DOE Program on Seismic Characterization for Regions of Interest to CTBT Monitoring

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ABSTRACT

The November 1993 transfer of responsibility to the Department of Energy (DOE) for part of the Defense Department's research in support of a Comprehensive Test Ban Treaty (CTBT) has led to a significant reorientation of the DOE seismic research effort, with significant new efforts on Geophysical Characterization of the Middle East-North Africa (ME-NA) and Southern Asia (SA) regions, respectively guided by Lawrence Livermore National Laboratory (LLNL) and Los Alamos National Laboratory (LANL). These programs will provide detailed regional calibrations that can be used to improve seismic phase identification, association, event location and event identification. Parameters and other information generated by these efforts will be incorporated into the knowledge bases of the Prototype National Data Center (PNDC) operated by the Air Force Technical Applications Center (AFTAC), and the Prototype International Data Center (PIDC) being developed by the Advanced Research Projects Agency (ARPA).

Knowledge required for improved automated data processing by the PNDC and PIDC includes detailed, region-specific parameter sets related to traveltime, attenuation and frequency content of the various seismic phases that record at regional distances, plus information on seismicity, location and blasting practices of operating mines, structure of the lithosphere, topography and other data. For stations of the primary CTBT monitoring network, this information will be path-specific, with calibration parameters determined for the receiver sites, the source-receiver paths to potential source areas around the station, and the source areas. Insofar as possible these data will be formatted for direct incorporation into the knowledge base system of the data centers.

The DOE approach to characterization of the ME-NA and SA regions will be evolutionary -- initially building on the geophysical literature and experience that is being acquired during the current Conference on Disarmament, Group of Scientific Experts Third Technical Test (GSETT-3), then developing geophysical models to predict observables (traveltimes, amplitudes, etc.), checking the predictions against observations in the areas of interest, and fine-tuning this procedure as needed to produce an accurate knowledge base for the region. Both efforts, but in particular that of LLNL, will be aided by an external research program consisting of contracts with universities and industrial research groups. Deliverables on these contracts will be primarily in the form of scientific reports and/or waveform data sets -- LLNL and LANL will act as *integrators,* collecting region-specific data from the contractors and using the data to prepare input for the PNDC and PIDC knowledge base systems. Updates of the knowledge bases will occur through periodic synthesis of the results of network operations and investigation of "special events" or outliers -- events that fail to locate or discriminate during routine processing. The program is also intended to generate a prescription for calibrating other regions with which the U.S. has had little or no previous monitoring experience.

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Key words: Seismic, regional, characterization, Middle East, North Africa, Southern Asia, DOE

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Introduction

The primary goal of the DOE programs on Geophysical Characterization of 1) the Middle East and North Africa (ME-NA) and 2) Southern Asia (SA) is to provide the Air Force Technical Applications Center (AFTAC) with the analytic tools and knowledge base to permit effective verification of Comprehensive Test Ban Treaty (CTBT) compliance in those regions. The program also aims at using these regionalizations as models for the development of a detailed prescription for seismic calibration and knowledge base compilation in areas where the U.S. has had little or no previous monitoring experience.

For automated data processing systems of the Prototype National Data Center (PNDC, operated by AFTAC) and the Prototype International Data Center (PIDC, operated by ARPA) to be effective, a knowledge base is needed that contains specific information to calibrate the seismic analysis procedures -- *phase detection, phase identification, association, location (including depth determination) and identification.* Because CTBT monitoring will focus on small seismic events, often detected by only a few stations at regional distance ranges, U.S. capability to effectively monitor the treaty will depend critically upon accurate information on the velocity structure, scattering, attenuation and wave blockage of the earth's crust and upper mantle in regions of interest, as well as knowledge of the signal characteristics of different types of events (earthquakes, mine explosions, small decoupled nuclear tests, mine tremors, rockbursts, etc.).

In any given region, the CTBT seismic monitoring system will depend heavily on a few key arrays and/or three-component stations, and it will be important to know as much as possible about the physical properties of the earth's crust and upper mantle: 1) in the vicinity of these stations, 2) in areas of potential earthquake activity or commercial blasting in the region containing the stations, and 3) along the propagation path from the sources to the stations. To be able to discriminate between various source types, we will also need to know how well the various event characterization techniques perform when they are transported from one tectonic or geologic environment to another.

The Department of Energy's CTBT R&D program plan (DOE, 1994), which includes the ME-NA and SA characterization programs, incorporates an iterative process that combines field experiments, computer modeling and data analysis for the development, testing, evaluation and modification of data processing algorithms as appropriate to achieve specific U.S. monitoring objectives. This process will be applied to seismic event detection, location and identification.

An external research program to support and complement these tasks has been funded by DOE, using the Air Force Phillips Laboratory (PL) as its contracting agent. Through a Broad Agency Announcement in June 1994 PL advertised the research areas of interest to the ME-NA and SA programs, and in November 1994 a number of proposals were selected for funding. Under the current plan, LLNL and LANL will be responsible for integrating results of the ME-NA and SA research programs, respectively, into algorithms for the PNDC system and parameter sets to be installed in the PNDC and PIDC knowledge bases.

