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VERY LARGE TELESCOPE

Data Flow for VLT/VLTI Instruments

Deliverables Specification

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3.0	01/02/2011	4.9	Removed DFS Impact Document
		4.9, 4.10, 4.11	Added Obs.Prep.Tools documentation and software
		4.4, 6	Added DRL Validation and Test document
		5	Updated generic schedule
		3.4	Revised for science-grade data products
		3.5	Revised for ESO-Reflex

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Contents

Chapter 1

Introduction

The VLT Data Flow System (DFS) was first defined as a concept in 1995, several years after the VLT Control System was specified. It provides high level integration tools and utilities needed for the VLT Science Operations and service to the astronomical community. For efficient operation of the VLT, instruments must be well integrated into the Data Flow System.

1.1 Purpose

This document defines the interface between a VLT Instrument Consortium (VIC) and Data Flow System in terms of deliverables and dependencies. It lists a complete set of Data Flow System related tasks which should be completed by a VIC and specifies the products to be delivered. Depending on the complexity of a given instrument, some of these deliveries may be waived by ESO after an explicit agreement.

Dependencies on products provided by ESO are also listed to make it easier for a VIC to perform its planning. A typical schedule for the Data Flow System related tasks linked to a VLT instrument is given with the minimum set of milestones required.

1.2 Acknowledgments

The initial version (1.0) of this document was written by P.Grosbøl and P.Ballester for the 1st generation VLT instruments. The second revision (2.0) addressed VLT 2nd generation instruments and benefited from the contributions of F. Comeròn, R. Hanuschik, A. Kaufer, M. Péron and D. Silva. The third revision (3.0) addressed Reflex workflows and Observation Preparation Tools and benefited from the contributions of W. Freudling and M.Romaniello in particular to the Section 3 of the document, as well as Thomas Bierwirth for the Section 4.10. The document also greatly benefited from the comments provided by the internal reviewers and the instrument consortia.

1.3 Scope

The current specifications address all tasks related to the Data Flow System which must be considered by a VIC in the context of building and delivering a VLT instrument. Instruments build internally in ESO follow exactly the same scheme with ESO being in the role of the VIC.

1.4 Applicable Documents

The following documents form a part of this document to the extent specified herein. In the event of conflict between the documents referenced herein and the contents of this document, the contents of this document shall be considered as a superseding requirement.

[1]	Common Pipeline Library User Manual	VLT-MAN-ESO-19500-2720
[2]	ICD between VCS and P2PP System	VLT-ICD-ESO-17240-19200
[3]	Data Interface Control Document	GEN-SPE-ESO-19400-0794
[4]	VLTI Data Interface Control Document	GEN-SPE-ESO-15000-2764
[5]	VLT Science Operations Implementation Plan	VLT-PLA-ESO-10000-1674

1.5 Reference Documents

The following documents are referenced in this document.

[6]	International Standard - Programming Languages: C	ISO/IEC 9899:1999(E)
[7]	Gasgano User's Manual	VLT-PRO-ESO-19000-1932
[8]	P2PP User's Manual	VLT-MAN-ESO-19200-1644
[9]	ESO Reflex User Manual	VLT-MAN-ESO-19500-5037

1.6 Linked Documents

[10]	http://www.eso.org/pipelines	ESO Pipelines
[11]	http://www.eso.org/cpl	Common Pipeline Library
[12]	http://www.eso.org/gasgano	Gasgano
[13]	http://www.eso.org/reflex	ESO-Reflex
[14]	http://www.eso.org/observing/etc	Exposure Time Calculators
[15]	http://archive.eso.org/cms/tools-documentation/eso-data-interface-control	DICB
[16]	http://www.eso.org/qc	Data Quality Control
[17]	http://www.eso.org/sci/observing/phase2/sm_overview.html	Phase II Instrument Overview Table

1.7 Abbreviations and Acronyms

The following abbreviations and acronyms are used in this document as shown below:

CDR	Conceptual Design Review
CFP	Call for Proposals
COM	Commissioning Phase
CPL	Common Pipeline Library
DFI	Data Flow Infrastructure Department of SDD
DFS	Data Flow System
DICB	Data Interface Control Board
DID	Data Interface Dictionary
DMO	Data Management and Operations Division of ESO
DPQC	Data Products and Quality Control Group of DMO
DRL	Data Reduction Library
DRS	Data Reduction System
EIR	ESO Instrument Responsible
ESO	European Southern Observatory
ETC	Exposure Time Calculator
GTO	Guaranteed Time Observations
GUI	Graphical User Interface
FDR	Final Design Review
FITS	Flexible Image Transport System
HTML	Hypertext Markup Language
IDC	Instrument Description Database
IDF	Instrument Definition File of an Exposure Time Calculator
INS	Instrument Division of ESO
OB	Observation Block
OT	Observing Tool
P2PP	Phase 2 Proposal Preparation
PAC	Preliminary Acceptance Chile
PAE	Preliminary Acceptance Europe
PAF	Parameter File
PDR	Preliminary Design Review
PDRM	Pluggable Data Reduction Module
PH2	Phase 2
PI	Principal Investigator
PSD	Pipeline Systems Department of SDD
PSO	Paranal Science Operations
QC1	Quality Control Level 1
RB	Reduction Block
SDD	Software Development Division of ESO
SGDP	Science Grade Data Product
SO	Science Operations
SV	Science Verification

USD	User Support Department of DMO
VCS	VLT Control Software
VIC	VLT Instrument Consortium
VIT	VLT Instrument Team
VLT	Very Large Telescope

1.8 Glossary

Archive: see Science Archive Facility

Calibration Plan: instrument-specific description of what calibration data are acquired, and what QC1 parameters will be computed.

Calibration Products: the FITS frames or tables produced when raw calibration data are processed using a Pipeline recipe

Calibration Database, Master: a Science Archive database that contains calibration products certified by the Data Products and Quality Control group.

Calibration Database, Local: a set of static reference calibration products.

Data Products and Quality Control Group (DPQC): a group of the Data Management and Operations Division based at ESO-Garching. The main activities of this group are to produce master calibration frames for the ESO Science Archive and other customers, measure, score, and trend QC parameters, create science products for pipeline supported instrument modes, and organize and pack data for each VLT/I observing run.

Data Frame (frame): a FITS file produced by executing a VLT observation (raw data).

Data Interface Dictionary: A computer readable dictionary which defines all terms used by the Data Flow System to describe data, e.g. meaning of keywords in FITS headers and setup files.

Data Products: generic term for FITS frames or tables produced when raw science or calibration data are processed by a Pipeline recipe.

Frame: see Data Frame

Headers (FITS Headers): the standard FITS headers contained in all FITS files

Observation Block (OB): the fundamental scheduling unit of VLT science operations. An OB contains the parameters necessary to configure the VLT system (telescope and instrument) as well as execute a sequence of observations. In principle, OBs are indivisible - they are executed (or re-executed) in their entirety.

Observing run: a subset of an approved observing programme. All observations within an observing run are obtained with the same instrument (often the same instrument mode) under similar observing conditions.

Observing Tool (OT): a software application that supports the creation and execution of queues of Observation Blocks.

Paranal Science Operations (PSO): the group responsible on Cerro Paranal for executing Service Mode observations and supporting visiting astronomers during Visitor Mode observations. PSO consists of staff astronomers, fellows (post-docs), telescope-instrument operators (TIOs) and data handling administrators.

Phase 1: the bi-annual observing proposal management process. Activities include: Call for Proposals revision and release; proposal submission and tracking; proposal scientific and technical review; time allocation; semester schedule creation and management.

Phase 2: the Service Mode observing preparation process. During Phase 2, users create and submit Observation Blocks, as well as other supporting information.

Pipeline: the set of DFS tools used to invoke pipeline recipes and process instrument data. The pipeline can operate in three environments: on-line, off-line, or desktop.

QC1 parameters: parameters computed by the Pipeline used to assess the data quality. These parameters are used for Quality Control.

Quality Control: Operational applications needed to quantitatively control the proper realization of observations by tracking observation conditions, stability and accuracy of calibrations.

Raw Data: data produced by the execution of Observation Blocks

Recipe, Pipeline: An executable program performing a sequence of individual data processing steps turning raw frames into calibration or science data products. A piepline recipe takes as input a list of images (science or calibration), a list of calibration frames and control parameters. The product of a pipeline recipe is called a science product or a calibration product depending on the type of input images.

Reduction Block: a Pipeline file that contains the information necessary for the processing of raw data

Science Archive Facility (Archive): a collection of databases and the archive that contain all the raw data produced by the VLT/I, all certified calibration products, and all QC1 parameters.

Science Grade Data Products: data products which can be used as-is to extract scientific conclusions, or to carry out quantitative measurements. This implies that the instrument signature has been removed, the SGDP is calibrated in physical units, and the signal-to-noise ratio is close to the optimum which can be achieved (see Section 3.5.1).

Service Mode (SM): an operations mode where users allocated observing time do not travel directly to the telescopes, but submit Observation Blocks for ESO to execute on their behalf. Service Mode observations are flexibly (or dynamically) scheduled, i.e. OBs are executed based on a variety of scheduling constraints including scientific priority, instrument configuration, and requested observation conditions.

Trending (Trend Analysis): the process of tracking the values of QC1 parameters as a function of time.

Template, Instrument: A set of instructions for the performance of a standard operation on an instrument, the instrument and detector setups. The templates represent specially devised sequences for often used instrument operations and calibrations.

User Support Department (USD): part of the Data Management and Operations Division, this Garching-based operations group provides front-line user support for Phase 1 and Phase 2 activity, as well as OB scheduling support during Service Mode operations.

Visitor mode observing: an operations mode where users allocated observing time travel directly to the telescope and execute their Observation Blocks with direct on-site support of Paranal Science Operations.

Chapter 2

Overview

The Data Flow System provides a high level infrastructure for handling science data within the VLT environment. A consistent, homogeneous view is essential for the efficient operation of the observations, the successful population of the VLT archive, and the service to the ESO astronomical community, considering the large number of instruments available on the VLT. This can be achieved only if all VLT instruments implement a fully conforming interface to the Data Flow System. This document details all Data Flow System components and interfaces which an instrument must implement to ensure full compatibility. A summary of the Data Flow concept is given in Ch. 3 where the general infrastructure and terminology used are presented.

The instrument specific components of the Data Flow System are detailed in Ch. 3 which provides a general overview of their functionality and relation to the Data Flow System infrastructure. The dependencies between the individual items and other components are discussed to make possible constraints on the development plan clear.

The deliverables expected from an instrument consortium are described in Chapter 4. These deliverables consist of documents, software and data. Table of contents for the DFS documents are specified with a description of the main Sections and references to example documents.

A generic schedule for Data Flow System related activities of a VIC is given in Ch. 5 with the minimum required set of milestones and a typical phasing of these tasks.

The testing and acceptance procedures for items delivered by the instrument consortium are described in Ch. 6

The appendices provide examples of tables and figures that shall be provided in the Data Reduction Library Specifications and Design documents.

Chapter 3

The VLT Data Flow System

The Data Flow System provides a high level infrastructure for handling science data within the VLT environment. A consistent, homogeneous view is essential for the efficient operation of the observations, the successful population of the VLT archive, and the service to the ESO astronomical community, considering the large number of instruments available on the VLT. The Data Flow System infrastructure deals with the end-to-end management of VLT observation proposals and data. Instrument specific components are supported by implementing separated modules which obey the general interface definitions. This chapter gives a short description of the Data Flow System infrastructure and of the instrument specific components.

