ALMA Project Plan

May 29, 2002

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1. PROJECT DESCRIPTION

1.1 Project Overview

The Atacama Large Millimeter Array (ALMA) is a revolutionary instrument in its scientific concept, in its engineering design, and in its organization as a global scientific endeavor. ALMA will provide scientists with precise images of galaxies in formation seen as they were twelve billion years ago; it will reveal the chemical composition of heretofore unknown stars and planets still in their formative process; and it will provide an accurate census of the size and motion of the icy fragments left over from the formation of our own solar system that are now orbiting beyond the planet Neptune. These science objectives, and many more, are made possible owing to the design concept of ALMA that combines the imaging clarity of detail provided by a 64-antenna interferometric array together with the brightness sensitivity of a fully filled aperture.

The challenges of engineering the unique ALMA telescope begin with the need for the telescope to operate in the thin, dry air found only at elevations high in the Earth's atmosphere where the light at millimeter and submillimeter wavelengths from cosmic sources penetrates to the ground. ALMA will be sited in the Altiplano of northern Chile at an elevation of 5000 meters (16,500 feet) above sea level. The ALMA site is the highest, permanent, astronomical observing site in the world. On this remote site superconducting receivers that are cryogenically cooled to less than 4 degrees above absolute zero will operate on each the 64 12-meter diameter ALMA antennas. The signals from these receivers will be digitized and transmitted to a central processing facility where they are combined and processed at a sustained rate greater than 10^{16} operations per second. As an engineering project, ALMA is a concert of 64 precisely-tuned mechanical structures each weighing more than 80 tons, superconducting electronics cryogenically cooled, and optical transmission of terabit data rates--all operating together, continuously, on a site very high in the Andes mountains.

The challenges of communicating the mission and the excitement of ALMA to the citizens who ultimately sponsor the project is a task as vital as the engineering challenges. To this end a comprehensive program of education and public outreach is an integral part of the ALMA Project.

1.2 Project Technical Deliverables

The ALMA construction Project will deliver an antenna array capable of meeting the scientific requirements as summarized in Annex B. A tabular summary of the technical description of ALMA as derived from those science requirements is presented in Table 1-1. A brief description of the key elements is included here.

Table 1-1. ALMA Technical Summary

Array	
Number of Antennas (N)	64
Total Collecting Area ($\pi/4$ ND^2)	7238 m^2
Total Collecting Length (ND)	768 m
Angular Resolution	0".2 lambda (mm)/baseline (km)
Array Configurations	*{dimension of filled area}*
Compact: Filled	150 m
Continuous Zoom	200-5000 m
Highest Resolution	14.0 km
Total Number of Antenna Stations	250
Antennas[1]	
Diameter (D)	12 m
Surface Accuracy	20 micrometers RMS
Pointing	0".6 RSS in 9 m/s wind
Path Length Error	< 15 microns during sidereal track
Fast Switch	1.5 degrees in 1.5 seconds
Total Power	Instrumented and gain stabilized
Transportable	By vehicle with rubber tires
Front Ends[2]	*{All frequency bands}*
84 - 119 GHz SIS	*-Dual polarization*
211 - 275 GHz SIS	*-Noise performance limited*
275 - 370 GHz SIS	*by atmosphere*
602 - 720 GHz SIS	
Water Vapor Radiometer	183 GHz
Intermediate Frequency (IF)	
Bandwidth	8 GHz, each polarization
IF Transmission	Digital
Correlator	
Correlated baselines	2016 (=64 * 63/2)
Bandwidth	16 GHz per antenna
Spectral Channels	4096 per IF
Data Rate	
Data Transmission from Antennas	120 Gb/s per antenna, continuous
Signal Processing at the Correlator	1.6 x 10^{16} multiply/add per second

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[1]The antenna specifications are detailed in Request for Proposals for a Prototype Antenna for the Millimeter Array/Large Southern Array, dated March 30, 1999.

[2]These four frequency bands are those required on the first-light ALMA as specified by the ALMA Science Advisory Committee at the committee meeting of March 11, 2000. Receivers in six additional atmospheric windows are deferred to future development.

Array Site: ALMA will be built on the Chajnantor altiplano in the Atacama Desert of northern Chile. Its approximate coordinates are 90 degrees West, 23 degrees South. The site is at an elevation of slightly over 5000 m. The site land is administered by the Chilean Ministry of National Assets and set aside by Presidential decree as a protected region for science. Measurements made *in situ* continuously since 1995 of the atmospheric transparency and stability confirm that the site has superior conditions for millimeter-wave, and submillimeter-wave astronomy and it will meet the science requirements for the ALMA Project.

Antennas and Antenna Configurations: The sixty-four ALMA antennas each have a reflecting surface 12 meters in diameter with a parabolic cross-section. The number and size of the antennas is determined from imaging requirements; the materials used in their construction is dictated by the fact that ALMA will operate 24 hours a day and hence the antennas must maintain their performance when fully exposed to the thermal variations and wind gusts imposed by the site environment. Each antenna is fully steerable; more than 85 percent of the celestial sphere is above the horizon at the Chajnantor site.

The antennas are all movable among 250 prepared antenna foundations, or stations. Each station has a concrete foundation to support the antenna and provision for electrical power and data communications. The antennas are moved by a specially designed antenna transporter. The ability to move the antennas, and hence to rearrange them on the ground, provides ALMA with the capability to match its angular resolution to the science requirements of its users. Antenna configurations as small as 150 meters in diameter (for the study of large or low brightness objects) and as large as 14 km in diameter (for the study of small, high brightness objects) are deliverables of the ALMA construction project.

Front End Electronics: Each antenna will be equipped with a receiving system, or front end, capable of detecting astronomical signals in four frequency bands. These are coherent detectors, meaning that they employ a common local oscillator signal to convert the received signal frequency to a much lower intermediate frequency that is subsequently transmitted to the central electronics building where it is combined with the signals from all other antennas. The local oscillator is a deliverable of the front end electronics task, but the intermediate frequency transmission and processing is a task of the back end subsystem. Further, each of the four frequency band cartridges includes two receivers operating in orthogonal senses of linear polarization so that the full polarization state of the received radiation may be measured. The receivers are based on superconducting mixers that operate at temperatures below 4 K. All of the cartridges are included in a single cryogenic dewar located at the Cassegrain focus.

Also at the cassegrain focus, but removed from the optical axis of the telescope, is a water vapor radiometer tuned to the 183 GHz line of terrestrial water emission. Each antenna has such a water vapor radiometer that is used to measure the column of atmospheric water vapor above the antenna; from these measurements the phase distortion of an astronomical signal resulting from its passage through the screen of atmospheric water is determined and its deleterious effects may be removed from the measured astronomical signal. This is a technique identical in its purpose and application to adaptive optics as used for ground-based telescopes operating at visual and infrared wavelengths. For ALMA the technique is applied digitally after signal detection; for optical/infrared telescopes the technique is applied prior to signal detection using analog techniques (i.e., physically distorting the shape of one or more mirrors in the signal path).

Back End Electronics: The intermediate frequency that is output from the front end is amplified and digitized at the antenna by the backend electronics. In order to process the 8 GHz bandwidth of the intermediate frequency signal, the backend electronics subdivides that signal into four 2 GHz sub-bands for transmission to the correlator.

Correlator: The correlator is a special-purpose digital signal processor. It combines the digitized intermediate frequency signals from all the antennas pair wise; there are 2016 pairs of antennas in ALMA. Images of the astronomical source are created by Fourier inversion of these complex (phase and amplitude) data.

Computing and Software: The computing system has the task of scheduling observations on the array, controlling all the array instruments, including pointing the antennas, monitoring instrument performance, monitoring environmental parameters, managing the data flow through the backend electronics and presentation of these data to the correlator. The output of the correlator is again the responsibility of the computing task where it is processed through an image pipeline, calibration is applied, and first-look images are produced. Finally the science data and all associated calibration data, monitor data, and derived data products are archived and made available for network transfer.

The deliverables from the computing task include the software system necessary to achieve the functionality noted above and the hardware necessary to run that software and manage the data flow.

Organization: The system engineering, scientific oversight, and management necessary to coordinate the task activities of the ALMA technical team responsible for production of the ALMA technical system noted above are integral deliverables of the ALMA Project as well. The project safety office is included in the management function and reports directly to the ALMA Project Manager.

1.3 Project Programmatic Scope

1.3.1 Data Products

The fundamental data products from ALMA are calibrated, pipeline-processed, images. These images may be either be continuum images of astronomical sources or spectroscopic images which reveal the kinematics or distribution of different species. These images, together with the uv-data files (i.e., the cross-correlation data prior to the Fourier transform), calibration files, and monitor information files, will be delivered in a timely manner following completion of the scheduled observing program to the astronomer who proposed the observation. All of these same data will be written to a permanent archive.

The burden this programmatic deliverable imposes on the ALMA construction project is threefold. First, the ALMA software system must be capable of defining a default calibration strategy based on scientific key values assigned in advance to each scheduled proposal. This is needed to assure that the pipeline-processed images that go into the ALMA archive are of a consistent and understood quality. Second, the ALMA software system has a firm requirement for a pipeline-processing capability; this was highlighted in Section 2 above as a technical deliverable. Further, that pipeline processor must accommodate multiple datasets for the creation of a single image (e.g. observations made of a single source using two or more array configurations all addressed to a specific scientific goal). Third, the ALMA software system requirement includes provision for a permanent archive that is network-accessible—this involves both an adequate software system and the hardware needed to support the archive.

1.3.2 Array Operations Facilities and Infrastructure

A primary safety guideline for the ALMA Project is to minimize the number of staff assigned to the 5000m Array Operations Site (AOS). This guideline has many ramifications that can be summarized by the statement that ALMA will be operated remotely. That is, the array operator and all personnel involved with astronomical observations and maintenance of array instrumentation will be located at ALMA facilities at lower elevation. This leaves on the AOS only those personnel needed to assure the security of the site, people whose task it is to maintain the backend electronics and the correlator at the central electronics building on the array site, those responsible for module exchange—replacing failed instrument modules with functioning spares that are stored on the AOS—and those whose task it is to transport the antennas as needed for array reconfiguration. In order to achieve this goal the entire array must be designed and built to be modular in character, and wherever possible to be self-diagnosing. Each instrument must have provision for an adequate number of monitor points that are reported to the control computer in real time

The guidelines to minimize the size of the operating staff, maximize the operating effectiveness of that staff, and to minimize the instrumental "downtime" all lead to the Project requirement to locate the operating staff close to the AOS but at lower altitude. Here the considerations are to provide a work environment that is at an elevation where the deleterious effects of a reduced oxygen environment are minimized but nevertheless a work environment that is sufficiently close to the AOS that instrumental problems can be investigated and solved quickly. We refer to this operations and maintenance facility as the Operations Support Facility (OSF). One of the deliverables of the ALMA Construction Project is to connect the OSF to the AOS by means of a road for the transportation of the antennas and operations/maintenance staff, and a communications highway involving buried optical fibers over which the astronomical data and the instrument monitor data is carried in real-time, and at high bandwidth. These links will give the ALMA operations staff a virtual presence on the AOS that will be adequate to investigate problems quickly and begin the process of effecting a cure.

During construction, the antennas will be erected by the antenna contractor at the OSF and, once accepted by the project, they will be carried on the antenna transporter to the AOS. The location for the OSF is ~15 km east of San Pedro and south of the Paso de

Jama on land administered by the Chilean Ministry of National Assets. From this location a restricted-use road will be built connecting the AOS to the OSF in a direct line that can be used not only to transport the assembled antennas to the AOS without using the public highway, but can also be used to return the antennas to the OSF for repair and maintenance. Operationally, only routine antenna maintenance, and no antenna maintenance crew, will be located at 5000 m altitude. All major antenna work will be done at the OSF. The increased proximity of the OSF to the AOS makes it possible at some time in the future to locate the array correlator at the OSF thereby moving still more operations staff off the 5000 m site; this is a decision to be made later in the operational phase of the telescope operational life.

1.3.3 Construction Project Interface to ALMA Operations: Commissioning and Interim Operations

The sixty-four antenna ALMA array is kept coherent, that is, all antennas sample the incoming wavefront from an astronomical source at the same relative phase. This is done by transmitting to each antenna a common local oscillator signal and then delaying processing of the intermediate-frequency data from each antenna according to the instantaneous source-antenna geometry. The data received by each antenna and transmitted to the central array electronics building for processing by the correlator also takes into account the difference in transmission times from each antenna to the central building. Thus, ALMA has some components of its technical baseline that are multiples of 64 (e.g. the antennas, receiving system) and some components of the technical baseline that are individually unique (e.g. the local oscillator generator that serves as the reference for the whole array; the correlator). The array cannot function as a scientific instrument without all the unique devices, but it can function, albeit at reduced capability, with fewer than the full complement of 64 antennas or other equipment modules that are antenna-based.

Interim Science Operations: It is the fundamental programmatic goal of the ALMA construction project to begin operating ALMA as an interferometric array for scientific research as soon as it is possible. Scientific observations during commissioning of the array can: (i) make use of experienced scientists to uncover hardware and software problems so that such problems are readily identified and it is possible to implement design changes to solve those problems early in the construction project; (ii) refine array instruments and techniques that depend on actual array site conditions that affect science research programs; and (iii) gain early operating experience that can be fed back to the construction project and changes can be made to improve reliability or maintainability of the array. As soon as commissioned, the partial array will move to interim science operations in which the general community will be invited to apply for some fraction of the observing time.

Requirements for Instrument Priorities and Instrument Commissioning

- The one-of-a-kind array instrumentation modules must be given highest priority among construction tasks so that they are completed as early in the project as possible and the interim science operations may commence with the first few antennas in Chile.

- Hardware delivered will be integrated, verified, and commissioned subsystem module-by-subsystem module. Once commissioned, each subsystem module will be placed into service in the operating array.

Requirements for ALMA operations derived from the fundamental programmatic goal

- The initial complement of the ALMA operations team must be in place at the OSF and on the array site at the time the first array subsystem modules are commissioned. It will be the responsibility of these operational staff to maintain and operate the commissioned modules.
- The details of the scientific operations plan need to be defined and implemented at the time the first few antennas arrive on site.