Regional Calibration Data Needed by the PNDC and PIDC

The PNDC will require specific types of regional calibration data for areas of particular monitoring concern, and AFTAC desires that the data be in formats that will be appropriate for direct incorporation into the Knowledge Base System of the PNDC. The types of data required, illustrated in Table 1, will also be needed by the PIDC.

For ***phase detection and phase identification*** the system will need information on the phase velocity and frequency content of regional and teleseismic signals from events in areas of interest, together with information on seismic propagation characteristics for various azimuth and distance ranges around primary and key secondary stations.

Phase Detection/Identification	Association	Location	Identification
Sta. Noise	Traveltime curves	Traveltime corrections	mb, Ms corr'ns
Inst. Calibration	Azimuth	Expected phases	Topography
Beam Settings	Amplitude	Earth model	Regional tectonics
Filter Modes	Det. Probability	Lithosph. structure	Seismicity
Detection threshold		Reference events	Mine loc'ns
Phase velocity, freq			Reference events
Attenuation, scattering, phase blockage			Expected frequency content
			Expected amplitude ratio

Table 1. Examples of information needed by the PNDC and the PIDC for phase detection, phase identification, association and event location, and by the PNDC for event identification.

COUNTRY	ALG	EGP	IRN	IRQ	ISR	JRD	KWT	LBN	LIB	MRC	ARB	SYR	TUN	TRK	YMN
TRAVELTIME CURVES			BFI		B	B			L	B	BI	B		FI	
DEPTH TO BASEMENT		B	■	■	■	■	■	■		B	■	■			
DEPTH TO MOHO		■	BF	B	B	B	B	B	L	■	BI	B	B	F	
STRUCTURE			AFJ		D				L	■				AFJ	
SP ATTENUATION			A								I			AJ	
Lg, LP ATTENUATION		H	H		H	H	H	H	L	H	■ HI	H	H	H	
EQ CATALOG	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
GAMMA DATA		E			BD	BE		B	L	■		B		E	B
GEOLOGY/TECTONICS	B	B	B	B	B	B	B	B	BL	B	B	B	B	B	B
TOPOGRAPHY	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
GRAVITY	B	B	B	B	B	B	B	B	L	B	B	B	B		
LANDSAT IMAGERY	B			B	B			B		B		B	B		
M-T FOCAL MECH.	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B
DISCRIMINATION		CG	A		CDG	CG				CG	CG			ACG	
MINE LOCATIONS	▼	E	▼	K	E	BE			▼	BE	BE	BE			

Table 2. Expected data products from the ME-NA Characterization external program. Key to contractor designations is given below. Country designations: ALG -- Algeria, EGP -- Egypt, IRN -- Iran, IRQ -- Iraq, ISR -- Israel, JRD -- Jordan, KWT -- Kuwait, LBN -- Lebanon, LIB -- Libya, MRC -- Morocco, ARB -- Saudi Arabia, SYR -- Syria, TUN -- Tunisia, TRK -- Turkey, YMN -- Yemen. "GAMMA DATA" -- waveform or bulletin data from local and/or national networks.

■	Cornell U. (Barazangi)	Cornell U. GIS already contains this information
▼	U.S. Bureau of Mines	Survey of Mining Activity in Algeria and Libya - completed
A	Cambridge U. (Priestley)	Lithospheric Structure and Discrimination in MidEast
B	Cornell U. (Barazangi)	Geophysical Information System for ME-NA
C	ENSCO (Baumgardt)	Transportability of Regional Discriminants
D	IPRG (Shapira)	Discrimination Using the Israeli Seismic Network
E	Multimax (Grant)	Ground-Truth Database for Identification Research
F	New Mexico (Ni)	Regional Propagation in ME and Southern Asia
G	Radix (Pulli)	Transportable Seismic Discriminants
H	St. Louis U. (Mitchell)	Efficiency of Regional Wave Propagation in ME
I	UC San Diego (Berger)	Broadband Seismic Field Study of the Arabian Shield
J	UC Santa Cruz (Rogers)	Waveguide Effects on Broadband Signals in ME
K	U.S. Bureau of Mines	Survey of Mining Activity in Iran and Iraq
L	U. Texas El Paso (Doser)	Lithospheric Structure of North Africa

Table 2. Expected data products from the ME-NA characterization external program. Key to contractor designations is given below the table. Country designations are: ALG - Algeria; EGP - Egypt, IRN - Iran, IRQ - Iraq, ISR - Israel, JRD - Jordan, KWT - Kuwait, LBN - Lebanon, LIB - Libya, MRC - Morocco, ARB - Saudi Arabia, SYR - Syria, TUN - Tunisia, TRK - Turkey, YMN - Yemen. The term "GAMMA DATA" refers to waveform or bulletin data from local and/or national earthquake monitoring networks.

Association of detected arrivals with events will require a determination of the probability that a given station detected a particular event, and this in turn will depend on the event size, station noise level at various frequencies, and attenuation of regional seismic phases for particular source-receiver paths. To make such a determination requires knowledge of scattering, attenuation and blockage of particular phases due to structure along the path. Association will also require detailed knowledge of regional and teleseismic traveltimes for particular source-receiver paths.