3.1 Data Flow Concept

The Data Flow system is the scientific operating system of the VLT. It can be viewed as one machine with multiple components that interact. It is used to support proposal preparation and submission (Phase 1), observation preparation (Phase 2), observation execution, data processing, quality control, and archiving of raw data, as well as of data products (Phase 3). It consists of a set of applications that are generic, i.e. the same for all instruments and instrument specific modules. Instrument specific modules include instrument templates, exposure time calculators and pipelines.

3.2 Instrument Packages

The goal of the Instrument Package is to allow the definition of Observation Blocks (OBs), which are the fundamental scheduling units of VLT science operations. OBs consist of a sequence of templates that define the basic modes of operation for a given instrument. The actual template implementation is used by the instrument software and is typically written in the VLT Sequencer script language. Thus, the template scripts are not considered a part of the Data Flow System specific components.

The IP contains all the elements needed by the Phase 2 Proposal Preparation (P2PP) tool to define, edit, and verify the contents of an OB. Its current composition is the following:

- A set of Template Signature Files (TSF), one for each template, containing the complete set of parameters that must be entered for that template.
- An Instrument Summary File (ISF) containing the allowed values or ranges of each of the instrument setup parameters contained in the TSFs.
- The External Verification Modules (EVM), where a number of high-level validity checks on the contents of the OBs are coded.
- The External Time Report Modules (ETRM), containing the algorithms for the computation of the exposure and execution times of the OBs for the instrument under consideration.

3.3 Exposure Time Calculator

The exposure time calculators (ETCs) give astronomers the ability to estimate the signal to noise achieved under a set of assumptions about the performance of an instrument and the observing conditions. ETCs are usually provided for the main modes of all VLT instruments in the form of World-Wide Web applications [14] centrally maintained on the ESO servers. The ETCs are validated during the commissioning phase and released to the users together with the VLT Call for Proposals. After the first Call for Proposals, the ETCs are updated by ESO to reflect changes to the instrument configurations or optical throughput.

3.4 The Common Pipeline Library

The *Common Pipeline Library* (CPL, [11]) consists of a set of C libraries, which have been developed to standardize the way VLT instrument pipelines are built, to shorten their development cycle and to ease their maintenance. All ESO data reduction software must be developed with CPL The *Common Pipeline Library* was not designed as a general purpose image processing library, but rather to address two primary requirements. The first of these was to provide an interface to the VLT pipeline runtime-environment. The second was to provide a software kit of medium-level tools, which allows astronomical data-reduction tasks to be built rapidly into an instrument specific Data Reduction Library delivered by the instrument consortia to ESO for the integration of pipelines (Fig. 3.1)

The *Common Pipeline Library* provides:

- many useful data types (property lists, images, tables, ...),
- string and file utilities,
- medium-level data access methods (a simple data abstraction layer),
- image and signal processing capabilities,
- standard implementations of commonly used data reduction tasks,
- support for dynamic loading of recipe modules, and,

- standardized application interfaces for pipeline recipes.

Despite the bias towards instrument pipeline development, the library core provides a variety of general-purpose image and signal-processing functions. Thus, it also serves well as a basis for any generic data-handling package.

A few higher-level functions that implement standard data reduction algorithms are included in CPL (e.g. shift-and-add). If an algorithm is required for more than one instrument it canl be considered to become part of CPL (e.g. bias subtraction, wavelength calibration).

3.4.1 CPL Plugins

Pipeline recipes are executable programs performing a sequence of individual data processing steps turning raw or intermediate product frames into calibration or science data products. In order to be used as part of the DFS pipeline the recipes have to be implemented using the CPL library's plugin interface. A pipeline recipe implementation using the plugin interface results in a dynamically loadable software module, which can be executed by different front–end applications (the daemon process in case of the on–line pipeline or Gasgano [7] for instance.)

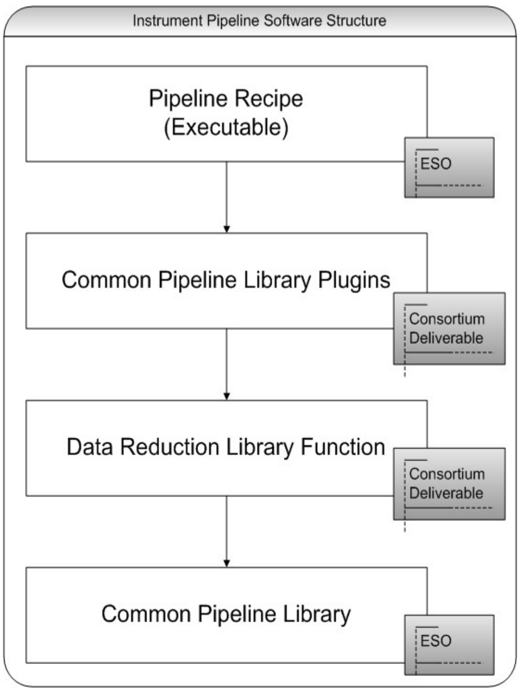

Figure 3.1: Building Pipeline Recipes from the Common Pipeline Library

The CPL plugin interface is used in order to:

- provide a standard API (Application Programming Interface) for pipeline recipes.

- share a single pipeline installation among several front–end applications
- insulate the recipe developer from the details and peculiarities of the recipes runtime environment.

Technically the plugin interface is a standardized function call on top of the actual data reduction functions provided by the Data Reduction Library. The necessary front–end applications to drive the plugin execution and the configuration files for pipeline recipes are provided by ESO.

A detailed presentation of the CPL plugin with examples of implementation is provided in [1] (Section 3.5, "How to implement a Pluggable Data Reduction Module").

3.5 DFS Pipelines and Data Reduction Environments

All instruments at the VLT have a pipeline which is used on-line and off-line on the mountain, off-line in Garching and distributed to the ESO astronomical community. Within the end-to-end operations concept, the main pipeline missions are:

- to process raw calibration frames into master calibration products
- use these master calibrations to produce QC parameters for monitoring telescope, instrument and detector performance
- to process raw science frames, using master calibration products, into science data products. Those data products consist of data with the instrumental signature removed and whenever possible calibrated into physical units (e.g. flux, wavelength) with associated error bars.

Conceptually, the DFS pipeline system has two parts: data management and data processing. Data processing is instrument specific and the data processing executables are called pipeline recipes. Data management is instrument independent and is implemented as part of the DFS infrastructure. Data management can be interactive (e.g. when used by the external users) or automatic (in the operational environment). The goal of data management can be divided in four parts:

- data classification ("what kind of data am I")
- data grouping ("To which group do I belong?")
- data association ("What calibration products are needed to process me?")
- pipeline recipe selection

Each pipeline recipe accepts as input a list of images to be processed, a list of calibration frames required to process the input frames and control parameters. The pipeline recipes must be built in such a way that they can be operated within and outside the DFS infrastructure. In other words, instrument pipelines do not access databases and do not visualize or plot any data. For instance pipeline recipes do not write any information in the calibration database. They may create pipeline products, generate quality control parameters such as zero-points. The ingestion of this information in the database is done by DFS infrastructure modules. The pipeline recipes are for a large part identical in all three environments listed below (Observatory Pipeline, Quality Control Pipeline and Science-Grade Desktop Environment), the difference comes from the way they are being operated.

3.5.1 Pipeline Data Products

Science grade data products (SGDPs) are data products which can be used as-is to extract scientific conclusions, or to carry out quantitative measurements. This implies that the instrument signature has been removed, the SGDP is calibrated in physical units, and the signal-to-noise ratio is close to the optimum which can be achieved. The achieved data reduction accuracies shall not degrade the top-level requirement specifications as defined in the Technical Specifications and the Statement of Work of the instrument project. All SGDPs also include error estimates. SGDPs should be free of systematic errors that would prevent to reach demanding science goals.

SGDPs may involve the combination of data taken from different Observation Blocks, on different nights. Typical SGDPs are fully calibrated and mosaiced images which include noise maps, one or two-dimensional flux calibrated spectra with error bars, or three dimensional position-wavelength cubes. Any assumption used in the creation of SGDPs are independent of the science goals, such as assumptions on instrument properties, environmental conditions or noise properties. Assumptions on the scientific contents of the data, external knowledge which is not generally valid or depends on the targets, or scientific judgment related to the contents of the images is not used for the production of SGDPs. SGDPs are therefore general purpose data products and independent of specific targets. For example, photometric redshifts are not SGDPs since they depend on spectral templates. Single-line redshifts (e.g. the results of Ly-α or Hα) searches are also not SGDPs since they depend on external judgment to identify the line. On the other hand, redshifts based on unambiguous sets of lines might be SGDPs.

A **Science Data Reduction Package (SDRP)** is an integrated software package which can be used to convert raw data into SGDPs. A SDRP typically includes a number of modules which are run in sequence. These modules are called recipes. Ideally, SGDPs can be produced without any interactivity, but there are observing modes where interactive recipes are necessary to create SGDP. A SDRP might therefore include both interactive and non-interactive recipes. A **pipeline** is a sequence of non-interactive recipes which can be run stand-alone.

3.5.2 Observatory Pipeline

The observatory pipeline runs in quasi real-time and in an automatic manner without user interaction. Default parameters and standard calibration solutions are being used. Those calibration solutions are being updated regularly but might not be the best ones for a given night. The primary goal of the on-line pipeline is to support the on-line quality control process by deriving Quality Control parameters per generated pipeline product. The main customer of the on-line pipeline is Paranal Science Operations. Visiting astronomers using data modes supported by the pipeline may also benefit from this tool.

The DFS pipeline infrastructure runs as a daemon waiting for new frames to be generated and delivered to the pipeline workstation. It is implemented as a set of rule-based modules. The modules themselves are instrument independent while the rules encompass all the required instrument knowledge. This information is extracted from the FITS headers of the data being processed. The daemon reacts upon 1) arrival of single frames and 2) upon termination of a template. This means that the set of frames produced by a template is the biggest unit of raw data which can be processed together in the on-line environment. The pipeline infrastructure first classifies the data into categories, groups the data, and associates to the raw frames the appropriate calibration data. All this information forms a so-called Reduction Block.

3.5.3 Quality Control Pipeline

Quality Control in the Data flow System is the set of operational applications needed to quantitatively control the proper realization of observations by tracking observation conditions, stability and accuracy of calibrations. The constant flow of raw data from the VLT instruments splits into data streams for the science data and the calibration data. The calibration data stream has three major components: 1) calibrations taken to remove instrument signatures from science data, 2) conversion to physical units, and 3) calibrations taken for routine daily instrument health checks. Fundamental in the QC process is the use of automatic data processing packages, the pipelines. The pipeline generates from the data Quality Control Level 1 (QC1) parameters, which characterise the observational performance of the instrument (e.g. image quality, photometry zeropoints, optical throughput, sensitivities, offsets). For each instrument project, the QC1 parameters are defined in the Calibration Plan and generated by the pipeline recipes.

At Paranal, the QC1 parameters are logged by the on-line pipeline into the Paranal Automatic Reporting system (AUTREP). The QC1 parameters on the mountain can be retrieved and visualised together with the other engineering parameters logged in the AUTREP system. They are also transferred daily to Garching where they are compared to earlier data. The system which combines the most recent quality data from Paranal and the full historical record for trending is called Health Check System. At Garching, the Data Products and Quality Control group uses the QC information to control the quality of the raw data, the quality of the products and product creation process, and the performance of the instrument component involved. QC1 parameters as well as the calibration products are stored in the Archive. They are used to create trending reports which provide feedback about the data quality and the instrument performance to the Paranal staff and to the end users. All users can browse the database of QC1 parameters stored in the Science Archive. Trending reports are displayed on the ESO Web pages of the Data Products and Quality Control Group [16].

