OPERATIONS PLAN FOR THE ATACAMA LARGE MILLIMETER ARRAY

(Draft Revision[1] 24 August 2001)

1. OVERVIEW

1.1 Operation of the Atacama Large Millimeter Array

ALMA is a joint scientific venture between Europe, North America and Japan with participation by the Republic of Chile. The ALMA operation will serve these four communities in a way that distributes the burdens and the benefits in a mutually agreeable way. The organizational structure for ALMA operations is derived from the organization of the project for the construction phase. It involves participation by the three Executives as described below and coordination between the Executives that occurs through ALMA Operations as illustrated below. Note that the "Joint ALMA Office" that served to coordinate work in the construction phase of the project has been subsumed in the operations phase by "ALMA Operations"; this is the operating entity in Chile supported jointly by the two Executives as can be seen in Figure 1.

The function of the European, Japanese and North American Executives is to handle the necessary ALMA scientific interactions with their respective communities and sponsoring agencies. This certainly includes accountability for funds spent and benefits realized, but it also includes receipt and review of ALMA scientific proposals, support for their respective science community of ALMA users, development of new instrumentation and software for ALMA, and support for access to the joint ALMA archive.

1.2 Basic Principles of ALMA Operations[2]

When construction of ALMA is completed the participating nations of four continents will have invested the better part of one 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, must embody the guiding principles jof the ALMA Agreement (Article 2), namely parity, merit, utilization of existing facilities, and free movement of materials;

[1] Original text Chapter 6 of the ESO Proposal for involvement in ALMA.
[2] Adapted from the document "Toward an Operating Plan for ALMA: Basic Principles and Guidelines" presented at the June 11-12, 2001 meeting of the Expanded ALMA Coordinating Committee.

(b) To maximize the scientific productivity of ALMA the operations plan should incorporate structures that facilitate and encourage the fullest possible engagement of ALMA user communities, beyond their use of observing time, in the further development of ALMA;

(c) The operations plan should provide for efficient and cost-effective operation of ALMA , also to maximize scientific output.

1.3 Guidelines for the ALMA Operations Plan

The principles noted above have consequences that are summarized in the following guidelines for the ALMA operating plan:

(d) ALMA operational activities in Chile and the scope of those activities should be limited to what is required to acquire the scientific data of the scientific teams proposing observations; this also includes certain business functions and other activities requiring proximity to the array;

(e) Development work should occur in the existing institutions of the participating countries both for electronics and software unless there is a demonstrated requirement for locating a particular activity of this nature in Chile. The operating plan shall include a process for allocating priorities, establishing plans and determining the values of development activities;

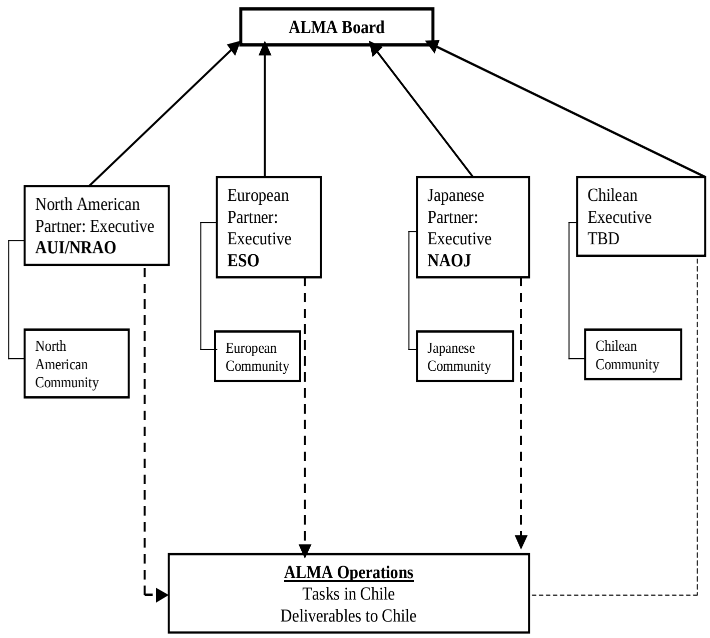
(f) Activities that are part of the ALMA interface to the user communities should occur in those communities, including development and operation of the data management system, proposal submission to archive operations.

2. MODEL FOR ALMA OPERATIONS AND MAINTENANCE

2.1 Tasks and Deliverables of ALMA Operations

In accordance with the “guidelines” enumerated above, in the ALMA operational model it is assumed that the astronomer-users will propose a program of observations to their respective Executive in Europe, North America or Chile. Once reviewed and accepted for observation, the astronomer will provide to the observatory 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 ALMA Operations to deliver to the astronomer the following:

Figure 1. ALMA Organization for Operations



- real-time calibrated, pipeline-processed, image of the target object;
- calibrated uv-data set including tables of the calibrations that have been applied;
- tables of the monitor data, including prevailing meteorological 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 that he/she has to that data (if any).