Accurate ***event location*** will be even more dependent on detailed knowledge of path-specific corrections to traveltimes and azimuths, and these should be empirically determined using "ground truth" data from local or national networks in the ME-NA region, or based on models of the lithosphere along particular source-receiver paths. A library of reference events will be useful for locating repeated events in mining districts or in known earthquake source areas.

Event identification will require most of the knowledge listed above, with particular importance attached to an accurate picture of attenuation of the various regional phases as a function of distance and frequency. In addition, information will be needed on source/spectral characteristics of earthquakes and explosions in the areas of interest, location of mines, seismicity, geologic/tectonic features. For most regions of the world, the signature to be expected from nuclear tests under various assumptions relative to coupling will have to be simulated by waveform modeling techniques. These techniques will be extrapolated from U.S. and Russian experience, based on an improved understanding of the dependence of seismic propagation parameters on regional structure and other properties to be defined under the various elements of this program. For earthquakes, mine explosions and mine collapses, a library of waveforms for known event types in the areas of interest will be invaluable to the discrimination process.

The reader should note that in the above listing there is a progression, in terms of amount and detail of the knowledge required, for succeeding stages of the data processing. It should also be noted that to the maximum extent possible, the PNDC and PIDC will need datasets in a form that can be directly incorporated into system knowledge bases -- e.g., tables of traveltime and amplitude corrections to standard curves, calculated for each of a large number of grid points distributed over a range of azimuths and distances around the station locations. It will be a primary goal of the LANL and LLNL programs to collect data -- from the literature, historic waveform archives, the PNDC and PIDC databases, local and regional networks in the ME-NA and SA regions, and from contractor reports and datasets -- to convert these data into the parameters needed for the knowledge bases of the PNDC and PIDC, and to deliver the parameter sets to AFTAC and ARPA. In many, or perhaps most cases this conversion will not be straightforward, but will require extensive data interpretation, modeling, testing and evaluation by Laboratory seismologists to insure that the parameters and algorithms delivered to AFTAC will actually improve AFTAC's capability to monitor the regions of interest.

Elements of the LLNL Research Program

The Middle East and North Africa (ME-NA) comprise a unique natural laboratory that will be exploited by LLNL for the development of a seismological knowledge base and new data processing algorithms needed by the PNDC and PIDC for improved phase identification, association, location and event discrimination. A major objective of the ME-NA program will be to demonstrate that over a relatively short period of time both the tools and the knowledge can be acquired for effective CTBT verification in a region that has not previously been a major focus of U.S. monitoring efforts.

Tectonically, the ME-NA region is as complex as any on earth, with major features including a stable platform (Arabian plate), sea-floor spreading (Red Sea, Gulf of Aden, Afar region, western Arabia), continental collision zone (Zagros Mountain fold belt), recent volcanism (western margin of Arabian plate), and transform faulting (Dead Sea, Anatolian fault zone in Turkey). Significant seismicity is observed in many of these zones, and mining activity is ubiquitous -- at least some

mining is conducted in most or all of the countries, and large explosions are regularly detonated in potash mines in Morocco, Jordan and Syria; in addition, numerous offshore explosions and earthquakes have been reported off the coast of Israel. Short-period earthquake monitoring networks are common to most of the countries and now include more than 300 stations for the whole ME-NA region. Some countries have deployed digital, broadband, wide dynamic-range stations at key locations. New regional seismic arrays have been or will be deployed at a number of sites within regional distance ranges from ME-NA seismic source areas, including arrays in Turkey, Egypt, Pakistan, Israel, Spain, Turkmenistan and the Caucausus. Taken together, the geophysical/tectonic features and the potentially excellent seismic coverage make this region ideal for research and experimentation aimed at developing methods and algorithms for network data processing, as well as a prescription for the timely acquisition of calibration information in other regions with which the U.S. has had little previous monitoring experience.

Figure 1 shows elements of the LLNL external program, with data collected from seismic stations and arrays in the ME-NA region being used for the extraction of data products, which are used in turn for research to improve location and identification of events recorded in that region. The data products will also be used to produce deliverables for the AFTAC knowledge base: improved velocity structure of the earth's crust and upper mantle in the ME-NA, improved traveltime curves for regional distance ranges, maps of seismicity, and tabulated estimates of background seismic noise at station sites. A second set of deliverables will consist of calibration parameters to improve event locations in the ME-NA region, and these locations will in turn be used in discrimination research to produce improved methods for event identification in the region. The collected data and data products will also be used for comparison with synthetic waveforms, developed to model regional wave propagation effects and source phenomenology.

