PROPOSAL FOR THE SYNCHRONISATION OF PROJECT PLANNING AND IMPLEMENTATION PROCEDURES FOR LARGE EUROPEAN ASTROPARTICLE PHYSICS INFRASTRUCTURES

ASPERA

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TABLE OF CONTENTS

1 INTRODUCTION

Astroparticle Physics started twenty years ago as a specialised endeavour, pursued by a few charismatic pioneers who reached out beyond traditional disciplinary boundaries and used unconventional, innovative experimental techniques. Since then, the field has become a mature, European-integrated research activity, involving 3,000 full-time equivalent researchers and a consolidated annual budget of two hundred twenty million euro (220 M€).

After Nuclear Physics, Particle Physics and Astronomy, Astroparticle Physics entered recently in the era of Large Infrastructures or, more colloquially, the "Big Science" era. In response to the expressed needs of the Astroparticle Physics scientific community, national governments and the European Union make substantial annual investments in creating and operating large Astroparticle Physics infrastructures, characterised by high costs, long development times, advanced technological characteristics and partnering.

In the beginning of the century a series of medium- to large-scale projects entered in the construction phase, among them: the gravitational antennas VIRGO and LIGO, the Pierre Auger Observatory, the Cherenkov Telescope arrays HESS and MAGIC, the Neutrino telescopes ANTARES and IceCube, as well as large underground experiments for the search of dark matter and neutrino properties. They have produced a series of extraordinary results or impressive increases of sensitivity.

More recently the community proposed a series of new infrastructures that clearly enter in the large infrastructure category costing from hundred million to a billion euro (e.g. CTA, KM3NeT, LAGUNA, ET, etc). These instruments have been prioritised in the Astroparticle Physics Roadmaps produced by ASPERA (2008, 2011)[1] since they stand on the threshold of an era of discovery likely to deliver scientific breakthroughs based on enhanced sensitivity and resolution. Furthermore, two of them – CTA and KM3NeT – have been included in the European Strategy Forum on Research Infrastructures (ESFRI) Roadmap as well.

The currently deployed infrastructures have used a series of organisational modes that extend from a

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[1] European Roadmap for Astroparticle Physics (2008) http://www.aspera-eu.org/images/stories/Roadmap/ASPERA_ROADMAP.pdf
European Strategy for Astroparticle Physics" (2011): http://www.aspera-eu.org/images/stories/roadmap/SAC-Roadmap-14-7-2011.pdf

simple collaboration scheme organised around a Memorandum of Understanding to a civil society structure. A rich experience has been obtained on implementation strategies in “green field” territories (e.g. the Argentinean pampa for Pierre Auger Observatory or the planes of Tuscany for VIRGO), ways of construction, operating fund sharing, data access etc. The different schemes have been implemented by consortia characterised by a single leading nation, bi or tri-national collaborations up to large multi-national endeavours. In the case of the latter, costly extra layers of complexity are added to project planning, funding and development, so the difficulties funding agencies face in coordinating planning and development efforts when in partnership have already been demonstrated.

In addition, by taking the tools of particle physics from the confined environment of the laboratory into the natural environment to study the particles of the cosmos, this new field of research has developed interfaces with a remarkable number of other sciences: atmospheric physics and chemistry, climatology, geology, seismology, planetary sciences, volcanology, marine biology, oceanography, glaciology, space weather and biology in extreme conditions. As a result, the collaborations had to face a series of challenging issues concerning the use of the proposed infrastructures by a variety of users beyond the Astroparticle Physics community. In addition, large infrastructures engage the attention of many stakeholders in both the public and private sectors who have great interest in the process, performance and outcomes of these projects.

It is time therefore to draft a more coherently European approach to the issues of planning, construction, operation and decommissioning of the large-scale infrastructures for Astroparticle Physics research. ASPERA has used the accumulated experience of the medium- and larger-scale infrastructures, has consulted experts and documents from fields that are historically more advanced in the domain of large infrastructures (space, high energy physics, astronomy) and prepared this proposal for the synchronisation of planning and operation mechanisms across European agencies in view of the realisation of large Astroparticle Physics infrastructures.

Since one should not recreate the schemes used in Europe or in the world for project planning and implementation, this proposal is largely inspired by the European Space Agency (ESA) practice in the space project management[2] and also tries to compare with practices in US-based funding agencies[3]. The

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[2] In particular the document ECSS-M-ST-10C-Rev.1, ESA (2009).

[3] In particular the study comparing the NASA, DOE and NSF methods (Miller, 2010) and the NSF Large Facilities Manual (2011).

adoption of the ESA schemes has the advantage of having already been adopted by a series of European agencies and therefore serves the purpose of a quasi-unified approach across different infrastructures. There are of course obvious differences in space projects with respect to ground-based Astroparticle Physics infrastructures, such as the after-launch non-accessibility, which is a major cost driver in the case of space projects, but usually a small factor in Astroparticle Physics infrastructures[4]. As a result, in many cases the ESA processes were adapted to "lighter" protocols.

Furthermore, the full list of processes should be applied with flexibility and be fully applicable only to projects that fall under the denomination of "large-scale" projects[5], i.e. projects

a) that are developed in response to the expressed needs and priorities of the European Astroparticle Physics community;
b) whose scale necessitates major development and construction efforts beyond the capability of individual countries;
c) whose cost engages direct oversight by a European and/or global consortium; and
d) which eventually are used via an open, merit-based system of access.

In this context, project planning and implementation encompasses a coherent set of processes for all aspects of project management and control[6]. This is done by:

- **Defining phases and critical decision points** enabling the progress of the project to be controlled with respect to cost, schedule and technical objectives.
- **Defining a project management plan**, defining the set of authorities providing oversight and guidance over the life-cycle of the project and authorising "phase transitions", as well as project management bodies that will perform all the necessary activities on the project.
- **Defining project breakdown structures,** which constitute the common reference system for the project management to identify the tasks and responsibilities of each actor, to facilitate the coherence between all activities, and to identify the deliverables of each phase, perform scheduling and costing activities.

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[4] Nevertheless, in some cases, the deployment of infrastructures in hostile environments can introduce similar constraints (e.g. KM3NeT will be placed in the deep Mediterranean sea).

[5] See discussion in Miller (2010).

[6] As listed in ESA (2009).

Whereas these steps apply to large-scale projects in most disciplines, Astroparticle Physics infrastructures have a number of particularities that need special attention. In particular:

1) Astroparticle Physics research infrastructures are constructed in a "green field", far from a specific laboratory or an established observatory able to provide project management: this in turn implies a certain complexity in site selection issues;
2) Construction is very often made by a consortium of agencies from different countries, with different funding cycles, processes and procedures, so
    a. new institutional entities are necessary in the remote areas where the infrastructure is located, whose task is to manage funds, personnel, ownership and other legal matters;
    b. distributed sources of funding, acquisition and property are implicated,
    c. strong constraints are put on cost and performance tracking, and
    d. a challenge for project assurance, governance and oversight is constituted;
3) Data access, availability and interdisciplinary use of the infrastructure are all issues of increased complexity due to particularities 1) and 2) above.

If these particularities are not addressed early enough, diffuse relationships can be installed between the scientific body - represented by the collaboration of scientists – and the programmatic authority - represented by the consortium of funding bodies/agencies. These diffuse relationships can be the source of major programmatic delays.

In the following sections we describe the ASPERA proposal for a common Large-Scale Project Planning and Implementation scheme specifically for Astroparticle Physics infrastructures. The text of the "Space Project Management" (ESA, 2009) and the OECD (2010) report were taken verbatim where appropriate, modified in many places according to the vocabulary and traditions of Astroparticle Physics, as well as of adjacent ground infrastructure fields (e.g. Particle Physics or Astrophysics). In addition, great efforts were put to approach the definitions of non-European traditions so that a global common understanding of the different schemes is established, in view of the global character of Astroparticle Physics projects. In this second task, Miller (2010) provided an insight and many formulations[7], since he compared project Pre-construction Planning and lifecycle in the three main US-based funding agencies: the Department of

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[7] This task is facilitated by the fact that, historically, NASA and ESA have very similar schemes, providing inspiration to ground-based methodologies.

Energy (DOE), the National Aeronautics and Space Administration (NASA) and the National Science Foundation (NSF). He used the documents prepared by all three agencies[8] in which they define a) project lifecycle stages, b) management and oversight activities to be performed at each stage, and c) decision-making mechanisms for advancing projects from one stage to the next. It should be noted that even if these documents describe the full project lifecycle, the Pre-construction Planning and Construction phases occupy the largest part of these documents, reflecting their importance in the ultimate success of the projects.

The structure of the ASPERA proposal is as follows. Section 2 proposes a scenario for the Phases and important Decision Points of the lifecycle of large Astroparticle Physics projects. We propose to adopt a phasing scheme covering Conceptualisation, Pre-construction Planning (with two sub-phases), Construction, Operations and Decommissioning. The deliverables, tasks and requirements at decision points are described.

In Section 3, the set of bodies necessary to assure the Governance and Oversight of a project is proposed. These are

- **internal:** associated with the scientific collaboration, the project management and quality assurance, conducting regular internal reviews of project performance;
- **programmatic:** assessing the health and progress of the project and authorising the transition between phases when milestones have been reached; and
- **external:** associated with scientific and technical evaluation and/or site selection.

For this aspect of project management, this proposal is meant to serve more as a form of a toolbox that will be adapted to each project. The thrust of the proposal is that the clarification of the relationships between the scientific and programmatic authorities must be at the centre of the attention.