In order to supply these deliverables to the astronomer it is the task of ALMA Operations to carry out the following functions:

- Review the source script supplied by the astronomer and to select a sequence of calibration observations that will enable the astronomer to meet his/her goals;
- Review the source plus calibration observing script with the astronomer and modify as necessary assuring that the calibration is adequate for the initial image to be consistent with the archive policy (a task done by email);
- Determine whether the program script should be executed in *chapters*—a few hours around source meridian transit over several days in order to accumulate the

integration time necessary—or whether the science can be achieved in a single source transit;

- Assign to the program script codes for the threshold criteria for atmospheric transparency and stability that need to be met before the program is run;
- Conduct pre-observations, as 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 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 pipeline-processed images and the monitor data to the ALMA archive including with that data a date at which the proprietary period for the proposing astronomer ends.

2.2 Guidelines for Array Operations

A few general principles established to maximize the safety and operating efficiency of the ALMA staff form the basis for the model for ALMA operations. Prominent among these are the following:

- ALMA is a *service observing* facility. The astronomer is not normally expected to be present when his/her observations are executed;
- The ALMA observing program will be done dynamically with a running optimization made to ensure that all programs in the queue are run when the prevailing meteorological conditions are suitable;
- The number of ALMA staff assigned to the Array Observing Site (AOS) at 5000 meters elevation must be kept to an absolute minimum;
- ALMA will operate as a full-time research facility for which the scientific demand will be very high;
- ALMA operations must insure that the instrumental "downtime" does not exceed the level achieved on major research telescopes elsewhere;
- It is the desire of the ALMA partners to minimize the size of the operating staff, and to maximize the effectiveness of that staff.

2.3 An Implementation Plan for the ALMA Operations Guidelines

The guideline to minimize the ALMA staff assigned to the 5000m AOS 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, 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 speak to the need 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 rarefied 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. The proposed solution to accomplish this objective is to locate the operations and maintenance staff at a facility as close to the AOS as possible, but at an elevation no higher than 3000m. We refer to this operations and maintenance facility as the *Operations Support Facility* (OSF). We will connect the OSF to the AOS by means of a road (public or private) for the transportation of the antennas, 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. All the professional staff assigned to the OSF will work *turno* shifts. A turno of 8 days on followed by 6 days off is common in Chile.

The final action in the plan to maximize the effectiveness of the staff is to locate in Santiago all those functions that are not directly related to the science operations and maintenance of the array. Santiago is the functional node for nearly all governmental relations, contracting, and import/export administration in Chile. It also provides a living environment (schools, medical care, shopping, spouse 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 the north.

3. FUNCTIONAL ORGANIZATION OF ALMA BY LOCATION

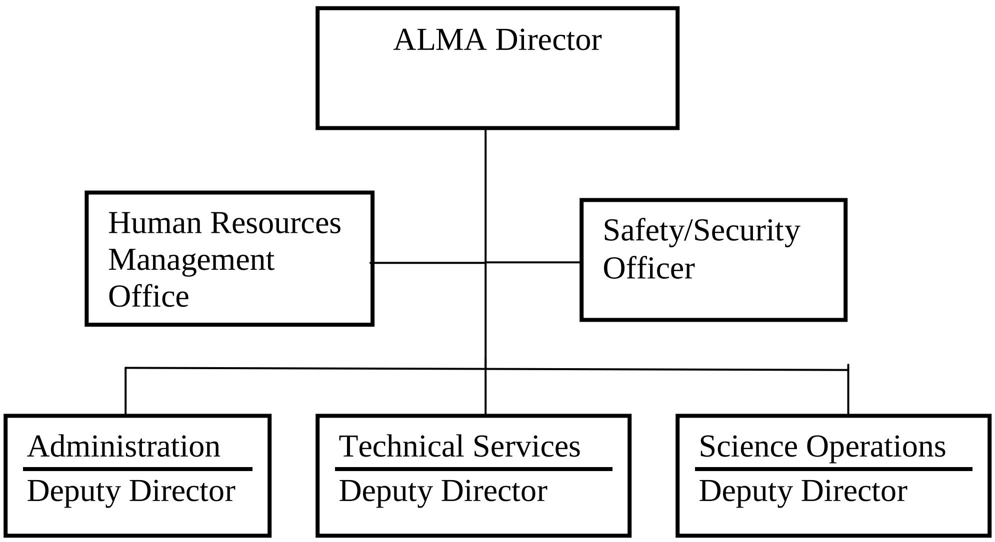
As mentioned above, ALMA operations will be done jointly by AUI/NRAO as the North American Executive, NAOJ as the Japanese Executive, and by ESO as the European Executive. These three agencies have responsibilities to their respective communities that they will handle in their respective countries; and they have responsibilities for the scientific operation of ALMA that they will handle jointly in Chile. There are four functions that are handled in their respective communities:

- Proposal submission and review;
- ALMA user support;
- Operation and support of the ALMA archive;
- Advanced instrumentation and software development program

Within their respective institutions, the Executives will each establish an ALMA Regional Center to carry out these functions.

