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Background Noise Spectra of Global Seismic Stations

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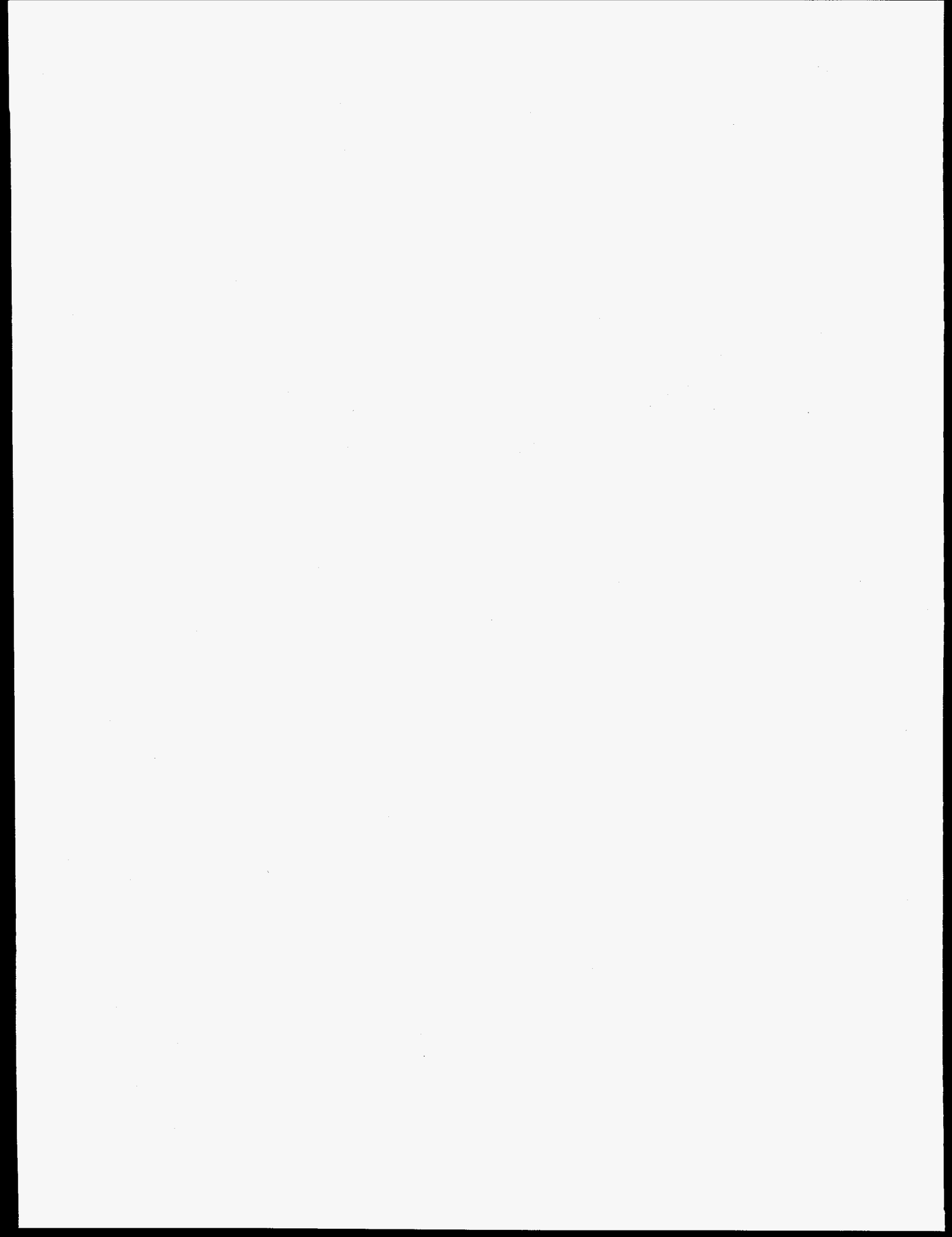
Abstract:

Over an extended period of time station noise spectra were collected from various sources for use in estimating the detection and location performance of global networks of seismic stations. As the database of noise spectra enlarged and duplicate entries became available, an effort was mounted to more carefully select station noise spectra while discarding others. This report discusses the methodology and criteria by which the noise spectra were selected. It also identifies and illustrates the station noise spectra which survived the selection process and which currently contribute to the modeling efforts. The resulting catalog of noise statistics not only benefits those who model network performance but also those who wish to select stations on the basis of their noise level as may occur in designing networks or in selecting seismological data for analysis on the basis of station noise level. In view of the various ways by which station noise were estimated by the different contributors, it is advisable that future efforts which predict network performance have available station noise data and spectral estimation methods which are compatible with the statistics underlying seismic noise. This appropriately requires 1) averaging noise over seasonal and/or diurnal cycles, 2) averaging noise over time intervals comparable to those employed by actual detectors, and 3) using logarithmic measures of the noise.

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Acknowledgments

The authors wish to acknowledge and thank the many people who contributed noise spectra to this work. Jon Peterson of ASL/USGS provided the noise spectra for the GSN and USGS stations. This station noise database was extended by the analysis of noise data from the GEOSCOPE stations as provided by J. P. Montagner. Michel Morand of GEOSCOPE provided the software for reading their SEED formatted data. Additional noise spectra, primarily for the AFTAC and GSETT-3 stations, were provided by Keith McLaughlin of S-Cubed. D. R. Breeding, D. B. Carr, E. P. Chael, and P. B. Herrington of Sandia National Laboratories provided helpful reviews of this work and report.

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1.0 Introduction

Over an extended period of time station noise spectra were collected from various sources for use in estimating the detection and location performance of global networks of seismic stations. The goal of the underlying effort was to 1) evaluate global networks which have been proposed for monitoring a CTBT, 2) develop viable physical and theoretical bases for modeling network performance, and 3) develop a framework for understanding the performance of seismic networks. As the database of noise spectra enlarged and duplicate entries became available from various sources, an effort was mounted to more carefully select station noise spectra while discarding others. This report discusses the methodology and criteria by which the noise spectra were selected. It also identifies and illustrates the station noise spectra which survived the selection process and which currently contribute to the modeling efforts. The utility of this catalog of noise statistics not only benefits those who model network performance but also those who wish to select stations on the basis of their noise level as may occur in designing networks or in selecting seismological data for analysis on the basis of station noise level.

2.0 Approach

In order to systematically review a large set of noise files, a graphics program (QC_SPECTRA) was prepared to plot all the available noise spectra from various sources. The program was controlled by a master list of the station noise files. The program excluded noise files whose maximum frequency was less than 0.1 hertz. The program was flexible enough to read files containing or missing the noise standard deviation as a function of frequency. Some station noise spectra included estimates at frequencies lower than 0.001 Hz, but that portion of the spectrum was not illustrated in this report.

The spectra plotted by QC_SPECTRA for the same station were comparatively examined for consistency 1) across overlapping bands of frequencies, 2) between estimates from different sources (USGS, IRIS, CMR, AFTAC, SNL, etc.), and 3) within the constraints imposed by the Peterson high and low noise models¹. In cases where the noise spectra were available for the same seismographic station and the SNL estimates were among the choices, the SNL estimates were accepted because the estimates were based

on a procedure consistent with the statistics associated with seismic noise models in the detection algorithms.

Based on the span of frequencies associated with the station seismometers, the noise spectra were identified as high frequency (HF), very broad band (VBB), broad band (BB), short period (SP), long period (LP), or very long period (VLP) using a bandpass convention similar to that used by the Federation of Digital Seismographic Networks (FDSN). Except for the SP spectra, the spectra noise files which qualified for inclusion in the database were renamed incorporating these channel designations within their names, e.g., "xxx_vbb.noi". The SP files were identified with special names such as "xxx_day.noi" or "xxx_nig.noi" to reflect their daytime and nighttime noise characteristics, respectively. Here "xxx" designates the station code. For those stations having only a single SP spectral estimate, the spectrum was arbitrarily associated with the daytime condition.

Modifications were applied to some of the selected station noise spectra. A few of the spectra were smoothed using a 3 point moving average. This smoothing of the spectra avoided "singularities" as might be introduced by NetSim² as it interpolates or extrapolates noise spectra upon data entry. Other files had their last point(s) removed or replaced when the noise value(s) deviated drastically from the preceding values. These large deviations are typically caused by the large uncertainties associated with compensating for the hard roll-off characteristic of the seismometer digital filter when translating the sensor output into ground motion.

The noise standard deviation as a function of frequency was not universally available for spectra produced by others. For these stations, a standard noise deviation of 0.3 magnitude units was assigned uniformly at each frequency. In a few cases the 5 and 95 percentile estimates together with the median noise level were available. From these latter estimates it was assumed that the median noise represented the mean noise level required by the detection model. The standard deviation of the noise was roughly estimated from the 5 and 95 percentile levels.

Finally some of the station names have been altered to be consistent with designations assigned by others in earlier efforts and maintained in our database. Table 1 identifies these changes and the one mentioned above.

3.0 Station Noise Spectra

The stations for which noise spectra were accepted after the consistency checks are listed in Table 2. This table primarily documents the station locations and lists the bands for which noise spectra are available. The station "mean" spectra together with the assigned or computed standard deviations are illustrated alphabetically by station code in Appendix A.

Table 1. Modifications to the Station Noise Spectra

STATION CODE	OLD NAME	NEW NAME	ACTION
ARAO	arao_day.noi	arao_day.n	Station code changed from ARCES
ARAO	arao_nig.noi	arao_nig.noi	Station code changed from ARCES
ARU	ARU.m.noi	aru_day.noi	Deleted last point
ATTU	fx.30.noi	attu_sp.noi	Station code changed from ATAK
BDFB	BDFB.m.noi	bdfb_day.noi	Deleted last point
BGCA	BGCA.m.noi	bgca_day.noi	Deleted last point
BOSA	bosa_day.noi	bosa_day.noi	Preferred SNL estimates
BOSA	bosa_nig.noi	bosa_nig.noi	Preferred SNL estimates
CLZ	CLZ.m.noi	clz_day.noi	Deleted last point
DRLN	DRLN.m.noi	drln_day.noi	Deleted last point
ENH	enh_day.noi	enh_day.noi	Smoothed estimates
ENH	enh_nig.noi	enh_nig.noi	Smoothed estimates
FCC	FCC.m.noi	fcc_day.noi	Deleted last point
FINO	FINES.m.noi	fino_day.noi	Station code changed from FINES
FINO	FINES.m.noi	fino_day.noi	Deleted last point
GECZ	GEC2.m.noi	gecz_day.noi	Station code changed from GERES
HIA (HAI)	HAI.m.noi	hia_vbb.noi	Station code changed from HAI
HIA	hia_day.noi	hia_day.noi	Smoothed estimates
LMN	LMN.m.noi	lmn_med.noi	Deleted last point
LMQ	LMQ.m.noi	lmn_med.noi	Deleted last point
MBC	MBC.m.noi	mbc_day.noi	Deleted last point
MIAR	MIAR.m.noi	miar_day.noi	Deleted last point

Table 1. Modifications to the Station Noise Spectra

STATION CODE	OLD NAME	NEW NAME	ACTION
PDAR	PD05.m.noi	pdar_day.noi	Deleted last point
PDY	PDY.m.noi	pdy_day.noi	Deleted last point
PGC	PGC.m.noi	pgc_day.noi	Deleted last point
PLCA	PLCA.m.noi	plca_day.noi	Deleted last point
PMB	PMB.m.noi	pmb_med.noi	Deleted last point
PMSA	pmsa.bhz.noi	pmsa_vbb.noi	Deleted last point
RAR	rar_day.noi	rar_day.noi	Preferred SNL estimates
RAR	rar_nig.noi	rar_nig.noi	Preferred SNL estimates
RES	RES.m.noi	res_day.noi	Deleted last point
SADO	SADO.m.noi	sado_day.noi	Deleted last point
SBC	sbc_day.noi	sbc_day.noi	Preferred SNL estimates
SBC	sbc_nig.noi	sbc_nig.noi	Preferred SNL estimates
SCHQ	SCHQ.m.noi	schq_day.noi	Deleted last point
SPITS	SPITS.m.noi	spits_day.noi	Deleted last point
SSE	sse_day.noi	sse_day.noi	Smoothed estimates
SSE	sse_nig.noi	sse_nig.noi	Smoothed estimates
TXAR	TX02.m.noi	txar_day.noi	Deleted last point
ULM	ULM.m.noi	ulm_day.noi	Deleted last point
UNM	unm.thz.noi	unm_day.noi	Smoothed estimates
VNDA	VNDA.m.noi	vnda_day.noi	Deleted last point
WALA	WALA.m.noi	wala_day.noi	Deleted last point
WMQ	wmq_day.noi	wmq_day.noi	Smoothed estimates
WMQ	wmq_nig.noi	wmq_nig.noi	Smoothed estimates
YKA	YKR8.m.noi	yka_day.noi	Deleted last point
YSS	yss.bhz.noi	yss_vbb.noi	Deleted last point

The reader should be aware that since most of the noise spectra came from outside sources, the actual quality of the estimates cannot be assured by the authors of this work. It is reasonable to assume that the spectral densities produced by other were accurately estimated using conventional and in some

cases advanced procedures. However, to establish the mean and standard deviation of the spectral estimates for use in network modeling requires careful sampling of the noise records throughout an entire annual or a diurnal cycle. The particular circumstances under which the noise was sampled by others is not known by the authors. Further, most of the spectra were not averaged on a logarithmic basis as required by the network models nor were the standard deviations in logarithmic noise estimated. Both the mean and standard deviation of logarithmic noise can significantly influence detection performance.

It can be stated that those daytime SP spectra estimated by the authors were carefully produced from noise records available over an entire calendar year within 2 hours of local noon to document the seasonal effects. The nighttime SP spectra, when available, were estimated from noise data recorded during the pre-dawn hours over a calendar year. These two periods of time are thought to represent the worst and best noise cases, respectively. The frequency dependent noise standard deviations, which are essential to network modeling, were included in the SNL estimates. This technique was applied to the NORESS, ARCESS, and GEOSCOPE station noise records.

4.0 Conclusions

Since station noise has a significant influence on the performance level of monitoring networks, it was extremely important to have available measures of actual station noise in estimating the performance of proposed monitoring networks. The authors were grateful to all who contributed noise spectra, in some cases from stations only recently installed. The duplicate measures of station noise from various sources provided an opportunity to build better confidence in some of the noise measures and, as a consequence, better confidence in the network predictions.

In view of the various ways by which station noise can be estimated, it is advisable that future efforts which predict network performance have available station noise data and spectral estimation methods which are compatible with the statistics underlying seismic noise. This appropriately requires 1) averaging noise over seasonal and/or diurnal cycles, 2) averaging noise over time intervals comparable to those employed by actual detectors, and 3) using logarithmic measures of the noise. For those estimates which were based on the mean spectral density, it can be stated that when the noise

standard deviation is small the log of the mean spectral density is approximately the mean of the log spectral density. For some stations, this is a good assumption, but not for all stations. For example, the standard deviations for the noisy stations are typically large and would not satisfy this criterion.

As additional station noise data become available for the primary and auxiliary stations proposed in monitoring a CTB treaty, these data should be analyzed to derive the noise statistics as required by NetSim. These additional spectra should then be used to upgrade the network performance estimates for the proposed networks. Where necessary, the station noise statistics in the existing database should be re-examined using log normal statistics as a basis for the spectral estimates. Coda noise models for other media are also required.

Table 2. Stations for Which the Background Noise Spectra are Available

Station Code	Latitude	Longitude	Location	Available Bandpasses
AAK	42.640	74.490	Ala-Archa, Kirghizstan	SP,VBB
AFI	-13.910	-171.780	Afiamalu, Samoa Islands	SP
AGD	11.530	42.820	Arta Grotte, Djibouti	BB
ALE	82.480	-62.400	Alert, N.W.T., Canada	SP,VBB
ALQ	34.940	-106.460	Albuquerque, New Mexico, U.S.A.	SP
ANMO	34.950	-106.460	Albuquerque, New Mexico, U.S.A.	SP,VBB)
ANTO	39.870	32.790	Ankara, Turkey	SP,VBB
AQU	42.350	13.400	L'Aquila, Italy	VBB
ARAO	69.535	25.506	Karasjok, Norway (R array)	HF
ARU	56.400	58.600	Arti, Russia	SP,VBB
ASAR	-23.666	133.905	Alice Springs, Australia (T array)	SP
ATTU	52.8821	173.1642	Attu Island, Alaska	SP
BBB	58.180	-125.360	Bella Bella, B.C., Canada	HF
BCAO	4.440	18.550	Bangui, Central African Republic	SP
BDF	-15.660	-47.900	Brasilia, Brazil	VLP
BDFB	-15.642	-48.015	Brasilia, Brazil	SP
BFO	48.330	8.330	Schiltach, Germany	HF

Table 2. Stations for Which the Background Noise Spectra are Available

Station Code	Latitude	Longitude	Location	Available Bandpasses
BGCA	5.170	18.400	Bogoin, Central African Republic	SP
BGY	44.800	20.520	Beograd, Yugoslavia	VBB
BJI	40.040	116.180	Baijatuan (Beijing), China	HF, VBB, VLP
BKS	37.880	-122.240	Berkeley, California, U.S.A.	HF
BLA	37.210	-80.420	Blacksburg, Virginia, U.S.A.	HF
BNG	4.440	18.550	Bangui, Central African Republic	BB
BNI	45.050	6.680	Bardonecchia, Italy	VBB
BOCO	4.590	-74.040	Bogota, Columbia	SP
BOSA	-28.614	25.555	Boshof, South Africa	SP
BRTR	39.00	34.00	Belbashi, Turkey (R array)	SP
BUG	51.490	7.210	Bochum, Germany	HF
CAN	-35.320	149.000	Canberra, (ANU) Australia	SP, VLP
CAY	4.950	-52.320	Cayenne, French Guyana	BB, LP
CCM	38.060	-91.240	Cathedral Caves, Missouri, U.S.A.	SP, VBB
CHTO	18.810	98.940	Chiang Mai, Thailand	SP, VBB, VLP
CLZ	51.840	10.370	Clausthal, Germany	HF
CMAR	18.824	98.947	Chiang Mai, Thailand (T array)	SP, VLP
CMB	38.040	-120.380	Columbia, California, U.S.A.	VBB, VLP, SP