Next, Section 4 addresses the project breakdown structures needed to define a unique reference system for project management. These structures identify the tasks and responsibilities of each actor, facilitate the coherence between all activities and perform scheduling and costing activities. Here we

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[8] DOE (2006): Program and Project Management for the Acquisition Of Capital Assets (Order 413.3A); NASA (2007): Space Flight Program & Project Management Requirements (NPR 7120.5D); and NSF (2007): Large Facilities Manual (NSF 0738).

propose the adoption of the Project, Work and Organisational Breakdown Structures methodology, defined with increasing detail depending on the scale and the phase of the project. The report ends (section 5) with a discussion and concluding remarks.

2 PHASES AND CRITICAL DECISION POINTS

Although nomenclature employed for the different lifecycle stages of a large-scale project varies across different agencies, the sequence of activities performed are similar. Here we propose to divide the life cycle of large-scale projects into five major activity phases (see also Figure 1 below):

1. **PHASE A: CONCEPTUALISATION** (equivalent to the Conceptualisation phase in DOE/NASA/NSF and the Mission analysis (0) and Feasibility (A) phases in ESA);
2. **PHASES B and C: PRE-CONSTRUCTION PLANNING** (equivalent to the Pre-construction Planning phase in DOE/NASA/NSF, where it comprises of a number of sub-phases, and to the Preliminary Definition (B) and Detailed Definition (C) phases in ESA);
3. **PHASE D: CONSTRUCTION** (equivalent to Construction/Implementation phases in DOE/NASA/NSF, and to the Qualification and Production (D) phase in ESA);
4. **PHASE E: OPERATIONS** (equivalent to the Operation phase in DOE/NASA/NSF and to the Utilisation (E) phase in ESA); and
5. **PHASE F: DECOMMISSIONING** (equivalent to Decommissioning phase in DOE/NASA/NSF and to the Disposal (F) phase in ESA).

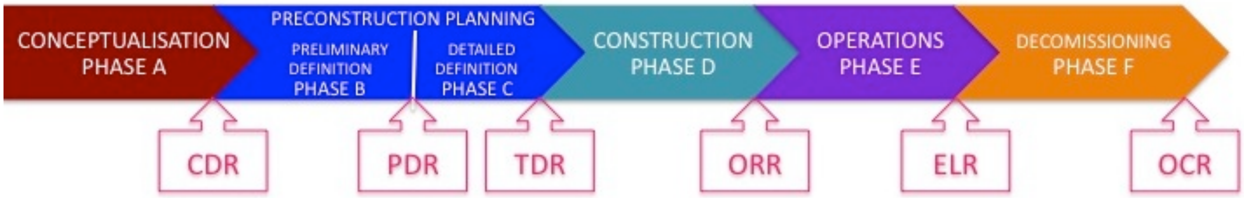

Figure 1 Project Lifecycle

In addition to similarities in the phases chosen by the four agencies examined here, project lifecycles have two more features in common. First, at each phase one or more reviews of project status and performance are carried out. Whereas the nomenclature used by the agencies differs, the content and structure of these reviews are similar. Second, the transition from one phase to another is determined through formal examination of key reviews at critical decision points. At DOE these are named "Critical Decisions" 0-4 and at NASA and ESA "Key Decision Points" A-F.

Both of these common features will be used in the ASPERA proposal presented here. Each of the phases listed above will be followed by a **Decision Point (DP)**, named after the phase preceding it (DP-A, to DP-E). In addition, one or more reviews will accompany each phase, each of which will be described in the corresponding section below.

Finally, before we proceed to a more detailed description of each phase, it should be mentioned that while the phases are depicted sequentially in Figure 1, in practice some overlapping of phase-related tasks often occurs. For example, early acquisition of components or subsystems (e.g. “long-lead items”) may begin prior to the construction stage. Similarly, when a project consists of a large network of detecting elements (e.g. the Pierre Auger Observatory), operations may begin before the full deployment of the network and end of construction.

2.1 PHASE A: CONCEPTUALISATION[9]

This first phase concerns the identification, evaluation and selection of potential of a new project and includes: a) the determination of the science case in the context of ongoing strategic (roadmap) and programmatic activities (community input and proposals, prioritisation of research portfolios and adjustment of the later based on funding availability and estimated costs), b) the development of preliminary technical system specifications, including different scenarios, c) the assessment of technical and programmatic (e.g. resources needed, costing) aspects and risks. The major stakeholders at this phase are the project initiators, the funding agency management and representatives of the scientific community (end users).

The major tasks[10] of this phase are the:

- Definition of the science case/mission statement, including the necessary resources, performance that will be expected and operating constraints that will be encountered.
- Elaboration of possible system architectures and operation concepts (including a discussion of the

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[9] The corresponding phases in space agencies are labelled: a) Phase 0 and Phase A in ESA, and b) Concept Studies and Phase A in NASA. For both agencies the reviews are preceding key decision points: KDP-A and KDP-B. In US ground agencies the corresponding phases are labelled: a) Pre-conceptual Planning and Conceptual Design phases ending at Critical Decisions 0 and 1 (CD-0, CD-1) at DOE,and b) Horizon Planning and Conceptual Design at NSF.

[10] Modified from ESA (2009).

needs and risks), prototypes and verification approaches.

- Assessment of the technical and programmatic feasibility of the concepts, by identifying constraints relating to implementation, costs, schedules, organisation, operations, maintenance, construction and decommissioning.
- Critical technology specification and proposal of pre-development activities,
- Establishment of a preliminary management and product assurance plan for the project.
- Quantification and characterisation of critical elements for technical and economic feasibility.
- Establish the function tree of the Product Breakdown Structure (PBS) (see Section 4.1).

At the end of this phase, this information is expected to be presented to the programmatic authority in a review, whose name depends on the agency: Preliminary Requirements Review (PRR) in ESA, Mission Definition Review (MDR) in NASA, Concept Design Review (CDR) in DOE and Conceptual Design Review (CDR) for NASA.

For the Astroparticle Physics infrastructures and for reasons of continuity with tradition, we propose to use the term **Conceptual Design Review** for the review associated with Phase A. In the CDR, the project initiators, presenting a document traditionally in Particle/Astroparticle Physics called **Conceptual Design Report (CDR*)*,*** are expected to have converged into a system and operations concept(s) and to have specified the technical requirements for the achievement of the project. In addition, preliminary management, engineering and product assurance plans are expected, each with an associated feasibility assessment. If the CDR is approved, the project passes **Decision Point-A (DP-A)** and proceeds to Phase B.

2.2 PHASES B AND C: PRE-CONSTRUCTION PLANNING[11]

Miller (2010) summarises the objectives of the Pre-construction Planning phase as: a) bringing the project design to readiness for construction and subsequent operations, b) obtaining commitment of the programmatic authority for implementation and funding of project realisation and c) rendering the project manageable in compliance with best practices. In recent years, increasing attention to and

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[11] The corresponding phases in space agencies are labelled: a) Phase B and Phase C in ESA and NASA preceding key decision points: KDP-C and KDP-D. In US ground agencies (DOE, NSF) the corresponding phases are labelled Preliminary and Final Design, preceding Critical Decisions 2 and 3 (CD-2 and CD-3) for DOE.

investment have been put to this phase, both in the public and the private sector, since it has been shown that the quality of Pre-construction Planning positively correlates with performance, outcome and ultimate success of a project, in terms of cost, schedule and achieved scope.

Pre-construction Planning begins with initial investment in the planning and development of a single or competing project concept(s) and ends with a decision of project readiness for construction. To reach the latter stage, program- and project-level planning needs to be carried out. Program-level planning includes the development of internal management structure, acquisition strategy and governance plans (see Section 3). Project-level planning involves the development of the project baseline and management plan, the associated Work-Breakdown Structure (WBS, see Section 4.2) and the assembly of the project team (see Section 4.3).

According to Miller (2010) additional activities taking place during Pre-Construction are:

- Establish goals, scope of work, requirements and specifications leading to design efforts to bring a project to construction readiness;
- Fund and perform identified R&D for necessary technologies, adapt heritage components and designs, and bring these to construction readiness;
- Estimate development and lifecycle costs and development schedule, based on scope of work, identified risks and contingency/reserve policies;
- Execute project oversight (including formal assessments), make progress decisions and project approvals, and request and obtain funding for development.

Even though the completion of all the above tasks should allow the programmatic authority to approve the project's readiness for construction, when more than a single funding body/agency is involved like in the case of Astroparticle Physics infrastructures, it is not easy to identify when exactly a project fully enters the construction pathway. It is thus strongly recommended that at **Decision Point C (DP-C),** at the end of the pre-construction phases, all funding bodies involved participate concurrently in the decision to move to the Construction phase, since such a commitment will ensure the development and building of a given project concept in time. This synchronisation of funding body commitment should not deter funding bodies from making investments in the early development of projects (e.g. for technology R&D, early acquisition of components, prototyping, etc).

In all agencies examined here, Pre-Construction is further divided into two or three sub-phases, in each agency named slightly differently, but all aiming at the development of both program management and project execution plans, effort baselining (scope, cost, schedule) based on a WBS, risk analysis, and at projecting performance tracking systems and change control processes (Miller, 2010). Given the importance of this phase in the project's success, two sub-phases were considered adequate for Astroparticle Physics projects, named "**Preliminary Definition Phase**" (Phase B) and "**Technical Definition Phase**" (Phase C) and described in turn below.

2.2.1 PHASE B: PRELIMININARY DEFINITION PHASE (PRELIMINARY DESIGN REVIEW)

The major tasks of this phase are similar but not identical to those of the ESA Phase B:

- Confirm technical system solution(s) and operations concept(s), as well as their feasibility with respect to programmatic constraints. Conduct "trade-off" studies to select the preferred system concept/technical solution(s) combination, which should be followed by the establishment of preliminary design definition.
- Verification of the preliminary design against project and system requirements.
- Release of updated technical requirements specifications.
- Determine prototype philosophy and verification approach.
- Examine site qualities towards a site selection (when relevant)
- Initiate any long-lead item procurement required to meet project schedule needs. Prepare the next level specification and related industrial agreement documents.
- Conduct reliability and safety assessment and update the risk assessment.
- Finalise the project management, engineering and product assurance plans. Establish the baseline timeline for design and construction and baseline cost at completion.
- Finalise the product and specification trees of PBS (see Section 4.1) and the WBS (see Section 4.2). Elaborate the preliminary Organisational Breakdown Structure (OBS) (see Section 4.3).

