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DESIGN CONCEPTS FOR A GLOBAL TELEMETERED SEISMOGRAPH NETWORK

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1. INTRODUCTION

This study represents a first step in developing an integrated, real-time global seismic data acquisition system -- a Global Telemetered Seismograph Network (GTSN). The principal objective of the GTSN will be to acquire reliable, high-quality, real-time seismic data for rapid location and analysis of seismic events. A secondary, but important, objective of the GTSN is to augment the existing off-line seismic data base available for research.

The deployment of the GTSN will involve a variety of interrelated activities -- development of the data acquisition and receiving equipment, establishment of satellite and terrestrial communication links, site selection and preparation, training of station personnel, equipment installation, and establishment of support facilities. It is a complex program and the development of a sound management plan will be essential. The purpose of this study is not to fix design goals or dictate avenues of approach but to develop working concepts that may be used as a framework for program planning.

The international exchange of seismic data has been an important factor in the progress that has been made during the past two decades in our understanding of earthquakes and global tectonics. The seismic data base available for analysis and research is derived principally from the Global Seismograph Network (GSN), which is funded and managed by the U.S. Geological Survey (USGS). The GSN comprises some 120 seismograph stations located in more than 60 countries of the world. Established during the 1960's with the installation of the World-Wide Standardized Seismograph Network (WWSSN), the GSN has been augmented in recent years by the installation of more advanced data systems, such as the Seismic Research Observatories (SRO), the modified High-Gain Long-Period (ASRO) seismographs, and the digital WWSSN (DWWSSN). The SRO, ASRO, and DWWSSN stations have the common, distinctive feature of digital data recording, so they are known collectively as the Global Digital Seismograph Network (GDSN).

The fundamental objective in operating the GSN is to create and update a seismic data base that is accessible without restrictions to organizations and research scientists throughout the world. The USGS provides cooperating stations with instrumentation, training, and continuing support, including supplies and on-site maintenance. In return, the host organization operates the equipment and sends the recorded data to the USGS. Analog data (seismograms) are microfilmed and about four million copies are requested annually by researchers. Digital data, which are recorded on magnetic tape, are organized by the USGS Albuquerque Seismological Laboratory (ASL) into network-day tapes and copies of the day tapes are furnished to data users through national and regional data centers. After copying, original data are returned to the stations and used for local research.

Most of the stations in the GSN also provide the USGS with seismic readings -- phase arrival times and amplitudes scaled from the seismograms. These readings are transmitted on a daily or biweekly basis via commercial or diplomatic communication channels. They are used by the USGS National Earthquake Information Service (NEIS) to determine the location and magnitude of earthquakes occurring throughout the world. The results are published monthly in bulletins that are distributed to the participating stations and virtually all scientific organizations that are involved in seismological studies. It is a much-valued service that provides a current, updated catalog of seismic activity on a global scale.

The NEIS also has the responsibility for rapid reporting of large and potentially destructive earthquakes. The NEIS issues news bulletins as soon as possible after the occurrence of magnitude 6.5 or greater earthquakes (magnitude 5 or greater in the conterminous United States). The news bulletins are sent to disaster relief, public safety, and other interested organizations. Tsunami warnings issued to countries bordering the Pacific Ocean are based initially on earthquake location and magnitude data. Rapid reporting of earthquakes requires real-time waveform data or readings. Currently, signals are being telemetered from more than thirty stations in the United States to the NEIS, which is located in Golden, Colorado. An extension of the telemetry network to other countries will provide the seismological community with a significantly improved means of monitoring earthquake activity in real time; it will lower the response time for determining the location and magnitude of potentially destructive or tsunamigenic earthquakes and it will provide more timely information that may be needed by governments to respond promptly.

2. NETWORK CONCEPT

The GTSN will consist of a number of seismic stations (10 - 12 for planning purposes), satellite telemetry links, and at least one data receiving terminal, which will be located at ASL (see Figure 1). Most of the stations will be equipped with a new data acquisition system developed specifically for this program. In a few cases, signals may be derived from existing SRO and ASRO systems. Most of the stations will be manned on a day-to-day basis by personnel from the host organization. It is conceivable, however, that a few stations in the network will be operated remotely, unattended except for periodic (perhaps monthly) maintenance visits by U.S. technicians. This might be the case, for example, if a country asked to host a station does not have a program in seismology or if a station must be colocated with a satellite earth station far from existing seismological facilities.

Seismic stations will operate asynchronously; that is, independent of real-time commands from a network control center. However, accurate clocks, synchronized by satellite signals, will be used so that data will be sampled simultaneously (to within 1 millisecond) at all sites. Seismic data, in digital format, will be transmitted continuously from the stations to the data receiving terminal (DRT). In addition to the data channel, a two-way communication link will be established between each station and the DRT and used to transmit messages. Messages from the stations to the DRT will be multiplexed with the data but the return link will be established as a separate channel.

Data and messages will be transmitted via the International Telecommunication Satellite Organization (INTELSAT) system. Several options are shown in Figure 1 for inputting data to the INTELSAT system. One possibility is to locate the seismic station at an INTELSAT earth station site. Another possibility is to place a remote earth terminal at the seismic station and transmit directly to the satellite. A third possibility is to use ground communication links (telephone circuits or radio) to transmit data from the seismic station to the nearest INTELSAT earth station. These options will be discussed in more detail later. For several important reasons, the use of remote earth terminals

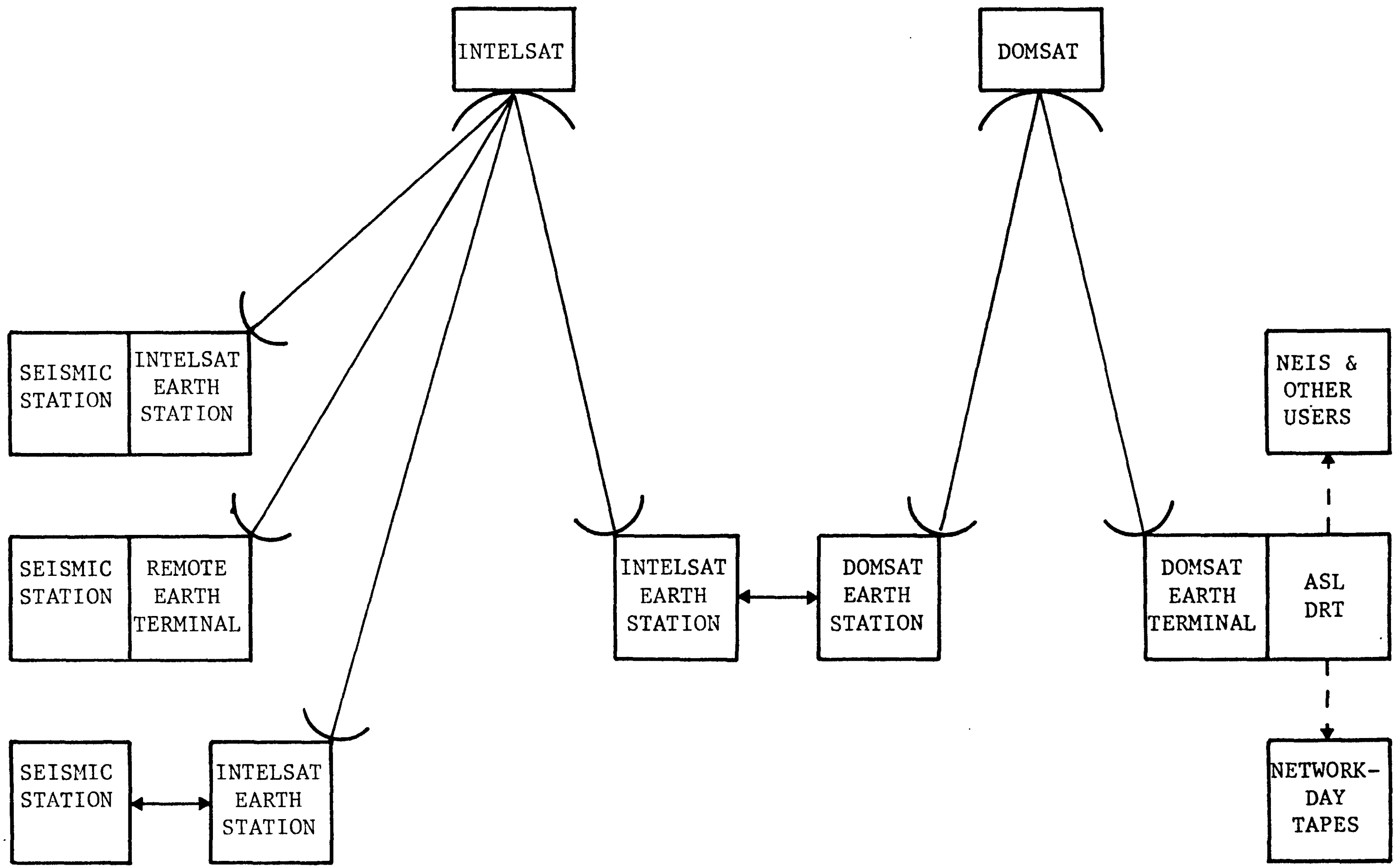

Figure 1.--GTSN Network Concept

is preferred.

The DRT will acquire station data directly from an INTELSAT satellite or relayed via a domestic satellite from an INTELSAT earth station in the United States (as shown in Figure 1). Direct acquisition would have to be from the Pacific INTELSAT satellite as low elevation angle and interfering topography east of Albuquerque will preclude the use of the Atlantic satellite for this purpose. Signals are relayed via satellite in a broadcast mode; hence, any organization can acquire the real-time GTSN data simply by installing a receiving terminal.