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Table 2. Stations for Which the Background Noise Spectra are Available

Station Code	Latitude	Longitude	Location	Available Bandpasses
COL	64.900	-147.790	College Outpost, Alaska, U.S.A.	SP,VBB,VLP
COR	44.590	-123.300	Corvallis, Oregon, U.S.A.	SP,VBB
CPUP	-26.331	-57.329	Villa Florida (Caapucu), Paraguay	SP
CRZF	-46.430	51.860	Port Alfred, Crozet Islands	BB
CSY	-66.290	110.530	Casey, Antarctica	SP
CTA	-20.09	146.26	Charters Towers, Queensland	SP
CTAO	-20.090	146.250	Charters Towers, Queensland	SP,VBB,VLP
DAWY	64.07	-139.39	Dawson, Canada	HF
DLBC	58.42	-130.06	Dease Lake, B.C., Canada	HF
DRLN	49.000	-57.800	Deer Lake, Newfoundland, Canada	HF
DRV	-66.660	140.010	Dumont d'Urville, Antarctica	BB
DUG	40.200	-112.810	Dugway, Utah, U.S.A.	HF
EDM	53.220	-113.350	Edmonton, Alberta, Canada	HF
EKB	55.340	-3.180	Eskdalemuir, Scotland, U.K.	BB
ELAK	64.771	-146.886	Eielson AFB, Alaska (T array)	SP
ENH	30.270	109.490	Enshi, China	HF,VBB,VLP
ENN	50.77	5.92	Epen, The Netherlands	SP
ERM	42.020	143.160	Erimo, Japan	SP,VBB

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Table 2. Stations for Which the Background Noise Spectra are Available

Station Code	Latitude	Longitude	Location	Available Bandpasses
ESDC	39.674	-3.963	Sonseca, Spain (R array)	SP
ESK	55.320	-3.200	Eskdalemuir, Scotland, U.K.	BB
FCC	58.760	-94.080	Churchill, Manitoba, Canada	HF
FFC	54.720	-101.980	Flin Flon, Manitoba, Canada	SP
FINO	61.440	26.080	Helsinki, Finland (R array)	HF
FL	54.719	-101.995	Flin Flon, Canada (T array)	SP
FRB	63.740	-68.540	Iqaluit (Frobisher Bay), N.W.T., Canada	HF
GAC	45.700	-75.470	Glen Almond, Quebec, Canada	HF
GAR	39.000	70.320	Garm, Tajikistan	SP,VBB
GBA	13.604	77.436	Gauribidanur, India (T array)	SP
GDH	69.250	-53.533	Godhavn, Greenland	SP,VLP
GECZ	48.820	13.570	GERESS Site, Freyun, Germany (R array)	HF
GFA	31.340	9.730	Gafsa, Tunisia	VBB
GNI	40.050	44.720	Garni, Armenia	SP,VBB
GRA	47.727	15.442	Graz (Seiermark), Austria	SP
GRF	49.690	11.220	Graefenberg, Germany	SP
GSC	35.300	-116.800	Goldstone, California, U.S.A.	SP,VBB
GUMO	13.540	144.920	Guam, Marianas Islands, U.S.A	SP,VBB

Table 2. Stations for Which the Background Noise Spectra are Available

Station Code	Latitude	Longitude	Location	Available Bandpasses
HFS	60.13	13.70	Hagsfor, Sweden (array)	SP
HIA	49.270	119.742	Hailar, China (R array)	HF,VBB,VLP
HRV	42.510	-71.560	Harvard, Massachusetts, U.S.A.	SP,VBB
HYB	17.420	78.550	Hyderabad, India	SP,VLP
INK	68.290	-133.500	Inuvik, N.W.T., Canada	HF
INU	35.350	137.030	Inumaya, Japan	SP
ISA	35.660	-118.470	Isabella, California, U.S.A.	SP,VBB
KAAO	34.5407	69.0428	Kabul, Afganistan	SP
KAF	62.11	26.31	Kangasniemi, Finland	SP
KEG	29.930	31.830	Kottamya, Egypt	VBB,VLP
KEV	69.760	27.010	Kevo, Finland	SP
KIP	21.42	-158.02	Kipapa, Hawaii, U.S.A.	SP,VBB,VLP
KIV	43.950	42.680	Kislovodsk, Russia	SP,VBB
KIVO	43.955	42.695	Kislovodsk, Russia (R array)	HF
KMI	25.120	102.740	Kunming, China	HF,VBB,VLP
KONO	59.650	9.600	Kongsberg, Norway	SP,VBB
KSAR	37.454	127.923	Wonjo, Korea (T array)	SP
KSP	50.8303	16.2893	Ksiaz, Poland	HF

Table 2. Stations for Which the Background Noise Spectra are Available

Station Code	Latitude	Longitude	Location	Available Bandpasses
LBNH	44.240	-71.930	Lisbon, New Hampshire, U.S.A.	HF
LBTB	-25.015	25.597	Lobatse, Botswana	SP
LEM	-6.833	107.616	Lembang, Indonesia	SP
LMN	45.850	-64.800	Caledonia Mountain, New Brunswick, Canada	HF,LP
LMQ	47.540	-70.330	La Malbaie, Quebec, Canada	HF
LON	46.750	-121.810	Longmire, Washington, U.S.A.	SP,VLP
LOR	47.268	3.859	Lormes, France	HF
LPAZ	-16.288	-68.131	La Paz, Bolivia	SP
LSA	29.700	91.150	Lhasa, Tibet, China	HF,VBB,VLP
LVZ	67.900	34.650	Lovozero, Russia	VBB
LZH	36.090	103.840	Lanzhou (Lanchou), China	HF,VBB,VLP
MAIO	36.3000	59.4945	Mashad, Iran	SP
MAJO	36.540	138.210	Matsushiro, Japan	SP,VBB
MAW	-67.600	62.870	Mawson, Antarctica	SP
MBC	76.240	-119.360	Mould Bay, N.W.T., Canada	HF
MBO	14.390	-16.960	M'Bour, Senegal	BB
MDJ	44.620	129.590	Mudanjiang, China	HF,SP,VLP
MDT	32.740	-4.580	Midelt, Morocco	VBB

Table 2. Stations for Which the Background Noise Spectra are Available

Station Code	Latitude	Longitude	Location	Available Bandpasses
MIAR	34.550	-93.580	Mount Ida, Arkansas, U.S.A.	HF
MJAR	36.54	138.21	Matsushiro, array, Japan	HF
MLR	45.492	25.944	Muntele Rosu, Romania	SP
MYNC	35.0739	-84.1279	Murphy, North Carolina, U.S.A.	HF
NCB	43.9708	-74.2235	Newcom, New York, U.S.A.e	SP
NEW	48.260	-117.120	Newport, Washington, U.S.A.	HF
NIL	33.600	73.100	Islamabad, Pakistan	HF
NNA	-11.990	-76.840	Nana, Peru	BB
NOU	-22.100	166.300	Port Laguerre, New Caledonia	BB
NPO	64.771	-146.886	North Pole, Alaska	HF
NRAO	60.740	11.540	Hamar, Norway (array)	HF
NRIL	69.500	88.440	Norilsk, Russia	HF,SP,VBB
NVS	54.840	83.240	Novosibirsk, Russia	SP
NWAO	-32.930	117.240	Narrogin, Western Australia	SP,VBB
OBN	55.110	36.570	Obninsk, Russia	SP,VBB
OSS	46.4126	10.08372	Ova Spin, Switzerland	HF
OXF	34.480	-89.340	Oxford, Mississippi, U.S.A.	HF
PAB	39.550	-4.350	San Pablo, Spain	SP,VBB

Table 2. Stations for Which the Background Noise Spectra are Available

Station Code	Latitude	Longitude	Location	Available Bandpasses
PAF	-49.350	70.210	Port-aux-Francais, Kerguelen Island	BB
PAS	34.150	-118.170	Pasadena, California, U.S.A.	SP,VBB
PDAR	42.786	-109.581	Pinedale, Wyoming	Existing
PDY	59.633	112.700	Peleduy, Russia (R array)	HF
PFCA	33.609	-109.558	Pinon Flats, CA	SP
PFO	33.610	-116.460	Pinon Flat, California, U.S.A.	VBB
PGC	48.650	-123.450	Pacific Geoscience Centre, B.C., Canada	HF
PLCA	-41.150	-70.550	Paso Flores, Argentina	SP
PMB	50.52	-123.07	Pemberton, Canada	HF
PMG	-9.410	147.150	Port Moresby, Papua, New Guinea	SP
PMSA	-64.770	-64.070	Palmer Station, Antarctica	VBB
PNT	49.310	-119.610	Penticton, B.C., Canada	HF
PPT	-17.570	-149.580	Papeete, Tahiti, France	BB
QIZ	19.030	109.840	Qiongzong, China	SP,VLP
RAR	-21.210	-159.770	Rarotonga, Cook Islands	SP,VBB,VLP
RER	-21.200	55.580	Plaine des Cafres, La Reunion Island	BB
RES	74.680	-94.900	Resolute, N.W.T., Canada	HF
RPN	-27.160	-109.430	Rapa Nui, Easter Island	SP

Table 2. Stations for Which the Background Noise Spectra are Available

Station Code	Latitude	Longitude	Location	Available Bandpasses
RSCP	35.600	-85.590	Cumberland Plateau, Tennessee, U.S.A.	HF
RSNT	62.4797	-114.5920	Yellowknife, NWT, Canada	Conti
RSNY	44.550	-74.530	Adirondack, New York, U.S.A.	HF
RSON	50.860	-93.700	Red Lake, Ontario, Canada	HF
RSSD	44.120	-104.040	Black Hills, South Dakota, U.S.A.	HF
SADO	44.77	-79.14	Sadowa, Canada	HF
SBC	34.440	-119.710	Santa Barbara, California, U.S.A.	SP,VBB
SCHQ	54.8319	-66.8336	Scheltaville, Quebec, Canada	HF
SCP	40.800	-77.870	State College, Pennsylvania, U.S.A.	SP,VLP
SCZ	36.600	-121.400	Santa Cruz, California, U.S.A.	BB
SHIO	25.57	91.88	Shillong, India	SP
SLR	-25.740	28.280	Silverton, South Africa	SP,VLP
SNZO	-41.310	174.700	South Karori, New Zealand	SP,VBB
SPA	-90.00	115.00	South Pole, Antarctica	SP,VBB
SPITS	78.180	16.360	Longyearbyen, Norway (R array)	HF
SQTA	47.13138	11.12313	Saint Quirin, Austria	HF
SSB	45.280	4.540	St. Sauveur Badole, France	SP,BB,VLP
SSE	31.091	121.185	Sheshan, China	HF,VBB,VLP

Table 2. Stations for Which the Background Noise Spectra are Available

Station Code	Latitude	Longitude	Location	Available Bandpasses
STI	42.4808	-111.03030	Star Valley, Idaho	HF
STKA	-31.880	141.590	Stephens Creek, New South Wales	SP
SUR	-32.380	20.810	Sutherland, South Africa	SP,VBB
SVD	34.100	-117.100	Seven Oaks Dam, California, U.S.A.	SP
TAM	22.790	5.530	Tamanrasset, Algeria	SP,VBB,VLP
TATO	24.980	121.490	Taipei, Taiwan	SP,VBB,VLP
TAU	-42.910	147.320	Hobart, Tasmania	SP,VLP
TBT	28.680	-17.910	Taburiente, Canary Islands	VBB
TKL	35.6580	-83.7740	Tuckaleechee, Tennessee	HF
TLY	51.680	103.640	Talaya, Russia	SP,VBB
TNS	50.220	8.450	Taunusobservatorium(Frankfurt), Germany	HF
TOL	39.881	-4.048	Toledo, Spain (Bordering)	SP,VBB
TUC	32.310	-110.780	Tucson, Arizona, U.S.A.	SP,VBB
TUL	35.910	-95.790	Leonard, Oklahoma, U.S.A.	HF
TXAR	29.330	-103.670	Lajitas, Texas, U.S.A.	HF
ULM	50.250	-95.875	Lac du Bonnert, Manitoba, Canada	HF.VLP
UNM	19.330	-99.190	UNAM, D.F., Mexico	SP,VLP
USU	44.000	132.000	Ussuriysk, Russia (R array)	HF

Table 2. Stations for Which the Background Noise Spectra are Available

Station Code	Latitude	Longitude	Location	Available Bandpasses
VAF	63.04	22.67	Ylistaro Finland	HF
VNDA	-77.514	161.846	Vanda (Dry Valleys), Antarctica	SP
VRAC	49.31	15.59	Vranov, Czechoslovakia	HF
VSL	39.500	9.380	Villasalto, Sardegna, Italy	VBB
WALA	49.060	-113.920	Waterton Lake, Alberta, Canada	HF
WEL	-41.171	174.46060	Wellington, New Zealand	HF
WFM	42.610	-71.490	Westford, Massachusetts, U.S.A.	BB,LP
WHY	60.66	-134.88	Whitehorse, Canada	HF
WMQ	43.820	87.700	Urumqi (Wulumuqi), China	HF,VBB,VLP
WOOL	-31.07	121.68	Woolibar, Australia	SP
WRA	-19.940	134.340	Warramunga, Australia (T array)	SP
WUS	41.200	79.220	Wushi, China	SP,LP
XAN	34.04	108.92	Xi'an, China	VBB
YKA	62.489	-114.603	Yellowknife, N.W.T., Canada (array)	SP
YSS	47.000	142.800	Yuzhno-Sakhalinsk, Russia	SP,VBB
ZALR	53.940	84.805	Zalesovo, Russia (R array)	HF
ZOBO	-16.270	-68.120	La Paz, Bolivia	SP,VLP

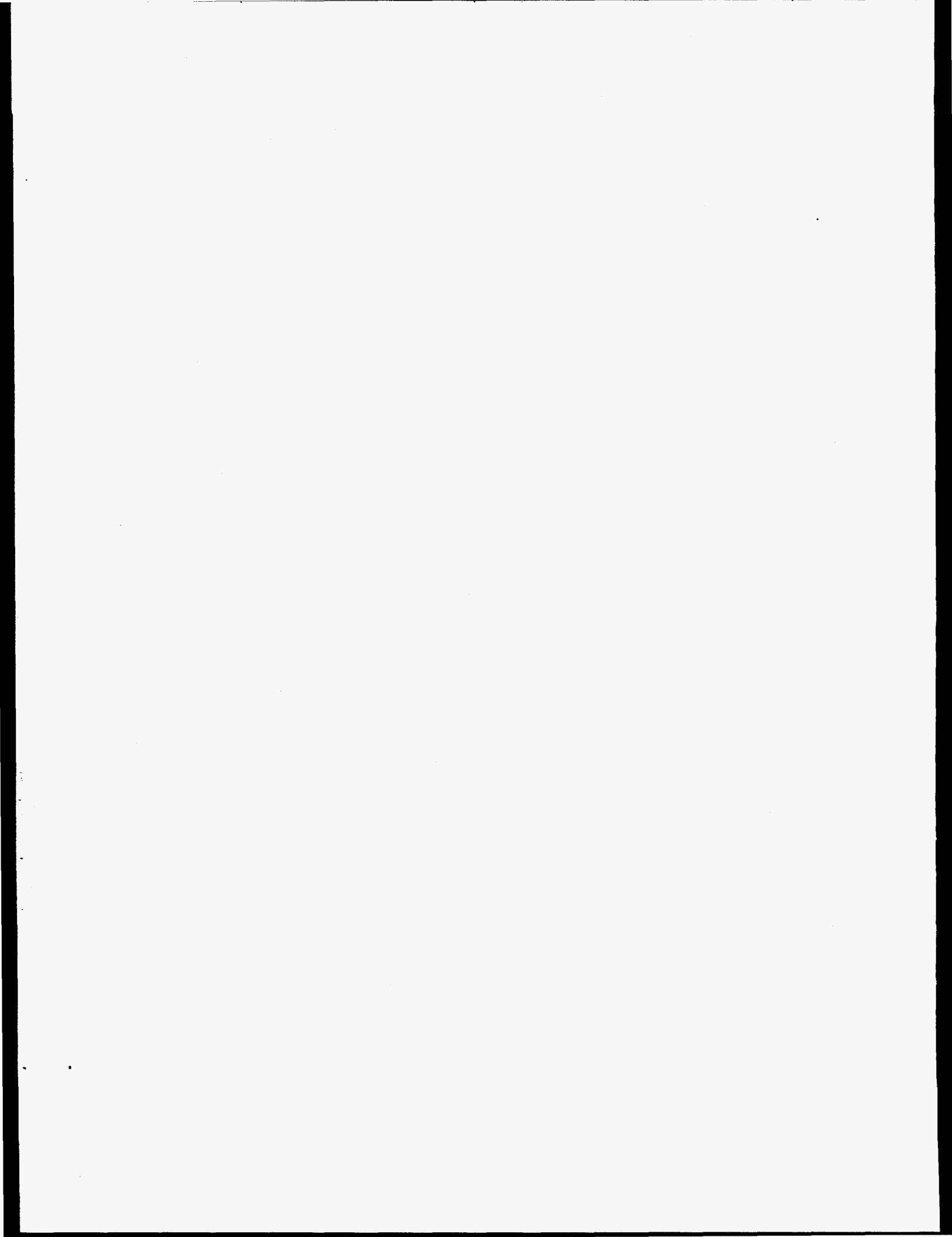
5.0 References

¹J. Peterson, Jon, "Observations and Modeling of Seismic Background Noise," Open File Report 93-322, United States Department of Interior, Geological Survey, 1993