1.4 Education and Public Outreach

The ALMA partnership will develop an active program of educational activities with ALMA as its focus. This program will be a cooperative endeavor of the NRAO Education and Public Outreach office and the ESO Education and Public Relations Department. The goals are:

1) to communicate the scientific mission of ALMA accurately and appropriately to students of all ages;
2) to illustrate, through visual material accessible via the internet, the technical concepts of ALMA including those that form the basis for superconducting electronics, the transmission of electromagnetic waves as digital signals, and the formation of an image from multi-aperture data. The primary thrust will be to communicate the fact that these techniques, although developed for radio astronomy, are not unique to radio astronomy, but instead they touch many aspects of everyday life including medical diagnostics, transportation systems, and weather forecasting;
3) to "personalize" scientific research by emphasizing that "real people" are engaged in that research. Here the intent is to make available through print and the internet the photographs and background of those scientists using ALMA at a particular moment. An important goal is to highlight the diversity of those individuals illustrating that scientific research is a career option available to everyone.

The public information goals of the education and public outreach (EPO) task include all of the above with the additional highlight of making available to the public contact information for the scientists who use ALMA. This provides a close and personal connection between the individuals who benefit directly from ALMA and the people who provide the opportunity for that benefit. It also serves to provide a very large number of contact points enabling the public to address questions to scientists with whom they may share common interests or common background.

In Chile, ALMA Operations will work cooperatively with Regional Chilean officials to: (1) provide an additional tourist destination near the commune of San Pedro de Atacama; (2) enlarge the educational opportunities, particularly technical opportunities, in the locality; and (3) provide full employment opportunities in the breadth of ALMA operational activities for citizens of the region. Accomplishing these goals may involve establishing an appropriate visitor center illustrating ALMA, its scientific mission and its user community, and providing technical educational programs either in, or in conjunction with, local schools.

2. ALMA SCIENCE REQUIREMENTS

The Atacama Large Millimeter Array (ALMA) Project will provide scientists with an instrument uniquely capable of producing detailed images in the continuum and of spectral lines of the formation of galaxies, stars, planets and of the chemical precursors necessary for life itself.

ALMA should provide astronomers a general purpose telescope which they can use to study at high angular resolution millimeter wavelengths emission from all kinds of astronomical sources. ALMA will be an appropriate successor to the present generation of millimeter-wave interferometric arrays and will allow astronomers to:

- Image the redshifted dust continuum emission from evolving galaxies at epochs of formation as early as z=10;
- Trace through molecular and atomic spectroscopic observations the chemical composition of star-forming gas in galaxies throughout the history of the universe;
- Reveal the kinematics of obscured galactic nuclei and Quasi-Stellar Objects on spatial scales smaller than 300 light-years;
- Image gas-rich, heavily obscured regions that are spawning protostars, protoplanets and pre-planetary disks;
- Reveal the crucial isotopic and chemical gradients within circumstellar shells that reflect the chronology of invisible stellar nuclear processing;
- Obtain unobscured, sub-arcsecond images of cometary nuclei, hundreds of asteroids, Centaurs, and Kuiper-belt objects in the solar system along with images of the planets and their satellites;
- Image solar active regions and investigate the physics of particle acceleration on the surface of the sun.

No instrument, other than ALMA, existing or planned, has the combination of angular resolution, sensitivity and frequency coverage necessary to address adequately these science objectives.

ALMA is conceived and designed to be a long-lived user observatory. Its scientific impact at any time will be facilitated by the quality of its instruments and limited only by the creativity and industry of its scientist-users.

ALMA will have the capability to extend the high-resolution imaging techniques of radio astronomy to millimeter and submillimeter wavelengths to achieve an astronomical imaging capability equal in clarity of detail to the imaging capability of the Hubble Space Telescope (HST) and large ground based telescopes. It will do so at wavelengths where the richness of the sky is provided by thermal emission from the cool gas and dust from which stars and all cosmic objects form. In this sense, ALMA is the appropriate scientific complement to the VLT and Gemini, to the HST, and its successor instrument the Next Generation Space Telescope (NGST) instruments which image light from stars and collections of stars such as galaxies.

The primary science requirement for ALMA is the flexibility to support the breadth of scientific investigation to be proposed by its creative scientist-users over the decades long lifetime of the instrument. However, three science requirements stand out in all the science planning for ALMA done in both Europe and in North America. These three level-1 science requirements are the following:

1) The ability to detect spectral line emission from CO or C in a normal galaxy like the Milky Way at a redshift of $z = 3$, in less than 24 hours of observation.

2) The ability to image the gas kinematics in a solar-mass protostellar/ protoplanetary disk at a distance of 150 pc (roughly, the distance of the star-forming clouds in Ophiuchius or Corona Australis), enabling one to study the physical, chemical, and magnetic field structure of the disk and to detect the tidal gaps created by planets undergoing formation.

3) The ability to provide precise images at an angular resolution of 0".1. Here the term *precise image* means accurately representing the sky brightness at all points where the brightness is greater than 0.1% of the peak image brightness. This requirement applies to all sources visible to ALMA that transit at an elevation greater than 20 degrees.

These requirements drive the concept of ALMA to its current technical specifications. A simplified flowdown of Science requirements into Technical Specifications is:

1) For high redshift galaxies, the translation of the science requirement into a performance specification can be easily made by comparison with the results obtained by current millimeter arrays, which have collecting areas between 500 and 1000 square meters. These arrays can detect CO emission from the brightest galaxies, amplified by gravitational lensing in one to two days of observations. Signals from normal, unlensed objects, will be typically 20-30 times fainter.

The sensitivity of an array is essentially controlled by three major terms: the atmospheric transparency, the noise performance of the detectors, and the total collecting area. Compared to current mm arrays, by locating ALMA on a better site, the contribution of the atmosphere will be minimized. The noise level of the detectors cannot be reduced by much more than a factor of 2, because these receivers are approaching fundamental quantum limits. An important factor of square root 2 will be gained by the requirement that ALMA support front end instrumentation capable of measuring both states of polarization. The remaining factor 7-10 can only be gained by increasing the collecting area by a similar amount. Hence, the ALMA goal is to achieve at least 7000 square meters in collecting area.

The spectral lines of scientific interest as diagnostics of the gas content and dynamics of a galaxy early in the history of the universe have frequencies that are fixed in the rest frame of the galaxy, but we observe these lines at a frequency that depends on the redshift of the particular galaxy. Since galaxies are found at every redshift (i.e., age) the goal of the ALMA Project is to provide the capability to observe in all atmospheric windows from 30-950 GHz so that galaxies of all ages may be studied. Initially, the Project will support observations in the four highest-priority frequency bands. Additional capabilities can be added in the operational phase of ALMA. Since the redshift of the galaxies will initially be essentially unknown, the instantaneous bandwidths of the receivers should also be as large as possible.

2) A similar sensitivity argument can also be made for the studies of protoplanetary disks: going from the 0.5" angular resolution obtained in the best images with current millimeter arrays to the 0.1" resolution comparable with that of optical telescopes requires a factor 25 improvement in sensitivity, similar to that mentioned above. In addition, proper study of the kinematics requires spectroscopy with velocity resolutions finer than 0.05 km/s, or a few 10 kHz only.

Gaps created by proto Jupiter-mass planets in protoplanetary disks are expected to be of the order of 1 AU in size. Combined with the distance of the nearest star forming regions, 60--140 pc, this implies that ALMA needs to provide 10 milli-arcsecond resolution or better. This can be obtained by combining high frequency (650 GHz and above) observations with array configurations approximately ten kilometers in physical dimension.

For the larger protostellar disks, the sensitivity of ALMA highlighted above will allow, for the first time, the opportunity to investigate the structure of the magnetic field in a gas disk by observing polarized emission from dust. The spatial morphology of a rotating, solar-mass, disk of gas and dust provides us with insight into the hydrodynamics of star formation; the morphology of the magnetic field provides us with insight into the magnetodynamics of star formation. A comparison of the two will allow astronomers the opportunity to discover the physical process by which magnetic fields accelerate or impede the process of star formation. The requirement to support these observations emphasizes again the firm requirement for the ALMA receiving system to have full polarization capability. The formation of protostars and planets also causes changes in the density, temperature and chemistry in the envelopes and disks. Wide frequency coverage is essential to probe these different conditions.

3) High fidelity imaging requires a sufficient number of baselines, in order to cover adequately the uv plane (i.e., the time/frequency domain plane in which the data are sampled. Detailed studies of the imaging performance of aperture synthesis arrays have shown that imaging performance implies a minimum number of antennas, 40 or above, and accurate measurements of the shortest baselines, as well as of the large scale emission measured by total power from the antennas. Such accurate measurements can only be obtained with high quality antennas, with superior pointing precision. High fidelity imaging also requires the ability to perform calibrations to ``freeze" the atmospheric turbulence which distorts the radiation coming from celestial sources.

The combination of these three major requirements calls for a reconfigurable zoom-lens array covering baselines from a few meters up to several kms, observing over the full mm and submm atmospheric windows. The maximum size of the individual antennas is driven by the required pointing and surface precision: a choice of 12-m antennas offers an excellent technological compromise. To provide no less than 7000 m^2 of total collecting area, 64 antennas are needed, which is a large enough number to guarantee excellent imaging performance.

Finally, to allow cancellation of atmospheric disturbances, the antennas must be equipped with Water Vapor Radiometers (WVR) to measure atmospheric pathlength variations and correct the image distortions such phase variations create. This is a technique identical in its purpose and application to adaptive optics as used for ground-based telescopes operating at visual and infrared wavelengths. In addition, ALMA is designed to be able to detect calibration sources such as quasars in a time short enough to minimize the atmospheric phase fluctuations so that the needed correction may be as small as possible. Detecting weak sources requires wide instantaneous bandwidth for all the front end receivers to maximize the continuum sensitivity.

The final major scientific requirement affects the diverse community that will use and benefit from the scientific capabilities that ALMA brings to extend their research endeavors: ALMA should be "easy to use" by novices and experts alike. Astronomers certainly should not need to be experts in aperture synthesis to use ALMA. Automated image processing will be developed and applied to most ALMA data, with only the more intricate experiments requiring expert intervention.

3. WORK BREAKDOWN STRUCTURE, SCHEDULE OF VALUES AND ASSIGNMENT OF DELIVERABLES FOR ALMA CONSTRUCTION

3.1 Work Breakdown Structure

The ALMA Work Breakdown Structure (WBS) is a detailed description of all the tasks necessary to construct the instruments and software required for ALMA; to construct the buildings, roads, antenna foundations, utilities and infrastructure needed for the support of those instruments and software; to integrate the whole into a properly functioning synthesis array telescope on the Chajnantor site in northern Chile; and to manage the construction project on behalf of the two sponsoring ALMA partners.

The ALMA construction project has adopted a management structure based on the Integrated Product Team (IPT) concept. The IPT concept provides a method of managing tasks carried out across multiple organizations and locations. Each Level One WBS element is managed by an IPT responsible for delivering the required products on time, within the specified cost and meeting the project requirements. The implementation of the IPT concept is described in detail in the ALMA Management Plan.

The ALMA WBS was derived in three steps. First, the scientific requirements for ALMA were specified by the ALMA Science Advisory Committee (ASAC). Second, a technical description of an array capable of meeting those requirements was outlined by the technical leaders of the ALMA Project in North America and Europe. Close and frequent interaction was required between the ASAC and the technical project leadership to assure that the planned technical capabilities met the science requirement priorities. Third, a plan for design and fabrication, or procurement, of all the hardware modules and subsystems was established. Costs were estimated for all tasks and subtasks. The process was informed and constrained by the estimated resources the sponsors were intending to commit to ALMA. The resulting project description was organized into the WBS which specifies in sufficient detail the tasks and the resources, both personnel and financial, required to realize those tasks for the completed project.

The WBS for the ALMA construction project is included below. The WBS is organized into nine level-1 tasks:

1. Management/Administration (*)
2. Site Development
3. Antenna Subsystem
4. Front End Subsystem
5. Back End Subsystem
6. Correlator
7. Computing Subsystem
8. System Engineering and Integration
9. Science (*)

* Note: Education and Public Outreach is a functional task of the Science IPT and Safety is a task of Management/Administration.

3.2 Schedule Of Values

Costs and contingencies were developed for each subtask of the WBS and rolled up as the summed costs of tasks; the task costs were subsequently rolled up as the summed Project cost. The basis for the cost estimates was a bottom-up sum of the costs associated with each subtask of the Project-wide WBS. The European and North American technical leaders, working together, developed estimates for the entire task product tree using a standard project-supplied *ALMA Cost Data Sheet* that asked the technical leaders to provide for each task:

- Task description;
- Task duration (or start and stop dates and predecessor tasks);
- Currency used for materials, supplies and contract expense;
- Basis of the estimate;
- Contingency;
- Staff Effort;
- List of materials and estimated cost of each;
- List of contracts and estimated cost of each;
- Cost parameterization.

Personnel costs are fully burdened costs. That is, the personnel costs include personnel benefits and a percentage of institutional indirect costs. The institutional indirect cost is a uniform percentage derived from the major partner institutions; this is done to make the personnel cost independent of where the work is performed.

Contingency was separately calculated for each subtask. The contingency methodology used was a *bottom-up* computation of the sum of three separately calculated contingencies. These three contingencies correspond to three different risk factors: the technical risk (how difficult is the task?), the cost risk (what is the uncertainty on the cost?), and the schedule risk (how does this task affect the overall schedule?). Estimators evaluated the technical, cost and schedule risk factors for a particular WBS task and then entered those factors in the ALMA Cost Data Sheets.

The resulting costs and contingencies are shown on the WBS at level-3. Where the costing estimates were made at a lower level, these have been rolled up and displayed at level-3. Three cost columns are shown: the level-3 task cost, computed as described above, the computed task contingency, and the task *value* which is the sum of cost and contingency for each task

3.3 Assignment of Deliverables

As stated in Article 2 of The Agreement, the two ALMA Parties, North America and ESO, will make equal Value contributions to ALMA with the work equally and equitably shared between North America and ESO. Therefore, using the *values* assigned to level-3 tasks, the tasks were divided between the two Parties in a manner that (a) led to an equal assignment of value to both sides; (b) led to a division of equal risk, as measured by contingency, to both sides; and (c) respected particular institutional experience on both sides. The division of values was also informed by the funding schedules planned by both parties over the ten year duration of the construction project.

The resulting division of value is presented in the WBS for each level-3 task as a percentage division between Europe and North America. A Cost Summary sheet, included with the WBS, presents explicitly this same information rolled up to level-1.

Value: An ALMA Partner executing a particular level-3 task will receive for the successful completion of that task credit for the *value* assigned in the WBS. The Partner has the discretion to carry out the task in the manner the Partner chooses to be in its best interest, but the *value* is not affected by that choice.

Responsibility: Task responsibility is assigned at WBS level-2. This is noted for each task in the final (right-most) column in the WBS. The level-2 tasks are referred to as *work packages* that the responsible partner may wish to assign to one of its participating institutions. Each work package is sub-divided into *work elements*. These are the level-3 tasks to which *value* is assigned. Usually the work elements are assigned wholly to one partner or the other. In the case of shared level-3 tasks the division of effort as 100 percent to one side or another is made at a still lower level. This information is given on the individual ALMA Work Element sheets that are not included here.