The joint science operation of ALMA includes all the remaining responsibilities that will be centered in Chile around the joint entity called *ALMA Operations* in Figure 1 above. Figure 2 shows the top-level organizational view of *ALMA Operations.* Figures 3 – 5 in the following sections show the organizations of the three major elements of *ALMA Operations.*

Figure 2. ALMA Operational Structure in Chile



3.1 Location of Operational Entities in Chile

Using the guidelines described above that (i) restrict the staff on the AOS to those individuals involved with antenna reconfiguration, routine antenna maintenance and routine instrument module replacement; (ii) limit the remaining operational staff to the OSF where they are needed for the conduct of the science program and for maintenance of the array hardware; and (iii) assign the remainder of the ALMA operations staff to the Santiago office, we can illustrate the functional distribution of ALMA activities in Chile as follows:

Activity	Location
Administration	
Business	Santiago
Logistics	OSF
Facilities	OSF
Technical Services	
Antennas	AOS and OSF

	Instrumentation	OSF and AOS
	Computing	OSF and Santiago
Science Operations		
	Program Operations	OSF and Santiago
	Data Management	OSF and Santiago
	Science Validation	OSF and Santiago

3.2 Consequences of the Turno System

Professional employees whose work assignment is at the OSF will work turno shifts. It is likely that most will choose to live in Santiago but some may prefer to live elsewhere in Chile. The consequences of employees working one place and living another are the following:

- It is the responsibility of the observatory to transport these professionals from their residence to the OSF on their turno schedule;
- Residential housing will need to be provided at or near the OSF for the turno staff; this is part of the ALMA development plan;
- For astronomers working turno shifts, allowance will need to be made for them to pursue their personal research effectively. This requires time to be allocated for research in addition to time for functional duties, and the time off required by the turno shift work;
- The management of two or more employees *sharing* a job needs special attention.

None of these considerations is unique to ALMA. The other observatories in Chile that work turno shifts encounter, and solve, the same problems.

4. SCIENCE OPERATIONS

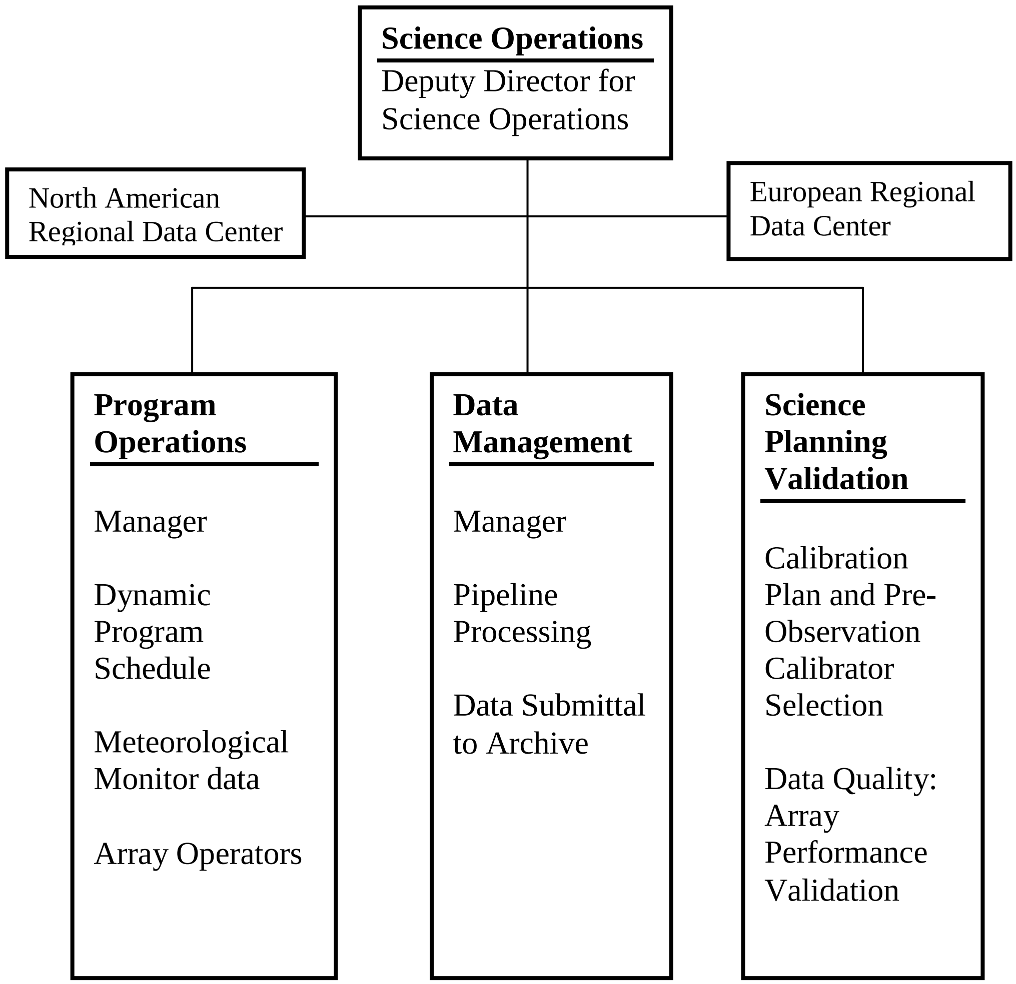
4.1 The Overall Science Operations Concept

Flexible (or dynamic) scheduling is essential for ALMA, and this defines the overall 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 opens new possibilities in this respect, since 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 many 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 calibration of the array. Service observing has been used for years at other radio arrays. 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 mm/submm specialists. Therefore the input from the astronomer should be focused on the scientific objectives rather than technical aspects, and the default output to the astronomer should be reliable images that can be readily understood. This objective also implies service observing. The ALMA Observatory will be responsible for the final quality of the data products.

To assure that the major objectives are met and that the final archived data are of a high and consistent quality, a complete and comprehensive end-to-end data management plan will be implemented for ALMA.