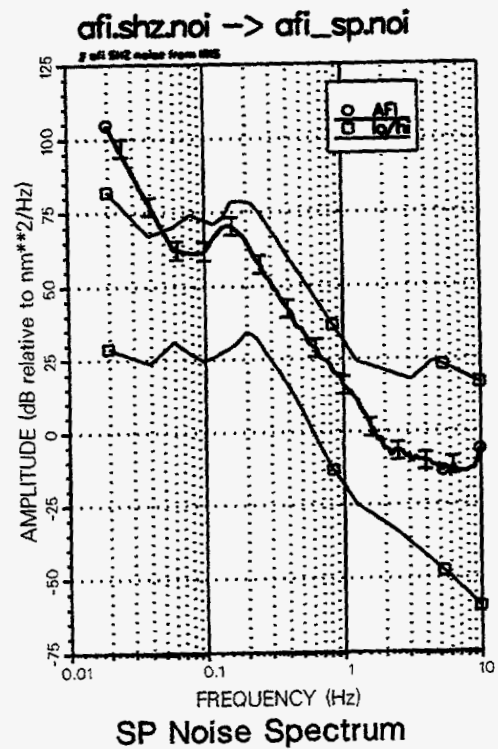
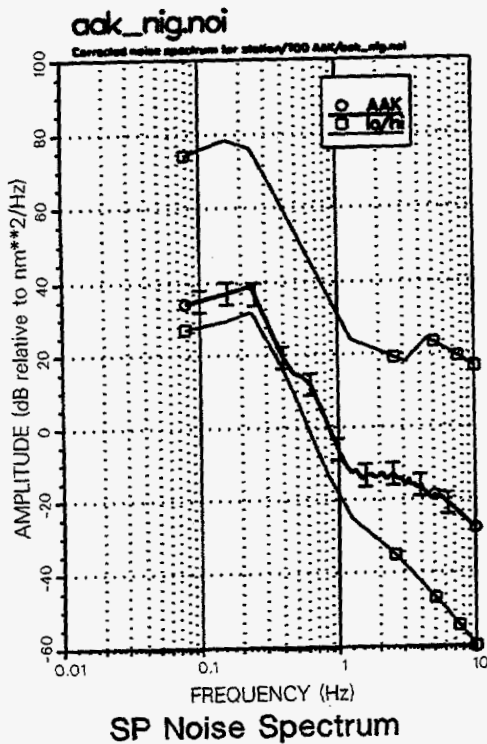
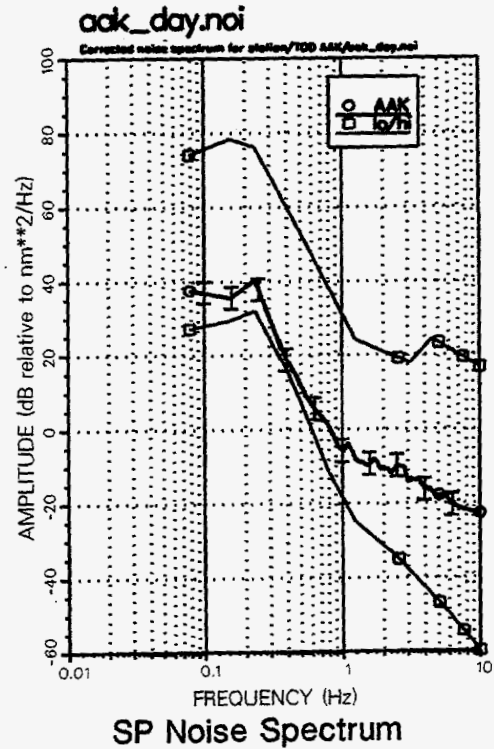
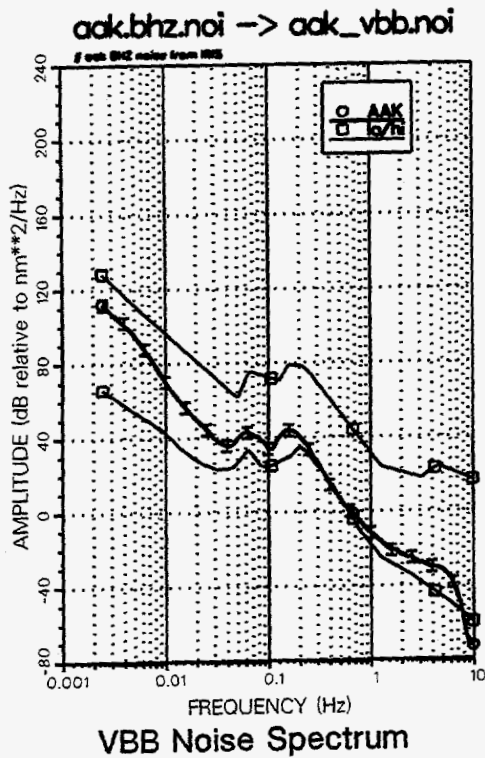
²Claassen, John, "Network Modeling and Evaluation of a CD Proposed ISMS" SAND Report No.96-0585, Sandia National Laboratories, March 1996

Appendix A

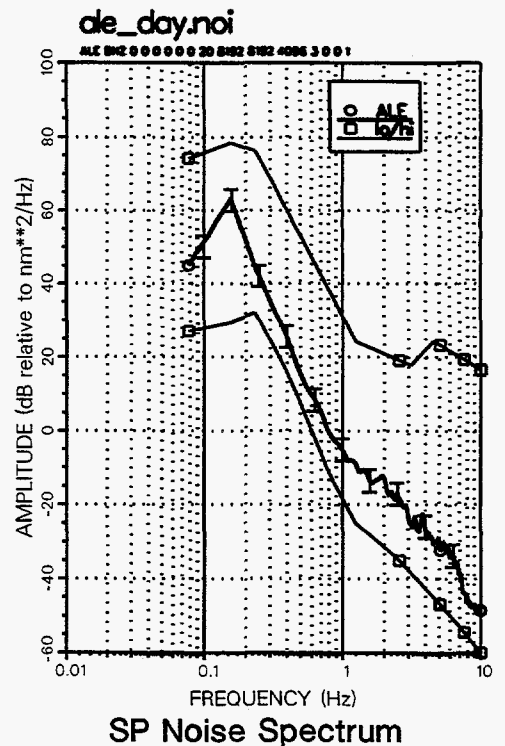
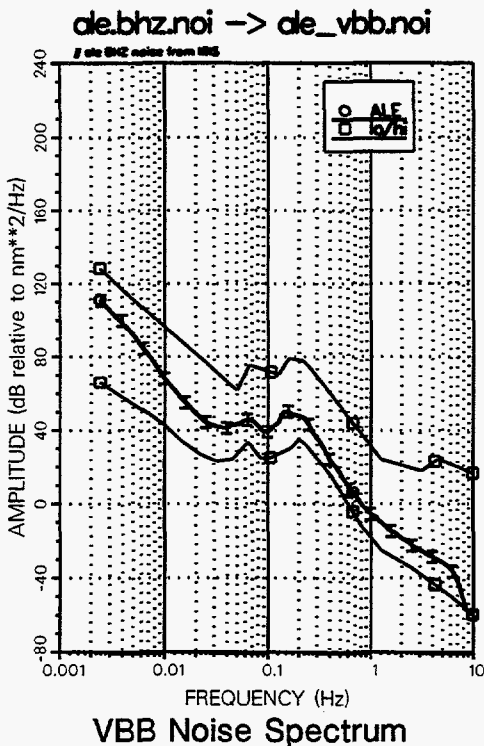
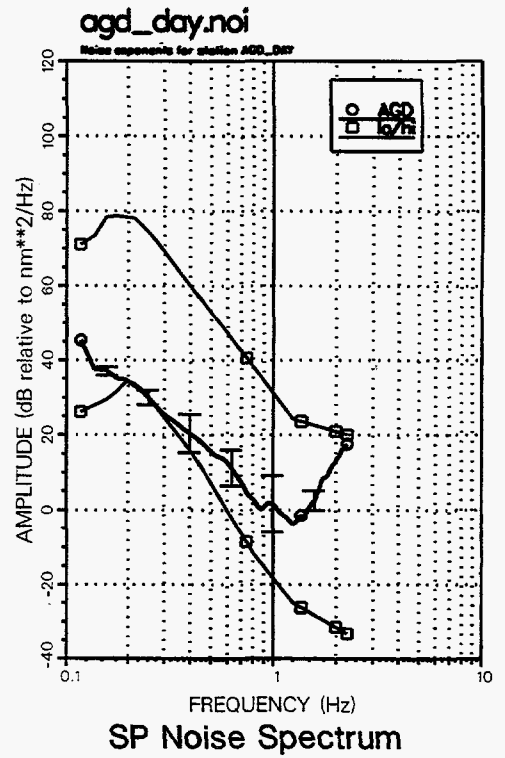
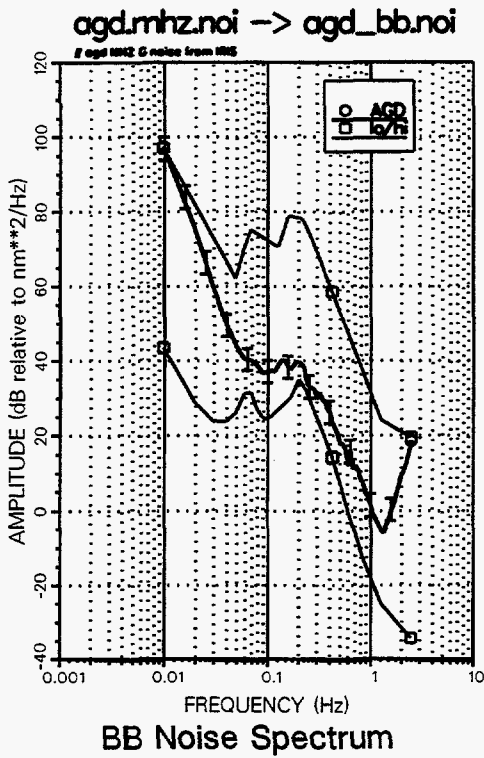
Graphs of Station Noise Spectra



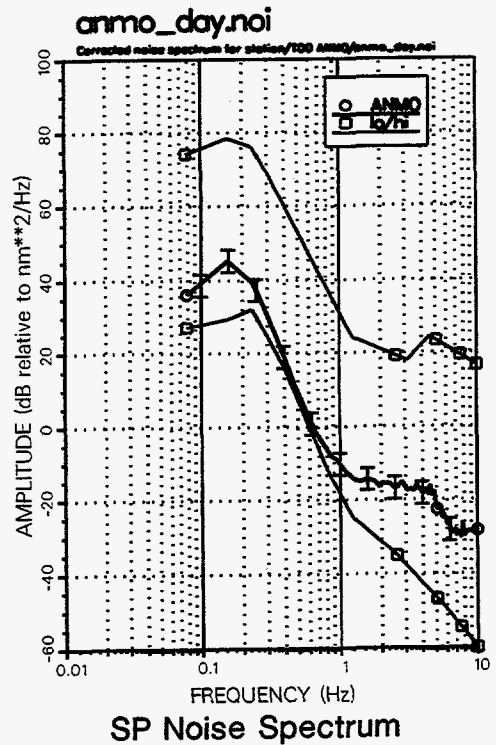
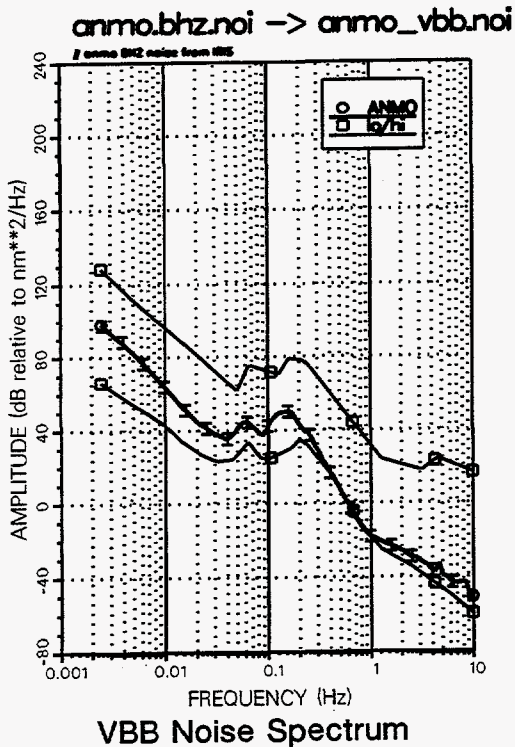
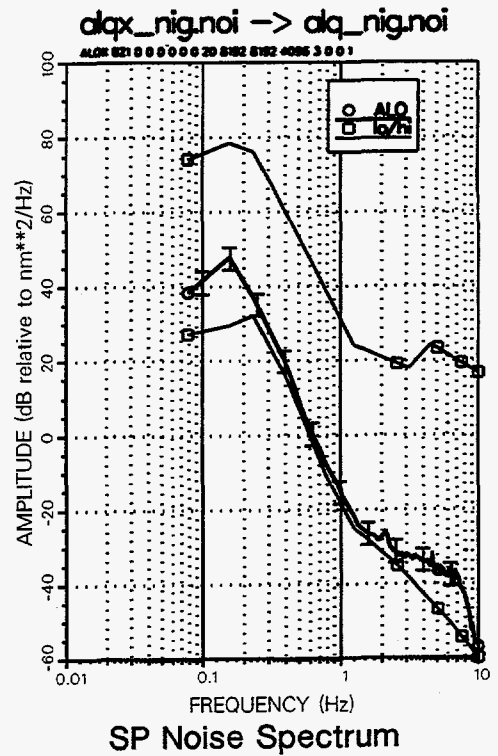
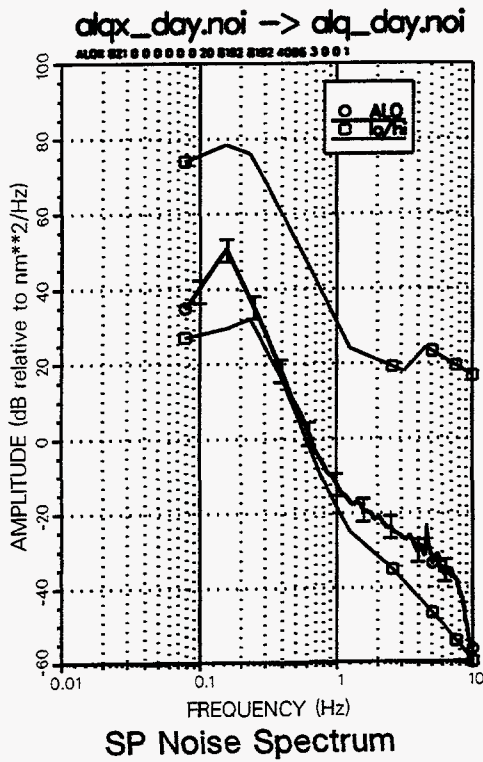
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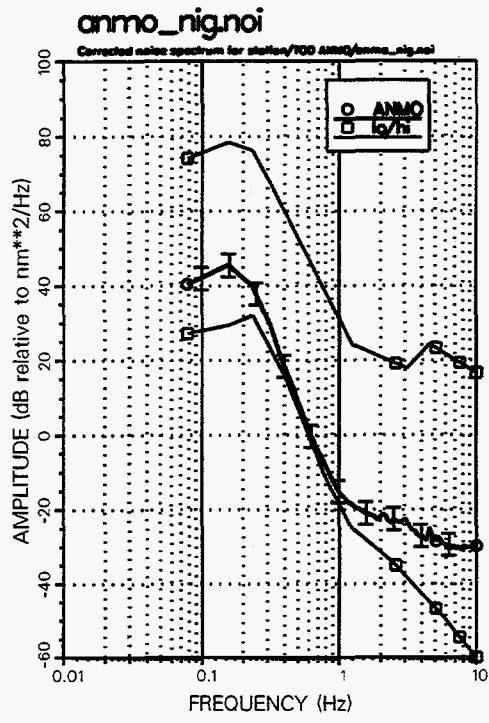
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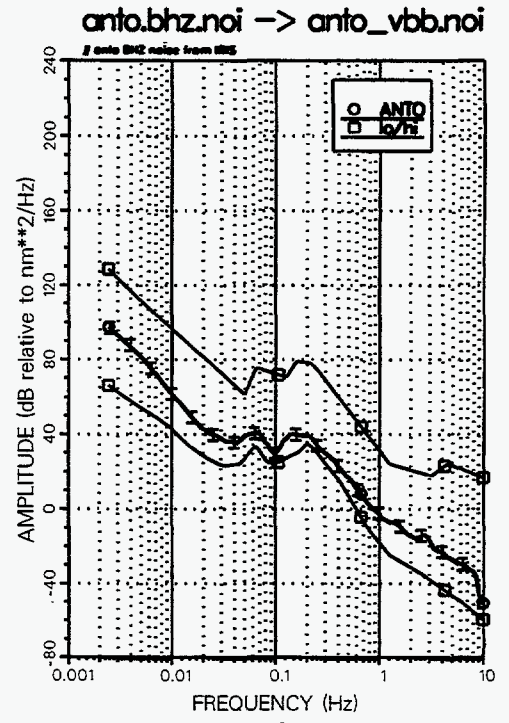
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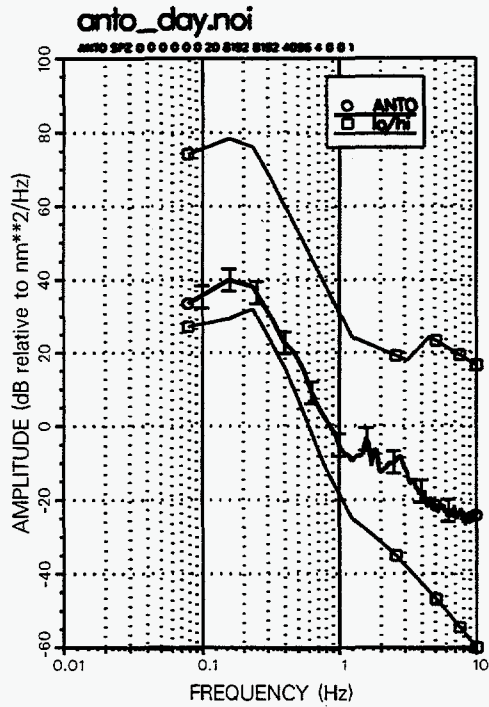
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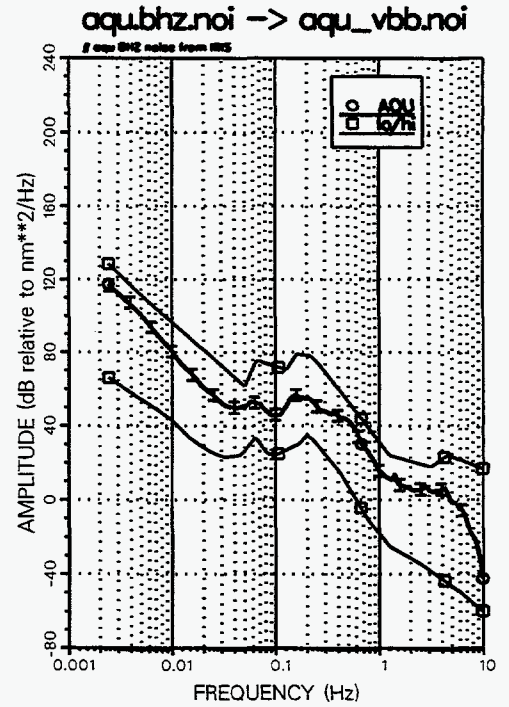
SP Noise Spectrum



