provide the capability to utilize a backup distribution channel for quick-look data products.

3.2.4.5.7 The TDCF shall provide the capability to distribute production data products by primary electronic or non-electronic methods as required for timely utilization by each user.

3.2.4.5.8 The TDCF shall provide an appropriately commensurate backup mode for each of the primary electronic or non-electronic distribution methods.

3.2.4.5.9 The TDCF shall provide the capability to support the concurrent distribution of data products to the TSDIS SDAC and the JDRN.

3.2.4.5.10 The TDCF shall support the electronic distribution of appropriate production data products including, but not limited to, Precipitation Radar and associated engineering and ancillary data to the JDRN.

3.2.4.5.11 The TDCF shall provide the capability to retransmit production data products upon user request in the event that initial transmissions to a user are unsuccessful and the retransmission requests are made within a designated period after the initial transmission attempt.

3.3 SYSTEM PERFORMANCE REQUIREMENTS

3.3.1 Throughput

3.3.1.1 The TDCF shall provide the capability to receive return link data at a peak aggregate rate of up to 2.4 Megabits per second (Mbps).

3.3.1.2 The TDCF shall provide the capability to receive up to 8 concurrent return link virtual channels.

3.3.1.3 The TDCF shall provide the capability to receive any single return link virtual channel having a maximum rate of up to 2 Mbps.

3.3.1.4 The TDCF shall provide the capability to throughput data at an average rate of 200 kilobits per second (kbps) (TBR).

3.3.1.5 The TDCF shall provide sufficient capacity to process an average throughput rate of 240 kbps (TBR), which includes a 20% contingency, for periods of up to 24 hours.

3.3.1.6 The TDCF shall provide the capability to transmit quick-look and production data products to the POCC at a minimum aggregate rate of 1 Mbps (TBR).

3.3.1.7 The TDCF shall provide the capability to transmit quick-look and production data products to the TSDIS SDAC at a minimum aggregate rate of 1 Mbps (TBR). (Note: A rate of 5 Mbps is being requested and will be reviewed for this interface.)

3.3.1.8 The TDCF shall provide the capability to transmit real-time data products to the TSDIS SOCC at a minimum aggregate rate of 177 kbps (TBR).

3.3.1.9 The TDCF shall provide the capability to transmit quick-look and production spacecraft ancillary data products to the FDF at a minimum aggregate rate of TBD.

3.3.1.10 The TDCF shall provide the capability to transmit production data products to the designated JDRN at a minimum aggregate rate of 1 Mbps (TBR).

3.3.1.11 The TDCF shall provide the capability to concurrently capture all return link data and process real-time data for up to 16 acquisition sessions per day.

3.3.2 Real-Time, Quick-Look, and Production Processing

3.3.2.1 The TDCF shall provide the capability to perform real-time processing, including transmission to a user's communication link, of received and reassembled packets for a designated APID within 1 (TBR) second of receipt of the data. The TDCF shall generate and report summary quality information for the entire TDRS acquisition session.

3.3.2.2 The TDCF shall provide the capability to perform real-time processing for up to 16 TDRS acquisition sessions per day as required for a maximum period of 3 days. Regularly-scheduled real-time processing shall be limited to a maximum of 3 TDRS acquisition sessions per day.

3.3.2.3 The TDCF shall provide the capability to process and electronically deliver quick-look data products to users within 2 hours (TBR) of reception of the last bit of data included in the defined quick-look primary data set.

3.3.2.4 The TDCF shall provide the capacity to perform quick-look processing for up to 3 TDRS acquisition sessions per day.

3.3.2.5 The TDCF shall provide the capability to process and electronically deliver routine production data products to users within 24 hours of reception of the last bit of data comprising the defined primary data set.

3.3.2.6 The TDCF shall provide the capability to process and deliver routine production data products via non-electronic media within 36 hours of reception of the last bit of data comprising the defined primary data set.

3.3.3 Storage Capacity

3.3.3.1 The TDCF shall provide the capability to capture and store a daily volume of raw return link data of at least 2.2 Gigabytes (TBR).

3.3.3.2 The TDCF shall provide data storage for unprocessed return link data for 2 years.

3.3.3.3 The TDCF shall provide the capability to transmit raw (unprocessed) data upon request via electronic or non-electronic methods as expeditiously as the production schedule permits.

3.3.3.4 The TDCF shall provide the capability to retain production data products for a maximum of 72 hours (TBR) in order to confirm delivery of the data to users.

3.3.3.5 The TDCF shall provide the capability to retransmit production data products via electronic distribution methods within 1 hour of receipt of a retransmission request received within the 72-hour storage period.

3.4 OPERATIONAL REQUIREMENTS

3.4.1 Reliability

3.4.1.1 The TDCF shall provide a Mean Time Between Failures (MTBF) in excess of 1000 (TBR) hours.

3.4.2 Maintainability

3.4.2.1 The TDCF shall meet a Mean Time To Restore (MTTR) of not greater than 1 (TBR) hour.

3.4.2.2 The TDCF shall have the capability to transfer from the primary to a secondary mode of data distribution for transmitting routine production data products to the TSDIS and the designated JDRN within 24 hours of a primary distribution system failure.

3.4.2.3 The TDCF shall have the capability to transfer from a primary to a secondary mode of data distribution for transmitting real-time and quick-look data products to the TSDIS and the POCC within 1 hour of a primary distribution system failure.

3.4.3 Availability

3.4.3.1 The TDCF shall provide the capability to support operations 24 hours a day, 7 days a week on a continuous basis.

3.4.3.2 The TDCF shall provide an availability in excess of 0.9990 (TBR).

4.0 ASSUMPTIONS

This section highlights the assumptions that have been made with regard to the mission requirements and/or currently planned mission implementation that will have some impact upon the TDCF. Since the Project is still in a formative stage and the final needs of the Project have not been completely codified, this section reflects our best understanding of the current mission requirements as of September 1990. These assumptions generally serve as the bases for the Level Zero processing requirements identified in Section 3. If future needs of the Project evolve in such a way as to make these assumptions inappropriate it will be necessary to review the related requirements and update them accordingly. It is also quite possible that implementation characteristics and resulting design conclusions will be affected by any changes in these assumptions.

The assumptions presented in this section were developed to facilitate the design of the TDCF architectures and the definition of appropriate operations scenarios. These assumptions are not intended to impose requirements on the TRMM spacecraft or supporting systems such as the SN, Nascom, Pacor or CDOS. If the assumptions made are determined to be inappropriate to the mission or supporting systems, the related TDCF requirements, architectures and operations scenarios should be updated to reflect any necessary changes to the assumptions.

4.1 SCHEDULE

4.1.1 The TRMM spacecraft will be launched in August 1997. It should be noted that an earlier date is being reserved by the Japanese launch facilities. If this earlier date is accepted it will significantly affect the recommendations of this study.

4.1.2 The first month after launch will be utilized for system checkout.

4.1.3 The operational life shall be 3 years.

4.1.4 System-level testing of the entire TRMM Ground System will begin no later than June 1996.

4.1.5 TRMM Ground System elements, including the TDCF, will be functional and will have completed essential element testing by June 1996 in order to support system-level testing.

4.2 DATA RATES

The following is a summary of the baseline data rates expected to be generated on-board the spacecraft and included in the return link as well as the expected forward link data rates to the spacecraft.

4.2.1 Science Instruments

AVHRR	50	kbps
SSM/I	4.3	kbps
ESMR	1	kbps
Precipitation Radar	85	kbps
Total Science Rate	140.3	kbps
Maximum Science Rate	169.3	kbps

It should be noted that over the past several months the instrument data rate for the AVHRR has been reduced by about 30 kbps to its current value of 50 kbps. There is also some discussion regarding the best estimate of the average rate for the Precipitation Radar. In addition, discussions and studies are underway that may result in the change-out of several of the instruments, replacing them with a single instrument and resulting in a net increase in the current estimate of the data rate by about 20 kbps. To handle this uncertainty in the estimate of the data rate, the TRMM Project is assuming a cumulative instrument data rate of 169.3 kbps in its initial design studies. This number is being considered as a not-to-exceed value for spacecraft design and presumably will continue to serve that purpose until all instrument selections are finalized and revised best estimates are accepted by the Project Scientist and the Project. For purposes of this study we will use the same approach. Since the currently estimated data rates appear to be smaller than the baseline, however, it is assumed that the overhead associated with all packet level artifacts (primary and secondary headers and any error control trailers) is a conservative 3.3% of the total input science stream. With these assumptions the following values are used in this study:

4.2.2	Maximum Allowable Science Data Rate (assumed to include all packet-level artifacts)	175	kbps
4.2.2.1	Present Science Data Rate Estimate (assumed to include all packet-level artifacts)	145	kbps
4.2.3	Spacecraft/Instrument Engineering/ Health and Safety	2	kbps
4.2.4	Total Packet-Level Data Rate (generated on the spacecraft)	177	kbps
4.2.5	Maximum Frame-Level Overhead	23	kbps
4.2.6	Maximum On-Board Data Generation	200	kbps
4.2.7	Nominal Return Link	2	Mbps
4.2.8	Emergency Return Link	2	kbps
4.2.9	Nominal Forward Link	1	kbps
4.2.10	Maximum Forward Link	2	kbps

4.3 SPACECRAFT DATA FORMAT

4.3.1 The TRMM spacecraft will utilize packet telemetry communications standards that are compliant with CCSDS recommendations, as specified in "Packet Telemetry", CCSDS 102.0-B-2, Blue Book, dated January 1987, for the space-ground link.

4.3.2 Reed-Solomon error decoding and correction will be supported for the return link data.

4.3.3 No Version 2 packet telemetry segmentation or use of segmentation flags, as defined in CCSDS 102.0-B-2, will be supported.

4.3.4 A small number of APIDs (of the order of 10 or less) will be used to identify return link packets.

4.3.5 The spacecraft will require only 3 virtual channels to support the transport of real-time, playback, and fill data. A maximum of 8 virtual channels will be permitted (1 real-time, 1 fill, and up to 6 playback (TBR)).

4.4 ANCILLARY DATA HANDLING

4.4.1 The orbital positions propagated on-board the spacecraft and transmitted down with the instrument data will be of sufficient accuracy to be used directly by the TSDIS without correction by FDF.

4.4.2 Any attitude sensor data that requires additional processing for use in science data processing and analysis will be formatted into separate packets and assigned appropriate an APID to permit routing to the FDF or the TSDIS as appropriate.

4.4.3 Spacecraft engineering data required for science data processing and analysis will be formatted into CCSDS source packets.

4.4.4 Instrument engineering data required for science data processing and analysis will be combined with the instrument science data and formatted into packets having an APID unique to the instrument that generated the data.

4.4.5 All spacecraft and/or instrument data generated during a TDRS contact that are required for operational control will be formatted into packets and assigned to the real-time virtual channel which the POCC will be capable of processing independently.

4.5 ON-BOARD DATA RECORDING

4.5.1 The spacecraft will utilize two solid state recorders, each capable of storing more than one orbit's data.

4.5.2 All data, including any data broadcast as real-time data, will be stored on the flight recorders and broadcast as playback data.

4.6 RETURN LINK STRATEGY

4.6.1 The SN (TDRSS and WSC) will provide the space-to-ground link to support the transmission of all return link data from the TRMM spacecraft to the ground.

4.6.2 Spacecraft contacts will occur 16 times per day for a maximum of 10 minutes each contact.

4.6.3 All return link data (real-time and playback) will be transmitted on a single physical channel, specifically the TDRS S-band Single Access (SSA) Quadrature (Q) channel.

4.6.4 Nominally, all return link data will be transmitted to the TDRS using a directional dish on the TRMM spacecraft.

4.6.5 In the event of an emergency, instrument and spacecraft engineering and health and safety data will be transmitted to the TDRS using the omni-directional antenna on the TRMM spacecraft.

4.6.6 In the event of a failure in the SN, instrument and spacecraft engineering and health and safety data will be transmitted to the DSN using the omni-directional antenna on the TRMM spacecraft.

4.6.7 Real-Time data will be assigned a unique VCID and will be interleaved with playback data during TDRS contacts.

4.6.8 Playback data will be assigned one or more unique VCIDs.

4.6.9 Playback data will be transmitted on the return link in forward time order, i.e., the order in which the data were recorded on-board the spacecraft. There is no requirement to reverse the order of playback data on the ground.

4.6.10 There will be a unique virtual channel designation for fill data required to maintain the 2 Mbps return link rate.

4.7 REAL-TIME PROCESSING

4.7.1 Real-Time processing will be limited to no more than 3 scheduled acquisition sessions per day to support science instrument testing, calibration, and field experiments through the TSDIS.

4.7.2 There is no requirement to deliver any real-time data to the Japanese users or to any users other than the TSDIS as noted in 4.7.1.

4.8 JAPANESE USERS

4.8.1 Japanese users will be provided with production data products on a standard delivery schedule with electronic delivery to a JDRN on the west coast of the United States.

4.8.2 Nascom II will provide an interface between the TDCF and the JDRN to support the required delivery of production data products.

4.9 TDRSS BACKUP APPROACH

4.9.1 In the 1997+ time frame, there will be sufficient internal backup within SN such that additional backup will be a low priority.

4.9.2 If required, the DSN will provide the necessary backup to the SN. The TRMM Ground System will be capable of interfacing with the DSN.

4.10 DATA STORAGE

4.10.1 The mission processing requirement that imposes a 2-year storage period for maintaining a backup copy of all raw data is considered valid. This requirement is under review in light of current policy directions.

4.10.2 There is no requirement on the TDCF to archive or maintain any long-term storage of production products. The TSDIS will archive Level 1A products, from which Level Zero products can be recovered.

4.11 DATA DISTRIBUTION

4.11.1 The Nascom II Network will provide all electronic communications links required to transport unprocessed data and real-time, quick-look, and production data products to their destinations.

4.11.2 The Nascom II Network will adopt a protocol identical to the 4800-bit Nascom block to allow the continued support of missions and facilities currently using the existing Nascom network.

4.11.3 The Nascom II Network will have the capability to interface directly to the WSGT and STGT at the WSC to support data transport to the TDCF. If this assumption is incorrect, existing Nascom facilities will be used.

4.12 TDCF WORK LOAD ESTIMATES

4.12.1	Ingest Rate:	Peak	2.0	Mbps (16 contacts/day, 10 minutes/contact)
		Average	196.7	kbps (Packet level, Playback+Real-Time)
			222.2	kbps (Frame level, Playback+Real-Time)
4.12.2	Processing:	Production	1,912	MB per day (All 16 contacts per day, Playback data - additional Real-Time data if necessary)
			177	kbps daily average throughput rate
		Quick-Look	359	MB per day (3 of 16 contacts/day, Playback data, 120 MB/contact)
			33.2	kbps daily average throughput rate
		Real-Time	213	MB per day (16 contacts/day, Real-Time data, 13.3 MB/contact)
			19.7	kbps daily average throughput rate
4.12.3	Distribution:	Production	3.8	GB per day (1.9 GB to GSFC(local), 1.9 GB to JDRN)
		Quick-Look	359	MB per day (120 MB to GSFC - 3 times/day) (Small amounts to other users occasionally.)
		Real-Time	213.	MB per day (13.3 MB to GSFC - 16 times/day)
		Tapes/Disks	----	It is assumed that no regularly scheduled data will be sent by tape or disk. Only unscheduled occasional event data will be sent using this mode.

A graphic summary of the work load estimate is presented in Figure 4-1.

TDCF WORK LOAD ESTIMATES	INGEST RATE			PROCESSING				DISTRIBUTION		STORAGE	
	PEAK (kbps)	CONTACT PERIOD (min)	AVERAGE (kbps)	DAILY VOLUME (MB)	AVERAGE THROUGHPUT (kbps)	VOLUME PER ACQUISITION (MB)	NUMBER OF ACQUISITIONS	DAILY VOLUME (MB)	DESTINATION	DAILY VOLUME (MB)	DURATION
RAW DATA	2000	10								2,400	2 Years
FRAME LEVEL			222.2								
PACKET LEVEL			196.7								
PRODUCTION PROCESSING				1,912	177	120	16	1,912	JDRN	1,912	72 hours
								50	FDF		
								1,912	TSDIS SDAC		
QUICK- LOOK PROCESSING				359	33.2	120	3	359	TSDIS SDAC	NOT STORED	
REAL-TIME PROCESSING				213	19.7	13.3	16	213	TSDIS SOCC	NOT STORED	

Figure 4-1 Summary of TDCF Work Load Estimate

4.13 CDOS

4.13.1 All functions related to data handling, from data receipt and capture through the processing and distribution of real-time, quick-look, and production data products, will be performed by the CDOS Data Interface Facility (DIF) located at the White Sands Complex (WSC).