Cost Summary for 2 Partner ALMA

2002 March 12

WBS Task Description	Labor (Staff years)	Labor Y2000 $	Travel Y2000 $	Materials & Contracts Y2000 $	Task Subtotal Y2000 $	Contingency Percent	Contingency Y2000 $	Task Total Y2000 $
1 Management / Admin. (including safety)	83	10,467	1,328	5,085	16,880	5.0%	844	17,724
2 Site Development	43	4,969	314	56,757	62,040	14.3%	8,899	70,939
3 Antenna Subsystem	63	8,890	1,189	190,461	200,539	14.8%	29,729	230,268
4 Front End Subsystem	442	35,901	2,045	55,546	93,492	19.5%	18,188	111,680
5 Backend Subsystem	151	14,220	825	26,467	41,512	21.7%	8,991	50,502
6 Correlator	49	4,460	246	8,637	13,343	12.4%	1,653	14,995
7 Computing Subsystem	230	22,155	2,303	7,129	31,586	14.7%	4,628	36,214
8 System Eng. & Integration	152	14,587	892	3,236	18,716	10.4%	1,954	20,670
9 Science (including E&PO)	74	7,447	693	915	9,055	5.0%	453	9,507
Subtotals (Year 2000 US Dollars)	**1,287**	**123,096**	**9,834**	**354,232**	**487,162**	**15.5%**	**75,338**	**562,500**

Cost Summary Breakdown for 2 Partner ALMA

North American Tasks

2002 March 12

WBS Task Description	Labor (Staff years)	Labor Y2000 $	Travel Y2000 $	Materials & Contracts Y2000 $	Task Subtotal Y2000 $	Contingency Percent	Contingency Y2000 $	Task Total Y2000 $
1 Management / Admin. (including safety)	42	5,234	664	2,543	8,440	5.0%	422	8,862
2 Site Development	16	1,873	120	21,425	23,418	14.4%	3,371	26,789
3 Antenna Subsystem	31	4,330	582	92,012	96,924	14.8%	14,380	111,305
4 Front End Subsystem	221	18,474	900	24,512	43,886	21.4%	9,408	53,293
5 Backend Subsystem	96	9,234	512	14,259	24,004	18.4%	4,413	28,417
6 Correlator	43	3,909	230	8,537	12,675	12.8%	1,619	14,295
7 Computing Subsystem	115	11,171	1,170	3,564	15,905	14.4%	2,295	18,200
8 System Eng. & Integration	76	7,294	446	1,618	9,358	10.4%	977	10,335
9 Science (including E&PO)	37	3,724	346	458	4,527	5.0%	226	4,754
Subtotals (Year 2000 US Dollars)	**677**	**65,241**	**4,970**	**168,927**	**239,138**	**15.5%**	**37,112**	**276,250**

Cost Summary Breakdown for 2 Partner ALMA

European Tasks

2002 March 12

WBS Task Description	Labor (Staff years	Labor Y2000 $	Travel Y2000 $	Materials & Contracts Y2000 $	Task Subtotal Y2000 $	Contingency Percent	Contingency Y2000 $	Task Total Y2000 $
1 Management / Admin. (including safety)	42	5,234	664	2,543	8,440	5.0%	422	8,862
2 Site Development	27	3,097	193	35,332	38,622	14.3%	5,528	44,150
3 Antenna Subsystem	32	4,559	607	98,448	103,615	14.8%	15,349	118,964
4 Front End Subsystem	221	17,427	1,145	31,034	49,606	17.7%	8,780	58,387
5 Backend Subsystem	55	4,986	314	12,208	17,508	26.1%	4,578	22,085
6 Correlator	6	551	16	100	667	5.0%	33	701
7 Computing Subsystem	115	10,984	1,133	3,564	15,681	14.9%	2,332	18,014
8 System Eng. & Integration	76	7,294	446	1,618	9,358	10.4%	977	10,335
9 Science (including E&PO)	37	3,724	346	458	4,527	5.0%	226	4,754
Subtotals (Year 2000 US Dollars)	**610**	**57,855**	**4,864**	**185,305**	**248,025**	**15.4%**	**38,225**	**286,250**

Atacama
Large
Millimeter
Array

ALMA Construction Plan 2002-Mar-12

All Tasks selected
All Costs in Year 2000 US Dollars

WBS	Task	Task Cost	Cont.	Task Value	NA %	Eur %	Responsibility
	ALMA Project Plan 2002Mar12			$562,500			
1	**Management / Admin.**			$17,724			
1.010	Management And Administration			$11,116			JAO
1.010.0100	North American Project Office	5293	5%	$5,558	100%		
1.010.0120	European Project Office	5293	5%	$5,558		100%	
1.015	Joint ALMA Office			$6,609			JAO
1.015.0160	Joint ALMA Office (including safety)	6294	5%	$6,609	50%	50%	
2	**Site Development**			$70,939			
2.020	Site Construction Management			$4,577			Site IPT
2.020.0200	Site Development Management	4359	5%	$4,577	35%	65%	
2.025	Site Development			$66,362			Site IPT
2.025.0210	Site Infrastructure	4748	15%	$5,463	71%	29%	
2.025.0220	Array Site	29351	15%	$33,769	49%	51%	
2.025.0240	Operations Support Facility (OSF)	14104	15%	$16,227	0%	100%	
2.025.0260	Array/OSF Access Roads	6708	15%	$7,718	33%	67%	
2.025.0280	Array/OSF Communication Links	1823	15%	$2,098	100%	0%	
2.025.0300	Chilean Phase 2 Facilities	946	15%	$1,088	0%	100%	
3	**Antenna Subsystem**			$230,268			
3.030	Antenna Management/Engineering			$5,615			Ant IPT
3.030.0320	Antenna Management Phase 2	3358	5%	$3,526	50%	50%	
3.030.0340	Production Antenna Engineering Support	1928	8%	$2,089	50%	50%	
3.035	Prototype Antenna Evaluation Support			$2,181			Ant IPT
3.035.0360	North Am. Post Acceptance Evaluation	889	23%	$1,090	100%		
3.035.0380	Euro Post Acceptance Evaluation	889	23%	$1,090		100%	
3.036	European Prototype Antenna Phase 2			$2,500			Europe
3.036.0410	European Phase 2 Prototype Antenna	2381	5%	$2,500		100%	
3.045	Antenna Contract Tendering/Supervision			$2,345			Ant IPT
3.045.0440	Final Design Mods & Documentation; Prepare Bid Package	203	11%	$225	50%	50%	
3.045.0460	Production Antenna Contracting	1778	13%	$2,001	50%	50%	
3.045.0480	Final Foundation Design	109	8%	$118	50%	50%	
3.050	Antenna Procurement			$211,048			Ant IPT
3.050.0500	Production Antennas	183520	15%	$211,048	49%	51%	
3.060	Production Antenna Acceptance at OSF			$2,595			Ant IPT
3.060.0560	Production Antenna Acceptance at OSF	2288	13%	$2,595	50%	50%	

Atacama
Large
Millimeter
Array

ALMA Construction Plan 2002-Mar-12
All Tasks selected
All Costs in Year 2000 US Dollars

WBS	Task	Task Cost	Cont.	Task Value	NA %	Eur %	Responsibility
3.065	Nutator Design/Fabricate			$796			N. Am.
3.065.0580	Production Antenna Nutator	645	23%	$796	100%		
3.070	Transporter Design/Fabricate			$3,189			Europe
3.070.0600	Transporter Design / Fabrication	2550	25%	$3,189		100%	
4	Front End Subsystem			$111,680			
4.075	Frontend Management/Subsystem Engineering			$6,595			FE IPT
4.075.0620	Front End Subsystem Management	3928	5%	$4,124	50%	50%	
4.075.0640	Front End Subsystem Engineering	2353	5%	$2,470	50%	50%	
4.080	Cryostat Design/Prototype			$440			Europe
4.080.0660	Cryostat Design/Prototype	311	42%	$440		100%	
4.085	Cryostat Production			$12,290			Europe
4.085.0680	Cryostat construction	7364	15%	$8,472		100%	
4.085.0700	Cryocooler	3606	6%	$3,818		100%	
4.090	Windows/IR/Common Optics Design/Prototype			$648			Europe
4.090.0720	Windows/IR/Common Optics Design/Prototype	457	42%	$648		100%	
4.095	Windows/IR/Common Optics Production			$1,728			Europe
4.095.0740	Common Optics	627	27%	$795		100%	
4.095.0760	Windows and IR Filters	766	22%	$933		100%	
4.100	Electronics/M&C Design/Prototype			$593			N. Am.
4.100.0780	FE Electronics / M&C Design/Prototype	418	42%	$593	100%		
4.105	Electronics/M&C Production			$6,025			N. Am.
4.105.0800	Production Front End Electronics	2347	23%	$2,897	100%		
4.105.0820	Front-end IF Selection Switch	1403	18%	$1,661	100%		
4.105.0840	Front End Monitor and Control System	1016	44%	$1,466	100%		
4.110	FE Subreflector Calibration System Development			$964			N. Am.
4.110.0860	Photonic Phase Cal Development	684	41%	$964	100%		
4.115	FE Focal Plane Calibration System Development			$340			Europe
4.115.0880	Calibration System Development	287	18%	$340		100%	
4.120	FE Subreflector Calibration System Production			$4,634			N. Am.
4.120.0900	Photonic Phase Cal Production	2724	41%	$3,840	100%		
4.120.0940	Subreflector Calibration System - control s/w and h/w	255	17%	$298	100%		
4.120.0960	Subreflector Calibration System - hardware at subreflector	451	10%	$497	100%		
4.125	FE Focal Plane Calibration System Production			$1,809			Europe
4.125.0920	Calibration System	872	18%	$1,033		100%	

ALMA Construction Plan 2002-Mar-12

All Tasks selected

All Costs in Year 2000 US Dollars

WBS	Task	Task Cost	Cont.	Task Value	NA %	Eur %	Responsibility
4.125.0980	Solar Filter	665	17%	$776		100%	
4.140	Band 3 Cartridge Design/ Prototype			$470			N. Am.
4.140.1003	Band 3 Cartridge Design / Development	331	42%	$470	100%		
4.145	Band 3 Cartridge Production			$9,684			N. Am.
4.145.1063	Signal and LO Sources Band 3	155	12%	$173	100%		
4.145.1080	Band 3 SIS Mixer	750	43%	$1,076	100%		
4.145.1103	LO Production Band 3	1281	22%	$1,560	100%		
4.145.1123	SIS Mixer Production Equipment Band 3	657	12%	$734	100%		
4.145.1140	IF amplifier 4-12 GHz (Band 3 SIS option only)	534	12%	$597	100%		
4.145.1163	Build SIS mixer fabrication equipment Band 3	293	12%	$328	100%		
4.145.1180	Band 3 - SIS mixer option: Other components	3586	17%	$4,186	100%		
4.145.1203	Cartridge Body construction Band 3	161	15%	$185		100%	
4.145.1303	Cartridge test cryostat Band 3	0		$0		100%	
4.145.1403	SIS Junctions Band 3	780	8%	$846	100%		
4.160	Band 6 Cartridge Design/ Prototype			$477			N. Am.
4.160.1006	Band 6 Cartridge Design / Development	336	42%	$477	100%		
4.165	Band 6 Cartridge Production			$11,178			N. Am.
4.165.1066	Signal and LO Sources Band 6	180	12%	$201	100%		
4.165.1106	LO Production Band 6	1415	23%	$1,746	100%		
4.165.3106	LO Production Diode Multipliers Band 6	305	23%	$376	100%		
4.165.1126	SIS Mixer Production Equipment Band 6	657	12%	$734	100%		
4.165.1166	Build SIS mixer fabrication equipment Band 6	287	12%	$320	100%		
4.165.1206	Cartridge Body construction Band 6	161	15%	$185		100%	
4.165.1240	Band 6 SIS Mixer	750	43%	$1,076	100%		
4.165.1260	Production Band 6 Orthomode Transducer (OMT)	902	53%	$1,377	100%		
4.165.1280	14 IF amplifier 4-12 GHz (Band 6 only)	534	12%	$597	100%		
4.165.1306	Cartridge test cryostat Band 6	0		$0		100%	
4.165.1320	Band 6 Other components	3187	17%	$3,720	100%		
4.165.1406	SIS Junctions Band 6	780	8%	$846	100%		
4.170	Band 7 Cartridge Design/ Prototype			$532			Europe
4.170.1007	Band 7 Cartridge Design / Development	375	42%	$532		100%	
4.175	Band 7 Cartridge Production			$11,455			Europe
4.175.1107	LO Production Band 7	1415	23%	$1,746	100%		
4.175.3107	LO Production Diode Multipliers Band 7	305	23%	$376	100%		

ALMA Construction Plan 2002-Mar-12
All Tasks selected
All Costs in Year 2000 US Dollars

WBS	Task	Task Cost	Cont.	Task Value	NA %	Eur %	Responsibility
4.175.1207	Cartridge Body construction Band 7	161	15%	$185		100%	
4.175.1307	Cartridge test cryostat Band 7	0		$0		100%	
4.175.1340	Band 7 Internal optics, feed & polarizer baseline	390	23%	$481		100%	
4.175.1360	Band 7 SIS Mixer baseline	1258	43%	$1,805		100%	
4.175.1407	SIS Junctions Band 7	780	8%	$846		100%	
4.175.1420	Band 7 Other Components baseline	4876	23%	$6,017		100%	
4.190	Band 9 Cartridge Design/ Prototype			$588			Europe
4.190.1009	Band 9 Cartridge Design / Development	414	42%	$588		100%	
4.195	Band 9 Cartridge Production			$14,058			Europe
4.195.1109	LO Production Band 9	1415	23%	$1,746	100%		
4.195.3109	LO Production Diode Multipliers Band 9	305	23%	$376	100%		
4.195.1209	Cartridge Body construction Band 9	161	15%	$185		100%	
4.195.1309	Cartridge test cryostat Band 9	0		$0		100%	
4.195.1409	SIS Junctions Band 9	780	8%	$846		100%	
4.195.1460	Band 9 cartridge parts (excl. mixer)	4781	22%	$5,820		100%	
4.195.1480	Band 9 fabrication equipment Part 1	663	9%	$724		100%	
4.195.1500	Band 9 fabrication equipment Part 2	328	9%	$358		100%	
4.195.1520	Band 9 mixer	2790	43%	$4,004		100%	
4.210	WVR Radiometer Design/ Prototype			$304			Europe
4.210.1011	WVR Cartridge Design / Development	214	42%	$304		100%	
4.215	WVR Radiometer Production			$7,823			Europe
4.215.1560	183GHz WVR Production, Installation & Commissioning	7219	8%	$7,823		100%	
4.220	Integration Test Facilities Develop/Procure			$1,322			N. Am.
4.220.1580	Front End Test Station Development	1116	18%	$1,322	100%		
4.225	Integration Test Facilities Duplicate			$770			Europe
4.225.1600	Front End Test Station Replication	711	8%	$770		100%	
4.230	Frontend Integration			$9,777			FE IPT
4.230.1620	Front End Integration Center #1 Setup and Operation	4183	17%	$4,883	100%		
4.230.1630	Front End Integration Center #2 Setup and Operation	4193	17%	$4,894		100%	
4.235	Frontend Mechanical Chasis/Mount			$1,054			N. Am.
4.235.1660	Front End Chassis	748	41%	$1,054	50%	50%	
4.240	Front End Service Vehicle			$669			N. Am.
4.240.1680	Front End Service and Exchange Vehicle	599	12%	$669	100%		
4.245	Photonic LO Development			$1,515			FE IPT