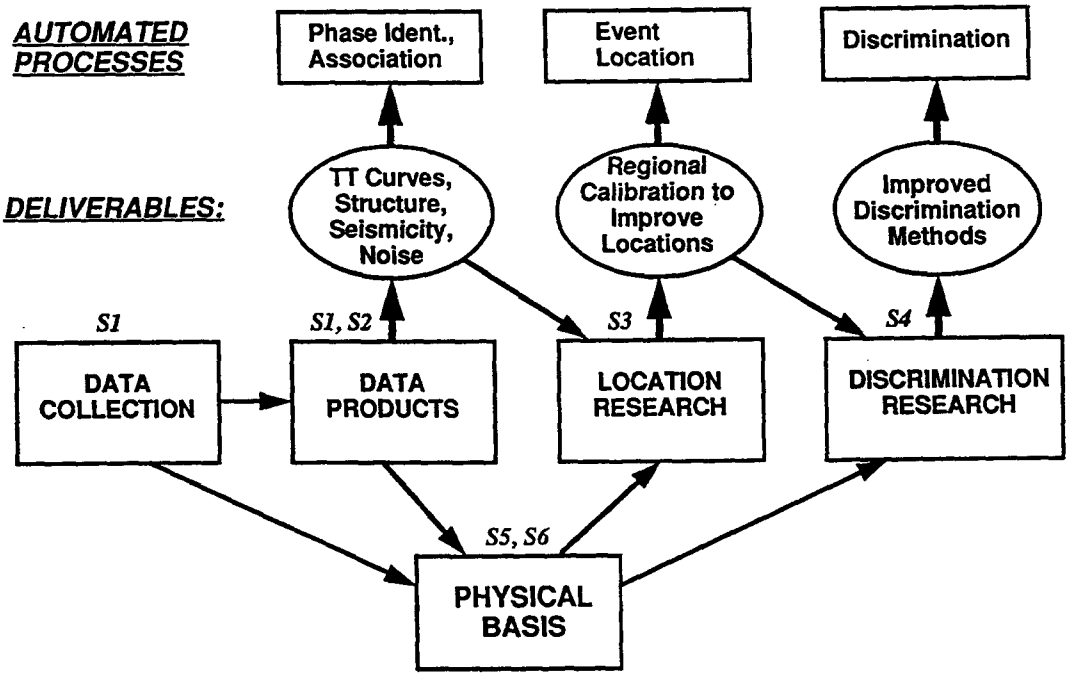

Figure 1. Elements of the LLNL *Middle East-North Africa Geophysical Characterization Program.* Labels *S1, S2...* correspond to designations in DOE R&D plan (DOE, 1994).

In the following sections we describe the individual contractor efforts in four of the eight task areas cited in the DOE R&D plan (DOE, 1994). Deliverables on these contracts are categorized in chart form in Table 2, above.

Data Collection (S1)

A key contract in the data collection element of the ME-NA program is the continuation with DOE support of Cornell University's effort to develop a Geophysical Information System (GIS) for the ME-NA region. The objective of the Cornell effort is to collect and organize seismological, geophysical and geological datasets for the ME-NA region. These datasets are incorporated into a digital information system that is accessible via the Internet, and can be used by the National and International Data Centers (PNDC, PIDC) and by other researchers in the nuclear monitoring research community. Previous work by the Cornell group produced digital datasets for Eurasia containing depth to Moho and to basement, crustal velocity and density structure, and other geophysical information and considerable progress has already been made in compiling a variety of datasets for Egypt, Iran, Iraq, Israel, Jordan, Syria, Lebanon and Saudi Arabia. All data are stored in Cornell's Arc/Info Geographic Information System (GIS). A comprehensive bibliography of all relevant references is maintained in a computer database. Preliminary versions of these databases are being released in different forms, including a Web page available over the Internet.

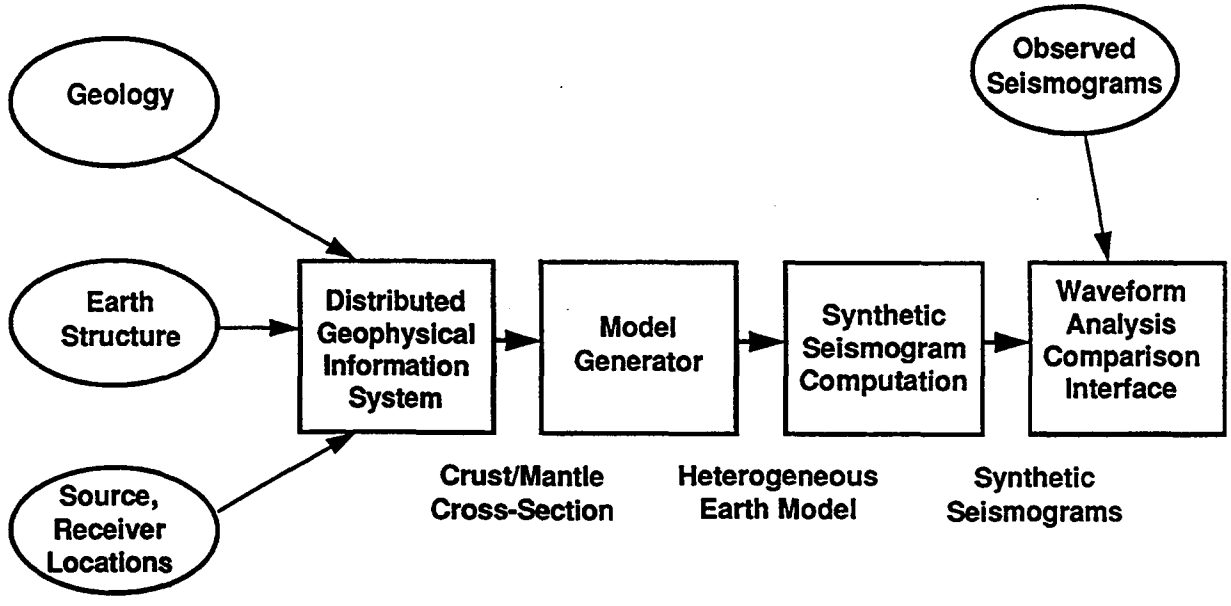

Figure 2. Geophysical information system, earth model generator and synthetic seismogram computation modules for characterizing seismic propagation paths