The DRT at Albuquerque will be a computer-based, fully automated signal monitoring and processing system. One important function of the DRT will be to monitor the continuity and quality of incoming signals. Error messages will alert DRT personnel to possible problems and they will be able to communicate with station personnel via the message link. It should also be possible for the DRT to transmit diagnostic instructions directly to the station processors via the message link, although normally this action would be coordinated with station personnel. A second function of the DRT will be to process the incoming data. Phase parameters will be determined automatically and transmitted to NEIS and other data users via a TTY link. Event detected waveform data will be reformatted and stored for later merging with GDSN data on the network-day tapes.

The GTSN will be serviced from ASL. Supplies, spare parts, repair services, and on-site technical assistance will be furnished as needed. Because of the importance of data continuity to the objectives of this program, the network stations will receive a much higher level of support than normally provided GSN stations.

3. COMMUNICATIONS

3.1 Communication Study

The most critical milestone in the development of the GTSN will be the completion of a communications study (development of a communications plan). The preliminary phase of this study will address technological feasibility and choice of options for acquiring real-time seismic data via satellite. The experiences of Sandia Laboratories in operating the Regional Seismic Test Network (RSTN) will be useful at this stage. The second phase of the study, which will include site surveys, will address the economic and political feasibility of specific options for the proposed sites. Political considerations involve more than a host government agreement in principle; INTELSAT will have to approve the use of remote terminals for transmitting and receiving data via their satellites; local organizations, usually post, telegraph, and telephone (PTT) agencies, will have to license remote terminals used in the country or the use of existing INTELSAT earth stations and the use of any landline or RF telemetry links that may be needed. Bureaucratic delays are almost inevitable; hence, it is important that the communication study be given the highest priority in program planning.

3.2 Transmission Rate and Errors

A fundamental transmission rate from each station of 2400 bits per second (BPS) has been assumed for planning purposes. This bandwidth is more than sufficient to transmit short-period, intermediate-period, and long-period data continuously. It would be technically feasible, however, to event detect the short- and intermediate-period signals at the site, buffer the data, then transmit the events and continous long-period data at a lower rate, say 800 BPS. The economic advantages in this are questionable, as the costs are more likely to be predicated on the dedication of the circuits than the data rate (which in either case is extremely low compared with typical satellite communication), but the option will be studied.

Assuming that satellite links are used on the entire transmission path, and assuming that data link specifications provided in various COMSAT reports are accurate, transmission errors should not be a significant problem in this program. A bit error rate of 1 in 10^7 is specified for the INTELSAT link provided that forward error correction is used, which will double the transmission rate to 4800 BPS. This would correspond to an average of one error per hour if the errors are random in time. Random single sample errors in the data can be detected and repaired at the DRT if they cause amplitude spikes. Likewise, errors in station time and other header information can be repaired. State-of-health flags will be ignored unless a flag is set for several successive frames, and a smart receiving terminal should be able to accommodate errors in frame synchronization. Transmission outages in the satellite link should not be a problem either. The percentage of uptime for the INTELSAT system is quoted as 99.98%.

Transmission errors and outages are likely to be a far more serious problem if ground telemetry links (VHF, microwave, landlines) are used between the station and a satellite terminal. It may be necessary to cope with error rates of 10^{-4} to 10^{-3} and, to make matters worse, the errors due to line noise or radio frequency interference often occur in bursts. Redundant transmission may be necessary if the circuits are this noisy. A 5 - 10 minute buffer would be used at the station and both real-time and delayed data streams would be multiplexed on a single 4800 BPS circuit. The most error-free frames would be selected at the DRT. Redundant delayed transmission would also prevent total loss of data during short transmission outages.

3.3 Acquisition of Station Data

All of the proposed GTSN sites appear to be within range of the INTELSAT Atlantic satellite, although local topographic interference will have to be considered during site selection if remote earth terminals are used. There are basically two methods of entering transmissions into the INTELSAT system; through an existing INTELSAT earth station or through a dedicated remote earth terminal. An early decision on the method to be used will be needed as it impacts both system design and site selection.

There are nearly 250 earth stations operating in more than 125 countries throughout the world. They are owned and operated by the telecommunications agencies in the countries where they are located. The earth stations are used to transmit and receive telegraphic messages, telephone calls, and high speed data, including television. Any earth station can communicate with any other earth station in the INTELSAT network. With a suitable interface, data generated at a GTSN station could be transmitted continuously through an existing earth station to the United States. The advantage in using an existing earth station is lower initial cost, especially if the seismic station could be located within hardwire distance of an earth station. However, this is not likely to be possible in most cases because of seismic noise considerations or because a host organization would be unable to service the station. A ground telemetry link between the seismic station and an existing earth station may be feasible in some cases. Line-of-sight radio telemetry would be preferred; telephone circuits should not be considered except under the most unusual circumstances where circuit reliability and quality can be guaranteed by the host. The feasibility of using ground telemetry at the specified sites will be addressed during the communications study. Tests will be necessary on any proposed telemetry link before a final decision is made.

In some of the proposed host countries, the earth stations are located at noisy sites (near the coast, for example) and ground telemetry links to quieter sites are not possible. In these instances the use of remote earth terminals is the only practical alternative. Dedicated earth terminals with 3-meter dish antennas are being used successfully with the RSTN systems, and they are now available commercially. The great advantage in using remote terminals is that they permit almost total flexibility in siting the stations. They also provide the most direct path for the signals and may cost less than installing and operating a ground telemetry link. Although the technology is proven, the protocols may not have been established for using remote earth terminals in the countries that are asked to host GTSN stations. Plowing new ground of this sort is certain to take considerable time, which again emphasizes the importance of pursuing the communications study without delay.

4. DATA SYSTEM CONCEPTS

4.1 Data Requirements

The first step in the design of a seismic data system is the specification of data needed to meet program objectives. In this case, the primary objective is to locate and determine the magnitude of seismic events in near real time and possibly perform other near real-time analyses to define other source parameters. A minimum requirement for these purposes would be three-component short- and long-period data. Computer processing and the high resolution of digital data has made it possible to extract useful information from the intermediate-period band as well. The acquisition of three overlapping bands -- short period (SP), intermediate period (IP), and long period (LP) -- permits the reconstruction of a single broadband signal during post processing. Whether or not the IP data are used in real-time analyses of seismic events, they should be recorded, as broadband data have become an almost fundamental requirement for contemporary research. Since the borehole seismometer generates a broadband signal, it is not difficult to obtain data in all three bands and this will be considered a basic design objective for the GTSN. Transmission bandwidth permitting, it would also be useful to acquire low-gain signals from accelerometers installed at each station. This will insure that the station is not overdriven during large earthquakes or strong local shocks.

If the data are transmitted as separate bands, the sampling rates used will be 20, 10, and 1 sample per second (SPS) for the SP, IP, and LP bands, respectively. The data word format will be based on a 16-bit gain-ranged word with 14 bits used for quantization and 2 bits used for specifying gain. This will provide 78 dB of resolution and a total of 120 dB of amplitude range. The combined data rate for all bands will be 1488 BPS. The seismic data will be formatted into 1-second frames together with station identification (8 bits), time of year to the nearest millisecond (56 bits), message text (80 bits), state-of-health flags (16 bits), and frame synchronization (16 bits). This totals 1664 bits, leaving space in a 2400 bit frame for additional information. Three accelerometer (AC) channels, sampled at 10 SPS, could be added (480 bits), and it might be useful to include meteorological data (wind speed and direction, outside temperature, micropressure variations) sampled once each second.

There is an attractive, although untested, alternative to the transmission of separate bands. Several manufacturers are proposing high-resolution (120 dB minimum) digital encoders for seismic applications, and these should be investigated for possible use in the GTSN. One achieves high resolution using a delta modulation technique and the other using an averaging technique. In both cases the signals will be sampled at a high rate, digitally filtered to prevent aliasing, then decimated to the desired final sampling rate. Both are intended to generate 24-bit words with 21-bit accuracy. One potential advantage in high resolution encoding is that it may be possible to transmit single broadband signals rather than three separate bands. At the DRT, the broadband signals could be digitally filtered to produce any desired response in the .001 to 10 Hz band. After filtering, the data could be reformatted to a 16-bit floating-point word where this is necessary to conform to existing formats, such as in the GDSN network-day tape. Resolution would be lost during the reformatting, but it is not needed for most narrow-band analyses. The advantages of these procedures are that response shaping can be tailored to site characteristics or to suit the specific needs of an analyst, and the unfiltered, broadband data will be useful for a variety of research applications that require spectral analysis of the waveform. Three-component, broadband (BB) signals, sampled at 20 SPS, and formatted into 24-bit words will generate 1440 BPS. Again, it would be possible to transmit accelerometer data as well (high resolution encoding will not improve the clipping threshold).