The results of these studies will be collected in a Preliminary Design Report (PDR) document and presented in the Preliminary Design Review. If approved (Decision Point B -DP-B) by the programmatic authority the project will proceed to the next stage, Phase C.

2.2.2 PHASE C: DETAILED DEFINITION PHASE (TECHNICAL DESIGN REVIEW)

Since this sub-phase is similar to ESA Phase C, the major tasks of that phase are:

- Completion of the detailed design definition of the system at all levels
- Production, development testing and pre-qualification of selected critical elements and components.
- Completion of assembly, integration and test planning for the system and its constituent parts (hardware and software).
- Production and development testing of engineering models, as required by the selected prototype philosophy and verification approach.
- Detailed definition and assessment of compatibility of internal and external interfaces, including site selection.
- Issue a preliminary data access model
- Update of the risk assessment.
- Assess the qualification and validation status of the critical processes and their readiness for construction.

The associated report is the **Technical Design Report (TDR),** presented in a **Technical Design Review**[12]**,** is the final design of the project and should be sufficiently detailed for construction to start. Whether the project will enter the construction phase will be determined by the programmatic authority at DP-C.

2.3 PHASE D: CONSTRUCTION[13]

Phase D involves the following major tasks:

- Complete qualification testing and associated verification activities.
- Complete manufacturing, assembly, testing and deployment of hardware, software and associated data management.
- Complete the interoperability testing between data acquisition, storage and management.

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[12] At ESA and NASA this is called Critical Design Review (PRR). At NASA this precedes key decision point KDP-D. In US ground agencies (DOE, NSF) this review is called Final Design Review (FDR), preceding Critical Decision 3 (CD-3) for DOE.

[13] The corresponding phase in ESA is named Qualification and production (Phase D), whereas in NASA it is composed of two phases: Final Design and Fabrication (Phase C) and Assembly, Integration & Testing, Launch (Phase D), ending with key decision point KDP-E. In DOE and NSF this phase is named Construction and for DOE ends with Critical Decision CD-4.

- Prepare data-access.

For a project to pass **Decision Point D (DP-D)**, the **Operation Readiness Review**[14] **(ORR)** is examined in order to judge the readiness of the project for operation. The programmatic authority should be verify that

- the infrastructure is free of workmanship errors;
- all deliverable products are available according to the approved deliverable items list;
- the "as-built" infrastructure and its constituent components are according to the required "as designed" infrastructure;
- the acceptability of all waivers and deviations;
- readiness of the operational procedures and their compatibility with the operation of the infrastructure;
- accept and release the data-centre for operations.

During this phase several Qualification Reviews (QR) will judge the readiness of each sub-component deliverable. And in particular, they confirm that the verification process has demonstrated that the design, including margins, meets the applicable requirements.

2.4 PHASE E: OPERATIONS

The main tasks carried out during the Operations phase are very varied and most of them are implemented in parallel:

- Commissioning activities
- Monitoring of data acquisition and access issues
- Maintenance activities
- Multidisciplinary access activities
- Outreach and education activities

In addition, this phase includes a number of tasks that are carried out at specific points of the

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[14] This is actually a combination of the aims of the Operation Readiness Review (OPR) and Acceptance Review (AR) of ESA.

Operations phase: upgrade activities, activities towards the extension of the lifetime of the infrastructure, and finalisation of the decommissioning and data-archiving plan. As a result, instead of a single review, a number of reviews are associated with this phase:

- **Upgrade Readiness Review (URR)**: part of the participating teams or the entire scientific collaboration may propose upgrades of the infrastructure. These extensions will follow the construction lifecycle defined above (Phases A to D), so they have to be examined in a specific review to assess the impact of the integration of the upgraded elements in the infrastructure.
- **Extension of Operations Review (EOR)**: this review is held at the end of the predetermined lifetime of operations of the project, in order to assess any reasons of the extension of the project lifetime.
- **End-of-Life review (ELR**): this review is held at the completion of the operations in order to verify that the operations have been completed and to ensure that all elements are configured to allow decommissioning.

Even though all of these reviews are associated with Phase E, it is only the ERL that will allow the project to advance through **Decision Point D (DP-E)** and proceed to the final Decommissioning phase.

2.5 PHASE F: DECOMMISSIONING

The major task of this phase is the implementation of the decommissioning plan and to hold the **Operations Close-out Review (OCR)** at the end of this phase, in order to ensure that all decommissioning activities are adequately completed.

3 GOVERNANCE AND OVERSIGHT

Once the phases of the project lifecycle have been defined, the next step is to define in more detail what is meant by a project management plan, i.e. to define the set of authorities providing oversight and guidance over the life-cycle of the project and authorising "phase transitions" (so far referred to as programmatic authority), as well as the project management bodies that will perform all the necessary activities on the project (so far referred to as the scientific authority).

As mentioned in the introduction, the absence of a central programmatic authority of the type ESA, NASA, CERN or even a national agency playing a central role[15], makes the task of governance and oversight a challenging task. In addition, depending on the phase of the project (see Section 2 above) different legal/administrative structures may be appropriate for the varying requirements in financing, management, and oversight (OECD, 2010).

Furthermore, when one talks about project governance and oversight, one is not just referring to the decision-making and governing bodies, but to a set of structures, principles, rules and procedures according to which a collaboration operates and takes decisions (OECD, 2010). Governance and oversight comprises regular internal and external reviews of project performance, followed by critical decisions and disposition of proposed changes in the project baseline. These functions are carried out by a number of different bodies, depending on the organisational structure of each project, but it is recommended that Astroparticle Physics projects include one body in each of the following four broad categories:

1. **Oversight Committee**: the body[16] formed by the funding bodies, having the programmatic authority to approve a project and authorise transitions from one phase to the next;
2. **Scientific Collaboration**: a set of bodies representing the scientific authority, assuring the scientific responsibility for the project status, the data analysis and/or modes of data access, proposing eventual upgrades, the accession of new scientific teams to the project consortium, etc.
3. **Project Management**: the Project Management team or Project Office, assisted in some cases from the Site Management team(s) are overseeing the day to day operation of the project.
4. **External Advisory Committee(s)**: external panels of individuals charged with assessing the scientific

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[15] As is the case for instance for NSF and the neutrino telescope IceCube.

[16] For example, in DOE: Acquisition Executive (AE) that varies depending the cost of the project; NASA: Decision Authority (DA); NSF: NSF Director and National Science Board (NSB)

and technical health or progress of a project;

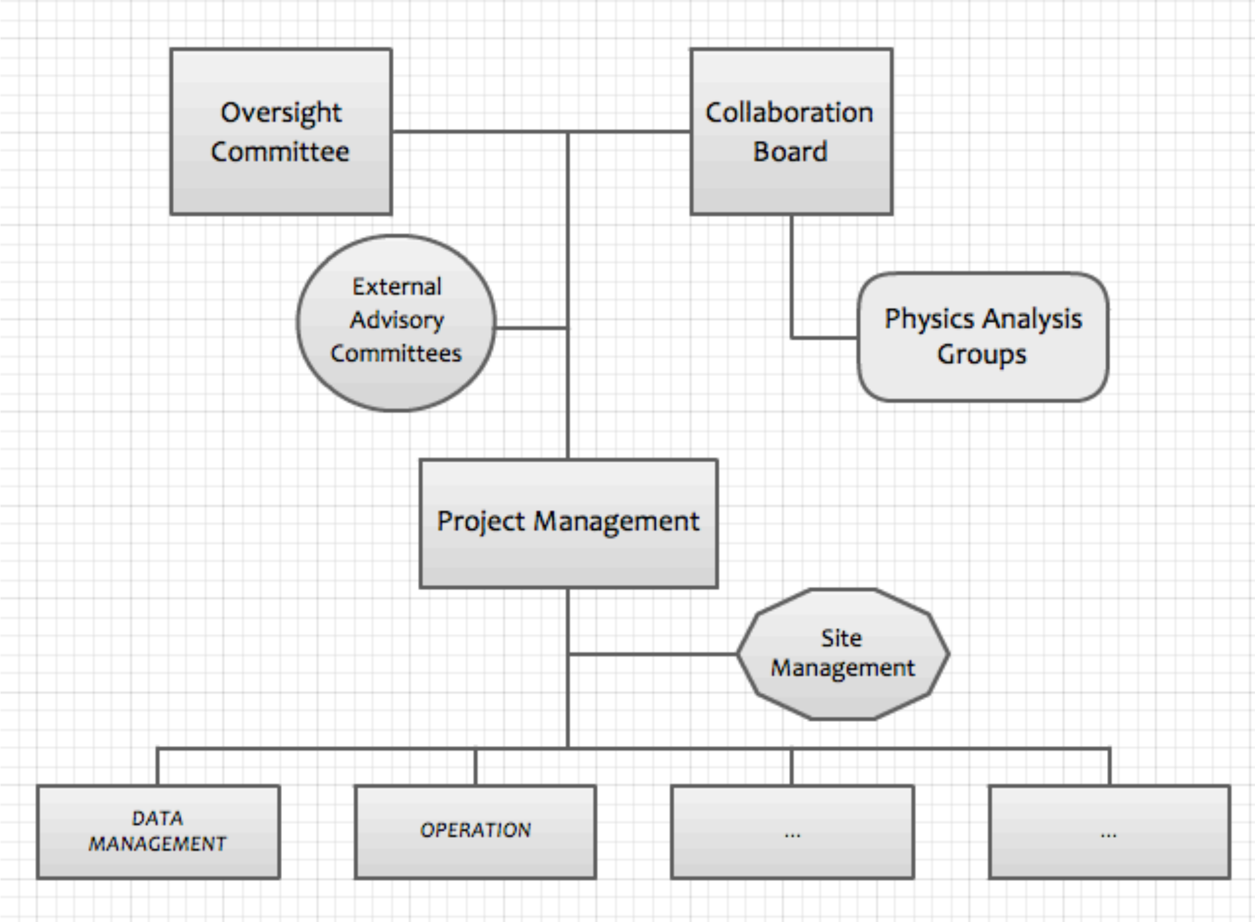

Figure 2 A generic realisation of the ideas presented in the text for an organisational structure.