The Cornell GIS will be used in a distributed system, illustrated by Figure 2, in which tabulated information on geology, earth structure, seismicity and other information is accessed through the system. The system will also have the capability to generate crust-mantle cross-sections, and to synthesize heterogeneous earth models based on the cross-sections. The third block of the system shown on Figure 2 is a "user-friendly" environment for the generation of synthetic

seismograms. This module will be developed under a separate contract with S-Cubed, discussed below under task S5. Together, the GIS, model generator and synthetic seismogram computation programs will allow researchers to examine tradeoffs in structure as these tradeoffs affect seismic wave propagation. Synthetic seismograms generated by the system will be compared with actual recordings from the ME-NA region to validate or reject the structural models being tested.

A second project under the data collection element will be the compilation, by Multimax, Inc., of a "ground-truth" database (GTDB) for regional identification research. This effort will begin with the collection of in-country seismic bulletins, and other contractors will be contacted to determine the availability of older data from the Iranian Long-Period Array (ILPA) and other deployments. Later, as new arrays become operational in Turkey, Egypt, Pakistan and other ME-NA countries, continuous data from those arrays will be scanned to select "interesting" events from the viewpoint regional characterization and/or event identification research, and supplemental data will be requested from earthquake networks already operating in the region. Particular attention will be paid to the collection of ground truth data for source areas where, based on the GSETT and national earthquake bulletins, events tend to cluster -- e.g., repeated events in known mining districts, earthquake aftershock zones, etc. As the database is developed, it will be ported to an archive at LLNL, for use by Laboratory researchers for investigations to improve event location and identification capability. The data will also be accessible over the Internet to authorized researchers within the CTBT R&D Program.

Several other contracts in the ME-NA program are aimed at collecting data from that region. In a joint effort, the University of California San Diego (UCSD), Boise State University and King Saud University will undertake during the fall of 1995 a field program in Saudi Arabia. This experiment involves the deployment of six portable broadband seismic stations along three profiles on the Arabian Shield, for a recording period of about a year. During this period the team will collect a suite of broadband seismic waveform data and the associated parametric data describing the sources (event location, depth, magnitude and type) of events recorded by the field stations. Data will also be collected from other broadband stations operated by IRIS, GEOSCOPE and MEDNET in the ME-NA region. Most of the events recorded will be in tectonically active areas of Iran and Turkey to the northeast. The main objectives of the investigation will be to study seismic propagation, seismicity and crustal structure of the Arabian Shield, and to characterize potential sites for permanent seismic stations in the region. When archived at LLNL and combined with recordings of the same events from new arrays in Turkey, Egypt and possibly Pakistan, these data will be a valuable resource for studies to improve event location and discrimination capability. Supplementary information on at least some of the recorded events can be obtained from seismic bulletins distributed by various national networks in the region.

Under another contract, workers at the University of Texas El Paso will construct a model of the North African lithosphere, via an integrated analysis of seismic, potential field and geologic data. Particular emphasis in this research will be on the construction of two-dimensional models from known earthquake source regions to key seismic monitoring stations in the region. The principal investigators on this project have had over ten years' experience working in Libya, and have supervised a number of graduate thesis projects by Libyan students. An outgrowth of this effort will be a database of geological and geophysical information that will enhance the GIS development being pursued by Cornell University.

A project being conducted by Cambridge University is aimed at determining the structure of the Iranian Plateau, characterizing regional seismic propagation (in particular the amplitude and frequency characteristics of seismic phases Pn, Pg, Sn and Lg), and testing the effectiveness of regional discriminants for that region. The Cambridge group now operates three-component broadband digital seismic stations at six sites around the South Caspian Sea and in the republics of Turkmenistan and Azerbaijan, and these stations will be operated until the end of 1995.

Under a previous Department of Defense (DoD) contract, seismologists at the New Mexico State University (NMSU) initiated a study of the lithospheric structure of the Turkish-Iranian plateau, using Pn tomography, Sn attenuation and Lg propagation, and have published two papers describing

their results. During the next two years they will extend this study for DOE, to focus on amplitude measurements of regional phases and regionalization of seismic propagation characteristics for the Middle East and southern Asia. Data for these investigations will include data from an array (ILPA) operated in Iran during the 1970's (recordings of more than a hundred regional events are already on hand), the IRIS Caucausus Network (CNET), ten stations in Kyrgystan (KNET), the Chinese Digital Seismic Network (CDSN) and nine stations operated briefly in Pakistan (over 800 local and regional events were recorded). Data collected for this project will be accessible to LLNL and other nuclear monitoring researchers in CSS database format.