Figure 3. Organization of ALMA Science Operations Function



4.2 Proposal and Observation Preparation

The proposal submission and observation preparation will be done electronically. All observer input will be in electronic form. The proposal form will be used largely for scientific evaluation, but it will also contain enough information for an assessment of technical feasibility. The staffing required to support Phase 1 (proposal submission and evaluation) is mostly administrative.

The overall long-term schedule (array configuration plan) will be prepared before each Call for Proposals is sent out, and users will apply for time using the specified configurations. The configuration schedule can be modified over the years in accordance with demand.

The scientific proposals are peer-reviewed by an external team of examiners in the manner decided by the Executives. The prioritization established by the referees will be used by a scheduling committee to select the proposals to be run in a particular period of time. Technical assistance if needed by the proposing astronomer will be provided by the Executive's Regional Center.

The Regional Centers will provide the operations team in Chile with a set of "Scheduling Blocks" (SBs). These will be the smallest observing units. A single observing program may comprise several SBs, some of which may have to be carried out at different times (e.g. for different array configurations). The SBs will contain all the necessary information to define an observation, and also the information required to prioritize observations based on the science ratings and observing conditions.

4.3 Observation Support

A database of Scheduling Blocks will provide the basis for the actual sequence of observations performed by ALMA. During the actual observations they will be prioritized in real time by a support astronomer on duty assisted by an automatic scheduler at the OSF, in accordance with a variety of factors, including science rating, configuration requirements, source position, atmospheric conditions, and hardware status.

In addition to the standard flexible scheduling service observing mode, other possibilities may exist for various special cases. In rare cases it may be necessary for the user to be present during the observations, working either through the standard SBs or possibly with a more direct interface. Eavesdropping, in which the astronomer monitors the observations in real time, is planned capability

Pipeline data processing will be an essential element of the ALMA operation. The pipelines will support calibration, quick look, and final science data reduction. 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 apply any other meteorological information as may be provided (such as measurements made with an FTS). Phase and amplitude calibration results will be fed back both to the scheduler as the observing processes. Whenever the calibration data identifies hardware problems, a status report will be logged at system level for maintenance purposes, and made available both to the operator and to the dynamic scheduler.

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 produce interim science results when requested (current spectrum, quick look images).

4.4 Post Processing and Quality Control

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. 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. In the default mode the images will be restored with a single standard well-defined algorithm. Another algorithm may be used if it has been specifically requested by the user. The resulting cleaned image will be the one sent to the end user and also to the archive.

The pipeline data products sent to the users will include the calibrated images, the raw data and the calibration data. A copy of the pipeline data products will also be sent to the three archives at the Regional Centers operated by the Executives in Japan, Europe and the U.S. for further processing and analysis. Each Executive will receive a copy of all the data taken by ALMA.

Taking into account actual science operations, other service activities, research time and the turno in Chile, we would expect the total staff for these aspects of ALMA science operations (excluding array operations) to number about 25 persons. A substantial effort will be required at the Regional Centers as well. The astronomers in Chile will function as astronomers on duty at the OSF for 25% of their time and as support astronomers in Santiago for 25% of their time. The remaining 50% of their time will be devoted to research. To attract young scientists to ALMA, we expect that Research Fellows and post-docs would spend a smaller percentage of their time on ALMA functional duties.

4.5 Data Analysis Support and Archive Operation

Once the data have been shipped to the user in Europe, Japan or North America, the loop has been closed and the observation process is complete. However, there are two further important elements in the system - data analysis support and archive operation. 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. However, there will also be many cases in which special effort involving a variety of algorithms will be required to extract the science from the data. Support will be provided by the Executives in their Regional Centers, with services ranging from simple advice, to provision of appropriate data analysis documents and products (which could include pipeline software), to in-depth assistance for users who require it.

The proprietary period for science data will generally be one year, and then 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 only after all the data have been collected. Phase and flux calibrator data, on the other hand, will be made public immediately.

A complete archives will be maintained by the Executives in Europe, Japan and the U.S. The archive will include raw data, calibration data, and the images produced by the 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, and the pipeline reduction scripts. When long integrations have been used for the images, they will be stored in the archive. When shorter integrations have been used, the images could be generated on-the-fly from the visibilities upon extraction from the archive. The archives will be accessed through a GUI, the Archive Search Tool. Assistance will be provided by the respective Executive to Japanese, European and North American astronomers in the use of the archive.