4.13.2 The CDOS data archive will have sufficient capacity to satisfy the TRMM requirement to store raw data for a period of 2 years.

4.13.3 The CDOS data archive will accommodate the short-term storage of production data products necessary to permit limited retransmission to users.

4.14 PACOR

4.14.1 The Pacor will be an available support option for TRMM in the 1996-2000 time frame.

4.14.2 Current institutional planning calls for the Pacor to be upgraded to meet the requirements of TRMM.

4.14.3 The basic fault-tolerant design of the Pacor, with redundant processors each having 0.98 availability and the concurrent 0.9999 availability of the GBRS, will permit the Pacor implementation to meet the RMA requirements of TRMM with no additional changes beyond those required to meet the performance requirements.

4.15 FORWARD LINK DATA

4.15.1 Forward link data will be formatted in accordance with the CCSDS COP-1 protocol specified in "Telecommand, Part 2: Data Routing Service, Architectural Specification", Recommendation CCSDS 202.0-B-1, Blue Book, January 1987 or later issue.

5.0 EXTERNAL INTERFACES

This section provides a discussion of the interfaces between the TDCF and external facilities and communication networks. The interfaces and interface descriptions presented are based on the generic TRMM end-to-end data system concept illustrated in Figure 1-1. Both data and control interfaces are addressed in this section. Any differences in the physical interfaces or in the data types, formats, or data rates flowing across these generic interfaces that are specific to the Pacor and CDOS TDCF implementations are discussed in the appropriate system configuration description for each implementation in Section 6.

Figure 5-1 is a modified N-squared diagram that illustrates the interfaces between the TDCF and external facilities and communication networks. Interfaces among the external facilities and networks are beyond the scope of this document and are not shown. Tables 5-1A and 5-1B summarize, to the extent they are known, the characteristics of the data flowing across each interface shown in Figure 5-1. Table 5-1A summarizes the characteristics of the data flows from the TDCF to the other elements; Table 5-1B summarizes the characteristics of the data flows from the other elements to the TDCF. These characteristics include data type, format, rate, and frequency of transmission.

The TDCF will support interfaces with SN, Nascom, POCC, TSDIS, FDF, JDRN, and DSN. These interfaces are discussed in the subsections that follow.

5.1 SPACE NETWORK INTERFACES

The SN interfaces with the TDCF are provided by the WSGT, STGT, and the NCC. The WSGT or STGT receives the TRMM return link data stream from the TDRS and transmits the data to the TDCF either directly or via the Nascom Service Gateway (NSGW) located at the WSC. The return link data stream is comprised of CCSDS Version 1 Transfer Frames, and is transmitted at a rate of 2 Mbps once per TDRS contact (once per orbit).

The NCC performs network management functions for the SN, including planning and scheduling and data recovery and retransmission. Coordination of the TDRS acquisition sessions to support the TRMM is accomplished by the POCC and the NCC. The NCC transmits the active schedule to the TDCF on a daily basis, 16 hours prior to the first event on the schedule, to facilitate any reconfigurations necessary to receive and process the TRMM return link data stream. Any changes to the schedule subsequent to delivery of the active schedule to the TDCF are delivered as required. Scheduling messages are transmitted over a GSFC LAN using a TBD protocol. The data unit formats are defined in STDN No. 101.2, Revision 6, NCC Schedule Messages 94 or 99. The assumed data rate is TBD; schedules are updated daily or as required.

Data recovery and retransmission functions are coordinated by the NCC as requested by the POCC (assuming a GSFC TDCF location). The TDCF performs quality and accounting checks of the return link data stream received over the Nascom II Network. If these metrics do not meet predefined criteria, the TDCF sends an alert to the POCC for the data in question. If appropriate, the POCC sends a retransmission request to the NCC. The NCC initiates the requested retransmission from the appropriate source or notifies the POCC that the requested retransmission is not possible. The POCC then has the option of requesting retransmission of the data from the spacecraft. The retransmission message formats are TBD. The frequency of the retransmission message is as required.

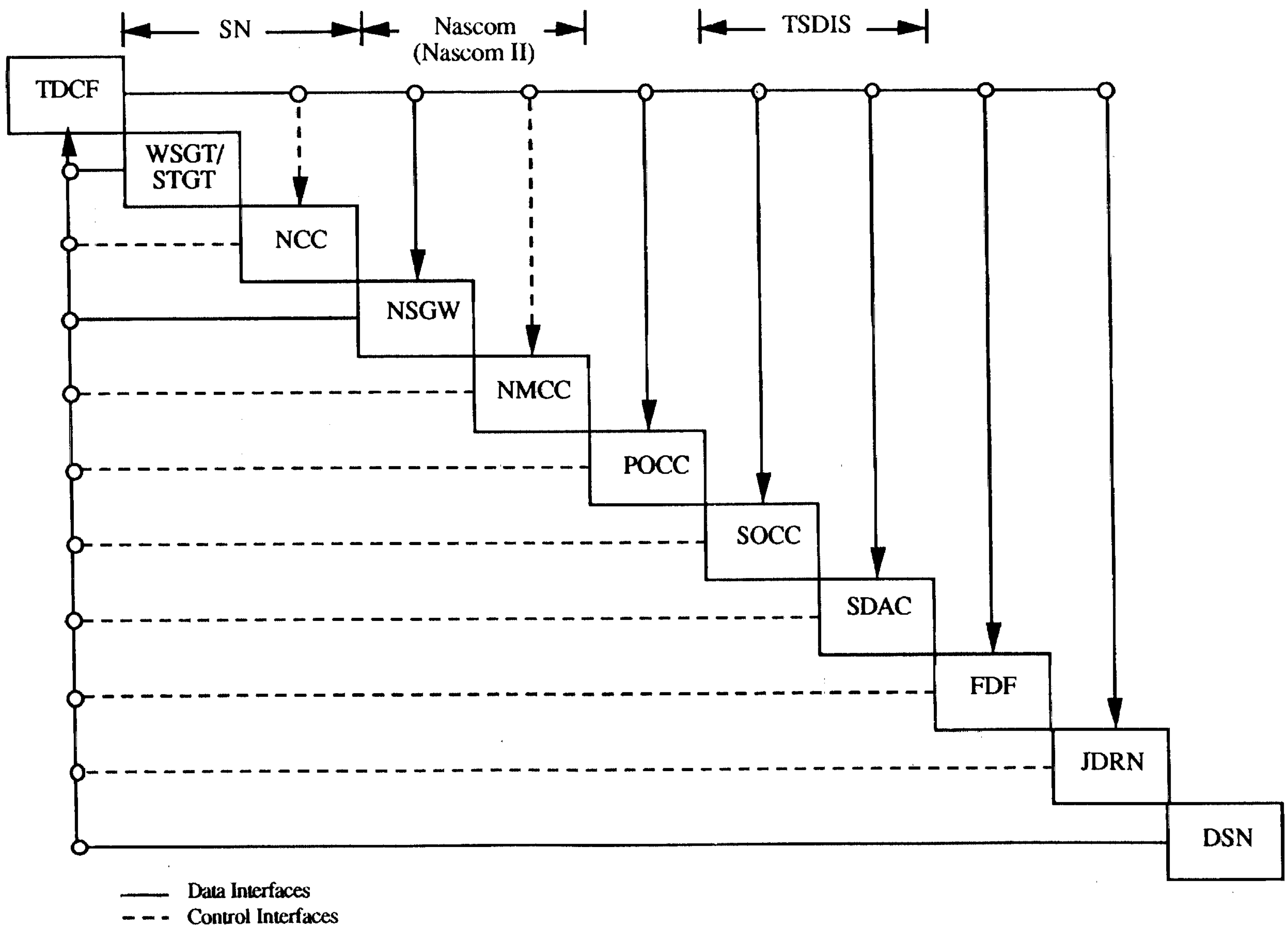

Figure 5-1. TDCF External Interfaces

Table 5-1A. Characteristics of Data Flows from the TDCF to Other Elements

From	To	Data Type	Format	Data Rate	Frequency
TDCF	NCC	Post-Event Rpts LOR Retx Req*	TBD TBD*	TBD TBD*	Per Orbit As Required*
TDCF	NSGW	Production RT* QL*	Files of CCSDS Packets	1.0 Mbps 200 kbps* 1.0 Mbps*	Daily Schedule* Schedule*
TDCF	NMCC	Resource Msgs	TBD	TBD	As Required
TDCF	POCC	Q/A Alerts Raw Data** QL** Production**	TBD Com Blocks Files of CCSDS Packets	TBD Mag Tape** 1.0 Mbps** 1.0 Mbps**	As Required Request** Schedule** Daily**
TDCF	SOCC (TSDIS)	RT	Files of CCSDS Packets	200 kbps	Per Orbit
TDCF	SDAC (TSDIS)	QL Production	CCSDS Packets	1.0 Mbps 1.0 Mbps	Schedule Daily
TDCF	FDF	QL** Production (Ancillary)	Files of CCSDS Packets	TBD	Schedule** Daily
TDCF	JDRN	Production	Files of CCSDS Packets	1.0 Mbps	Daily

*Implementation dependent.
**If requested by destination.

Table 5-1B. Characteristics of Data Flows from Other Elements to the TDCF

From	To	Data Type	Format	Data Rate	Frequency
DSN	TDCF	Return Link Data (via Nascom II)	CCSDS Transfer Frames	2.0 Mbps	Per Orbit
JDRN	TDCF	Retx Req (Prod)	TBD	TBD	As Required
FDF	TDCF	Retx Req (QL**, Prod)	TBD	TBD	As Required
SDAC (TSDIS)	TDCF	Retx Req (QL, Prod)	TBD	TBD	As Required
SOCC (TSDIS)	TDCF	Retx Req (RT)	TBD	TBD	As Required
POCC	TDCF	Tx Req (Raw**, QL**, Prod**) Retx Req	TBD TBD	TBD TBD	As Required As Required
NMCC	TDCF	Resource Msgs	TBD	TBD	TBD
NSGW	TDCF	Return Link Data* (from SN or iaw Retx Req)	CCSDS Transfer Frames	2 Mbps	Per Orbit or Retx Req
NCC	TDCF	TDRS Schedule	NCC Schedule Msg 94 or 99	TBD	Daily or As Required
WSGT/ STGT	TDCF	Return Link Data	CCSDS Transfer Frames	2 Mbps	Per Orbit

*Implementation dependent.
**If requested by destination.

The TDCF sends post-event reports to the NCC following each TDRS acquisition session to provide data reception confirmation and to summarize the data transmission quality. In the event of a line outage or catastrophic TDCF failure, the TDCF may request retransmission of any data lost during the outage or failure from the WSGT or STGT LOR. LOR retransmission requests are coordinated with the NCC.

5.2 NASCOM INTERFACES

The Nascom interfaces with the TDCF are provided by the appropriate NSGWs and the NMCC at GSFC. The NSGWs and NMCC are elements of the Nascom II Network.*

If the TDCF is located at WSC, the return link data stream of CCSDS Version 1 Transfer Frames is transmitted directly from the WSGT or STGT to the TDCF at a rate of 2 Mbps. The return link data are transmitted once every 90 minutes (once per TDRS acquisition session/TRMM orbit). Subsequent to completion of appropriate processing by the TDCF, real-time, quick-look, and production data products are distributed to users via the WSC NSGW. The data products are formatted as files of CCSDS packets. Real-time packets and associated summary quality and accounting information are transmitted at a rate of 200 kbps; quick-look and production data products are transmitted at a rate of 1 Mbps.

If the TDCF is located at GSFC, the return link data stream is transmitted to the TDCF at a rate of 2 Mbps via the WSC NSGW using a TBD network protocol. The GSFC NSGW receives the return link data and removes the network protocol artifacts to yield a stream of CCSDS Version 1 Transfer Frames. This data stream is then transferred to the TDCF in the Version 1 Transfer Frame format at the 2 Mbps rate. Return link data are transmitted once every 90 minutes (once per TDRS contact/TRMM orbit). Subsequent to completion of appropriate processing, the TDCF transmits production data products to the GSFC NSGW for transmission to the JDRN on the west coast of the United States. The production data products are formatted as files of CCSDS packets and are transmitted at a rate of 1 Mbps once per day.

The NMCC performs the network management functions for the Nascom II Network, including coordinating resources for data transmission. The data transmission function is accomplished by the WSC and GSFC NSGWs as described in the preceding paragraphs. Coordination of Nascom II resources is accomplished by the TDCF and the NMCC.

5.3 POCC INTERFACE

The POCC interface with the TDCF is accomplished via Nascom II and a GSFC LAN if the TDCF is located at WSC, or via a GSFC LAN if the TDCF is located at GSFC. The POCC contains the Flight Operations Team (FOT) that is responsible for maintaining the health and safety of the TRMM spacecraft and instruments, for spacecraft operations, and for performing trend analyses.

The POCC receives data quality and accounting alerts from the TDCF if the quality of the data received by the TDCF falls below specified criteria. The POCC evaluates the quality of the return link data stream received at the POCC and determines if data retransmission from the NCC or from the spacecraft is required. The format of the data quality and accounting alert is TBD, and may take the form of a voice communication.

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*Reference Section 4.11.

The POCC also receives, upon request, raw (unprocessed) data and quick-look and production data products. The raw data are used to analyze discrepancies or trends in successive real-time data sets or to perform more in-depth analyses of a problem on-board the spacecraft, and are transferred on magnetic tape to the POCC as communication blocks containing CCSDS Version 1 Transfer Frames. Quick-look data products may be used to augment the real-time data processed by the POCC to ensure the continued health and safety of the TRMM spacecraft and instruments. Quick-look data products requested by the POCC are formatted as files of CCSDS packets and transmitted within 2 hours after completion of the TDRS acquisition session designated as a quick-look session. Production data products may be used to perform trend analyses and to create a mission history for the FOT. Production data products are formatted as files of CCSDS packets and transmitted once per day when requested. Quick-look and production data products are transmitted electronically to the POCC at a rate of 1 Mbps (TBR). If the data received from the TDCF do not meet established quality and accounting criteria, the POCC may request retransmission of that data as required.

5.4 TSDIS INTERFACES

The TSDIS interfaces with the TDCF are provided by the SOCC and the SDAC via Nascom II and a GSFC LAN if the TDCF is located at WSC, or via a GSFC LAN if the TDCF is located at GSFC. The TRMM instrument team and the TRMM Science Team are located at the SOCC, which is responsible for instrument monitoring and coordination and science planning. The SDAC performs higher-level processing (to Levels 1 through 4) of the production data products generated by the TDCF.

The TDCF transmits real-time, quick-look, and production data products to the TSDIS as files of CCSDS packets. Real-time packets and associated summary quality and accounting information are transmitted at a rate of 200 kbps; quick-look and production data products are transmitted at a rate of 1 Mbps (TBR). These data products are distributed to the TSDIS SOCC and the TSDIS SDAC in accordance with their current requirements. The TSDIS SOCC nominally receives only real-time data products; the TSDIS SDAC nominally receives both quick-look and production data products.

Real-time packets are transmitted immediately upon completion of processing (within 1 second of receipt) by the TDCF. Quick-look data products are transmitted within 2 hours after completion of the scheduled quick-look (TDRS) acquisition session. Production data products are transmitted once daily, within 24 hours after receipt of the last bit of data comprising the production primary data set. The TSDIS may request retransmission of data products received from the TDCF if the quality of the initial transmission is unacceptable.

