# IMAGING THE EARTH'S INTERIOR: DETAILED STUDIES OF THE EARTH AND OF THE SEISMIC SOURCE WITH NEW GLOBAL AND TRANSPORTABLE ARRAYS

A Proposal to the

NATIONAL SCIENCE FOUNDATION

from

IRIS: THE INCORPORATED RESEARCH INSTITUTIONS FOR SEISMOLOGY

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# APPENDIX 1C

## Design Considerations

## for a

## New Global Seismographic Network

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# APPENDIX 1C: O U T L I N E DESIGN CONSIDERATIONS FOR A NEW GLOBAL SEISMOGRAPHIC NETWORK

## 1. INTRODUCTION

### 1.1. Purpose

The purpose of this study is to translate the IRIS scientific goals and objectives, as presented in the Science Plan for a New Global Seismographic Network (GSN), into realizable technical goals and objectives for a 100-station global telemetered network with support facilities. In this conceptual stage it is important to identify those many elements of design and planning that must be considered, survey available options, and identify those areas of uncertainty where trade-off studies, design studies, and development are required. The specifications and operational plans that result from this initial study will serve as the master planning document for design, deployment, and operation of the new network.

### 1.2. Scope and Complexity

The establishment of a 100-station telemetered seismograph network with its support facilities will rank as one of seismology's most ambitious data acquisition programs. It will be a complex and many-faceted program. What are the major tasks that must be undertaken to design, deploy, and operate the GSN and how are they related?

### 1.3. Summary of Requirements

What are the fundamental network requirements that will lead to the realization of the goals and objectives in the IRIS Science Plan? The GSN cannot be expected to serve the data needs of the entire seismological research community. What will be its limitations, and how will the new network interface with and overlap other data acquisition efforts (the large portable array, local and regional networks, the strong-motion network?) NH 2 Network Organizational Concept

What will be the major components of the GSN and how will they interface for data flow, communications, and support services? What are the external interfaces (with data centers and other organizations)? A diagrammatic representation of the network organizational concept will be useful. functions, and outputs of the individual stations? What are the major functions of a data collection center? What are the organizational requirements for managing and supporting a 100-station telemetered network?

What will be the relationship of the IRIS GSN with other global and national seismic networks? Will the GSN be a closed network, much like the WWSSN, GDSN, or IDA networks, or will there be international participation in decision making, funding, and operational responsibilities?

One of the most important ingredients in the success of an international network is the active (preferably enthusiastic) cooperation of the participating governments and host organizations. What are the tangible benefits that a station will enjoy by participating in the IRIS GSN?

## 2. BACKGROUND

### 2.1. Development of Modern Networks

### 2.2. Operational Global Networks

#### 2.2.1. Introduction

The GSN technology will be new, but global networks are not. What lessons can be learned from past experience? The 120-station WWSSN was installed over a five-year period in a program that, in many respects, is similar to the GSN in scope and complexity. What are the elements that made the WWSSN successful and enduring?

#### 2.2.2. World-Wide Standardized Seismograph Network

#### 2.2.3. Global Digital Seismograph Network

#### 2.2.4. International Deployment of Accelerometers

#### 2.2.5. Regional Seismic Test Network

#### 2.2.6. Geoscope Network

### 2.3. National Networks and Seismic Arrays

#### 2.3.1. Canadian Standard Network

#### 2.3.2. China Digital Seismograph Network

#### 2.3.3. Norwegian Seismic Array

#### 2.3.4. Grafenburg Array

## 3. DATA REQUIREMENTS

### 3.1. Introduction

In designing a seismograph system, the foremost issue is a definition of the data requirements (bandwidth, resolution, and dynamic range). There is a general consensus among seismologists that new data systems should record "broadband" signals and have "large" dynamic range. These terms must be precisely defined in specifying instruments, and quite often compromise is necessary. Data requirements are rarely (and only very expensively) defined without regard to currently available technology; hence, they tend to lock in specific hardware solutions. should the GSN data requirements be rigidly defined based on the most advanced technology, or should they be flexible enough to permit a range of hardware solutions?

### 3.2. Bandwidth and Amplitude Range

#### 3.2.1. Seismic Signal Resolution

What is the desired resolution of a GSN station? Over what frequency band?

Presuming that self-noise is not a factor, the threshold of seismic signal detection is established by resolution (in units of motion) of a seismograph. Resolution is fixed by the analog sensitivity settings; it varies as a function of frequency due to transfer characteristics and possible bit enhancement in the digital encoder. The detection of small earthquake signals is limited by earth noise, which is both frequency- and site-dependent. If the objective of a seismograph is to detect the smallest earthquake signals, the resolution must be set at or below earth noise through the band of interest. Earth noise models are available and used to determine the appropriate sensitivity settings at seismically quiet and noisy sites. Since the dynamic range of a seismograph is limited, the specification of resolution also fixes the clipping threshold. Thus, the decision involves important trade-offs.