The off-line pipeline is used by the Data Products and Quality Control Group in Garching to process all calibration data taken in standard modes into calibration products. These are quality-checked, archived and used by the pipeline to process all service mode science data. The calibration products are delivered to Paranal at regular intervals of time for usage by the on-line pipeline. The primary goal of the quality control pipeline is, as in the observatory environment, to support quality control. DFO also uses the quality-control pipeline to produce science data products for Service Mode programmes that used pipeline supported instrument modes. Those pipeline products will be made available to the community through the ESO archive.

3.5.4 Science-Grade Desktop Environment

All pipeline recipes are callable from the command-line (esorex front-end) and can be used by external users to re-process their data. Gasgano [7, 12], an interactive data management tool, can also be used as a front-end application to the pipeline recipes: it provides the means for classifying and grouping the data before calling the recipes (one at a time) with the appropriate parameters. ESO Reflex [9, 13] is a software tool to render and control the data reduction sequence as a graphical workflow. This allows the users to follow and interact with the data reduction flow in an intuitive manner, without the need for complex scripting. The easy-to-use graphical user interface (App. E) allows the user to make changes to existing workflows or create new ones of their own.

In addition to the pipeline recipes, the consortium shall provide a set of science-grade recipes which will differ from the pipeline ones in supporting more options (modularity, science-driven parameters, interactive improvements) and will make it possible to reduce the data to deliver science-grade data products (SGDPs), if necessary by combining observations from different Observation Blocks. The pipeline and science-grade recipes should share as much code as possible, for instance by relying on the same functions of the Data Reduction Library. The desktop set of recipes may also include a few utility functions (basic artihmetic, etc..) appropriate to the data generated by the instrument. The consortium shall also insure the availability of adequate visualisation tools for the raw instrument data and the reduced data generated by the recipes.

The consortia shall provide CPL recipes for the three mentioned environments, esorex, Gasgano, and ESO Reflex. The consortia shall provide Reflex workflows for desktop data reduction that include pipeline calibration recipes as well as (when relevant) specific desktop recipes for the generation of science-grade data products and interactive scripts. The expected accuracy achieved by the science-grade desktop environment are defined by the Technical Specifications of the instrument project and the Data Reduction Library Specifications. At the observatory, the desktop environment can be accessed on the off-line workstation.

Chapter 4

Deliverables

The explicit deliverables associated with the instrument specific Data Flow System components are listed in this Chapter and include documents, software and data. The set of documents includes the Data Flow System Impact, the Calibration Plan, the Data Reduction Library Specifications, the Data Reduction Library Design and the Exposure Time Calculator Specifications. Depending on the complexity of the instrument project some of these documents may be waived after explicit agreement with ESO. This Chapter describes the purpose and content of the documents to be provided and refers to existing similar documents. The software components include the Data Reduction Library and optional modules for the Exposure Time Calculators and DFS specific tools. These software components must comply with the SDD standards to be integrated by ESO in the VLT environment. The data to be provided include the Instrument Package, ETC Characteristic Data as well as the Instrument Test and Calibration data.

4.1 Calibration Plan

The Calibration Plan describes the calibration procedure for the instrument. It describes which instrument calibration data has to be collected with which frequency to allow one to remove instrumental signatures from the scientific data as well as to check the instrument health and to initiate corrective maintenance. The Calibration Plan shall contain the following information:

- Responsible group to carry out the calibrations (either Science Operations group or User)
- Phase, i.e. when the calibrations have to be carried out (day or nighttime)
- Frequency, i.e. how often the calibration task has to be carried out; expressed in 1/N days
- Purpose of the calibration
- Procedure, i.e. the way how the calibration is carried out,
- Pipeline outputs, including the Pipeline data products, the Quality Control (QC) parameters and/or the keywords entered into the VLT engineering data stream produced by the calibration task.
- Prepared Observation Blocks, i.e. the pre-prepared OBs to carry out the task and the corresponding queues in the Observing Tool.
- Prepared Templates, i.e. templates to carry out the task (if not composed in an OB).
- Duration, i.e. an estimate of the required time to execute the calibration task,
- Prerequisites, i.e. possible dependencies on instrumental or sky conditions or other calibration tasks are given.

The document includes the two main sections:

1. Scientific data calibrations: This section describes which instrument calibration data has to be collected with which frequency to allow one to remove instrumental signatures from the scientific data. If possible/applicable an estimate for the accuracy of the calibration products is given.
2. Instrument monitoring: This section describes which instrument calibration data has to be collected with which frequency to allow trend analysis of the instrument health and to initiate preventive maintenance.

Explicit deliverables: 1. Calibration Plan document

Requirements:
1. DFS documents shall be provided in Microsoft Word or Latex format as well as Acrobat Reader for archiving.
2. DFS documents shall conform to the standard VLT documents layout

Example document: FLAMES Calibration Plan, VLT-PLA-ESO-13700-3248

Usage by ESO: This document defines calibration and quality control operational procedures for an instrument. It identifies the required pipeline recipes.

4.2 Instrument Package

The core of the Instrument Package (IP) is formed by the templates to be used for the build up of OBs. A detailed list of the set of templates planned in order to define the basic modes of operations of an instrument shall be presented as part of the Preliminary Design Review.

The following explicit deliverables must be made available to ESO by the time of Commissioning 2:

- The Template Signature File (TSF) for each template
- A complete Instrument Summary File (ISF)
- A definition of the functionality of each template.

ESO reserves the right to introduce modifications in the templates based on the experience gained at commissioning 2 or later during dry runs, science demonstration, or regular operations.

ESO will be in charge of completing the IP by providing the External Verification Modules (EVMs), the Execution Time Report Modules (ETRM) and the External Constraints Set Modules (ECSMs). External Verification Modules (EVMs) provide a scripting interface permitting Support Astronomers to develop instrument and period specific scripts for testing and verifying observation blocks. By performing detailed tests on the OBs before they are submitted to the ESO repository, a reduced number of inconsistent OBs are sent to the observatory. The Execution Time Report Modules (ETRM) use the EVM scripting technology to generatee exposure and execution times for a given set of OBs. Further releases of P2PP and OT will support external instrument specific constraints by means of External Constraints Set Modules (ECSMs)

Explicit deliverables: 1. Instrument Packages

Requirements: 1. Instrument packages shall conform to the P2PP interface

Usage by ESO: Verification with P2PP, development of External verification modules

4.3 Data Reduction Library Specifications

The Data Reduction Library Specifications provides a technical description of the instrument modes, data formats and data processing routines required for both the scientific calibrations and the instrument monitoring tasks listed in the Calibration Plan.

4.3.1 Document Structure

The Data Reduction Library Specifications document shall include the following main Sections:

1. Instrument Modes and Configurations
2. Instrument Data Description
3. Data Processing Overview
4. Pipeline Recipes
5. Development Plan
6. Appendix: QC1 Parameters

Section: Instrument Modes and Configurations

The Instrument Modes and Configuration Section lists the instrument modes and sub-modes and instrument configurations. It identifies when relevant the standard settings of the instruments and those instrument modes which will be supported by the pipeline.

Section: Instrument Data Description

Raw data from the VLT instruments are stored according to the ESO Data Interface Control Board specifications [3,4] based on the FITS format.

The Instrument Data Description Section describes the specific structure of the data generated by the instrument, i.e. how the data are spatially projected onto the detector system (e.g. in terms of quadrants or detector subwindows) and stored in the FITS files produced by the instrument. This description covers the different observing modes and exposure types supported by the instrument.

The Instrument Data Description section describes only the instrument raw data. The structure of intermediate calibration data and reduction products will be provided in the Data Processing Overview and the Pipeline Recipes sections.

Section: Data Rates

An evaluation of the raw and reduced file size, data rates (MB/sec, GB/night, TB/period), as well as the specifications on processing time, shall be provided.

Section: Data Processing Overview and Reflex Workflows

The Data Processing Overview provides a summary description of the reduction process including in particular the instrument data table (see Appendix C of this document) and the calibration data table providing the PRO keywords identifying calibration products. It identifies the individual pipeline recipes that will be described in the Pipeline Recipes Section of the DRL Specifications.

The general organisation and specification of Reflex workflows for the different instrument modes are provided. The workflows can make use of any recipe developed for the observatory or quality-control pipeline, as well as recipes designed specifically for the workflow environment. The workflows will usually include iterative subworkflows, allowing the user to verify the achieved accuracy by means of plots or displays.

Section: Pipeline Recipes

The Pipeline Recipes section describes the science and calibration recipes and the instrument monitoring recipes in accordance with the Calibration Plan. The overall data calibration process usually involves two stages: first calibration solutions are determined from instrument calibration data, then these calibration solutions are applied to the science data. The science recipe derives physical quantities (e.g flux, polarization, or visibilities) as a function of position, time, or wavelength together with an estimate of the accuracy of these measurements.

The instrument independent calibration data (e.g. lists of arc line wavelengths, photometry and spectrophotometry flux references, visibility, radial velocity standards) which are required for the calibration will be described. Relevant sources for these data will be identified and such data provided to ESO.

For simple instruments there is only a single science reduction recipe which applies to all instrument modes. Generally there will be different science reduction recipes depending on the instrument modes and possibly sub-modes, and it might be necessary to identify general and special science reduction recipe.

Instrument monitoring recipes allow one to check the instrument health, and to initiate preventive maintenance. The instrument monitoring recipe rely on calibration exposures either internal or reference targets. Instrument monitoring recipes are usually distinct from instrument maintenance procedures which should be dealt with at the level of instrument templates and should not rely on pipeline processing.

Each recipe will be specified by describing:

- the name of the recipe
- the purpose of the recipe
- the type (Science, Calibration)
- input raw data and if relevant previous intermediate calibration data and static calibrations, mentioning for each file whether it is mandatory or optional
- recipe input parameters, and their default value for pipeline processing
- the processing algorithm, with a justification of the algorithm
- the resulting calibration or science data products including FITS data structure, data content and identification keywords such as PRO keywords [3]

- the expected accuracies, for example 90% of the theoretical achievable signal-to-noise for the photometry calibration, or 1/10 pixel for geometric calibrations like astrometry or wavelength calibration.
- the QC1 parameters that are produced by this recipe

Section: Development Plan

The development plan shall be defined in accordance with the major milestones of the instrument. The development plan must identify successive module deliveries, by which new functions are added to the Data Reduction Library. The development plan shall take into account the availability of data (either simulated, from other instruments or real data) to schedule tests of the Data Reduction Library.

Appendix: QC1 Parameters

The different pipeline recipes for calibration, reduction and instrument monitoring produce results in the form of FITS files, PAF files and Quality Control parameters. The Quality Control parameters are defined in a dictionary (see Appendix A of this document) and an initial list must be provided at PDR time. The QC1 parameters and the name of the corresponding FITS keywords to be written in headers of the FITS data products are specified in this Section.

Explicit deliverables:
1. Data Reduction Specifications document

Requirements:
1. DFS documents shall be provided in Microsoft Word or Latex format as well as Acrobat Reader for archiving.
2. DFS documents shall conform to the standard VLT documents layout

Example Document: X-Shooter Data Reduction Library Specifications (X-SH-SPE-FRA-10000-0014). Note that the X-Shooter documentation follows the template 1618/2.0.