ALMA Construction Plan 2002-Mar-12
All Tasks selected
All Costs in Year 2000 US Dollars

WBS	Task	Task Cost	Cont.	Task Value	NA %	Eur %	Responsibility
4.245.1700	Photonic LO Development N. Am.	721	5%	$758	100%		
4.245.1705	Photonic LO Development Europe	721	5%	$758		100%	
4.250	LO Driver Development			$1,070			N. Am.
4.250.1720	LO driver continued development section	407	22%	$496	100%		
4.250.1740	Cold multiplier continued development section	492	17%	$574	100%		
4.255	Multiplier/Driver Production			$2,869			N. Am.
4.255.1760	LO Multiplier Drivers fabrication and test	1871	22%	$2,278	100%		
4.255.1800	Cold multiplier fabrication and test equipment	542	9%	$591	100%		
5	**Backend Subsystem**			**$50,502**			
5.260	Backend Management Subsystem Engineering			$3,186			BE IPT
5.260.1880	Backend Mgmt/Subsystem Engineering Phase 2	2200	5%	$2,310	75%	25%	
5.260.1840	LO Ref Engineering Field Support	372	8%	$404	100%		
5.260.1860	Photonic Dist Engineering Support	256	8%	$278	100%		
5.260.1900	Backend Engineering Support	186	5%	$196	67%	33%	
5.265	Backend Analog Processing Design/Prototype			$719			N. Am.
5.265.1920	Prototype System IF Down-converter	599	20%	$719	100%		
5.270	Backend Analog Processing Production			$9,431			N. Am.
5.270.1940	IF Down-converter	7323	17%	$8,547	100%		
5.270.1960	Power Supply Modules	405	5%	$426	100%		
5.270.1980	BE Production Test & Lab Equipment	416	10%	$458	100%		
5.275	Backend Digitizer Design/Prototype			$1,297			Europe
5.275.2000	Backend Digitizer/Sampler Prototype	1051	23%	$1,297		100%	
5.280	Backend Digitizer Production			$4,212			Europe
5.280.2020	Digitizer/Sampler	2101	23%	$2,593		100%	
5.280.2040	DeMultiplexer for Digitizer/Sampler	1260	28%	$1,619		100%	
5.285	Backend Data Transmission Design/Prototype			$869			N. Am.
5.285.2060	Prototype System Digital IF Tx & Rx	745	17%	$869	50%	50%	
5.290	Backend Data Transmission Production			$15,329			N. Am.
5.290.2080	Sampler Clock	759	17%	$886		100%	
5.290.2100	Digital IF Transmitters and Receivers	11101	30%	$14,443	25%	75%	
5.295	LO Frequency Synthesis Design/Prototype			$1,065			N. Am.
5.295.2120	LO Reference Prototype	778	17%	$908	100%		
5.295.2140	FO Transmitter, LO Ref - Low Freq	127	24%	$157	100%		
5.300	LO Frequency Synthesis Production			$13,040			N. Am.

ALMA Construction Plan 2002-Mar-12
All Tasks selected
All Costs in Year 2000 US Dollars

WBS	Task	Task Cost	Cont.	Task Value	NA %	Eur %	Responsibility
5.300.2160	FO Receiver, LO Reference	1615	23%	$1,993	100%		
5.300.2180	Two-Laser generator, RF synthesizer	353	10%	$388	100%		
5.300.2200	Second LO Synthesizer	3981	20%	$4,780	70%	30%	
5.300.2220	Fringe Generator	309	17%	$361	100%		
5.300.2240	Central LO Reference Generator	101	10%	$111	100%		
5.300.2260	H-maser Frequency Standard	386	17%	$451		100%	
5.300.2280	Power Supply Modules	462	5%	$485	100%		
5.300.2300	LO Ref Production supervision & int.	679	12%	$758	100%		
5.300.2320	LO Ref Production test & lab equipment	270	9%	$293	100%		
5.300.2335	Photonic Dist Prototype	784	25%	$981	100%		
5.300.2340	Fabricate Photonic Dist Production System	1795	36%	$2,440	50%	50%	
5.305	Backend Installation/Integration in Chile			$1,355			BE IPT
5.305.2360	LO Reference On Site Integration and Test	346	23%	$428	50%	50%	
5.305.2380	Photonic Dist On Site Integration and Test	405	23%	$500	50%	50%	
5.305.2400	Backend On Site Integration and Test	346	23%	$428	50%	50%	
6	**Correlator**			**$14,995**			
6.310	Correlator Management/Subsystem Engineering			$906			Corr IPT
6.310.2420	Baseline Correlator Mgmt/Subsystem Engineering Phase 2	453	5%	$475	100%		
6.310.2440	Baseline Correlator Continued Support	397	8%	$431	100%		
6.315	Baseline Correlator Design/Prototype			$911			N. Am.
6.315.2460	Prototype Correlator Production	738	23%	$911	100%		
6.320	Baseline Correlator Production			$12,478			N. Am.
6.320.2480	First 1/4 correlator	2749	13%	$3,094	100%		
6.320.2500	Second 1/4 correlator	2744	13%	$3,088	100%		
6.320.2520	Third 1/4 correlator	2744	13%	$3,088	100%		
6.320.2540	Fourth 1/4 correlator	2850	13%	$3,208	100%		
6.325	Second Generation Correlator Design/Prototype			$701			Europe
6.325.2570	Second Generation Correlator Development	667	5%	$701		100%	
7	**Computing Subsystem**			**$36,214**			
7.340	Computing			$36,214			Com IPT
7.340.2640	Computer Subsystem Management	2534	5%	$2,660	63%	38%	
7.340.2660	Computing Hardware	7129	12%	$7,963	50%	50%	
7.340.2680	Science Software Requirements	820	17%	$957	44%	56%	
7.340.2700	High Level Analysis & Design	461	17%	$538	44%	56%	

ALMA Construction Plan 2002-Mar-12
All Tasks selected
All Costs in Year 2000 US Dollars

WBS	Task	Task Cost	Cont.	Task Value	NA %	Eur %	Responsibility
7.340.2720	Software Engineering	1947	17%	$2,272	42%	58%	
7.340.2740	Common Software	2408	17%	$2,810	43%	57%	
7.340.2750	Executive Software	307	17%	$359		100%	
7.340.2760	Control Software	2459	17%	$2,870	81%	19%	
7.340.2780	Correlator Software	1537	17%	$1,794	100%		
7.340.2800	Pipeline Software	1742	17%	$2,033	65%	35%	
7.340.2820	Archiving	1742	17%	$2,033	24%	76%	
7.340.2840	Scheduling	512	17%	$598	100%		
7.340.2860	Observing Preparation & Support	1639	17%	$1,913		100%	
7.340.2880	Off-line Data Processing/Analysis	1537	17%	$1,794	70%	30%	
7.340.2890	Data Reduction User Interface	717	17%	$837		100%	
7.340.2900	Telescope Calibration	922	17%	$1,076		100%	
7.340.2920	Integration, Test & Support	3176	17%	$3,707	53%	47%	
8	System Eng. & Integration			$20,670			
8.360	System Engineering Management			$2,351			Sys IPT
8.360.2940	SE&I Management	2239	5%	$2,351	50%	50%	
8.365	System Engineering Development Support			$8,225			Sys IPT
8.365.2960	Phase 2 System Engineering	7591	8%	$8,225	50%	50%	
8.370	Test Interferometer Support			$2,695			Sys IPT
8.370.2980	ALMA Prototype Antenna Evaluation	1804	13%	$2,046	50%	50%	
8.370.3000	Prototype ALMA System Integration	556	17%	$649	50%	50%	
8.375	System Validation, Integration, Acceptance			$7,398			Sys IPT
8.375.3020	ALMA System Integration	6525	13%	$7,398	50%	50%	
9	Science			$9,507			
9.380	Science			$9,507			Sci IPT
9.380.3040	Phase 2 Science Support	9055	5%	$9,507	50%	50%	
9.385	Education and Public Outreach *			$0			Executives
9.385.3060	North American EPO	0 *		$0	100%		
9.385.3080	European EPO	0 *		$0		100%	
9.385.3100	Chilean EPO	0 *		$0			

* Education and Public Outreach is carried out by the Executives as an indirect expense.

4. ALMA CONSTRUCTION PROJECT TIME SCHEDULE

Number	Milestone or Deliverable	Date
1	VertexRSI Antenna Available at ALMA Test Facility	2002 July
2	A/C/E Antenna Available at ALMA Test Facility	2003 April
3	**Milestone:** Antenna Procurement Plan Approved	2003 April
4	Begin Initial Phase of Civil Works in Chile	2003 October
5	Front End and Back End Subsystem CDRs	2003 December
6	First Quadrant of Correlator Ready for Installation at Array Site	2005 January
7	Central Back End Subsystem Ready for Installation at Array Site	2005 January
8*	First Production Antenna Available in Chile at the OSF	2005 March-December
9	Initial Phase of Civil Works in Chile Complete	2005 May
10	First Antenna-based Back End Subsystem Ready for Installation at OSF	2005 June
11	Initial Front End Subsystem Available at the OSF	2005 December
12**	**Milestone:** Start Science Commissioning Observations	2006 October-December
13**	**Milestone:** Start Interim Science Observations	2007 July-December
14	**Milestone:** Completion of Construction Project	2011 December

* The actual date that the first production antenna will be available at the OSF (Deliverable 8) is dependent on the antenna procurement plan (Milestone 3) approved by the ALMA Board.

** The start of science commissioning observations and interim science operations (Milestones 13 and 14) is dependent on all preceding milestones, but particularly the availability of the first production antenna, the antenna-based back end, and the front end ready for installation at the OSF (Deliverables 8, 10, and 11).

5. ALMA ORGANIZATION AND MANAGEMENT PLAN FOR CONSTRUCTION

The entities that create the ALMA Project are the *Parties*, who are the funding sources for the project. The Parties have two initial responsibilities: (1) to establish jointly, and by agreement, an oversight body for the Project, the *ALMA Board*; and (2) to each appoint an *Executive Agency,* or *Executive,* to manage the project tasks and responsibilities that are agreed to belong to each Party. Although, the ALMA Board is not a legal entity, the Executives are legal entities and they can enter into contracts, employ staff, etc., on behalf of ALMA. In order to carry out their ALMA functions each of the Executives will create an *ALMA Project Office* and secure for that office the staff and resources necessary for the performance of the ALMA tasks assigned to that Executive. The ALMA Board has the responsibility to establish a *Joint ALMA Office* (JAO) that is authorized to direct and manage the overall ALMA Project. The JAO will carry out its management function by specifying the scope, schedule, and tasks of the Project and then managing the efforts of the Executives to provide the necessary deliverables. The ALMA Board also appoints the ALMA Science Advisory Committee (ASAC) and the ALMA Management Advisory Committee (AMAC).

5.1 Management Structure

The ALMA Project management structure, shown in Figure 5-1, is based on the concept of *Integrated Product Teams* (IPTs). By focusing on the right side of the figure, one can see that the ALMA Project has a traditional hierarchical management structure. The ALMA Board serves the function of a board of directors, the JAO functions as the project management, and the IPTs function as task managers.

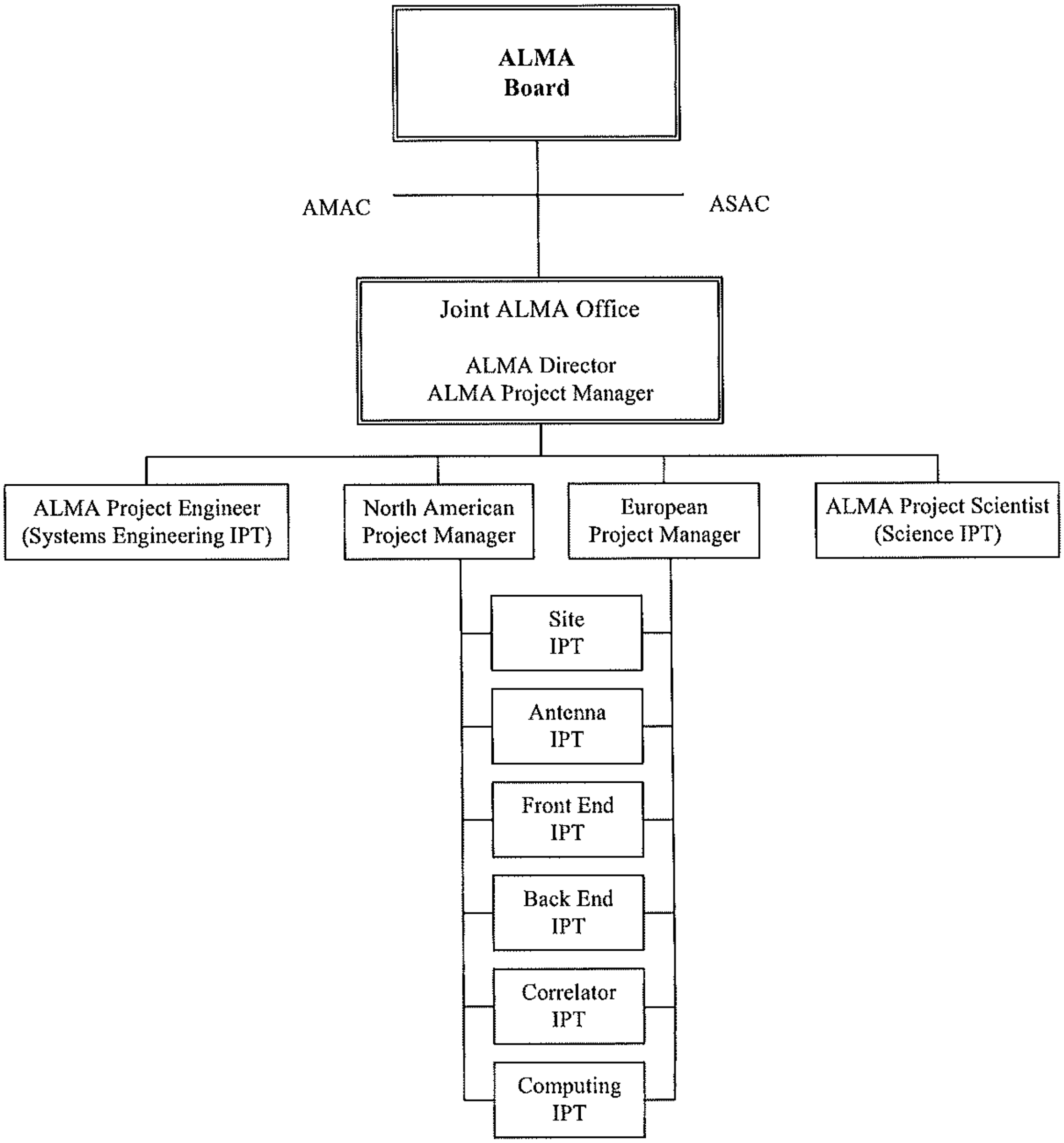

Figure 5-1. ALMA Project Management Structure - Construction Phase

5.1.1 Joint ALMA Office (JAO)

The Joint ALMA Office is the focal point for implementation of the ALMA Project. In accordance with Article 17 of the ALMA Agreement, the JAO will be composed of the following key personnel who report to the ALMA Board:

- ALMA Director
- ALMA Project Manager
- ALMA Project Scientist
- ALMA Project Engineer

The responsibilities and authorities of each of the key personnel are defined by the ALMA Board.