4.2 Station Instrumentation

4.2.1 General

Each new GTSN station will have a seismometer system, an uphole digital system, and a power system (see Figure 2). Most will have a recording system and possibly a remote earth terminal as well. The recording system will be coupled through a 2400 BPS telemetry port on the communication interface, such that a ground telemetry link could be inserted at this point if it is

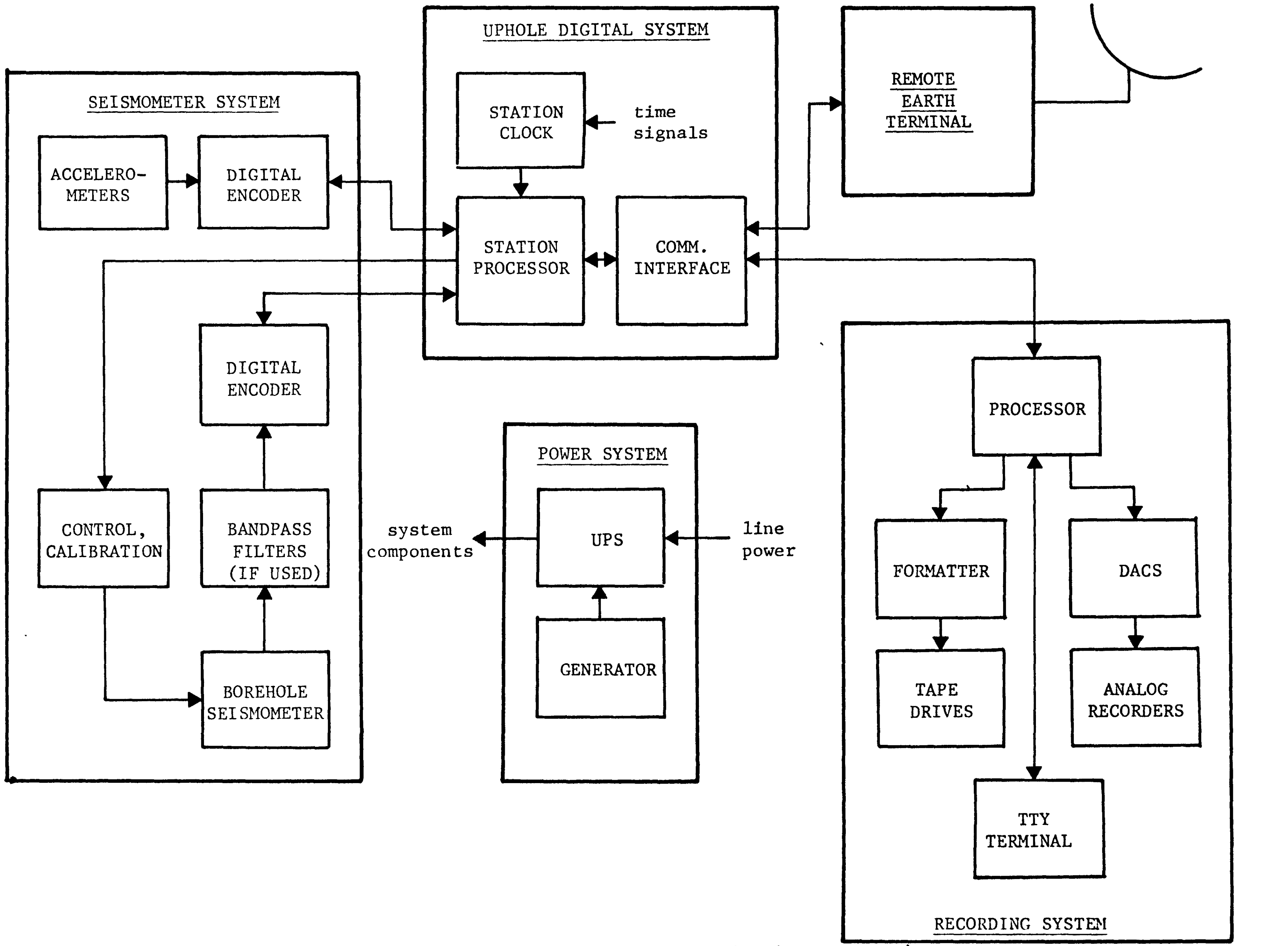

Figure 2.--Simplified block diagram of GTSN station instrumentation.

necessary to operate the recording system at some distance from the borehole site. Failures in this link, or in the recording system, will not affect the satellite-transmitted data.

4.2.2 Seismometer System

The seismometer system is defined to include the borehole seismometer, any analog signal conditioning that might be used, the digital encoder, the auxiliary equipment needed to install, control, and calibrate the borehole seismometer, and the accelerometer subsystem. One of the Teledyne-Geotech KS-series borehole seismometers will be used in the new GTSN systems. The choice will depend upon the results of a seismometer system study at ASL, which will include testing and evaluation of two new versions of the borehole seismometers.

There are several versions of the KS 36000 seismometer in operation. The original model (01) is being used in the SRO network. This instrument has proven to be reliable and it has not been excessively noisy in the short-period band, at least in the original units. One significant disadvantage of the SRO borehole seismometer has been the lack of adequate amplitude range (earth noise to clipping) in the short-period band.

The model 03 KS 36000 seismometer is a modified version produced for the Air Force. The sensitivity was reduced in the SP band to improve operating range, and the corner frequency was extended from 1 to 4 Hz to achieve better control of response parameters. Also, the calibration drive was changed from constant acceleration to constant velocity (to improve calibration at higher frequencies) and an externally actuated module locking device was added so that it is unnecessary to open the seismometers during installation. The vertical component sensor in the model 03 seismometer is excessively noisy in the short-period band, and the magnitude of the noise is such that a separate vertical-component seismometer must be used to provide quiet signals. The cause of the noise is not fully understood.

The model 04 KS 36000 seismometer is an extensively modified version developed for the RSTN system. The corner frequency was extended to 20 Hz, the sensor modules were modified, and the entire package was redesigned with high-reliability components. In this version, the filters and digital encoder are placed in the downhole package and three bands (SP, IP, LP) are generated, shaped to provide velocity outputs. The vertical sensor in the NSS KS seismometer has been excessively noisy.

Geotech has developed a new borehole seismometer, the KS 44000. It has a smaller diameter than the KS 36000 and will have several other improved features. For example, it will operate with a larger angle of tilt (which eases the borehole specifications) and it will have a microprocessor-controlled leveling mechanism. The KS 44000 is designed to meet or exceed the performance of the KS 36000 with respect to signal quality, but it will not be known if this goal has been met until the instrument is tested. The first operational unit is expected to be ready for testing about 1 April 1982.

An SRO borehole seismometer is being modified under an ARPA-sponsored USGS project. Three mass position signals are being brought uphole in place of the filtered and amplified "data outputs" and the sensor modules are being upgraded with low-noise electronics. The mass position signals will have greater bandwidth (to several thousand seconds) and a higher clipping level. The modified seismometer will be available at ASL for testing about 1 January 1982.

The KS 44000 and the modified SRO KS 36000 are prime candidates for the GTSN seismometer. The selection, which cannot be made earlier than mid 1982, will be an important milestone in the development of the GTSN system. One of the most important of the selection criteria will be the level of instrument noise in the short-period band. Hopefully, it will not be necessary to operate a separate vertical-component seismometer as it is in the case of the NSS and Air Force versions of the KS 36000.

The seismometer calibrator, which will be located on a board downhole, will generate sine waves at selectable frequencies, random pulses, and possibly step functions. Ideally, it will be possible to apply calibration signals independently to each of the three sensors. Routine periodic calibration will be initiated automatically by commands from the station processor in the uphole digital system, but inhibited if events are in progress. It should also be possible to calibrate manually, by both the station operator and the DRT. Sine waves will be used for routine calibrations and the onsets will be carefully synchronized so that phase as well as amplitude information can be derived from the calibration signal.

The seismometer study will include a digital encoder recommendation. If one of the high resolution encoders is used, it will be located in the downhole package in order to avoid noise and nonlinearities that might be in the line or the line drivers. The encoder decision will also involve the selection of bands, in particular whether three separate bands or a single broadband signal will be encoded from each component. If a 16-bit gain-ranged encoder is used to encode separate bands, the encoder could be located uphole (as it is in the SRO system) or in the seismometer package. However, the preferred location will be in the downhole package. If a 16-bit encoder is used, the NSS encoder will be a logical choice, since it is a proven design and it is configured for the borehole package.

At this point, the accelerometer subsystem is considered an option that will be studied more fully when the data link specifications are defined. The accelerometers and encoders will not add significantly to the cost of the station, but the data could be exceedingly important in studies of large earthquakes. The accelerometer sensitivities would be set so that the amplitude range overlaps the IP channels and the spectral band would permit recording of both body waves and surface waves. The accelerometers would be installed at the surface. A separate encoder may be needed if the seismometer encoder is placed in the borehole.

4.2.3 Uphole Digital System

The uphole digital system is defined to include the station processor, the station clock, a communication interface (which will probably be part of the station processor), and any other components that are needed to process the data on site or control station operation. A prime candidate for the station clock is the Frequency and Time Systems T-200 satellite timing receiver, which has an accuracy of 10 microseconds or better. Timing signals are received from the Transit or Nova satellites, corrected for offset, and applied to an internal clock that generates the station time. Timing corrections are programmable and fully automatic. Since polar orbiting satellites are used, these clocks will function at any location in the world.

The major functions of the station processor will include clocking and control of real-time operations, buffering and formatting, calibration, state-of-health monitoring, and event detection. It will function independent of operator control but will respond to commands from the station operator or the DRT that may be used to change parameters, calibrate, or initiate diagnostic routines. Event detection will be used to inhibit calibration and may conceivably be used to select data for transmission if data link bandwidths do not permit the full transmission of the data.