Usage by ESO: This document specifies the detailed data reduction recipes to be applied to raw data frames.

4.4 Data Reduction Library Validation and Test

The Data Reduction Library Validation and Test document addresses the scientific validation of the algorithms and CPL recipe implementation. It describes the validation strategy, making use of previously existing data, simulated data, laboratory, commissioning and science verification data to formulate a complete validation strategy of the observatory, quality control and science-grade reduction recipes.

4.4.1 Document Structure

The Data Reduction Library Validation and Test document shall include the following main Sections:

1. Validation Plan
2. Simulated Data
3. Instrument Test Data
    - Data from similar instruments
    - Laboratory Integration Data
    - Commissioning Data
    - Science Verification Data
4. Additional Calibration Data

4.4.2 Section: Validation Plan

The Validation Plan describes the verification process of the data reduction software. Verification matrices shall be defined providing the list of requirement ID, description, test plan section and test verification method to be verified at the Preliminary Acceptance Europe (PAE) and Preliminary Acceptance Chile (PAC).

Validation procedures shall be developed along with the software for the different function levels:

- unitary test for each low-level Data Reduction Library function
- reduction tests based on the generic CPL plugin application
- end-to-end tests of Reflex workflows

With each delivery of the Data Reduction Library, a set of test procedures shall be provided, including input and result test data as well as a validation set (Section 4.6.4). The tests will be based on real and simulated instrument data, which can be obtained by using an existing instrument in a configuration as close as possible from the new instrument and by producing simulated data See 4.4.3) It is mandatory that all raw data produced by the instrument are fully documented as defined by the Data Interface Dictionary [3,4]. The test data (simulated or resulting from preliminary integration) shall contain all the keywords needed for the execution of data reduction recipes and workflows.

4.4.3 Section: Simulated Data

This Section describes the generation of simulated instrument raw data for the purpose of testing the data reduction functions and the pipeline recipes during the first phases of development. The validation sets delivered to ESO include only the simulated data, and not the simulation software used to generate the data.

The simulated data shall include the typical noise, cosmic ray hits, bad pixels, and other possible contamination which are typical of actual observation data, and will allow the developers and ESO to verify the robutsness and accuracy of the DRL and the noise, wavelength, background, fluxes, contrast or sensitivities as derived in the final pipeline products. These estimates derived from the the final pipeline products may then be compared to estimates from first principles.

The tests of the DRL that can be peformed using simulated data are described in this Section.

4.4.4 Section: Instrument Test Data

A full set of raw data frames from the instrument must be provided. At the different stages of the project these data will be used to:

- verify the conformance of the data to the Data Interface Dictionary.
- generate a set of master calibration frames in the Calibration Database
- test the DRL modules, the ESO pipeline, and the Reflex workflows

Subsection: Data from Similar Instruments

This Section describes the data available from similar instruments, which could be adapted for the validation of the data reduction software. The required modifications, limits of validity and schedule of availability of the data will be described.

Subsection: Laboratory Integration Data

This Section describes the instrument data that can be acquired during the phase of integration Europe, before the PAE. The tests can be performed on Laboratory Integration Data are described in this Section.

Subsection: Commissioning Data

This Section describes the instrument data that can be acquired during the phase of commissioning at Paranal, until the Science Verification. The tests can be performed on commissioning data are described in this Section.

Subsection: Science Verification Data

This Section describes the instrument data that can be acquired during the phase of Science Verification at Paranal. The tests can be performed on science verification data are described in this Section.

4.4.5 Additional Calibration Data

In addition the physical data required for calibrations and quality control must be defined as specified in the Calibration Plan if they are specific to the instrument. This may include for example tables of wavelengths for spectral calibration lamps and lists of standard stars with their magnitudes and positions.

The Consortium shall identify in this Section the possible lack of suitable calibration data, and the actions required to provide them.

Explicit deliverables:
1. Data Reduction Library Validation and Test Document.

Requirements:
1. DFS documents shall be provided in Microsoft Word or Latex format as well as Acrobat Reader for archiving.
2. DFS documents shall conform to the standard VLT documents layout

Example Document: N/A

Usage by ESO: The Data Reduction Library Validation and Test document will be used to plan the operational and scientific validation of the data reduction recipes and reflex workflows delivered by the Consortium. In the course of the project the Consortium shall provide sets of test data together with test reports. The data sets will be used the check the DID/DICB compliance of raw data and verify pipeline reduction procedures. Further, the calibration frames produced will initiate the first version of the Calibration Database.

4.5 Data Reduction Library Design

This document defines all modules of the Data Reduction Library (DRL) provided by an instrument consortium to process the data from an instrument. The Data Reduction Library shall be based on the ESO Common Pipeline Library [1]. Any usage of software libraries other than CPL and the libraries listed in [1] is not allowed unless it has been justified at PDR or FDR time and has received ESO approval. With regard to the Data Reduction Library Specifications, this document updates the general overview of the data processing and describes in detail each function provided by the Data Reduction Library.

4.5.1 Document Structure

The Data Reduction Library Design document shall include the following main Sections:

1. Mathematical Description
2. Functional Description
3. Instrument Data Description
4. DRL Data Structures
5. DRL Functions
6. Data Reduction CPL plugins
7. Validation, including tests and accuracy control
8. Development Plan
9. Appendix: QC1 Parameters
10. Appendix: Data processing table

Section: Mathematical Description

A mathematical description of the reduction process shall be provided, in particular for those parts of the processing involving advanced signal, image or statistical processing of the data. The methods are identified, reference is made to available publications. The accuracy limits are identified as well as error propagation formulae.

Section: Functional and Workflows Description

The Functional Description Section shall make use of functional diagrams to present the hierarchical structure of pipeline recipes and their decomposition in DRL functions (see Appendix D of this document). The context of utilization of the different reduction recipes and the calibration data required for each step are described by means of association maps (see Appendix B of this document).

The detailed structure of the Reflex workflows is described. The iterative subworkflow, visualisation windows, or specific procedures are described in this Section. This Section also provides an overview of the OCA rules for the workflow.

Section: Instrument Data Description

The Instrument Data Description Section shall describe the specific structure of the data generated by the instrument and is an updated version of the Section provided in the DRL Specifications document. The Instrument Data Description provides a definition of raw data types in the form of a data processing table (see Appendix C of this document).

The raw data are described, including the values of DPR keywords for each data type. It identifies the different type of data products generated by the instrument and the valid combinations of FITS DPR keywords. The DPR keywords correspond to the three FITS keywords HIERARCH ESO DPR CATG, HIERARCH ESO DPR TYPE, HIERARCH ESO DPR TECH that uniquely identify the type of data produced by the instrument for the pipeline processing [3].

The structure of intermediate data structures and pipeline products will be provided in the DRL Data structures and DRL Plugins Chapters.

Section: Data Rates

An evaluation of the raw and reduced file size, data rates (MB/sec, GB/night, TB/period), as well as the specifications on processing time, shall be provided.

Section: Data Reduction Library Structures

The intermediate data structures involved in the processing shall be defined and described. These will be ISO-C structures which must be stored in the form of FITS files to be reused by the pipeline.

The final data products will be FITS files with a header section composed of keywords taken from the raw data as well as additional processing (HIERARCH ESO PRO) and quality control (HIERARCH ESO QC) keywords. The data provided in the FITS files, either in image or binary table extensions, shall be specified.

Section: Data Reduction Library Functions

Each low-level function of the library must be described. Its input and output parameters shall be listed using the data structures previously defined. The main steps of the processing shall be identified making use when relevant of a pseudo-code description.

For each DRL Function the following information is provided:

- Name
- Working remarks
- Purpose
- Function parameters (name , type, default value, description)

- Input frames (data type, relevant FITS keywords)
- Other inputs
- Output frames (data type, relevant FITS keywords)
- QC1 outputs (QC1 parameters produced by this function)
- Other outputs
- General description, with a justification of the algorithm for the purpose of automatic pipeline processing and the expected accuracies
- Mathematical description
- Quality assessment (how to assess the quality of the results)
- Error conditions and handling
- Unit tests

Section: CPL Plugins

Each CPL plugin shall be described. It is expected that there is a one to one correspondence between instrument raw or intermediate product data types, pipeline recipes and a corresponding CPL plugin. This correspondence is documented in the Data Processing Table (see appendix C of this document). For each CPL plugin the following information is provided:

- plugin name
- purpose
- type (Science, Calibration)
- input raw data and if relevant previous intermediate calibration data
- plugin parameter list, and their default value required for unsupervised, automatic pipeline processing.
- algorithm pseudo-code including the reference to the previously defined DRL functions.
- the resulting calibration data including FITS data structure, data content and identification keywords such as PRO keywords
- the QC1 parameters that can are produced by this plugin in the form of parameter (PAF) files.
- Error conditions and handling

Section: Development Plan

A development plan shall be provided that lists the sequence of deliveries of functions and recipes and outlines the milestones in relation with the main phases of instrument schedule. It may not be necessary in this Section to mention actual dates but one may rather refer to main milestones of the instrument project (see Chapter 5 of this document).

Appendices

A number of appendices shall be provided including the data processing table and list of QC1 parameters as described in Appendices A and C of this document. Further information may be provided in additional Appendix sections.

Explicit deliverables:

1. Data Reduction Library Design document

Requirements:

1. DFS documents shall be provided in Microsoft Word or Latex format as well as Acrobat Reader for archiving.
2. DFS documents shall conform to the standard VLT documents layout
3. This document must be updated if any change is required to the Data Reduction Library.

Example document: X-Shooter Data Reducton Library Design (XSH-SPE-FRA-10000-0022). Note that the X-Shooter documentation follows the 1618/2.0 guidelines.

Usage by ESO: This document defines the detailed data reduction functions and plugins to be applied to raw data frames including input data and algorithms required.

4.6 Data Reduction Library

The DRL functions defined in the Data Reduction Specifications and Design documents must be implemented and delivered according to the following specifications:

- the Data Reduction Library shall be developed in ANSI/ISO-C99,
- and shall use the CPL functions [1] whenever available. Any usage of software libraries other than CPL and the libraries listed in [1] is not allowed unless it has been justified at PDR or FDR time and has received ESO approval.
- The DRL shall be verified on Linux operating systems (Section 4.6.1)

The set of pipeline recipes implementing these algorithms will be verified in the Data Flow System Pipeline for the instrument by ESO. The configuration of the Pipeline will also be made by ESO based on the Calibration Plan.

4.6.1 Development Environment

The version of the compilers, development tools and platforms used for the development and acceptance of the Data Reduction Library will be defined at the Final Design Review. It is normally based on packages used by the VLT Control Software and on versions that have been released and used for at least 6 months at ESO. The Consortium shall adapt the DRL software for new versions of the ESO development libraries (e.g. CPL) until final delivery to ESO.

A comprehensive description of the CPL development environment is provided in [1]. It includes a description of the pipeline environment, directory structures, build tools, test environment, and lists the programming standards and a set of allowed application libraries.

4.6.2 Copyright

The Data Reduction Library shall contain exclusively ESO copyright and license notices according to the standard header provided in [1].

4.6.3 Configuration Control

The ESO standard configuration control system for pipeline related development is the CVS system. The Data Reduction Library (which coding starts after FDR) will be placed by ESO under version control. All further developments on the library can be shared between ESO and the instrument consortium. Starting with version 1.0 all change requests to the Data Reduction Library shall be logged in the DFS Problem Report System. No changes to the DRL can be performed without ESO approval.