In addition, the JAO will have the necessary staff to provide project control, scheduling, and supporting administrative functions. The staff of the JAO will be co-located. With approval of the ALMA Board, each member of the JAO will be employed by one of the Executives.

Project Scope and Schedule. The JAO will:

- Define and maintain the top-level scientific requirements and scope of the project. This is done in conjunction with the user communities (as represented by the ASAC) and with the approval of the ALMA Board.
- Establish the requirements for the ALMA system. Working in conjunction with the IPT Leaders and Deputies, the JAO establishes the technical specifications corresponding to the top-level scientific requirements.
- Establish and maintain the Project Work Breakdown Structure(WBS) and Schedule.
- Establish and control the configuration. When the specifications or WBS must be changed the JAO controls the change process and manages the consequences of a change.
- Define, maintain and enforce Interface Control.

Costs. The JAO will:

- Provide an impartial, and consistent, accounting of the costs. This applies both to the cost of the baseline project and the cost of any additions or proposed alternatives.
- Negotiate an adjustment of the value of contributions in the face of experience where necessary.

Accountability. The JAO will:

- Establish and enforce acceptance criteria for delivered hardware and software.
- Be accountable to the ALMA Board for achieving the ALMA scientific requirements cognizant of the advice of the ASAC.
- Be accountable to the ALMA Board for management of the Project, cognizant of the advise of the AMAC.

5.1.2 North American ALMA Project Office

ALMA work packages assigned to North America will be the responsibility of the North American ALMA Project Office, which will be part of the North American Executive (NRAO). The North American ALMA Project Manager will report to the JAO Project Manager. Working through the project IPT structure, the North American Project Manager will be assisted by ALMA Division Heads within NRAO, each of whom have the responsibility for tasks within a given level-1 WBS. The Division Heads will act either as the IPT Leader or Deputy in the corresponding IPTs.

5.1.3 European ALMA Project Office

The ALMA work packages assigned to Europe will be the responsibility of the European ALMA Project Office, which will be part of the European Executive (ESO). These work packages will be carried out in existing institutions across Europe, including ESO. The European ALMA Project Manager will report to the JAO Project Manager. The European Project Office that will be responsible for ensuring that the resources are made available to carry out the European work packages to performance and schedule. Each work package will be covered by a formal agreement between the institution concerned and ESO. Working through the project IPT structure, the European Project Manager will be assisted by European Team Managers drawn from the participating institutions. The European Team Managers will have the responsibility for tasks within a given level-1 WBS and will act either as the IPT Leader or Deputy in the corresponding IPT.

5.1.4 Integrated Product Teams

The essence of the IPT concept is the recognition that the level-1 WBS tasks are shared between the two Executives. For this reason the leadership for those level-1 tasks is also shared. The IPT is that shared leadership. Each IPT consists of all those individuals who are assigned by one or another of the Executives with significant responsibility for work elements within a given level-1 WBS task. The Executives' respective task leaders provide the leadership of each IPT. One of these persons will be identified as the IPT Leader and the other will serve as the IPT Deputy Leader. The intent is that these individuals will normally resolve by consensus any technical issues that arise within the IPT.

The IPT Leader and the Deputy are vested with the responsibility to assign, coordinate, and monitor subtasks as specified by the ALMA WBS. In practice, this means that each of these individuals is responsible for completing the assigned subtasks using the resources provided by their respective Executives.

The IPT management structure is a powerful method of organizing work carried out across geographic, institutional, and professional boundaries. It allows work packages assigned to different organizations utilizing different skill sets to be effectively coordinated. The IPT model is adopted for the ALMA Project to achieve the following goals:

- Provide a single point of integrative responsibility for each major work package. A single individual, the IPT Leader, is identified for each IPT. This Leader is responsible for assuring that the various work packages, when completed, will meet the project schedule and the performance specifications.
- Provide common, coordinated, management of the IPT and the work groups within the Executives. The IPT Leader and the Deputy are themselves the work managers for the Executives. Common management provides the link between

the project coordination function and the means to accomplish the work within the Executives.

- Make decisions at the lowest level in the organization where sufficient knowledge is available. The organizational and technical complexity of the ALMA Project makes it impossible for all significant decisions to be deliberated project-wide. Instead, responsibility will be delegated to the IPTs and will carry with it authority to make decisions within that particular IPT provided that the result is compatible with the overall scope and schedule of the Project.

The Management IPT differs functionally from the other IPTs. The composition of the Management IPT is the Project Managers from the Executives, just as is the case for the other IPTs with their managers, with the addition of the ALMA Director and Project Manager, who are on the staff of the JAO. Within the Management IPT, the Project Managers from each of the Executives report to the ALMA Project Manager, who reports to the ALMA Director, who reports to ALMA Board.

In a similar manner the Project Scientist will serve as the Leader of the Science IPT, and the Project Engineer will serve as the Leader of the System Engineering IPT.

5.1.5 ALMA Scientific Advisory Committee

The ALMA Science Advisory Committee (ASAC) will provide regular scientific oversight and advice to the project through reporting to the ALMA Board. The ALMA Board, in consultation with the Executives, will define the terms of reference of the ASAC and appoint its members. Written reports of the ASAC's discussions will be made to the ALMA Board by the chair of the ASAC following each committee meeting.

5.1.6 ALMA Management Advisory Committee

The ALMA Management Advisory Committee (AMAC) will provide regular management, cost, and technical oversight and advice to the project through reporting to the ALMA Board. The ALMA Board, in consultation with the Executives, will define the terms of reference of the AMAC and appoint its members. Written reports of reviews and assessments will be made to the ALMA Board by the chair of the AMAC following each committee meeting.

5.2 Management Controls – Relationship of JAO to Executives

Relationships of JAO to the Executives the organization of the JAO (Management IPT) provides the efficient decision making and project direction required to maintain the project schedule and successfully manage ALMA construction. On the other hand, the risks in ALMA are borne by the Executives. It is recognized that there may be instances when the Executives cannot accept the legal, financial, or political risk associated with a proposed JAO decision. In these cases, of necessity, the JAO will need to seek an acceptable alternative. But the Executives agree not to impose their prerogatives unnecessarily, exercising their right after JAO decisions only in cases where the risks are judged to be large. The career development decisions of ALMA Project Office personnel reside with the Executives. It is important that the JAO participate in the processes which lead to these decisions for key ALMA personnel: IPT leaders and deputies and above. That is, annual performance reviews, salary reviews, and promotion recommendations for these ALMA personnel are to receive JAO input and the opportunity for review and comment.

5.2.1 Budget Process

The value of each work package in the WBS is the estimated cost plus a contingency that reflects the risks and uncertainty of the estimated cost. The budgeted value of each work package will be established as the estimated cost at the outset of Phase 2, exclusive of any contingency. A time-phased budget based on this value, broken down into the major categories of expenditure (labor, materials, travel, contracts, etc.), will be established and documented for each work package. The Work Package Manager must request approval of any changes to this budget. Documented requests for budget changes will be directed to the Project Manager of the responsible Executive. The responsible Executive Project Manager can approve the budget change request, if it can be absorbed within the overall budget, including contingency, of the responsible Executive. The Management IPT must be informed of any budget change that is so approved. Any budget change that cannot be absorbed within the overall budget of the responsible Executive must be brought to the attention of the Management IPT. If the responsible Executive wants to request a corresponding change in the value of its contribution, the change must be submitted to the ALMA Board for approval.

5.2.2 Cost Control

Primary responsibility for cost control rests with each Executive. Each Executive will use their established financial reporting and information system to track expenditures and provide this information to the central Management IPT. At the lowest level the Work Package Managers regularly monitor expenditures versus the budget (expenditure plan). Financial information comes either from the responsible Executive or the financial reporting and information system of the institution responsible for the work package, as appropriate. In addition, the Work Package Manager produces an estimated cost to complete the work at least twice per year. The Project Manager of the responsible Executive monitors regularly the cost performance of the aggregate of work packages for which s/he is responsible and reports the status to the Management IPT. The Management IPT in turn monitors the total project performance and reports it to the ALMA Board in semi-annual reports and meetings. However, responsibility for taking corrective action and/or requesting a budget change rests with the responsible Executive.

5.2.3 Contingency

On each side the aggregate contingency of all of the work packages for which each Executive is responsible will be pooled at the level of the Executive. The contingency will be held and controlled by the Project Managers of each Executive. When a Work Package Manager is convinced that the tasks in the work package cannot be completed for the budgeted cost, the Work Package Manager will request a budget change as described in Section 5.2.1.

5.2.4 Business Procedures

Each Executive will use their established business and administrative procedures. These include personnel policies and procedures, contracting and contract management procedures, accounting and financial reporting procedures, travel policies and procedures, and shipping/import/export procedures. Because it is not a legal entity, the Joint ALMA Office will not need many of these procedures. Those business procedures that it does need can be adopted from either of the Executives, as the Joint ALMA Office chooses.

5.2.5 Schedule Control

Each Work Package Manager will develop and maintain a schedule of activities for their work package. Each IPT will build up a level-1 schedule of the activities for which it is responsible from the schedules for each of its work packages. The Management IPT will establish and maintain a project master schedule based on the level-1 IPT schedules. Schedule status will be reported up through the project organization – from work packages to IPTs to the Management IPT. The Project Managers for each Executive will get schedule status through the Management IPT.

5.2.6 Management Reporting

The Work Package Managers will receive monthly reports of the financial status of their work packages from the responsible Executive and provide a monthly report of technical, schedule, and financial status to the relevant IPT. The IPTs will conduct periodic reviews of the status of the work packages for which they are responsible and provide a report to the Management IPT. The Management IPT, through the Project Managers of the Executives, will provide status reports to the Executives. The Director will provide a semi-annual report of the project status to the ALMA Board.

5.2.7 Programmatic Reviews

The IPT reviews referred to in Section 5.2.6 will be informal programmatic reviews at the working level. In addition, the Director will conduct formal programmatic reviews of the entire project. Each IPT, including the Management IPT, will present the technical, schedule, and financial issues that will effect their ability to achieve their goals of the work packages for which they are responsible. The reports from the Director to the ALMA Board will follow from the Director's programmatic reviews.

5.2.8 Configuration Control

A well-defined and organized process for controlling and communicating changes throughout the complex and geographically diverse ALMA Project is essential. Configuration control processes ensure that changes proposed are accepted only after their impacts are well understood and that all parts of the project are aware of changes in a timely manner. A process involving a Configuration Control Board will be used to control changes affecting scope, schedule and performance.

The ALMA Configuration. The term "ALMA configuration" refers to all those documents that define the Project. For the purpose of configuration control, the ALMA documents are divided into four groups:

- Board-level documents;
- Project-level documents;
- IPT-level documents;
- Non-controlled documents.

Configuration control acts on the documents that define the project. The process that is used depends on the type of document to be controlled.

Configuration control is made up of four main elements:

- A means of formally requesting a change;
- A process for analyzing the technical, performance and schedule impacts of the proposed change;
- A process for making a decision concerning the change;
- A process for communicating that decision.

The application of these elements to each of the four types of ALMA documents is as follows.

Board-level documents include this Management Plan, official cost and task division documents, the top-level Science Requirements Document, and international agreements passed by the ALMA Board. Baselining of, and changes to, Board-level documents can be requested by Board members and require direct action by the ALMA Board; it is the responsibility of the ALMA Director to implement changes approved by the Board.

Project-level documents include the Project Book, top-level engineering requirements for each major subsystem, and ICDs between subsystems that cross IPT or WBS boundaries. Change Requests (CRs) to project-level documents can be initiated by any of the work package or work element managers and require action by the Configuration Control Board (CCB).

IPT-level documents include detailed drawings and documents intended to implement the contents of project-level documents. Control of these documents is the purview of the IPT management. It is the responsibility of the IPT management to ensure that these documents are consistent with all applicable project-level documents.

Non-controlled documents include the ALMA Memo Series and other documents that do not officially define the Project. Baseline and change authorization for these documents depends on the document type, but all such processes are outside CCB control.

The ALMA Project Manager defines which documents are project-level documents and s/he determines when a version of each document is to be submitted to the CCB for baselining. Once baselined, all change requests must be presented to the CCB.

Configuration Control Board (CCB). The Configuration Control Board is responsible for managing changes to all project-level documents. The CCB is chaired by the ALMA Project Manager. The System Engineering IPT Leader will serve as the CCB Secretary.

In addition to the Project Manager, the CCB shall consist of the following permanent members:

- The Project Managers from both Executives;
- Leader and Deputy Leaders of the Science IPT;
- Leader and Deputy Leaders of the Systems Engineering IPT.

Additional temporary CCB members may be added at the discretion of the CCB Chair when she/he feels that a particular issue needs special consultation. In any case, as noted below, the CCB solicits input from all IPTs prior to considering a requested change. It is anticipated that most actions will be carried out by consensus of the CCB membership. If efforts to reach consensus fail, a vote of the members will be necessary. The ALMA Director has the authority to rescind actions of the CCB by informing the ALMA Project Manager and the ALMA Board.