VBB Noise Spectrum

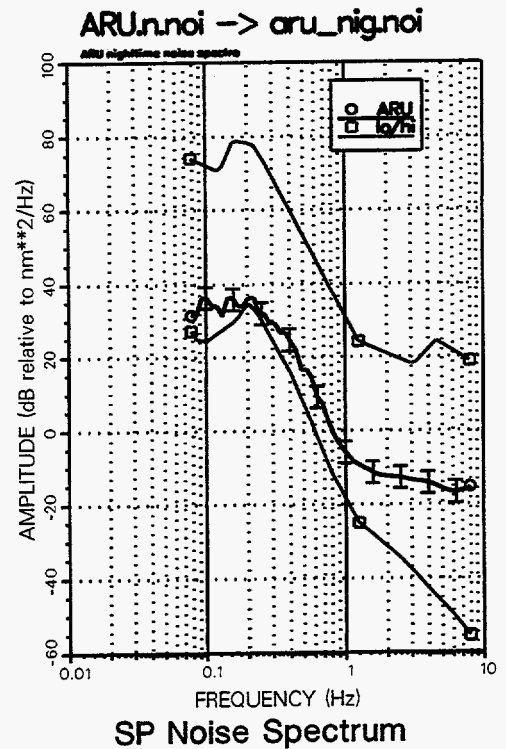
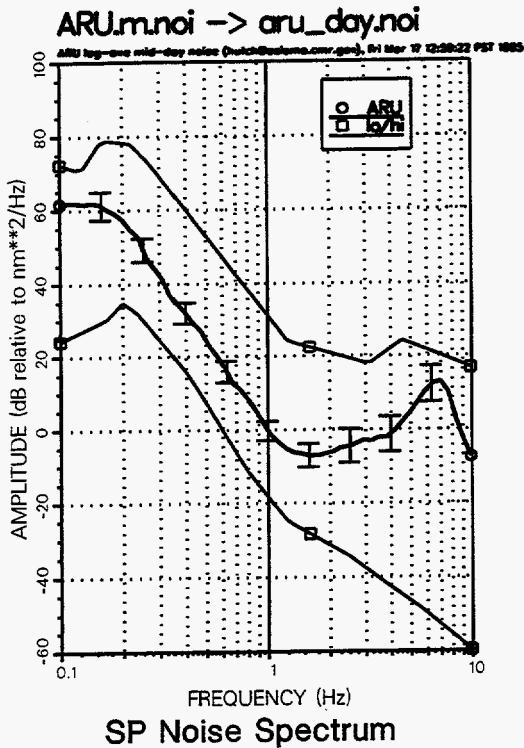
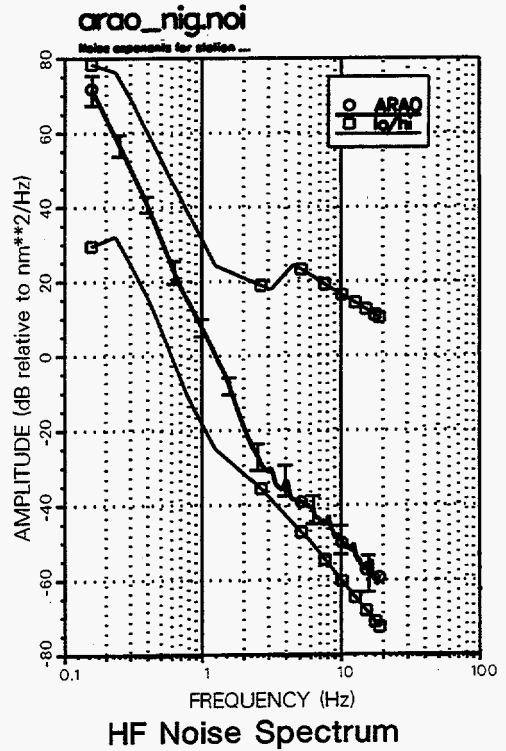
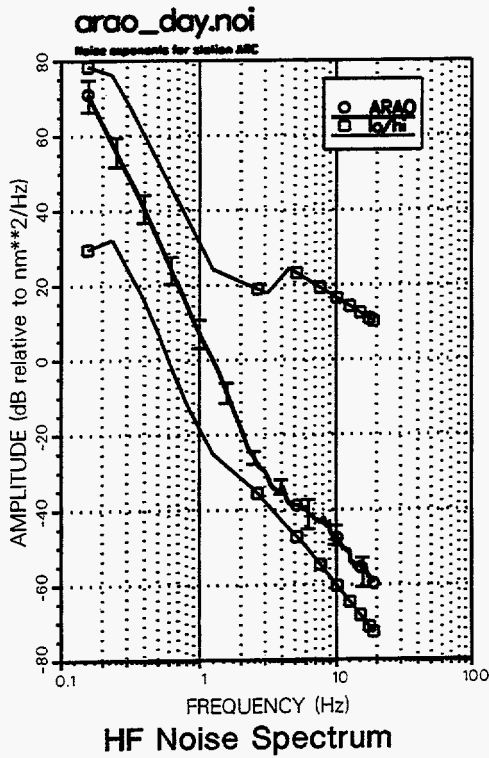


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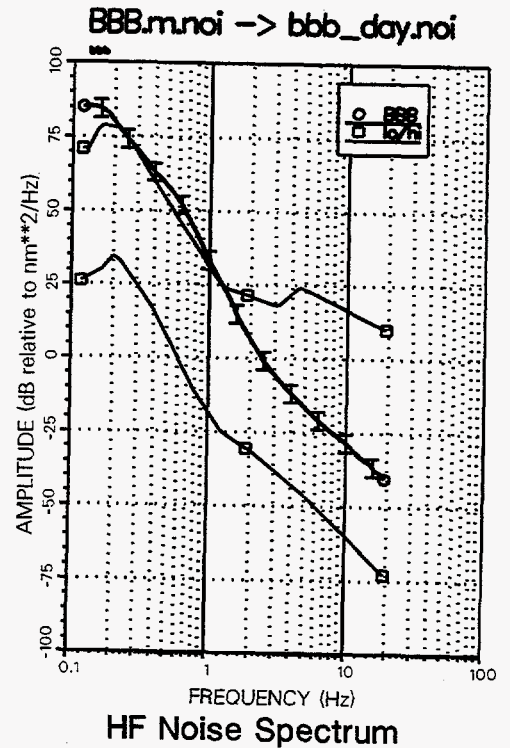
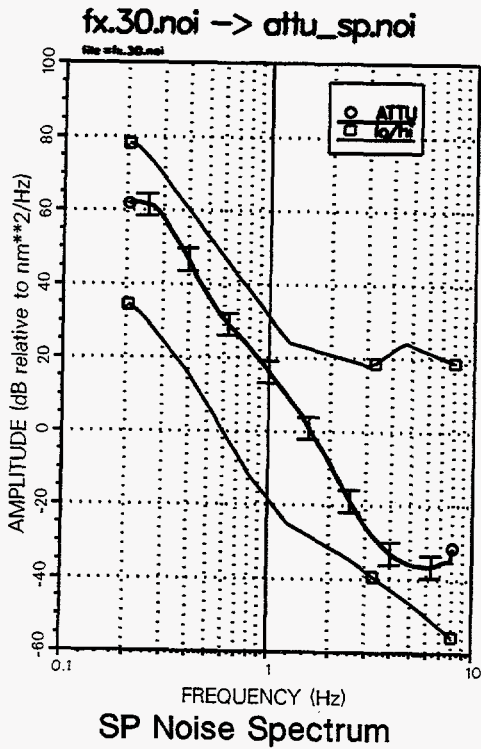
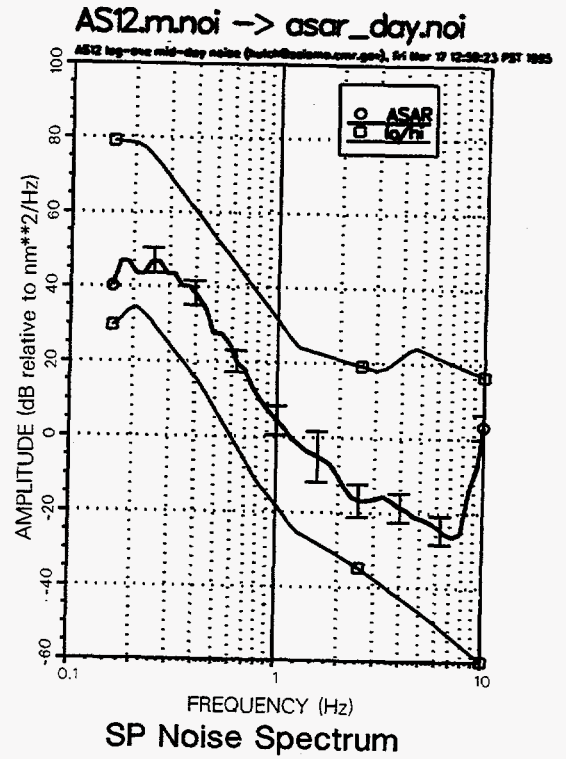
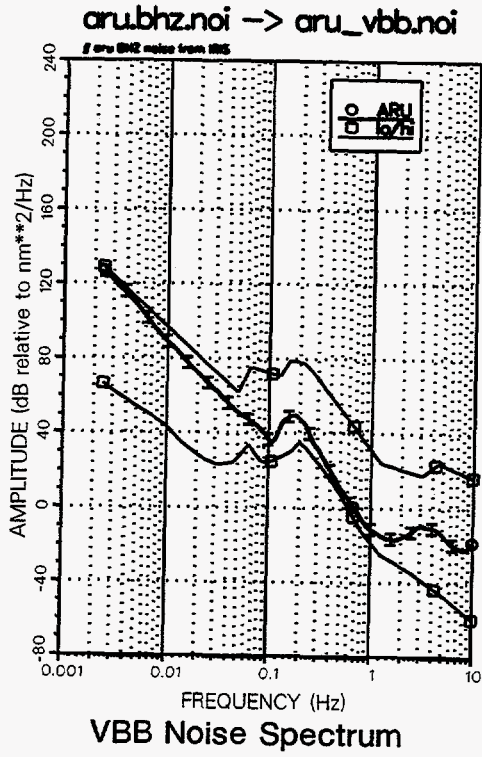


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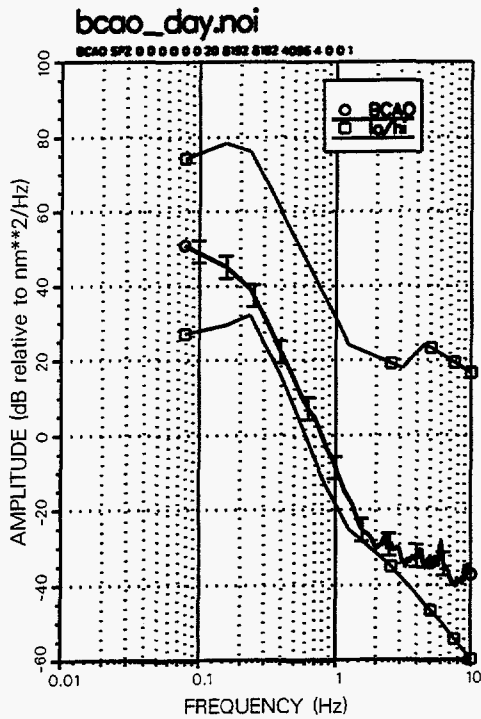
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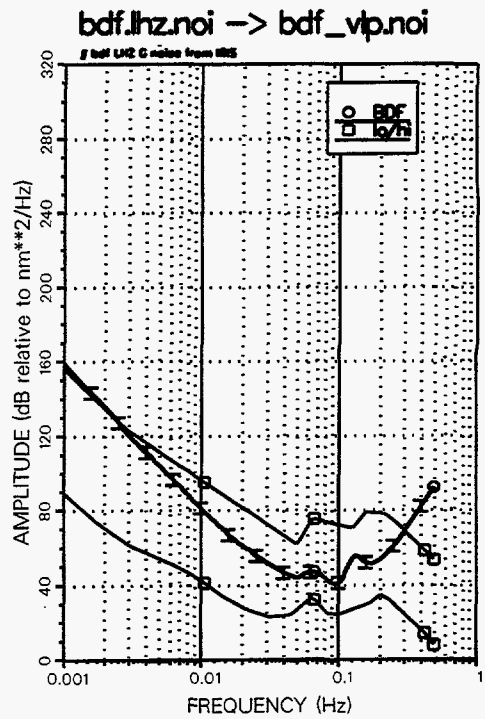
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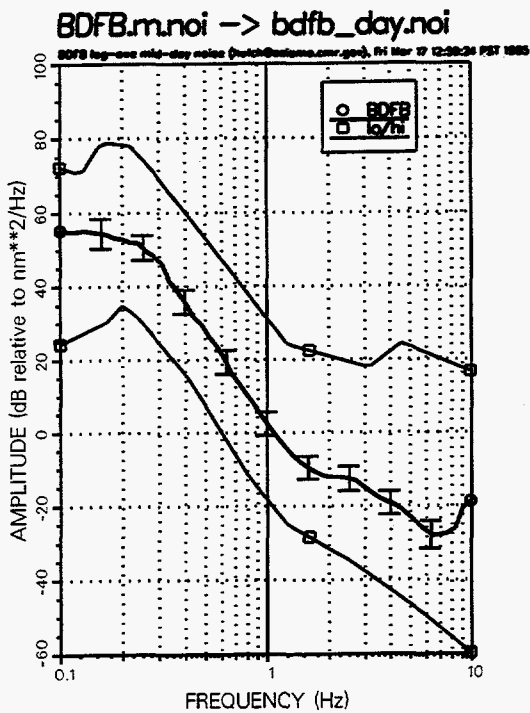
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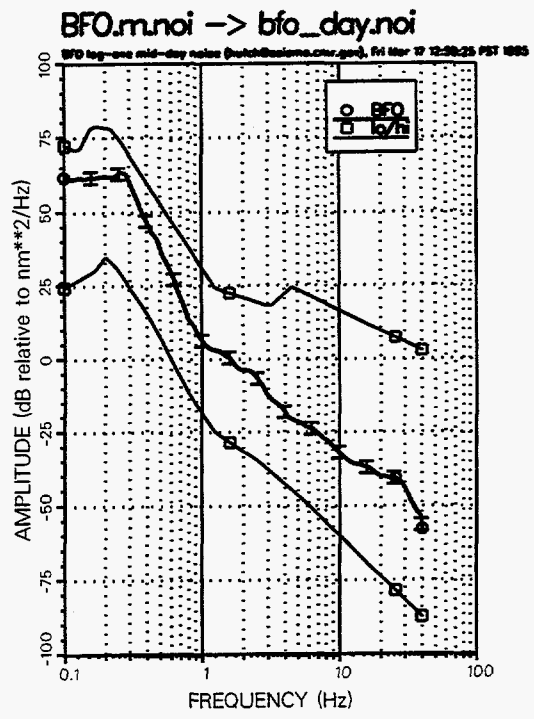
SP Noise Spectrum