The four interrelated bodies for governance and oversight of a project are examined in more detail in the Sections below[17].

3.1.1 OVERSIGHT COMMITTEE

The **Oversight Committee** is the body for oversight of the organisation and of financial management of the project. It is a consortium of representatives of the funding agencies[18]. As an example, the Oversight/Programmatic Committee in the Pierre Auger project is the Financial Board. The Committee examines programmatic issues and money flow, approves major scientific decisions implicating

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[17] Some of the definitions are inspired by IceCube and AUGER documents.

[18] Different names have been used up to now in different projects: Financial Resource Board, International Financial Committee, etc.

resources, etc. While the Collaboration Board carries the scientific authority (see subsection below), the Oversight Committee carries the programmatic authority, assisted by the independent evaluation of the External Advisory Committee(s) (see Section 3.2.3 below). The Collaboration Board and the Project management are expected to provide reliable yearly reports to the Oversight Committee on the status and finances of the project, which will be reviewed in order for the proposed schedule and budgetary goals to be approved.

When an external financial institution provides financial services (e.g. hold the common fund for a project purchase), this is usually either one of the institutional partners of the project, an international organisation (e.g. CERN), or sometimes the consortium can setup a legal entity for that purpose (an association, a limited liability company, the European ERIC[19] scheme etc.). Irrespective of its nature, this institution is accountable to the Oversight Committee.

3.1.2 SCIENTIFIC COLLABORATION

The main scientific authority lies with the **Collaboration Board** and its **Chair** as well as the **Spokesperson or Principal Investigator** as a Collaboration Executive.

The mandate of each of these entities, their interrelations and internal procedures are defined in the Agreement of the Collaboration[20] (very often a Memorandum of Understanding).

The **Collaboration Board** is defined as the entity that guides and governs the scientific activities of the Collaboration, thus it is composed of representatives of each of the scientific teams. It is convened by its **Chair** once or twice a year to review progress and to make major decisions. In the case of large collaborations, where the number of Board members is too large, it is sometimes considered appropriate to establish an Executive Committee, with some decision-making authority, especially in between Board meetings (OECD, 2010). The functionalities of the Collaboration Board are usually different for different projects, and therefore using the examples of the Pierre Auger[21] and IceCube[22] Collaborations, we

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[19] The possibilities of the ERIC scheme will be explored by many forthcoming large European Infrastructures.

[20] For more discussion on the Agreement see OECD[15] (2010)

[21] The Pierre Auger Collaboration has defined the Collaboration Board as "the oversight body concerned with scientific and technical aspects of the Collaboration and the Pierre Auger Observatory. It deals with issues including governance of the Collaboration, scientific policy, new members and institutions, publication policy and monitoring the operation of the Pierre Auger Observatory to ensure that the scientific objectives are being met".

arrived at an indicative spectrum of the functionalities that should be reached:

- governance of the Collaboration, e.g. election of the Spokesman and team leaders
- scientific policy and goals,
- new members and institutions,
- data access and publication policy and
- monitoring the operation to ensure that the scientific objectives are being met,
- representation of the Collaboration at topical and general conferences
- establishment of analysis teams, education and outreach.

The **Spokesperson** or **Principal Investigator** on the other hand:

- arranges and chairs general Collaboration meetings;
- speaks for the Collaboration when the latter is interacting with the scientific community;
- speaks for the Collaboration when the latter is interacting with the general public;

Furthermore, **science and analysis teams** are associated to the Collaboration Board and assure the data analysis along specific working groups. A **publication committee**, also associated to the Collaboration Board, is responsible for the quality of the scientific output of the collaboration.

3.1.3 PROJECT MANAGEMENT OR PROJECT OFFICE

Key to the success of a large infrastructure construction and operation is a solid project management team or project office. The project team consists of the **Spokesperson** of the Collaboration, as Collaboration executive, the **Project Manager**, the **Technical Manager**, the **Site Manager(s)**, the **Data manager** and other team leaders depending on the case and the phase **(Resource manager, Integration responsible, etc).** A central project office can take a holistic view of construction/operation/maintenance/upgrades (engineering and integration: mechanical, power, electronics, ambient environment and systems), develop a culture of quality control and safety, steer the early involvement of industry where possible, liaise with national laboratories to use their infrastructure

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[22] The Collaboration Board is the policy-making entity that guides and governs the scientific activities of the Collaboration. It establishes, and as necessary amends, governance procedures and has oversight and authority over the project.

and expertise[23]. Furthermore, the current experience proves that the project office is most effective if it draws resources and/or is located at a large existing laboratory (e.g. Fermilab in the case of AUGER).

The **Spokesperson** tasks have been defined in the previous section, the other profiles are as follows:

The **Project Manager** (or Director) is usually a key individual with great abilities, not only as a scientist, but also as a manager. As a consequence, Project Managers are usually people with large experience and stature, and most frequently assisted by a management team. S/he and his/her team are charge of the operation of the infrastructure (oversight of the day to day activities, preparation of budget, tracking of expenditures, annual reporting to the Oversight committee), system engineering and integration, maintenance and quality and data management. In this role, the Project Manager is assisted by a number of other people/bodies: the **Technical Director**, the **Site Manager/Director**, the **Data Manager** and a series of more specific managers (Integration, Maintenance, Monitoring, etc).

Especially during the construction phase, a **Technical Director** assures functions different from these of the Project Manager. He supervises R&D and technological issues, organising internal reviews, establishes procurement specifications, industrial relations, internal system qualification and integration reviews etc.

The **Site Manager or Director** leads the local institution that manages the site infrastructure and he is responsible for maintenance and operation of the observatory, the local management of the funds and property, human resources, insurance and liabilities. The local site institution is often organised as a legal/institutional form (association, limited liability company etc), This is often an important issue for Astroparticle Physics infrastructures, since they are usually deployed in “green field” areas, sometimes remote and/or hostile sites, and therefore there is the need to organise the site management locally.

Finally, the Data management team takes care of the data acquisition, storage and crunching issues, but also of data access.

The issue of data management will take a central place in the next generation of large Astroparticle Physics infrastructures since they will operate in observatory mode. For instance in observatories with a limited field of view, a scientific committee allocating observation time has to be constituted and for

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[23] See e.g. J. Virdee’s presentation to the Open Symposium of the European Strategy for Particle Physics forum in Krakow: http://espp2012.ifj.edu.pl/

large surveys a policy for data access has to be planned in advance. Currently, different models in use for data access are:

- exclusive access of the team that has built the observatory for a determined duration and then a public release (FERMI, IceCube);
- access conditioned by an annual fee (dark energy surveys: SDSS, LSST for non-US citizens etc.) determined by the operation costs if the infrastructure; or
- unconditional public access (LSST for US citizens, or members of the construction team).

Another important challenge is the modes of access to environmental data that usually accompany the operation of the Astroparticle Physics observatories (e.g. ANTARES or KM3Net, Pierre Auger, experiments in underground labs etc). Here a series of delicate issues have to be tackled that are due to different cultures of science operation, analysis, citation, etc.

Last but not least, a policy for data archiving has to be defined together with provisions for decommissioning etc.

3.1.4 EXTERNAL ADVISORY COMMITTEES

The **External Advisory Committees** are in principle nominated by the Oversight Committee, and thus they are reporting back to it. In some cases, however, these committees can be chosen upon proposal of the Collaboration Board and its Chairman.

These Committees review the status of the project as compared to the scientific objectives, technical and programmatic risks of the project as defined in varying detail according to the phase and maturity of the project in a series of documents: Conceptual Design Report, Preliminary Design Report, Technical Design report, Upgrade Proposals, etc. These reviews, conducted by the Oversight Committee, take place usually at the end of each phase as defined in Section 2.

The initial assessment and subsequent reviews (which include the key performance parameters and the technical and programmatic constraints of the project in different levels of detail) are mainly evaluated by an external **Scientific Advisory Committee (SAC)**. In addition, a **Technical Advisory**

Committee (TAC) carries out the technological assessment in order to identify the availability of scientific and technological know-how, as well as the technology needed to implement the project. The result of this assessment, which can be a significant cost and schedule driver, is a major input to the assessment of required resources and to the subsequent technical and programmatic risk assessment carried out by the SAC. Moreover, the technological assessment is complemented by an assessment of human resources, skills and technical facilities required to implement the project. In some cases both functions can be concentrated in a single **Scientific and Technical Advisory Committee (STAC)**.

Furthermore, when site selection issues are at stake, an independent **Site Selection Committee (SSC)** can be formed assessing both scientific and programmatic issues.

3.1.5 GENERAL REMARKS ON OVERSIGHT BODIES

Project planning implicates the above 4 types of bodies in clearly distinct roles. The definition and terms of reference of these committees, with respect to the project are usually included in the Agreement between the Partners of the Collaboration and the Project Management plan, the latter of which also codifies the project and work breakdown structures (see Section 4).