5.3 Safety and Health

Many ALMA construction activities will take place at existing organizations (e.g., NRAO, ESO, including Chilean operations, and other European and North American institutions) with established safety and health policies and regulations that comply with applicable national or international requirements. The ALMA Project will abide by these established policies and will only create new rules and regulations if no applicable rules and regulations exist. The persons responsible for safety and health management at the participating organizations will report the results of any relevant safety and health audits or reviews to the ALMA Director. Members of the ALMA project staff will serve on safety and health committees at their respective locations.

An ALMA Safety Committee reporting to the ALMA Director will be established to:

- Define project-wide safety policy;
- Establish safety standards applicable to ALMA;
- Oversee implementation of the safety program;
- Establish emergency procedures and a reporting process.

The ALMA site at 5000-meter altitude in Chile presents unique safety and health challenges. The ALMA Project will abide by all applicable safety and health rules and regulations imposed by Chile. The applicable Chilean rules and regulations will be defined in the course of the negotiations to obtain the necessary permissions for construction and operation of ALMA.

6. OPERATIONS PLAN FOR THE ATACAMA LARGE MILLIMETER ARRAY

6.1 Overview

6.1.1 Operation of the Atacama Large Millimeter Array

ALMA is a joint scientific venture between Europe, North America and possibly later Japan, with participation by the Republic of Chile. The ALMA operation will serve these three or four communities in a way that distributes the burdens and benefits in a mutually agreeable way. The organizational structure for ALMA operations in the bilateral project is derived from the organization of the project for the construction phase and is shown in Figure 6-1. Central in this organization is the "Joint ALMA Office", established by the ALMA Board and staffed and funded by the Executives. The Joint ALMA Office is led by the ALMA Director, who reports to the ALMA Board. The main function of the Joint ALMA Office is the operations and maintenance of the array at the Array Operations Site (AOS) and the Operations Support Facility (OSF) in Chile.

The necessary scientific interactions of the respective communities with ALMA will occur through Regional Support Centers (RSCs) in a manner to be defined by the ALMA Board. The RSCs are established by the European and North American Executives. Generally, the RSCs will have "core functions" determined by the ALMA Board and managed by the ALMA Director, as well as "additional functions" which may differ among the RSCs and are managed by the Executives. Development of new instrumentation for the array, both hardware and software, is carried out by the Executives, in possible collaboration with other institutes they may choose. New projects to be funded by ALMA Operations are put forward by the ALMA Director after consultation with the user community and the Executives, and they require approval and prioritization by the ALMA Board. Such development projects are conducted in a manner identical to the conduct of the ALMA construction project. Namely, the Executive having task responsibility will assign a project manager who will report to the Executive regarding matters of cost, and he/she will report to the ALMA Director regarding technical scope and schedule.

6.1.2 Guiding Principles of ALMA Operations

When construction of ALMA is completed, the participating nations will have invested more than one half billion dollars in a facility designed and built to answer some of the most important questions of 21st century astrophysics. An ALMA operations plan that enables scientists to realize the enormous potential of ALMA for answering those questions is a fundamental goal of the project. This goal can be achieved with the following principles underlying its operations plan:

(a) The operations plan, just as in construction, embodies the guiding principles of the ALMA agreement (Article 2), namely parity, merit, utilization of existing facilities, and free movement of materials.
(b) The operations plan incorporates structures that maximize the scientific productivity of ALMA by facilitating and encouraging the fullest possible

engagement of ALMA user communities, beyond their use of observing time, in the further development of ALMA. This includes opportunities for technical upgrades and development of new instrumentation and software over the lifetime of the array.

(c) The operations plan should ensure safe, efficient and cost-effective operations of the array, and at the same time ensure delivery of data products of high and consistent quality, which can be used by both experts and non-specialists for scientific analysis.

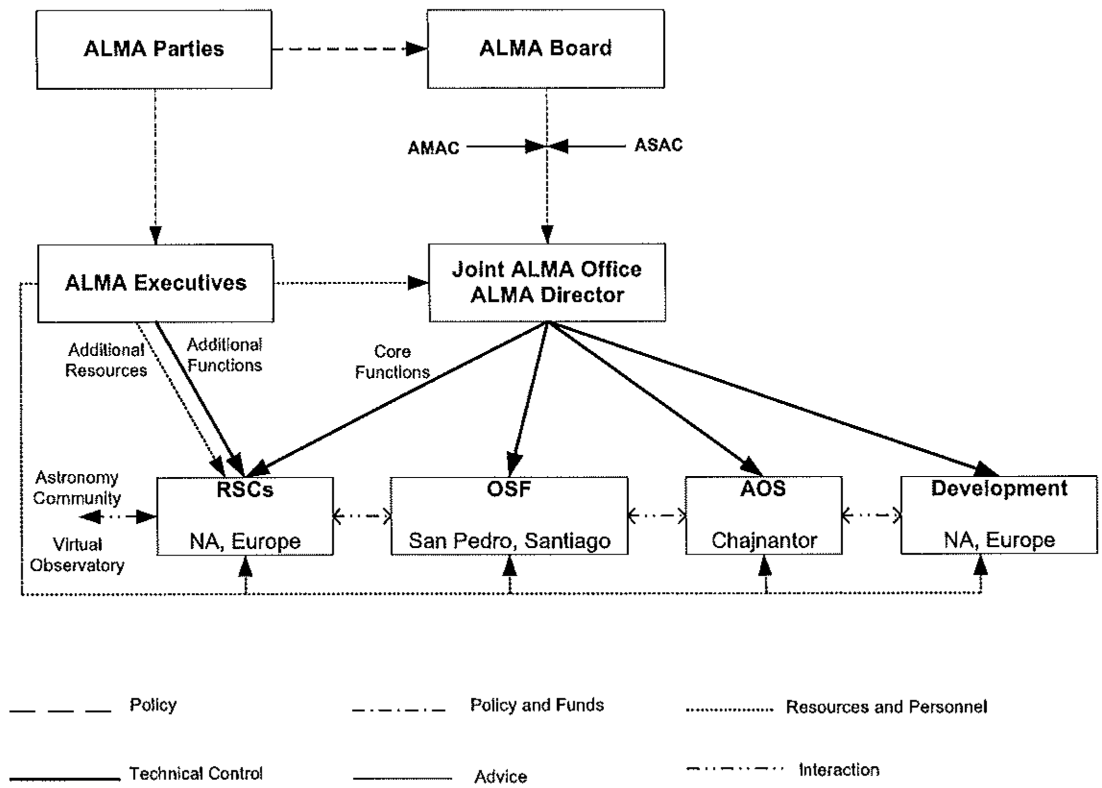

Figure 6-1. ALMA Organization for Operations in the Bilateral Project

These principles have consequences for the joint ALMA operations that are summarized in the following guidelines:

(i) ALMA is a service observing facility, for which the scientific demand will be very high. The astronomer is not normally required to be present when his/her observations are executed.

(ii) ALMA operational activities in Chile are limited to what is required to acquire, certify and archive the scientific data of the scientific teams proposing observations; this includes certain business functions and other activities requiring proximity to the array. For safety reasons, the number of ALMA staff working at the array site at 5000 meters elevation must be kept to an absolute minimum.

(iii) The main interface between the user communities and ALMA is through the Regional Support Centers, including proposal handling and support for data reduction and archival research.

(iv) Development work on hardware and software is the responsibilities of the Executives.

6.2 Model for ALMA Operations and Maintenance

6.2.1 Tasks and Deliverables of the Joint ALMA Office

The operational tasks of ALMA start with the receipt of proposals for observations from the astronomical community. In accordance with the "guidelines" enumerated above, it is assumed that the potential users will propose a program of observations to their respective Regional Support centers (RSCs). Once reviewed and accepted for observation in a manner to be decided by the ALMA Board, the astronomer will provide to the Operations Support Facility (OSF) an observing script that specifies the observational goals in astronomical terms. That is, the astronomer specifies the target object, frequency, spectral resolution, array configuration (if applicable) and the desired on-source integration time, signal-to-noise desired, or the *uv*-coverage needed. It is the task of the Joint ALMA Office to deliver to the astronomer the following:

- A proposal preparation package, including a time estimator and a data simulator, which is capable of complete end-to-end simulation of the observations.
- Raw data and real-time calibrated, pipeline-processed, image of the target object.
- Calibrated uv data set including tables of the calibrations that have been applied, and tables of the monitor data, including prevailing metrological conditions, atmospheric transparency measurements and instrumental performance measures.
- Data path to a copy of this same information that has been submitted to the ALMA archive and notification of the proprietary period to that data.
- User support, including an off-line software analysis package for data manipulation, analysis, imaging and presentation aimed at both non-specialists and experienced users.

In order to supply these deliverables to the astronomer, the following functions should be carried out:

- Review the source script and scheduling blocks with the astronomer. The observations may be split into several scheduling blocks which can be carried out at different times. Each script will have a scientific rating and a threshold criterion for "*stringency*" determined by the ALMA Program Committee that need to be met before the program is run.
- Ensure that the array hardware and software at the OSF and AOS is functioning and maintained to specifications.
- Select a sequence of calibration observations that will enable the astronomer to meet his/her goals and that are consistent with the archive policy.
- Conduct pre-observations, if necessary, to select a nearby source for fast-switched phase calibration. Determine the position of that phase calibration source to the precision needed.

- Execute the program observations, including standard pipeline processing of the data.
- Perform a data quality assessment to confirm that the pipeline-generated images are free of corruption resulting from defective instrumentation.
- Transmit all astronomical and monitor data to the astronomer.
- Transmit the raw data, pipeline-processed images and the monitor data to the ALMA archive including with that data a date at which the proprietary period for the astronomer ends.
- Transmit copies of the archive to the RSCs.
- Provide support to the astronomers on issues related to proposal preparation, data reduction and archival research.
- Provide user feedback to the array operations.
- Ensure that array instrumentation and software is regularly upgraded and expanded over the lifetime of the array.

The following section outlines the different locations at which the above functions are carried out. A summary is included in Table 6-1.

Table 6-1. Summary of the Main Functions at the Different Locations

Location		**Main Functions**
AOS		
-Chajnantor :		Antenna re-configuration Instrument module exchange Security of site
OSF		
-San Pedro :		Array scheduling + operations Quick-look reduction Maintenance + repair antennas Maintenance + repair instrumentation Administration, Safety
OSF		
-Santiago :		Standard pipeline reduction, quality assessment Archive production Business functions Science offices
RSCs		
- NA, Europe	Core:	Proposal handling User support for proposals, data reduction Host of archive copy, archival research support
	Additional:	Advanced software/techniques* Training, summer schools* Financial support users*
Development		
- NA, Europe		New/upgrades instrumentation New/upgrades software Additional functions for RSCs*

* Funded and managed separately by the Executives.

6.2.2 Implementation Plan

Array Operations Site (AOS)—Chajnantor:

ALMA will be operated remotely from the Operations Support Facility (OSF) near San Pedro to minimize the ALMA staff at 5000 m. This leaves on the AOS only those personnel needed to assure the security of the site, those responsible for module exchange —replacing failed instrument modules with functioning spares—and those whose task it is to transport the antennas as needed for array reconfiguration. The array will be designed and built to be modular in character and wherever possible self-diagnosing: each instrument will have provision for an adequate number of monitor points that are reported to the control computer in real time. The AOS will be connected to the OSF by means of a private road for the transportation of the antennas, and a communications highway involving buried optical fibers over which the astronomical data and the instrument monitor data are carried in real time and at high bandwidth. The AOS is further discussed in § 6.5.

Operations Support Facility (OSF):

San Pedro: The main function of the OSF near San Pedro is the operation of the array and the acquisition of the astronomical data based on the proposal scheduling blocks. This includes responsibility for the calibration sequence, dynamic scheduling and execution of the observations, and a quick-look processing and inspection of the data. Another important function is the maintenance and repair of instrumentation and antennas. The location of the OSF is discussed in the ALMA construction project plan, and includes residential facilities for staff at the OSF and AOS, and offices for administration, safety and health. The personnel at the OSF and AOS will work turno shifts.

Santiago: The standard pipeline data reduction and data quality assessment is done largely at the OSF in Santiago. All astronomical and monitor data and pipeline-produced images, once checked, are transmitted to the joint ALMA archive, with copies sent to the RSCs, to be distributed to the users. The Santiago facility will contain offices for the staff astronomers to pursue their personal research as well. The Santiago office is also the natural location for all those business and administrative functions not directly related to the operation and maintenance of the array, and is the functional node for nearly all governmental relations, contracting and import/export administration. Santiago provides a living environment (schools, medical care, shopping, partner employment) that will aid retention of those members of the ALMA professional staff who are hired from abroad and who will be working turno shifts in San Pedro/Chajnantor. The OSF is further discussed in § 6.4, 6.5, and 6.6.

Regional Support Centers (RSCs)—North America and Europe

The first and last steps in the sequence of functions described in § 6.2.1 are carried out at the RSCs in North America and Europe in a manner to be defined by the ALMA Board. The RSC core functions may include proposal handling and support to the astronomer for proposal preparation, data reduction beyond the standard pipeline data products and archival research. They may also provide user feedback on the array performance to the OSF and on the need for improvements, upgrades and future developments of hardware and software to the ALMA Director. Each RSC will host a copy of the ALMA archive or have a fast link to it. At the discretion of the respective Executive, a RSC may choose to add other functions which are not under the control of the Joint ALMA Office, including advanced software beyond the nominal operations, development of new interferometric data handling techniques, support for special projects, additional training, and financial support for ALMA research. The RSCs are further described in § 6.4.

Development—Executives in North America, Europe

The Executives are responsible for providing upgrades to existing instrumentation and development of new instrumentation for ALMA. The Executives will carry out these responsibilities in the same manner as the Construction Project, and with the affiliated institutes they deem most appropriate for the task. Such developments may range from hardware aspects (receiver upgrades, new receiver bands, second generation correlator, ...) to software improvements (operations, data simulator, off-line analysis package, ...). Development is discussed further in § 6.8.

6.3 Functional Organization of ALMA

The Joint ALMA Office is established by the ALMA Board and staffed and funded by the Executives. It is led by the ALMA Director and its top-level organizational view is shown in Figure 6-2. Figures 6-3 thru 6-5 in the following sections show the organizations of the three major sub-elements. The senior management shown in Figure 6-2, specifically the ALMA Director and the three Deputy Directors, are all appointed by the ALMA Board and report to the ALMA Board. The ALMA Director will have the responsibilities and authorities as stated in the Annex of the ALMA agreement. The remainder of the staff are to be hired in Chile by an organization established by the ALMA Board, or they are employees of the Executives assigned to ALMA. All such people are managed by, and report to, the ALMA Director.