A contract with the geophysics group at St. Louis University has as its goal characterization of regional variations in attenuation of regional seismic phases across a broad region of the Middle East and southern Asia. This work will be complementary to the NMSU project just described, as it will be based initially on analysis of long-period (5-50 seconds) Rayleigh waves, primarily recorded at pairs of stations, to determine S-wave attenuation models for the earth's crust in regions of interest. With the velocity and S-wave attenuation models they will then use waveform synthesis to predict the ground motion of Lg and other phases. Similar to work done by this group for Eurasia, products of this research will include maps of shear-wave Q, Lg Q and Lg coda Q for the region from India to the eastern Mediterranean.

One additional contract with the U.S. Bureau of Mines, Minerals Availability Field Office (MAFO) is supported with LLNL discretionary funds. The MAFO group is drawing from numerous sources to identify active mining operations in Algeria, Iran, Iraq and Lybia, and to estimate probable amounts of explosives used in operations at those mines. Final reports on mining operations in Algeria and Lybia have been delivered to LLNL, and the reports on Iran and Iraq are due by September 1995.

Empirical Discriminants (S4)

While work in this area emphasizes the development and testing of discriminants, rather than regional characterization *per se*, the contractors will be developing software tools for automatically extracting "features" from the data and for comparing those features and discriminants based on them (amplitude and spectral ratios, etc.) with features and discriminants predicted from theoretical modeling. For example, under a key DOE-funded effort ENSCO, Inc. will implement its Intelligent Seismic Event Identification System (ISEIS) at LLNL, and will work with Laboratory staff to test and improve this system as a tool to study regional waveform discriminants. ISEIS, developed under DoD support and used by ENSCO to test the portability of regional discriminants, has expert system capabilities as well as interactive features that permit it to be used as a testbed for the development of both rule-based and case-based event identification procedures.

A second discrimination research project by Radix, Inc. will utilize existing GTDB's for northern Europe as well as new GTDB's for the western U.S. and the ME-NA region to test a new cross-band spectral discriminant. The contractor will also work on optimizing feature extraction from seismic data with the goal of reducing discriminant variance from region to region, and thereby reducing the necessity of compiling GTDB's in regions that are relatively uncalibrated.

A contract with the Institute for Petroleum Research in Geophysics (IPRG) in Israel will focus on discrimination of seismic sources using the Israeli seismic network. This project will also provide nuclear monitoring researchers access to data from the Israel Seismic Monitoring Systems.

An effort by the University of California Santa Cruz (UCSC) will focus on the partitioning of seismic energy between the various regional phases as a function of crustal structure. This work will utilize new data from broadband stations in the ME-NA region as well as older data from the Iranian Long-Period Array (ILPA). This study will be a follow-on effort to work already completed for the Iranian region by UCSC.

Physical Basis for Regional Propagation and Discrimination (S5, S6)

It is anticipated that the LLNL research staff will provide most of the effort to develop models leading to a better physical understanding of regional propagation effects, factors that affect event location and discrimination, and the behavior of particular discriminants in different geologic or tectonic environments. A few of the DOE-supported contracts have been selected for their potential to fill in gaps in the program, and in one case to add new software tools to those now available for the modeling effort. In the latter case, a contract with S-Cubed, Inc., is for the development of a user-friendly interface for the efficient computation of synthetic waveforms, and for the archiving and retrieval of a library of syntheticwaveforms that can be used to test various concepts related to the regional characterization effort. The contractor will also investigate effects due to scattering and lateral heterogeneity in the crust and upper mantle -- both important for accurate event location and identification. The software developed under this contract, as well as synthetic waveforms for a wide range of source and path conditions, will be extremely useful to the LLNL staff in comparing the observed behavior of seismic signals in the ME-NA region with effects predicted from theoretical considerations, based in turn on earth models obtained from various sources -- published literature, surface-wave dispersion, field experiments, etc.

Elements of the Los Alamos Regional Characterization Research Program

To better integrate all CTBT Seismic R&D tasks, LANL has chosen to perform onsite most of the tasks related to characterization of the southern Asia region, using the regionalization effort as the primary data collection, processing and preliminary interpretation task for the Southern Asia region. Like LLNL, LANL's regional characterization task will be striving to fill in all of the needs of the KBS for Southern Asia (seismic, geophysical, geological, and cultural databases and models). We have begun with China and will be expanding to the area South of China and Mongolia late in FY 1996.

To assist with primary seismic data collection, processing and interpretation, LANL has let the following subcontracts to universities for support analyses of seismic data

1) University of South Carolina - Acquisition and analysis of data from the PASCAL deployment across central Tibet.

2) University of Arizona - Seismicity in the Region around the Lop Nor Test Site. This project involves obtaining seismicity catalogs from the State Seismological Bureau in Urumuqi to identify pockets of seismicity that may be associated with mine activity. SPOT photos will then be used to locate the mines and triggered IRIS data from WMQ will be obtained for mining explosions.

