REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release - Distribution unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION: Columbia University; 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION: Phillips Laboratory
6c. ADDRESS (City, State, and ZIP Code): Box 20, Low Memorial Library, New York, NY 10027	7b. ADDRESS (City, State, and ZIP Code): Phillips Laboratory/PKFA, KAFB, NM 87117-5320
8a. NAME OF FUNDING/SPONSORING ORGANIZATION: DARPA; 8b. OFFICE SYMBOL (If applicable): NMRO	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: F 29601-91-K-DB09
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
	FY-3592 91-1064		

11. TITLE (Include Security Classification)
Report of a visit to the Borovoye Geophysical Observatory (Seismic Station BRV) in Kazakhstan

12. PERSONAL AUTHOR(S)
Paul G. Richards* and Goran Ekstrom**

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Technical Rpt.	FROM 7/15 TO 8/31	1991 Sept. 18	25

16. SUPPLEMENTARY NOTATION
*Lamont-Doherty Geological Observatory, Palisades, NY 10964
** Dept. of Geological Sciences, Harvard Univ. Cambridge, Massachusetts 02138

17. COSATI CODES		
FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Seismic data, digital data, Soviet geophysics

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

During summer, 1991, the authors visited the Borovoye Geophysical Observatory (BRV) in Northern Kazakhstan. At this site, seismic data have been recorded digitally since 1966. There is an archive (about 70 Gbytes) of both explosion and earthquake data. We describe the history of this station, the characteristics of seismic data channels (~50) now routinely recorded, some of the routine analysis conducted at BRV, and the archive. It is possible to acquire digital data from the archive. At present, a considerable effort is needed to obtain detailed instrument responses for the many available channels. However, it appears that this effort, which we are pursuing, can be successful.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION: Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL: Alan S. Ryall, Jr.	22b. TELEPHONE (Include Area Code): 703/796-2246; 22c. OFFICE SYMBOL: DARPA/NMRO

REPORT OF A VISIT TO THE BOROVOYE GEOPHYSICAL OBSERVATORY (SEISMIC STATION BRV) IN KAZAKHSTAN

P. G. Richards (Columbia University)
Göran Ekström (Harvard University)

Lamont-Doherty Geological Observatory
of Columbia University
Route 9W
Palisades, NY 10964

18 September 1991

Technical Report No. 1

Work sponsored by Defense Advanced Research Projects Agency
Nuclear Monitoring Research Office under Contract F29601-91-K-DB09

REPORT OF A VISIT TO THE BOROVOYE GEOPHYSICAL OBSERVATORY (SEISMIC STATION BRV) IN KAZAKHSTAN

Paul G. Richards (Columbia University) and Göran Ekström (Harvard University)

SUMMARY

During summer, 1991, the authors visited the Borovoye Geophysical Observatory (BRV) in Northern Kazakhstan. At this site, seismic data have been recorded digitally since 1966. There is an archive (about 70 Gbytes) of both explosion and earthquake data. We describe the history of this station, the characteristics of seismic data channels (~50) now routinely recorded, some of the routine analysis conducted at BRV, and the archive. It is possible to acquire digital data from the archive. At present, a considerable effort is needed to obtain detailed instrument responses for the many available channels. However, it appears that this effort, which we are pursuing, can be successful.

INTRODUCTION

In March, 1990 at the IRIS workshop in South Carolina, Paul Richards was approached by two seismologists from the Soviet Union. They told him of a seismic station that has operated in Northern Kazakhstan since the mid-1960's. They said the data is of excellent quality, and has been digital since 1966. The station has been an activity of the Special Sector of the Schmidt Institute of the Physics of the Earth. Though many Soviet seismologists have known of the station, few had visited it and the data has not been available to scientists from the West. A decision was made in about 1989 to reveal information about the station. Richards was told that a substantial digital archive is held at the station, which is now operated from Moscow by the new Institute for Dynamics of the Geosphere. This Institute is headed by Professor Vitaly Vasiliovich Adushkin, who previously led the Special Sector. His staff in the new Institute includes most if not all of the former Special Sector.

In December, 1990, Richards made a request for digital data from the station, which is at Borovoye (station code BRV), 53° 03' 29" North, 70° 16' 58" East. The request (see Appendix I) was for signals of nuclear explosions at two Soviet test sites (Shagan River and Novaya Zemlya) and at the Chinese test site (Lop Nor); and for signals from earthquakes in Kazakhstan, Novaya Zemlya, and China. In March, 1991, Vitaly Adushkin visited the USA and gave Richards a nine-track tape with 43 examples of three-component signals that responded to the data request (see Appendix II).

The tape was written on a Soviet computer similar to a PDP 11. At Lamont-Doherty Geological Observatory, Dr. Won-Young Kim succeeded in reading the tape and in producing hard copy of the seismograms. Adushkin also gave Richards, in March, 1991, the Russian-language version of the December, 1990 issue of "Izvestiya Fizika Zemli", which included several papers describing the Borovoye station, and analyses of BRV data for nuclear explosions at the Nevada Test Site and East Kazakhstan.

The data received in March, 1991 included a variety of long-period (5 - 20 s) and short-period (0.1 - 2.0 s) signals. It was not clear exactly what instrument response to assume for each signal: the principal paper describing BRV ("Seismic Observations and Underground Nuclear Shot Monitoring at Borovoye Geophysical Observatory", by V. V. Adushkin and V. A. An, Izvestiya Akademi Nauk SSSR: Fizika Zemli, pp 47-59, December, 1990) describes twenty different responses (four analog instruments, sixteen digital), most being for 3-component instruments. Some of the data suffered from glitches – which would appear in many cases to be easily removable. Some of the data was severely clipped. However, in general it was apparent that much of the data was of good quality, and could be used for a variety of purposes once it was clear exactly what instrument response to assume for each of the 43 x 3 time series (43 examples, each with three components). Kim wrote in April, 1991 to the operators of the station, requesting calibration information, and received a detailed reply a few weeks later.

Richards made arrangements to visit BRV in July-August, 1991 in the company of Prof. Göran Ekström of Harvard University. By the time of their visit, a considerable number of papers in the open Soviet scientific literature were identified as using seismic data that appeared to be from BRV. In addition, a 1986 article from the Soviet newspaper *Pravda*, published during the time of the Soviet unilateral moratorium on nuclear testing, was identified as almost certainly describing the Borovoye station (see Appendix III).

With this information in hand (much of it received from Dr. William Leith of the U. S. Geological Survey), Richards visited the USSR in 1991 from July 19 through August 9, spending July 29 – August 8 at the station in Borovoye, Kazakhstan. Ekström was with him at BRV from July 29 – August 5. Ten other visitors, representing the U. S. side of the Joint Working Group of the Joint Seismic Program, also came to BRV from August 4 - 8.

The following sections of this report give technical information concerning digital seismic recording stations in the USSR (principally BRV), as given to Richards and Ekström. Also, we give a separate short summary of the interests of the scientific personnel with whom we came in contact (see Appendix IV).

Before further presentation of technical material, we wish to record our appreciation of the warmth of our welcome in Moscow and Borovoye. Our hosts solved many logistical problems of travel and lodging, and often took us into their homes. About 80 people (including 25 scientists/senior technicians) work at BRV. We were told we were the first visitors from the United States, and we met several scientists, formerly with the Special Sector of the Institute of Physics of the Earth, who have had little or no experience of working with scientists from the West. A small group from Germany visited a year or so earlier. Apparently, they were told that there had been a prior visit by personnel from the U. S. Department of Defense. Many recent reprints were given to us, often concerning the Soviet nuclear test program, describing work for which permission to publish was given in about 1989. At a time when the Soviet Academy of Sciences is experiencing severe difficulties, cooperative work in geophysics between the U. S. and U. S. S. R. is likely to be greatly helped by the influx of scientists associated with the new Institute for Dynamics of the Geosphere.

DATES OF TRAVEL IN USSR, INCLUDING OBNINSK AND MIKHNEVO STATIONS

July 23 at Obninsk.