5.5 FDF INTERFACE

The FDF interface with the TDCF is accomplished via either Nascom II and a GSFC LAN or via a GSFC LAN (for electronic transmission), depending on the location of the TDCF. Non-electronic transmission using a physical medium such as a magnetic tape is also an option for the FDF interface to the TDCF. Ancillary data products are sent to the FDF for refinement or repair and to calculate definitive orbit and attitude and their related parameters for subsequent uplink to the spacecraft. Ancillary data are assumed to be downlinked from the TRMM spacecraft in packets having an APID unique to ancillary data. Ancillary quick-look and routine production data products are formatted as files of CCSDS packets and sent to the FDF as scheduled. Quick-look data products are transmitted within 2 hours after completion of the scheduled quick-look (TDRS) acquisition session. Production data products are transmitted once daily, within 24 hours after receipt of the last bit of data comprising the production primary data set. A data rate of TBD Mbps is assumed for an electronic interface; specifications for the non-electronic interface medium are those set forth in the FDF Interface Control Document (9-track, 1600- or 6250- bits per inch (bpi), unlabeled volume magnetic tapes). If the quality of the initial transmission is unacceptable, the FDF may request retransmission of the data from the TDCF.

5.6 JAPANESE INTERFACE

The baseline Japanese interface with the TDCF is provided by a designated data reception node on the west coast of the United States. For the purposes of this study the NSGW located at the Jet Propulsion Laboratory (JPL) is assumed to be the designated JDRN. The TDCF transmits production data products to the JDRN via Nascom II facilities on a daily basis. The data products are formatted as files of CCSDS packets and are assumed to be transferred at a rate of 1 Mbps (TBR). If the quality of the initial transmission to the JDRN is unacceptable, retransmission of the data may be requested from the TDCF. The possible requirement for the TDCF to transmit additional data products to the JDRN is subject to future negotiations and is not considered here.

5.7 DSN INTERFACE

The DSN interface with the TDCF is provided by the DSN Ground Communications Facility (GCF), located at JPL in Pasadena, California, via the Nascom II Network. The DSN acts as a backup to the SN, performing the functions required to support the space-to-ground link and the transfer of the return link data stream to the TDCF in the event of a catastrophic failure of the SN.

The JPL GCF receives the TRMM return link data stream from space and transmits the data to the JPL NSGW for subsequent transmission to the TDCF. The return link data stream is comprised of CCSDS Version 1 Transfer Frames and is transmitted at a rate of 2 Mbps once per TRMM orbit.

6.0 TRMM DATA CAPTURE FACILITY ARCHITECTURE AND DESIGN OPTIONS

This section presents the TDCF architecture and design options. The TDCF provides the functions of data capture, level zero processing, and data distribution for TRMM instrument science and engineering data and TRMM spacecraft engineering data. Two specific implementations are considered for the TDCF: a Packet Processor (Pacor) based implementation and a Customer Data Operations System (CDOS) based implementation. These implementations are addressed in the subsections that follow. Each implementation is described in terms of the system configuration, operations concept, development and operating costs, and advantages and disadvantages.

The system configuration describes the physical architecture and design of the TDCF in terms of the supporting system(s). The architecture and design are also represented in pictorial form. Characteristics of the external data and control interfaces associated with the architecture are presented in tabular form.

The operations concept describes the TDCF operations specific to the implementation. The operations concept is a direct function of the specific implementation and differs slightly from the general concept presented in Section 2 in the manner in which data are routed to and from the TDCF. The operations concepts are intentionally limited in scope, beginning at the point at which the data are received on the ground and ending at the point at which real-time, quick-look, and production data products are distributed to users. Higher-level processing of Level Zero products is beyond the scope of this document.

Development and operating costs are discussed and quantified at a very high level. Only the factors contributing to deltas in the costs associated with each implementation are considered; costs that would be equally incurred regardless of the implementation selected are not discussed.

Finally, the advantages and disadvantages of each implementation are discussed. These may include ease of implementation, additional capabilities that, while not required, serve to reduce TRMM project costs, and others.

6.1 PACOR-BASED TDCF IMPLEMENTATION

This section presents the TDCF implementation option that utilizes the Pacor Data Capture Facility (DCF) at GSFC. This implementation of the TDCF represents perhaps the most conservative approach to satisfying the data capture requirements for the Tropical Rainfall Measuring Mission. The basic functionality required is currently available in the existing facility. The Pacor DCF was implemented as the first generic telemetry packet processing data system at GSFC. The Generic Block Recording System (GBRS), which will be used in this implementation to satisfy TRMM raw data storage requirements, supports all data capture requirements for Space Telescope (ST) and the Generic Time Division Multiplexed (GTDM) DCF as well as Pacor. Since both Pacor and GBRS are multi-user facilities, the capacity available to any particular mission will be subject to the launch schedule and competing mission requirements in the same time frame. As indicated later in this section, reasonable assumptions regarding TRMM requirements and other mission loading indicates that the existing capacity of both Pacor and GBRS will have to be expanded to meet the needs of TRMM. It is expected that only the costs of those upgrades that are unique to TRMM will be allocated to the Project. From the perspective of Code 560, which is the focus of this study, a limited marginal cost analysis is the most appropriate way to assess upgrade and operating costs. This means that costs will be attributed to TRMM if they are incurred to provide marginal (additional) capabilities necessary because Pacor and GBRS are supporting TRMM.

6.1.1 Pacor TDCF System Configuration

The basic configuration within the end-to-end ground system is driven by the location of the Pacor at GSFC. This permits a LAN interface with other elements located at GSFC. The interface with the WSC is a long-haul connection. Figure 6-1 presents a Pacor implementation of the generic TDCF shown in Figure 1-1. This implementation assumes that Nascom II will be available by June 1996, that the WSC NSGW will have the capability to interface directly to the WSGT and STGT, and that Nascom II will support both 4800-bit Nascom blocks and any other ground transfer frame that may be accepted to extend compatibility with CCSDS Recommendations.

Under normal operations, all return link data will enter the ground system through the WSGT or the STGT. The functional capacity of the Pacor will permit it to utilize data as directly received by the WSGT/STGT. The Nascom II will provide connectivity from the WSC to the GSFC NSGW. The GSFC NSGW will have a direct interface with the Pacor and the POCC to transmit all return link data for processing. The Pacor will use existing interfaces with the institutional facilities, namely the FDF, the POCC, and the NCC. Coordination with the NMCC and transmission of TDCF data products to the TSDIS will be accomplished using GSFC LAN facilities.

Production data products will be delivered to the Japanese data reception node using the Nascom II Network. The DSN will provide an emergency backup TRMM Ground System entry point in the unlikely event that the normal SN backups are not adequate. The DSN will interface with the TDCF through the Nascom II Network.

A more detailed functional configuration of the Pacor-based TDCF is illustrated in Figure 6-2. The complete functionality of the TDCF will be provided by the combination of the Pacor and the Generic Block Recording System (GBRS). All return link data entering the system will be routed in parallel to both of these systems. The GBRS will log and read to tape all incoming raw data. This facility will provide the two-year archival function required for all raw data.

Tables 6-1A and 6-1B summarize, to the extent they are known, the characteristics of the data flows across each external interface specific to the Pacor TDCF implementation shown in Figures 6-1 and 6-2. The data characteristics described include data type, format, rate, transport medium, and frequency of transmission.

The Pacor consists of a hardware front end, the Pacor Matrix Switch Subsystem (PMSS); the Front-End Processor Pool; and a pair of general purpose computers, all under the control of an Operator Console Pool. The current hardware configuration is presented in Figure 6-3. The PMSS accepts 4800-bit Nascom blocks either directly or as a playback from the GBRS. This subsystem also provides the interface with the NCC. The major portion of the processing is performed on the general purpose computers using the Pacor DCF software subsystem. The software subsystem is represented functionally in Figure 6-2 by the three applicable processing modes: real-time processing (RTP), quick-look processing (QLP), and routine production processing (PP). There is no attempt in Figure 6-2 to capture the actual software modules or the data flows among the processing modules. The interface to the users of the data products is provided by the PMSS. Tape products are generated on the main processor for distribution to users or the POCC as required.

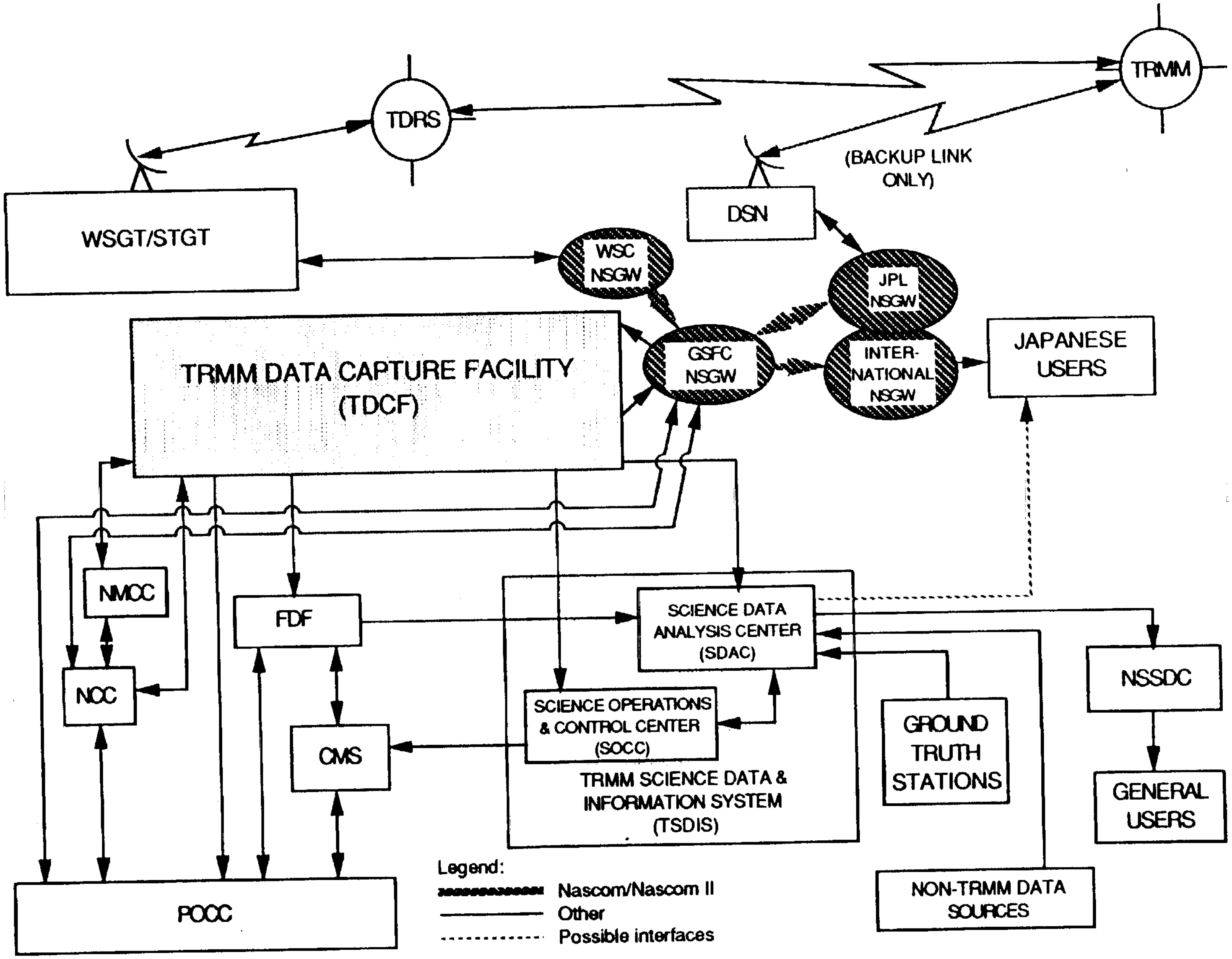

Figure 6-1. TRMM End-to-End System Concept: Pacor Implementation

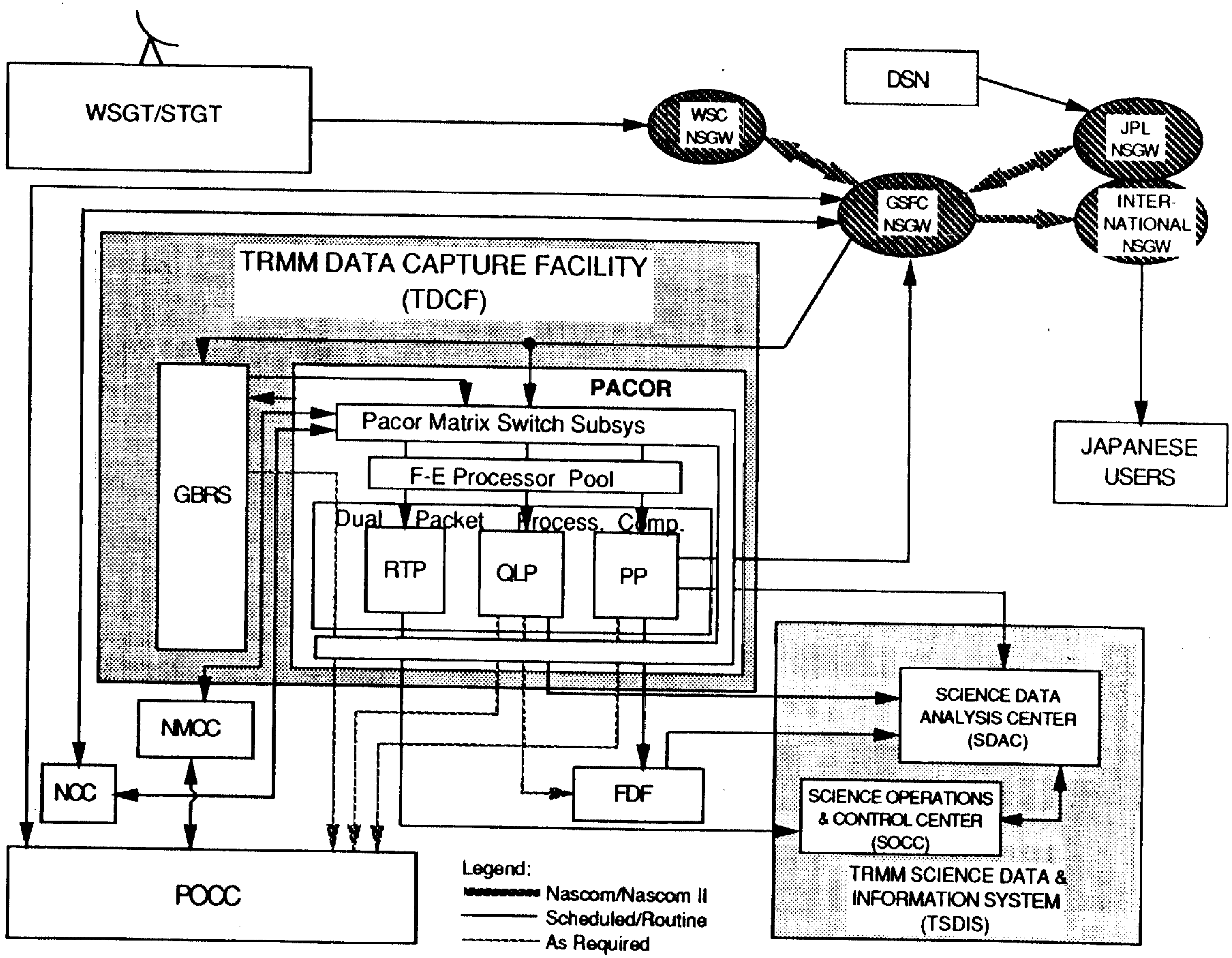

Figure 6-2. Conceptual Pacor TDCF Implementation

Table 6-1A. Pacor TDCF External Interfaces: Data Flow Characteristics from the TDCF to Other Elements

From	To	Data Type	Format	Data Rate	Transport Medium	Frequency
TDCF	NCC	Post-Event Reports	TBD	TBD	LAN	Per Orbit
TDCF	NSGW	Production	Files of CCSDS Packets	1.0 Mbps	LAN	Daily
TDCF	NMCC	Resource Msgs	TBD	TBD	LAN	As Required
TDCF	POCC	Q/A Alerts Raw Data* QL* Production*	TBD Com Blocks Files of CCSDS Packets	TBD Mag Tape* 1.0 Mbps* 1.0 Mbps*	TBD Mag Tape* LAN* LAN*	As Required Request* Schedule* Daily*
TDCF	SOCC (TSDIS)	RT	CCSDS Packets	200 kbps	LAN (X.25)	Per Orbit
TDCF	SDAC (TSDIS)	QL Production	Files of CCSDS Packets	1.0 Mbps 1.0 Mbps	LAN (X.25) LAN (X.25)	Schedule Daily
TDCF	FDF	QL* Production (Ancillary)	Files of CCSDS Packets	TBD* TBD	LAN* LAN	Schedule* Daily
TDCF	JDRN	Production	Files of CCSDS Packets	1.0 Mbps	LAN and Nascom II	Daily

*If requested by destination.