3) UC - Santa Cruz - Crustal and Lithospheric Structure in China: Waveguide Effects on Regional Phases Used in Nuclear Test Monitoring. Regional surface wave tomography will be conducted across China (having lateral resolution of 100 - 500 km). The velocity models will be combined with other geologic information to examine waveguide effects on regional phases used for seismic monitoring.

A larger contract was let to the US Geological Survey in Flagstaff, Arizona, to construct digital geologic maps (basement geology, surficial geology, and tectonic and structural features) of the Southern Asia region, beginning with China. These maps will serve as three of the GIS (Geographic Information System) planes for on-line source term analysis. Other GIS planes will include, among others, seismicity, topography, depth to Moho, depth to basement, mines and mineral deposits, Q, geographic information (roads, towns, etc.) and other seismic noise sources.

LANL is also conducting special studies on mining and blasting practices, explosions of interest, and tectonic/geologic features of interest (salt domes, soluble media layers, etc.). In addition, Los Alamos is exploring for an appropriate three-dimensional database management system to build

3-D models of various aspects of the geology, seismic parameters and ancillary information. Data generated at Los Alamos will soon be available to researchers in the program on a worldwide web server at Los Alamos. Access to this information will be through the future Sandia InfoWeb center.

A more detailed description of the initial LANL efforts on the regional characterization effort for Southern Asia can be found in the poster session "Regional Characterization of Western China" (this volume).

Discussion

Because monitoring small seismic events is essentially a regional problem, the DOE seismic characterization program will focus most of its effort on seismic monitoring at regional distance ranges, out to about 2,000 km. The program has begun with a literature search to obtain first-order regional traveltime and amplitude-distance relationships for the ME-NA and SA regions, with LANL and LLNL staff working with Cornell University and other DOE contractors to gather data and generate derivative products on a country-by-country basis. This search will result in a series of summary reports, and a computer database containing the references and key data (e.g., traveltime curves, amplitude-distance relationships, lithospheric models). Copies of national seismic bulletins are being requested from those countries that issue such bulletins, and these will be used, after consistency checking, as a source of ground truth information on event locations and, as a basis for requesting waveform data from national earthquake networks and the GSETT-3 global network. Reports and data products from contractors in the DOE external research program will be collected as they become available and integrated with information collected by the Laboratories. The research database that results from this process will be used to generate higher-order models of the lithosphere and improved knowledge of signal propagation in the regions of interest, and both the models and empirical data will be analyzed, compared and interpreted to produce specified parameter sets for incorporation into the knowledge bases of the PNDC and PIDC. This iterative process is illustrated by Figure 3 and described in more detail in the remainder of this section.

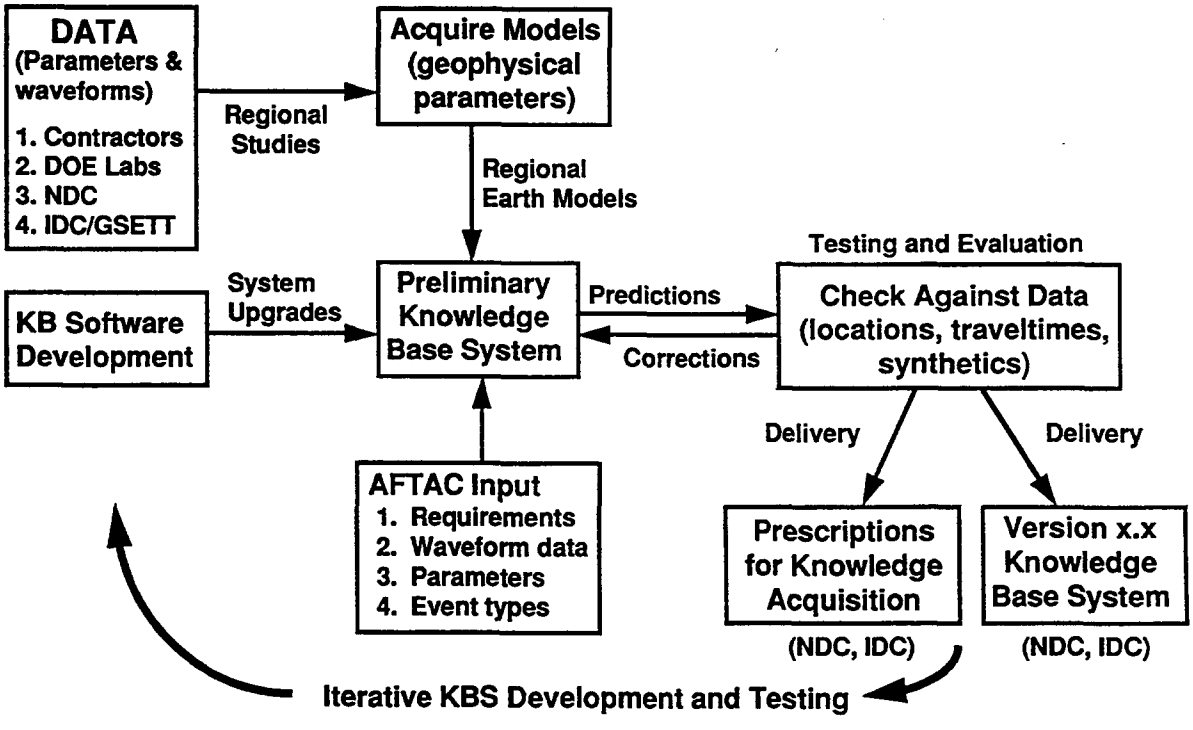

Figure 3. Elements of the DOE program for regional characterization and knowledge base system development, testing and evaluation.