Richards visited Obninsk (OBN), about 100 km southwest of Moscow and site of the USSR Data Center in seismology. The Director, Oleg Starovoit, described the USSR Unified Seismic Observation Network as a national net with 28 stations (including 2 in Antarctica). The most active station (i.e. reporting most data) is now Borovoye. A total of about 75 USSR stations routinely report seismic data to OBN, and the catalog in the USSR produced by OBN is "now complete at about magnitude 4.5." OBN issues a bulletin with 3,000 events per year, of which 15% are in the USSR.

Richards was driven into deep forest south of Moscow for an overnight at Mikhnevo, operated intermittently since 1970 as a digital seismic station. Data is stored at Borovoye.

July 24 at Mikhnevo.

This station, much quieter than Obninsk, has long served as a seismometer testing site within a few hours drive of Moscow. The principal building was constructed in 1953-54 to record signals from the first hydrogen bomb tests in the atmosphere. Richards was the first non-Soviet citizen to visit the site (nearer the village of Khatun than the town of Mikhnevo itself). There is a vault 21 meters deep with two chambers. A staff of five (plus their families) lives at the site and is supervised by Nicholai Pleskach as chief scientist. Figure 1 shows Earth noise at this site as measured by Pleskach. This Figure also shows noise levels at Borovoye and Kuldur, measured by Pleskach. Much of the digital seismic data from Mikhnevo was recorded on 17-track wide tape (35 mm), but at present a more standard 9-track tape system (PDP-like) from Bulgaria is used.

July 25 - 28 in Leningrad.

July 28, Richards and Ekström meet in Moscow and fly to Kokchetav, Kazakhstan, with Adushkin. Drive for about one hour to Borovoye, arriving July 29 at about 9 AM. The Borovoye Observatory is fenced and guarded, and is on the south side of a shallow lake about 4 km across. Foreign visitors stay in a Brezhnev-era guest house, apparently built by the Ministry of Atomic Energy and Power.

HISTORY OF THE FOUNDING OF BRV

Seismic measurements near the town of Borovoye were first made in 1951 by I. P. Pasechnik, and refraction surveys in Northern Kazakhstan were carried out in the 1950's and 1960's. We heard two somewhat different histories of the founding of the seismic station at Borovoye (BRV).

(1) Gamburtsev (who preceded Academician Sadovsky as Director of the Institute of Physics of the Earth) was an expert in seismic refraction and did early work in Kazakhstan. When Sadovsky tasked Pasechnik to find a good station for recording nuclear explosions (globally), Pasechnik went to Gamburtsev for advice and he suggested BRV. The site is on a pluton about

200 km across, with an ill-defined (but deep) Moho and monolithic granites. The Pg phase is sometimes seen from local earthquakes, ar ' has a velocity about 6.1 km/s. BRV has turned out to have excellent capabilities for recording NTS explosions.

(2) While deploying seismic equipment to record nuclear explosions at the "Semipalatinsk Polygon" (Test Site) in the 1950's and 1960's it was found fortuitously that NTS explosions had been recorded too. In 1960 a field station was organized at BRV, recording short-period signals continuously. By 1965, when it had become evident that NTS *P*-wave signals had good signal-to-noise at BRV, "an expedition was organized" and the site achieved the status of an observatory, with continuous photographic recording of short-period and long-period signals. Digital recording began in 1966, with a sensitivity of 2,500 counts per micron. The archive has digital data from virtually all NTS underground explosions since May 10, 1967. Recording at 250 counts per micron was used for Semipalatinsk explosions.

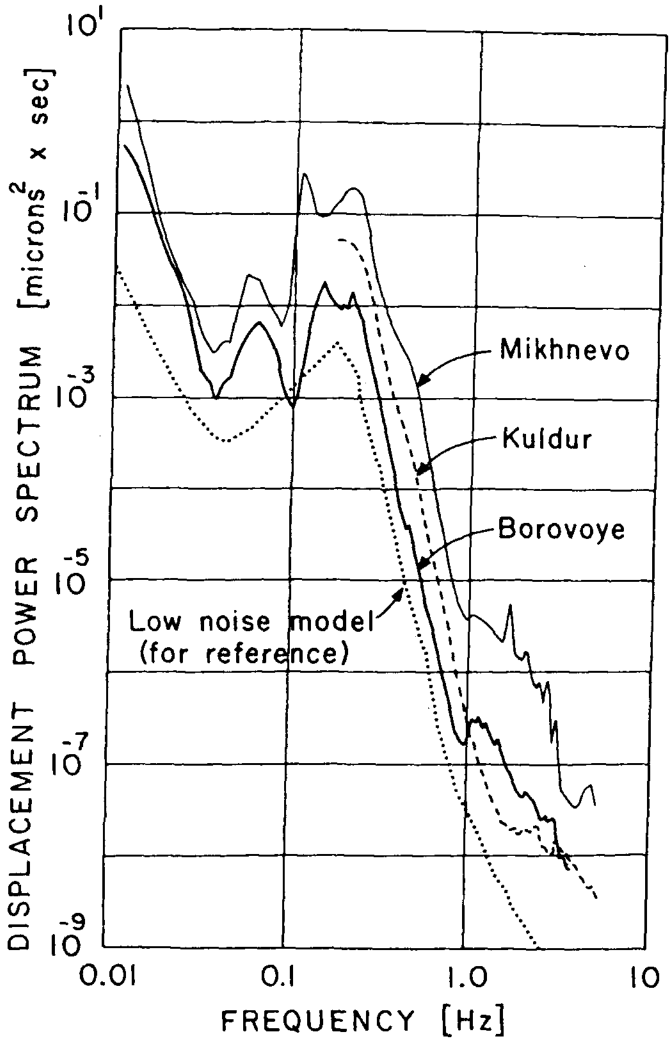

Figure 1. Power spectra of Earth noise at three seismic stations in the USSR, as measured by Nicholai Pleskach. A low-noise model (personal communication from Jon Peterson) is shown for reference.

Note that in the Izvestiya: Fizika Zemli paper of December, 1990 by Adushkin and An, there is an error in the claim that BRV records NTS explosions with a magnitude about 0.6 – 0.7 units greater than the ISC magnitude. In their paper, the BRV magnitude used a distance correction (due to Kulhanek and Kondorskaya) that differs from that used at the same distance (90°) by ISC (Gutenberg and Richter) by about 0.3 units. Therefore, the signals from NTS recorded at BRV should be characterized as about 0.3 – 0.4 units greater in magnitude than ISC. Several people told us that it was this property which has been the basis for operation of BRV.

The Observatory has also been the testing site for almost all the major developments of seismic instrumentation in the USSR since the mid 1960's. During our visit, a novel laser strainmeter was undergoing preliminary tests. It uses a diffraction grating, and sophisticated optics permitting displacements to be measured with a precision of $\pm$ 0.01 Angstrom (10^{-12}m).

EARTH NOISE AT BRV

The claims of excellent signal-to-noise at BRV appear surprising in view of the proximity of Borovoye Lake (4 km across, and a few meters deep). Winds at around 15 knots swept the Lake for some of the days while we were there. It was acknowledged that there is a problem with noise at around 10 Hz when the ice breaks up in late spring. Several residents spoke of the pervasive silence at BRV during winter.

Figure 1 shows the noise measurements made at three sites by Pleskach – including at BRV. Also shown for reference is a so-called low noise model provided (personal communication) by Jon Peterson.

We obtained some noise samples recorded during our visit, which we plan to use to calc ılate noise spectra.

NOTES ON THE MAIN DIGITAL SEISMIC SYSTEMS OPERATED AT BRV

Beginning in 1966, with continuous operation since 1967, the digital seismic system known as KOD (КОД in Russian) was operated until November, 1973. This system used three-component, short-period SKM (СКМ in Russian) seismometers (nominal seismometer period, 3.5s; nominal damping, 0.7). Polarity of all three components, in all digital data we have seen from the KOD system, is reversed. Usually the data are recorded at two different gain levels, listed by Adushkin and An (Table 2 of Izvestiya: Fizika Zemli, pp 47-59, December, 1990) as 3,000 counts/micron (normal), and 300 counts/micron (low-gain). A detailed description of the KOD system, and the data format of the associated 17-track wide tape, is given by Shishkevish ("Soviet Seismographic Stations and Seismic Instruments, Part II" , R-1647-ARPA, RAND, Santa Monica, June 1975). This format can have a glitch at regular (30s) intervals due to data replacement by a time stamp. Though the KOD system was replaced by better systems (see below), it is important as one of the few digital systems in the late 1960's – early 1970's.