4.2.4 Recording System

The station recording system will consist of a processor, magnetic tape drives, analog recorders, and a keyboard terminal. A GTSN system could function without the recording system, if necessary. The processor will be needed as a communication interface, to reformat data for recording, and to generate a time code for the analog recorders. The keyboard terminal will be used by the station operator to communicate with the DRT and the station processor. System faults detected by the processor in its state-of-health monitoring will be printed on the terminal to alert the station operator.

The purpose of the tape drives will be to provide backup recording so that data may be recovered in the event of a failure in the transmission link. At some stations the host organization may wish to use the recorded digital data for research; otherwise, the tapes will remain at the station and be recycled. Two high-density cartridge drives will be furnished and switchover will be automatic so that data are not lost if one fails. High capacity cartridges are available that will store up to 32,768 2048-byte records. If 14 bytes in each record are used for header information and the remaining 2034 bytes for data, a single cartridge will store 4 days of continuous data. If a segment of transmitted data is lost because of telemetry failure, the station operator will be notified by message to send the backup tape to the DRT.

Each recording system will be equipped with digital-to-analog converters (and filters if broadband signals are encoded), and at least four visual drum recorders. The host organization will select the data channels to be recorded.

The seismograms will be useful for local analysis and research and for monitoring system operation. They will remain at the station.

4.2.5 Station Power

GTSN systems will be designed to operate from line power but with sufficient backup and auxiliary capacity to accommodate most line power failures. The station power system will consist of an uninterruptible power supply (UPS) and a backup diesel generator that will switch on automatically if line power fails. Failures in station power systems are often the most common cause of station downtime, especially at locations where frequent line power failures or fluctuations stress the power system components. The GTSN power system must be well designed and have excess capacity. Two power systems will be needed if the recording system is separated from the borehole equipment by a telemetry link.

4.2.6 SRO and ASRO Station Modifications

Several existing SRO and ASRO stations may be incorporated into the GTSN network. A study will be needed, in conjunction with the design of the GTSN system, to determine if and how the existing equipment might be interfaced with the GTSN telemetry equipment. The major difference between the SRO and ASRO systems is that a borehole seismometer is used at the SRO stations and conventional short- and long-period seismometers are used at the ASRO stations. The digital encoding and recording equipment is identical. A serial stream of multiplexed digital data, clocked at 1720 BPS, is available from the Nova computers in the SRO and ASRO recording systems if a special I/O board is installed. However, the format would not be the same as the GTSN format, so it may be preferable to use GTSN digital encoders and the GTSN uphole digital system at SRO and ASRO sites. Horizontal-component short-period seismometers and amplifiers will be needed at the ASRO stations, as only vertical-component signals are presently recorded. Acquisition of intermediate-period signals will require additional amplifiers, such as those used in the DWWSSN system. Some additional improvements should be considered at the SRO and ASRO stations to increase reliability. It would be useful, for example, to increase the capacity of the power system and add a back-up generator, furnish a higher level of station spares, and provide a keyboard terminal for two-way message communication with the DRT. The study may indeed result in a finding that is would be cost effective to replace all of the existing equipment at an SRO or ASRO site, except the recording system, with GTSN instrumentation, including a borehole seismometer at ASRO stations.

4.3 Data Receiving Terminal

The detailed requirements and design of the DRT will be defined during an in-house study. The three main functions of the DRT are expected to be (1) continuous automated monitoring of data quality, (2) initiation of diagnostics and corrective maintenance when problems develop at the stations or in the transmission links, and (3) processing of the data for distribution and recording.

A flow chart of prospective DRT functions is shown in Figure 3. Incoming signals will be received at the DRT through its satellite earth terminal. The independent data streams will be examined in a computer and the waveforms will be available for scrutiny on an analog display. Timing errors, state-of-health faults, transmission errors, dropouts, and other defects will generate error messages and audio alarms. Some defects in the data can be repaired automatically; for example, timing errors can be corrected and single spikes caused by transmission errors can be removed. A method will be devised to monitor noise levels as well, possibly by continuous plots of RMS noise computations. Calibration signals will be analyzed in the computer and error messages will be generated if amplitude or phase falls out of acceptable limits. When problems develop, personnel at ASL will communicate with station personnel via the message channel so that diagnostics and repair can be coordinated. Since the stations will not be manned full time, it may be desirable to design the field systems such that diagnostics and perhaps some component switching can be controlled from the DRT. The ability to remotely insert a test signal at various points in the field system and telemetry link would be useful in isolating faults. If telemetry outages exceed some specified duration, the DRT will request backup data from the station.

The first step in processing the data will be event detection, although this may be preceded by digital bandpass filtering if the data are broadband. SP events, IP events, and continuous LP data will be stored temporarily on

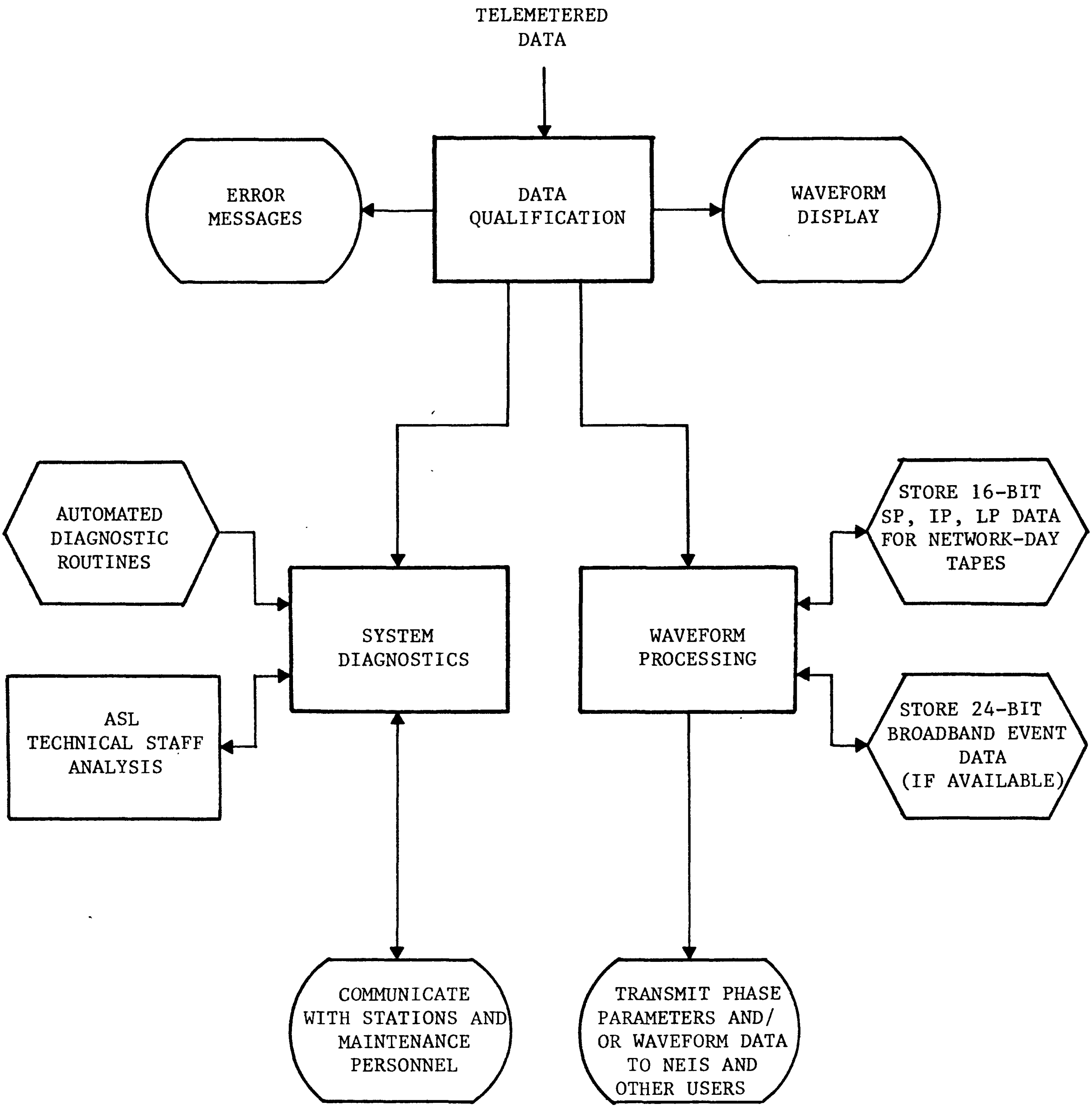

Figure 3.--Flow chart of possible DRT functions.

tape or disk, then merged with other GDSN data on the network-day tapes. High resolution broadband data, if available, would be stored on tape in its original 24-bit format. The event detection algorithm will generate phase parameters -- arrival times, sense of first motion, maximum amplitude and period of the first several cycles. The phase parameters will be transmitted automatically to NEIS and any other data users that establish dedicated TTY circuits with the DRT. Event-detected waveform data will be provided as well if they are needed and the circuits are established. Event data will be buffered in a disk for several days so that the phase parameters can be manually rechecked if necessary.

If it is feasible, depending upon final network configuration and development of a suitable program, preliminary event parameters (origin time, location, magnitude) will be computed automatically for major earthquakes in the regions covered by the GTSN stations and this information will be transmitted back to the GTSN stations via the message channel. For example, information on major earthquakes occurring in South America would be passed back to GTSN stations located in South America. If it is not feasible to automate this procedure at the DRT, preliminary earthquake parameters will be obtained from NEIS and retransmitted to the GTSN stations. In this way, the real-time acquisition of seismic data will be of direct benefit to the participating stations.