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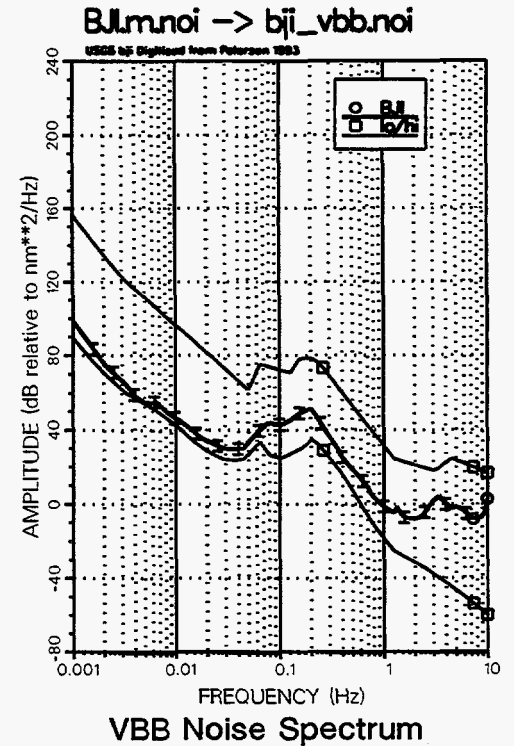
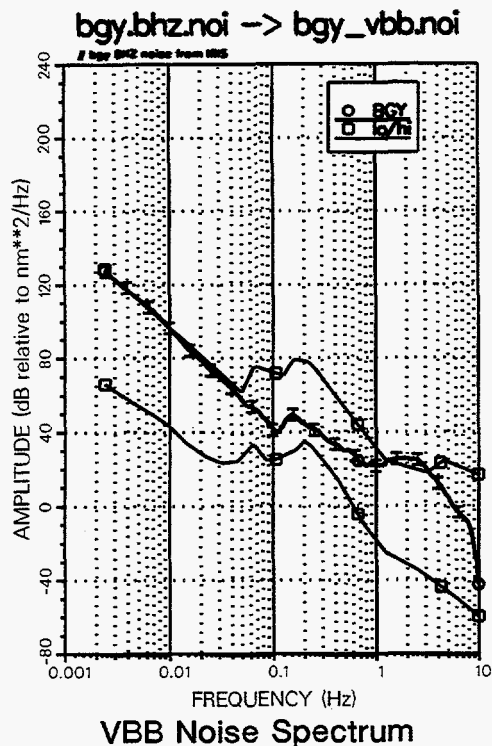
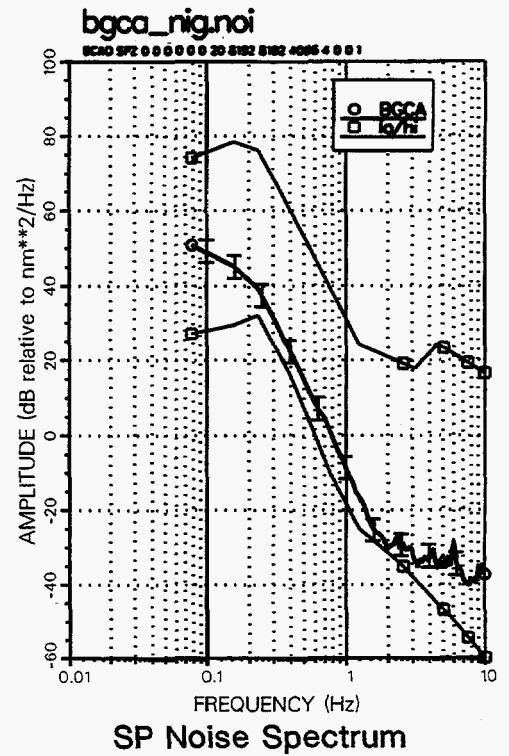
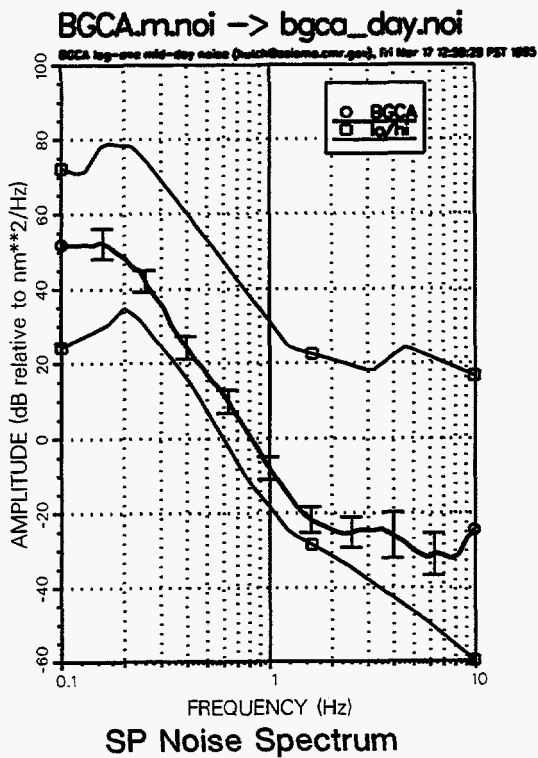


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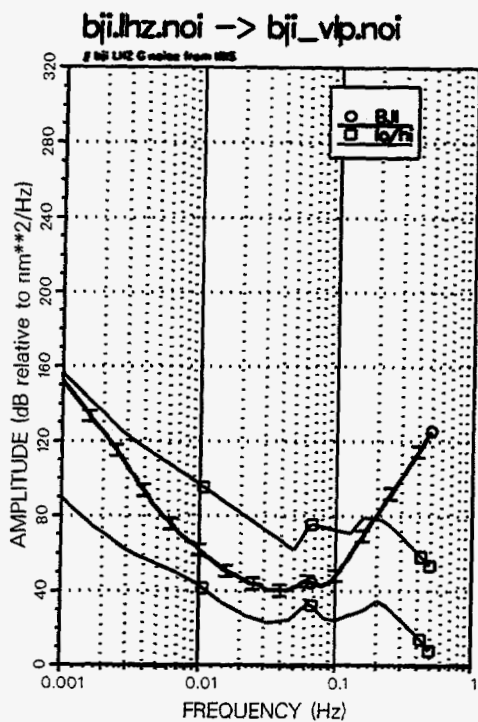


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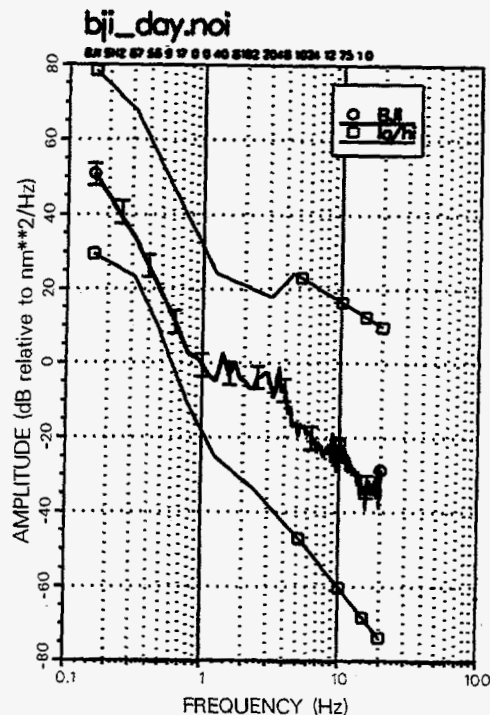
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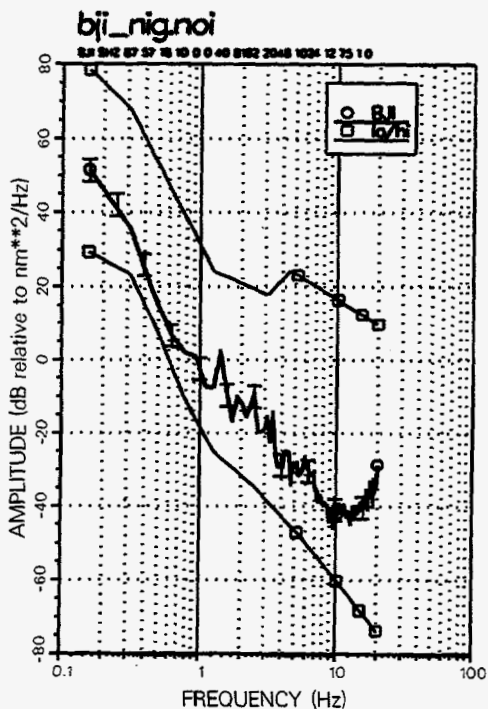
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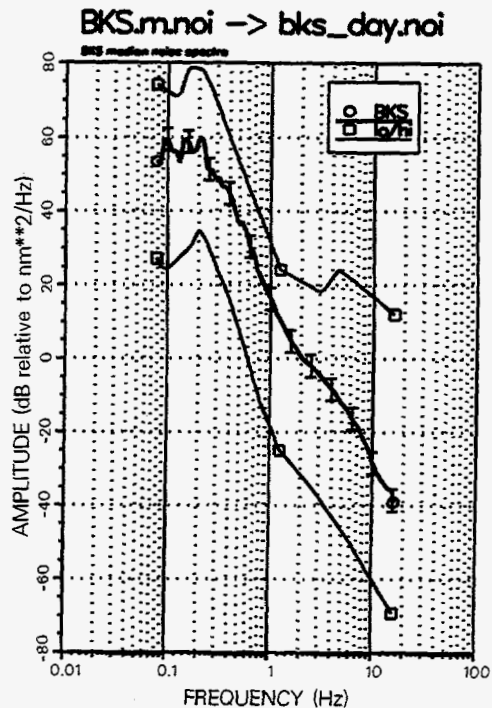
VLP Noise Spectrum



HF Noise Spectrum

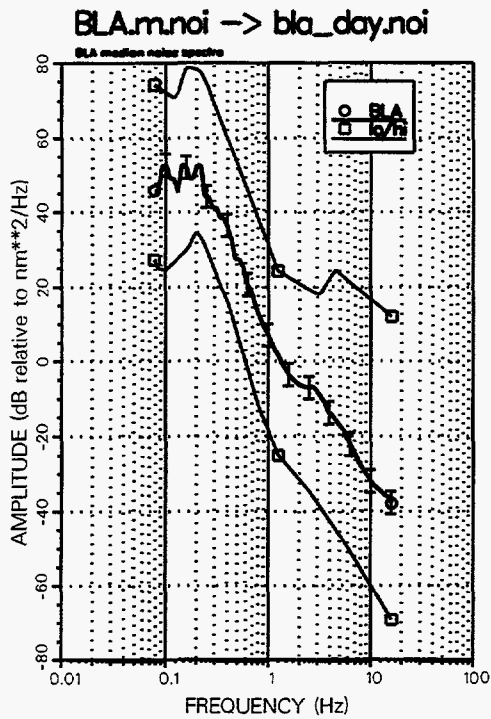


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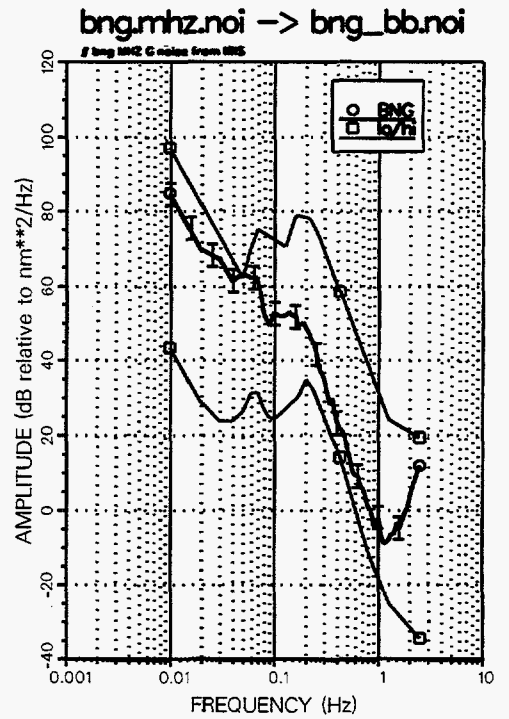


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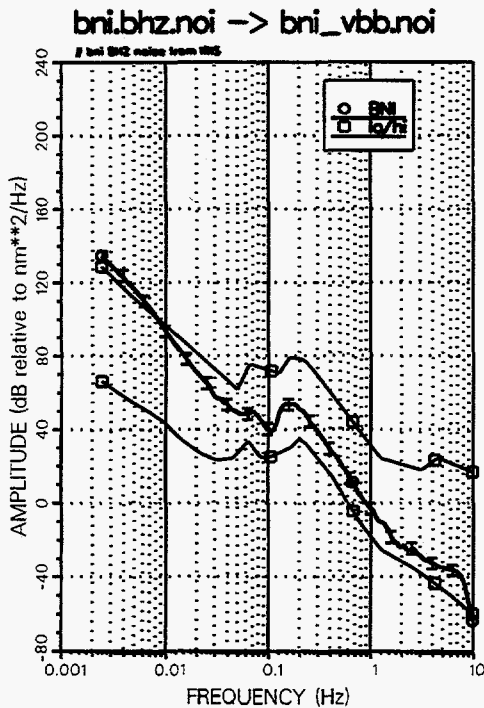
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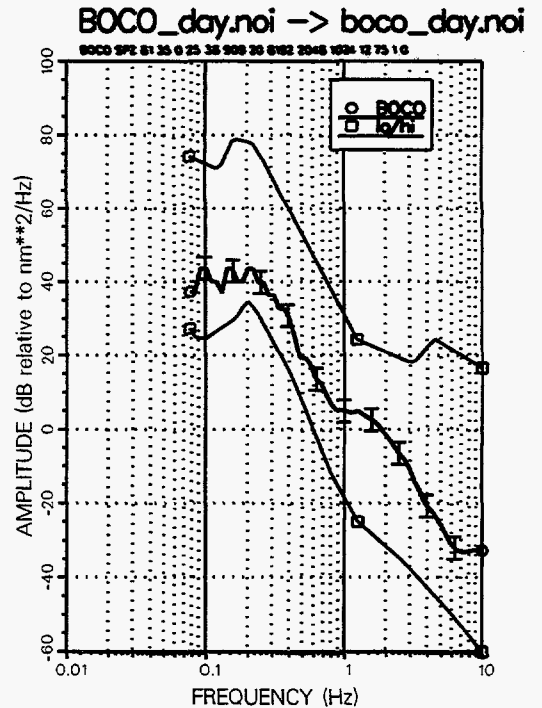
HF Noise Spectrum



BB Noise Spectrum

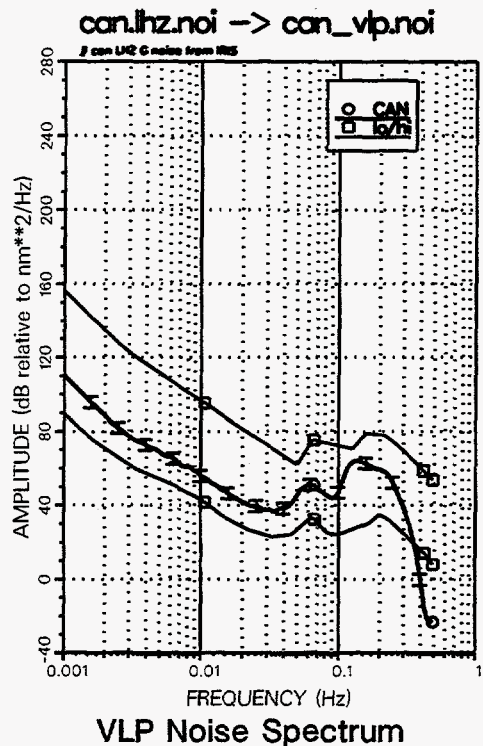
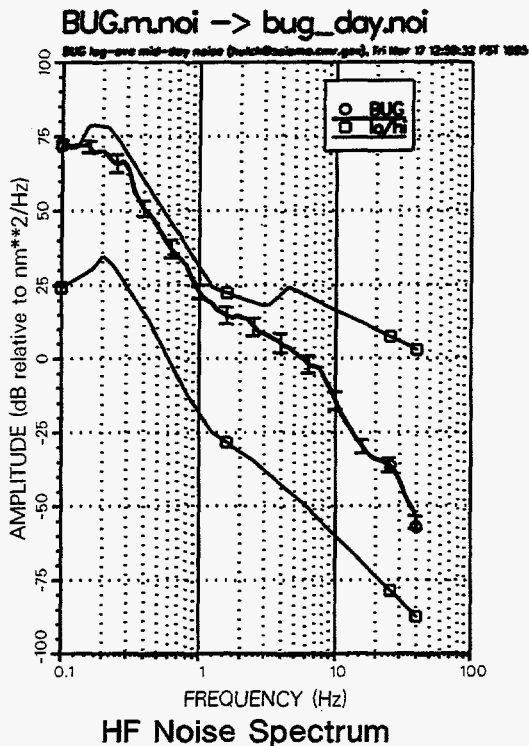
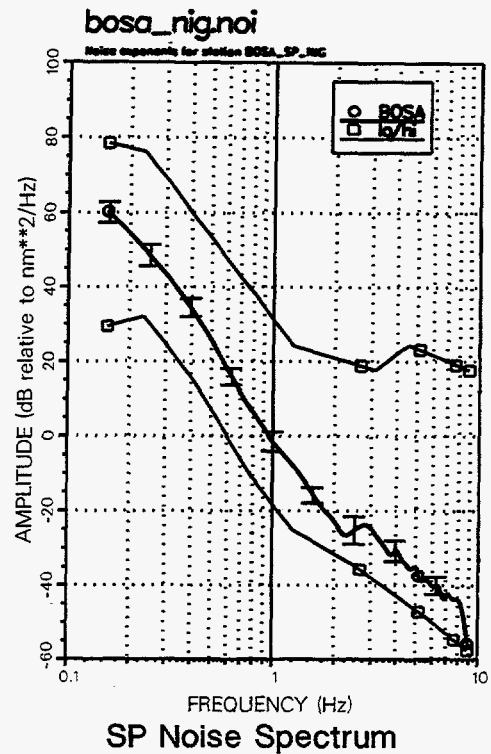
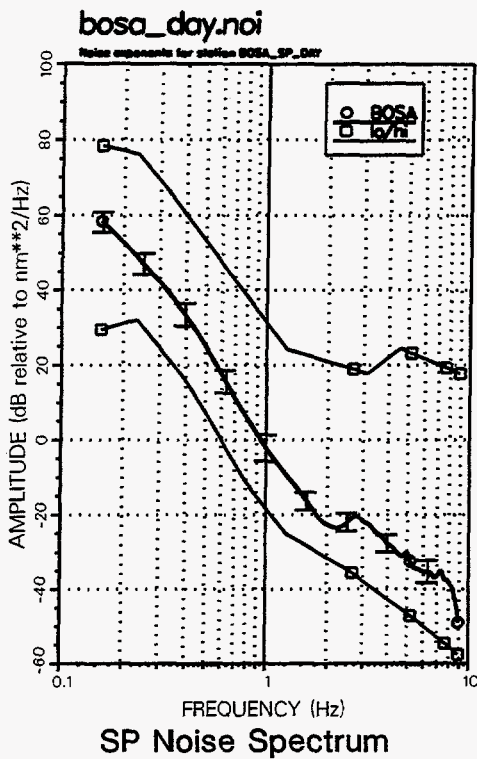