### 3.2.2. Encoder Resolution and Format

What is the optimum resolution for a GSN digital encoder? Should it have an integer or gain-ranged data word format?

Modern force-balance seismometers typically have a dynamic range (self noise to clipping) of 120 dB or better at midband. The resolution (or accuracy) of analog-to-digital converters has been less until recently, ranging from 72 dB (peak to peak) for a 12-bit encoder to 96 dB for a 16-bit encoder. In order to take advantage of the dynamic range of the seismometers, the operating range of encoders has been increased by a gain-ranging technique in which the analog signal is attenuated in a series of steps as the encoder output approaches full scale. The technique permits large signals to be recorded, but the resolution of the encoder, referred to input voltage or equivalent earth motion, decreases in proportion to the attenuation. In recent years, 24-bit encoders have been commercially developed and tested. The increased resolution of these encoders is achieved by bit enhancement (a process involving oversampling and averaging) and the actual resolution is frequency-dependent. However, they are expected to have a resolution of at least 120 dB at 0.1 seconds and higher resolution at longer periods. Although the new encoders appear promising, they have not been tested sufficiently and they may be expensive.

Some would argue that seismometer nonlinearities obviate the need for higher resolution encoders because distortion products create a noise floor 80–90 dB below the full-scale signal. However, the nonlinearities in seismometers have not been thoroughly studied, and the use of 24-bit encoders does avoid the distortion that can occur in the gain-ranging process.

### 3.2.3. Large Signals

What are the maximum body wave and surface wave amplitudes that must be recorded on scale at a GSN station?

The amplitude range between earth noise at a quiet site and 1 g of acceleration that can be measured at the epicenter of an earthquake is approximately 200 dB, a number that greatly exceeds the linear range of any currently available seismometer. Relatively few GSN stations are likely to be located in epicentral regions of major earthquakes, and many of these regions are instrumented with strong-motion seismographs. Nevertheless, it may be desirable for the GSN to overlap strong-motion recording, and it probably will be desirable to record the major earthquakes on scale at teleseismic distances. To define the requirement and, ultimately, to test the instruments, it will be useful to have synthetic waveforms and spectra as a function of epicentral distance for the maximum-credible magnitude earthquake.

### 3.3. Broadband Recording

Although the need for broadband recording at the GSN stations is not questioned, there remains a question at to whether the recording should be proportional to earth acceleration or velocity. What are practical bandwidth, dynamic range, and linearity specifications for broadband seismometers? What will be the sampling rate? Where should the voltage sensitivity of the seismometers be set, and will it be a uniform setting throughout the network?

### 3.4. Short-Period Recording

Depending upon self noise and the choice of sensitivity, the broadband recording may not have sufficient resolution at frequencies above 5 Hz to detect earth noise (and signals of equivalent amplitude) at quiet sites. Is there a need for a subset of stations at the quiet sites with separate short-period recording to supplement the broadband recording? If so, the sampling rate, response characteristics, and sensitivity must be chosen.

### 3.5. Very-Long-Period Recording

Does the broadband recording have adequate resolution at periods of 1,000 seconds and longer? If not, is there a need for a subset of stations with enhanced VLP recording? What will be the sampling rate and sensitivity?

### 3.6. Low-Gain Recording

Should some or all of the GSN stations be equipped with triggered low-gain velocity or acceleration channels to record signals that overdrive the broadband seismometers? What should be the sampling rate and sensitivity?

## 4. STATION INSTRUMENTATION

### 4.1. Introduction

The design an development of the GSN data system is one of the most important tasks in the program. The 100 sets of station instrumentation are also likely to be the most costly line item in the budget. Development risks do not appear to be significant; nevertheless, decisions must be weighed carefully and, wherever, possible, candidate instruments and techniques should be tested before selection is made.

What will be the principal components of station equipment and how will they interface? A diagrammatic representation of the data system concept will be useful.

### 4.2. Operational Configurations

Some of the data systems (preferrably all) will be equipped with transceivers for data telemetry and message communication via satellite circuits. Some stations may have to function without the telemetry link, and design should permit this. There could be telemetered data systems installed at remote locations that are unattended for long intervals (months). At some sites, it may be desirable to install the seismometers at a distance from the existing station facilities to avoid cultural noise. Should landline or radio telemetry be permitted for the convenience of the station? These and other possible configurations must be studies and chosen early because of their impact on system design.

### 4.3. Hardware Attributes

#### 4.3.1. Standardization

Should hardware standardization be a design goal or should the data requirements be standardized in a way that permits a variety of hardware solutions?