Changes to the Data Reduction Library are expected for a long period of time after the delivery of the version 1.0. These change requests shall be logged in the Problem Report System, checked in the version control repository and documented by updating the DRL Design document. Changes to the Data Reduction Design document shall also be logged into the DFS Problem Report System after FDR.

4.6.4 DRL Deliveries

Each delivery of the Data Reduction Library includes:

- a tar file of the source code until version 1.0, later versions shall be extracted from the CVS repository
- the QC1 dictionary for all parameters generated by the CPL plugins
- a test plan describing the sequence of tests performed on each CPL plugin and listing the input parameters, input instrument and ancillary data as well as the produced result data
- a set of raw instrument data for all instrument configurations supported by the delivered version of the DRL,
- ancillary data
- the result data (PAF, FITS and ASCII files) produced by the execution of the CPL plugins
- the updated Data Reduction Library Design document

The instrument consortium may be invited to deliver new upgrades of the library after the Preliminary Acceptance Chile, e.g. after the first period of Science Operations.

Explicit deliverables:

1. source code of the Data Reduction Library,
2. pipeline kit including recipes, workflows, and OCA rules,
3. one set of test data for each of these recipes.
4. a verification procedure for each of these recipes and a test report

Requirements:

1. The DRL shall be developed in ANSI/ISO-C 99
2. The DRL shall use CPL functions
3. The DRL shall be verified on Linux operating systems

Usage by ESO: The recipes will be integrated and verified in the DFS pipeline environment by ESO who also will configure it.

4.7 Exposure Time Calculator Specifications

The exposure time calculators (ETCs) give astronomers the ability to estimate the signal to noise achieved under a set of assumptions about the performance of an instrument and the observing conditions. ETCs are usually provided for the main modes of all VLT instruments in the form of World-Wide Web applications centrally maintained on the ESO servers. An Exposure Time Calculator must be available for all supported instrument mode.

A number of instrument models are already provided on the ESO ETC Web site: (http://www.eso.org/observing/etc). For all instruments projects it is required to provide the configuration information and ETC characteristic files. For some instruments it will be necessary to add functionalities to the existing ETCs. The Exposure Time Calculators Specification document provides the instrument description and data relevant for the development of the ETC.

4.7.1 Document Structure

The Exposure Time Calculators Specification document shall include the following main Sections:

1. Instrument Configurations
2. ETC Characteristic Data
3. ETC User Interface
4. Mathematical model
5. Calculation functions
6. Validation sets

Section: Instrument Configurations

The instrument modes and sub-modes relevant for the exposure time calculator are listed in this Section, including for instance main observation wavelength domains (short-, long-wavelength), the list of filters planned in each domain with the corresponding description, the list of wavelength settings for spectroscopy, or the list of detector settings. In each case all the corresponding numerical information shall be provided usually in the form of tables.

From this description ESO will define the ETC Instrument Definition File (IDF). The IDF is a configuration file of the ETC describing the optical paths of an instrument and the location of optical components along the allowed paths. It provides a syntax for describing exclusive or embedded optical paths and allows references to the optical components stored in the database, which can be filters, dispersive elements like grating or grisms, lenses, or detectors. From the IDF the ETC can access the actual ETC Characteristic Data relevant to each instrument configuration.

Section: ETC Characteristic Data

The ETC Characteristic Data include efficiency data for the different optical components of the instrument (e.g. telescope, fixed optical components, filter and grism, detector) as well as other data needed for ETC calculations. this Section of the document only lists and describes the files that will be delivered. The actual data are provided to ESO in the form of ASCII files (Section 4.8).

Section: ETC User Interface

The ESO Exposure Time Calculators involve an HTML template system that provides an homogeneous interface across all VLT instruments (http://www.eso.org/observing/etc). The Instrument Section of the input HTML form is specific to each project and shall be described in this Section of the document. When relevant specific information that should appear in the input or result form of the ETC shall also be described.

Section: Mathematical Model

The mathematical model for predicting the instrument performance shall be defined precisely by providing a mathematical description of the calculation as well as calculation forms based on Maple, Matlab, IDL or Microsoft Excel procedures.

Section:ETC Calculation Functions

For some ETC projects specific modules will have to be provided by the instrument consortium (e.g. dispersion relation, fiber loss, adaptive optics strehl ratio). The corresponding ISO-C modules will be specified in this Section of the document with their interface.

For each ETC Calculation Function the following information is provided:

- Name
- Purpose
- Function parameters (name , type, default value, units, description)
- Output parameters (name, type, units, description)
- General description, with a justification of the algorithm
- Mathematical description

Section: Validation Sets

A very important component of the consortium delivery are the validation sets for the Exposure Time Calculators and other tools that must provide a clear, verifiable and traceable calculation of the performance of the instrument that can be compared to the actual ETC results.

The ETC noise model shall be able to predict the error bars as included in the simulated data and commissioning data and as measured in the final pipeline products.

Explicit deliverables:
1. Exposure Time Calculators Specification document

Requirements:
1. DFS documents shall be provided in Microsoft Word or Latex format as well as Acrobat Reader for archiving.
2. DFS documents shall conform to the standard VLT documents layout

Example document: X-Shooter ETC Specifications (XSH-SPE-ESO-10000-0075)

Usage by ESO: The additional modules will be included in the general ETC library whereas the verification procedures will be included in the ESO regression tests of ETC's. ESO will create the GUI's required for the instrument ETC either by adding to existing ones or creating a new one.

4.8 ETC Instrument Description Database

The characteristic data shall be delivered in the form of ASCII files including a standard header documenting the origin and purpose of the file and the physical units of the data. It is not possible for ESO to make use of printed transmission curves and other graphical material.

The deliverable shall include the relevant tables of instrument configurations providing e.g. the list of spectrograph settings or fiber diameters involved in the different modes of the instrument.

When applicable the specific ANSI/ISO-C99 ETC calculation modules shall also be included in this delivery.

Explicit deliverables:

1. one file for each detector or optical component defining its properties,
2. ETC calculation modules as defined by the ETC Specifications document

Requirements:

1. The Instrument and Test Data shall be provided in FITS and ASCII format
2. The ETC calculation modules shall be provided as ANSI/ISO-C 99 functions.

Usage by ESO: The data and modules will be integrated into the ETC system by ESO.

4.9 Observation Preparation Tools Specifications

Note: The Observation Preparation Tool documents are optional and provided only when additional software is required for the preparation of observations.

Some instrument projects may identify tools that are necessary for the preparation of observations, operation or data processing and which are not already part of the standard DFS components P2PP or ETC.

For the VLT instrumentation, these tools should be be developed as Tcl/Tk Skycat plugins and described as part of the instrument control software documentation (e.g. FPOSS or FIMS, see [17]). The Consortia may however propose Java-based solutions, which will be evaluated by ESO. The software development standard will be defined in agreement with ESO, and reviewed during PDR and FDR.

The following information must be provided:

- Description of the proposed observation preparation tools
- Specification of observation preparation tools and of their interface to P2PP [8]. As an example the NAOS-PS observation preparation tool creates PAF files that are ingested in P2PP when creating Observation Blocks.
- Observing constraints to be added to P2PP [8] (e.g. Strehl ratio)

Explicit deliverables: 1. Observation Preparation Tools Specifications Document

Requirements:
1. DFS documents shall be provided in Microsoft Word or Latex format as well as Acrobat Reader for archiving.
2. DFS documents shall conform to the standard VLT documents layout

Example document: N/A

Usage by ESO: This optional document specifies the observation preparation tools that may be required in addition to the standard P2PP and ETC tools.

4.10 Observation Preparation Tools Design

Note: The Observation Preparation Tool documents are optional and provided only when additional software is required for the preparation of observations.

The Design document follows the Observation Preparation Tool Specifications document when a new tool is required. The design document shall describe the user interface, software design, and implementation plan for the planned observation preparation tool.

4.10.1 General Design Principles

The applications design shall at least be documented in terms of

- Important design decisions The most important design decisions and their underlying rationales
- Structural View Showing components and external libraries, their responsibilities, exposed interfaces and dependencies
- Interface Specifications For example Java interfaces and classes shall be described using Javadoc, following the SUN recomendations
- Deployment View In case a server-side is required, the physical deployment and the used control / data protocols shall be specified

The following usability features shall be taken into account druing the design:

- Conservative Usage of Colors Many users suffer from color blindness. Use color conservatively and provide alternative means of visual / textual differentiation.
- Popups The extensive usage of popup windows is discouraged. The application should have one integrated main window.

4.10.2 Interface to P2PP

P2PP allows attaching of parameter files (PAF files for short) to an OB's acquisition or science template. The PAF format is an ESO specific keyword-value format []. Basically this format allows one to define a map of keyword-value pairs like the example below. The # character is used for comments and keyword-value pairs (separated by a tab or a space) are defined one per line.

When a PAF file is attached to an acquisition or science template in P2PP, it carries out some basic validation, making sure that the following mandatory header keywords are present and that the file has correct format.

```
# PAF file header
PAF.HDR.START;
PAF.TYPE          "paramfile";
```

```
PAF.ID              "NAOS-2010-07-29T13:44:46.070";
PAF.NAME            "NGC4433.aocfg";
PAF.DESC            "NAOS PS - P2PP Parameter File";
PAF.CRTE.NAME       "NAOS Preparation Software - v1.105";
PAF.CRTE.DAYTIM     "2010-07-29T13:44:46.070";
PAF.LCHG.NAME       "";
PAF.LCHG.DAYTIM     "";
PAF.CHCK.NAME       "jnps";
PAF.CHCK.DAYTIM     "2010-07-29T13:44:46.070";
PAF.CHCK.CHECKSUM "3270103181";
PAF.HDR.END;
# <additional key/value pairs>
# . . .
```

If the file header is valid and only if it is attached to an acquisition template, P2PP looks for the following optional keywords in the remainder of the file. If these are valid, the values are assigned to the corresponding field of an OB.

```
# Constraint set parameters
SIM.ATM.AIRMASS  "1.5";          # Requested airmass (Decimal)
SIM.ATM.ZSEEING  "0.9";          # Requested seeing (Decimal)
SIM.PERF.ALTSTREHL "39.5";       # Requested Strehl Ratio (Decimal)
# Target parameters
TEL.TARG.NAME    "Your target"; # The target name (Alphanumeric 32 characters)
TEL.TARG.ALPHA   "122738.59";   # Right Ascension in hours (HH:MM:SS.sss or HHMMS
TEL.TARG.DELTA  "-081642.3";    # Declination in degrees (DD:MM:SS.sss or DDMMSS.
TEL.TARG.EQUINOX  "2000.0";     # Equinox (ALPHANUMERIC 8 characters)
TEL.TARG.EPOCH    "2000.0";     # Epoch  (ALPHANUMERIC 6 characters)
TEL.TARG.PMA "0.0";             # Proper motion RA (Decimal)
TEL.TARG.PMD "0.0";             # Proper motion DEC (Decimal)
```

The remaining keywords are not interpreted by P2PP, but are part of the OB and transparently passed along to the instrument software, meaning that they can be used while executing the OB. The output of an instrument-specific observation preparation tool must be in the form of one or more PAF files to be attached to the acquisition or science templates of an OB. It is currently not possible to programmatically interface to P2PP.

4.10.3 Client-Server Architecture

The usage of a server shall be avoided unless really justified. If necessary, the implementation of a server shall be discussed and aligned with ESO at an early stage. It shall be taken into account that usage of a server implies additional operational and maintenance overhead. If absolutely needed, the server should also execute on the Java technology stack using a servlet container. The server should be steteless, there shall be no server-side storage of client state between two requests of the same client.