Table 6-1B. Pacor TDCF External Interfaces: Data Flow Characteristics from Other Elements to the TDCF

From	To	Data Type	Format	Data Rate	Transport Medium	Frequency
DSN	TDCF	Return Link Data	CCSDS Transfer Frames	2.0 Mbps	Nascom II	Per Orbit
JDRN	TDCF	Retx Req (Prod)	TBD	TBD	Nascom II	As Required
FDF	TDCF	Retx Req (QL*, Prod)	TBD	TBD	LAN	As Required
SDAC (TSDIS)	TDCF	Retx Req (QL, Prod)	TBD	TBD	LAN (X.25)	As Required
SOCC (TSDIS)	TDCF	Retx Req (RT)	TBD	TBD	LAN (X.25)	As Required
POCC	TDCF	Tx Req (Raw*, QL*, Prod*) Retx Req	TBD TBD	TBD TBD	LAN LAN	As Required As Required
NMCC	TDCF	Resource Msgs	TBD	TBD	LAN	TBD
NSGW	TDCF	Return Link Data (from SN or Retx Req)	CCSDS Transfer Frames	2.0 Mbps	Nascom II	Per Orbit or Retx Req
NCC	TDCF	TDRS Schedule	NCC Schedule Msg 94 or 99	TBD	LAN	Daily or As Required
WSGT/ STGT	TDCF	Return Link Data	CCSDS Transfer Frames	2.0 Mbps	Nascom II	Per Orbit

*If requested by destination.

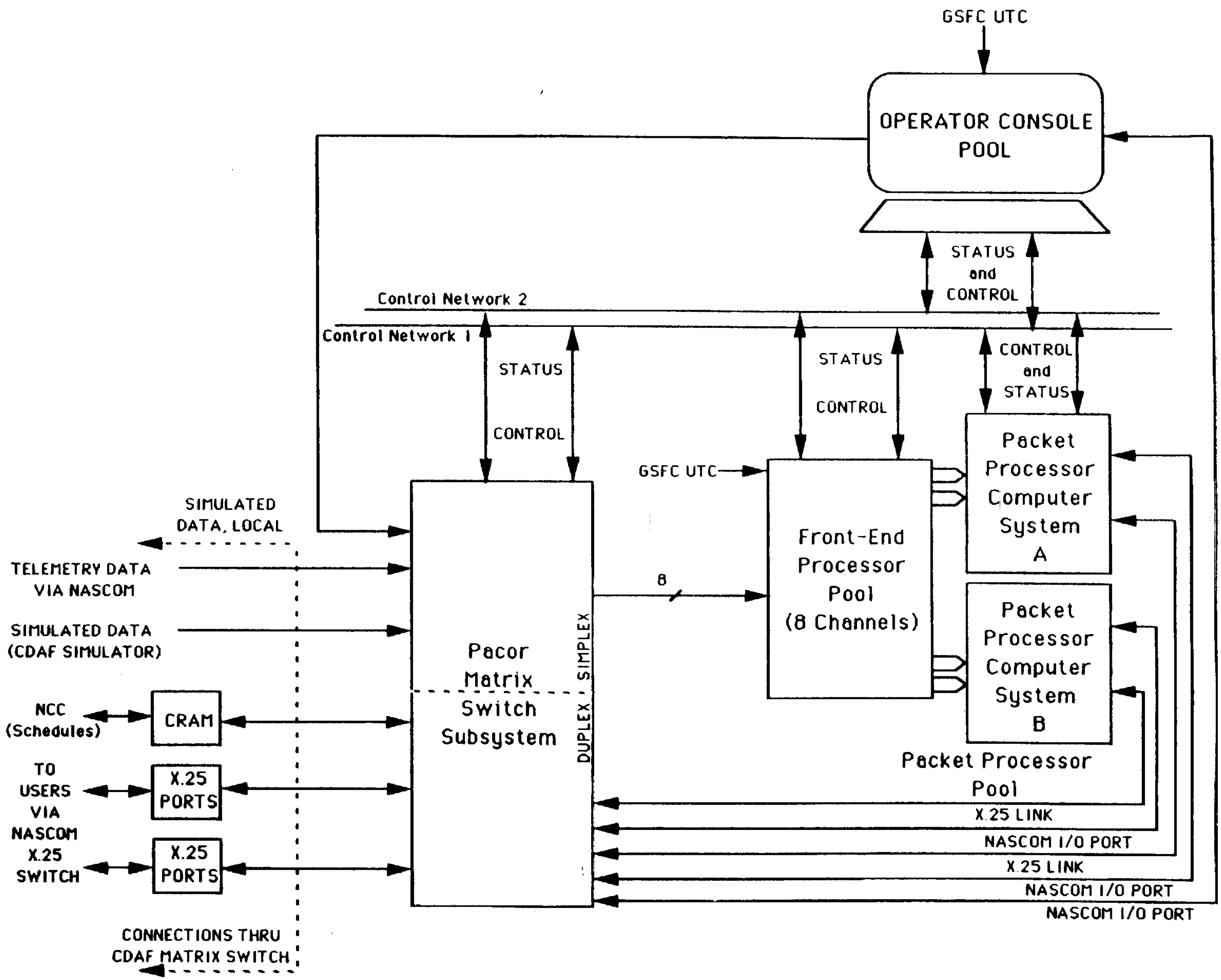

Figure 6-3. Current Pacor Hardware Configuration

The GBRS consists of three identically configured computer systems, each of which is independently capable of satisfying all of the processing requirements of the GBRS mission. During normal operations, two of the systems are in data capture mode and the third is in standby mode. Functions provided include data capture, log replay, data management, log tape generation, transmission of data to users, and status collection and reporting. The components of each computer system include the block recording computer (BRC), three front-end processors (FEPs), an output processor (OP), and a Sun Microsystems workstation (W/S). The FEPs interface with Nascom lines to receive the raw telemetry data from the SN or DSN. The FEPs, BRC, and OP interface to an Ethernet LAN to communicate with the W/S. Three high-speed data interfaces (HSDs) are used to input data to the BRC from the FEPs; a fourth HSD is used to output data to user facilities via the OP. Figure 6-4 provides a block diagram of the GBRS components.

6.1.2 Concept of Operations for the Pacor TDCF

The TDCF in this configuration is schedule driven and available for the reception of data 24 hours a day. It receives TDRSS schedule information from the NCC and is operationally prepared for the acquisition session. In the case of RTP it establishes communications with the requesting user several minutes before the start of the acquisition session. A post-event report is returned to the NCC after each acquisition session to provide reception confirmation and quality assessment.

It is assumed that the return link data stream is carried from the WSC to GSFC by Nascom II in standard 4800-bit blocks and that the Pacor will maintain the same functional Nascom interface it currently supports, synchronizing on the blocks and disassembling them into CCSDS Transfer Frames. The only differences from current operations will be that the interface will be at the GSFC NSGW and that an appropriate LAN or dedicated local line will provide the NSGW connectivity with the Pacor.

The return link data stream comprises real-time, playback, and fill data. The real-time data are contained in a separate virtual channel which is interleaved with the fill virtual channel and one or more playback virtual channels. Upon completion of error checking and correction and the separation of the virtual channels, the data are processed as required for the several users.

The two principal users of TDCF production data products are the TSDIS SDAC and the Japanese collaborators in the TRMM. Both of these users receive production data products on a regularly scheduled basis. It is expected that these production data products will include all instrument and spacecraft data packets. The distribution to the Japanese is accomplished by entering the processed data into Nascom II at the GSFC NSGW for transmission to Nascom II's International Gateway at JPL. The Japanese will provide an interface at that location for further distribution to their user community. The distribution to the TSDIS SDAC is performed using a LAN.

A limited subset of the production data, specifically packets containing ancillary data, will be provided to the FDF for orbit and attitude calibration, verification, and analysis. It is also expected that on a limited, as-required basis, production engineering and housekeeping data will be provided to the POCC to analyze spacecraft performance. Data products provided to the FDF and the POCC will normally be delivered via a LAN interface, but tape media may be used.

The Pacor-based TDCF also supports the requirement for quick-look processing. In the quick-look mode, the data from a single acquisition session is grouped and processed for

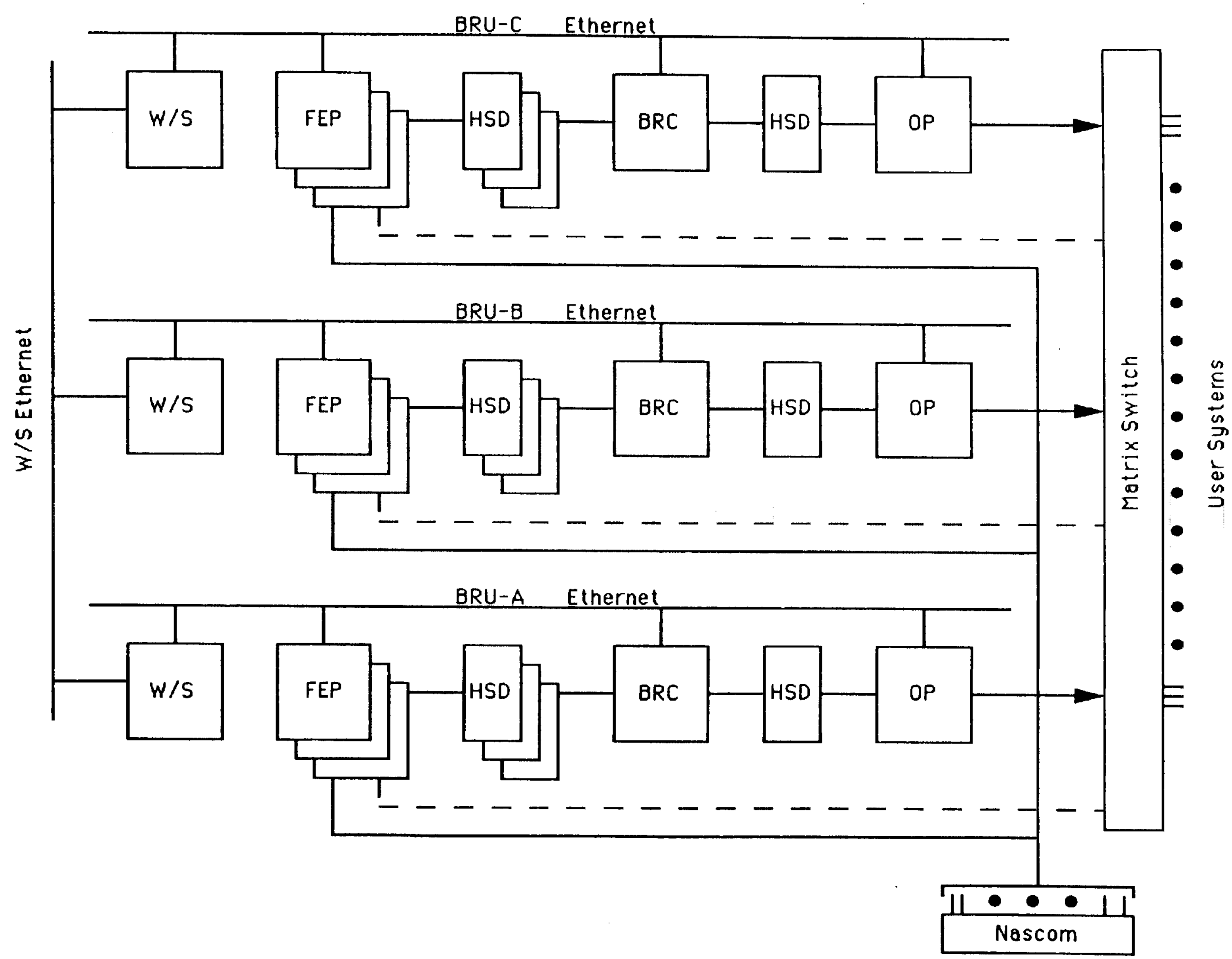

Figure 6-4. GBRS Block Diagram

distribution within two hours of receipt of the last bit of data in the session. Real-time data and playback data are not merged. The normal procedure is to use only playback data. The primary user for this processing mode is the TSDIS SDAC, which has introduced a requirement for three quick-look acquisition sessions per day. It is expected that the FDF may require limited amounts of quick-look processing for monitoring sensors and offering calibrations. It is also assumed that the POCC may require a limited amount of quick-look engineering data for problem analysis and monitoring.

The third processing mode supported by the Pacor is real-time processing. In this mode, the primary data set includes all real-time packets having a specified APID that are received during a single acquisition session. As with quick-look processing, there is no merging of real-time and playback data. The data are processed on the fly and the packets are received, reassembled and sent to the user within 1 second rather than being prepared by the data grouping subsystem. The primary user of the real-time processing capability is the TSDIS SOCC, which has requested up to 16 acquisition sessions per day in support of instrument monitoring and coordination. The average number of acquisition sessions requiring real-time processing will probably be considerably less than the peak requirement.

Data processed in any of the three modes are normally delivered through electronic transmissions. Since nearly all of the users of the TDCF data products are located at GSFC, it is expected that the interface will utilize a GSFC LAN that permits an X.25 interface. The Data Distribution Facility (DDF) at GSFC may be utilized for TRMM in this time frame. Although it is expected that in the 1996-2000 time frame electronic transfer will be the norm both in the primary and backup modes, the proximity of the user systems at GSFC will permit the use of physical media such as magnetic tape as a last resort. If required by the POCC, raw telemetry data captured by the GBRS at the communication block level will be sent to the POCC.

The Pacor TDCF implementation has several recovery mechanisms should there be inadvertent loss of data. The GBRS will record all incoming data streams in parallel with the Pacor. If data is lost in the Pacor or a regeneration of data is required, the tapes at the GBRS can be replayed and received electronically at the Pacor. If a ground transmission failure prevents the capture of data by either of these systems, the LOR at White Sands can be utilized for data recovery during the first 5 hours after the initial transmission. If the return link data have been contaminated on the spacecraft or during the downlink, a retransmission request can be initiated through the POCC. This retransmission request must be made within approximately one hour of the original transmission to avoid overwriting the data on-board the spacecraft. Finally, data loggers within the Pacor record the output production products and retain them for 30 days to permit retransmission to the users as necessary.

6.1.3 Development and Operating Costs

A comparison of the functional requirements in Section 3 with the capabilities of the Pacor-based system indicates that all of functional requirements can be met. Performance requirements may pose a significant problem, however. As indicated in the introduction to this section, Pacor and GBRS are institutional service facilities and their ability to support a given mission depends not only on existing capabilities but also on previous commitments to other missions. With the uncertainty in schedules it is difficult to predict just what the mission load will be in approximately 7 years when the system will be required for TRMM.

With regard to the Pacor, the current throughput processing rate is inadequate even when neglecting the load of other missions completely. The results of a system performance analysis conducted by Computer Sciences Corporation (CSC) in September 1988 indicate an ingest rate of 3 to 3.5 Mbps. For the single channel input of TRMM, the rated capacity is adequate to meet the requirement. The continuous processing throughput rate of all production and quick-look processing is 100 kbps, or only about 40% of the TRMM requirement. These ingest and throughput figures are expected to increase before the 1997 time frame, however. Currently scheduled upgrades to the Pacor will significantly increase the ingest rate and throughput capacity. The ingest rate after these upgrades are operational is estimated to be between 4 and 8 Mbps, or 200% to 400% of the TRMM requirement. The average throughput after the upgrades are operational is estimated to be 150 kbps, or about 62% of the TRMM requirement.