#### 4.3.2. Modularity

Modular system design is generally considered desirable as it supports flexibility in operational configuration and eases maintenance. However, it can increase costs and reduce design efficiency. Tradeoffs should be studied.

#### 4.3.3. Reliability and Maintainability

What is the practical goal for station uptime? This can be translated into specifications for mean time between failure and mean time to repair. A high uptime goal (greater than 95%) can be costly because of the requirement for better-than-commercial grade components and the need for a much higher level of station spares.

### 4.3.4. Exportability

Export licenses will be required for the station equipment regardless of destination. Licenses cannot be obtained until system design is complete and destinations are known, but it may be possible to obtain a preliminary judgement on the exportability of critical components while design is underway. If the data systems are assembled using the highest encoder and microprocessor technology, it is quite probable that licenses will not be granted for export to certain countries. How will this effect the program, and should a "low-tech" version of the GSN system be considered?

## 4.4. Sensor Systems

### 4.4.1. Broadband Seismometers

Functional requirements and critical specifications must be developed. The selection of a broadband seismometer (or seismometers) will be a most important design decision. Candidate seismometers will be identified and tested using standardized testing procedures. There are several possible installation techniques — surface vault, posthole, borehole. Should a single technique be adopted, or should it depend on the site?

### 4.4.2. Short-Period Seismometers (if required)

Candidate seismometers and preamplifiers should be identified and their performance characteristics compared before critical specifications and requirements are adopted.

### 4.4.3. Low-Gain Seismometers (if required)

Accelerometers of the type used in the strong-motion program, but with higher sensitivity, are a likely choice. Candidate instruments should be identified and tested. They may not have the dynamic range of the sensitive seismometers, but this may not be critical for the application.

## 4.5. Digital Encoder

Functional requirements and critical specifications must be developed. This is another important decision that has a direct effect on the quality of the data. Candidate encoders will be identified and tested using standardized testing procedures.

## 4.6. Station Processor

The station processor controls data acquisition, processing, transmission, and recording. The processing is likely to include automatic signal detection and data compression. There are many microprocessor and microcomputer options that will be studies before functional requirements and critical specifications are developed.

## 4.7. Station Timing

A station clock is needed to synchronize data sampling and to generate time codes for digital transmission and recoding. There are a variety of clocks available and a variety of methods for sychronizing the clocks to Universal Time. An automatic method of synchronization is much preferred, as manual synchronization is a potential (and often real) source of error. The options will be carefully studied before specifications are developed.

## 4.8. Calibration

Although modern force-balance seismometers are more stable than their forerunners, calibration is still essential in a seismograph system. It is needed during the installation to set the parameters and periodically during operation to confirm sensitivity and other transfer function characteristics. What type of calibration should be used at the GSN stations (step, since wave, pseudo-random telegraph), and what is the desired accuracy over the usual bandwidth? Should the calibration signal be applied automatically or manually, and how often should it be applied?

### 4.9. On-Site Digital Recording

Digital recording will be essential at those station that are not linked by telemetry circuits and it may be required at all stations for backup and to record signals that are not telemetered. Recording modes will have to be identified (continuous, triggered, compressed), and storage requirements computed. A one-week minimum storage capacity is desirable. There are several high-density recording options available and these will be studied before critical specifications are developed.

An important decision related to on-site recording concerns the distribution on processing. If long-period or very-long-period data will be derived from the broadband data for separate storage and processing, it is preferable to filter, decimate, and record the signals separately at the station or at the data centers?

### 4.10. Analog Recording

Analog recording of selected filtered channels should be available as an option to those stations that request it. The analog channels could be designed to emulate the WWSSN-type short-period and long-period responses, and the recording method could be chosen to eliminate the need for expensive photographic recording at stations that operate both WWSSN and GSN stations.

### 4.11. Operator Terminal

The need for operator intervention at the GSN stations should be minimized. Nevertheless, at the manned stations and operator interface will be useful for testing, trouble shooting, maintenance, and parameter adjustment. A keyboard and hard-copy terminal will be the minimum requirements for these purposes. The standard printout might include a log of operator actions, state-of-health messages from the system, automatic signal detections, and messages to and from the data collections center via the telemetry link. A number of interesting possibilities would become available if a small (PC-type) computer with monitor and disk drives was included as a part of the operator console. Real-time wave forms could be displayed, triggered events could be stored on the disks for off-line processing, and diskettes could be furnished to instruct the operator in step-by-step maintenance and trouble shooting.

### 4.12. Station Processor

According to network managers, a significant percentage of failures are related to power, partly because power reliability is poor in many areas of the world, and partly, perhaps, because system power is often the last item of design and given insufficient attention. Battery power (if the system power drain is low enough) or uninterruptible power subsystems will be required at each GSN station, and some stations may require a backup generator as well.