The second main digital system, known as STsR (СЦР in Russian), has operated from February, 1973 to the present day. The system consists of two similar parts which operate separately (different seismometers and data loggers). The STsR-SS equipment (СЦР-СС in

Russian) records at lower gain levels. The STsR-TSG equipment (СЦР-ТСГ in Russian) is said to be better for all purposes except strong ground motion recording, and is generally reckoned to be the best system ever operated at BRV.

The STsR-TSG system has many channels, based mostly on modified Kirnos seismometers, with sensitivities as high as 100,000 counts/micron. It is possible to control remotely the period and mass position of these instruments, which typically weigh about 70 kilograms each. The basic instruments are known as KS (short-period) and DS (long-period) (respectively КС and ДС in Russian). If the letter "M" is added, as KSM and DSM, the instrument has a stronger magnet, allowing twice the gain. If letter "V" (Russian В) is included, as KSVM (КСВМ), this signifies a sensitive channel, with special electronics. However, the most sensitive channel (short-period) is based on a KSM instrument, using a low noise amplifier (sensitivity 100,000 counts/micron).

The STsR-TSG system appears to have 20 channels of digital information: 3 components from KS and DS; 3 components from KSM and DSM, each at 2 gain levels; and a vertical component from KSVM at 2 gain levels.

Nominal gains/sensitivities of the STsR system are listed by Adushkin and An (Izvestiya: Fizika Zemli, Table 2 of pp 47-59, December 1990). But in practice the instrumental characteristics have frequently been changed. We were shown extensive tables listing gains at different frequencies for different time periods, for the many channels of digital data. We have copied about 1% of these tables, but were handicapped by lack of a xerox machine.

The third main system is known as ASSTs (АССЦ in Russian, these letters standing for "Automatic Digital Seismic Station"). It employs feedback seismometers, has operated from April, 1990 to the present day, and is described in the doctoral thesis of Igor Bashilov. The system utilizes a broadband seismometer and records long-period, short-period, and broadband channels. The seismometer, known as SSM-S (ССМ-С in Russian), is said to suffer from long-period noise, and the electronics too are noisy. The good feature of the system is its high dynamic range, achieved through gain-ranging. Some channels use a logarithmic amplifier, with amplitude linearly related to magnitude.

All three of these main systems are approximately flat to ground displacement over a range of frequencies.

Timing for these three systems has been good to ± 10 ms for the 25 years of digital recording. For the last 10 years, timing has come from the "exact time service of the USSR."

The Parus-2 borehole system was also installed for a few years, approximately 1987 - 1991 (two units in separate boreholes, presumably for comparison). According to Dr. Belanossov, who responded to our questions with a written statement, this borehole system has the specifications listed in Table 1. We did not see any data, however, despite requests. Note this system was not developed or operated by Borovoye Observatory staff. The system is also under test at the present time at the Albuquerque Seismological Laboratory (USGS).

1. Number of components — 3
2. Parameter — velocity
3. Frequency band — 0.02 to 10 Hz.
4. Passband of different channels after filtering:

0.02 – 0.05	(L)
0.02 – 0.7	(M)
0.5 – 10	(H)

5. Frequency of sampling:

1 Hz	L
5 Hz	M
40 Hz	H

6. Dynamic range — 120 dB
7. Nonlinearity in dynamic range — < 1%
8. Timing error — ≤ 10 ms
9. Capacity of seconds date — 2400 bit [??]
10. Sensitivity, noise — like KS 36000
11. Power supply — 20 watts (borehole units)

Table 1. Characteristics of the broadband borehole seismometer system "Parus - 2" (personal communication, Belanossov to Richards, 1991 Aug 5).

ROUTINE DATA ANALYSIS AND REPORTING PRACTICE AT BRV

There are three types of routine reporting: urgent, daily, and weekly. Urgent and daily reporting is via teletype to Obninsk. A weekly seismicity bulletin is published at Borovoye. Urgent reporting is done within the hour after a *P*-wave arrival from a large event. It was stated that a computer estimate of hypocentral coordinates is available two minutes after a *P* -wave arrival with good signal-to-noise ratio.

At approximately zero hours GMT, a daily message is sent to Obninsk, using a standard format for transferring level 1 data (arrival times, amplitudes, periods) recorded at BRV. An agreement has recently been concluded between Obninsk and the USGS/NEIC in Golden, Colorado concerning the rapid transfer between Golden and Obninsk of this type of data for large events.

We were told that BRV detects about 1000 seismic events every month, and that about 100 are routinely processed (including an estimate of source location) using only the data from this station. This information is summarized in a weekly bulletin, published in Borovoye. On July 30, 1991, we were given a copy of the bulletin for July 18 - July 24. It contains level 1 information on about 400 arrivals, and location estimates plus magnitudes for 17 events. Many of the reported arrivals are multiple reports of the same phase (e.g. the main *P*-wave) on different instruments. The weekly bulletin contains a wealth of information on global seismicity. Table 2 lists the hypocenter estimate, origin time estimate, and magnitude, as reported in the BRV weekly bulletin for July 18 - July 24. Table 3 gives the corresponding information from USGS/NEIC

Quick Determination of Epicenter (QED) listings, which of course are based on data from many stations around the world. We have included in Table 3 only those QED events with magnitude greater than 5.5, or which were reported by BRV. Data in italics in Table 2 are based on BRV data taken from Table 2, to enable comparisons between BRV and QED for those eleven events in common. The last two columns of Table 3 give the azimuth and distance from BRV to the estimated epicenter. It is disconcerting that the italicized azimuth/distance pairs of Table 3 are different (for corresponding events) from the azimuth/distance pairs listed as estimates in Table 2. That is, the azimuth/distance pairs in each line of Table 2 do not equal the azimuth/distance values one would obtain by spherical trigonometry for the BRV location (53° 03' 29" North, 70° 16' 58" East) and the listed (Table 2) BRV estimate of the epicenter.

We were told that BRV has a detection capability down to magnitude 4.2 for all parts of the globe. At some distances (e.g. in the core shadow) the detection is based on a phase other than *P*. It will be interesting to see the basis for this claim. We saw several charts used at BRV to provide azimuth and distance corrections to the initial azimuth/distance estimates, in order to provide the location estimates circulated by the Borovoye Observatory. Perhaps this correction is the reason for the difference, noted in the previous paragraph, between azimuth/distance pairs. From a comparison of italicized (BRV) and non-italicized numbers (QED) in the last two columns of Table 2, and by direct comparison of epicenter estimates, it is apparent that the single station location capability of BRV has RMS errors around 2° in distance (zero mean) and 5° in azimuth *(around a mean about 5° lower in value).*

We were told that whereas OBN operates LP instruments at gains of only 250 to 500, BRV is able to operate LP instruments at gains of 10,000 to 20,000. However, if events are detected only via surface wave signals, such events are not included in the Borovoye bulletin.

The work of routine analysis appears to be done mainly by women living a few km away in the town of Borovoye. With years of experience, several have become highly proficient in seismogram reading. Work is done around the clock in three shifts. More and more of the work is being transferred to computer-based analysis, using the ASSTs system. It is planned to compare the human and computer analyses for a period of three years. The comparison is a major project of Karim Khaidarov at BRV, and Vladimir Ovtchinnikov at Institute headquarters in Moscow. A paper by Kedrov and Ovtchinnikov, describing the automatic processing at "an experimental station in Eastern Kazakhstan....near Kokchetav" (it is obviously Borovoye, though this is not stated) appears in the Bulletin of the Seismological Society of America, special issue of December, 1990.

FACILITIES AND NON-SEISMOLOGICAL PROJECTS AT BRV

The early deployment of seismic instruments (1965) was in a tunnel driven horizontally into the granites rising to the south of Borovoye Lake. But now all seismometers are in a 15 m deep vault with three chambers.