The DRT is conceived as a dedicated facility at ASL. Major components will include an earth terminal for satellite data acquisition, a dedicated computer with disk drives, tape drives, and terminals, and an uninterruptible power system with a standby generator. Hardware redundancy will be needed so that the functions of the DRT can continue if there are failures and during routine maintenance. The DRT could be manned on a 24-hour basis if this proves to be desirable.

5. SITE DEVELOPMENT

5.1 Site Selection

The selection of countries asked to participate will be based on achieving a network configuration that will best meet the scientific objectives of the program. Other important factors include access to the INTELSAT system and the presence of a cooperating organization. Initial contacts will be made through diplomatic channels. When agreements in principle have been reached, the USGS will work directly with the cooperating organization to establish a formal working relationship and to plan for site selection and preparation. Under the terms of a typical agreement, after a mutually agreeable site has been selected, the USGS will prepare the site using local contractors, train station operators, establish the necessary communication links, furnish and install the instrumentation. When the station is operational, the USGS will provide operating supplies, replacement parts, and periodic on-site maintenance support. The host organization will assist in site development and installation, then operate the station and provide site-recorded data to the USGS for copying on request.

The selection of a general area for the station within the host country will be influenced by communication requirements, location of existing seismological facilities, and expected background levels (proximity to coast, cities, and other major noise sources). Ideally, the latter will be the most important factor, but this may not always be the case. If satellite earth terminals are used at the station, communications will not be an important factor in site selection. However, if it is necessary to use INTELSAT earth stations, the location of the existing earth station will become the dominant factor in siting the seismic station.

In any case, the station site will have to be accessible by road to heavy drilling equipment, and line power must be available to operate the instruments and support personnel requirements. Ideally, the GTSN station will be located at or very near an existing seismological observatory as this will preclude the need for a separate (and possibly expensive) operation by the host organization. The manpower required to routinely service a GTSN station is not likely to exceed an hour per day. However, the station should be serviced every day of the week, so a separate facility may have to be staffed by at least two personnel. The system will be designed so that all but the on-site recording equipment can be operated remotely. This will permit some flexibility in siting the borehole if existing facilities are not located at a quiet site. A telemetry link could be installed between the borehole and the recording site.

During the initial site survey by USGS personnel and the contractor performing the communications study, feasible sites for the station will be identified with the help of the host organization. Topographic maps, geologic maps, weather data, and other pertinent information concerning the prospective sites will be collected. Seismic site testing will be performed before a final decision is made on the specific site for the borehole. The site test equipment will be designed for recording and analysis of seismic background noise in the band from .1 to 50 Hz. The equipment will consist of vertical and horizontal component seismometers, two digital recorders, two analog recorders, and a portable minicomputer. Two sites can be monitored simultaneously, with the recorders programmed to turn on and off at specified intervals. One field system could be used as a control while the second is moved each day. The analog records will be used simply to select appropriate non-event periods for analysis. The digital data, which are recorded on cassettes, will be read into the computer for processing. Power spectral density estimates for the entire band and RMS amplitudes for selected subbands will be computed by the field team so that noise level differences between the tested sites can be determined in the field. Seismic data recorded at nearby observatories will be analyzed as well, in order to estimate seasonal variations in microseismic levels.

The station location will be chosen after considering the results of the communications study, recommendations of the host organization, problems related to land acquisition, and the results of the seismic field survey. The choice of a specific borehole site will depend upon depth of overburden, proximity to power, topography, geology, and security.

5.2 Site Preparation

The facilities required at each station will include the borehole, a shelter for the uphole digital system, a concrete pad and possibly shelter for the remote earth terminal, and a separate shelter for the power system. At some stations the recording equipment may be installed in existing buildings; otherwise, a building will have to be constructed for this purpose. If the GTSN station is remote from other host facilities, it may be necessary to construct housing for the operators and guards. A specific site plan will be developed for each station after the site has been chosen.

The borehole requirements will be identical at all stations. The hole will be drilled to a depth of at least 100 meters in rock (discounting overburden), cased, cemented, and plugged at the bottom. The borehole specifications may depend on the type of seismometer selected for the program. Borehole preparation is the first, and generally most difficult, part of site preparation. The difficulty is not so much in the drilling but in locating and contracting for a competent driller and in getting the rig to the site. These problems caused delays in the SRO program because different drillers had to be found for each site. A study may show that it is possible and cost effective to contract with a single firm for all of the holes

The uphole digital system and the remote earth terminal (or other data link terminal) will be located adjacent to the borehole. This equipment will not require servicing unless there is a component failure. A small underground vault, perhaps concentric with the top of the borehole, might be appropriate for the electronics as it will provide good protection and environmental control without the need for air conditioning. The earth terminal antenna will be mounted on a concrete pad near the wellhead. It may be necessary to enclose the antenna in a plastic dome at sites where snow and ice are expected.

The power system will require a well-ventilated, heated (in winter) surface shelter approximately 250 square feet in size. The building will be separated into two rooms, one for the batteries, charger, and regulator, and one for the auxiliary generator and its fuel. If the borehole site and the recording system are separated by a telemetry link, two power systems of smaller capacity will be needed, one at each site.

The recording system can be installed in an air-conditioned room about 250 square feet in size. A separate room of equal dimensions would be adequate for workspace and storage. The recording system might be separated from the borehole by hardwire or telemetry, and in some cases it is likely that this equipment can be installed in an existing building. If the recording system is operated at the borehole site, the housing for the recording system and the power system will be combined. It may be necessary to construct additional space and provide utilities to support station personnel.

Security will be considered when the site plan is developed. The borehole site will be fenced and guard quarters will be provided if this is recommended by the host organization. A complete station compound could be built in an area of about 100' by 100', although additional land may be desirable to prevent encroachment.

Station facilities, with the possible exception of the borehole, will be constructed by local contractors. Experience has shown that direct contracting with foreign contractors often results in difficulties, delays, and added cost because of contracting procedures. For example. normal U.S. Government procedures require foreign contractors to sign a disclosure agreement, which they may not be willing to sign. A practical alternative to direct contracting is for the host organization to arrange and monitor facility construction using grant funds provided by the USGS through the U.S. Embassy.

6. PROTOTYPE TEST AND EVALUATION

The development phase of the GTSN program will include the test and evaluation of a prototype field system, the test and evaluation of the data receiving terminal, and the evaluation of a demonstration system, which will be installed at one of the sites in the proposed list of stations. These activities will serve several purposes: one objective will be validation of system design; a second objective will be system integration, as there may be several contractors involved in manufacture; a third objective will be to provide USGS technicians with training; and a fourth objective will be to test and document site preparation, installation, operation, and support procedures.

During the production of the prototype field systems and the data receiving terminal, the USGS and contractors will jointly prepare a detailed plan to validate system performance characteristics and the compatibility of major components. The USGS will design and construct the necessary facilities at ASL to house the prototype field system and DRT. A small building will be needed near the ASL boreholes for the prototype system with sufficient space for personnel training. A separate building will be required to house the DRT. The equipment will be installed by contractor personnel and they will participate in the testing and evaluation. If an earth terminal is delivered with the prototype field system, it may be possible to exercise the communication equipment using a domestic satellite or the Pacific INTELSAT satellite; otherwise, it will be necessary to simulate the satellite communication link in order to test the functional compatibility of the field system and DRT. Preliminary system documentation accompanying the prototype system and DRT will be evaluated. The USGS and contractors will jointly draft installation, field test, calibration, and operation procedures, and the procedures will be tested and documented.

Following prototype test and acceptance, the system contractor(s) will provide training in depth for USGS and contract technicians who will install and service the GTSN systems. Similarly, the DRT contractor will provide USGS personnel with comprehensive training in the software, operation, and maintenance of the DRT.

The second prototype field system will be installed at the demonstration site. Prior to installation, the site will have been prepared and two station operators from the site will have completed the first training program for station personnel. The purpose of the demonstration is to validate site preparation procedures, shipping procedures, installation procedures, training, adequacy of support equipment, and the satellite communication link. System contractors may participate in the installation and test of the demonstration system.

The installation and evaluation of the demonstration system will complete the development phase of the program. The original prototype field system will remain at the Albuquerque Seismological Laboratory. It will be used for training and for testing software and hardware modifications, repaired components, and changes in operational procedures.

7. NETWORK DEPLOYMENT AND SUPPORT

One or two technicians, selected by the host organization, will be brought to the Albuquerque Seismological Laboratory for familiarization training. The prototype system will be the principal training aid, but the trainees will also become familiar with operations at both the DRT and NEIS. A secondary, but important, objective of the familiarization program is to establish personal relationships between the station operators and the personnel at Albuquerque who are responsible for network support and DRT operations. A more intensive training program will be conducted at the station just subsequent to the installation of the field system. The station operators will be provided detailed instructions in the use of test equipment, fault isolation, module replacement, and routine GTSN station operations and maintenance.

Heavy equipment, such as the winch, antenna, and power system, will be shipped to each station site via surface transportation while the site is being prepared. When work at the site is completed, the site will be inspected by a USGS representative to insure that it is ready for the installation team. If possible, the seismometer holelock will be installed and oriented during the inspection visit. The seismometer and system electronics will be shipped by air to the station shortly before installation. The host organization and U.S. Embassy will assist in planning and meeting the shipment so that delays in customs can be avoided.