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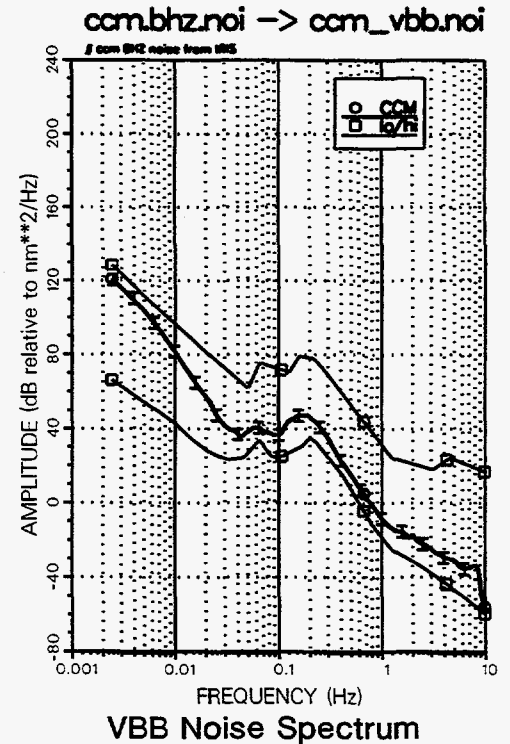
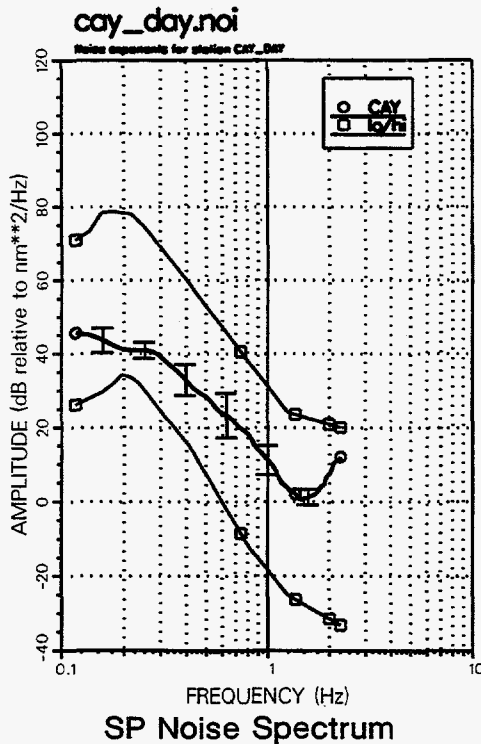
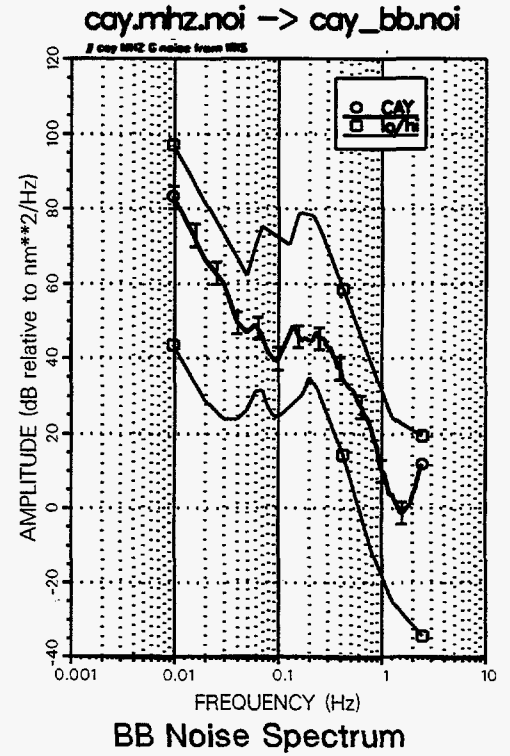
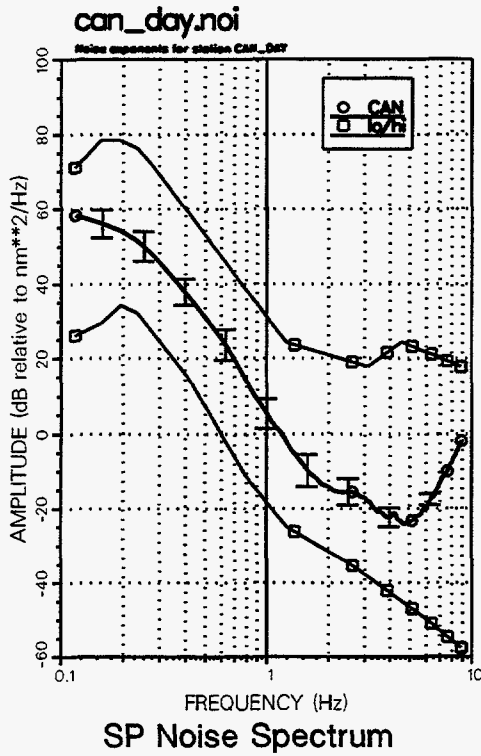


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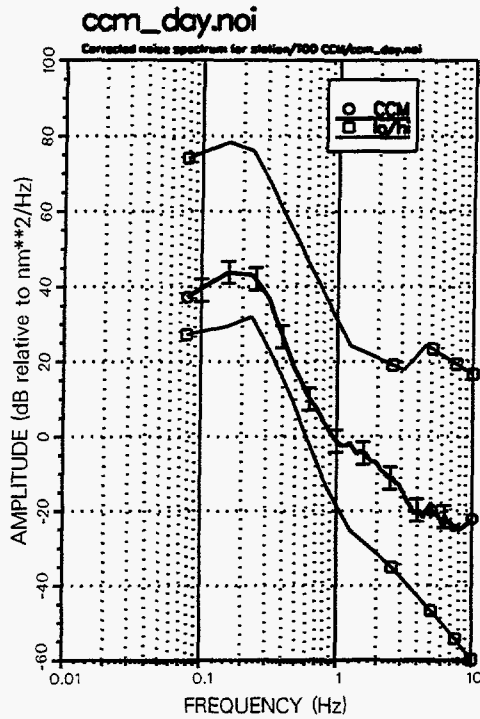
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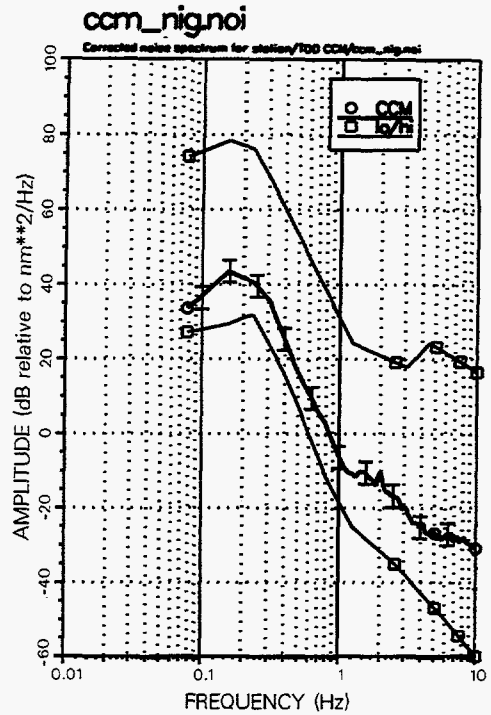
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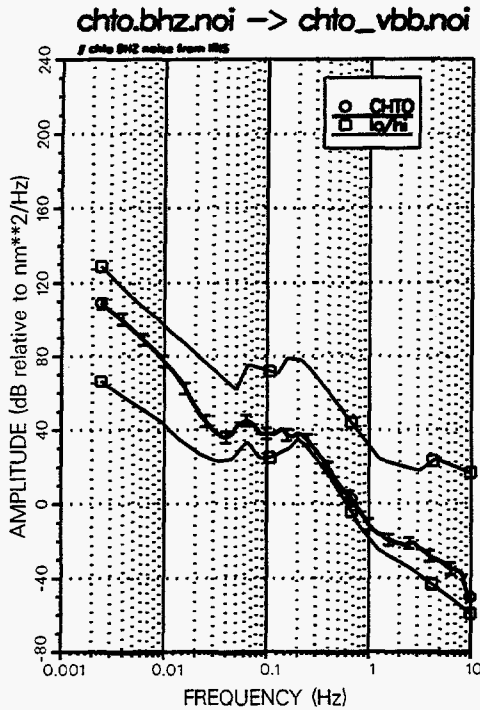
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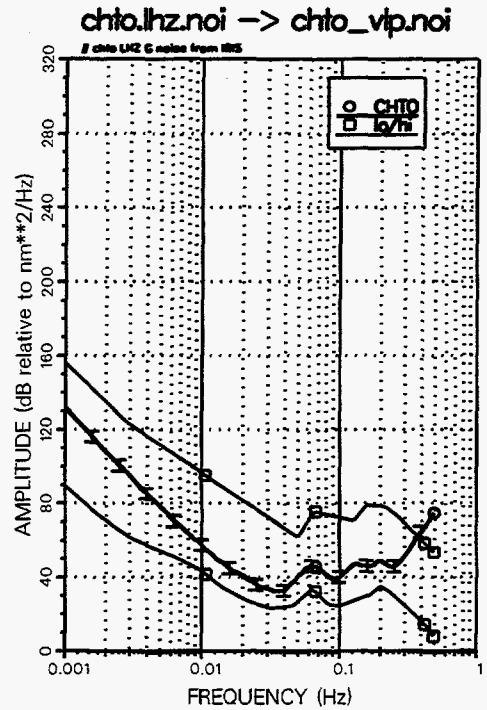
SP Noise Spectrum



SP Noise Spectrum

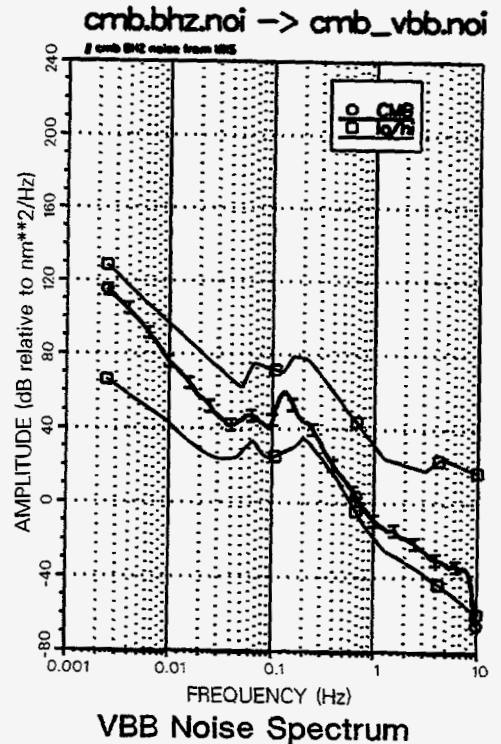
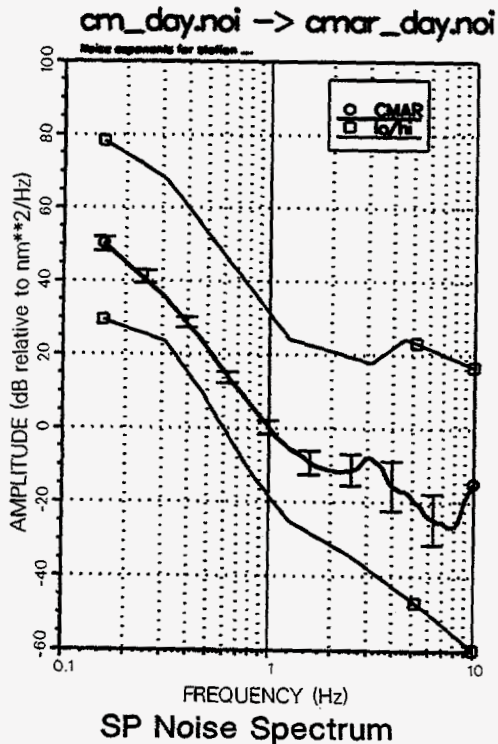
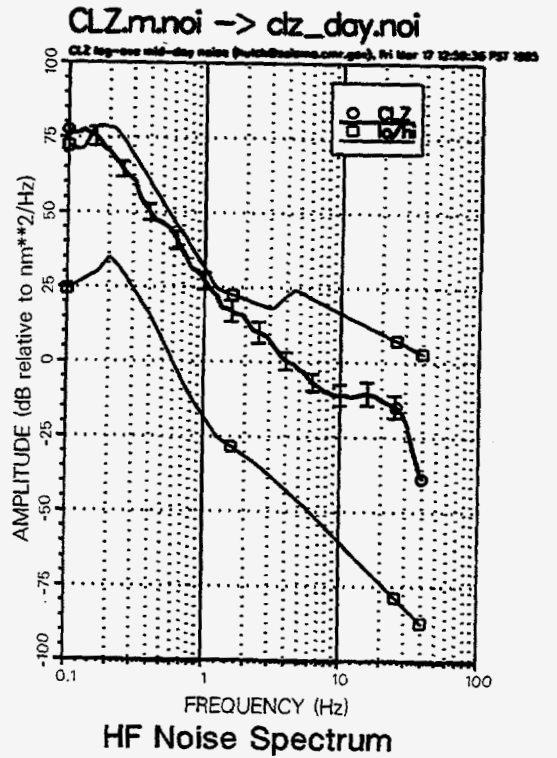
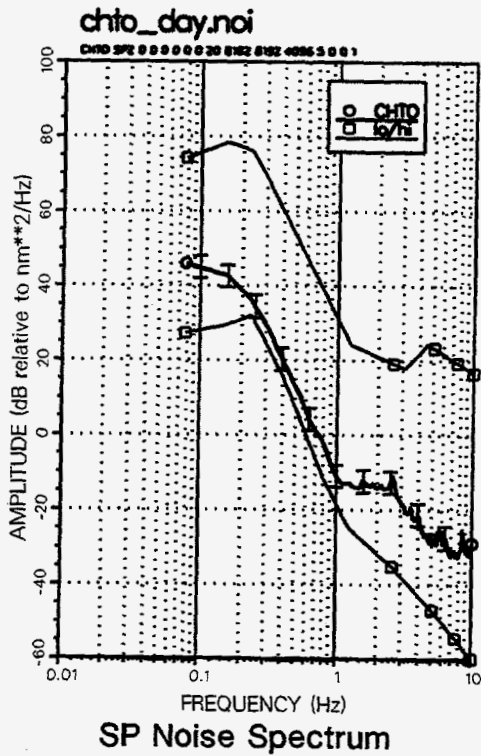


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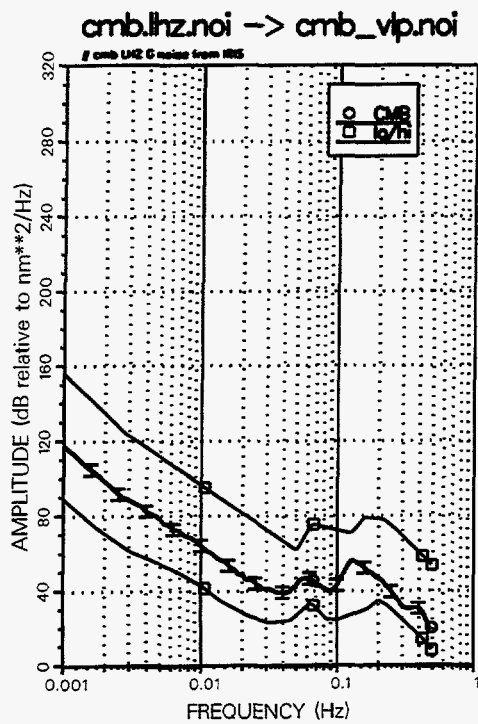


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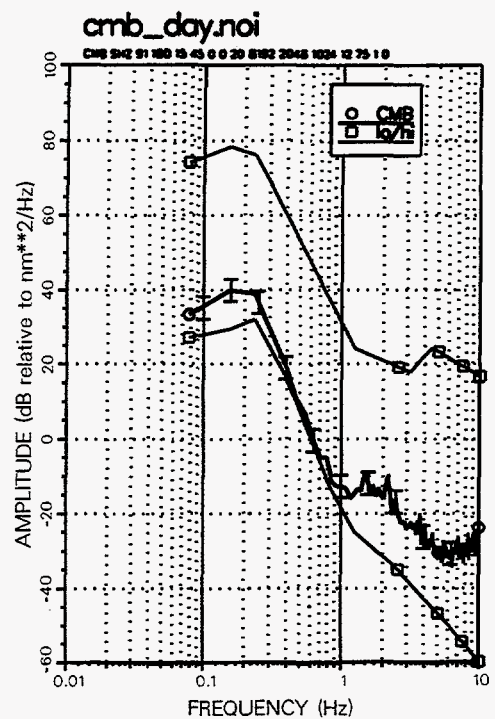
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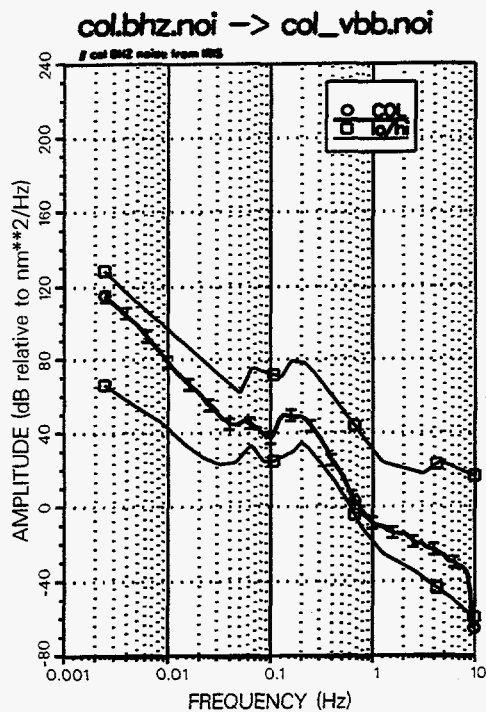
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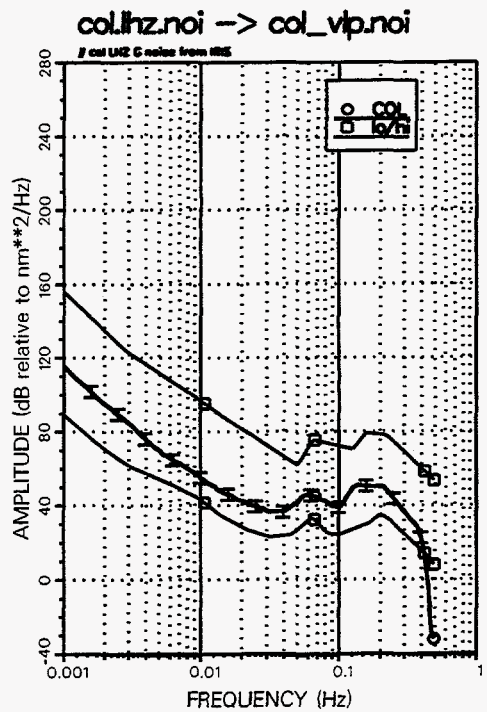
VLP Noise Spectrum