UTC TIME HRMNSEC	LAT° (COMP)	LONG° (COMP)	MPV (MANUAL)	MLH (MANUAL)	MPV (COMP)	REGION	AZ° (COMP)	AZ° (MANUAL)	DELTA° (MANUAL)
1991 JUL 18									
045446.0	2.32S	130.91E	6.0	-	-	NEW GUINEA		130.0	74.8
091521.0	3.53S	129.39	5.1	-	-	SERAM, INDONESIA		132.0	75.0
115615.0	44.57N	19.06E	5.8	5.5	6.04	YUGOSLAVIA	276.7		34.1
203349.0	5.78S	10.79W	5.0	-	5.02	MID-ATLANTIC RIDGE	259.4		89.3
1991 JUL 19									
012758.0	46.31N	24.23E	4.9	-	5.06	ROMANIA	270.6		30.0
1991 JUL 20									
114844.0	52.25N	165.63W	6.2	5.7	-	ALEUTIAN ISLANDS		30.0	64.8
1991 JUL 21									
143302.0	29.81N	91.65E	4.9	-	5.30	CHINA	147.0		28.0
225913.0	1.38N	124.40E	6.2	5.2	-	SULAWESI, INDONESIA		130.0	68.2
1991 JUL 22									
141328.0	41.86N	52.60E	5.4	3.8	-	CASPIAN SEA COAST	239.0		16.3
171252.0	21.29N	139.95E	5.3	-	5.37	MARIANA ISLANDS	91.6		61.0
1991 JUL 23									
112208.0	8.27N	126.25E	6.0	-	6.12	MINANAO, PHIL. IS.	123.7		63.4
132543.0	3.04N	93.64E	6.3	5.1	-	SUMATERA ISLAND		150.0	53.6
174545.0	38.67N	21.41E	4.6	-	4.65	GREECE	261.3		36.1
211637.8	3.82S	131.53E	5.5	-	5.49	NEW GUINEA (h=100)	130.3		76.4
1991 JUL 24									
094545.5	41.64N	37.64E	5.6	5.0		BLACK SEA		253.0	24.6
135416.7	20.22S	22.76E	5.4	-	5.39	SOUTH AFRICA	224.1		84.0
152446.0	45.29N	82.04E	4.7	-	-	USSR-CHINA BORDER		135.0	10.9

Table 2. The last page of the BRV weekly bulletin for 1991 July 18-24, giving epicenter estimates and magnitudes for seventeen earthquakes. Some columns are worked up automatically on the ASSTs system (COMP); some are done by hand (MANUAL).

NEIC QUICK EPICENTER DETERMINATIONS, compared with
BRV SINGLE STATION EPICENTER DETERMINATION

UTC TIME HRMNSEC	LAT	LONG	DEP	GS MB	MAGS Msz	SD	STA USED	REGION--COMMENTS	AZ(BRV)	DELTA(BRV)
1991 JUL 18										
115633.9	44.880N	22.280E	33N	5.8	5.6	1.1	121	ROMANIA	274.9	32.0
115615.0	*44.57N*	*19.06E*		*5.8*			*1*	*YUGOSLAVIA*	*276.7*	*34.1*
1991 JUL 19										
012732.8	45.373N	21.255E	33N	5.6		1.0	82	ROMANIA	276.4	32.4
012758.0	*46.31N*	*24.23E*		*4.9*			*1*	*ROMANIA*	*275.9*	*30.1*
1991 JUL 20										
114847.5	54.553N	161.637W	36D	5.8	5.5	1.3	133	ALASKA PEN.	30.6	64.5
114847.5	*52.25N*	*165.63W*		*6.2*			*1*	*ALEUTIAN ISLANDS*	*34.1*	*65.1*
1991 JUL 21										
225909.1	3.007N	128.477E	33N	5.8	5.2	1.0	67	NORTH OF HALMAHERA	114.6	68.9
225913.0	*1.38N*	*124.40E*		*6.2*			*1*	*SULAWESI, INDONESIA*	*119.2*	*68.1*
1991 JUL 22										
171245.5s	23.669N	143.961E	33N	5.0	4.1	1.8	18	VOLCANO ISL REGION	87.7	61.7
171252.0	*21.29N*	*139.95E*		*5.3*			*1*	*MARIANA ISLANDS*	*92.7*	*61.1*
1991 JUL 23										
112209.9	5.813N	125.957E	146s	5.6		1.3	63	MINDANAO, PHIL. ISLS	115.2	65.2
112208.0	*8.27N*	*126.25E*		*6.0*			*1*	*MINDANAO, PHIL. ISLS*	*113.4*	*63.4*
132545.8	3.790N	95.986E	33N	5.8	5.1	0.9	105	OFF W COAST OF N SUMATERA	147.4	53.5
132543.0	*3.04N*	*93.64E*		*6.3*			*1*	*SUMATERA*	*150.5*	*53.5*
174545.2s	34.631N	25.631E	33N	4.3	3.9	1.4	20	CRETE	257.7	36.4
174545.0	*38.67N*	*21.41E*		*4.6*			*1*	*GREECE*	*266.6*	*36.2*
211624.3s	6.155S	130.373E	33N	5.8	4.6	1.3	32	BANDA SEA	118.1	77.6
211637.8	*3.82S*	*131.53E*	*100*	*5.5*			*1*	*NEW GUINEA*	*115.8*	*76.3*
1991 JUL 24										
094542.7	36.483N	44.072E	33N	5.5	5.6	1.0	105	IRAN-IRAQ BDR REG.	238.4	24.7
094545.5	*41.64N*	*37.64E*		*5.6*			*1*	*BLACK SEA*	*255.6*	*24.7*
135447.9	18.382S	34.721E	10G	5.1	5.1	1.1	37	MOZAMBIQUE	214.4	77.5
135416.7	*20.22S*	*22.76E*		*5.4*			*1*	*SOUTH AFRICA*	*224.2*	*83.8*

Table 3. A comparison between the Quick Epicenter Determination (QED) listings of the US Geological Survey, and the epicenter determinations of the BRV bulletin, for the eleven events on both lists for the week of 1991 July 18-24. Lines in the table giving BRV measurements/estimates are italicized. For this week, all eight QED events with magnitude (NEIC) greater than or equal to 5.5 are in the BRV bulletin. Three smaller QED events are also listed by BRV. Each list has just one deep earthquake, but for QED it is the Philippines event of July 23 and for BRV it is the "New Guinea" event (Banda Sea, according to QED) of July 23. Finally, note that the complete BRV listing (Table 1) contains six events not listed by QED.

Although seismology dominates the work of the Observatory, we were told of studies of solar flares using "long radio waves", of studies of infrasound (for example from rocket launches), and of many years of recording the Earth's magnetic field (absolute, and variations) on a variety of magnetometers.

The present director of the Observatory, Valentin Lampei, is principally interested in studies of the ionosphere. The data for this work are acquired at a separate site a few km east of the main Observatory on Borovoye Lake.

In about 1986, the agency now known as the Ministry of Atomic Energy and Power built two boreholes 150 m deep and 30 cm in diameter at BRV. These were used by personnel of the Institute of Impulse Techniques for testing the Parus-2 seismic system in an effort headed by Dr. Belonossov (who was at Borovoye for part of our visit). The instruments are contained within a 2-meter long cylindrical package. In a typical test, one package was lowered into and clamped in each borehole. The depth was only 70 meters, due to water problems and a problem with the hoist. These borehole instruments had been removed from the Observatory not long before our visit.

The first building (1965) containing laboratories is a two-story wooden structure that still contains the original computer equipment (Seysmostantsya), now used only for calibration. It also houses the equipment used to receive OMEGA timing signals from six sites around the world, and to compare these times against a Soviet-made rubidium laser standard. A daily pattern of slight departures of OMEGA times from the rubidium standard has been established in years of observation at BRV. It is claimed that slight departures from this pattern appear to be followed within a few days by large earthquakes, with a probability much greater than that expected by random occurrence.

The second building (1978) containing laboratories/offices is a three-story brick and concrete structure almost entirely given over to seismology (computers, analysis, archive, offices).

About 80 people work at the Observatory – 25 of them scientists (who may be based in Moscow). There are no xerox or fax machines.

There is a building dedicated to an emergency power supply. It is of a type designed in the USSR for back-up to nuclear reactor control rooms. Based on batteries using sodium hydroxide (?), it can provide 40 kilowatts of power for 30 minutes (220 volts at 50 Hz). There is a fast switch-in that maintains phase. The system is often called upon in winter, and is said to be very reliable. The 30 minutes of battery power provides enough time to start a separate power generator at the Observatory.