### 4.13. Station Support Equipment

Station operators cannot be expected to repair boards or instruments, but most will be able to replace boards and other major modules with proper training. Downtime can be minimized by equipping each station with a high level of spare modules. However, this can be expensive, so an optimum level of station spares should be determined in a study concurrent with system design.

### 4.14. Environmental Specifications

The GSN station instrumentation will have to function at sites throughout the world. The ambient environment has a major impact on reliability. For example, the WWSSN systems are especially sensitive to high humidity, and most digital equipment is sensitive to heat and dust. The environmental specifications for the system components must be studied to determine permissible extremes of ambient operating environment. Some protection can be provided in the design of the system and packaging, but much may depend on station facilities and the provision of adequte environmental control. Lightning damage has been a serious problem in the past and deserves special attention.

#### 4.15. Test and Evaluation

It is insufficient to establish design goals and develop equipment specifications without parallel development of plans and procedures for test and evaluations to insure that design goals and specifications are met. Design studies should include the selection of parameters to be tested, development of test procedures, and determination of any special equipment or facilities that will be needed.

## 5. SATELLITE TELEMETRY

### 5.1. Introduction and Background

#### 5.1.1. Requirement for Real-Time Data

What are the requirements for real-time data (early earthquake reporting, tsunami warning, database management)? How many telemetered stations are needed to fulfill these requirements?

#### 5.1.2. Current and Evolving Technology

A survey will be needed of current and evolving satellite communication systems (methods and satellites used, data rates, bit error rates, reliability, costs), with special emphasis on the evolving technologies, such as spread spectrum, that promise lower cost. The RSTN is the only operational network that is using satellites for continuous transmission of seismic data; how is it working and what are the costs?

### 5.2. GSN Telemetry Requirements

#### 5.2.1. Transmission Rate

What channels of data will be telemetered and what is the base data rate? Is data compression feasible and what are the expected ratios? If compression is used, what size buffer will be needed for an occurrence of a magnitude 8+ earthquake followed by aftershocks?

#### 5.2.2. Reliability and Availability

What are the GSN requirements for communication network availability? What will be the effect if a part of the network goes down? The availability specification covers both the satellite circuits and the ground-based equipment.

#### 5.2.3. Transmission Errors

What are realizable error rates? Are the errors random or burst? Will errors cause a loss of single data words or entire data blocks? What effect will errors and dropouts have on the processing and analysis of telemetered data? The RSTN data should be a useful source of test data.

#### 5.2.4. Forward Link

The forward link will be used to transmit data from the stations to the data collection center and data centers that are equipped with receiving terminals. What will be the serial format? Will the blocks be fixed or variable in length, and how will they be synchronized? What error detection and correction techniques are applicable? Can message text be combined with the data?

## 6. GSN STATEMENT OF WORK

### 6.1. Introduction

The ten year project schedule illustrated in the "Milestones" chart of Figure 3.1, consists of three phases:

1. Design Specification.
2. Production and Deployment.
3. Network Operation

Phase One occupies the first two years and culminates in a contract for the production of seismographic station systems. Phase Two begins in year two with site preparation and continues through year eight with the deployment of the 100 station network. The last two years of the ten year program consist of Phase Three, routine network operations.

The principal activities are divided into six main categories:

1. Design, Test and Evaluation.
2. Network Deployment.
3. Communications System Deployment
4. Data Collection Facilities
5. GSN Staffing
6. Standing Committee Activities The Budget (Figure 3.2) projects the entire program through a ten-year period.

### 6.2. Design, Test, and Evaluation

The overall goal of this Phase One of the project is to design and produce a system that meets the specifications needed to achieve the scientific objectives. At the same time, the system must meet the practical goals of standardization and modularity that are necessary for cost-effective network operations. In this section, the equipment and physical plants of the remote seismic stations will be considered exclusive of the Communications system and the Data Collection system.

#### 6.2.1. Develop Design Goals

This is the initial stage of the process to translate the scientific needs as outlined in Appendix A. IRIS Scientific Objectives into equipment for the new global network. The result will be a short document that raises the pertinent questions and issues to be addressed in the design study below. draft of such a document is included as Appendix B, Design Considerations for a New Global Seismograph Network. It is presently planned for this concept to be developed by various IRIS committees and distributed widely for comment and review.

#### 6.2.2. Conduct Design Study

Guided by the results of the study in item 3.2.1 above, a design study would research the technical issues, reviewing the availability in the commercial market of system modules.