The installation team will proceed to the station after confirmation is received that the equipment has arrived in good order. The team will probably consist of two technicians, although it may be necessary to include a communication specialist as a third member of the team to install and test the satellite communication equipment. The team will be assisted on site by station personnel. The installation of the equipment at a station is expected to take about 4 weeks. The procedures will have been documented in a detailed checklist and the completed checklist will become part of the installation report. Final testing and operation of the station will be coordinated with the DRT to insure that the link is functioning properly and that data quality meets expectations.

Each station will be furnished with one year of operating supplies, test equipment, and critical spare components. The list of station spares will be based initially on recommendations of the manufacturers but modified as operational experience dictates. Diagnostic trouble shooting and repairs at the station will be coordinated with the Albuquerque Laboratory (unless there is a failure in communications). Routine tests, adjustments, or changes in operating parameters will be reported as well. These will be limited to the recording system.

Defective components will be returned to the Albuquerque Laboratory, where they will be repaired or returned to the manufacturer for repair. The Laboratory will stock a complete supply of system components, including a borehole seismometer ready for shipment. The prototype system will be available for testing repaired components, for simulating unusual equipment or software malfunctions, and for testing hardware and software modifications before they are implemented at the stations.

A U.S. technician will be sent to any station that requires his assistance. At least during the early phase of network operation, several technicians will remain in the field visiting each station periodically and available on very short notice for emergency visits. Such close support may not be needed after the equipment burns in and the station operators become experienced, especially in view of the close communication that will exist between the stations and the Albuquerque Laboratory. However, certain types of maintenance, such as communications equipment or seismometer replacement, will still require on-site assistance by U.S. technicians.

8. PROGRAM PLANNING

The GTSN program can be divided into three phases: (I) system development and validation, (II) network deployment, and (III) network operation. Only the first phase will be considered here, although clearly the three phases will overlap in time. The first phase will include planning, data system development, and the installation and evaluation of one of the field systems at a foreign site to demonstrate and validate the GTSN concept. Phase I could be completed in three years, about one year for communication and design studies and development of the procurement packages, about one year for design and assembly of the prototype field systems and data receiving terminal, and about one year for installation, test, and documentation. However, the program schedule is expected to be strongly influenced by the availability of funds.

A flow chart illustrating the relationship of major program tasks is shown in Figure 4. Flow charts of anticipated task activities are shown in Figures 5 through 12. They represent a first cut in program organization and will certainly be subject to modifications as plans are more fully developed. The selection of contractual arrangements will be one of the important early management decisions and will influence the relationships of task activities to some extent. The use of a single prime contractor for data system development and manufacture, and perhaps site preparation and installation as well, would significantly reduce the USGS workload in technical and adminstrative management. However, it may be more cost effective to contract separately for the seismometer system, the surface system, and the data receiving terminal, and use USGS contract technicians for installation. In either case, the communications study will be contracted separately (because of scheduling), and the USGS will perform all test and evaluation studies.

Communications network planning is a critical element in the program schedule. Until the decision is made concerning the use of remote earth terminals vs. INTELSAT earth stations, it will not be possible to initiate site testing or complete development specifications for the field system.

The only major decisions foreseen in data system development involve the selection of the seismometer and possible use of a high resolution encoder.

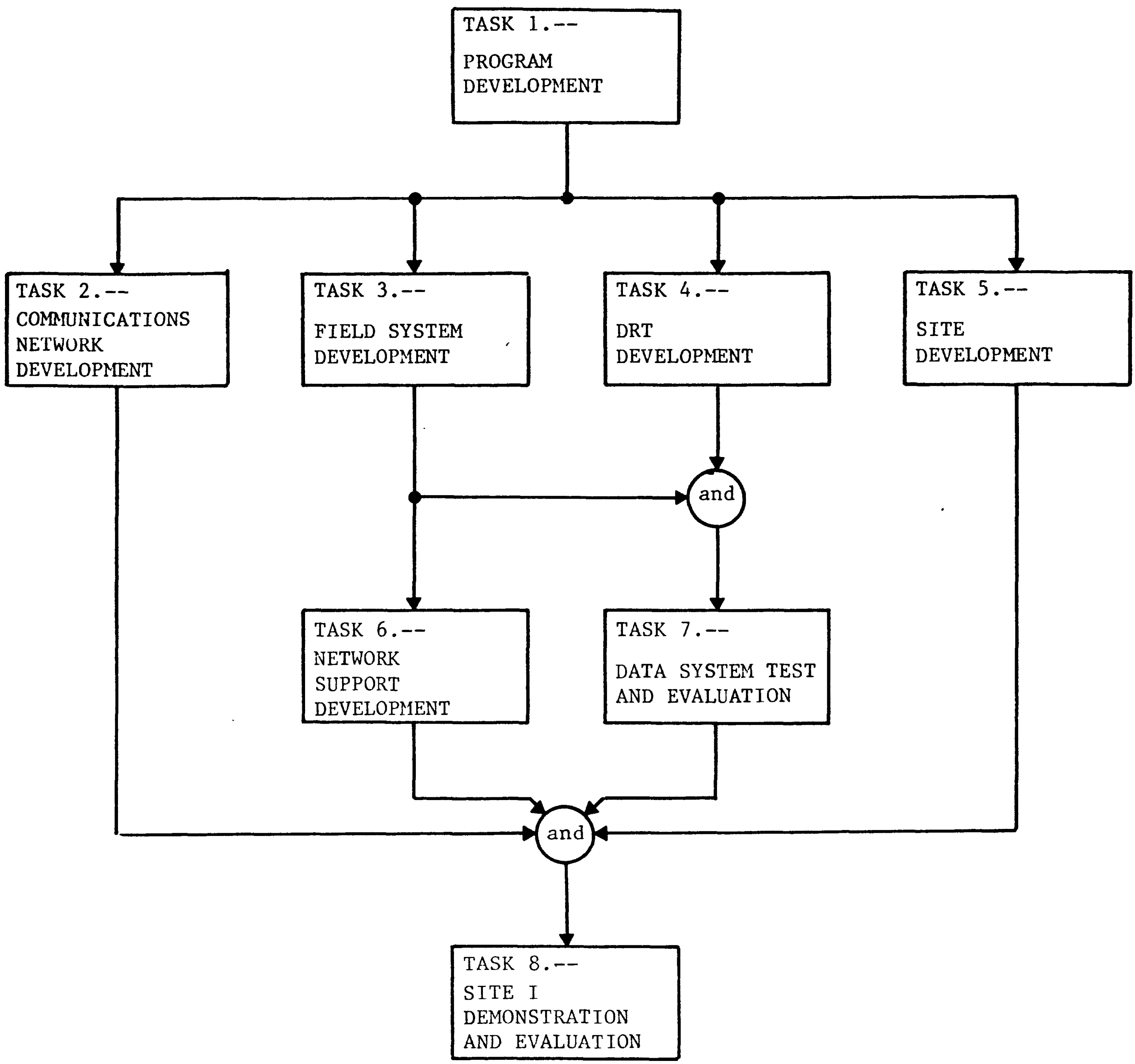

Figure 4.-- Flow chart of key activities during Phase 1.

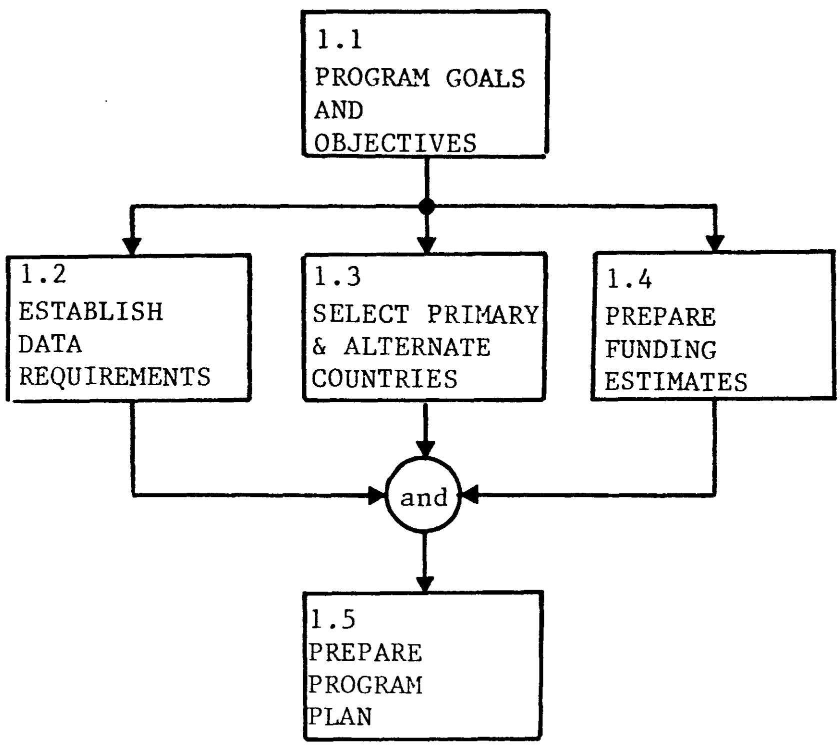

Figure 5.--Flow chart of Task 1 activities.