4.10.4 Application Distribution

The distribution of applications is subject to policies defined by ESOs User Support Department.

Explicit deliverables:
1. Observation Preparation Tools Design Document

Requirements:
1. DFS documents shall be provided in Microsoft Word or Latex format as well as Acrobat Reader for archiving.
2. DFS documents shall conform to the standard VLT documents layout

Example document: N/A

Usage by ESO: This document is only required if an Observation Preparation Tools Specification document has been produced. The document provides the design of the observation preparation tools that may be required in addition to the standard P2PP and ETC tools. This document will be used to verify the conformity of the proposed design with ESO DFS components and software development guidelines.

4.11 Observation Preparation Tools Software

Note: The Observation Preparation Tool are optional and provided only when additional software is required for the preparation of observations.

The observation preparation tools described in Section 4.9 shalll be delivered together with a User's Guide document.

Explicit deliverables:

1. Observation Preparation Tools Software and User's Guide

Requirements:

1. DFS documents shall be provided in Microsoft Word or Latex format as well as Acrobat Reader for archiving.
2. DFS documents shall conform to the standard VLT documents layout

Example document: TBD

Usage by ESO: TBD

Chapter 5

Generic Schedule

A typical schedule of the Data Flow System related deliverables is presented together with the minimum set of milestones. The version numbers indicated for each delivery correspond to successive stages of preparation of a given delivery:

- Document draft versions are noted v.1D1, v.1D2, etc...
- Documenty delivery associated with an official acceptance is noted v.1, v.2, v.3
- Software preliminary releases are noted v0.1, v0.2, v0.3, etc..
- Software delivery associated with an official acceptance is noted v.1
- Software upgrades are noted v.1.x, v.1.y, etc...

Note: The version numbers defined in this document do not imply any specific content. The detailed content and schedule of each delivery shall be defined in the documents submitted at the Preliminary and Final Design Reviews, as well as in the updated documents provided at Progress Meetings.

5.1 Milestones

A minimum set of DFS related milestones must be defined for an instrument project. The DFS milestones are related to the standard instrument project milestones:

Abbreviation	Milestone
PDR	Preliminary Design Review
FDR	Final Design Review
PAE	Preliminary Acceptance Europe
COM1	First Instrument Commissioning
COM2	Second Instrument Commissioning
CFP	Call for Proposals (Phase 1)
PAC	Preliminary Acceptance Chile
PH1	Phase 1 Observation Preparation
PH2	Phase 2 Observation Preparation
SO1	Science Operations (first observation period)
SO2	Science Operations (second observation period)
GTO	Guaranteed Time Observations

The following table lists the minimum set of milestones for DFS deliverables. The timeline of a delivery is relative to the instrument project milestone (e.g. DRL Specifications 1.0 shall be delivered 4 weeks before PDR).

Act ID	Milestone	Timeline	Deliv. ID	Deliverables	Section
M-01	PDR	-4w	DC1	Calibration Plan v.1D1	4.1
		-4w	DR1	Data Reduction Library Specifications v.1	4.3
		-4w	ET1	ETC Specifications v.1D1	4.7
		-4w	DF1	Observation Preparation Specifications v.1D1	4.9
M-02	FDR	-4w	DC2	Calibration Plan v.1D2	4.1
		-4w	DR2	Data Reduction Library Design v.1	4.5
		-4w	DT2	DRL Validation and Test Plan v.1	4.4
		-4w	ET2	Exposure Time Calculator Specifications v.1	4.7
		-4w	DF2	Observation Preparation Design v.1D1	4.9
M-03	FDR to PAE	every 3 to 6 months	DC3	Test and Calibration Data v0.x	4.4
		every 3 to 6 months	DR3	Data Reduction Library v0.x	4.6
		every 3 to 6 months	OP3	Observation Preparation Tools v0.x	4.11
		every 6 months	ET3	Instrument Description Data v0.x	4.8
M-04	PAE	-4w	DC3	PAE Test and Calibration Data	4.4
		-4w	DR3	Data Reduction Library v1.0	4.6
		-4w	DT3	DRL Validation and Test Plan v.2	4.4
		-4w	ET3	Instrument Description Data v1.0	4.8
		-4w	DF3	Observation Preparation Tools v1.0	4.11
		-4w	IP3	Instrument Package v1.0	4.2
M-05	COM1	-4w	DR4	Data Reduction Library v1.1	4.6
		-4w	DF4	Observation Preparation Tools v1.1	4.11
		-6w	ET4	Instrument Description Data v1.1	4.8
		-4w	IP4	Instrument Package v1.1	4.2
		-1w	DR5	Pipeline v0.5	
		+4w	DC5	Instrument Commissioning Data	4.4

Act ID	Milestone	Timeline	Deliv. ID	Deliverables	Section
M-06	COM2	-4w	DC6	Instrument Package v1.2	4.2
		-3w	DR6	Data Reduction Library v1.2	4.6
		-4w	DF6	Observation Preparation Tools v1.2	4.11
		-4w	ET6	Exposure Time Calculator v1.0	4.7
		+2w	DC7	Calibration Plan v1	4.1
		+2w	DR7	Pipeline v1.0	
		+2w	DC7	Science Test Data	4.4
M-07	CFP	-6w	DF7	Observation Preparation Tools v2.0	4.11
		-4w	ET7	Exposure Time Calculator v1.1	4.7
M-08	PAC	-4w	DR8	Data Reduction Library v1.x	4.6
		-4w	DR8	Data Reduction Library Design v2	4.5
		-6w	ET8	Instrument Description Data v1.x	4.8
M-09	PH2	-4w	ET9	Exposure Time Calculator v1.x	4.7
M-10	SO1	-16w	IP10	Instrument Package v1.y	4.2
		-4w	DR10	Pipeline v1.y	
		-4w	DR10	Pipeline/QC User Manual v2	
		+8w	DR11	Data Reduction Library v1.y	4.6
		+8w	DR11	Data Reduction Library Design v3	4.5
		+8w	DC12	Calibration Plan v2	4.1
M-11	SO2	-10w	IP11	Instrument Package v1.z	4.2
		+8w	DR12	Pipeline v1.z	
		+8w	DR12	Pipeline/QC User Manual v3	

5.2 Generic Schedule

A generic schedule is shown in Figs. 5.1 and 5.2. Different symbols are used to identify document, software and data deliverables. Grayed deliverables are prepared by ESO.

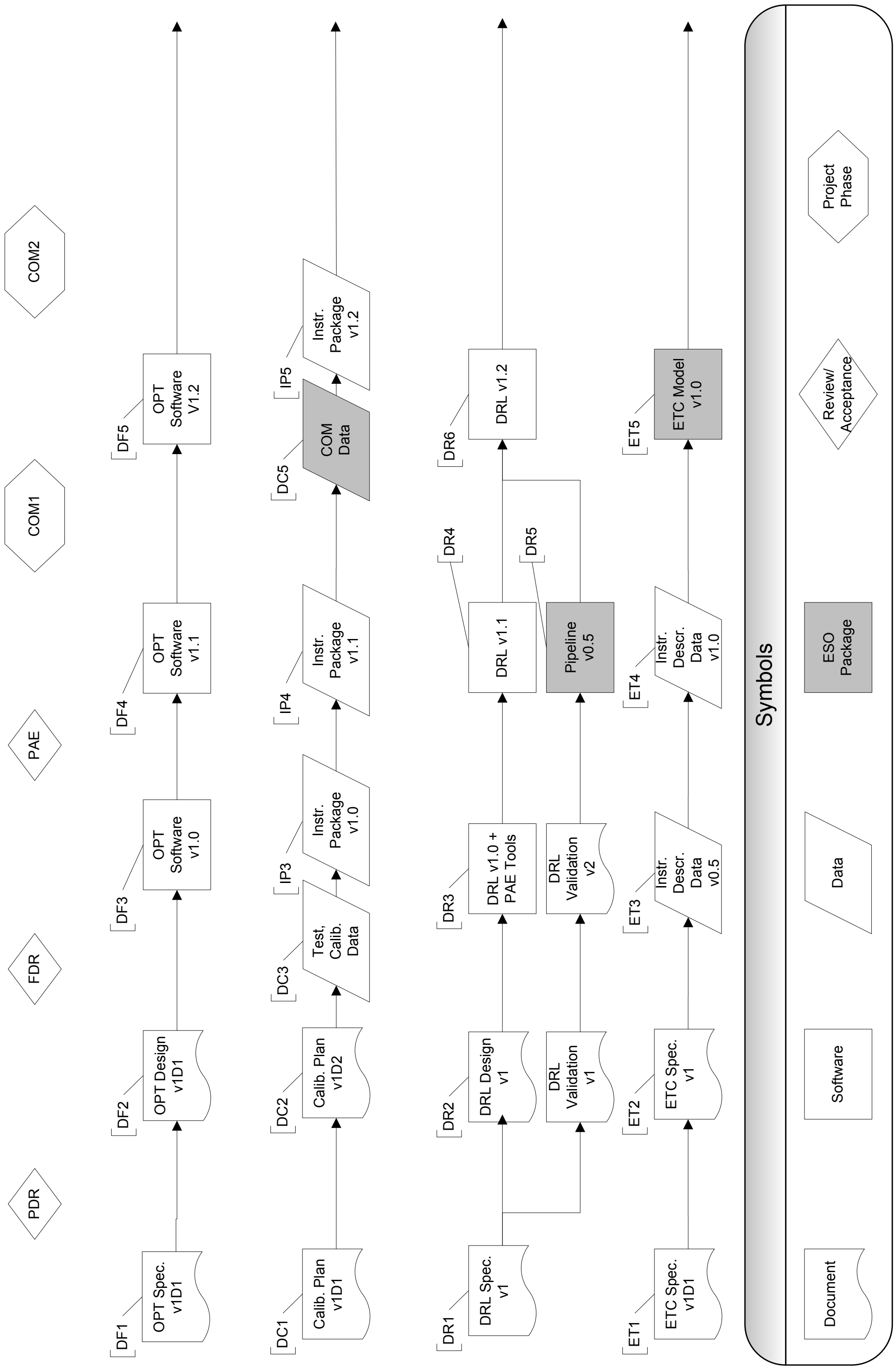

Figure 5.1: Generic schedule for Data Flow System deliverables (part 1)