CALIBRATION

From the analysis we saw, it was not clear how instrument transfer functions were used in the routine analysis of data. Our impression was that differences in channel gains were used in the polarization analysis, but that other (small) differences in the response characteristics were not. Poles and zeros are not used.

The instruments (the recorded channels) are calibrated carefully approximately once every year. It appeared that the computer initially used for the earliest digital system (Seysmostantsya) is now dedicated to the calibration analysis. This sounded like a traditional sine-wave analysis, with recordings of gain and phase shift. In the tables we were shown, we did not see any phase information, even though we were told several times that this information was collected.

On a more routine basis, impulse calibration pulses are generated and recorded. These are normally recorded in pairs, one positive and one negative. The onset of these pulses should be on the start of the second second of a minute (e.g. 12:37:01) and the duration of the impulse is 8 milliseconds. The amplitudes of these pulses are measured to check for variations of the digital sensitivity. We were told that the shape of the pulse is used for more detailed analysis of the instrument characteristics, but we saw no evidence of this. It is not clear how often impulse calibrations are performed, nor how often the digital records of these pulses are saved on archive tapes. Ekström was given a tape, generated during our visit, with impulse calibration pulses carried out in 1988 for several channels. We will use them to study the response functions and compare the obtained values with the calibration tables (which provide only the amplitude response).

In one of the log books for the TSG system, we were shown fairly detailed charts of the electronic design of the instrument, amplifiers, filters and digitizer. With a significant effort, it is likely that nominal (theoretical) transfer functions for all systems could be obtained. It is an open question how closely these would resemble the actual response, of course.

We copied tables with amplification information for all channels of the TSG system for 1988-1989, and were told that these had not changed significantly since then. [Indeed, quick checks of gain levels at other times showed them to be very close (within a few percent) to the ones copied]. We believe that if it is possible to extract the phase characteristics from the impulse calibration pulses, it may be sufficient to use the calibration tables to get an adequate description of the instrument characteristics. We do not think, at this point, that it is very useful to attempt a detailed analysis of the electronic recording systems.

As another approach to calibration, and to building confidence in use of the BRV data, we requested and obtained data for two earthquakes that have been studied in detail in recent years, using about 20 digital stations around the world. For these events, the focal mechanisms and radiation pattern are known with high confidence, and it is possible thus to predict the expected signal at BRV for different instruments.

EXTENT OF DATA ARCHIVE

On a typical day at BRV, the last three days of continuously recorded digital data for all channels are available on disk. An archive tape is then made for one day. The whole process of building the archive has been limited principally by the cost of acquiring magnetic tape. Thus in the routine processing of the data, phases are identified and data windows with phases are collected (about 100 files per day) in the data archive. Anything that looks like signal is saved, even if the source of the signal cannot be identified. There is no archive of continuous data. The archive consists of approximately 5000-10000 17-track tapes. Each tape contains around 10 megabytes of data. We were told that the archive contains 70 gigabytes of data going back to 1966.

Until recently, the tape used at BRV was manufactured in the former East Germany. Such tape is no longer available, and we were told that Russian-made tape is notably inferior. This is a serious problem for station operations. We were told that about 5% of the continuously recorded data is saved. This appears to mean that for about 5% of the time there is some saved data, but only those data channels deemed to have useful signal are then archived. For many of the channels (e.g. low-gain), presumably it is quite rare (< < 5%) for the data to enter the archive. The selection of time windows to be saved and copying of data into the archive is a time consuming process. Our understanding is that the archived data is in the same format as the original data, but not continuous. Our understanding is also that data from the new system (ASSTs) are recorded and archived on 9-track tapes, but that only phase windows are saved. The station now archives 2 gigabytes of data per year.

DATA FORMATS

Most of the data that we have received, both on the early tape and on more recent tapes, are in a processing format called ADM. That is, the data are not recorded in this format (except possibly ASSTs), but are copied and rewritten in this format for processing on the computers. The program that reformats data from the wide tape (35 mm) to the new format is very slow and can process only 3 channels (out of 24) at a time. We have a detailed description of the ADM format in Russian and Kim at Lamont has read data in this format from the the tape received in March, 1991.

We received some direct copies of data from the wide tape recording from the TSG system. These should be bit by bit copies, with the only difference being that the 35 mm tape writes 16 tracks (+parity track) and the half-inch writes 8 tracks (+parity track), i.e. each '16-bit sample' on the wide tape becomes 2 '8-bit half-samples' on the narrow tape. Each sample is contained in a 16-bit word with 11 bits of data and 5 bits for channel identification. Data from up to 24 channels are multiplexed in varying order on the tape. Time stamps are marked by channel numbers greater than 24. There are many time stamps embedded in the data. The writing of the time stamp sometimes prevents a data sample from being written, resulting in a missing sample in the time series.

The 16 bits of each sample are scrambled on the wide tape. This design was intended to put the most important bits of information in the center of the tape and the least significant bits of information at the edges of the tape. We have a description of this format which may be sufficient to decode the raw data format. This has to be explored, however.

OTHER SEISMIC DATA HELD AT BRV

In addition to the Mikhnevo digital data (see above), small arrays have occasionally been deployed in Kazakhstan and the data archived at BRV. Of particular interest is a triangle of sites surrounding BRV, each at a distance of about 80 km and on the same pluton, and at which recording was carried out intermittently during 1976 - 1982. The deployment was experimental and data were recorded at Borovoye using phone line telemetry. Thus, to the north is the station Chkalovo; to the west is the station Zerenda; and to the southeast is Vostok (see Figure 2). For the four stations taken in order Zerenda, Borovoye, Chkalov and Vostok, it was observed that *P*-wave amplitudes of NTS explosions are in the ratio 1: 0.8: 0.6: 0.6. Zerenda has the best signal-to-noise ratio for NTS explosions - even better than BRV.

We were told that short-period digital seismic data have been recorded on wide tape at the following stations:

Pulkovo (near Leningrad/St. Petersburg)
Pleshianitsy (near Minsk)
Sochi, Caucasus
Tblisi, Georgia
Leninakan, Armenia
Frunze, Kirgizia
Talgar (near Alma-Ata), Kazakhstan
Shikotan, Kurile Islands
Yuzno-Sakhalinsk
Obninsk.

Some or all of this data may be at BRV.

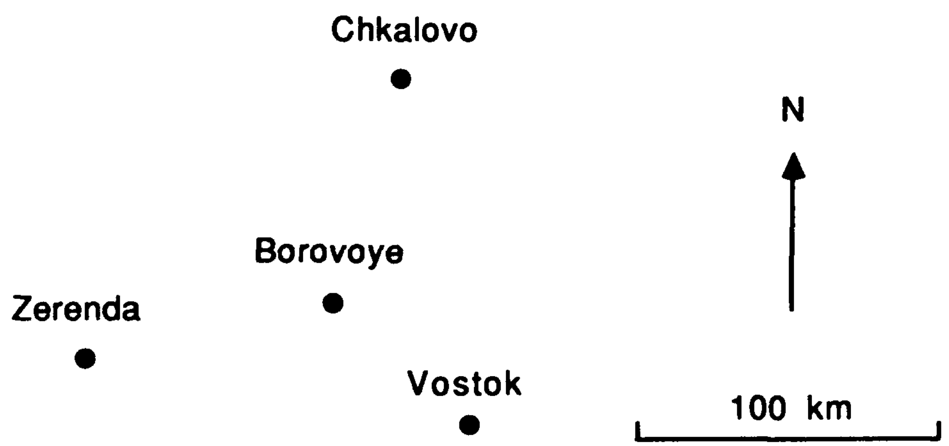

Figure 2. The location of four seismic stations in Northern Kazakhstan.

A SPECIAL PROJECT AT BRV: TRAVEL TIME FLUCTUATIONS

A controversial project that has been extensively pursued at BRV, particularly by Vadim An, is a careful comparison between *P*-wave arrival times for NTS explosions, and the shot times as announced by the Department of Energy (DoE) and predecessor agencies. A short paper by An, Luquet, and Pasechnik (Doklady, volume 285, number 4, 1985) claims that this comparison gives

P-wave travel times which for explosions grouped in each year can be measured to within about 50 ms; and that the resulting time varies cyclically over about 200 ms with a period of 10-11 years.