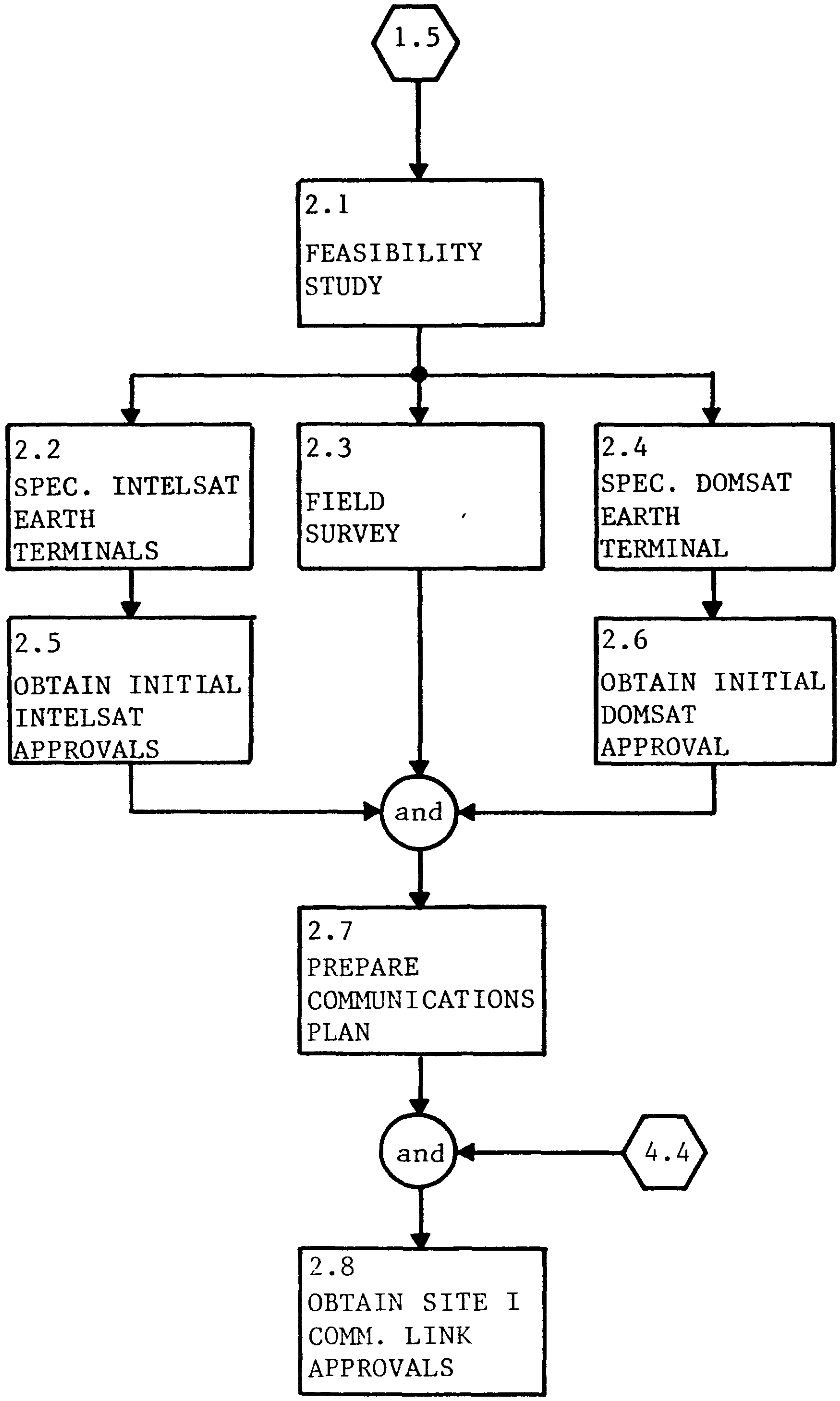

Figure 6.--Flow chart of Task 2 activities.

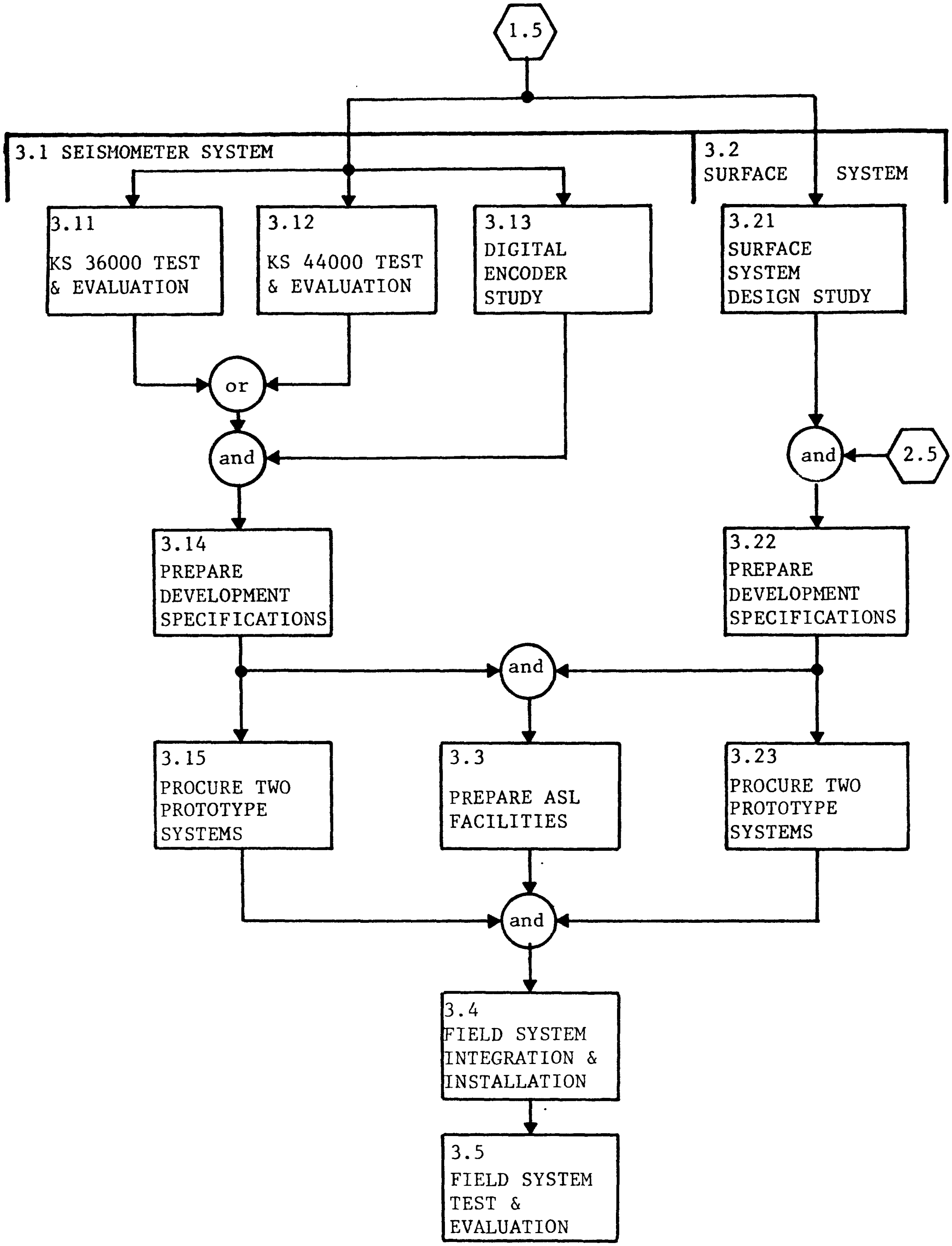

Figure 7.--Flow chart of Task 3 activities.

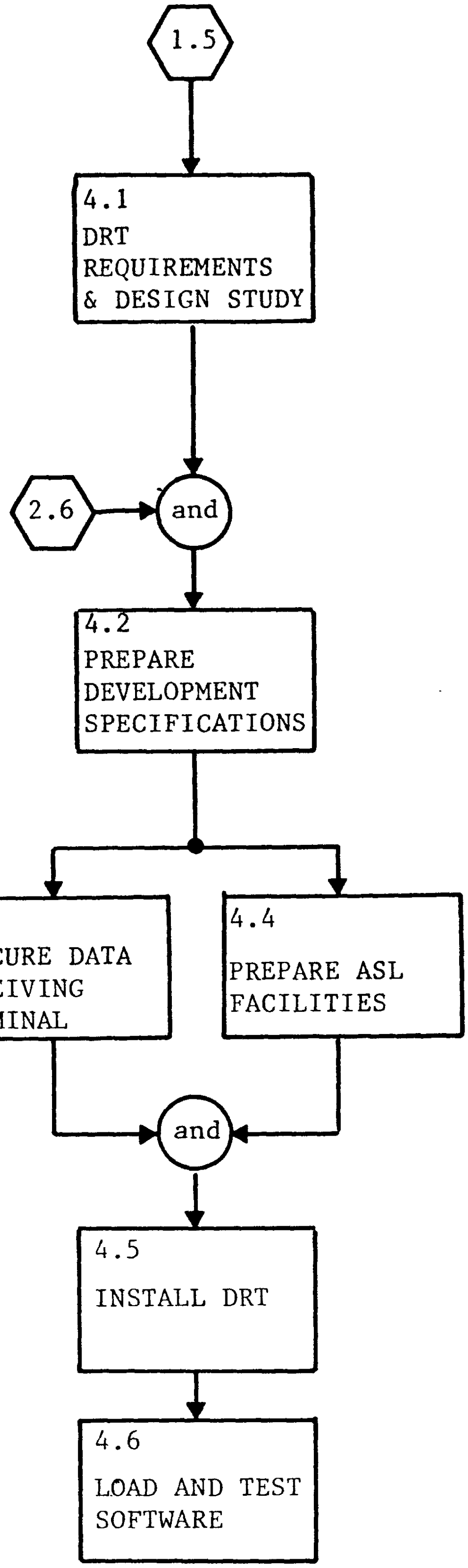

Figure 8.--Flow chart of Task 4 activities.