The missions that are currently scheduled for the Pacor include: Gamma Ray Observatory (GRO), which has a ten-year mission life and will therefore continue to impose requirements in the 1997 time frame; Solar and Heliospheric Observatory (SOHO),whose nominal mission life extends to August 1997 and will at a minimum impact testing and probably early TRMM orbits; 6 or 7 Small Explorer (SMEX) missions, of which perhaps 3 will be active in 1997; and Extreme Ultraviolet Experiment (EUVE) and its successor X-Ray Timing Experiment (XTE), at least one of which will be active in 1997. Orbiting Solar Laboratory (OSL) may require Pacor support, however, it will probably be supported by CDOS and will not be not considered here. The minimum mission load at TRMM launch in 1997 before considering TRMM requirements and based on current schedules and assignments would therefore include at least 6 missions with the estimated data rates presented in Table 6-2. A rate characteristic of the continuous real-time data acquisition mode of SOHO has been used to approximate the more severe impact this mission could have.

There are some uncertainties associated with the mission profile assumed for the facility, the most significant being the assumed extension of SOHO, with its maximum data rate of approximately 245 kbps, into the TRMM operational window. In any case it is clear that the Pacor with TRMM will be oversubscribed at least in terms of processing throughput.

The prudent approach is to assume that Pacor will have to be further upgraded to support TRMM, consistent with current planning, and that the upgrade will be sized to satisfy all of the TRMM requirements including a minimum contingency capability. It is further assumed that at some time in the future the function of Pacor will be assumed by CDOS or some other advanced facility. This would dictate that the upgrade should follow a minimum cost approach based only on the TRMM mission lifetime since the upgrade may not be used for further future missions.

With these assumptions, the scenario that suggests itself is one in which there is no significant change in the hardware and software architecture. The increased capability would be obtained by hardware upgrades that will have minimal impact on the software and external interfaces. To perform an analysis of this approach it will be necessary to assume a processing model that identifies the driving performance requirements and establishes estimates of capacity needs.

As discussed in Section 6.1.1, the GBRS will receive and log all incoming data in parallel with the Pacor. The projected Pacor loading of Table 6-2 will thus also impact the GBRS. In addition, the GBRS will be supporting additional TDM missions in this time frame. A review of GBRS design documentation and discussions with the GBRS Project Manager indicate that GBRS will also have to be upgraded to support TRMM due to the relatively

Table 6-2. Estimated Pacor Mission Support Requirements, 1996-2000

Mission Support Estimates	Estimated Average Processing Rate (kbps)	Peak Ingest Rate (kbps)
Possible Mission Profile		
GRO	32	512
SOHO	245	245
SMEX(N)	10	56
SMEX(N+2)	10	56
SMEX(N+2)	10	56
XTE	32	512
Projected Total Pacor Loading (Without TRMM)	339	1437
TRMM Nominal Mission Load	200	2000
TRMM Contingency Requirement	40	400
Projected Total Pacor Loading (With TRMM)	579	3837
Working Estimate of Pacor Projected Capacity (Assuming Currently Scheduled Upgrades)	150	8000
Excess (+) or Deficiency (-) of Capacity Over Load	-429	+4163

high ingest rate and data storage volume. A loading study is currently being conducted by GSFC to determine the required capacity of the upgrade. At the time this report was written, the GBRS upgrade strategy had not been finalized, precluding any authoritative estimation of the associated marginal development or operating costs. The GBRS marginal development and operating costs are not considered in the remainder of this section. When data becomes available upon completion of the GBRS loading study, any marginal costs attributable to TRMM should be considered.

6.1.3.1 Development Costs

If the Pacor system is to meet the minimum requirements for throughput identified in Table 6-2 it will be necessary to more than triple the currently estimated available capacity.

The requirements impose an additional 20% contingency capability on the system. In a multi-user environment, it is not necessary that the system design consider a worst/worst/worst situation so that the contingencies for each user need not be summed. It is necessary, however, that the total contingency be at least equal to the largest single contingency. Although the other contingencies are not known, a reasonable assumption is that the TRMM contingency will be the largest. A 20% contingency has been noted in Table 6-2. The total required increase in capacity would correspond to an additional throughput processing capability of approximately 429 kbps continuously.

At this time there is only limited information available regarding the total system loading that results from imposing a requirement to process a given telemetry stream. Studies are currently in progress to assess this issue for both operating cost estimates and future development planning. In order to perform such a loading study, the software must be understood and evaluated and any unique features of the hardware such as special function processors must be understood. It is outside of the scope of this study to perform such a detailed analysis and is probably not necessary for the TRMM mission until other issues are resolved. For purposes of this study a more general estimate of cost is sufficient.

It is valuable to identify the most significant parameters that characterize the computational work load generated by a processing requirement. Certainly the most important is the number of bits that must be processed. In addition, because of the nature of the processing, the number of packets or the average size of the packets will impact the processing loading. Since the data must be captured at the telemetry rate and stored or processed, the telemetry rate will certainly impact hardware configuration and, from a cost perspective, the impact may be greater than linear. The processing modes (real-time, quick-look, production) required to support a mission will have an effect and the nature of the distribution of data products will certainly affect operating cost.

For purposes of this study, it is assumed that the TRMM data stream is similar to that assumed for the current throughput capacity and the estimated capacity of the planned updates. Under this assumption, the additional 429 kbps net average throughput requirement means that it will be necessary to more than triple the capacity of the main processors as configured for the upgraded Pacor.

As stated earlier, the recent (June 1990) redefinition of CDOS strongly suggests that the CDOS facility will at some point assume the mission loads that might have otherwise gone to Pacor. In this environment the most reasonable way to address any Pacor upgrade associated with TRMM is to assume that the upgrade will not provide service beyond the TRMM mission and that the life cycle cost for the upgrade will be limited by the TRMM mission life. This will have the impact of increasing the importance of any development costs. In particular, there must be strong justification for redevelopment of any software. In the case of the Pacor software, approximately 37% of the code is written in assembly language and another 15% is written in Template, a special display language. Thus a significant portion of code could not be ported easily. If redevelopment of the software is to be avoided it may be necessary to obtain hardware with the same instruction set so that the optimized machine language portion does not have to be changed.

Unless hardware can be identified that increases by a factor of roughly 5 the present system processing capability, it will be necessary to acquire a separate processor, sharing any components that can be shared and run in parallel with the existing system. There are definite reliability advantages to having such parallel systems but there may also be additional operating costs. For present purposes it is assumed that the parallel system approach will be implemented, that modifications planned for the PMSS and other front end elements can be shared, and that the projected ingest rate of 8 Mbps will be supported by these front end elements.

The Pacor system is currently using ENCORE 32/9750 hardware for the packet processor computers. The simplest upgrade path would be to obtain instruction-set-compatible hardware with more processing power. It is our understanding that the ENCORE Concept 32/2000 hardware would provide the compatible instruction set with increased computational power. Clearly this upgrade path is not the only one, and if hardware costs become too large the cost and risk of breaking or losing the software may become the cheaper alternative. This may be particularly true in light of the availability of new special-purpose hardware. There may be other alternative hardware suites that would provide the same compatibility and these should be explored. The compatible instruction set approach, however, should be the first explored and used as a baseline for other alternatives.

Based on budgets associated with the current upgrades, the cost of hardware procurement, installation, and test are estimated to be on the order of $4.5 to $5.9 Million. These numbers assume a configuration in which three new higher-capacity processors will be installed, two to replace the existing machines and a third string to provide a new second operational capability. Figure 6-5 is a conceptual diagram of the Pacor hardware configuration upgrade. One of the processors will provide backup for the other two operational units. In order for the upgrade to be up and functional for testing 9 months to 1 year before launch, the procurement will have to be made in FY94. The cost will be a strong function of the peripherals required to support the mission in addition to the configuration of the main processor.

6.1.3.2 Operating Costs

Because the Pacor upgrade required to support TRMM is assumed to consist of a separate processing equipment string, additional operator support may be required specifically to handle that system. The cost of that support requirement would need to be considered as an additional operating cost of the Pacor. For budget planning purposes, Code 560 has developed operating cost estimates based on operations as a dedicated TRMM facility. The major cost element in this estimate is the labor cost for 3 shifts per day of operators, analysts, systems engineers and supervisors. Equipment maintenance contracts have been assumed for the processors and related equipment. Facilities costs unique to the TRMM operation, including expendables and service charges, are included. The costs incurred during the prelaunch testing period and the post-operational period range from $300K to $500K per year. During the 3-year operational period, the costs are estimated to be approximately $1 Million per year. For the assumed 5-year period (including prelaunch testing, mission operations, and post-mission operations), the average cost is estimated to be approximately $800,000 per year.

While the estimation of operating costs for a dedicated facility is relatively straight-forward, there is currently no algorithm available to allocate proportionate shares of operating costs in the Pacor multi-user environment. It can reasonably be assumed, however, that there would be a significant reduction in operating costs in a multi-user environment. An order of magnitude estimate might place the shared cost for TRMM at less than $500,000 per year during the flight operations period. It is understood that there is a study in process to provide such an algorithm for resource planning purposes.

The communication links necessary to support the distribution of data to and from the Pacor-based TDCF will be provided by Nascom/Nascom II as an institutional resource. The requirements to support the Pacor implementation include a 2 Mbps link between WSC and the GSFC NSGW as the primary return link channel. Since the POCC will handle all

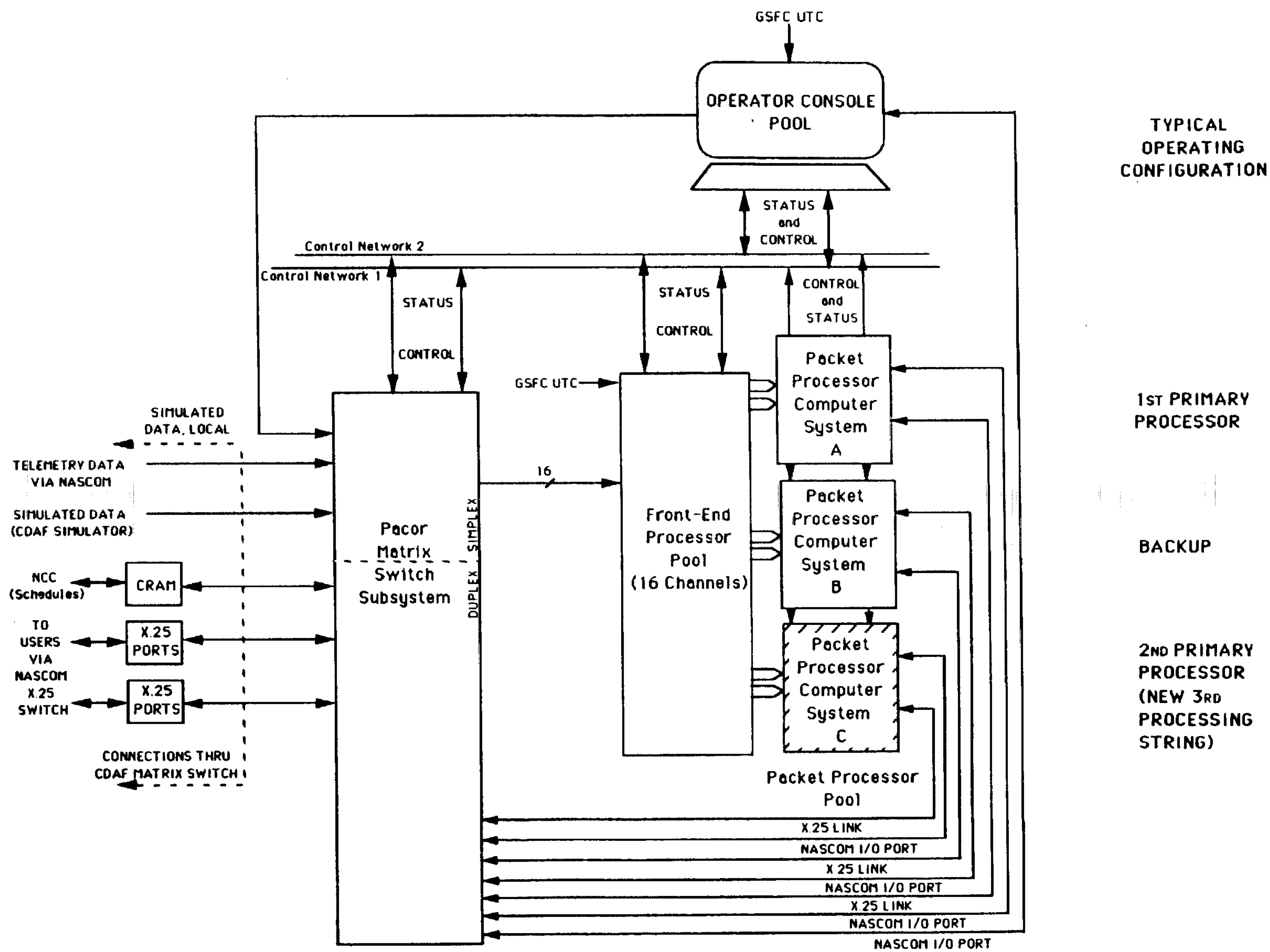

Figure 6-5. Conceptual Pacor Hardware Configuration Upgrade

operations data and since the NSGW will not separate the virtual channels, the POCC will need a 2 Mbps local link to the NSGW. The Pacor will also require a local 2 Mbps link to the NSGW to obtain the return link data stream. A 1 Mbps (TBR) LAN will distribute processed data to the TSDIS and other local GSFC users. A 1 Mbps (TBR) long-haul link will be needed to transmit production data products to the JDRN assumed to be located at JPL. The relative costs of these communications links are discussed in the cost trade-off presented in Section 7.1.2.

6.1.4 Advantages

The primary advantages associated with the Pacor implementation result from two key features of the system. First, even though the Pacor is an institutional facility, the upgrades required to support this mission will permit much of the customization that would result from a dedicated facility. Second, the facility would be collocated with all of its users with the exception of the Japanese users. Both of these features would permit more effective mission development and operation. The Pacor option represents a minimum development risk choice since existing capabilities would serve as the basis for any upgrades and a significant measure of local visibility and control would increase development schedule reliability.

6.1.5 Disadvantages

The disadvantages of the Pacor implementation result most significantly from the relatively small scale of the Pacor operation. The current system would not be able to handle the TRMM return link ingest rate or the aggregate throughput rate. Thus there would clearly be development costs incurred to upgrade the system. The exact system load imposed by TRMM becomes much more significant because the TRMM mission would be a large part of Pacor's total work load. In addition, with a smaller operation, contingency capabilities become more expensive since there is less statistical sharing of the contingency among missions. There is still some concern that existing software would function properly on a new host. Finally, if the actual load on Pacor is significantly greater than projected due to increases in TRMM requirements (considered to be a low probability) or to a larger-than-expected load from other missions during the TRMM mission, Pacor would not be easily expandable to meet such additional load.

6.2 CDOS-BASED TDCF IMPLEMENTATION

The CDOS implementation of the TDCF provides nearly all of the required functionality described for the TRMM ground system in the general implementation scenario presented in Section 2. The system configuration and operations concept described in the paragraphs that follow were developed on the basis of the CDOS Level II Requirements Document (CDOS 202.0002 V3 Review Copy, July 12, 1990), the CDOS Operations Concept Document (CDOS 0106.0002 V7, Draft, June 1990), and the current CDOS architecture.

6.2.1 CDOS TDCF System Configuration

The CDOS implementation of the TDCF in the TRMM end-to-end system concept is illustrated in Figure 6-6. Communication links are largely provided by the Nascom II Network. Figure 6-7 illustrates a more detailed functional configuration of the CDOS-based TDCF. Tables 6-3A and 6-3B summarize the data flow characteristics of the logical and physical interfaces between CDOS and applicable external entities and networks. The data flow characteristics described include data type, format, rate, transport medium, and frequency of transmission.