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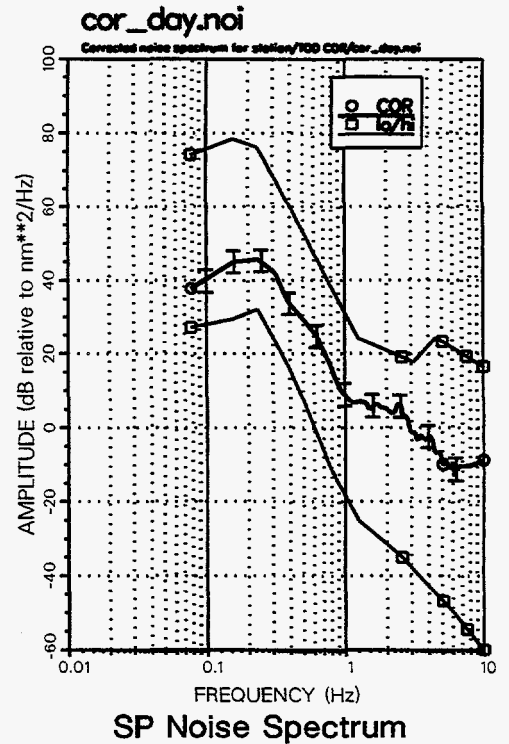
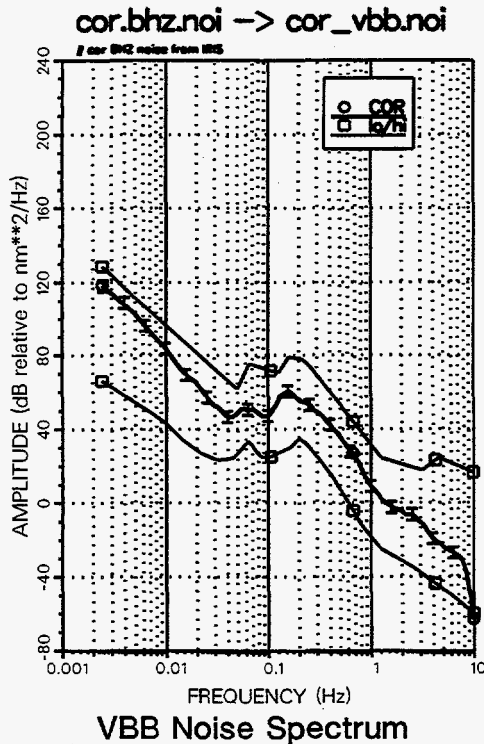
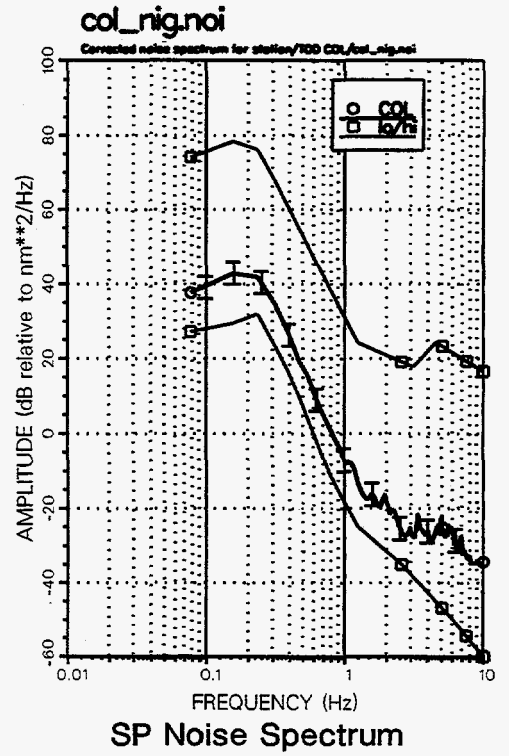
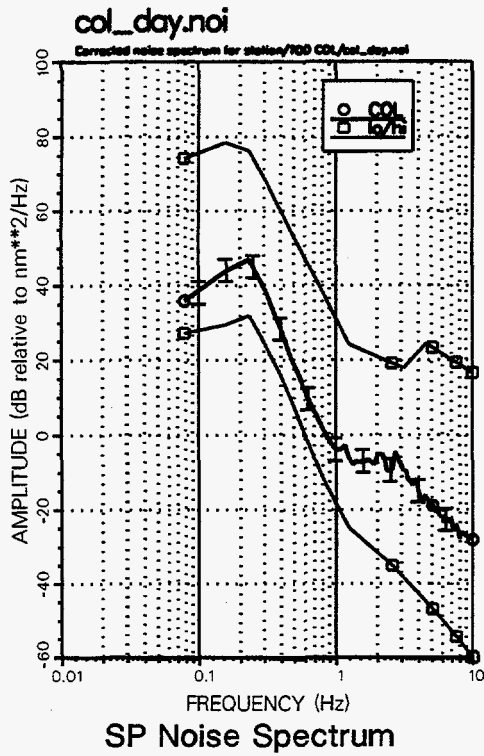


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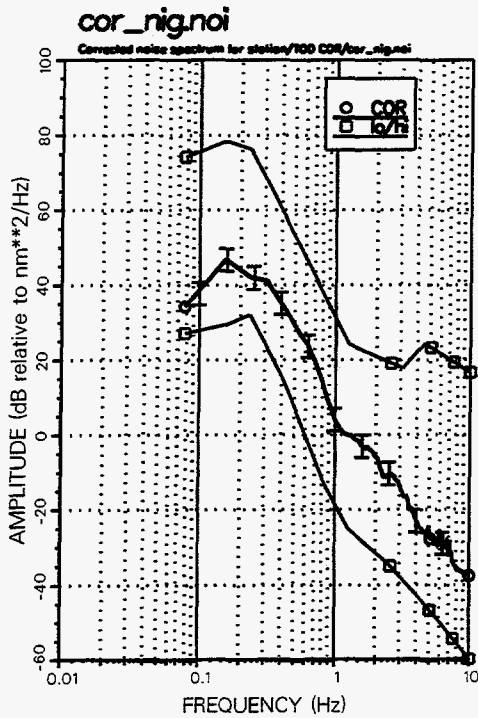


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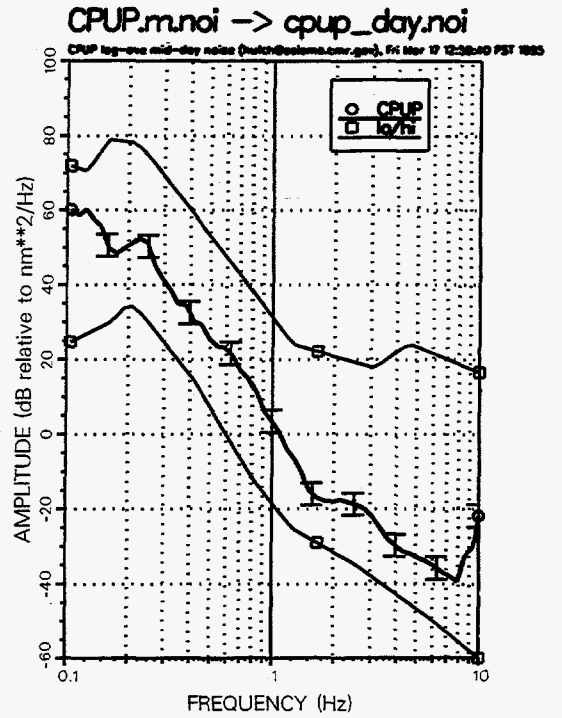
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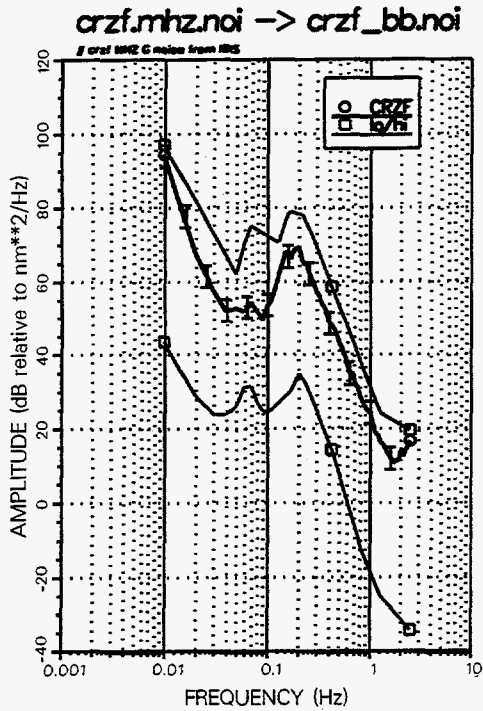
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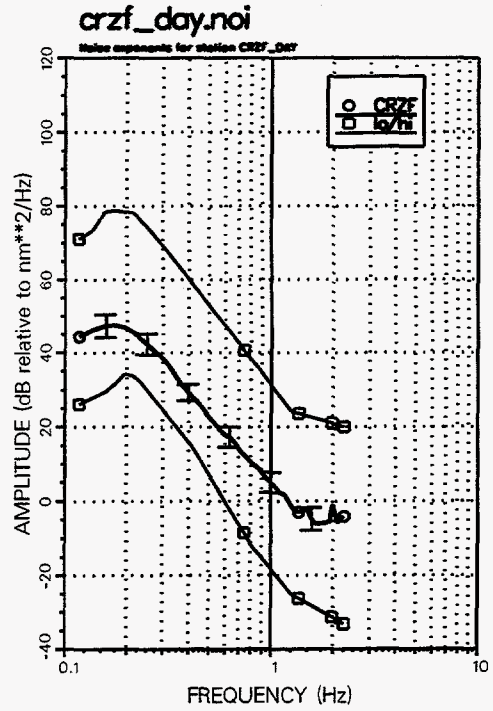
SP Noise Spectrum



SP Noise Spectrum

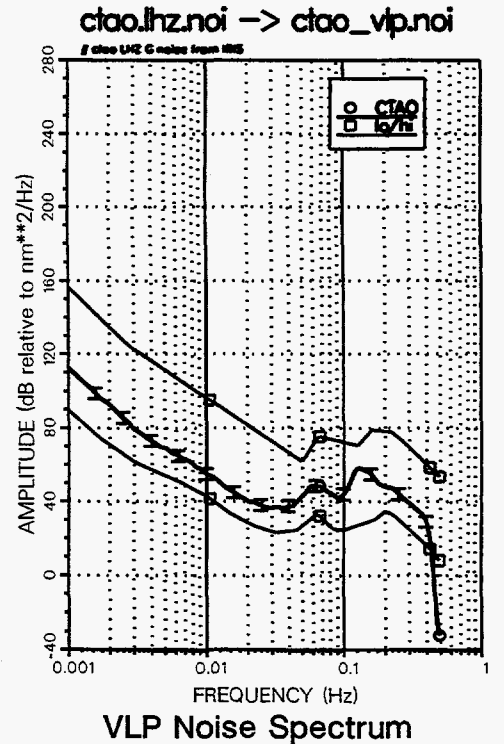
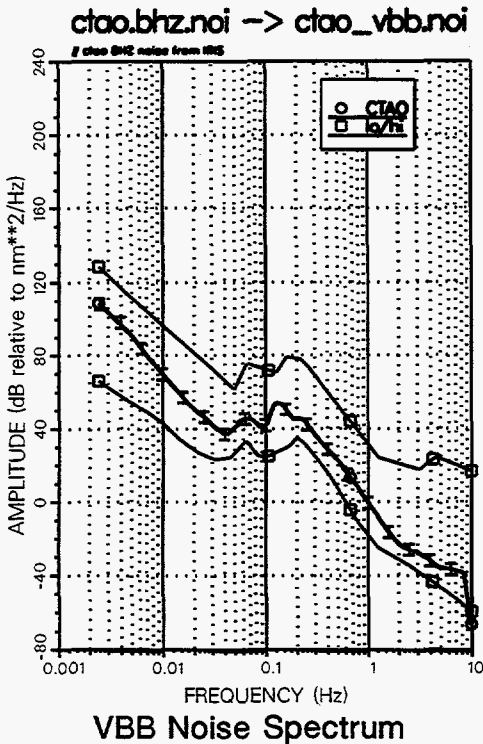
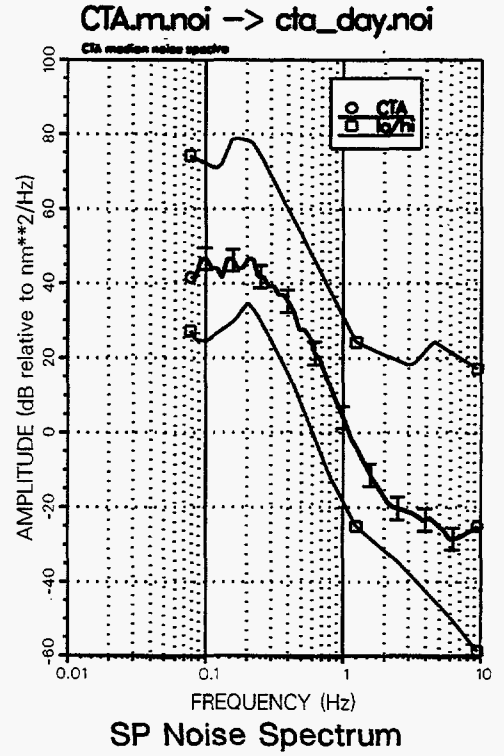
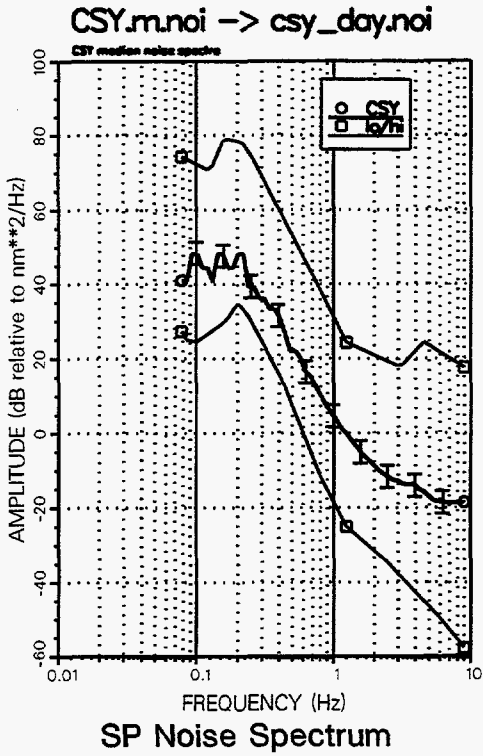


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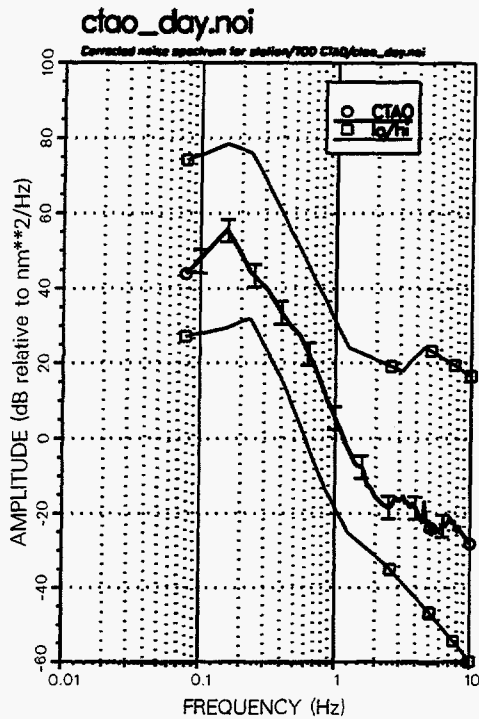