Design Study sub-tasks include:

- Begin with Design Concepts document
- Review candidate designs for system modules

- Research off-the-shelf versus custom system hardware modules
- Address maintainability, reliability, exportability, operability of candidate systems
- Review technical requirements of cost trade-off
- Discuss interfaces of seismic system with other elements of the proposed network
- Conclude with recommended system specifications

It is estimated that this design study will take approximately two and one-half man-years to conduct and would most likely be contracted to an outside firm.

### 6.2.3. Prepare RFP

After review of the design study recommendations, an RFP could be issued for proposals to build the system. Depending upon the system complexity and the amount of custom modules, the RFP could call for the prototype system to be tested and evolved prior to production of multiple units. If the system specifications look fairly straight-forward, however, the procurement stage cculd begin immediately. This is a fairly critical decision and can only be made after careful review of the design study and a thorough analysis of the risks involved in immediate system production. For the purposes of this budget discussion it is assumed that there will be a separate prototype procurement phase.

### 6.2.4. Proposal Evaluation

A panel of scientific and technical experts will be convened to review the results of the proposal solicitation. Most likely, the responses will deviate in some details from the design specifications and/or present new ideas that merit consideration. Typically this situation leads to a revision of the RFP technical section and a second round of solicitations. With a properly-conducted RFP and review process, the next stage of procurement should be straight-forward.

### 6.2.5. Award Contract

It is assumed that there will be a single overall systems contractor. It would be possible to procure the system under a number of independent contracts for various system modules and have IRIS personnel be responsible for systems integration; but while this may appear to be the less expensive approach in the short- run, there is considerable risk involved. Each module vendor may meet its specifications yet the integrated system may still not function adequately.

### 6.2.6. Prototype Test and Evaluation

Some of the modules of the seismic system are fairly conventional, multi-use items such as the tape recorder or the microprocessor. Production units for these items can be readily specified without extensive experimentation. Other items, however, are rather special-purpose or state-of-the-art. In this category are:

1. The seismometer package
2. The analog-to-digital encoder
3. The satellite communications system

Programs for test and evaluation of candidate modules are scheduled to begin in year one of the project and funds are included in the budget for these purposes. In fact, work is already in progress on several items:

- seismometer systems by the USGS A.S.L.
- analog-to-digital encoders by Sandia National Labs
- satellite communications by Stanford University and UCSD

These activities and those planned by IRIS in the first year can be conducted in parallel with the Design Study with the goal of specifying the entire system by early in the second year.

The contract award will result in the delivery of one or more prototype (or pre-production) systems to IRIS. These units will undergo extensive tests and evaluation under a range of operating conditions. Most likely, these tests will reveal the necessity of some modifications of the design specifications to which the units were built before full production begins.

#### 6.2.7. Contract Production Systems

#### 6.2.8. Reverse Link

Is a reverse link from the data collection center to the individual stations needed to transmit control signals or messages? Will the capacity be sufficient to transmit PDE and other earthquake information to the stations? What error detection and correction techniques might be applicable?

### 6.3. Proposed Telemetry Network

#### 6.3.1. Overview

The preferred communication network will consist of remote earth terminals, called micro-earth stations in spread-spectrum technology, located at the stations and communicating directly with the satellite, satellite circuits, and data receiving terminals, called master stations in spread-spectrum technology, for receiving data at data centers and for retransmitting data from one satellite to another. Design studies and pilot projects will be essential to develop and test the concept for seismic data telemetry.

#### 6.3.2. Remote Terminals

Functional requirements and critical specifications must be defined during the design studies. Will the remote terminals be suitable for unattended operation? Are any special technical qualifications needed for installation and maintenance? Some stations are likely to be screened from the satellites by local topography; can remote terminals be linked to the stations by land-line or radio telemetry?

#### 6.3.3. Satellites

Which satellites will be used for transmission of the data and what is their coverage? What is the overall network coverage?

#### 6.3.4. Master Stations

Functional requirements and specifications must be developed during the design studies. How many master stations will be needed to provide global coverage? How will they be manned and serviced? What is their reliability?

#### 6.3.5. Licensing

What are the international and host country licensing requirements for operating the remote terminals and master stations? What is the feasibility and cost of obtaining these licenses?

## 7. DATA COLLECTIONS AND INITIAL DISTRIBUTION

### 7.1. Introduction

Efficient collection and initial distribution of the IRIS GSN data is essential to the success of the program. A data collection center will be needed to monitor and communicate with the network stations, receive telemetered data, collect recorded data, merge the GSN station data, and possibly data from other sources, and assemble the data onto high-density storage media for initial distribution. Because of the volume of data that will be received and processed, the data collection center has the potential of becoming a serious bottleneck in the operation of the network if not adequately designed and staffed. Design studies are needed to survey current data collection operations and current or near-term technology that might be applied to the GSN requirements.