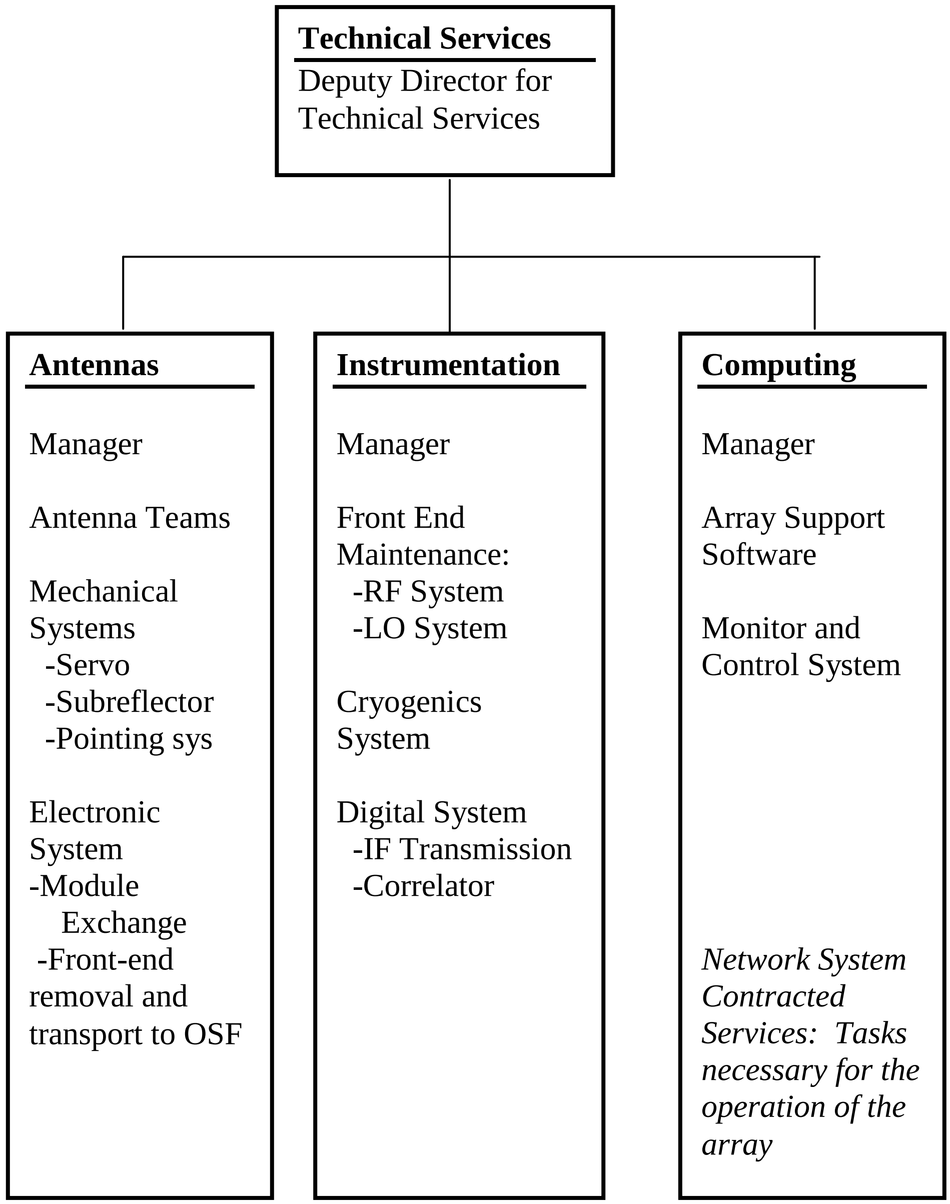
4.6 Phase-in of Science Operations during Construction

When a sufficient number of antennas are available, science operations can start - some years before completion of the full array. The exact definition of a "sufficient number" is not critical in determining when operations will start, as antennas will be installed on the site at the rate of about 10-15 per year. The number should however be sufficient to allow operations in the style of the full array from the outset, to avoid wasteful parallel developments. It is expected that the first science operations would start in 2006-2007. Initially, commissioning activities and science operations will overlap, and experienced radio astronomers would be invited to apply for observing time on a "shared risk" basis, with the expectation that they would provide important technical feedback on the facility and operations. This will also be a period when observations relevant to the long-term operation of ALMA will be made - surveys for calibration sources etc. As soon as possible after this initial period, the partial array would be open to general users for some fraction of the time.

Thus, many elements of the operational setup must be in place from the outset. On the other hand, individual observations will be longer (fewer baselines), with a lower data rate and fewer users than after completion, so not all of the support staff need be in place at this early stage, and the staffing can ramp up to full operations over some period of time.

5. TECHNICAL SERVICES

Figure 4. Organization of ALMA Array Operations Function



5.1 Operating ALMA at the AOS

Overall concept. The environmental factors will impose severe constraints on the working conditions at Chajnantor. This leads to the decision of establishing the Operation Support Facility (OSF) at a lower elevation where the observatory control center and a large fraction of the technical services are to be located. We believe that the OSF should also be the place where all the activities at the AOS are programmed and monitored on a real-time basis. The fundamental guideline is: whenever feasible execute the support tasks at the OSF, without incurring unreasonable overhead burdens. Last but not least, the activities at the AOS should be closely framed by well-established procedures, in order to optimize both the efficiency and the safety.

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 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. This group will execute the maintenance tasks that cannot be performed at the OSF, as well as the configuration deployment of the array. This group is split into antenna teams with the capability to handle both the maintenance and antenna transport functions. These teams are supported from the OSF where the more complex antenna repairs and major overhaul will take place.

The activities of the antenna team are to be planned at the OSF and, while working at the AOS, online support and monitoring are provided by a controller at the OSF. To establish a flexible work schedule for the corrective maintenance, the configuration changes and the preventive maintenance at the Array site, under changing weather conditions (high winds being a major factor), is a major challenge.

Safety for the staff and the equipment is to be ensured as a first priority requirement.

Scope of activity of the antenna teams. The antenna team at the AOS will essentially handle the following tasks:

- Repair (including module exchanges for the instrumentation)
- Array reconfigurations
- Preventive maintenance at the Array Site
- Antenna transports between OSF and AOS.