An organisational chart showing the interrelations of the above entities in the Pierre Auger Observatory is shown in ANNEX I. Although the Project Management office is in FERMILAB, i.e. a large laboratory, there is no single majority institution driving the project. A different example is this of the IceCube Collaboration, which led and managed by a single agency (NSF), the corresponding organisation structure is shown in ANNEX II In both cases, however, there is a clear distinction between the Collaboration, the Project Management and Oversight authorities, and the Oversight Committee has occasionally resorted to the advice of External Advisory Committees, e.g. for approval of major upgrades.

One has also to note that major agencies have dedicated offices for project assurance[24]. Project assurance is the system facilitating the accomplishment of the desired outcomes of projects, through 1) establishment of policy, procedures and best practices for project management, governance and

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[24] For instance: DOE: 1) Office of Engineering and Construction Management (OECM) and 2) The Office of Project Assessment (OPA); NASA: The Office of the Chief Engineer (OCE); NSF: The Large Facilities Office (LFO). More details can be found in Miller(2010).

oversight and 2) conducting regular assessment of project performance and adherence to management best practices. The multiplicity of agencies coming together to build an Astroparticle Physics research infrastructure, makes the creation of a such a centralised office, organising e.g. the reviews, a rather ambitious goal for the long term. This role, for the time being, has to be taken by the Oversight Committee of each project.

4 PROJECT, WORK AND ORGANISATIONAL BREAKDOWN STRUCTURES

The establishment of a well-structured and coherent organisational structure for implementing a project is a key factor for its success. It is essential that this structure is arranged to include all expertise essential to implement the project with well-defined functions, clear reporting lines, integration procedures and interfaces. The organisational structure should provide a clear and unambiguous definition and allocation of individual roles and responsibilities together with the necessary authority to implement them. The general questions one has to ask are: a) what needs to be produced? b) how will one produce it? c) who will be responsible to produce it? The three questions of what, how and who are then mirrored in the Project (PBS), Work (WBS) and Organisational (OBS) Breakdown Structures. They are presented in some detail below[25].

4.1 PROJECT BREAKDOWN STRUCTURES (PBS)

The Project Breakdown Structure (PBS) provides the basis for creating a common understanding between all actors of what needs to be produced by "breaking" the project down into manageable elements. These elements are a tool for analysing, documenting and communicating the outcomes of a project. The PBS provides an exhaustive, hierarchical tree structure of deliverables (which may be physical, such as a specific instrument, or functional, such as the data monitoring) that make up the project.

The resulting diagrammatic representation of project outputs provides a clear and unambiguous statement of what the project is to deliver. In particular, the PBS is composed of the following two "trees":

1. **Product tree**: the breakdown of the project into successive levels of hardware and software products or elements. It includes the development models, the integration tools and test equipment, and external items necessary to validate the end product. The product tree forms the basis for the elaboration of the project WBS (see below) and is determined at Phase B

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[25] The three types of structures are sometimes contracted in the presentation of only two (PBS and WBS) defining implicitly the third (OBS).

described above.

2. **Function tree**: the breakdown of the system performances into functions. A function is a combination and interaction of a number of operations or processes, which together achieve a defined objective. Each function is decomposed into sub–functions independent of the type of products involved. The “function” approach is applied during project start–up or during Phase A.

Different products can be articulated to perform the functions identified in the function tree and therefore the function and product trees do not necessarily mirror each other. In addition, sometimes a specification tree is defined in order to establish the hierarchical relationship of all technical requirement specifications for the different elements of a system or product.

An example of a Product Breakdown Structure is shown in ANNEX II.

4.2 WORK BREAKDOWN STRUCTURES (WBS)

An accepted definition of a Work Breakdown Structure (WBS) is “an exhaustive, hierarchical (from general to specific) tree structure of deliverables and tasks that need to be performed to complete a project”[26]. The WBS is identical in format to the PBS described above, but while the PBS includes only the physical architecture of a product, the WBS includes the data and service elements necessary to complete the system. The WBS is derived from the product tree, selected elements of which are extended to include support functions (i.e. management, engineering, product assurance) and associated services (e.g. test facilities).

The WBS divides the project into manageable work packages, organised according to the nature of the work by breaking down the total work to be performed into increasing levels of detail. A work package (WP) can be any element of the WBS down to the lowest level that can be measured and managed for planning, monitoring, and control. Control WPs are identified in the WBS at the level where visibility and control is required, and for which reporting is to be performed.

One of the main advantages of a WBS is that it provides a common approach and framework for cost

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[26] U.S. Dept. of Energy, Office of Management, Budget, and Evaluation, “Work Breakdown Structure,” Rev E, June 2003.

estimates among all subsystems thus producing a comprehensive, accurate, and defensible cost estimate[27]. WBS will also structure schedule planning, tracking of actual costs and progress, so it is important to not make the common mistake of developing it in a way to keep accountants happy or to reflect geography or existing organisations. Equally important is the maintenance of the WBS throughout the project.

The steps to develop the WBS and cost estimates are the following:

1. Develop a list of all components and tasks, organised by subsystem, that constitute the work to complete the project. Each component and task is a WBS "element" (see below). The Collaboration should Include all physical deliverables and subsystems, for each of these all the different steps should be considered (R&D, design, prototyping, fabrication, assembly, installation, acceptance testing leading to a deliverable product), but also administration, system engineering, purchasing, reporting not directly related to deliverable products.
2. Estimate the cost of the components and activities that comprise the lowest level of the WBS, and complete the **Basis of Estimate** document for such activities. Each estimated item should have all information supporting the estimate for that item recorded in the Basis of Estimate worksheet for that item (Sanders, 2009). The Basis sheet should be signed and dated by the estimator. A written Cost Estimating Plan that defines uniform formats and procedures for all estimators should be established as a first step. Cost estimates should be produced by both the scientists and the engineers.
3. Complete the WBS dictionary and cost basis (see below) for each WBS element. Each dictionary entry should clearly state what each element means, but also what it does not mean.

4.2.1 ELEMENTS AND ACTIVITIES

Generally the first three levels of the so-called WBS elements are deliverables and for the most part they are described as nouns. The first level corresponds to the major systems, while the second level to the major components. One can think of a deliverable as a tangible product or component (e.g. mirror, camera, or phototube). The lower the level, the more detailed the definition of the top element. The

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[27] The lines below are based on the WBS tutorial written by H. Glass for the Pierre Auger project.

number of levels depends on the scope and complexity of the individual project and the degree of control it warrants. The only high-level WBS elements that are not deliverables are the “subsystem assembly”, “installation”, “system integration and test“ and “project management”. WBS elements are numbered in the classical dotted decimal format and are arranged in numerical order in a spreadsheet, where each row corresponds to a single WBS element.

Activities are the steps needed to produce the deliverables. For example, if the deliverable is “mirror segments,” then the activities might be “design,” “procure materials,” “fabricate,” and “test.” Activities, such as engineering design procurement, appear at the lowest level of the WBS. For example, in Advanced LIGO, a US-based Astroparticle Physics project, the following activities were included in the WBS (Sanders, 2009):

Table 1 Activities in the Advanced LIGO WBS

Activity number	Activity description
4.0	Advanced LIGO
4.1	Facility Modifications (FAC)
4.2	Seismic Isolation (SEI)
4.3	Suspensions (SUS)
4.4	Prestabilized Laser (PSL)
4.5	Input Optics (IO)
4.6	Core Optics Components (COC)
4.7	Support Optics (SOS)
4.8	Interfer. Sensing & Control (ISC)
4.9	Data Acquisition and Diagnostics (DAQ)
4.10	Support Equipment (SUP)
4.11	Not used
4.12	Computing & Data Analysis (LDAS)
4.13	Installation (INS)
4.14	Project Management (PM)
4.14.1	Project Management
4.14.2	Project Controls
4.14.3	Administration
4.14.4	Document Control
4.14.5	System Engineering

4.2.2 GUIDELINES FOR COST ESTIMATION

The success of a project and the efficiency of management depend on credible cost estimates, which are carried out during Phases B and C of the project lifecycle. Cost estimates are calculated using a detailed bottom-up estimate, starting with the lowest WBS elements. Each higher level of the WBS summarises the cost estimates calculated for the lower levels. The supporting documentation consists of the **WBS Dictionary** and the **WBS Cost Book**. The WBS Dictionary provides a link between the costs listed in the WBS spreadsheet and the justification of the cost estimates. As the number of Astroparticle Physics projects increases, it will be possible to compare these bottom-up estimates to top-down estimates, derived from past projects and other methods.

The WBS Cost Book contains supporting information, such as vendor quotes, invoices from previous procurements, and copies of catalogue pages. The aim of the Cost Book is to summarise the philosophy and parameters used to prepare the detailed cost items. This information will be used for both internal and external reviews of the system costs. The Cost Book also contains a contingency analysis, i.e. analysis of the additional funding – above and beyond the estimated cost - required to ensure the project's success. This money is to be used only for omissions and unexpected difficulties that may arise. Contingency is held entirely by the project management and not by individual subsystem managers. Contingency costs are explicitly part of the total cost estimate.

Given that many of the most advantageous locations of Astroparticle Physics projects are in countries that are suffering from high inflation rates and highly variable exchange rates, it is important to take these factors into account when costs are estimated. All estimates should be performed in the currency for the year in which the estimate is made, as if all the work to be performed will take place in the current year, but then a standard table of currency inflation should be produced for all years in which the project is to be executed (Sanders, 2009). When previously used price quotes are utilised, these should be corrected for inflation up to the current year if a new estimate is not obtained.