Careful consideration has been given to the effects of *pP* and *PcP* (BRV is at the core shadow boundary distance from NTS). The work uncovered errors in the Russian Time Service, and Table 4 lists seven NTS explosions (out of 252 studied) for which BRV seismologists believe DoE must have announced an incorrect shot time — because the travel time residuals appear to be so large.

An extended paper on the apparent variability of travel times from NTS explosions, using BRV data, is to appear in the December 1991 issue of Izvestiya: Fizika Zemli.

Discussion at BRV on a non-geophysical cause, included the suggestion that the shot time of a complicated nuclear weapons test may differ from the time when the main *P*- wave is generated.

NAME	DATE	SHOT TIME	LAT N (°:':")	LONG W (°:':")	SURFACE	DOB	Δt (s)	REF.
ARTESIA	1970 DEC 16	16:00:00.09	37:06:00.6	116:00:28.6	1329m	485m	-0.53	1
CREAM	1970 DEC 16	16:00:00.17	37:08:34.4	116:02:02.4	1298	294	-0.57	1
PEDERNAL	1971 SEP 29	14:00:00.04	37:00:39.7	116:00:26.4	1207	379	-0.35	2
CROWDIE	1983 MAY 05	15:20:00.085	37:00:44.31	116:05:21.18	1336	390	-0.50	3
DUORO	1984 JUN 20	15:15:00.089	37:00:01.36	116:02:35.01	1194	381	+1.03	3
DELAMAR	1987 APR 18	13:40:00.60	37:14:52.39	116:30:32.90	1902	500	-0.35	3
CONTACT	1989 JUN 22	21:15:00.83	37:16:58.35	116:24:44.30	2007	500	-0.76	4

REFERENCES FOR SHOT TIME (last column above):

1. SPRINGER, D., KINNAMAN, R. Seismic source summary for U.S. underground nuclear exlosions, 1961-1970, Bull. Seimol. Soc. Amer., v 61, no. 4, 1073-1098

2. SPRINGER, D., KINNAMAN, R. Seismic source summary for U.S. underground nuclear exlosions, 1971-1973, Bull. Seimol. Soc. Amer., v 65, no. 2, 343-349

3. Regional catalogue of earthquakes, International Seismological Center, Newbury, UK, 1983-1987

4. Preliminary determination of epicenters, U.S. Department of the Interior, Geological Survey, Nos. 25-89, July 13, 1989.

Table 4. Data on seven explosions at the Nevada Test Site, for which the *P*-wave arrival time at Borovoye differs significantly from the time expected. The precision of estimating the arrival time at BRV, if the shot time is correct, is claimed to be ± 0.25 s. Δt is the observed arrival time minus that expected based on the announced shot time.

DATA REQUESTED

(1) Three events from Sykes' and Ruggi's "Nuclear Weapons Data Book" article (Table 10:4 , "Soviet Seismic Events that have not been Identified as being Earthquakes, Large Chemical Explosions, or Nuclear Explosions").

(2) Concerning the original data request (Appendix I) and the resulting 43 examples of data received (Appendix II), we held extensive discussions on whether we had been given the best data channels, and on calibration. We were told that it had taken from two to twenty hours of work to dig out each of the 43 examples from the archive. In August, 1991, Richards submitted a detailed list of questions and comments on the 43 examples, requesting that different channels of data be provided for those examples which were low-gain, or clipped.

(3) In Moscow, at the Institute for Dynamics of the Geosphere, Richards was shown some BRV data on a PC display. In Borovoye, we heard reference to a set of digital data for the period 1967 - 1983, consisting of "20 to 30 explosions at Shagan River, plus about 40 PNEs", the point being that the work of retrieving this data from the Borovoye archive had already been done, and calibrations checked. Richards was told this was the data he had seen in Moscow. We requested this data, and were told it would be made available "in about two months".

(4). We showed to seismologists at Borovoye the list of 96 explosions in East Kazakhstan for which Bocharov *et al* published detailed source information in 1989. It was apparent that the list was familiar. We requested BRV data for those explosions on the list, post 1966, for which a specific yield (rather than a yield range) was given.

(5) We submitted a list of nine well-studied earthquakes, for which we requested BRV data. The list included Loma Prieta, California (1989 October 18); Spitak, Armenia (1988 December 7); Georgia (1991 April 29); Mexico City (1985 October 15); Macquarie Island (1989 May 23); Zaisan Lake, Kazakhstan (1990 June 14, magnitude 7, resulting in 770 microns of ground displacement at long-period in BRV); Imperial Valley, California (1979 October 15); and the earthquake of 1976 March 20 near the Semipalatinsk test site, for which we already have some BRV data.

DATA RECEIVED DURING OUR VISIT

Although we took twenty blank tapes with us to Borovoye, it was soon apparent that they would not be filled with BRV data during our stay (less than two weeks). It took time to agree on what data would be given us, time to find the desired data in the archive, and then time to make our copies. Note that the standard 17 track tape holds 24 channels, and that only 3 can be transferred at a time onto 9-track tape. It is not easy to see which 3 of the 24 are most appropriate for a given event.

We were able to take away three tapes with us (leaving the remaining tape for future copying).

We got data for:

(1) The Bering Sea event of 1991 February. 21, all TSG channels and all archived triggers (P, S, surface waves) (ADM format)

(2) The Sakhalin Island deep event of 1991 May 12, all TSG channels and all archived triggers (ADM format)

(3) Calibration pulses for 02/08/88 for the high-gain TSG channels (ADM format)

(4) Noise samples (18 minutes) from 08/01/91 for high-gain TSG channels (ADM format)

(5) The same data as 3 and 4 except in the raw TSG format. (Direct copies from the wide tape).

(6) Twelve channels (from STsR-SS) for the Zaisan Lake, Kazakhstan, earthquake (magnitude 7) of 1990 June 14.

(7) Twelve channels (STsR) for the Spitak, Armenia, earthquake of 1988 December 7.

(8) Two aftershocks of the Kazakhstan earthquake described in Item 6.

MISCELLANEOUS

On July 30 during our visit, the Observatory received an important visitor: the Vice President of the Kazakh Academy of Sciences, who is an ecologist. It is hoped at the Observatory that the Kazakh Republic will provide some funding in future, particularly to support work that will provide estimates of seismic hazard. We discussed with the visitor the fact that the seismogram archive at BRV is a unique resource for study of Kazakhstan seismicity.

BRV is at a distance of about 142° from the French nuclear test site at Mururoa, and hence strong signals are received near the *PKP* caustic from French explosions.

DISCUSSION OF FUTURE RESEARCH PROJECTS

We agreed informally with Adushkin and Khaidarov to undertake joint research on the following five projects:

(1) Interpretation of BRV data for regional earthquakes such as the large 1990 June event at Zaisan Lake;

(2) study of tectonic release for large Balapan explosions, in particular a reconciliation of BRV data with teleseismic surface waves for those events for which a non-isotropic moment tensor has been inferred teleseismically;

(3) calibration of *Lg* at Mikhnevo and Borovoye versus yield for Soviet explosions of announced yield;

(4) a study of arrival times teleseismically from large explosions at Balapan and NTS;and

(5) a study of Azgir nuclear explosions recorded at BRV.

There were expressions of interest (from BRV staff) in software for picking and analyzing weak signals in noisy data, with the goal of improving the fraction of detections (~ 1000 per month) that are currently turned into location estimates (~ 100 per month) in their weekly bulletin.

It was our impression that the people working in the USSR on BRV data are among the most sophisticated data-oriented seismologists in the Soviet Union, and that they are interested in cooperative work on a variety of subjects with U.S. seismologists.

CONCLUSIONS AND RECOMMENDATIONS

We now have 37 examples of digital data from BRV for nuclear explosions conducted at Shagan River (Balapan), Novaya Zemlya, and Lop Nor. At least two of these examples (1972 December 10, 1978 August 29) are double explosions. We also have data on about 10 earthquakes (some regional, some teleseismic). We are pursuing the question of calibration (amplitude and phase responses) for all the data so far received.

In the process of acquiring this data, we were given much information on what clearly is the most sophisticated seismic station in operation in the Soviet Union. We were also told of further data that would be made available, in about two months, in response to our written requests.