## 7.2. Functions of a Data Collection Center

### 7.2.1. Overview

What are the essential functions of a data collection center? A flow chart will be useful. There almost certainly will be both telemetered and site-recorded data to process. The volume will be very high when the network is in full operation, so it will be essential to automate operations, with operation intervention needed only when problems are detected, and there must be sufficient excess data handling capacity to permit orderly recovery in the event of a hardware or software failure.

### 7.2.2. Network Monitor

One of the major functions of the data collection center is likely to be the monitoring of the data quality and network state of health. Indicators might be dropouts and bit errors, timing errors, running RMS noise estimates, state-of-health flags transmitted with the data, and messages that may be transmitted with the data. The analysis of calibration signals can be automated, with error messages when parameters fall out of specified bounds. Quality control procedures will be applied to both the telemetered and site-recorded data. Logs will be kept of errors and any other defects so that decisions can be made concerning which data (telemetered or site-recorded) will be selected for permanent storage if both are available. The data collection center will be a quick-response when problems develop at any of the stations.

### 7.2.3. Data Merging

Another likely function of the data collection center will be to merge and reformat all of the network data onto a high-capacity storage medium, such as a laser disk. The disks, which might hold one network day of data, cannot be compiled until all of the site-recorded data are received through the mails, perhaps 30-60 days after recording. If the site-recorded data includes backup for the telemetered broadband data, a decision must be made as to whether the network disks are to be compiled from the backup data alone or a choice of either telemetered or backup data. The latter will entail the need for high-capacity storage of the telemetered data for up to 60-90 days. As the disks are compiled, many minor errors (timing, header information, spiking, etc.) can be repaired. Decisions must be made concerning the format of the network disks and the types of logs and other information that should be included.

### 7.2.4. Initial Distribution

The network disks assembled at the data collection center will constitute the complete GSN data output in raw, unprocessed form. What will be the distribution procedures?

### 7.2.5. Archival Storage

There are likely to be a number of archives established for GSN data. The data collection center will be one, and it will have the added archival responsibility for edit logs, station operation and maintenance logs, calibration data, and any other information that should be saved.

### 7.3. Requirements of a Data Collection Center

#### 7.3.1. Data Throughput and Storage Requirements

A good estimate of data volume is needed before specifications for hardware and software can be developed, and the estimate would include data from other networks that might be merged with the GSN data at the data collection center.

#### 7.3.2. Hardware

What is the optimum size computer configuration needed to handle the full operation load? Does the entire computer facility have to be built as a single full-capacity unit, or can it be assembled in modular steps that keep pace with the development of the network? Should there be a single large mainframe computer, or parallel smaller computers to minimize the impact of scheduled and unscheduled downtime? How much excess capacity is needed.

#### 7.3.3. Software

What are the software requirements? A detailed flow chart will be developed during a design study. The requirements are likely to include a real-time operating system, I/O interface and handlers, compilers, text editors, and file management utilities, as well as application software.

#### 7.3.4. Facilities

What are the space and utility requirements for the master station, computers, and archive? Are there any special requirements for backup power, environmental controls, and security?

#### 7.3.5. Staffing

How many and what types of personnel will be needed to manage and operate the data collection center? How many hours per day and how many days per week should it be manned? Double and triple shifting reduces hardware requirements, but increases operating costs.

## 8. NETWORK DESIGN AND SITE SELECTION

### 8.1. Introduction

The design of the IRIS network and specific site selection will be a complex task involving the consideration and collation of the many scientific objectives of the network, the definition and application of site selection criteria, and the assignment of priorities. Work should begin early. The time needed to contact prospective stations, conduct site surveys, obtain approvals and licenses, and perform any site preparation that many be needed is likely to average two years or more per station. An initial list of 20 to 30 stations is needed to permit the site arrangements to begin so that some site could be ready for the instruments when they arrive in 2 to 3 years.

### 8.2. The Existing Network Infrastructure

There are 108 seismic stations worldwide that participate in the WWSSN, GDSN, or IDA networks. Ninety-seven of these are active WWSSN stations, some of which also operate GDSN or IDA instruments. Of the 97 active WWSSN stations, 22 are located in the United States and its possessions, and the remaining 75 are located in 51 other countries and Antarctica. Most of these stations have been in operation for 20 years or more. The distribution of stations in the existing networks is not ideal for the GSN and some new station sites are needed to improve geographic coverage. Nevertheless, it is likely that the majority of the new GSN broadband seismographs will be installed at WWSSN. GDSN, or IDA station sites and, in fact, replace existing equipment. This will greatly reduce site development efforts (new contracts, agreements, facilities, and so forth).