Labour rates are also a common source of cost estimate divergence, so all generic labour categories charged to the project should be defined from the beginning (e.g. manager, engineer, scientist, technician, secretary, construction worker, etc) (Sanders, 2009). These categories should not be based only on the labour to be hired at the beginning of the project: roles that could be needed when the project matures should also be included. Once the categories have been defined, a standard labour rate should be defined for each category based upon market survey in base currency year. These can be replaced with specific rates only when actual labour source is certain and is not likely to change in the long term. Vacation time, sick leave and other such time factors should also be taken into account. Man-hours should be estimated first and standardised rates should be applied after, necessarily including a "learning curve" factor. Collaborations are bound to face the trade off between cost and productivity both related to the quality of the employees, so it should be decided in advance of how to deal with this trade-off.

A cost estimate for each item should be the expected cost of the item excluding unusual or adverse risks. Nevertheless, collaborations should separately estimate the technical, cost and schedule risks for that item, using a standardised and disciplined method for all items and estimators (Sanders, 2009). All agencies examined here have their own such contingency cost estimates[28]. Contingency funds equal the cost of the average of all risks and are not designed to cover every possible risk occurring during the project. These funds should be held in the reserve by the Project Manager to deal with the risks if and when they come about (i.e. each Task Leader controls the budget for a subsystem without the contingency funds). Once in the reserve contingency funds lose their identification with each item. As the project progresses, contingency funds can be requested by written application to the Project Manager and requests are then reviewed by Technical Board consisting of all other system leaders.

In the case of Astroparticle Physics infrastructures, collaborations so far have been determining their own project-specific contingency costs. In the Pierre Auger Observatory for example, the Collaboration uses the percentages presented in Table 2.

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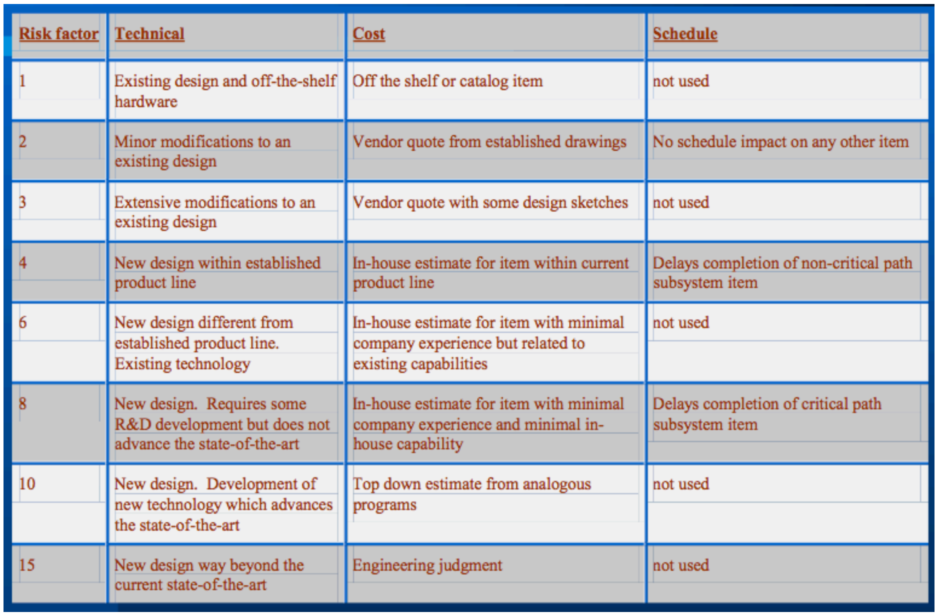
[28] NASA projects must develop full bottom-up Life Cycle Cost Estimates (LCCE), including costs for the operations phase. DOE projects must develop lifecycle cost estimates during the definition phase, which will be important features of alternatives evaluation at the CD-1 milestone. OECM contracts for bottom-up Independent Cost Estimates (ICE) or Independent Cost Review (depending on project cost category) as part of its External Independent Reviews (EIRs) at major project milestones. OECM maintains a Cost Estimation Guide. http://www.er.doe.gov/SC-80/sc-82/430-1.shtml. NSF also requires increasingly detailed cost estimates and for a number of large facilities it has engaged contractors to produce comparative parametric cost estimates ahead of major project milestones.

Table 2 Generic cost contingency based on quality of the source

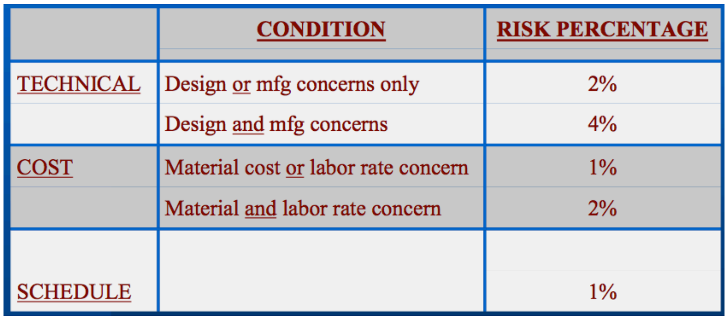
Estimate Source	Contingency (%)
Actual Cost – for deliverables already purchased	0%
Vendor Quote	10%
Vendor Information	20%
Engineering Estimate	30%
Physicist Estimate	≥50%

This is the simplest method that can be used to calculate contingency cost estimates. The best method would be to use cost point design response to each risk estimated one by one, but this method is not usually practical. An intermediate method, which uses **Standard Risk Factors** and **Risk Percentages**, has been applied successfully, and extended, by numerous science projects (Sanders, 2009). According to this method the percentage Contingency is calculated as Technical risk factor x Technical risk % + Cost risk factor x Cost risk % + Schedule risk factor x Schedule risk %. An exemplary list of risk factors is presented in Figure 3, whereas examples of the corresponding percentages are shown in Figure 4, both figures taken from Sanders (2009). In this example, Risk Factors range from 1 to 15 and Risk Percentages from 1% to 4%, so the range of contingency generated falls between 5% and 98%.



Risk factor	Technical	Cost	Schedule
1	Existing design and off-the-shelf hardware	Off the shelf or catalog item	not used
2	Minor modifications to an existing design	Vendor quote from established drawings	No schedule impact on any other item
3	Extensive modifications to an existing design	Vendor quote with some design sketches	not used
4	New design within established product line	In-house estimate for item within current product line	Delays completion of non-critical path subsystem item
6	New design different from established product line. Existing technology	In-house estimate for item with minimal company experience but related to existing capabilities	not used
8	New design. Requires some R&D development but does not advance the state-of-the-art	In-house estimate for item with minimal company experience and minimal in-house capability	Delays completion of critical path subsystem item
10	New design. Development of new technology which advances the state-of-the-art	Top down estimate from analogous programs	not used
15	New design way beyond the current state-of-the-art	Engineering judgment	not used

Figure 3 Risk factors used to calculate Contingency percentages (Sanders, 2009)



	CONDITION	RISK PERCENTAGE
TECHNICAL	Design or mfg concerns only	2%
	Design and mfg concerns	4%
COST	Material cost or labor rate concern	1%
	Material and labor rate concern	2%
SCHEDULE		1%

Figure 4 Risk percentages used to calculate Contingency percentages (copied from Sanders, 2009)

The **Cost Baseline**, i.e. the direct costs and contingency funds estimated before the start of the project, must be entered into a database and maintained throughout its lifecycle (Sanders, 2009). As the project progresses, direct cost estimates are exceeded necessitating the use of contingency funds. Costs ideally should be measured monthly against the Cost Baseline in order to detect cost deviations as early as possible. In addition, periodically (and preferably annually) cost estimates should be revised to reflect all new information, including possible use of contingency funds. These new estimates are called **New Estimate to Complete** so that they do not replace the original Cost Baseline in the database. If the Cost Baseline has been estimated properly, at the completion of the project, the collaboration will have used the entire direct estimate funds and the entire contingency funds.

Furthermore, for better synchronisation of Astroparticle Physics infrastructures and given that many of the components used in the construction of these infrastructures are similar among different projects, funding agencies should consider using an institution that can provide independent cost estimates for these large-scale infrastructures, an equivalent to NASA's Independent Program Analysis Office (IPAO), which provides cost estimates for potential future agency programs, assesses current agency cost estimation methods, and maintains a publicly-available Cost Estimation Handbook[29] (Miller, 2010).

The need of such an independent cost estimate organisation is exemplified by the diversity of factors that have been found to affect reliable cost estimation. Unfortunately, despite all the efforts taken so far (see footnote 28), the agencies examined here are still facing difficulties in accurately predicting the cost of building their infrastructures.

Miller (2010) summarises the factors that are leading to increased spending by the collaborations.

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[29] http://www.nasa.gov/pdf/263676main_2008-NASA-Cost-Handbook-FINAL_v6.pdf

First, because of the funding constraints and timeframes, agencies are putting pressure on the collaborations to predict the cost of their project earlier and earlier in the project lifecycle. However, reliable baseline estimates can only be obtained the earliest at Phase C (see Section 2). The balance of these two opposing forces has a strong influence on the reliability of cost estimates.

Second, there is a number of unpredictable factors that could affect cost estimated. These can be external (e.g. delays in partner funding contributions, cuts in national funding, changes in fuel prices, inflation and exchange rates, etc), or internal (e.g. increased cost associated with delays in one project can contribute to an extended "domino" effect on agency project portfolios, leading to loss of funding previously dedicated to new projects). Given the scale of most Astroparticle Physics infrastructures, these factors can have a far larger impact than they have for small-scale projects. Fortunately, these factors can also be a positive influence on a project, by giving a Collaboration additional time to spend in Phase B.

Finally, unpredicted cost increases are quite common when a project reaches the integration and testing part of Phase D, when all components of a system must work together for the first time, so these unpredicted costs are another major factor that can affect cost estimates. These increases are mainly due to overoptimistic assessments of resources required for R&D and of the readiness of new technologies, or due to immaterialised savings from use of previously used designs, which are later found to be maladapted to the new portions of the system.