It is understood that the major antenna overhauls and the more complex interventions on the antennas (e.g., subreflector exchanges) will be performed at the OSF.

In order to quantify approximately the man-year requirements of the antenna teams, the following requirements were considered:

- Three or four array reconfigurations per year (200 to 250 antenna position changes per year).
- One first-level preventive maintenance, at the Array Site, per antenna, every year.
- A failure rate of one antenna or associated equipment per week. Such failures will either be solved at the Array Site or will be dealt with at the OSF, if the nature of the failure requires.

The antenna teams are essentially dedicated to the antennas and their maintenance. The teams will not be able to handle tasks on the ancillary instrumentation, except for the exchanges of instrumentation modules.

To minimize the presence at Chajnantor of the staff specialized in front-end equipment, simple interventions and checkouts by the antenna teams at the front-end are also included in their scope of activities. This applies mainly to the cryogenic equipment. The team must be able to exchange the cryogenic pump units and perform the related checkouts. Front-end engineers may occasionally join the team in case of more complicated interventions.

Team structure. Following the IRAM experience, an antenna team should include:

- One electronic technician
- One mechanical technician
- One front-end technician (with cryogenic knowledge)

It is anticipated that the team members will develop inter-disciplinary skills and will be able to back each other up in their respective specialties. In case of antenna or receiver module exchanges, a specialized driver will be included in the team. The team will handle a relatively broad spectrum of tasks and, therefore, must include all the required skills. The *ingeniero de ejecución* training level in Chile seems to be an adequate background for this.

To cope with the scope of tasks defined above, three daytime teams working on turno are being considered, i.e., six teams in total will be required. The number of teams will be reduced during the holiday periods. The work planning should take into account that the repair activities should be handled without restrictions during these periods. Each team will work effectively on the site for a period of six hours each day, excluding the commuting time between the AOS and OSF.

The teams will generally operate during the morning hours when the wind conditions are favorable. The schedule will also allow all the team members to catch the commuting facilities out of Calama the last day of the shift. It is understood that all the team members will travel to the OSF the day prior to the initiation of the shift.

The estimated staffing is 22 ALMA employees (6 AOS antenna teams of 3 technicians + 4 drivers)

Array reconfiguration potential. During the array reconfiguration periods (3 to 4 times every year for discrete array configurations as distinguished from continuous zoom configurations), two of the teams will be exclusively dedicated to the antenna displacements, leaving the third team for repair and checks on the array segment under science operations. Two teams can move 4 antennas every day (3 hours being required for an antenna). In other words, in a period of 2 weeks, 56 antennas can be moved, i.e., approximately 60 days per year are focussed on this operation.

Repairs and preventive maintenance at the Array Site. All the six teams are staffed to handle the same jobs (repairs, configurations and preventive maintenance). Repairs (corrective maintenance) have priority, in order to ensure the permanent operation of the ALMA Array. Preventive maintenance is to be executed during periods of no configuration exchanges. Preventive maintenance should be established through well-defined procedures, at the level of interventions that are feasible at the array site and whenever the overheads of moving the antennas to the OSF would be unreasonably large.

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.

Safety has two essential components:

- Safety and health of the Chajnantor staff
- Safety of the equipment.

Safety of the staff must be implemented by the safety crew present on the site. Safety of the equipment is to be handled by the leader of the antenna teams.

Covering all the safety aspects "on site" requires the presence of four people, at any given time. During daytime this is feasible without overhead, but a night crew may be required both to monitor the Array at the site and provide an adequate safeguard for the staff. A remote "on-site" alarm monitoring for the array is to be foreseen for this purpose at the AOS building facilities.

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. Furthermore, a number of domestic functions will have to be performed by contractors. It is estimated that this can be done twice a week, under the monitoring of the safety staff.

5.2 Operating ALMA at the OSF

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. An elevation around 2,800 meters is envisaged for its location. 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, if feasible, 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.

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 detailed in the Section 5.1. These teams are complemented by a continuous, on-line, support from the OSF where the planning, scheduling and monitoring of their tasks is established. In each shift (7 days), two supervisors will work at the OSF during daytime. One of them will monitor the sequence of the tasks at the Array Site and ensure that all the procedures are followed and the checks performed. He will issue the green light “Antenna X” ready to resume operation.

The other supervisor will focus on scheduling the next engineering/technical activities in coordination with the science operations input and the atmospheric conditions. He will be responsible for the overall coordination of the antenna teams. He will be the shift leader. It should be stressed that this shift leader must be the single entry point channel from the science operations scheduling. He will interface with the science operations and participate in the development of the observing schedules, in order to provide the regular technical status of the array, and ensure that the observing programs are developed in a realistic manner.

In order to maintain a full yearly staffing coverage at the OSF to assist the antenna teams a total of 6 high-level staff are considered.

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 on the other hand will be scheduled by the antenna engineering services, based on major servicing and realignment of each antenna every 5 years.

Electronic and mechanical skills are required for these services. The electronic skills for the antenna controls, auxiliary functions and monitoring systems, and the mechanic skills for the defective or scheduled component replacements, alignment checks, etc. The overhaul time will be in the order of 6 to 8 days.