We shall of course make this data generally available. Note that if all our current requests are honored, we shall still have, at best, about two hundred examples – only a small fraction of a unique digital database that consists of at least tens of thousands of earthquakes, and several hundred nuclear explosions.

If the research community in the U.S. deems these data valuable, then there will be some consideration of an effort to copy as much as possible of the whole digital archive at BRV into a modern format, for use by seismologists in the Soviet Union as well as the United States.

Such an effort may usefully be thought of as consisting of two separate steps. First, to copy all the wide tapes (we believe there are 5,000 - 10,000 of them) to a modern recording medium such as Exabyte tapes. This would not be a major project, but some consideration would have to be given to special staff support at BRV for the duration of the copying, in addition to hardware. The goal here is very simple: to salvage as soon as possible an archive that is degenerating and that will be lost in the next few years if nothing is done (since many of the wide tapes are in poor and worsening condition). Second, to work with BRV personnel on the design of a suitable new format for the archive; to incorporate all the available information on instrument responses; to develop software for reading the old data (transferred to a new medium in Step 1); and thus to implement a new format with appropriate quality controls. The second step requires a plan with milestones and an agreed schedule, and might take a few years to execute. The need will be not for massive funding, but rather for a few knowledgeable people on each side to agree on a program of steady work at a moderate budget.

We are not advocating either the first step, or the two steps together, at the present time. But if the data we have so far acquired, supplemented by the data we have been told will be forthcoming, is found to be of high quality, then we expect to be making the case for salvaging and modernizing what clearly is a unique digital archive at Borovoye.

APPENDIX I: DATA REQUEST, DECEMBER 1990

S H A G A N R I V E R E X P L O S I O N S

YR	DOY	MON	DAY	HR	MI	SEC	LAT	LON	MB	MS	# STA	STATIONS/ COMMEMTS/INFO
72		DEC	10	4	27	08.4			5.96			(AWE) 2 EVENTS
73		JUL	23	1	22	57.8			6.17			(AWE O 15/88)
78		AUG	29	2	37	06.5			5.90			(AWE)
80		SEP	14	2	42	39.3			6.21			(AWE)
88	044	FEB	13	3	05	05.9	49.954N	78.910E	6.1	4.5	470	
	094	APR	03	1	33	05.8	49.917N	78.945E	6.1		467	
	125	MAY	04	0	57	06.8	49.928N	78.769E	6.1		463	
	166	JUN	14	2	27	06.4	50.045N	79.005E	5.0	4.1	154	
	258	SEP	14	3	59	57.4	49.833N	78.808E	6.10	4.5	551	ARU KIV OBN GAR
	270	SEP	26	7	45	0.0	50.000N	79.000E	4.30	(NAO only)		ARU GAM (zip NEIS)
	317	NOV	12	3	30	3.7	50.078N	78.988E	5.30	4.3	236	ARU GAR
	352	DEC	17	4	18	6.9	49.886N	78.926E	5.90	4.5	440	ARU OBN

N O V A Y A Z E M L Y A E X P L O S I O N S

YR	DOY	MON	DAY	HR	MI	SEC	LAT	LON	MB	MS	# STA	COMMENTS
77		SEP	01	02	59	58.0	73.339N	54.626E	5.71			(AWRE O 17/86)
77		OCT	09	10	59	58.1	73.414N	54.935	4.51			(AWRE O 17/86)
88	128	MAY	07	22	49	58.1	73.364N	54.445E	5.6	3.8	384	
	339	DEC	4	5	19	53.0	73.387N	54.998E	5.9	4.6	416	GAM
90	297	OCT	24	14	58	00			5.7			(NORSAR)

U S S R E A R T H Q U A K E S

YR	DOY	MON	DAY	HR	MI	SEC	LAT	LON	DEPTH	MB	MS	COMMENT
76		MAR	20	04	03	39.3	50.02N	77.37E		5.1		(ISC, E. KAZ.)
86		AUG	01	13	56	37.1	72.93N	55.8E		4.8		(ISC, NOV. ZEM.)
89	128	MAY	08	00	03	13.5	44.792N	79.785E	33	4.6		aru gar kiv obn

O T H E R E A R T H Q U A K E S

YR	DOY	MON	DAY	HR	MI	SEC	LAT	LON	DEPTH	MB	MS	COMMENT
68		JUL	01	19	14	54.7	44.0N	79.3E		4.8		(LANDERS)
68		JUL	13	05	05	54.2	30.3N	94.6E		5.0		(LANDERS)
68		JUL	14	18	12	40.9	30.3N	94.8E		4.9		(LANDERS)
68		JUL	15	05	09	05.9	30.3N	95.0E		4.8		(LANDERS)
69		MAY	01	04	00	08.7	44.0N	77.9E		4.9		(LANDERS)

C H I N E S E E X P L O S I O N S (DATES, AND APPROX. TIMES

69 SEP 22 1615	82 OCT 05 0800	84 DEC 19 0600	90 AUG 16 0500
75 OCT 27 0100	83 MAY 04 0500	87 JUN 05 0500	
76 OCT 17 0500	83 OCT 06 1000	88 SEP 29 0700	
78 OCT 14 0100	84 OCT 03 0600	90 MAY 26 0800	

APPENDIX II: BRV DATA RECEIVED IN MARCH 1991

SHAGAN RIVER EXPLOSIONS

ORIGIN YR	DOY	MON	DAY	TIME HR	MI	SEC	LOCATION LAT	LON	MAGNITUDES MB	MS	BOROVOYE DATA TIME SERIES NUMBER
72		DEC	10	4	27	08.4			5.96		1
73		JUL	23	1	22	57.8			6.17		2
78		AUG	29	2	37	06.5			5.90		16
80		SEP	14	2	42	39.3			6.21		3, 4
88	044	FEB	13	3	05	05.9	49.954N	78.910E	6.1	4.5	5
	094	APR	03	1	33	05.8	49.917N	78.945E	6.1		6, 7, 13
	125	MAY	04	0	57	06.8	49.928N	78.769E	6.1		8
	166	JUN	14	2	27	06.4	50.045N	79.005E	5.0	4.1	9
	258	SEP	14	3	59	57.4	49.833N	78.808E	6.10	4.5	10, 11, 14
	317	NOV	12	3	30	3.7	50.078N	78.988E	5.30	4.3	12, 15
	352	DEC	17	4	18	6.9	49.886N	78.926E	5.90	4.5	17, 18

NOVAYA ZEMLYA EXPLOSIONS

ORIGIN YR	DOY	MON	DAY	TIME HR	MI	SEC	LOCATION LAT	LON	MAGNITUDES MB	MS	BOROVOYE DATA TIME SERIES NUMBER
77		SEP	01	02	59	58.0	73.339N	54.626E	5.71		19
77		OCT	09	10	59	58.1	73.414N	54.935	4.51		20
88	128	MAY	07	22	49	58.1	73.364N	54.445E	5.6	3.8	21, 22, 23
	339	DEC	4	5	19	53.0	73.387N	54.998E	5.9	4.6	24, 25
90	297	OCT	24	14	58	00			5.7		33, 34

USSR EARTHQUAKES

ORIGIN YR	DOY	MON	DAY	TIME HR	MI	SEC	LOCATION LAT	LON	DEPTH	MAGNITUDES MB	MS	BOROVOYE DATA TIME SERIES NUMBER
69		MAY	01	04	00	08.7	44.0N	77.9E		4.9		43
76		MAR	20	04	03	39.3	50.02N	77.37E		5.1		38, 39
89	128	MAY	08	00	03	13.5	44.792N	79.785E	33	4.6		40, 41, 42

CHINESE EXPLOSIONS

69		SEP	22	16	15	26
83		OCT	06	10		27, 28
84		OCT	03	06		29
84		DEC	19	06		30
87		JUN	05	05		31, 32
90		AUG	16	05		35, 36, 37

APPENDIX III: Excerpt from *Pravda,* 26 July 1986 (English version)

I "See" a Nuclear Explosion

Report from the Seismic Expedition of the USSR Academy of Sciences Institute of Geophysics

All over the official quarters here, electronic clocks are ticking off the seconds, but not with our time, local, or Moscow time. You look at them with a certain amount of apprehension. They are expected to determine the time of any global event buzzing through the earth's crust with the precision of up to a hundredth of a second Greenwich mean time. This includes natural events, such as an avalanche, tsunami or earthquake, or artificial ones, such as a nuclear explosion.