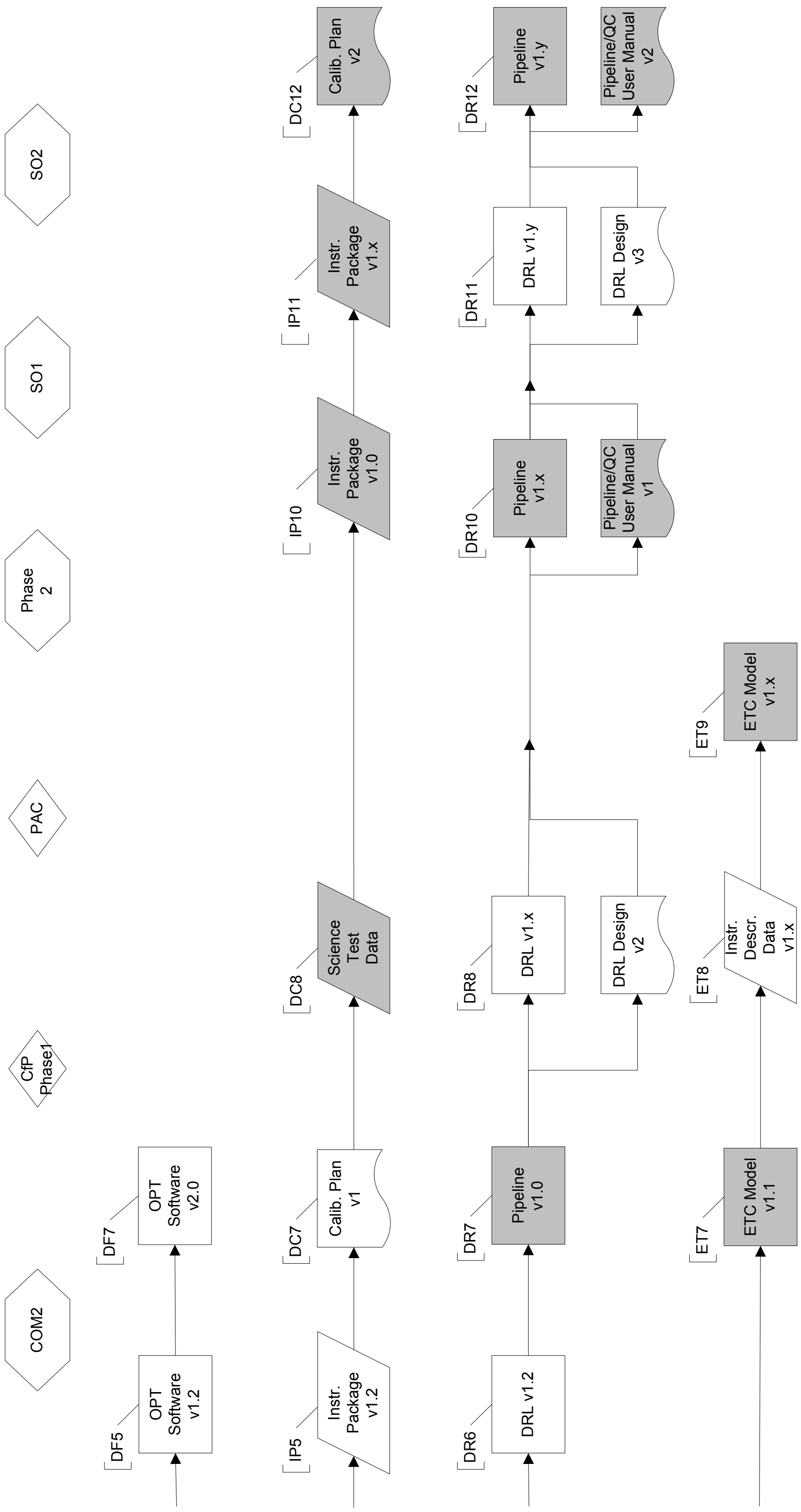

Figure 5.2: Generic schedule for Data Flow System deliverables (part 2)

Chapter 6

Acceptance Tests

DRL deliveries will be checked against the verification matrices and an acceptance test will be performed including code inspection, execution of CPL plugins in the ESO pipeline environment with a comparison of the produced result data with the data set provided by the instrument consortium. The completeness and quality of products will also be reviewed, in particular for science-grade data products.

Intermediate and final deliveries of the Data Reduction Library will be subject to acceptance tests. The following acceptance tests have been defined by the pipeline team in order to help verifications from the consortium and from ESO sides in order to bring the Instrument Data Reduction Library to PAE level. We recommend the consortium to use them during the implementation. Verifications from ESO should be done every 3 months on the software+data package delivered by the consortium. This verification should follow what is specified in the DRL manual, as approved by the FDR. All the tests will be part of the PAE verification process.

Compliance and Initial Verification

- Usage of CPL recipe template
- Following CPL coding standard
- Usage of external libraries
- Namespace protection

Execution Tests

- Completeness of the set of recipes and DRL functions
- Availability/representativity of test data and simulated data
- Proper execution of recipes
- Generation of products
- Memory leaks

- Unit tests
- Documentation

Detailed Validation

- Correctness of results
- Validation of input
- FITS compliance
- User-friendly documentation
- Completeness of the data reduction cascade
- Availability of unit tests for the DRL Functions

Performance and Portability

- Execution speed
- Portability to the standard platforms

Appendix A

QC1 Dictionaries

Quality Control dictionaries define all QC1 parameters produced by an instrument pipeline. They comply to the syntax of instrument dictionaries [3]. The values of QC1 parameters are written by the CPL plugins in parameter (PAF) files. An example of QC1 dictionary entries for the ISAAC pipeline is shown below.

```
#******************************************************************************
# E.S.O. - VLT project
#
# $Id: ESO-DFS-DIC.ISAAC_QC,v 1.18 2003/04/24 15:44:22 yjung Exp $
# $Author: yjung $
# $Date: 2003/04/24 15:44:22 $
# $Revision: 1.18 $
#
#******************************************************************************
#   NAME
#   ESO-DFS-DIC.ISAAC_QC - Data Interface Dictionary for ISAAC Quality control
#                          (level 1) parameters.
# -----------------------------------------------------------------------------
Dictionary Name:   ESO-DFS-DIC.ISAAC_QC
Scope:             QC
Source:            ESO DFS/DMO
Version Control:   "$Id: ESO-DFS-DIC.ISAAC_QC,v 1.18 2003/04/24 15:44:22 yjung Exp $"
Revision:          1.0
Date:              2001-06-28
Status:            submitted
Description:    ISAAC Quality Control dictionary.


# QC Category

Parameter Name:    QC DID
Class:             header|qc-log
Context:           process
Type:              string
Value Format:      %30s
```

```
Unit:
Comment Field:     Data dictionary for QC
Description:       Name/version of ESO DID to which QC keywords comply.

#
# Produced by the arcs recipe
#

Parameter Name:     QC LAMP
Class:              header|qc-log
Context:            process
Type:     string
Value Format:     %30s
Unit:
Comment Field: Type of lamp used
Description: The possible values are "argon", "xenon", "argon+xenon".
Depending on what lamp is used, the adapted lines
catalog is used to find a pattern match with the
observed lines.

Parameter Name:     QC WLEN
Class:              header|qc-log
Context:            process
Type:               double
Value Format:       %e
Unit:               angstroem
Comment Field: Central wavelength
Description: This is the central wavelength computed by the recipe,
not the one read in the input file header.

Parameter Name:     QC DISPCO1
Class:              header|qc-log
Context:            process
Type:               double
Value Format:       %e
Unit: angstroem
Comment Field: Dispersion relation: wl=DISPCO1+DISPCO2*pix+DISPCO3*pix*pix
Description: The polynomial gives the relation between pixels and
wavelength in angstroems: wave = f(pixel).

Parameter Name:     QC DISPCO2
Class:              header|qc-log
Context:            process
Type:               double
Value Format:       %e
Unit:               angstroem/pix
Comment Field: Dispersion relation: wl=DISPCO1+DISPCO2*pix+DISPCO3*pix*pix
Description: The polynomial gives the relation between pixels and
wavelength in angstroems: wave = f(pixel).
```

Appendix B

Association Map

Association maps are for a given instrument mode the graphical representation of interdependencies between recipes, input data, calibration products and output frame.

Each vertical line represents a raw data type (i.e. BIAS, FLAT, WAVE), the recipe to be applied on this type of data (i.e. uves_calmkmaster), and the product which will be generated as result of the execution of the recipes (i.e. MBIA). Each horizontal line represents a data product and its usage by the different reduction recipes. For instance, line tables are created as output of the uves_calwavecal recipes and required as input to the uves_calresponse recipe. External calibration products (e.g. Extinction Table) are also identified.

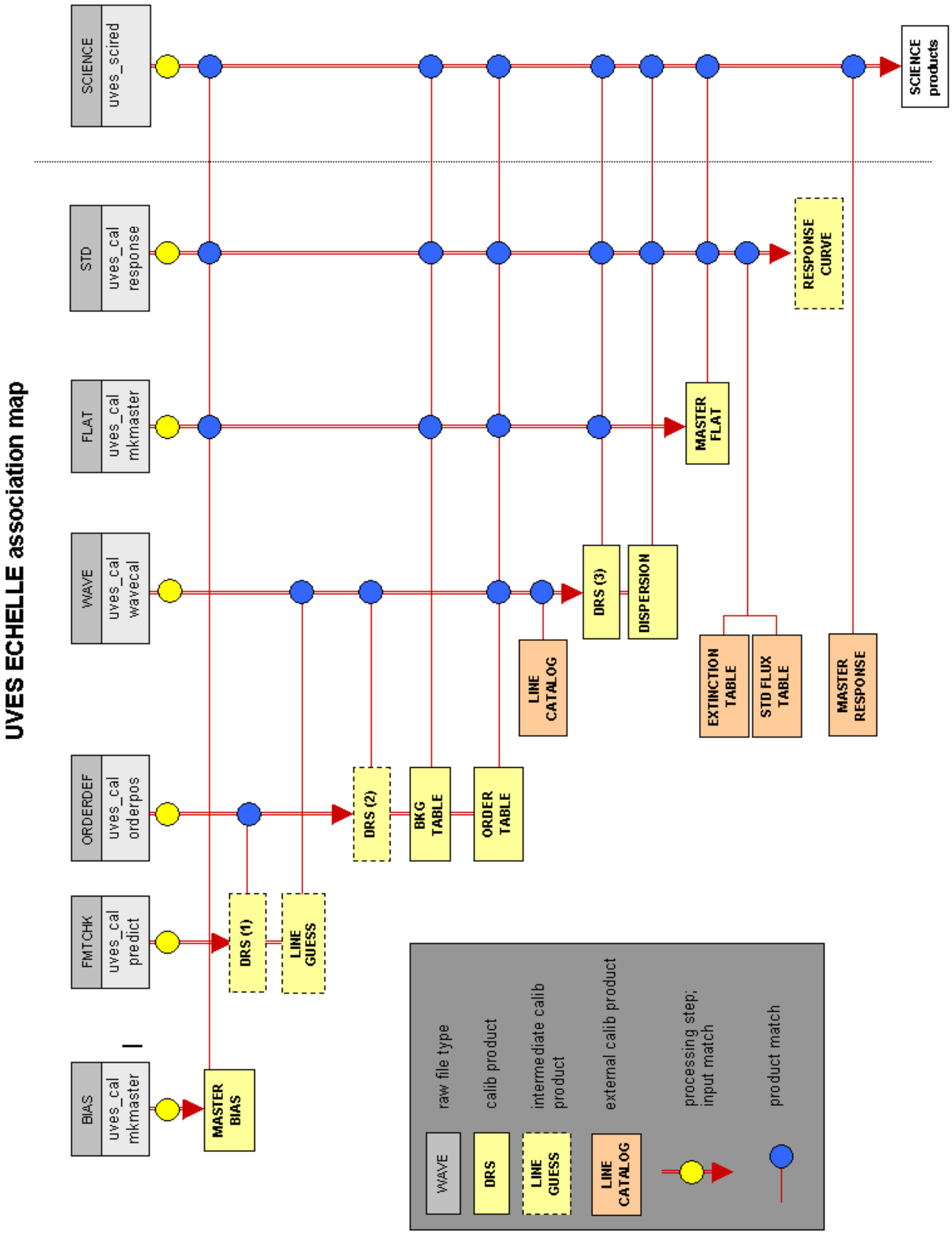

Figure B.1: Association Map

Appendix C

Data Processing Table

The data processing table relates instrument raw data types to pipeline recipes. For each raw data type it provides the values of the DPR keywords identifying it, the templates that generate this data type and the recipe invoked by the pipeline. The table also provide more information for each recipe, namely the processing steps involved, the required FITS keywords values, the calibration database files required and the pipeline products.