### 8.3. Network Design

The overall design of the network, that is, planning the distribution of stations and selecting any subsets of stations that may record special data, is a task to be assigned to a committee of scientists representing a broad range of research interests. As a first cut, it might be useful to plan a network with total disregard of existing networks, political realities, and all but the most compelling technical constraints. Such an idealized network might serve as a goal, an impetus to continued technological development (ocean-bottom seismometers, for example) and to improved international participation, especially with those countries that do not routinely exchange data. The final cut in network design will have to be based on practical considerations.

### 8.4. Site Selection Criteria

#### 8.4.1. General

The realization of scientific objectives is the foremost factor in selecting station sites. However, the program is not well served by stations that do not function because of inaccessibility, poor organizational support, or other factors related to the chosen site. Usually (but not always), there are options available in choosing a specific site for a station and, in these instances, other site selection criteria can be applied. Detailed information should be compiled on each candidate station site for review before final selections are made.

#### 8.4.2. Organizational Support

Based on past experience, the data systems most likely to function well will be operated by organizations that have a real interest in and use for the data. Conversely, data systems operated by organizations that derive no benefit from the data have a low survival rate. This is why it is so important to design the system so that the local operators benefit. Approximately 1/4 of the non-U.S. WWSSN systems are operated by universities, and the remainder are operated by government agencies or by government-sponsored research institutes.

Given a choice between two or more host organizations, one might consider the potential use of the data, the past record of cooperation, and technical capability.

At some desirable locations there may not be any existing seismic stations or organizations with an interest in seismology. In these instances, it may be possible to obtain government permission to install stripped-down unattended versions of the GSN system to be serviced periodically by visiting technicians.

#### 8.4.3. Site Characteristics

Accessibility is an obvious factor to be considered in site selection. Some sites may have only limited accessibility due to weather (Antarctica, for example), maintenance support is more difficult and any data recorded on-site may not be immediately available. Some stations in the WWSSN have restricted accessibility due to political factors and are, therefore, difficult to supply and service.

The importance of background noise in the selection of GSN station sites depends to a large extent on the scientific objectives and their priorities. In a well-distributed station network, high levels of microseismic noise cannot be avoided and, perhaps, should not be a matter of concern. However, efforts should be made to avoid cultural noise and environmental noise, where possible. This will require study and possibly field measurements. Environmental noise can be reduced using improved installation techniques (postholes and boreholes, for example).

The reduction of cultural noise may involve site surveys at new or existing station locations. Unfortunately, a number of WWSSN stations have, over the years, fallen victim to cultural encroachment and are no longer good sites for sensitive seismographs, so it may be necessary to find new sites with station help.

There are a number of other factors that should be considered (wind is a major noise source), near-surface geology, topography (in the case of telemetered stations), power (especially reliability), and available facilities.

## 9. DEPLOYMENT

### 9.1. Introduction

Deployment of the network involves more than the physical installation of the data systems; it begins with initial contracts with the prospective stations and ends when the network is fully operational. The deployment of 100 data systems, on the scale of the WWSSN, is a major operation that will require intensive management.

### 9.2. Site Negotiations

The first contact with a prospective station should include a summary of the scientific objectives (a copy of the Science Plan), a description of the proposed instrumentation, anticipated operational requirements, proposed support for the station, and a summary of benefits that the station will receive by participating in the program. Ideally, this will have been preceeded by sufficient international publicity for the IRIS GSN that most scientists are aware of the program and its objectives.

A follow-up visit will often be required, and it is during the follow-up visit that negotiations take place concerning the sharing of responsibilities and costs pertaining to site preparations and costs that may be involved in licensing and operating remote terminals for satellite telemetry. Virtually every organization that is asked to participate will be in a somewhat different position with respect to its ability to share costs; hence, it is best to negotiate these terms individually. Negotiations with local PTT organizations concerning telemetry licensing should be handled by a special team familiar with communication networks and organizations.

The agreement results should be in the form of a letter that clearly establishes responsibilities. In a few cases, the agreement may be obtained through the simple exchange of letters, taking perhaps several months to complete. The requirement for satellite telemetry is a new wrinkle that one suspects will complicate the proceedings. In many, if not most, countries, the decision to participate in the IRIS GSN will be made at a high level of government after lengthy deliberations.

### 9.3. Site Preparation

As soon as the data system concept has developed sufficiently, it will be necessary to prepare drawings and specifications; for example, site configurations. The site plans might specify vaults, postholes, boreholes, recording room facilities, antenna mounts, and any other facility requirements; and they should include power requirements, environmental limits, maximum cable lengths, and so forth. The sample drawings and specifications will be used to prepare detailed contractor specifications for each site that requires new or modified facilities.

It would be hoped that the host organization can contract for and supervise most site preparation work. The more complex site preparation work, such as borehole drilling and finishing, will sometimes require outside assistance and equipment. One or two project specialists will be needed to assist stations in plans and contracting and in monitoring site preparation throughout the network.