Under the external research contracts described in previous sections of this report, U.S. seismologists will be collaborating with in-country scientists to develop models of the lithosphere, study attenuation of regional seismic waves, etc. In the course of these investigations it is anticipated that a considerable amount of data will be accumulated, including waveform data and information on chemical explosions and earthquake hypocenters determined by local and national networks. LLNL and LANL will be responsible for collecting this data, subjecting it to quality assurance procedures and archiving it in databases that will be used for detailed studies, e.g., of regional traveltime and amplitude corrections. As waveform data become available from the ME-NA and SA regions -- either data from arrays and stations of the GSETT-3 network or data that may in the future be supplied by local and regional earthquake monitoring networks in the region -- these data will be collected and archived in the research databases, including the Ground Truth Database for those events for which independent confirmation can be obtained on event location, depth and source type.

Within the Laboratories' internal research programs a number of additional investigations are planned or in progress that will complement and strengthen the regionalization effort. For example, field studies are under way in Nevada and Colorado that will lead to new insights into source characteristics of mine explosions and mine tremors. Theoretical waveform modeling calculations are being conducted to develop a better better understanding of the various types of sources (earthquakes, mine explosions, rockbursts, mine tremors) that may be observed in the regionsof interest, and to develop a comprehensive picture of tradeoffs between effects due to event type, depth, size, structure along the path, and other factors. Because it will not be possible to acquire data from most areas within the ME-NA or SA regions for direct application to the problem of identifying nuclear explosions in those areas, every effort is being made to save the information that is now available for nuclear tests conducted in Nevada and elsewhere, and to make those data available to the research community. Synthetic data may be the only means of evaluating nuclear explosion signals in structures typical of those in a particular region, and synthetic data will be generated under varying assumptions as to coupling, depth, source medium, etc.

As the various datasets are compiled, they will be interpreted by LANL and LLNL researchers in terms of the parameters needed for improved phase identification, association, event location and discrimination, and the parameter sets will be entered into the knowledge base of a testbed system being operated at the PNDC. Assessment of improvements in monitoring capability due to these parameters will be done by reanalysis of data for events with known location, magnitude and event type (i.e., events in the Ground Truth Database), using the testbed system with the new sets of corrections and other parameters. This process will be both evolutionary and iterative, with future updates to the knowledge base tied to results obtained during operation of the PNDC, as well as to results of investigations of "special events" (i.e., those events that fail to locate or discriminate during automated processing of the monitoring network data).

While developing and testing the corrections and other parameters needed by the automated processing systems, the DOE Laboratories will also have the opportunity to independently test and evaluate the algorithms used for the PNDC operations illustrated in Table 1, and will develop improved algorithms when new or revised procedures are needed to improve system performance. To avoid duplication of effort this development will build on experience that has been gained with the PNDC and the PIDC systems, and those technologies, datasets and formats that are found to perform satisfactorily and are technically sound will not be changed.

Within the DOE program the overall design of the KBS will be a responsibility of Sandia National Laboratory, but this design will be driven in large part by seismological considerations based on the regional characterization efforts of LANL and LLNL. The final knowledge base must contain traveltime corrections and other parameters that will be specific to regions of interest to CTBT monitoring, and in many cases specific to source-receiver paths around stations of the primary monitoring network and key stations of the secondary network. Parameters tabulated in the knowledge base must be appropriate for routine automated processing of network data, and must also be available for analyst-intensive work on "special" events. For efficient automated data processing the KBS will appear to the user as a hierarchical system containing global, regional and local

parameter sets, with the various algorithms incorporating "inheritance," in the sense that the local features inherit those of the regional model, and the regional parameters inherit features of the global model. Thus, lacking local corrections, automated data processing routines will default to the regional database, and if the latter do not exist global features will be used.

In all cases, the relationships between the performance of algorithms and the properties of the databases must be explicit and well understood. In addition, for the KBS and its datasets to be usable by AFTAC the algorithms and databases must be system-ready, thoroughly tested, and demonstrated to be effective for monitoring seismic events in the regions of interest. To accomplish these goals will require close coordination between all participants in this program -- the DOE Laboratory teams, the DOE contractors, AFTAC, ARPA and contractors involved in developing, testing and operating system components.

References

U.S. Department of Energy (1994). *Comprehensive Test Ban Treaty Research and Development FY95-96 Program Plan,* DOE/NN-0003, November 1994, 60 pp.

For a list of references on geophysics of the ME-NA region, the reader is referred to a database that has been compiled by workers at Cornell University. This database can be accessed via the Internet under the World Wide Web address:

http://www.geo.cornell.edu/geology/me_na/main.html