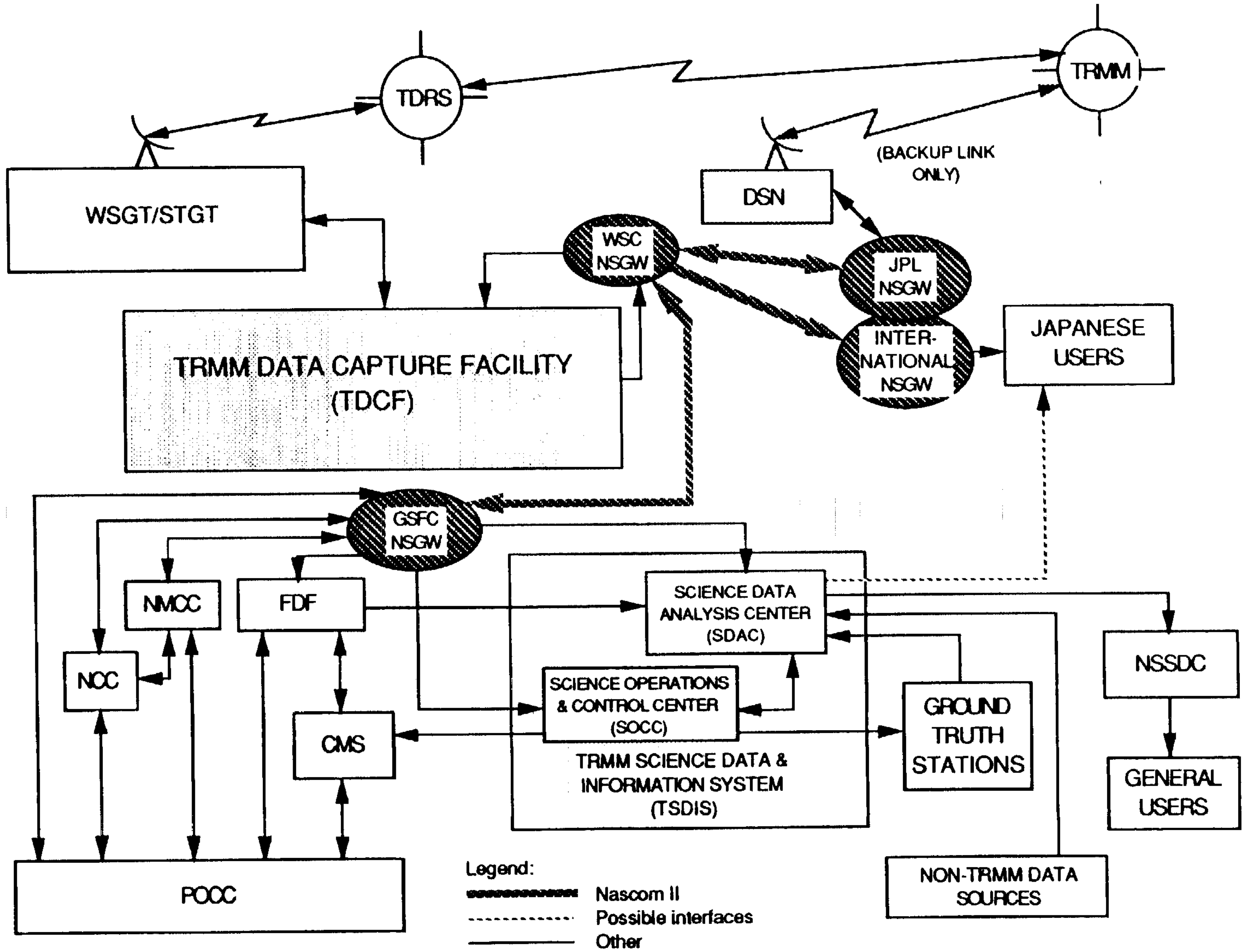

Figure 6-6. TRMM End-to-End System Concept: CDOS Implementation

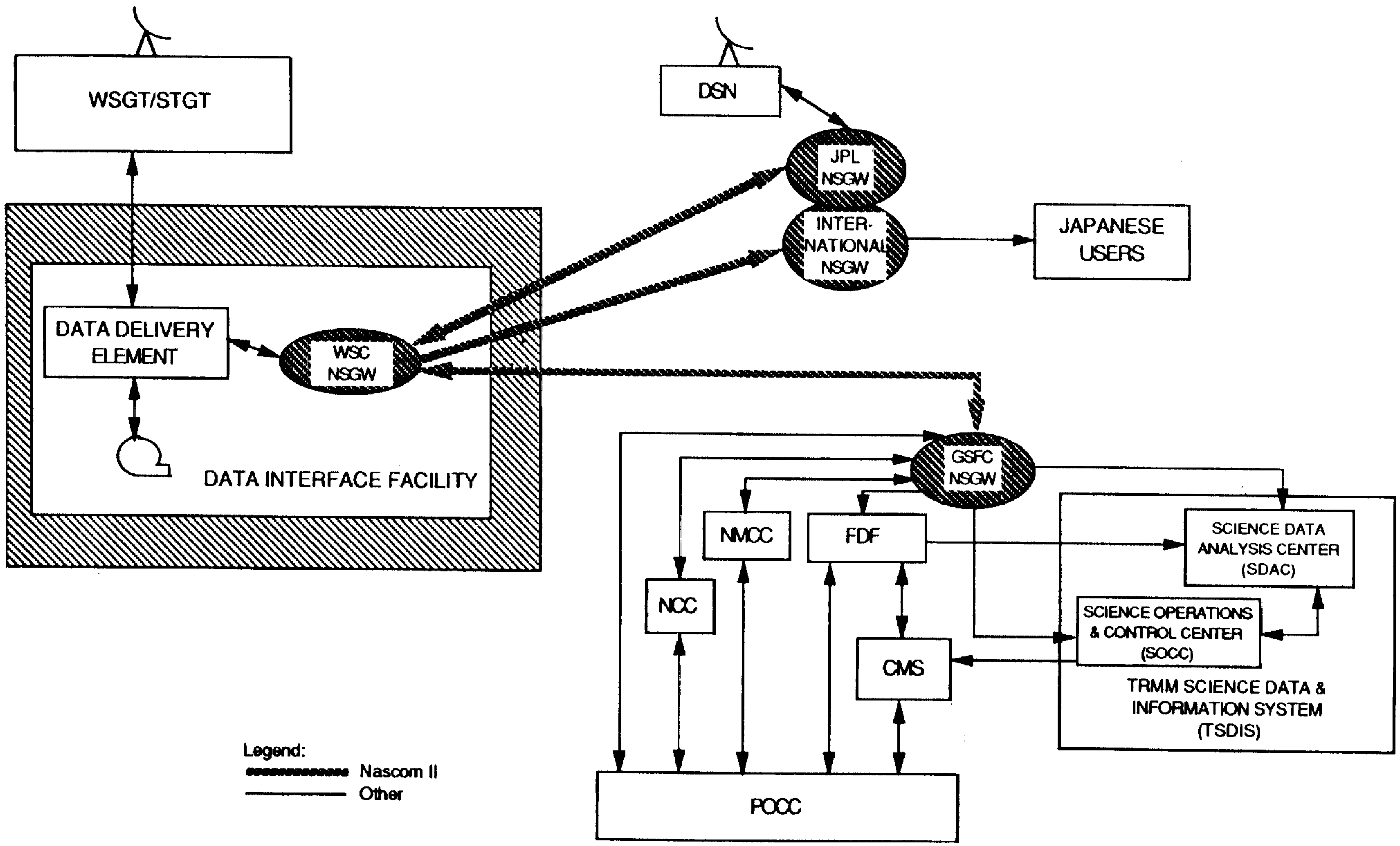

Figure 6-7. Conceptual CDOS TDCF Implementation

Table 6-3A. CDOS TDCF External Interfaces: Data Flow Characteristics from the TDCF to Other Elements

From	To	Data Type	Format	Data Rate	Transport Medium	Frequency
TDCF	NCC	Post-Event Reports LOR Retx Req	TBD TBD	TBD TBD	Nascom II/ LAN Nascom II/ LAN	Per Orbit As Required
TDCF	NSGW	Production RT QL	Files of CCSDS Packets	1.0 Mbps 1.0 Mbps 1.0 Mbps	Direct Wire Direct Wire Direct Wire	Daily Schedule Schedule
TDCF	NMCC	Resource Msgs	TBD	TBD	Nascom II/ LAN	As Required
TDCF	POCC	Q/A Alert Raw Data* QL* Production*	TBD Com Blocks Files of CCSDS Packets	TBD Mag Tape* 1.0 Mbps* 1.0 Mbps*	TBD Mag Tape* Nascom II/ LAN*	As Required Request* Schedule* Daily*
TDCF	SOCC (TSDIS)	RT	CCSDS Packets	200 kbps	Nascom II/ LAN	Per Orbit
TDCF	SDAC (TSDIS)	QL Production	Files of CCSDS Packets	1.0 Mbps 1.0 Mbps	Nascom II/ LAN	Schedule Daily
TDCF	FDF	QL* Production (Ancillary)	Files of CCSDS Packets	TBD* TBD	Nascom II/ LAN	Schedule* Daily
TDCF	JDRN	Production	Files of CCSDS Packets	1.0 Mbps	Nascom II	Daily

*If requested by destination.

Table 6-3B. CDOS TDCF External Interfaces: Data Flow Characteristics from Other Elements to the TDCF

From	To	Data Type	Format	Data Rate	Transport Medium	Frequency
DSN	TDCF	Return Link Data	CCSDS Transfer Frames	2 Mbps	Nascom II	Per Orbit
JDRN	TDCF	Retx Req (Production)	TBD	TBD	Nascom II	As Required
FDF	TDCF	Retx Req (QL*, Production)	TBD	TBD	LAN/ Nascom II	As Required
SDAC (TSDIS)	TDCF	Retx Req (QL, Production)	TBD	TBD	LAN/ Nascom II	As Required
SOCC (TSDIS)	TDCF	Retx Req (RT)	TBD	TBD	LAN/ Nascom II	As Required
POCC	TDCF	Tx Req (Raw*, QL*, Prod*) Retx Req	TBD TBD	TBD TBD	LAN/ Nascom II LAN/ Nascom II	As Required As Required
NMCC	TDCF	Resource Msgs	TBD	TBD	Nascom II	TBD
NCC	TDCF	TDRS Schedule	NCC Schedule Msg 94 or 99	TBD	LAN/ Nascom II	Daily or As Required
WSGT/ STGT	TDCF	Return Link Data	CCSDS Transfer Frames	2 Mbps	Direct Wire	Per Orbit

*If requested by destination.

The Data Delivery Element (DDE), located at the CDOS DIF, provides the functionality specified in the CDOS Level II Requirements Document for the Data Delivery Service and for the Archival Data Management Service. Applicable TDCF functions include data receipt and capture, R-S error decoding and correction, virtual channel separation, packet demultiplexing, real-time, quick-look and production data processing, data quality assessment and accounting, short-term storage of routine production data products, and distribution of both unprocessed data streams and processed data products.

Data are routed from the DIF to their intended destination(s) by means of the Nascom II Network. The data rate to each destination is the rate previously established by negotiation between CDOS and the destination. CDOS will rate convert the data as required to provide the desired data transmission rate to the destination.

6.2.2 Concept of Operations for the CDOS TDCF

CDOS operates primarily as a table- and data-driven system. The DDE operates as an active service in that it is continuously ready to receive data. Scheduling information is not required to process or deliver the data, since processing and delivery requirements are established during the pre-mission phase. These requirements may be modified if necessary during operations through negotiation with the CDOS Operations Management Service. Physical reconfigurations of the system are not required under normal circumstances.

In the CDOS TDCF implementation, the return link data stream is routed from the WSGT/STGT directly to the CDOS DIF collocated at the WSC. A signalling protocol is used to verify the operational readiness of the interface between the WSGT/STGT and the DDE. The DDE receives the return link data stream from the WSGT/STGT, performs any required error checking and correction, and separates the physical data stream into its component virtual channels. The fill virtual channel is discarded. The real-time and playback virtual channels are captured on some kind of physical medium and stored for a period of 20 years. Quality and accounting information is generated for each real-time and playback virtual channel.

All real-time and playback data and data products are routed to their destination(s) using Nascom II facilities. If required by the data destination, the DDE demultiplexes packets from the virtual channels. The DDE transmits the virtual channels and packet channels to the NSGW collocated at the DIF (the WSC NSGW). Multiple channels bound for a single destination are multiplexed by the NSGW prior to transmission over the long-haul links.

Real-time CCSDS packets are immediately routed to the POCC for use in monitoring spacecraft and instrument health and safety. Real-time packets and their associated data quality and accounting summary are transmitted to the POCC at a rate of 200 kbps, the rate at which the data are received by CDOS, in order to minimize the delay incurred. The POCC is required to perform any additional packet processing required to support health and safety monitoring.

Real-time and playback packet streams receive additional processing by CDOS in accordance with negotiated user requirements. The data are identified as requiring real-time, production, or quick-look data processing on the basis of current data processing parameters associated with each packet channel (e.g., APID).

Real-time processing provides summary quality and accounting information for real-time packets received during a single TDRS acquisition session having the specified APID(s).

The real-time packets and summary quality and accounting information are transmitted to the TSDIS SOCC for instrument operations and science planning. Each real-time packet is transmitted upon completion of the necessary processing; the quality and accounting summary is transmitted upon completion of processing of the last real-time packet comprising the primary data set.

For data requiring routine production processing, the DDE reconstructs instrument and spacecraft data sets, merging real-time and playback data, time-ordering the data, removing redundant data packets, identifying gaps in the data, and annotating the data with appropriate quality and accounting indicators. The resulting production data products are transmitted to a data store to be staged and formatted for distribution to users. Data distribution is accomplished by the DDE via Nascom II facilities. Production data products are delivered to users within 3 hours nominal, 21 hours maximum, of receipt of the last bit of data comprising the primary data set by CDOS. Production data products containing science, engineering, and ancillary data are distributed to the TSDIS SDAC for higher-level processing (Levels 1 through 4) and to Japanese users.

Quick-look processing is also performed by the DDE. Quick-look processing is identical to routine production processing with a few exceptions. Quick-look processing uses only playback data, i.e., it does not merge real-time and playback data or provide redundant data removal. In addition, quick-look primary data sets are bound by a single TDRS acquisition session. Quick-look data products are delivered to users within 10 minutes of receipt of the last bit of data comprising the quick-look primary data set by CDOS. Quick-look science and engineering data products are distributed to the TSDIS SDAC for science coordination.

Ancillary data are processed in both the quick-look mode (if scheduled) and the routine production mode. The resulting data products are transmitted to the FDF for definitive orbit processing and analysis. (Definitive data products are transmitted to the TSDIS by the FDF for use in higher-level processing.)

Quick-look and production data products transmitted to users over electronic media use protocols that support computer-grade communication error rates and "registered delivery". Two delivery options are available. In the first option, users are notified when their data products are ready. The users then notify CDOS to establish a session for delivery of the data products. In the second option, data products are transmitted upon completion of processing and establishment of a signalling protocol with the user. Production data products may also be delivered on a scheduled basis.

Quick-look and production data products are transmitted using a File Transfer, Access and Management (FTAM) protocol at a rate of at least 1.5 times the average instrument data generation rate. Data products are stored until users confirm receipt. Users are given an inventory of their data products residing in the DDE to use in accounting for their data.

If the quality and accounting data generated by the DDE indicates that the quality of the return link data is unacceptable, CDOS will alert the POCC. Processing and delivery of the current data will continue. Since CDOS receives the data directly from the WSGT/STGT, retransmission of the data for reasons other than line (interface) outage or a catastrophic failure within CDOS must come from the spacecraft. The POCC may request retransmission from the TRMM spacecraft within approximately 1.5 hours of the initial dump. If a catastrophic failure occurs at the WSGT/STGT - CDOS interface, the data may be recovered from the WSGT/STGT LOR for up to 5 hours after the initial dump.