It is estimated that a total of 5 mechanics (2 engineers) and five electronics (2 engineers) will be required to cope with the tasks. The engineering services will be responsible for certifying the status of the antennas and for maintaining the logging files for the components and structures.

c) Mechanical Workshops

One can argue that the antennas and ancillary equipment will be shipped to Chile only in full compliance with high industrial standards of product assurance. In principle, no modifications or enhancements will be developed ad-hoc, but only by the original designers and manufacturers. At the OSF, however, the real life of the equipment starts. Assembly/ disassembly is the daily routine. Not only the operating equipment is concerned but, also, the tools, the mountings, the fixtures, the interfaces and the alignment accessories. The antenna and receivers might be perfect, but the handling procedures will evolve as experience is gained. Over the years and, probably through the lifetime of ALMA, better handling methods will be developed for the antennas and the receivers.

To ship pieces of equipment for modifications is not the most speedy and economic solution for mechanical repairs or modifications. Last, but not least, occasionally, the receiver service engineers will profit from the support of a precision mechanic. A small machine shop is foreseen, therefore, manned by three machine tool mechanics, working on a Monday-Friday schedule.

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. It is proposed to separate the activities into two sections:

- Support for the front-end equipment, including LO
- Support for the back-end equipment, including correlator

a) Front-end and LO support

In ALMA, antenna front-ends will be designed in a modular manner. The band receiver cartridges are to be 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 dewar cryogenic maintenance will require a great deal of manpower time when vacuum leaks occur and dewar openings, i.e., cryogenic re-cyclings are involved. 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.

The front-end units are replicated 64 times (+ spares). It is estimated that, as an average, each front-end assembly has to be serviced once a year.

To cope with the maintenance support for the front-end and LO, the following specialists are being considered:

RF engineers	6	RF technicians	8
IF engineers (1 LO engineer)	3	IF technicians	3
Cryogenic engineers	2	Cryogenic technicians	4
Total		19 support staff	

b) Back-end support

The second segment of technical support will deal with all the electronic equipment at the back-end, the interfacing point being the entry at the station cards for the correlator. Its span of activities, essentially, includes the correlator, the interfaces and the real time computer. Most of the equipment consists of solid state electronic components with very high reliability.

The task of this team will be more oriented towards system overview, to ensure an efficient failure diagnostic capability in view of the complexity of the correlator functions. Therefore, emphasis is placed on the engineer-level staff for the support. A total of 3 engineers and 2 technicians is planned for the staffing.

Computing and Software Group

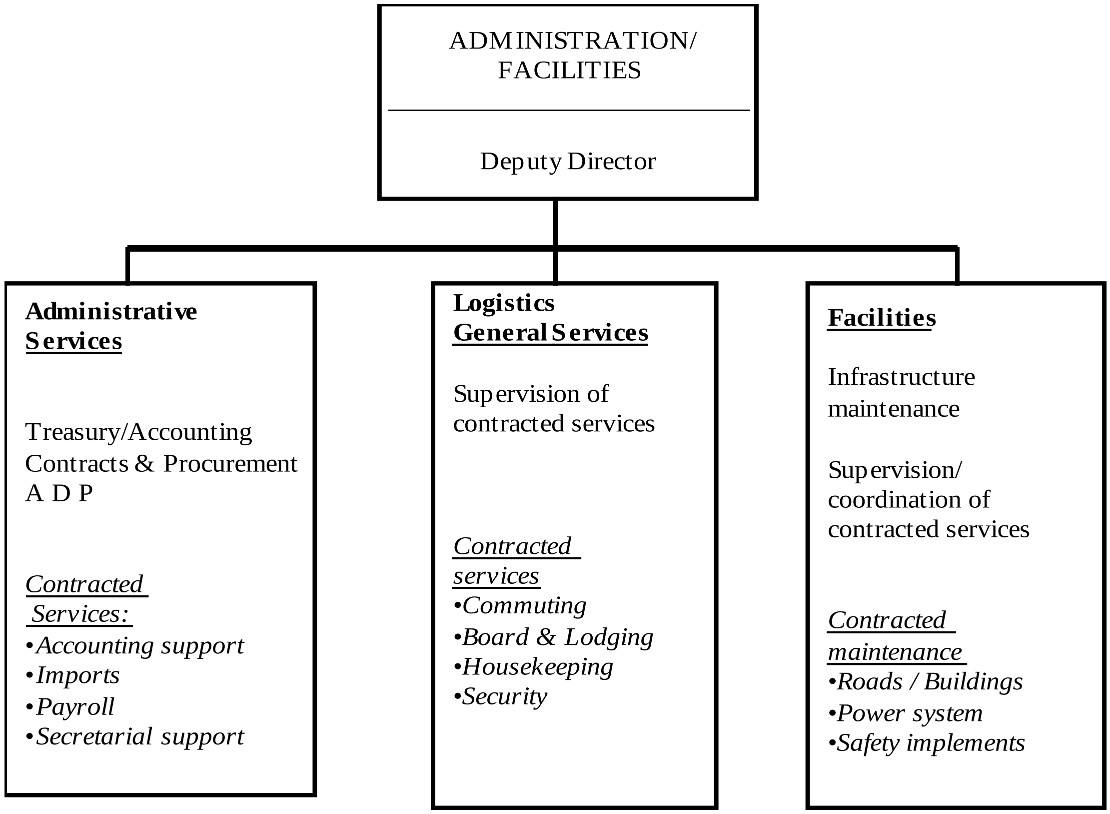
It is difficult to assess how much software development should take place at the OSF. The software maintenance, however, cannot be carried out without a deeper system knowledge. Consequently, the software team should be involved in the development phase of the programming efforts, both for the instrumentation, the antenna controls and the alarm monitors. Team members may also rotate assignments between the OSF and Santiago.