An example of a WBS element description, relevant in large distributed observatories, is shown in ANNEX III.

4.3 ORGANISATION BREAKDOWN STRUCTURES (OBS)

The Organisation Breakdown Structure (OBS) provides an organisational rather than a task-based perspective of the project. The OBS depicts the proposed project organisation, including the interface and contractual responsibilities. OBS groups together similar project activities (the WBS WPs) and relates them to the structure of the organisation, showing key personnel and the assigned responsible parties for each WP. The OBS should parallel the WBS.

It is a hierarchical model describing the established organisational framework for project planning, resource management, time and expense tracking, and cost allocation. Thus, it is used to define the responsibilities for project management, cost reporting, billing, budgeting and project control. The hierarchical structure of the OBS allows the aggregation of project information to higher levels. The steps for the development of the OBS are: a) draw the entire organisation structure, as a hierarchy, b) define all project teams, c) specify functional and approval groups for every member of the project. An example of an OBS structure (preliminary CTA) is shown in ANNEX IV.

5 CONCLUSIONS AND RECOMMENDATIONS

Whereas each of the "neighbour" to Astroparticle Physics fields has an international centre (ESA, ESO, CERN, JINR, etc), there is no equivalent for Astroparticle Physics itself and its infrastructures are placed in a great variety of locations and their funding is coming from multiple agencies. As a result, synchronisation of project planning and implementation procedures becomes of paramount importance in this field.

In this deliverable, the construction of the first large Astroparticle infrastructures as well as the status quo in agencies with long history in funding large-scale projects was examined in order to propose procedural guidelines for project planning and implementation for the forthcoming large Astroparticle Physics infrastructures.

First, a phasing scheme for Astroparticle Physics project lifecycles was proposed, with defined Reviews and Decision Points. This scheme involves the following phases: Conceptualisation, Pre-Construction Planning (with two sub-phases), Construction, Operations and Decommissioning (Phases A-F respectively). The major tasks involved, the associated reviews and the prerequisites at Decision Points associated with each phase were described in Section 2.

Next, a set of bodies essential for the oversight and governance of Astroparticle Physics projects was proposed, once again based on the tradition in the field and the adjacent ones. It was emphasised that the proper balance between the programmatic aspects (oversight, project assurance) and the scientific/technical aspects (project management, governance) is extremely important for the success of the project and needs to be clarified at a very early stage.

Finally, Breakdown Structures needed to define a unique reference system for project management were proposed, defined with increasing detail depending on the scale and the phase of the project: Work, Product and Organisation Breakdown Structures (WBS, PBS and OBS respectively). These structures are important in the identification of the tasks and responsibilities of each actor, the coherence between all activities of a project, and the performance of scheduling and costing activities.

Recommendation 1: **We propose to use the above grid of analysis (lifecycle phases, governance and oversight bodies, breakdown structures) in order to project and analyse past and current**

experience of construction of large infrastructures, in order to confirm its relevance for the field and also prepare the future large infrastructures.

In fact, after the development of a 'fact sheet template', which will be used to maintain up to date information on the progress of each of the large infrastructure projects of the European Astroparticle Roadmap, ASPERA made its first step towards capture and dissemination of common challenges and lessons learned through the organisation of the first Project Management Workshop for Astroparticle Physics projects (18/19 October 2012, Gran Sasso Underground Laboratory in Italy). This workshop involves sessions on each of the issues mentioned in this report as well as communication issues. All these steps are taken, in order to capture, and disseminate of the 'lessons learned', which has been a great common challenge so far in all disciplines (e.g. see Miller, 2010[30]).

Recommendation 2: It is important to develop adequate tools for the tracking of project performance in terms of cost, schedule and scope relative to initial baseline. It is also important to establish procedures of hierarchical approval in case of cost and schedule slips with respect to the baseline, based on these tools.

At CERN and in the United States, a cost and schedule tracking tool for large projects (the Earned Value Management System (EVMS)) has been used to report accurate information on the achievement of the baseline cost, schedule and performance goals. Using this tool the agencies are able to monitor performance of their projects, but they have chosen to start doing so at different stages in the project's

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[30] DOE, NASA and NSF, as well as many of their European equivalents, have experienced a number of project failures and severe overruns. DOE has recently carried out root cause analysis in areas of contracting and project management, suggestions on to how to implement a lessons learned system have been given, lessons learned reports are collected, an internal online lessons learned database has been created and yearly Project Management Workshops are run. NASA has a long tradition of executing and disseminating technical solutions, post-mishap studies and "lessons learned". It has also developed a database, the NASA Technical Reports Server (NTRS, containing NASA and previous government technical documents going back to the beginnings of aeronautics and space fields) and runs a yearly two-day intensive Project Management Challenge for all NASA personnel and contractors as part of its extensive Academy of Program/Project and Engineering Leadership (APPEL) training organisation. Finally, even if NSF has not yet implemented a systematic practice of capturing lessons learned, some reports have been submitted by developed projects. In addition, NSF runs a yearly Large Facilities Workshop on operations issues and sponsors a near-yearly "Project Science" workshop on facility planning and development topics.

lifecycle[31].

In response to project performance challenges, the agencies have also been facing challenges on containing costs during the final design and/or construction stages. Implementation of cost containment policies for construction is facilitated by transparent commitment to initial baselines and the compulsory use of EVMS tools. For example, Oversight Committee's (e.g. the council of EGO In the case of advanced Virgo construction) must approve performance baseline changes if a project incurs a cost increase in excess of an threshold with respect to the TDR cost baseline or a large delay (cumulative) slip of original project completion date.

As important as controlling cost growth is during construction, growth in estimated project lifecycle cost can be equally or much more substantial during Pre-construction Planning, i.e. even before a performance baseline commitment has been made, frequently due to a change in project scope during Phases B and C. It is thus recommended that in the final guidelines for Astroparticle Physics projects, similar procedures are put in place to contain the costs.

> **Recommendation 3: Special care should be taken to attract, and/or train qualified managerial and technical project leadership, which becomes a central element in the deployment of future large infrastructures.**

Another well known issue is the need for qualified project leadership and technical personnel. Miller (2010) concluded for example, that qualified managers and technical personnel specifically for large-scale science projects are becoming scarce resources[32]. Thus, the importance of qualified project management personnel, trained specifically for large-scale projects and owing strong leadership skills, is an issue that should be of vital importance to bodies funding Astroparticle Physics projects.

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[31] DOE tracks projects during Pre-construction Planning and Construction phases (reference baselines change between these phases), NASA from the beginning of the Final Design and Fabrication phase (Phase C) whereas NSF at the beginning of the construction phase.

[32] The U.S. Government Accountability Office (U.S. GAO) in 2008 noted that "given continued budgetary pressures, which have been forecast to increasingly constrain the nation's discretionary spending, plus an aging workforce nearing retirement, Science is likely to face two primary challenges to its project performance in the future: a) heightened funding and market uncertainties and b) a shrinking pool of qualified people to manage projects." NASA officials have arrived in the same conclusion and cite two additional factors related to this challenge. First, the increased complexity of projects, both technically and in terms of external partnering, and the increased competition for available talent due to the growth of a global market for project and technical personnel.

> **Recommendation 4: The plurality, different procedures and temporalities of funding sources, will be one the major challenges of the next generation of large Astroparticle Infrastructures. The agencies should examine this issue in depth, by examining the synchronisation of streamlined procedures but also exceptional situations as for instance of temporary inabilities of some partners to fulfil their obligations, situations of inflation in host country etc.**

For the scale of projects discussed here, great complexity is introduced by the fact that sources of funding are coming from entirely different funding stakeholders and timeframes, with substantial differences in management culture and development practices. Up to now in Astroparticle physics there has been two ways to cope with that: a) one member of the collaboration is the dominant funding body (e.g. NSF and IceCube), or b) there is an effective governance structure (an integrated, transparent and stable collaboration characterised by effective, regular communication) and/or a strong project leadership team under one manager/director who is uniquely responsible for project performance. This has been to a large extent the achievement of the Pierre Auger Observatory, although the scale of next generation projects will be an order of magnitude more complex, demanding enhanced care.