In addition, the Executives will establish the ALMA Regional Support Centers (RSCs), whose primary task is scientific support to their respective communities in their respective countries. Each RSC will have its own manager, who reports to the ALMA Director for the core functionalities of the RSCs (see § 6.2 and 6.4), and to their respective Executive for the additional functionalities.

Development of new instrumentation and software, as defined by the ALMA project and funded by the ALMA Board, is the responsibility of the Executives. Each project will be led by a manager, who reports to the ALMA Director for matters of scope and schedule, and to his/her Executive regarding matters of cost.

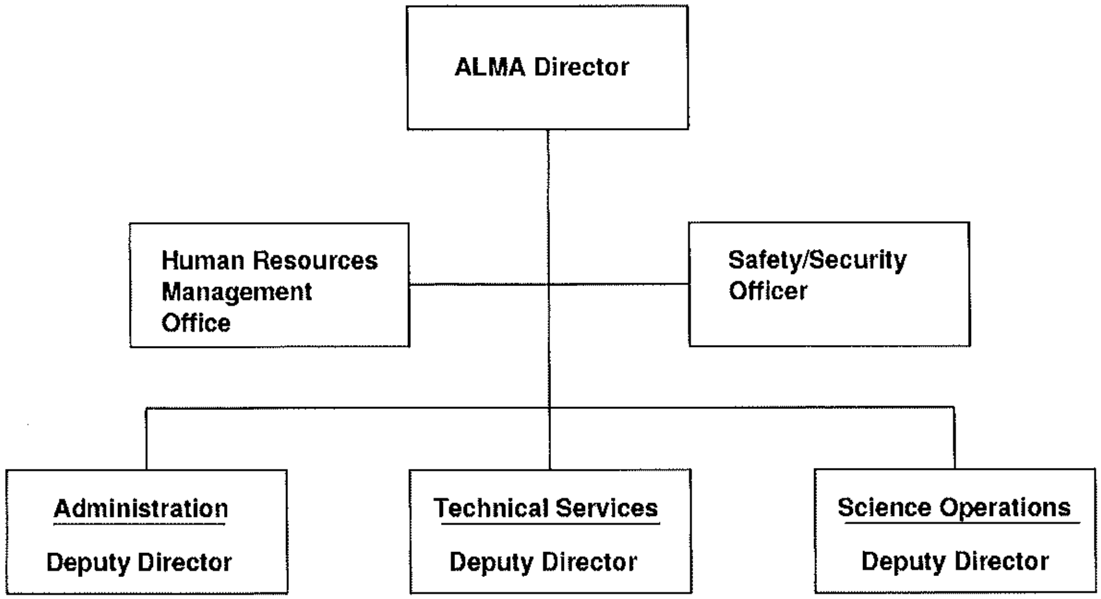

Figure 6-2. ALMA Operational Structure

6.4 Science Operations

6.4.1 The Overall Science Operations Concept

Flexible (or dynamic) scheduling is essential for ALMA, and this defines the overall science operations concept. The necessity for flexible scheduling arises because millimeter and especially submillimeter observations are critically dependent on atmospheric conditions. The capability of ALMA to make instantaneous images in continuum and spectral lines opens new possibilities in this respect: a given observation can be split into several shorter ones to optimize the use of the best atmospheric conditions.

Flexible scheduling implies service observing, and this brings several other advantages. Short projects, which may be commonplace with ALMA, can be handled easily in this framework, as well as "target of opportunity" observations of unpredictable phenomena. Service observing also facilitates the long-term monitoring and consistent calibration of the array. Service observing has been used for years at radio arrays and is the default mode of operation for the current millimeter/submillimeter interferometers. Another major objective for ALMA science operations is to make the millimeter and submillimeter Universe accessible to a wide range of astronomers, particularly those who are not specialists in this area. Therefore the input from the astronomer should be focused on scientific objectives rather than technical aspects, and the default output to the astronomer should be reliable images that can be readily used for scientific analysis. This objective also implies service observing. The Joint ALMA Office will be responsible for the quality of the data products and delivery to the ALMA archive.

To assure that the major objectives are met and that the archived data and pipeline-produced images are of a high and consistent quality, a complete and comprehensive end-to-end data management plan will be implemented for ALMA. Such complete data management systems are currently also in use or being developed at other facilities, including the ESO-VLT and NRAO-VLA. In the following, the different steps in the entire observing process are described in more detail.

6.4.2. Proposal and Observation Preparation

The proposal submission (Phase I) and observation preparation (Phase II) will be done electronically. The Phase I proposal form will contain the scientific case and will be used largely for scientific evaluation, but it will also have enough information for an initial assessment of technical feasibility, done largely automatically by the data simulator.

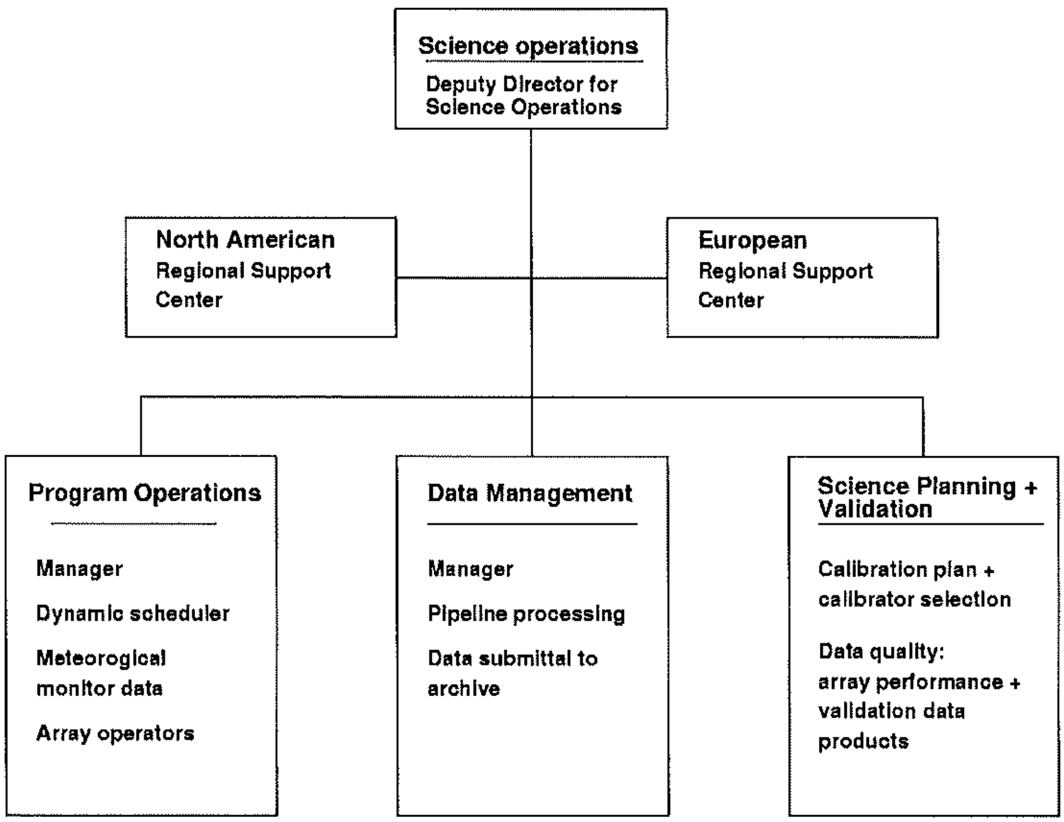

Figure 6-3. Organization of ALMA Science Operation

The scientific Phase I proposals will be peer-reviewed in the manner to be decided by the ALMA Board. A prioritization of approved proposals will be used by the dynamic scheduler at the OSF to select proposals to be run in a particular period of time.

The astronomers of successful proposals interact in Phase II with the RSCs to produce scheduling blocks (SBs) which contain the detailed technical specifications of the observing program and which will be provided to the OSF in Chile. The SBs will contain all the necessary information to define an observation, including the information required to prioritize observations based on the science ratings and the stringency conditions.

6.4.3 Array Observations

The data base of scheduling blocks (SBs) will provide the basis for the actual sequence of observations performed by ALMA at the OSF near San Pedro. The first step is to determine and review the sequence of calibration observations and assure that it is adequate for the astronomer to meet his/her goals and is consistent with the archive policy. During the actual observations, the SBs will be prioritized in real time by an automatic dynamic scheduler at the OSF, in accordance with a variety of factors, including science rating, configuration requirements, source position, "stringency" (e.g., atmospheric conditions and phase stability) and hardware status.

Observations are carried out 24 hr per day, except during planned maintenance and instrumental downtime or when weather conditions prevent acquisition of scientifically useful data. The observations are carried out by a team of array operators and support scientists who work in shifts.

In addition to the standard flexible scheduling service observing mode, other possibilities may exist for various special cases. Eavesdropping, in which the astronomer monitors the observations in real time, and preset "breakpoints" in the program are planned capabilities in accord with the recommendations of the ASAC.

Pipeline data processing will be an essential element of ALMA operation. The pipelines will support calibration and quick look data reduction, and provide calibrated images for science analysis. For calibration, the pipeline will apply all phase and amplitude calibration data, including the results from the water vapor radiometers; it will apply passband calibrations to spectral line observations and any other meteorological information as may be provided (such as measurements with an FTS). Phase and amplitude calibration results will be fed back to the scheduler and operator as the observing progresses. Whenever the calibration data identify hardware problems, a status report will be logged at system level for maintenance purposes, and made available to both the operator and dynamic scheduler, with the relevant information also submitted for incorporation into the ALMA archive.

The quick-look pipeline will keep up-to-date calibration data as new data are taken, including antenna and baseline-based amplitude and phase. It will apply calibration data to the science data on-the-fly to monitor the incoming data for an initial assessment of the quality (e.g., does the calibrator have the expected flux? is a strong line detected where expected?), and to produce interim science results (current spectrum, quick-look images) when requested (e.g., after breakpoints).

6.4.4 Post-Processing, Quality Assessment and Archiving

For standard observing modes, the science data pipeline will operate in fully automated mode. The products will be calibrated images. The science data pipeline will be run at the OSF where a data quality assessment will also be made by a support astronomer. It is the vision that support astronomers rotate between the OSF in San Pedro and Santiago, and that with time, experience and increased automation, an optimum division of tasks between Santiago and San Pedro will be found. It is essential that this task is carried out by a single team to ensure homogenous, consistent reduction and calibration of the data and uniform data quality.

All the data previously obtained since the project started will be available for processing. This means raw data and calibration data obtained in different array configurations, including total power data for measurements of zero and short spacings. Another algorithm may be used if it has been specifically requested by the user. The information on the data quality and array performance will be fed back to the array observations at the OSF-San Pedro on a daily basis. Feedback on array performance and calibration strategies will also be given regularly to the RSCs.

The raw and calibration data, all monitor data, and the standard pipeline-produced calibrated images will be delivered to the archive. A copy of the entire archive will be hosted at each RSC for further processing and analysis. Each Executive will receive a copy of all the data taken by ALMA. The data should be made available promptly to the users.

6.4.5 Data Analysis Support and Archival Research

Once the data have been shipped to the user in Europe, North America, Chile or elsewhere, the loop has been closed and the observation process is complete. However, there are three further important elements in the system—data analysis support, archival research and user feedback. In many cases where the observation was a straightforward image and the default or requested pipeline processing was adequate, no further interaction will be required. There will also be cases, however, where the astronomer has questions on the standard pipeline products and may want to try a different reduction scheme, or special programs where a variety of algorithms will be required to extract the science from the data. This support will be provided by the Regional Support Centers (RSCs) with core services ranging from simple advice, to provision of appropriate data analysis documents and products (which could be standard pipeline or off-line data processing software packages), to in-depth assistance for users who require it. The software packages are developed by the Executives and the affiliated institutes the Executives may choose to involve. It is also the core function of the RSCs to provide user feedback to the OSF in Chile, both electronically and through regular visits to Chile.

The proprietary period for science data will be as decided by the ALMA Board, after which they will be made publicly available in the archive. For complex projects, such as surveys or projects requiring many configurations, it may be appropriate for the proprietary period to start once all the data have been collected. Phase and flux calibrator data, on the other hand, will be made public immediately.

A copy of the complete archive will be maintained by the RSCs in Europe and North America. The archive will include raw data, calibration data and the images produced by the standard pipeline. They will also include header information such as all user input, scientific case from the proposal, observing scripts as used, the observation descriptors, relevant environmental data, the monitor data, relevant fault logs, and the pipeline reduction scripts. Except for the most complex programs, the images could also be re-generated on-the-fly with the latest version of the standard pipeline using the reduction script and the visibilities extracted from the archive. The archives will be accessed through a GUI, the Archive Search Tool. Assistance in the use of the archive will be provided by the respective RSCs. The RSCs plan to interact with the Virtual Observatory to make the ALMA archive available to the world-wide community after the proprietary periods for the data have expired.

The Executives may choose to add other functionalities to the RSCs (e.g., development of new interferometric data techniques, support for special surveys, interferometer schools and training, user funding, ...) from their own resources outside the ALMA Operations budget. The RSCs should be operated with an international and collaborative spirit, and some of the additional functionalities (e.g., advanced software) should be coordinated between the various RSCs.

6.4.6 Phase-in of Science Operations During Construction

When sufficient science capability is available, science operations will start—some years before completion of the full array. Initially, experienced millimeter astronomers will be asked to join in the commissioning activities, with the expectation that they would provide important technical feedback on the facility and operations. This will be followed as soon as possible by a period of interim science operations in which the general community will be invited to apply for some fraction of the observing time with the partial array. This will also be a period when observations relevant to the long-term operation of ALMA will be made (e.g., surveys for calibration sources) and first-look surveys which illustrate the capabilities of the array.

Thus, many elements of the operational setup must be in place from the outset and interim operations staff is needed when the hardware arrives on Chajnantor. Initially, individual observations will be longer (fewer baselines), with a lower data rate and fewer users than after completion.

6.5 Technical Services

6.5.1 Operating ALMA at the AOS-Chajnantor

Overall concept. The environmental factors will impose severe constraints on the working conditions at Chajnantor. This leads to the decision of establishing the Operations Support Facility (OSF) at a lower elevation where the observatory control center and a large fraction of the technical services are to be located. The OSF is also the place where all the activities at the AOS are programmed and monitored on a real-time basis.