Data Type (Templates)	Classification Keywords	Recipe (Level) Processing steps	FITS Keywords	CalibDB	Products
All frames (All templates)	N/A	UVES_PREPROCESS (Frame) Determine arm Extract detector image Rotate to standard orientation	INS.MODE DET.WINi.*, Binning Arm definition		Extracted/rotated sub-frames
BIAS_BLUE (UVES_sws_cal_bias)	DPR.CATG==CALIB DPR.TYPE==BIAS NCHIP==1	UVES_MASTER_BIAS_B (Template) Average frames Average frames	CCD readout mode		Averaged bias frame
DARK_BLUE (UVES_sws_cal_dark)	DPR.CATG==CALIB DPR.TYPE==DARK NCHIP==1	UVES_MASTER_DARK_B (Template) Filter, Average frames	CCD readout mode Exposure time		Averaged, normalised dark frame
ORDER_FLAT_BLUE (UVES_narrow_flat)	DPR.CATG=CALIB DPR.TYPE=ORDERDEF NCHIP==1	UVES_CAL_ORDERPOS_B (Template) Define orders	Central wavelength		Order & background position tables
FLAT_BLUE (UVES_sws_cal_flat)	DPR.CATG==ECHELLE DPR.TYPE=FLAT SLIT1.NAME==FREE NCHIP==1	UVES_MASTER_FLAT_B (Template) Average and filter	slit width	Geometric solution	Normalized spectral flat
ARC_LAMP_BLUE (UVES_sws_cal_thar1)	DPR.CATG=CALIB DPR.TYPE=WAVE NCHIP==1	UVES_CAL_WAVECAL_B (Frame) Extract, Calibrate in 3 windows	INS.GRATi.WLEN	Order positions Dispersion Relation Guess	Dispersion Relation in 3 std windows
ARC_LAMP_FORM_B (UVES_narrow_thar)	DPR.CATG==CALIB DPR.TYPE==FORMATCHK NCHIP==1	UVES_CAL_PREDICT_B (Frame) Calibrate with physical model	Central wavelength Cross-disperser INS.GRATi.WLEN		Geometric solution
SCIENCE_BLUE (UVES_sws_obs_redX)	DPR.CATG==SCIENCE DPR.TECH==ECHELLE DPR.TYPE==OBJECT NCHIP==1	UVES_OBS_SCIRED_B (Frame) Bias, dark correction Interorder background Cosmic rays correction Optimal extraction (3" window) Optional FF correction Sky linear extraction Resampling Sky subtraction Efficiency correction Order merging	Number of exposures DPR.CATG (STD/SCIENCE) Binning Conversion factor	Bias, dark images Geometric solution FF correction frame Read-out noise Std stars positions & flux Instrument response	for each CCD: for each CCD: Wav. calibrated object object, sky, object-sky FF_sky1, FF_sky2, FF_obj For STD stars: Instrument efficiency

Figure C.1: Pipeline Processing Table

Appendix D

Functional Diagrams

The functional diagram provides a hierarchical decomposition of the Data Reduction Library functions. It shows the relationship between the data structures and the functions of the library. The following diagram shows an example taken from the X-Shooter documentation.

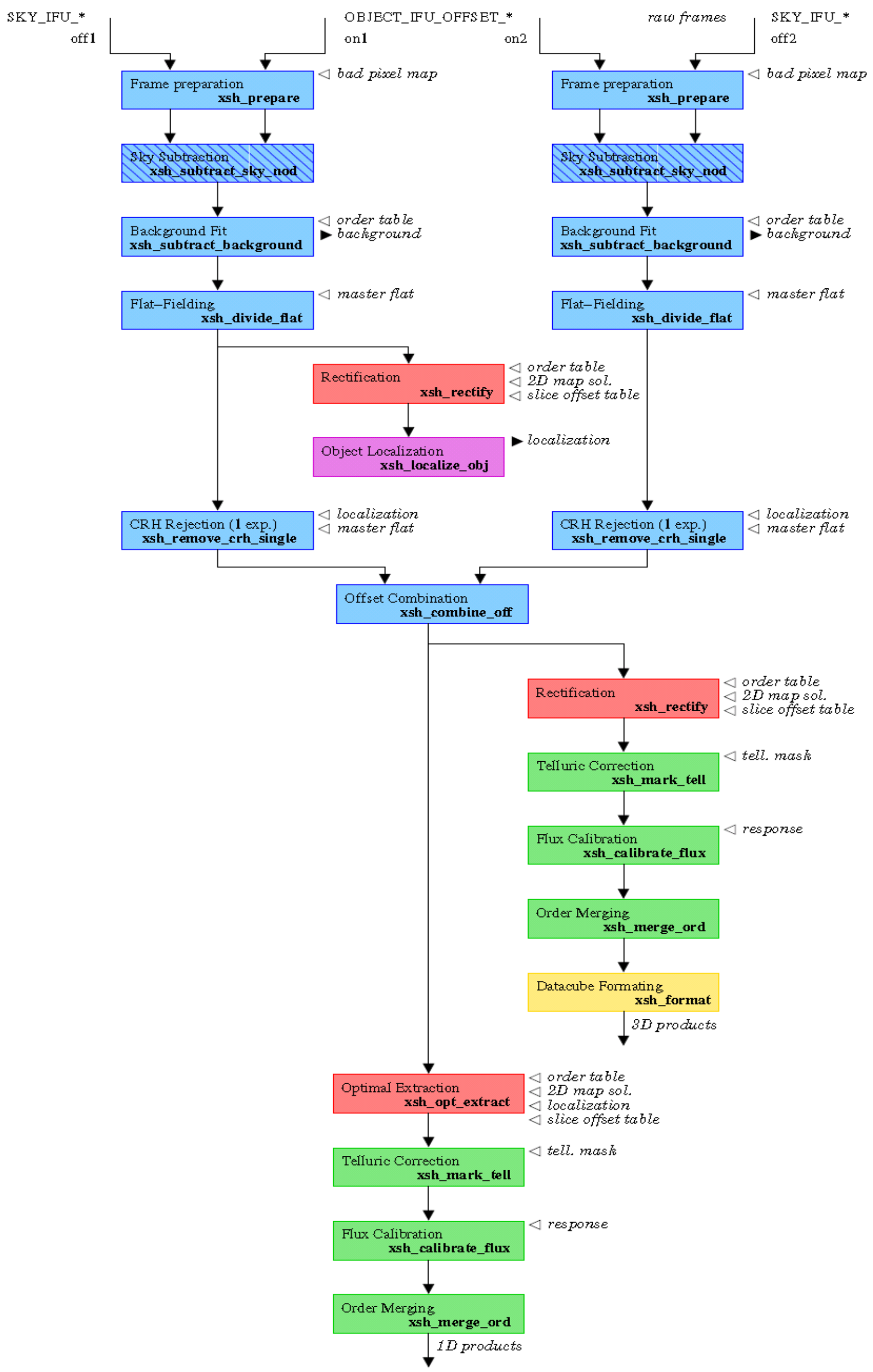

Figure D.1: X-Shooter Pipeline High-Level Functional Diagram

Appendix E

Reflex Workflows

The ESO Recipe Flexible Execution Workbench (Reflex) is an environment which allows an easy and flexible way to execute VLT pipelines. Reflex allows the user to process his scientific data in the following steps: associate scientific files with required calibrations, choose datasets to be processed, execute several pipeline recipes. The following example shows the UVES workflow [10].

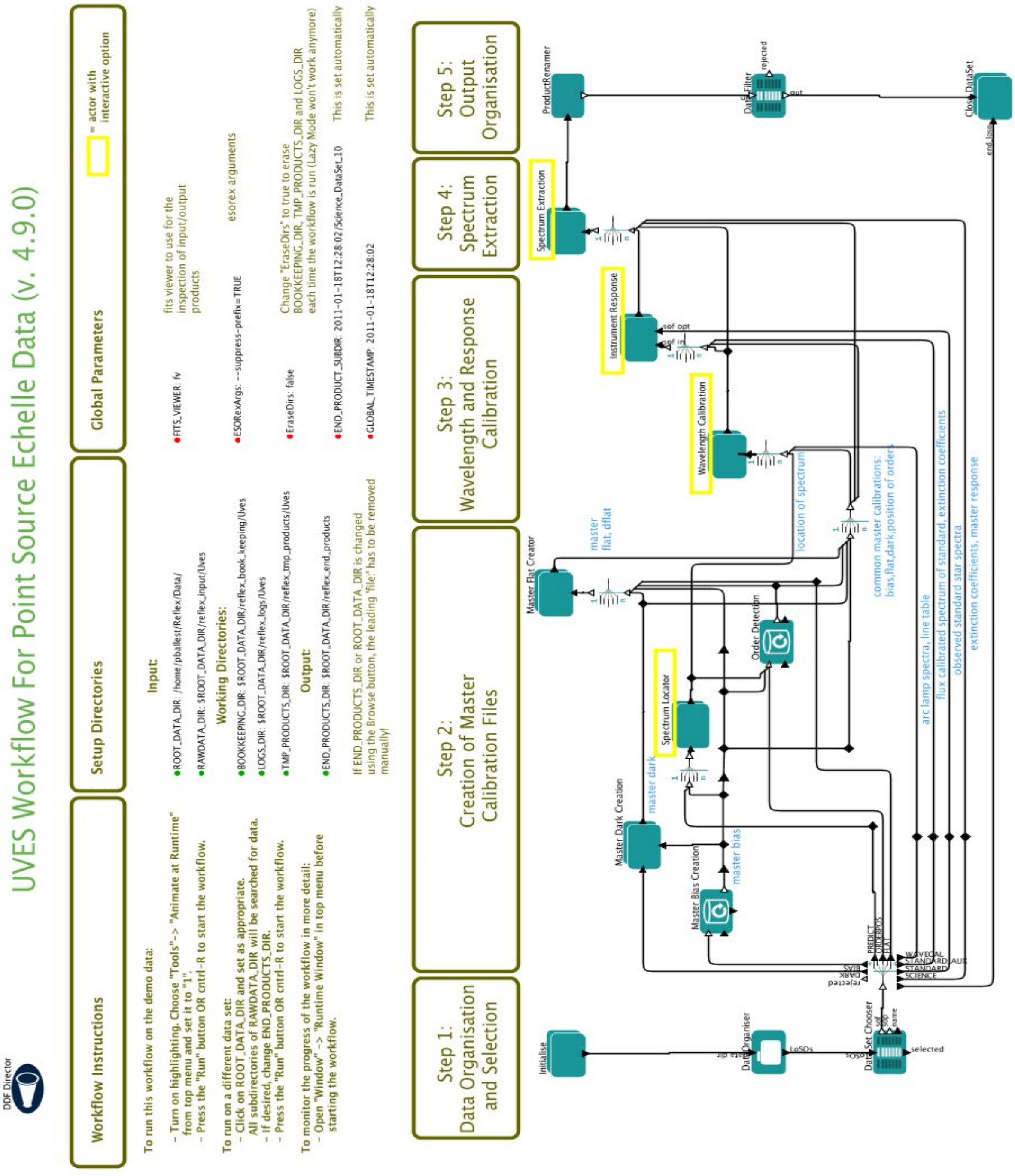

Figure E.1: UVES Reflex workflow

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