Right now we are awaiting the moment of explosion in Nevada, the 15th since the Soviet Union announced its unilateral moratorium. The previous one, the 14th, was carried out quite recently. Its exact time is noted here: July 17, 9:13 p.m., 1.16 seconds Greenwich mean time. It was done suddenly, without notice. And it was precisely fixed at a distance of almost 10,000 kilometers.

We did not know when this test was to occur. There is nothing to do but wait for the readings of the instruments. With the naive habit of one waiting, I wanted to see with my own eyes how, in a 15-meter shaft somewhere under us, the needles of the seismometer would tremble from the far-off shock. It is not allowed. Not only the rumble of my steps, but the temperature of my body would influence the readings of the sensitive instruments, as they are called upon to reflect the smallest change in the world surrounding them.

However, the electronic amplifiers and numerical stations developed at the Institute of Geophysics will show in synchrony and even "explain" what ought to be happening somewhere below us.

"Approximately such a seismograph will result." The expedition head V. Lampei and his assistant in the science department, V. An, indicated a long tape on which the trace of the events on the Nevada range burst up as a mountain peak, 40 times greater than the usual microseismic background. Now the electronic computer "printout" table, produced by a specially developed program, "Seismostation" is put into use.

I read the information listed there: the azimuth of the approach of the seismic wave, the angle of incidence, latitude and longitude. With it, even a non-specialist can easily determine the coordinates of the explosion's epicenter. And finally, the last figure: the magnitude of the explosion is in the 5.2 - 5.3 range.

"This is of a very large magnitude for our instruments", our companions explained. "It even allows us to draw precise conclusions about the time and coordinates of the event on the basis of readings from only one observation station. Here in northern Kazakhstan we can 'hear' whatever you want – even the shock of a large wave in the Barents Sea."

Earthly firmness – no, from the point of view of seismology, this is not a very accurate expression. The planet heaves and sounds in various "voices" under our feet; with each shock it is as if a spasm runs through its body; on some small part a particle of soil moves and a seismic wave results. And like the electron microscope, contemporary seismological instruments are capable of magnifying the echoes of these motions a million times. So, in today's expedition, the fluctuations of the soil are registered to the hundredth place of one-billionth of a meter.

Here is more about one of the Earth's peculiarities. It is generally known that it is best to place seismological instruments on a firm foundation so that outside interferences do not influence them. The granite of the Kazakhstan platform satisfies these conditions in the best way possible. But several decades ago, when this region (speaking in the language of specialists), with its low level of microseismic vacillations and industrial interferences, began to be used for tests of seismological instruments, still one more of its curious properties was discovered. The platform, like the violin of a good master, resonates and responds to the smallest underground "sounds". Exactly why and how this happens is still unclear. But it has been precisely established that this is the best region of the continent to "hear" what is happening, for example, in the underground galleries of the state of Nevada. Incidentally, even American scientists were recently convinced of this. Their instruments which were set up in Karkaralinsk, also on a granite platform – and not even in a shaft, but directly on the surface – distinctly detected the explosion whose seismogram now lies in front of us.

Of course, seismology as a science was not created and developed for verifying the level of weaponry. In a way, the seismic waves picked up by the instruments are X-raying the planet, enriching our fundamental knowledge about its structure and providing practical information about mineral deposits. Unfortunately, in recent decades signals from underground nuclear explosions have interfered here.

"But surely it is still necessary to distinguish them from signs of the turbulent inner life of our uncooled planet?"

"Specialists learned to do that long ago. Here, look at this collection for example."

I looked at the book *Underground Atomic Explosions*, published in Moscow back in 1962. This is a translation of articles by American specialists, based on investigation materials of underground nuclear tests conducted in the U.S. The phenomena in zones close to, between sites, interstitial, and far from the explosion are examined here, and corresponding calculations and graphs are listed. I remember that at approximately the time that the articles were written and when specialists were becoming more and more convinced that with national means of verification it was possible to detect violations of a ban on underground tests, the US did not engage in concluding a corresponding agreement. Then President Eisenhower declared that tests were necessary for the US in creating a "completely clean bomb."

Since then, national methods of verification have been improved even more. In particular, an article by one of my interlocutors, V. Anom, in co-authorship with Ye. Lyuke and I. Pasechnik, analyzing tapes of the explosions carried out by the US on the Nevada Range from 1961 through 1983, was published in volume No. 285 of the 1985 reports of the USSR Academy of Sciences. On this basis, the authors succeeded in establishing extremely precise regularity, such as a 10-11 year period of variation in the parameters of seismic waves.

"You know," relates Vadim Aleksandrovich, "the subject of our particular pride is the expedition's activities. During 20 years of work, practically all the underground nuclear explosions conducted in the US and other countries with a force of from one to two kilotons to five megatons were recorded. More than 200,000 magnetic digital recordings of earthquakes are included in the archives as well. In a word, the basis for the most profound analysis and comparison has been accumulated.."

It remains to be said that, in addition to seismic waves, explosions are accompanied by an infrasonic acoustic wave which gives rise to disturbances in the ionospheric stratum and the Earth's magnetic field. Therefore, there are other methods as well for verification – surface and satellite means. The scientific base and the reliability of methods of verification are broadening. Unfortunately, the position of the US administration remains unchanged. It stubbornly rejects various proposals to conclude an agreement on a comprehensive nuclear test ban. Only now, in place of the dream of a "clean bomb," the intention to create a military space system has set in.

"...There it is!" softly says one of the operators who monitor the instruments here on a round the clock basis. The spasm from the latest explosion in Nevada ran through the body of the Earth to its very core, and having been reflected off it somewhere under the North Pole, it headed toward the Kazakhstan platform, abruptly shooting up its "cardiogram" measuring the planet's pulse. After a minute or two we will receive the precisely measured parameters of the signal. But here they have learned to recognize news from Nevada at the first glance. It is already clear that 780 seconds ago a new nuclear explosion took place. . .

Leaving the expedition, we dropped in at a rather new building. There, in a granite body, 100-meter slits for a seismic device, whose potentialities are many times greater than the instruments operating today, have already been drilled. On behalf of a peaceful future for humanity, science is strengthening its arguments in the struggle with the atomic threat. In the future, let everyone's clocks – Greenwich, Moscow or Washington – read only a peaceful time.

A. POKROVSKY
(Spec. *Pravda* corr.)

Kazakh SSR.

APPENDIX IV: Personnel associated with BRV

Adushkin, Vitaly Vasiliovich

Director of the Institute for Dynamics of the Geosphere – which operates the Borovoye Geophysical Observatory. Worked closely with Academician Sadovsky for 35 years on physical phenomena (e.g. physics of shock waves) associated with all types of explosions. Chief technical advisor on uses of chemical explosions to build dams in Central Asia. Studies of cavity decoupling.

An, Vadim Alexandrovich

Former technical director of seismology at the Borovoye Geophysical Observatory, now (after 25 years work at Borovoye) the person with most knowledge of history and seismological practice at BRV; detailed studies of NTS explosions, and of *P* -wave travel times (which he claims show slight variability on a time scale of 10-11 years).

Bashilov, Igor Gorfirievich

A specialist in seismic instrumentation, his doctoral thesis describes the ASSTs seismometers and recording system.

Kaazik, Peter

Expert programmer, has developed PC-based quick displays and analyses of Borovoye data.

Khaidarov, Karim

Computer scientist in charge of seismic data acquisition and routine analysis at Borovoye.

Kitov, Ivan

Uses of high-frequency seismic waves for explosion monitoring. Studies of cavity decoupling.

Marenko, Vladimir

User of OMEGA time signals from six stations, compared at BRV with a rubidium clock, for purposes of research in earthquake prediction.

Ovtchinnikov, Vladimir

Analyses of automatic (i.e. computer assisted) detection and location capability of the Borovoye station, studies of dispersion in crustal reflections.

Pleskach, Nicholai Constantin

Studies of Earth noise, chief scientist at Mikhnevo seismic station (south of Moscow).

Spivak, Alexander

Studies of low-magnitude seismicity following nuclear explosions, and estimates of extent of crushed rock in the vicinity of the shot point of Soviet nuclear explosions. Many studies of rock properties near the shot point.