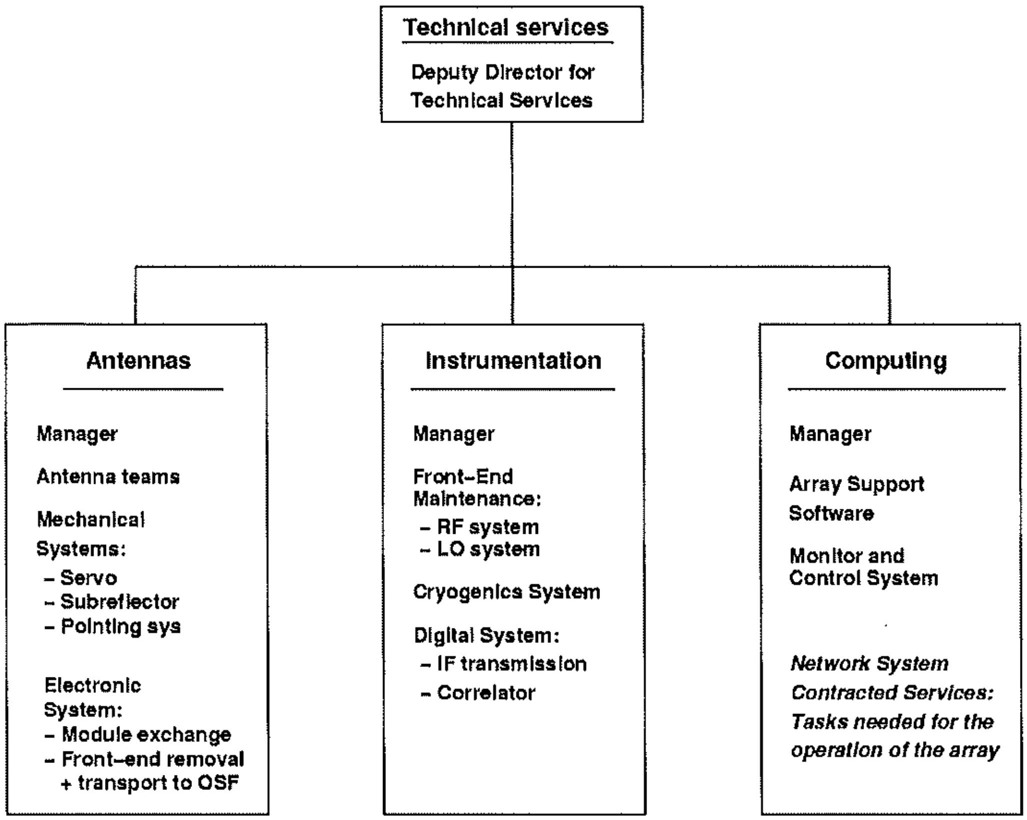

Figure 6-4. Organization of ALMA Array Operations

The aim is not only to minimize the number of staff at the AOS, but also to limit the number of the different crews operating at the high site. Essentially, only the antenna transport teams should be present on a daily basis at the AOS. When we speak of antennas here, we mean the antennas including all of the equipment and instrumentation installed on the antenna—most particularly the front-end equipment. Therefore, all the support functions at Chajnantor for the antennas, including the exchange of the instrumentation modules, would be integrated under a single group belonging to the antenna group.

Safety integration at the AOS. Safety is an essential component of the ALMA operations. It is of crucial importance at Chajnantor. The safety procedures have to be fully integrated into the activities of the antenna teams. Their work checklists have to include all the safety requirements.

Other activities at the AOS. The antenna teams will not handle any infrastructure maintenance or domestic functions (cleaning, provision of supplies, etc.) at the array site. The infrastructure maintenance will be provided by the Facility Group stationed at the OSF. This group will go to the AOS for emergency cases and for scheduled maintenance (roads, buildings, power supply, etc.). They will not be on site on a daily basis.

6.5.2 Operating ALMA at the OSF-San Pedro

Overall concept. The OSF will be the focal place for the ALMA operations in Chile. The plan is to locate this facility at an elevation where the staff can work efficiently in a comfortable environment. The array will be remote-controlled from the OSF, and the main facilities for the technical support will be established there. Consequently, the OSF will include operations, maintenance and residential facilities. It will also provide the infrastructure for assembling antennas and outfitting them with receivers during the construction phase of ALMA.

Planning and monitoring of the tasks to be performed at the high site will also be provided from the OSF. The goal is not only to minimize the presence of the people at the high site, but also to supervise and control the activities at the array site to ensure efficiency and safety.

The OSF will be linked to the array site with a communications highway and with a direct road connection. It should be stressed that the OSF and the array site represent a fully integrated unit, from the functional, managerial and social point of view.

Location of the OSF. The ALMA project plan is to locate the OSF near, but not in, the village of San Pedro de Atacama. San Pedro is a historic village that is a popular tourist attraction owing to its historic and cultural significance. The OSF is not congruous with this particular appeal. Being not too distant from San Pedro, however, has the advantages of being near public transport, restaurants, hotels, some limited shopping, emergency medical care and police security. ALMA will not depend on San Pedro for utilities (potable water, electrical power, sewage); all these services will have to be provided privately for ALMA's own needs at the OSF.

The location selected for the OSF is about 15 km east of San Pedro and south of the Paso de Jama road on land administered by the Chilean Ministry of National Assets. From this location a restricted-use road will be built connecting the AOS to the OSF in a straight line that can be used not only to transport the assembled antennas to the AOS without using the public highway, but also to return the antennas to the OSF for repair and maintenance. No antenna maintenance, and no antenna maintenance crew, will be located at 5000 m altitude, since all antenna work will be done at the OSF. The direct link provides increased staff efficiency and safety at the expense of moving the OSF further from the amenities provided by San Pedro.

Scope of activities for the technical services. The technical services include the Antenna Group, the Instrumentation Group and the Computer Group. Only the latter will rely extensively on contracted services, while the first two groups will be staffed by ALMA employees as their activities are highly specialized and represent a vital component of the project core operation.

Antenna Group

a) Antenna teams
The scope of the activities of the antenna teams working at the array site is described in Section 6.5.1. These teams are complemented by continuous, on-line, support from the OSF where the planning, scheduling and monitoring of their tasks is established.

b) Antenna engineering services
The antenna arriving from the array site will be earmarked either for repair or overhaul. The repair work request will originate from the antenna teams. Prior to any antenna removal decision, a joint assessment of the failure will be established between the teams and engineering services. The regular overhaul scheme will be scheduled by the antenna engineering services, based on major servicing and realignment of each antenna every five years.

Instrumentation Group

This group will be required to maintain a broad spectrum of equipment, both at the front-end and back-end side of the instrumentation chain. RF, LO, digital electronics, and cryogenic specialists will have to be included in the group.

a) Front end and LO support
In ALMA, antenna front ends are designed in a modular manner. The receiver band cartridges are built as separate units, which can be tested, and serviced, individually. Modularity and reliability should ease the maintenance efforts for the OSF engineers and technicians. Servicing will, therefore, basically consist of receiver cartridge tests and repair, and their insertion into the dewar. The RF support will also include the servicing of the water vapor monitors. The team specializing in the IF area will maintain the digitizing units and the fiber transmission equipment.

b) Back end support
The second segment of technical support will deal with all the electronic equipment at the back end, including the IF transmission system and first LO. Most of the equipment consists of solid state electronic components with very high reliability.

Computing and Software Group

Most of the efforts of the computing group at the OSF at San Pedro and in Santiago will focus on the integration of new software packages and updated versions of existing packages. Little software development is planned to take place in Chile. The software packages originate from the Executives and those affiliated institutes the Executives may choose to involve. The team will have to provide feedback information to those sources and manage the integration of the updates on site. This implies a close collaboration with the Executives where the software is developed. The Joint ALMA Office will have the overall responsibility for assuring that the software packages are developed according to common specifications.

The software team will also manage the networking and computer hardware maintenance for which contracted services will be used (computer peripheral exchanges, cabling, etc.).

6.6 Administration/Facilities

The scope of activities for Administration covers the functions necessary to provide an efficient support to the scientific and technical operations of ALMA:
- Administrative services;
- Logistics/general services;
- Facilities for the infrastructure support.

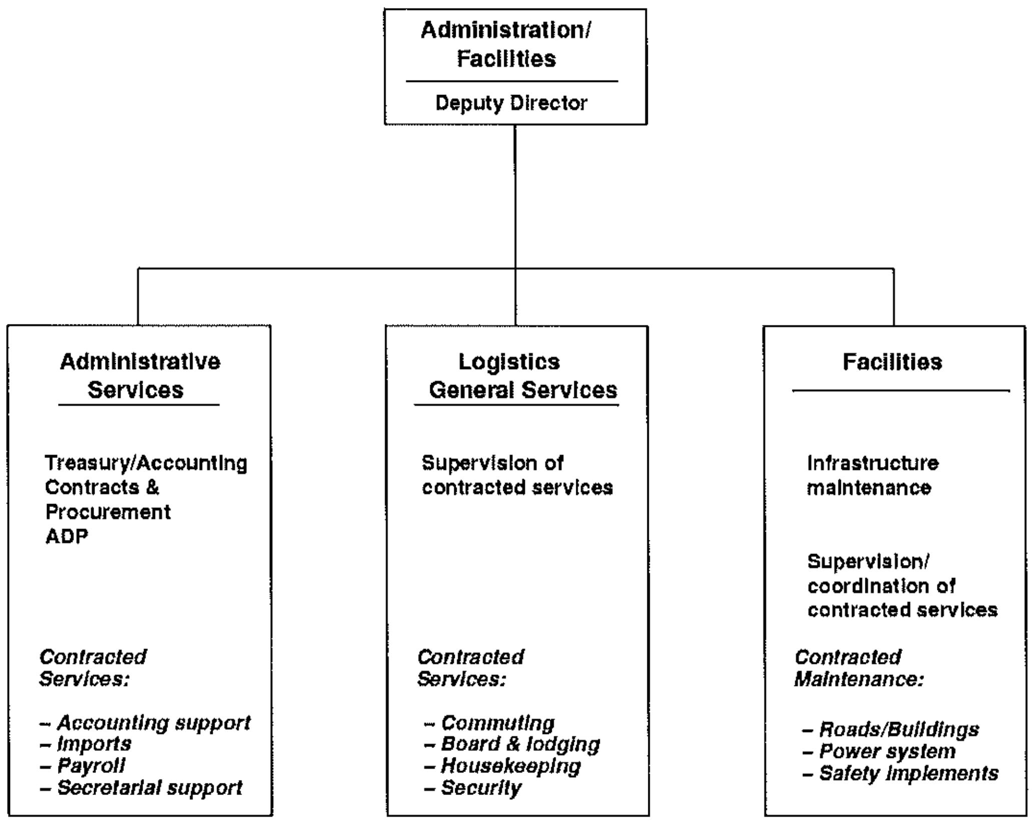

Figure 6-5. Organization of ALMA Administration

6.6.1 Administrative Services

Budget and accounting. Accounting and budgeting will support the ALMA activities in Chile, in the frame of the financial rules and procedures to be developed for the project. It includes accounting of the assets, billing services, insurance, the administration of the budget information according to the WBS for the in-house users and feedback to the regional centers abroad. It does not include the overall financial and budgetary management between the ALMA partners. The local accounting service will be largely automated and rely on contractors for the detailed development.

Contracts and procurement. This service will establish the contracts according to the ALMA policies and procedures, including price inquiries, calls for tenders, and assessment of the offers. Procurement for the supplies according to the purchase requests from internal users is another essential function of the service. This requires a close coordination with the users requirements and objectives, therefore the service must operate in close collaboration with the technical and scientific teams at the OSF.

Human resources management. This is the domain of the Head of Personnel who will report directly to the ALMA Director, to ensure an active development of staffing according to requirements of the ALMA technical and operational services. The staff concerns should be properly addressed, in view of the particular conditions and environment of the ALMA Observatory. The Head of Personnel and the assistants will also be responsible for harmonizing the staff regulations and procedures to ensure a coherent policy across the organization.

6.6.2 Logistics --- General Services

Logistics and General Services provide the following support:
- Staff commuting (OSF/Array Site, OSF/home station);
- Board & Lodging – Travel agency;
- Housekeeping;
- Security.

All of these services will be subcontracted.

6.6.3 Facilities

The Facilities Group will provide the support for the ALMA infrastructure, both at the OSF and the array site. Its scope of activities include:
- Supply and distribution of the power network;
- Maintenance of the roads;
- Maintenance of the buildings;
- Maintenance of the outdoor safety implements.

The group will focus on the supervision and coordination of the contracted support in the area of civil engineering and electrical installations (not including the power installation at the antenna and ancillary instrumentation). It is the group's responsibility to develop the working programs, maintenance schedules and, thereafter, to monitor and commission the execution phase. Last, but not least, the contractor compliance with the safety regulations is under their responsibility. While functionally detached from the antenna teams, their activities are to be coordinated closely with the team leaders. As already mentioned in the case of the antenna teams, the decision processes and the task scheduling are to be managed and administrated from the OSF.

6.7 Education and Public Outreach

The ALMA education and public outreach activities are described in Section 1 of this Project Plan.

6.8 Continuing Technical Upgrades and Development

Continuing technical upgrades and development of new capabilities will be required to maintain ALMA as the state-of-the-art facility for millimeter/submillimeter astronomy over the course of its projected life of up to 50 years. In particular, the rapid progress of electronic technology should make new hardware components and subsystems offering improved performance and higher reliability available for insertion into ALMA on much shorter time scales. Equally important, advances in software and computing should also offer improved performance and reliability that translate into more capability and reduced costs of operation.

Development projects are the responsibility of the Executives. The normal procedure is that the ALMA Director, in consultation with the user community and Executives, will put forward proposals to the ALMA Board for upgrade and development projects. The ALMA Board then decides on the projects, prioritizes them, assigns values and assigns responsibility to one (or both) of the Executives. Thereafter, development projects are conducted in a manner identical to the conduct of the ALMA construction project. Namely, the Executive having task responsibility will assign a project manager who will report to the Executive regarding matters of cost, and he/she will report to the ALMA Director regarding technical scope and schedule.

DOCUMENTATION

This operation plan is based on the documents:

- "Toward an Operating Plan for Atacama Large Millimeter Array", presented by the (E-)AEC to the (E-)ACC meeting of October 30--31, 2001;
- "Operations Planning for ALMA: Status Report" submitted to the ESO council June 2001;
- The September 2001 and March 2002 reports of the ALMA Science Advisory Committee;
- "Recommended Location of the ALMA Operations Support Facility: The Direct Link Option'", by D. Hofstadt, E. Hardy, and R. L. Brown, February 2001.

ANNEX A: PERSONNEL STAFFING

TO BE PROVIDED.

ANNEX B: COST

TO BE PROVIDED.