Users requiring retransmission of captured data may obtain that data from CDOS in either of two ways: electronically from CDOS, if an electronic interface exists between the user and CDOS; or on a physical medium if no electronic interface exists. If the data requested are currently contained in the on-line data base and the user has an electronic interface to CDOS, retransmission is accomplished simply by a line replay of the requested data. If the data are currently contained in the on-line data base and the user does not have an electronic interface to CDOS, a tape or disk is generated and sent to the user. If the desired data do not reside in the on-line data base, they must be recovered from the off-line archive and replayed electronically or used to generate the appropriate physical media.

Users requiring retransmission of production data products generated by CDOS may obtain them from CDOS via an electronic interface at any time within the 7-day storage period. Production data product retransmissions requested after the 7-day period must be either reprocessed from raw (captured) data (negotiated with CDOS on an individual basis) or recovered from Level 1A data products stored by the TSDIS.

6.2.3 Development and Operating Costs

The TDCF requirements presented in Section 3 are compatible with and satisfied by existing CDOS requirements. Development costs for a CDOS-based TDCF will therefore be inherently borne by the CDOS Project. Operations costs associated with processing TRMM data are likewise incurred within CDOS, but should be included in the TRMM Project costs to ensure proper budget allocations, since CDOS operating costs are reimbursable at the Code S/Code O Level. Communications costs associated with delivering TRMM data and data products are directly attributable to the TRMM Project.

6.2.3.1 Development Costs

The TRMM-specific development costs associated with the CDOS implementation of the TDCF are the costs of integration and test activities attributable to the TRMM mission. These costs cannot be quantified at this time due to the evolving nature of both TRMM and CDOS.

6.2.3.2 Operating Costs

Operating costs are assumed to include those incurred for CDOS services. CDOS has not yet identified the method by which processing costs will be allocated to users. A preliminary CDOS life-cycle cost analysis providing a rough-order-of-magnitude (ROM) estimate for annual operating costs has been developed, but the cost data are procurement-sensitive and are not currently available for use in estimating TRMM processing costs. It is not clear that CDOS will in fact establish a method to allocate costs to users, since CDOS is intended to be an institutional service funded by Code O. A ROM estimate of the TRMM processing costs could be derived on the basis of the preliminary life-cycle costs once they are made available by assuming that TRMM processing costs would be in some way proportional to the volume of TRMM data processed relative to the CDOS data processing capacity, and taking into account some percentage of the amortized development costs.

The communications costs associated with delivering TRMM data and data products to users are a function of the volume of data transferred as well as the rate at which the data are transferred. Since the CDOS DIF is collocated with the WSGT and STGT at the WSC, communications costs are incurred only for the distribution of data products; delivery of the raw data to the CDOS TDCF is accomplished via "holes in the wall" at the DIF rather than long-haul communications links. The CDOS TDCF data delivery requirements necessitate a 1 Mbps (TBR) link from the WSC NSGW to the GSFC NSGW to support the delivery of real-time, quick-look, and production data products to users at GSFC; a 1 Mbps (TBR) link from the WSC NSGW to the JPL NSGW to support delivery of production data products to the JDRN; and 1 Mbps (TBR) LAN facilities at GSFC. In addition, two 200-kbps links are required -- one from the GSFC NSGW to the POCC and one from the GSFC NSGW to the TSDIS SOCC -- to permit real-time data delivery. The relative costs of these communications links are discussed in the trade-off presented in Section 7.1.2.

6.2.4 Advantages

The CDOS-based TDCF implementation offers a number of potential advantages to the TRMM Project, including centralized virtual channel separation and packet demultiplexing functions and a forward link capability. Use of these services, negotiated as required with CDOS, may serve to reduce TRMM Project costs.

CDOS performs the functions of virtual channel separation and packet demultiplexing at the WSC. The centralization of these functions at the WSC reduces the amount of processing that must be done by the POCC to obtain the real-time data necessary to monitor spacecraft health and safety. The reduction in the amount of processing at the POCC simplifies POCC operations and potentially allows a reduction in processing costs to the TRMM Project.

The forward link capability of CDOS provides a reliable and cost-effective means of uplinking commands and ancillary data to the TRMM spacecraft. Forward link data may be transmitted from TRMM facilities at GSFC to the WSGT/STGT facilities at White Sands via the intervening Nascom II facilities and the DDE at the CDOS DIF. The DDE will properly format the data into the specified CCSDS protocol and transmit the data to the WSGT/STGT. The TRMM Project would incur only the costs of using the CDOS and Nascom II services, which is a fraction of the cost of providing those services for a single user. For example, instead of leasing a secure Nascom circuit to transmit data from the POCC to the WSGT/STGT, the TRMM Project would pay for the use of an existing trunk, perhaps shared with other CDOS and Nascom II customers, that provides the required connectivity. Interfaces would be simplified and reduced in number since the POCC would only interface with CDOS rather than with both CDOS (return link) and WSGT/STGT (forward link), and the CDOS DDE would provide the necessary CCSDS formatting and synchronization for the uplink.

6.2.5 Disadvantages

There are two primary disadvantages to the CDOS TDCF implementation: the location of the production data processing function and schedule.

The current CDOS architecture provides centralized production processing at White Sands. Although the long term impact may not be significant, there is an inherent disadvantage to this architecture in that the TSDIS SDAC, which receives the Level Zero data products and performs higher-level processing, will require an interface to Nascom II facilities that does not currently exist. At present, all Level Zero processing is performed at GSFC by the IPD. Level Zero data sets are transmitted to the SDAC over existing GSFC LANs. In order to receive Level Zero data sets transmitted from White Sands via Nascom II, an additional and potentially more complex interface between Nascom II facilities and the TSDIS SDAC will be required.

The primary disadvantage of the CDOS TDCF implementation is the current CDOS schedule. The TRMM spacecraft is scheduled for launch in August 1997, and will require CDOS support for prelaunch testing in June 1996. The current CDOS schedule provides an implementation milestone of First Quarter 1996. If the launch occurs earlier than the scheduled August 1997 date, as might happen to accommodate the Japanese launch schedule, CDOS would not be available in time to meet testing requirements. In addition, it is unknown at this time what functions and capacities will be available at the time of the first milestone and, hence, whether the CDOS Level Zero processing capabilities required by the TRMM Project would be available within the TRMM Project schedule constraints. This issue needs to be clearly resolved in order to permit a decision regarding a CDOS-based TDCF. If the schedules can be reconciled, the CDOS TDCF implementation offers many advantages to TRMM and is the preferred implementation.

7.0 CRITICAL ISSUES AND TRADE-OFFS

The proposed Pacor and CDOS implementations presented in Section 6 each fulfill the TDCF requirements identified in Section 3. The advantages and disadvantages of each implementation highlight the critical issues and trade-offs that must be considered in selecting the TDCF implementation that best satisfies the Project and Code 560 requirement for a cost-effective Level Zero processing capability. These issues and trade-offs include cost factors, risk factors, and operational factors as well as other considerations such as the appropriateness of certain driving functional and performance requirements.

7.1 COST FACTORS

A number of cost factors specific to each TDCF implementation are discussed in this subsection. The development and operations cost factors considered are primarily the result of the TRMM processing rate and volume requirements relative to the TDCF implementation processing capabilities. TRMM represents a large customer to the Pacor, with an average processing throughput requirement of 240 kbps with contingency as opposed to the Pacor's current 100 kbps average processing throughput capacity. Conversely, TRMM represents a very small customer to CDOS when considering CDOS's proposed 216 Mbps average processing throughput capacity.

7.1.1 Development Costs

Since the current Level II CDOS requirements fully satisfy the functional, performance, and operational requirements identified for the TDCF in Section 3, the only additional development costs that would be incurred to implement a CDOS-based TDCF are those incurred in support of integration and test activities. The Pacor implementation would also incur costs in support of integration and test activities. For the purposes of the trade-off study, the integration and test costs are assumed to be equivalent for both TDCF implementations and will not be considered further.

The existing Pacor facility satisfies the functional and operational TDCF requirements, but would need augmentation to meet the performance requirements. The current Pacor configuration supports a 3 Mbps to 3.5 Mbps ingest rate and a 100 kbps average throughput rate, compared to the TDCF requirements to support a 2 Mbps ingest rate and a 240 kbps average processing throughput rate (with contingency). Section 6.1.3 identified the most cost-effective approach to modifying the Pacor to satisfy all of the TRMM performance requirements as a hardware upgrade in which there is no significant change in the hardware and software architecture. This upgrade would entail the purchase of a second redundant equipment string with increased capacity sufficient to handle the specified ingest and peak throughput rates. The approximate cost of the upgrade, outlined in Section 6.1.3.1, is $4.5 Million.

7.1.2 Operations Costs

Operations costs comprise data processing and data communications costs. The operations costs associated with each TDCF implementation are examined in this subsection.

The computer operations costs associated with processing the TRMM return link data stream to Level Zero are assumed to be comparable for both the Pacor and CDOS TDCF implementations. Both implementations perform the same type of processing for the same data rates and volumes and on the same schedule. However, the Pacor implementation, with its TRMM-dedicated processing string, will require additional operations and maintenance personnel whose costs are directly attributable to the TRMM Project. In addition, the CDOS implementation may achieve a reduction in the overall TRMM Project operations costs by reducing the amount of processing that must be performed by the POCC and through economies of scale resulting from the magnitude of the CDOS processing capabilities.

As noted in Section 6.1.3.2, operating costs have been estimated by Code 560 for the Pacor TRMM equipment string and support facilities as a dedicated operation. Operations and maintenance personnel, system engineers, and supervisory staff will be required to operate and maintain the TRMM-dedicated equipment string. As a starting point, a minimum operations staff of 6 would yield an estimated annual personnel cost of $300,000. Equipment maintenance contracts for the new string would be an additional cost. Operation and support personnel training would be required during the start-up period with this cost averaged over the TRMM mission life. A rough order of magnitude cost for these operations costs along with contingency would drive the total cost to over $500,000. The budget estimate for operations of the new system is approximately $1 Million per year for each of the three operational years. Prelaunch testing and post-mission operations are estimated to cost an additional approximate $1 Million. There is some question as to the allocation of such operations costs among mission since such an allocation is not performed. It is clear that the bulk of the estimate would be allocable to TRMM using the marginal cost approach indicated earlier. For purposes of this initial estimate a total annual operating cost of $800,000 will be assumed to be attributable to the TRMM for the five-year period (including prelaunch testing, mission operations, and post-mission operations).

In the Pacor implementation, the entire 2 Mbps return link data stream is routed to both the Pacor and the POCC at GSFC. The Pacor and the POCC must perform identical virtual channel separation and packet demultiplexing functions, with the Pacor then processing the data in real-time or in the quick-look or production modes, and the POCC processing only the real-time packets.

In the CDOS implementation, separation of the real-time and playback virtual channels and, if required by the user, packet demultiplexing from the virtual channels occurs at the WSC immediately after receipt of the return link data stream by the WSGT or STGT and CDOS. Real-time data and summary quality and accounting information are transmitted to users, including the POCC, within 400 to 600 milliseconds of receipt by the CDOS DIF. This capability substantially reduces the amount, and consequently reduces the cost, of front-end processing that must be performed by the POCC to obtain the real-time packets necessary to accomplish the POCC's mission to maintain spacecraft health and safety. The POCC is relieved of the tasks of separating and identifying the real-time virtual channel and demultiplexing and sorting by APID the constituent real-time packets, instead receiving packet channels organized by APID that are ready for immediate analysis. The 400 to 600 millisecond delay imposed by CDOS is comparable to the delay that would be incurred by the POCC performing the same functions for the entire return link data stream received directly from the WSGT or STGT via Nascom. Operationally, it is more efficient and cost-effective to perform the tasks of virtual channel separation and packet demultiplexing at a single location rather than at multiple locations.

The second operations cost component that must be considered in the Pacor versus CDOS trade-off is that of communications costs. The Pacor implementation requires a 2 Mbps link between the WSC and the GSFC NSGW, a 1 Mbps (TBR) link between the GSFC NSGW and the JDRN assumed to be located at JPL, and 1 Mbps (TBR) LAN facilities at GSFC. There must also be dedicated 2 Mbps links between the GSFC NSGW and both the Pacor and the POCC at GSFC to support real-time delivery of the return link data stream.

The CDOS implementation requires a 1 Mbps (TBR) link between the WSC NSGW and the GSFC NSGW, a 1 Mbps (TBR) link between the WSC NSGW and the JDRN at JPL, and 1 Mbps (TBR) LAN facilities at GSFC. The CDOS capability to perform centralized virtual channel separation and packet demultiplexing at the WSC reduces the required dedicated link data rate to support real-time data delivery from the GSFC NSGW to the POCC by an order of magnitude, from 2 Mbps to 200 kbps.

Table 7-1 summarizes the communications links associated with the Pacor and CDOS implementations. The 1 Mbps GSFC LAN(s) are assumed to be identical and are not shown in the table. For trade-off study purposes, the approximate length in miles of each link is presented to permit a qualitative comparison of the costs associated with the link. The estimation of ROM installation and operations costs associated with the Nascom links is a Nascom consideration and beyond the scope of this study. Link redundancy or alternate routing necessary to achieve the required link reliability and availability are also not considered.

Table 7-1. Pacor and CDOS TDCF Communications Links

Communications Link	**Miles**	**Pacor Data Rate**	**CDOS Data Rate**
WSC - GSFC	1860	2 Mbps	1 Mbps
GSFC - JPL	2310	1 Mbps	N/A
WSC - JPL	865	N/A	1 Mbps
GSFC NSGW - POCC	0.45	2 Mbps	200 kbps
GSFC NSGW - Pacor	0.33	2 Mbps	N/A

Based on the data rates and links lengths presented in Table 7-1, the CDOS implementation appears to incur approximately one-half of the annual communications costs incurred by the Pacor implementation.

7.2 RISK FACTORS

There are three risk factors of significance to the Pacor - CDOS TDCF trade-off: development schedule, capacity, and operational reliability, maintainability, and availability. These factors are discussed in Sections 7.2.1 and 7.2.2.

7.2.1 Development Risks

There are development risks associated with each of the proposed TDCF implementations. These development risks are primarily related to schedule and so are of a non-technical nature.

As noted in previous sections, the Pacor implementation will require the acquisition of a new equipment string dedicated to Level Zero processing TRMM return link data. This new equipment string must be of higher capacity than the existing Pacor equipment strings to accommodate the 240 kbps average processing throughput rate. Using the strategy suggested in Section 6.1, upgrading the hardware with minimal impact on software poses a limited risk. The schedule risk is estimated to be low since the hardware is available, software modifications should be minimal, and Pacor is a proven system.

The schedule risk associated with the CDOS TDCF implementation is somewhat greater than that associated with the Pacor TDCF implementation. The CDOS Project completed its Phase B Architecture Studies in June 1990. The Level III requirements specification is still under development at GSFC. The Phase C/D Design and Implementation contract is expected to be awarded sometime in 1991; the CDOS implementation schedule is at this time only vaguely defined. The TRMM will require CDOS support for prelaunch testing no later than June 1996. It is not currently known whether the CDOS Level Zero processing capabilities required to support the TRMM will be available within the TRMM Project schedule constraints.

7.2.2 Operations Risks

The operations risks significant to the TDCF implementation trade-off study are related to two issues that deal primarily with Pacor. The first, which represents a minimal risk, is that the system availability specification for the Pacor implementation is met because of the parallel capture function provided by the highly reliable GBRS. There is no reason for concern regarding the primary capture function or loss of data as a result of the GBRS reliability. There may, however, be some loss of response-time performance for Pacor functions (e.g. real-time processing) unless the Pacor operates in a hot backup mode. The Pacor currently operates in a cold backup mode.

The second issue is associated with the relatively small size of the Pacor relative to CDOS and the variability of the load requirements. As our limited analysis indicates, a reasonable mission load in the TRMM time frame will stretch the capacity of an upgraded Pacor. If additional unanticipated mission requirements are levied on Pacor due to schedule changes near to the TRMM launch it may be very difficult to make further unplanned upgrades and satisfy all of the requirements. Although this is a real risk it is regarded as low since such a dramatic schedule change would normally occur enough in advance to permit the major upgrade that might be required.

7.3 OPERATIONAL FACTORS

Operational convenience and flexibility also contribute to the TDCF implementation trade-off. These factors are not easily quantifiable, but may be identified as having positive or negative, weak or strong effects relative to the trade-off study.