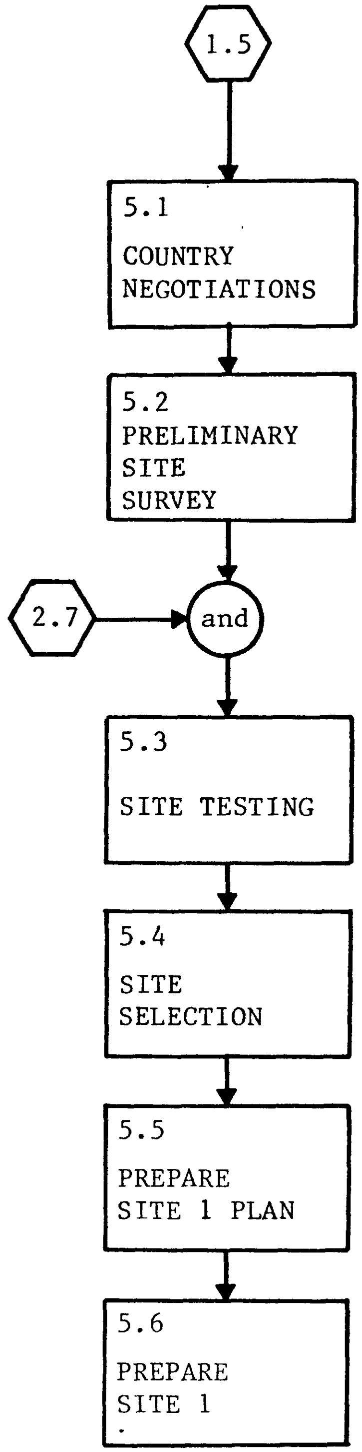

Figure 9.--Flow chart of Task 5 activities.

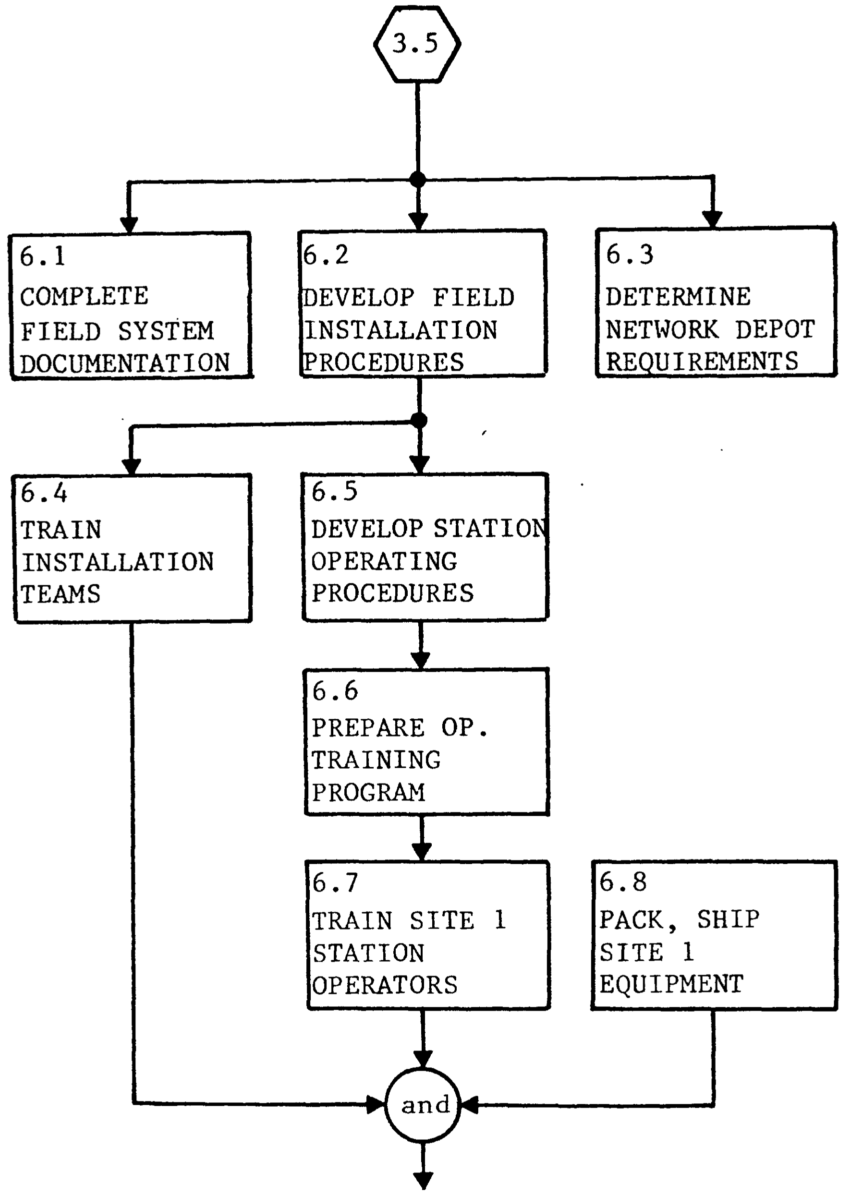

Figure 10.--Flow chart of Task 6 activities.

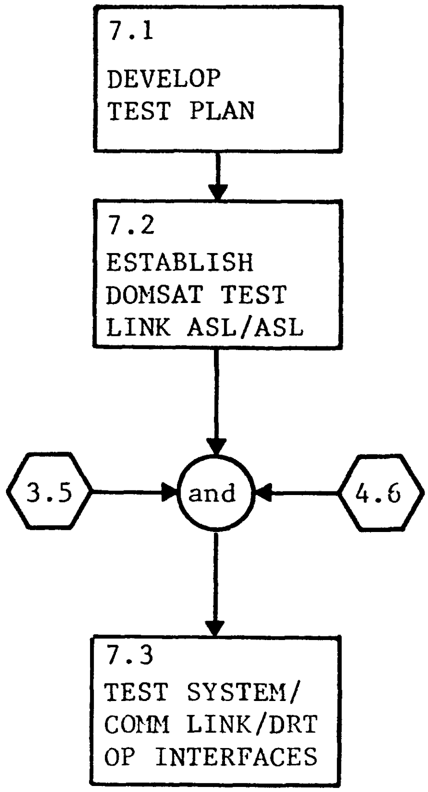

Figure 11.--Flow chart of Task 7 activities.

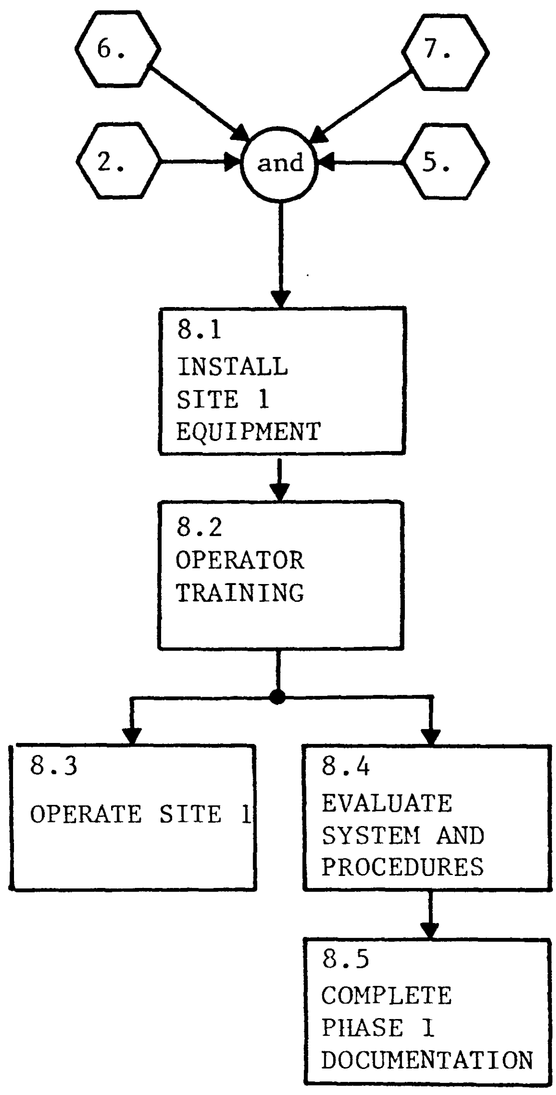

Figure 12.--Flow chart of Task 8 activities.

Although there will be many decisions to be made while defining and developing the surface system and data receiving terminal, neither system is considered to be a particularly high-risk development; hence, the scheduling should not be difficult to manage.

Site development, on the other hand, is certain to present unforeseen challenges in program management and should be initiated as soon as possible. The negotiation of formal agreements and communication link approvals are both subject to bureaucratic delays and, hence, very difficult to schedule. Generally, the only effective way of maintaining progress in negotiations, and site preparation when that stage is reached, is to plan for frequent follow-up visits to the site by USGS or contractor representatives.

Much of the preparation for the deployment of the entire network will take place during Phase I. Site development and the establishment of communication links at all the sites will parallel the preparation activities for the demonstation site. The first production system should become available six months after acceptance of the prototypes, with subsequent units produced at a rate of one per month. With two installation teams deployed, the GTSN could be fully operational within two years following the completion of Phase I.