6 REFERENCES

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ANNEX I AUGER OBSERVATORY MANAGEMENT AND OVERSIGHT

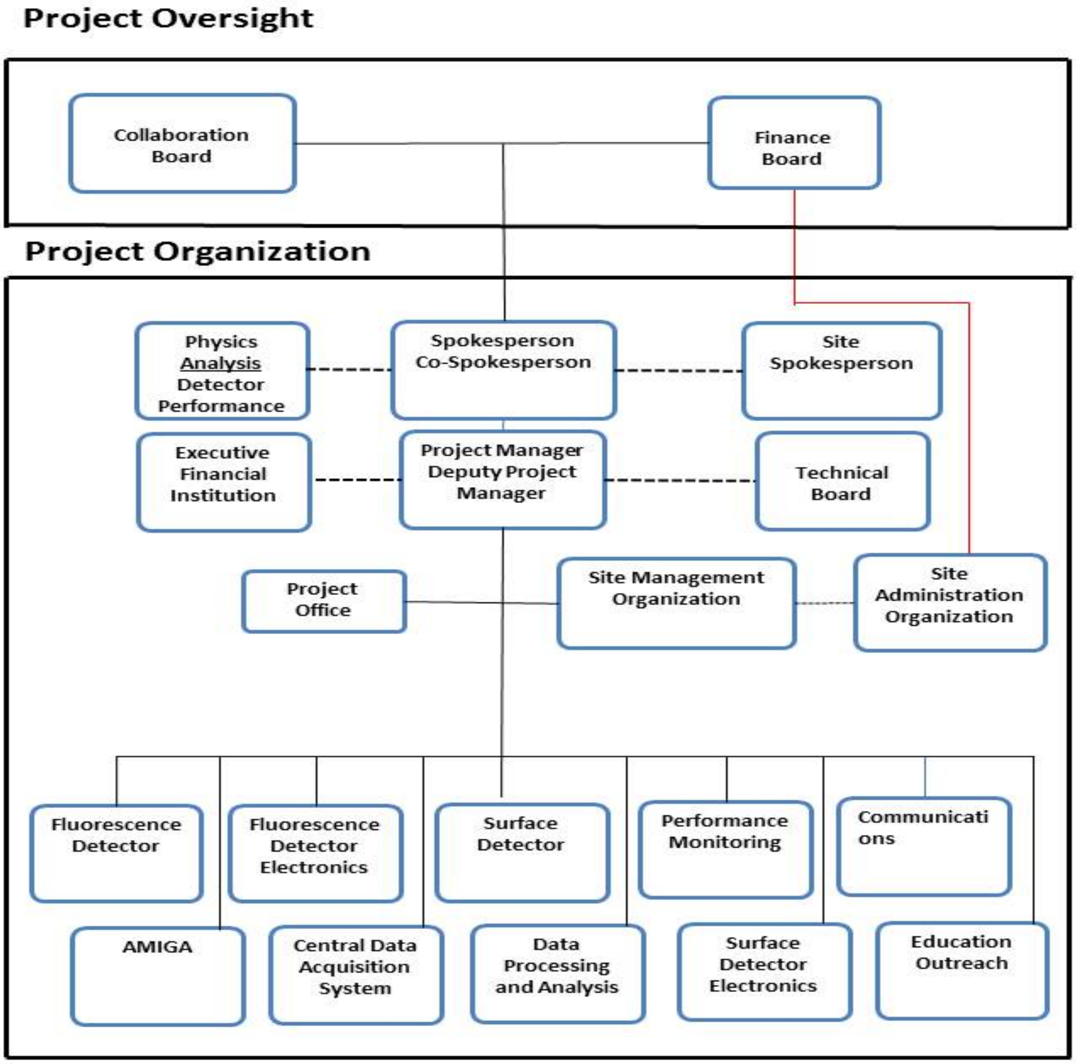
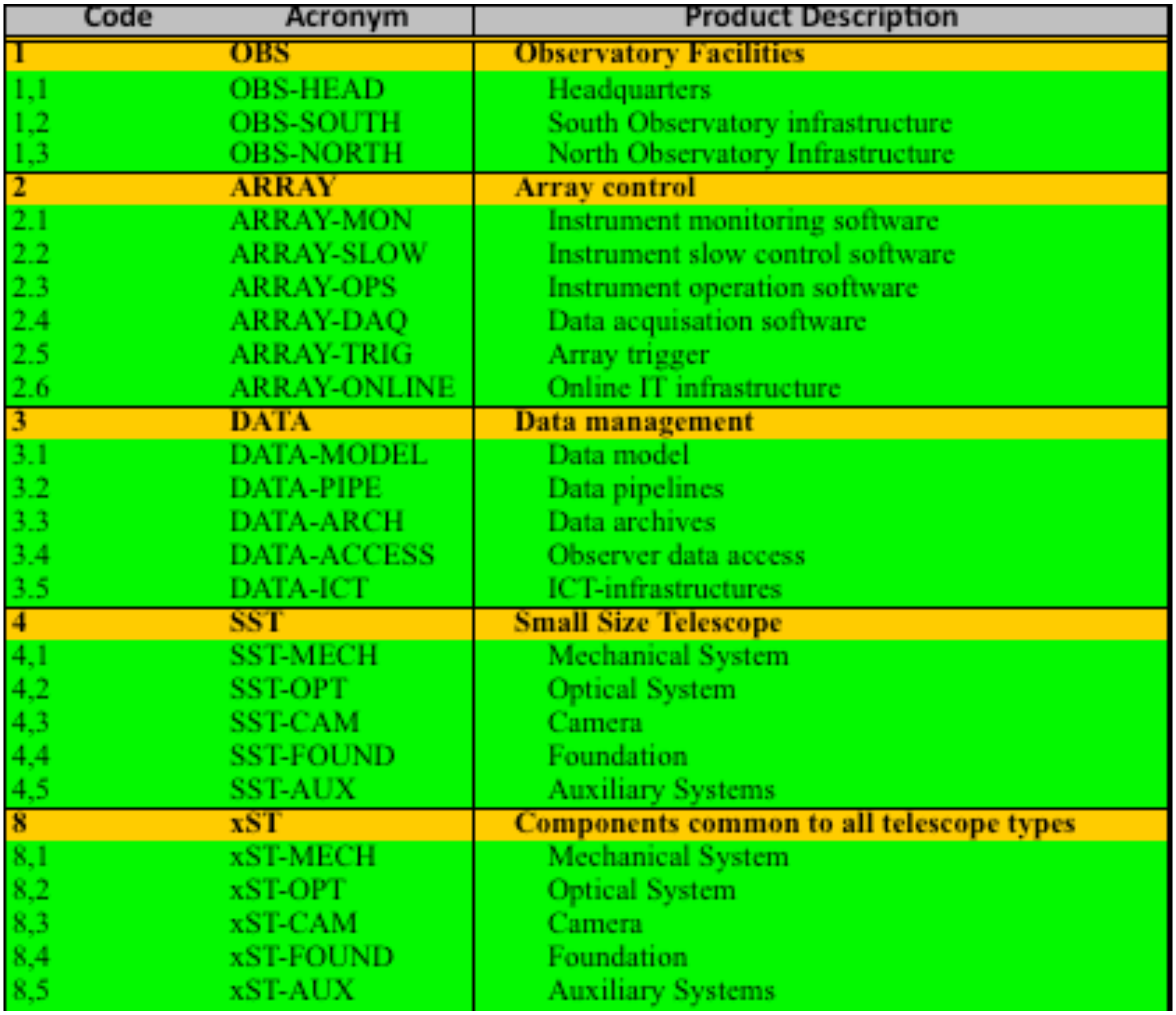


Figure 5 Organigram of the Pierre Auger Observatory

ANNEX II CTA PRODUCT BREAKDOWN STRUCTURE (PRELIMINARY)



Code	Acronym	Product Description
1	**OBS**	**Observatory Facilities**
1,1	OBS-HEAD	Headquarters
1,2	OBS-SOUTH	South Observatory infrastructure
1,3	OBS-NORTH	North Observatory Infrastructure
2	**ARRAY**	**Array control**
2.1	ARRAY-MON	Instrument monitoring software
2.2	ARRAY-SLOW	Instrument slow control software
2.3	ARRAY-OPS	Instrument operation software
2.4	ARRAY-DAQ	Data acquisation software
2.5	ARRAY-TRIG	Array trigger
2.6	ARRAY-ONLINE	Online IT infrastructure
3	**DATA**	**Data management**
3.1	DATA-MODEL	Data model
3.2	DATA-PIPE	Data pipelines
3.3	DATA-ARCH	Data archives
3.4	DATA-ACCESS	Observer data access
3.5	DATA-ICT	ICT-infrastructures
4	**SST**	**Small Size Telescope**
4,1	SST-MECH	Mechanical System
4,2	SST-OPT	Optical System
4,3	SST-CAM	Camera
4,4	SST-FOUND	Foundation
4,5	SST-AUX	Auxiliary Systems
8	**xST**	**Components common to all telescope types**
8,1	xST-MECH	Mechanical System
8,2	xST-OPT	Optical System
8,3	xST-CAM	Camera
8,4	xST-FOUND	Foundation
8,5	xST-AUX	Auxiliary Systems

Figure 6 A preliminary PBS for Cherenkov Telescope Array (CTA)

ANNEX III WBS COST ELEMENT ANALYSIS (EXEMPLES: AUGER SURFACE STATIONS, CTA TELESCOPES OR KM3NET LINES

The remaining columns (not shown) may present the contribution from each of the countries in the scientific collaboration. In addition there can be a column representing contributions from the host country infrastructure costs, and also a Common Funds column. The sum of these columns equals the amount in the “Total Contributions Project” column. Finally, the “Needed to Complete Project” Column is the difference between the required cost (Total Project w/ Contingency) and the total contributed cost.

Column name	Description
WBS	The WBS number, e.g., 1.2.2.4
Activity	A brief description of the deliverable or activity
Quantity	The quantity required per component
Base unit	Units of Quantity column. Typically “each” for deliverables, “hours” for labour
Trade code	Further specifies the activity e.g. the labour type (e.g. Engineer, Technician etc).
Cont. %	Contingency percentage
Wastage	Units wasted in the process of implementation, expressed as a fraction of the total quantity,
Spares	Spare units, expressed as a fraction of the total quantity.
Cost / Unit	The cost for the Base Unit.
Materials/component	Total materials cost for one component = Quantity * (Cost/Unit) * (1 + Wastage + Spares)
Labour / Component	Total labour cost for one component = Quantity * (Cost/Unit)
N	The number of components
Esc. Factor	Escalation factor. An estimate of the percentage that costs will rise during the procurement
Total M&S	The total Materials & Services (M&S) cost for the deliverable = (Materials/Component) * N
Total Labour	The total Labour cost for the deliverable = (Labour/Component) * N
Total EDIA	Estimated cost of Engineering, Design, Inspection, and Administration (EDIA)
Esc.	Total Escalation = (Esc. Factor) * [(Total M&S) + (Total Labour) + (Total EDIA)]
Estimated Cost (Escalated)	= (Total M&S) + (Total Labour) + (Total EDIA) + (Esc.)
Total Cont	Total contingency = (Estimated Cost Escalated) * Cont %
Total Project	Sum of previous 2 columns. Total cost of this WBS element.

ANNEX IV CTA ORGANIZATION BREAKDOWN STRUCTURE (PRELIMINARY)