7.3.1 Convenience

Each of the proposed TDCF implementations is in some way more convenient or efficient from a total Project perspective. In Section 6.1.4, the centralization of all TRMM data processing, from Level Zero through Level 4, and most TRMM data users at GSFC was identified as an advantage of the Pacor TDCF implementation that would permit more effective mission development and operation. In Section 6.2.4, the centralization of the virtual channel separation and packet demultiplexing and sorting functions at the WSC was identified as an advantage of the CDOS TDCF implementation that would simplify POCC operations and reduce overall Project operating costs. From a Project perspective, while both of these features are desirable -- centralization at GSFC and centralization of front-end virtual channel processing -- the centralization of all TRMM data processing capabilities at GSFC is considered slightly more desirable. Although these benefits do not specifically impact the Level Zero processing function, the centralization of all processing at GSFC is also operationally more desirable from a Code 500 perspective.

7.3.2 Flexibility

Operational flexibility to accommodate TRMM-unique processing and data handling requirements is an extremely desirable feature for the TDCF. The ability and willingness to respond to and satisfy new or modified requirements as well as emergency situations may be a significant factor in the final trade-off evaluation.

The TRMM is a relatively large customer to the Pacor, and a relatively small customer to CDOS. One potential benefit of being viewed as a large customer is an increase in the degree to which the system may be able to accommodate customer-specific requirements. Conversely, a potential disadvantage of being viewed as a small customer is the lack of influence over the services offered and functions performed by the system. While the relative size of the mission does not appear to be a significant discriminator, there may be some impact with regard to the flexibility of the TDCF to accommodate TRMM-unique requirements.

Since the Pacor will have to acquire an entirely separate equipment string to accommodate the TRMM, it is likely that the TRMM-dedicated string will be sized and configured to completely satisfy the identified TDCF requirements. In addition, since the Pacor-based TDCF supports the TRMM with a separate equipment string and may be viewed in a larger sense as a dedicated TRMM Level Zero processing facility, changes in the TDCF requirements subsequent to the initiation of operations could be more readily implemented. Emergency situations requiring real-time processing or other special processing to support data analysis on very short notice can be managed quickly and efficiently without interruption from a larger or higher-priority customer.

The TRMM will probably have little effect on CDOS with regard to TDCF functions and services required by the TRMM but not envisioned to be supported by CDOS. For example, the functions of the CDOS data archive are only vaguely defined at this time. The CDOS archive is required to store data for a period of 20 years; the type of data to be stored (raw or Level Zero) is not defined. For the purposes of this study it has been assumed that the CDOS archive will store the raw data for a period of 2 years as required by the TRMM. If subsequent CDOS archive requirements dictate that only Level Zero data products shall be archived, the TRMM raw data would probably have to be transmitted to the GBRS at GSFC for storage, since it is unlikely that this TRMM requirement would drive the CDOS data archive requirements.

CDOS will offer great flexibility in that there will be a broad range of services available to users. However, users must select from among the available services and may not be able to customize the services to exactly meet all of their data processing and data handling needs.

CDOS will support manned platforms such as Space Station as well as unmanned free flyers such as TRMM. In the event of schedule conflicts or emergencies occurring on a manned (or large) platform and the TRMM spacecraft, the manned (or large) platform would most probably take priority over the TRMM spacecraft emergency and potentially result in the loss of TRMM data.

7.4 TRADE-OFF SUMMARY

Sections 7.1, 7.2, and 7.3 identified the trade-offs pertinent to the final selection of the TDCF architecture. The results of the trade-off analyses are summarized in Table 7-2 for the Pacor and CDOS implementations. The trade-offs are quantified to the extent possible. Other trade-offs are assigned a relative ranking of low, medium, or high within the appropriate context.

Quantitatively, the CDOS option is significantly lower in cost than the Pacor option. Qualitatively, however, the Pacor option appears to have a slight advantage over the CDOS option. This advantage could increase or decrease upon finalization of the CDOS implementation schedule and identification of the RMA specifications for the Pacor.

7.5 OTHER ISSUES

In addition to the trade-offs identified in Section 7.1, 7.2, and 7.3, there are several issues that may significantly affect the TDCF implementation decision. The first relates to the TDCF performance requirements. The second relates to the assumptions used to develop the TDCF requirements and the Pacor and CDOS TDCF architectures. The third relates to whether there will be a Code 500 policy for the 1997 time frame that prescribes the Level Zero processing facility to be used by TRMM.

The majority of the TDCF performance requirements specified in Section 3.3 have associated with them a "(TBR)", indicating that the values stated in the requirements have not yet been finalized. These values must be validated and all "(TBR)"s removed prior to a final evaluation of the TDCF implementation. Significant changes in any of these values could result in significant cost or performance impacts which could in turn determine the final TDCF selection.

The assumptions used to develop the TDCF requirements as well as both TDCF architectures must also be validated to ensure the conformance of the proposed architectures with appropriate functional, performance, and operational requirements. Of particular interest are the development schedules associated with the Pacor and GBRS upgrades (Section 6.1.3) upgrades and the CDOS implementation (Section 6.2.5), and the resolution of the type(s) of data stored by the CDOS Archival Data Management Service (Section 6.2.2).

Finally, as noted in Section 6.1.3.1, the recent CDOS decision to support the Packet Telemetry CCSDS Recommendation (CCSDS 102.0-B-2, January 1987) strongly suggests that at some time in the future CDOS will assume mission loads that might otherwise have

Table 7-2. Trade-Off Study Summary

Trade-Off Issue	Pacor Implementation	CDOS Implementation
Cost Factors		
Marginal Development	$4.5 - 5.9 Million	Unknown
Marginal Operations	$800,000/Year	Unknown
Communications	$2X/Year	$X/Year
Risk Factors		
Development/Schedule	Low	High
Operations	Low	Low
Operational Factors		
Operational Convenience	High	Medium/High
Flexibility	Medium	Low
Other Processing Impacts	None	Lower POCC Processing Costs

been assigned to the Pacor. An issue to be investigated is whether Code 500 will establish a policy requiring all missions launched subsequent to a to-be-specified cut-over date or having data rates greater than a to-be-specified maximum rate to use the CDOS Level Zero processing capability. If there is a high probability that such a policy will in fact be implemented prior to the TRMM launch, the trade-offs presented in this section may become irrelevant.

8.0 RECOMMENDATIONS FOR THE FINAL TDCF SELECTION PROCESS

This document has identified the baseline TDCF requirements and the assumptions upon which those requirements are based, defined two possible TDCF architectures that satisfy the specified requirements, and presented the various trade-offs associated with those architectures. The final selection process regarding the TDCF architecture must include the resolution of several fundamental issues, including the validation of the requirements and their underlying assumptions, the validation of the trade-off analyses subsequent to any changes in the requirements or assumptions, and the likelihood of a future Code 500 policy regarding the use of institutional LZP facilities. The proposed TDCF architectures presented in this report should be re-evaluated if requirements or assumptions change and as new information becomes available.

8.1 VALIDATION OF TDCF REQUIREMENTS AND UNDERLYING ASSUMPTIONS

A TRMM Science Team has not yet been formally established by the Project. It is necessary to identify the TRMM Science Team as soon as possible to confirm the propriety of the TDCF requirements and assumptions upon which the architecture options and trade-offs are based.

The TDCF requirements presented in Section 3 were developed on the basis of historical Level Zero processing functions and the mission assumptions identified in Section 4. As the TRMM project progresses, both the assumptions and the requirements should be carefully reviewed by the TRMM Science Team and coordinated with the Project and with Code 500 to ensure both the scientific appropriateness and the functional feasibility of the TDCF requirements. It is critical that the TDCF be neither over-specified nor under-specified and that all of requirements levied on the TDCF be clear and appropriate. Over-specification, under-specification, or inaccuracies in the requirements due to inaccurate or incorrect assumptions could result in the selection of a TDCF architecture that does not cost-effectively provide the necessary functional, performance, or operational capabilities.

Requirements that are currently considered issues are primarily performance requirements whose stated values must be validated as the TRMM Project is refined. Performance requirements potentially of issue include the number of virtual channels to be supported (3.3.1.2); the data transmission rates from the TDCF to users (3.3.1.6 through 3.3.1.10); the daily real-time (3.3.2.2) and quick-look (3.3.2.4) processing capacities; the 2-year storage of raw data (3.3.3.2); temporary storage requirements for production data products (3.3.3.4); and operational requirements for MTBF (3.4.1.1), MTTR (3.4.2.1) and availability (3.4.3.1). These requirements generally have a "(TBR)" associated with the performance specification value.

8.2 RE-EVALUATION OF PROPOSED TDCF ARCHITECTURES

Once the TDCF requirements and assumptions have been validated by the TRMM Project, the proposed TDCF architectures should be reviewed to ensure their continued conformance with the TDCF requirements. This evaluation should also take into account new information not available at the time this study was conducted. For example, the CDOS Level III requirements specification scheduled for release in late 1990 as part of the Request for Proposal (RFP) for the CDOS Phase C/D implementation should be carefully reviewed in conjunction with the CDOS assumptions and scenarios developed in this report. The proposed architectures should be iterated as necessary to incorporate any changes in the TDCF requirements or assumptions as well as additional supporting data.

8.3 VALIDATION OF TRADE-OFF ANALYSES

Subsequent to the validation of the requirements and assumptions and any necessary modifications to the proposed Pacor-based or CDOS-based TDCF architectures, the trade-offs presented in Section 7 should be reviewed and updated as necessary. For example, changes in the currently specified data transmission rates to users could impact the communications costs associated with each proposed architecture.

The development and operations costs associated with each TDCF implementation should be revised to reflect any modifications to the architectures. These estimates should be refined upon completion of current analyses being conducted by Pacor and CDOS staff.

The TRMM-specific processing costs incurred in the production of TRMM Level Zero data products should be assessed and incorporated in the cost trade-offs presented in Section 7.1. Neither Pacor nor CDOS currently has in place a methodology for apportioning the cost of processing resources required to support individual users. Studies are underway for both systems to establish a means of tracking resource usage by user; the assignment of resource costs would be a natural extension to these studies.

The actual development risks associated with the CDOS implementation should be assessed as better data becomes available. The Statement of Work (SOW) included in the RFP for the CDOS Phase C/D implementation should provide the required insight. The RFP is currently scheduled for release in late 1990; a preliminary version may be available at an earlier date.

Similarly, the operations risks associated with the Pacor implementation should be evaluated and revised if it is merited.

8.4 OTHER CONSIDERATIONS

Section 7.5 identified a critical issue in the TDCF architecture evaluation to be the possibility of a future Code 500 policy regarding the use of CDOS for any new missions requiring a Level Zero processing capability. The probability that such a policy might be implemented should be carefully investigated and quantified, since such a policy would potentially preclude the selection process and negate the need to update the trade-off study.

APPENDIX A - GLOSSARY OF TERMS

Ancillary Data - Data other than instrument data required to perform an instrument's data processing. They include spacecraft/platform engineering data (e.g., orbit data, attitude data, time information, pointing information, optics temperature, structure temperature, instrument mounting alignment), calibration source data and data from other instruments (e.g., cloud information derived from a second instrument, status of items in a second instrument which could create interference with the instrument data being processed, map data, atmosphere temperature grids).

Auxiliary Data - Data not available from on-board sources, but obtained from other sources, which are used with ancillary data in the processing or interpretation of given data set. Auxiliary data include FDF processed refined/repaired ancillary data and can include engineering data from external sources, system test data or management data.

Captured Data - The set of all return link data that have been stored on a nonvolatile storage medium by the TDCF prior to processing of any kind. The captured data include all spacecraft/platform data, instrument data, and ancillary data downlinked from the spacecraft.

Commands - The set of data that effect and control instrument and spacecraft operations. Commands are generated by the POCC as necessary to ensure spacecraft health and safety, and by the TSDIS SOCC to ensure proper instrument operation to maximize the utility of the instrument data.

Data Product - One (or more) processed Primary Data Set(s) and associated quality and accounting information.

Engineering Data - The set of data comprising spacecraft engineering data, health and safety engineering data, and instrument engineering data.

Health and Safety (Engineering) Data - That set of Spacecraft Health and Safety Data, Instrument Health and Safety Data, and possibly Instrument Science Data required to operate and maintain all on-board spacecraft systems, including all scientific instruments, within a predefined safe operating regime, including appropriate emergency safe states.

Housekeeping Data - See Spacecraft Engineering Data

Instrument Data - All data originating from within the scientific instrument systems.

Instrument Engineering Data - Data produced by engineering sensor(s) of an instrument, used either for operating the instrument or for processing the science data generated by the instrument.

Instrument Health and Safety Data - That subset of instrument engineering and/or science data needed to permit the instrument to be operated within a predefined safe regime including appropriate emergency safe states.

Instrument Science Data - Data produced by the science sensor(s) of an instrument, providing direct or indirect measurements of the external physical parameters being investigated by the instrument.

Level Zero Processing - That processing performed by the TDCF to yield real-time, quick-look, or production data products.

Orphan Packets - Packets that have become separated from and were not included in the appropriate Primary Data Set during production processing. Orphan packets may result from an incomplete or interrupted tape recorder dump during the scheduled TDRS acquisition session. Orphan packets are anticipated to be encountered very infrequently.

Playback Data - Spacecraft/Platform Data, Instrument Data, and Ancillary Data that have been recorded on one of the TRMM spacecraft's solid state recorders during the previous orbit for replay to the ground during the next scheduled TDRS contact.

Primary Data Set - The set of all packets having a single APID, and having a source packet time code between a predefined start and stop time. For real time and quick-look processing the start and stop times coincide with the scheduled start and stop times of a TDRS acquisition session; for production processing the start and stop times coincide with a 24-hour period commencing at midnight.

Production Processing - The TDCF process that separates virtual channels, demultiplexes packets, and, on the basis of the APID, merges real time and playback packet channels, time orders the primary data set, deletes redundant packets, performs data accounting and analyzes data quality. The resulting production data products are transmitted to users within 24 hours of receipt of the last bit of data comprising the primary data set by the TDCF.

Quick-Look Processing - The TDCF process that separates virtual channels, demultiplexes packets, and, on the basis of the APID and the established quick-look schedule (TDRS acquisition session), time orders the primary data set, performs data accounting, and analyzes data quality. The resulting quick-look data products are transmitted to users within 2 hours of receipt of the last bit of data comprising the primary data set by the TDCF. Quick-look primary data sets are limited to a single TDRS acquisition session and playback packet channel. No merging of real time and playback data is performed.

Raw Data - Data as it is received from the spacecraft, prior to any processing on the ground. Raw data becomes captured data upon storage of the raw data on a nonvolatile medium by the TDCF.

Real-Time Processing - The TDCF process that separates virtual channels, demultiplexes packets from the real time virtual channel (if required by the user), and summarizes data quality and accounting information for packets having specified APID(s) received during a single TDRS acquisition session. The real time data are forwarded to users within 1 second of receipt by the TDCF.

Real-Time Telemetry (Real-Time Data) - Spacecraft/Platform Data, Instrument Data, and Ancillary Data that are downlinked to the ground immediately after being generated on-board the spacecraft during a scheduled TDRS acquisition session. Real-Time Telemetry Data are also recorded on one of the TRMM spacecraft's solid state recorders to ensure against the loss of data generated during a TDRS contact.

Science Data - See Instrument Science Data.

Software Updates - Revisions to on-board software to correct errors or to enhance on-board operations. Software updates are generated on the ground by the TSDIS SOCC or the POCC and uplinked to the spacecraft via the SN.

Spacecraft/Platform Data - All downlinked data originating from spacecraft level systems excluding that data generated by the scientific instruments.

Spacecraft Engineering/Housekeeping Data - Data which describes the physical condition and operation of the spacecraft platform and interfaces to the instruments on the platform. Parameters might include temperatures at specific points, voltages, power levels, switch settings, recorder status, on-board computer status, etc.

Spacecraft Health and Safety Data - That subset of the Engineering Data required to maintain all on-board spacecraft platform systems within a predefined safe operating regime.

TDRS Acquisition Session - The period of time during which data are received from the TDRS.