Being at the receiving end of the software packages developed abroad, the team will have the responsibility for the integration of the new software versions, originating at multiple sources. The team will have to provide feedback information to the sources and manage the integration of the updates on site. The commissioning and subsequent release of the new software packages will be under its full control. The team will participate in the diagnostic of the failure and corrections. This implies a close collaboration with the back-end support.

The software team will also manage the networking and computer hardware maintenance for which contracted services will be used (computer peripheral exchanges, cabling, etc.). A total of 6 software engineers, working on shift, are foreseen for this activity.

6. ADMINISTRATION/FACILITIES

Figure 5. Organization of the ALMA Administrative Function



The scope of activities for Administration covers the functions necessary to provide an efficient support to the scientific and technical operations of ALMA. Essentially, three branches of activities are merged under a single management:

- Administrative services
- Logistics/general services
- Facilities for the infrastructure support

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. One Head of Accounting, with two assistants as ALMA staff, will be needed to ensure appropriate in-house control of the accounting and reporting. One treasurer will handle the funds flow coming from abroad to finance the operations in Chile.

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. Four staff with support from contractors for imports/exports are required for this purpose.

Human Resources Management. This is the domain of the Head of Personnel and two personnel officers, who will report directly to the Observatory Director, to ensure an active development of staffing according to requirements of the ALMA technical and operational services. The objective is to limit the number of persons involved in human resource management, in order to focus them on essential issues, such as a proactive recruitment scheme to be developed with the line managers. At the same time, the staff concerns should be properly addressed, in view of the particular conditions and environment of the ALMA Observatory. The Head of Personnel and his assistants will also be responsible for harmonizing the staff regulations and procedures to ensure a coherent policy across the organization.

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. Three staff members are required to supervise and monitor the contractors – a team leader with two assistants.

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 contractors' 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. The following staffing are considered for the Facilities:

- One Facilities manager
- One electrical engineer
- One civil engineer
- Two site infrastructure supervisors
- One draftsman

One should be aware of the fact that the different services are to be contracted out under a close supervision of ALMA staff. The alternative of outsourcing complete operations without ALMA direct involvement could be considered in specific cases when the service reliability allows for it (e.g., power networking).

7. CONTINUING TECHNICAL UPGRADES, DEVELOPMENT OF NEW CAPABILITIES

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. While it is impossible to predict today precisely which new or upgraded capabilities will make the most sense in the operational era of ALMA, we can foresee a scenario that provides a reasonable basis for estimating funding requirements for new or upgraded capabilities.

In the front-end subsystems on-going development of more sensitive, lower noise receivers will make replacement or addition of receiver bands on a two-to-three-year cycle reasonable. Full photonic local oscillators are another technological development that can be reasonably expected to be ready for implementation well within the operational life of ALMA.

In the back-end subsystems advances in high-speed digital electronics and opto-electronics will make upgrading of the digital processing electronics (sampler/digitizers, FIR filters, etc.), fiber optics transmission subsystems, and/or the correlator on a ten-year cycle reasonable.

In the area of software and computing, we make the assumption that software development and replacement of computing equipment should continue on a pace equivalent to replacement of the computing subsystems on a ten-year cycle.

Finally, we assume that selected portions of the facilities at the Array Operating Site, the OSF, and in Santiago will be refurbished and upgraded on a twenty-year life cycle. This includes buildings, roads, utilities such as power generating equipment, as well as communications, safety, and office equipment.

The priorities for what upgrades are to be carried out, by whom, and in what manner will be decided by the three ALMA Executives working in concert in the framework of the ALMA Board.

8. CHILEAN INVOLVEMENT IN ALMA OPERATIONS

8.1 Technical cooperation

Chile has a good educational system for applied engineering. This has been instrumental in its fast-growing economy over the past 15 years. ALMA will offer job opportunities in the various engineering disciplines – civil, electrical, mechanical, electronic, software, etc. The development of ALMA will be an opportunity to set up cooperative programs with Chilean educational establishments. Properly managed, such programs will be of benefit both for ALMA and Chile. The ALMA operation will require highly specialized skills in areas like RF technologies, cryogenics, and fiber optical transmission. A number of Chilean universities will welcome training programs in these fields from ALMA. This will be a practical way to initiate the cooperation and, in turn, enable the ALMA managers to identify young talents for recruitment. It is also essential for the long-term recruitment, as most of the technicians and engineers are to be hired locally.

8.2 Scientific involvement

Through recent years, the number of Chilean astronomers has substantially increased. ALMA will offer job opportunities for them, mainly in the frame of its science operations. It is expected that a number of Chilean scientists will be recruited, either as staff or through fellowship association.

8.3 Scholarships and student involvement

Like other international observatories operating currently in Chile, ALMA will provide for scholarships to promote the development of astronomy. Furthermore, at the Santiago base and the OSF a number of students will be trained "hands-on" in the specific technologies used for the operations and instrumentation. ALMA will naturally offer a career prospect for successful and motivated technicians/engineers who undertake such training.