### 9.4. Installation

The data collection center, or at least part of it, must be operational before installation of the stations can begin. Presumably parts will have been installed to test the satellite telemetry and prototype systems.

The station equipment will have to be carefully prepared for export shipment and probably air-shipped to the designated station after detailed arrangements have been made for customs clearance and entry into the country. Two-man teams have been used for installing WWSSN and GDSN systems. Three-man teams may be required if a technician or engineer with special qualifications is needed to install the remote satellite terminal. At least one month should be allowed for the installation -- sufficient time to allow setup, thorough testing and documentation, calibration, and training of the station operators.

The number of installation teams in the field will depend on production and site preparation schedules. At the peak of the WWSSN program, there were 12 two-man teams installing stations.

### 9.5. Training

Technical training is a vital and on-going program requirement. It begins with the installation teams being trained by the equipment manufacturers. Installation teams will be expected to isolate and repair at the board component level using field test equipment and portable software diagnostics. A well-organized 2-3 month training program is likely to be necessary. Identical training will be required for field maintenance personnel.

The training of station operators will emphasize basic digital electronic technology, routine station operation, trouble shooting to the board level, and replacement of boards and other major components. Technical training of foreign station operations in the United States, as in the case of the GDSN, has not been especially effective in many cases because of cultural barriers; however, it is considered to be one of the major benefits of participating in a U.S.-sponsored program, and it does establish a useful rapport between station personnel and network support personnel, so it definitely should be considered. In any event, there must be training or retraining of station operators during installation of the system.

## 10. NETWORK SUPPORT AND MAINTENANCE

### 10.1. Introduction

The network will not function long without adequate support and maintenance. Past experience would indicate that there will be a need for a central network maintenance center, regional maintenance centers, and field technicians who will service individual stations as needed. Plans for network support should be developed and implemented as the data systems are being developed so that facilities and personnel are in place when the first stations are installed.

### 10.2. Functions of a Network Maintenance Center

#### 10.2.1. Communications

Rapid and efficient communication between the maintenance center and the stations will be essential for transmitting requests and instructions. In the case of telemetered stations, it may be possible to communicate via the satellite link; otherwise, Telex or a TTY dial-up circuit connected to the operator's terminal will be needed.

### 10.2.2. Supply, Repair, Documentation, Training

The center will furnish the stations with operating supplies on a routine basis and replacement parts and modules as needed; repair or contract for the repair of defective equipment returned from the stations; provide manuals, special instructions, logs, forms, and other updated documentation; and establish training programs for new maintenance personnel and station operators. The center will maintain detailed records of equipment and station performance.

### 10.2.3. Engineering Support

The first system modification always precedes the installation of the first system, and modifications are a continuing practice thereafter. Engineering support for the network is needed to monitor network performance and identify design problems, and to design, test, and evaluate hardware and software changes.

### 10.3. Requirements of a Network Maintenance Center

What are the facility, equipment, and staffing requirements for a GSN network maintenance center? Examples in place can be studied. There will be an obvious need for supplies, parts, modules, and test equipment. Special facilities that may be needed include vaults, postholes, and boreholes for testing seismometers under operating conditions. At least two complete data systems will be needed, one operated continuously for long-term evaluation of hardware and software modifications, the other set up in the laboratory for testing modules and components that have been repaired. Staffing should include and adequte number of shop technicians for continuous board and module repair uninterrupted by field activity.

### 10.4. Regional Maintenance Centers

Past experience by network managers indicates that regional maintenance centers would be valuable in reducing the time required to provide emergency support to the stations. Regional centers would be stocked with major replacement modules and serve as operational bases for field technicians. There should be at least two (Europe and the Far East) and perhaps more when the network is fully operational.

### 10.5. Field Maintenance

On-site maintenance by trained technicians will be a vital part of network support if high network uptime is a serious goal. There are instances of GDSN stations having been down for months, but repaired and running within hours after the arrival of a field technician. Ideally, technicians will be within one or two day's travel of all but the most remote stations. When not engaged in emergency calls, the field technicians routinely visit operating stations, update hardware and software with changes, and train station operators.

## 11. PROGRAM PLANNING

The establishment of a 100-system global network promises to be a very complex effort that will involve a multitude of tasks and activities. It will require intensive management planning. The development of a comprehensive program plan should be the first milestone accomplishment. This will require:

- identification of major tasks, subtasks, and activities,
- an estimate of the time required for each activity,
- an estimate of the cost of each activity,

- assignment of organizational responsibility for each activity,
- assignment of priorities, and
- networking of activities to determine order and precedence.

The development of the program plan will, in itself, provide managers with a valuable insight into program complexities and costs that will assure more complete planning and better decision making. The developed plan will be a framework for management estimate and control of budget and schedules.