SP Noise Spectrum

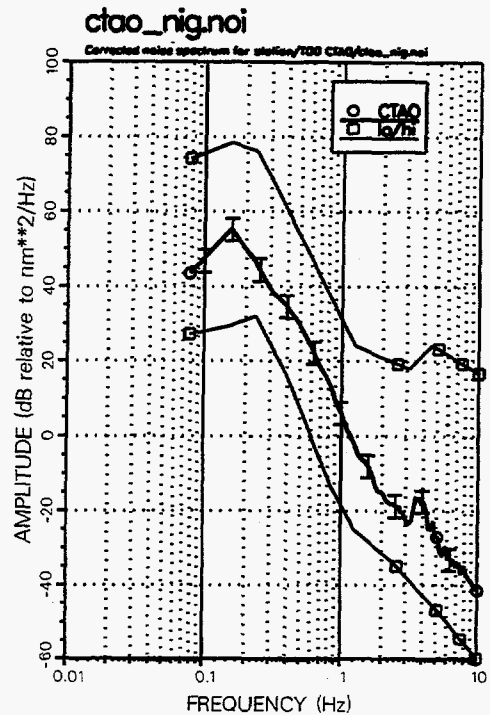
Station Noise Spectra



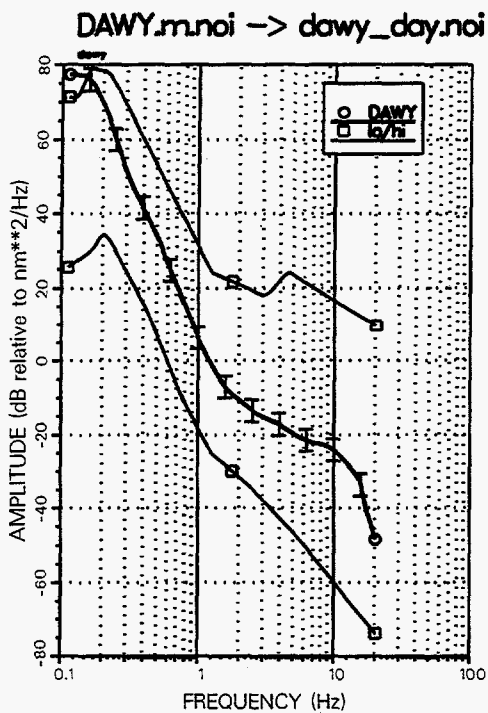
Station Noise Spectra



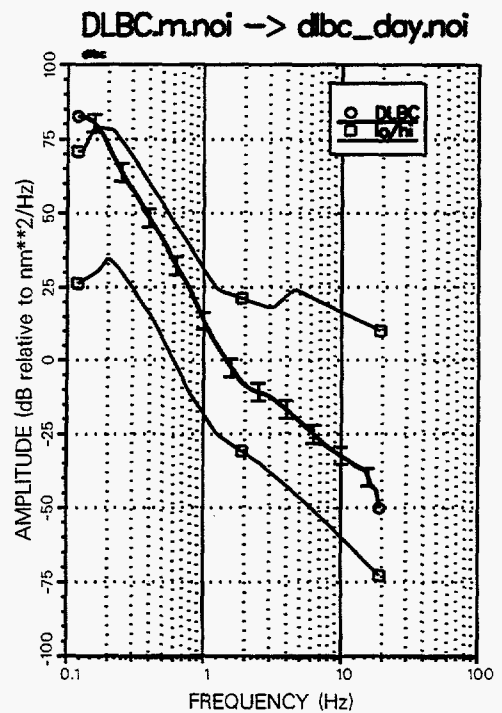
SP Noise Spectrum



SP Noise Spectrum

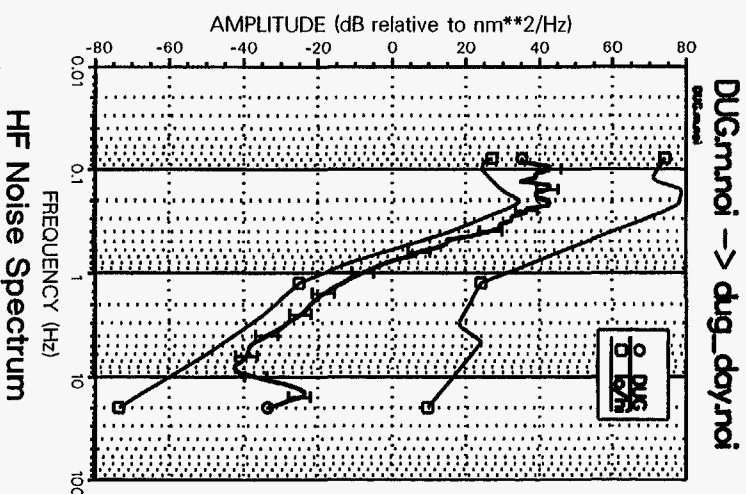
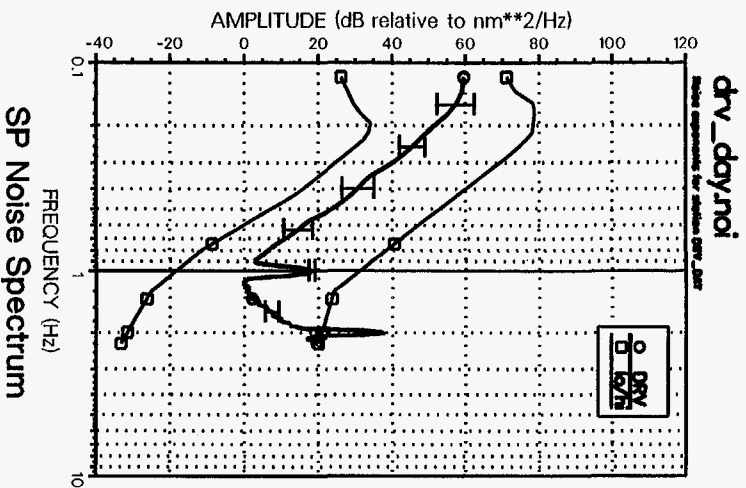
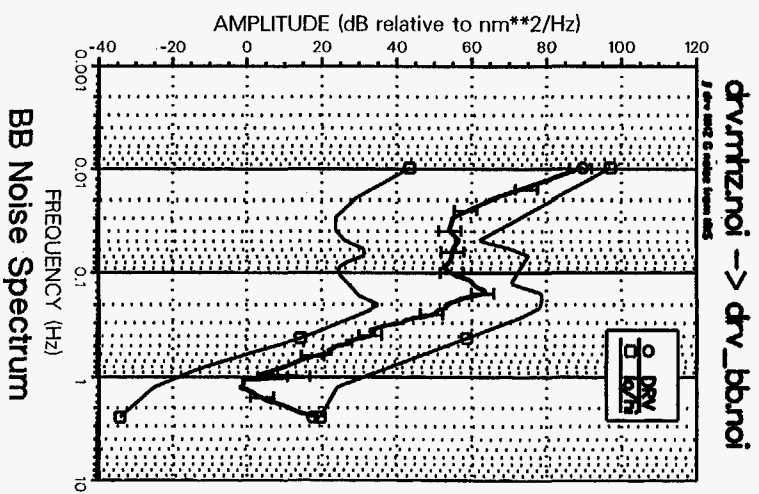
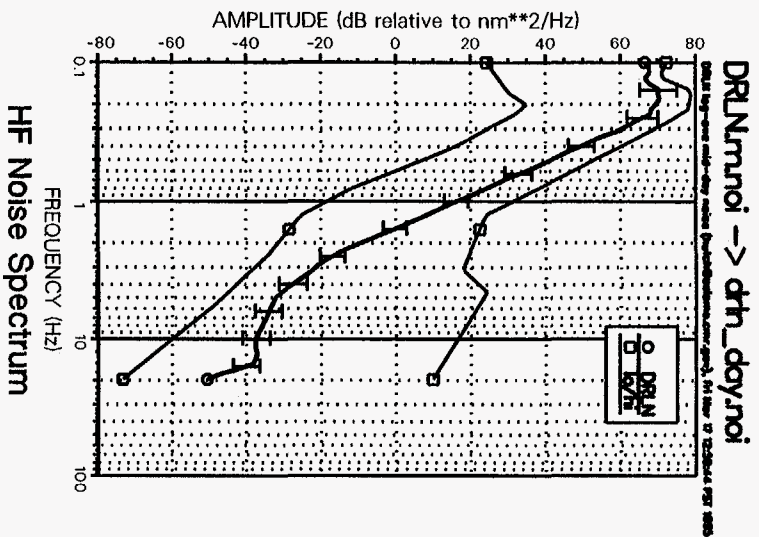


HF Noise Spectrum

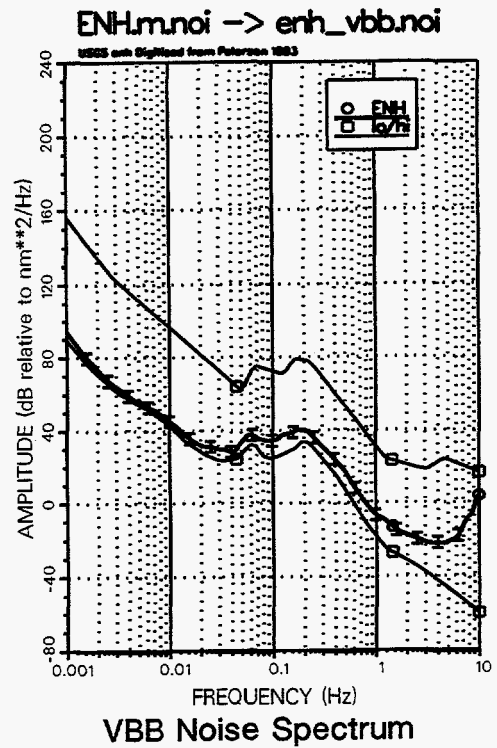
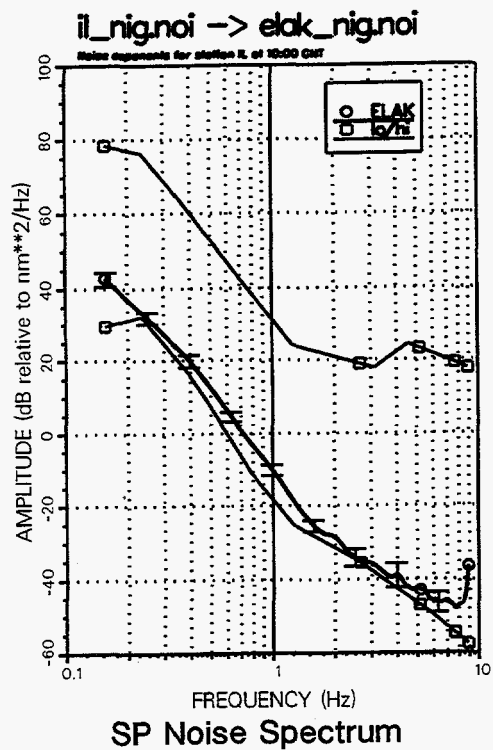
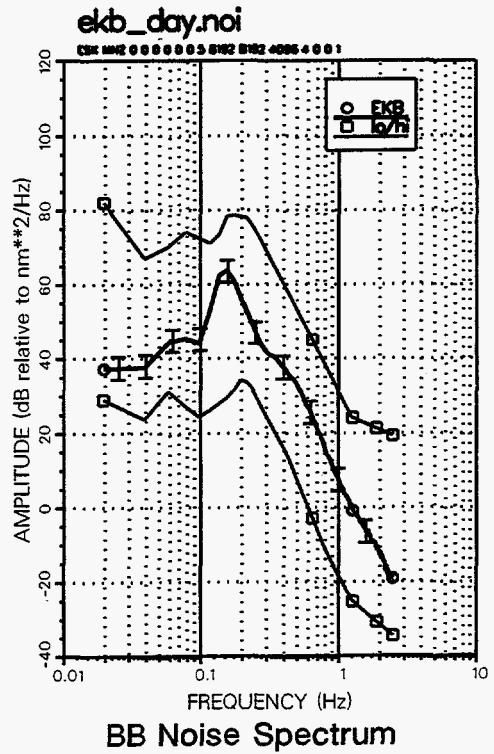
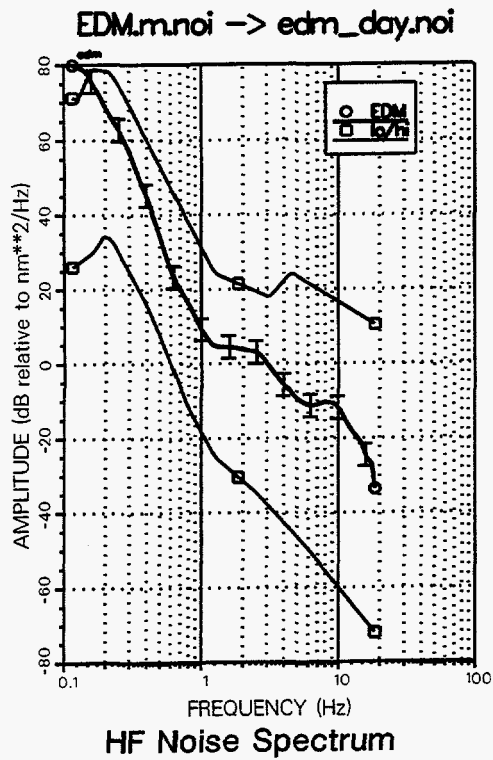


HF Noise Spectrum

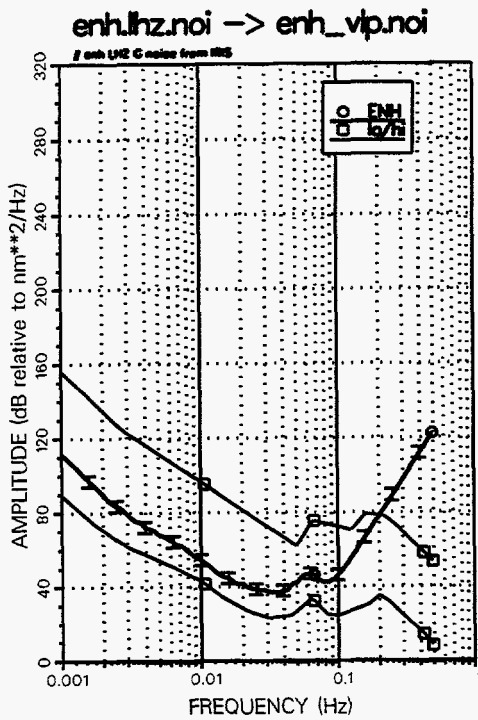
Station Noise Spectra



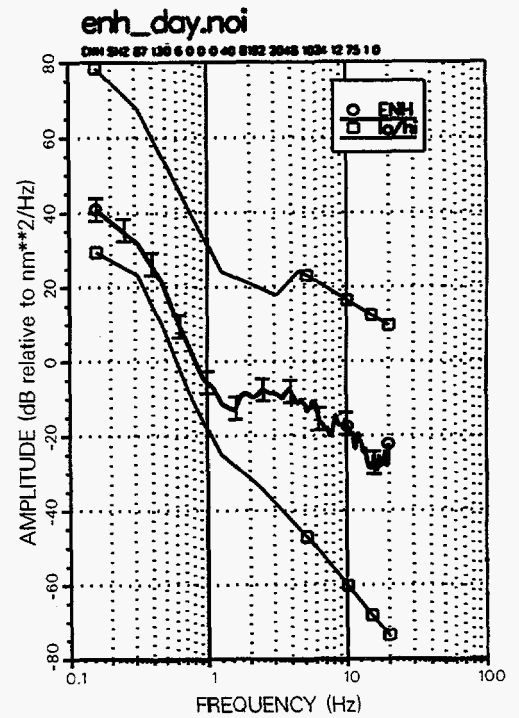
Station Noise Spectra



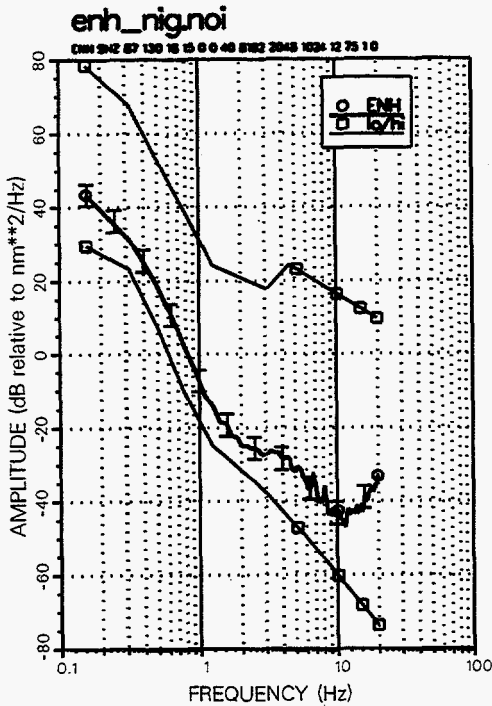
Station Noise Spectra



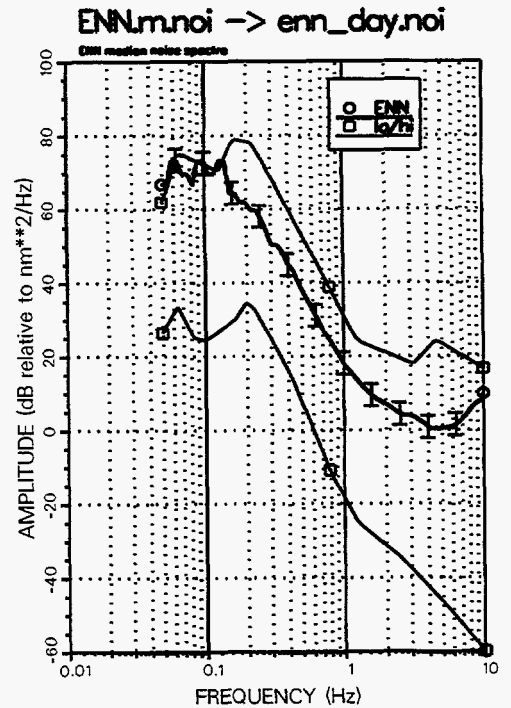
VLP Noise Spectrum



HF Noise Spectrum

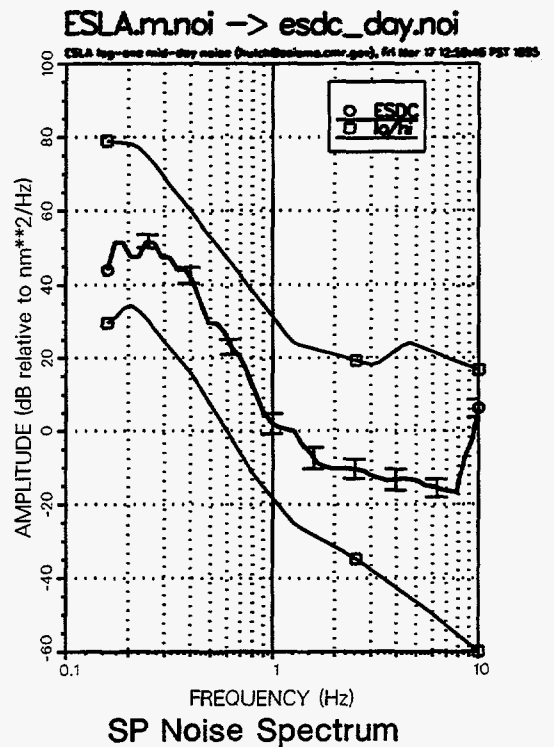
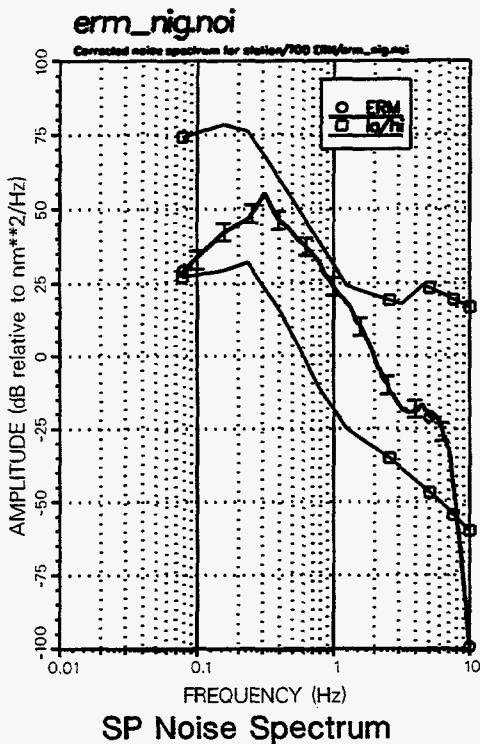
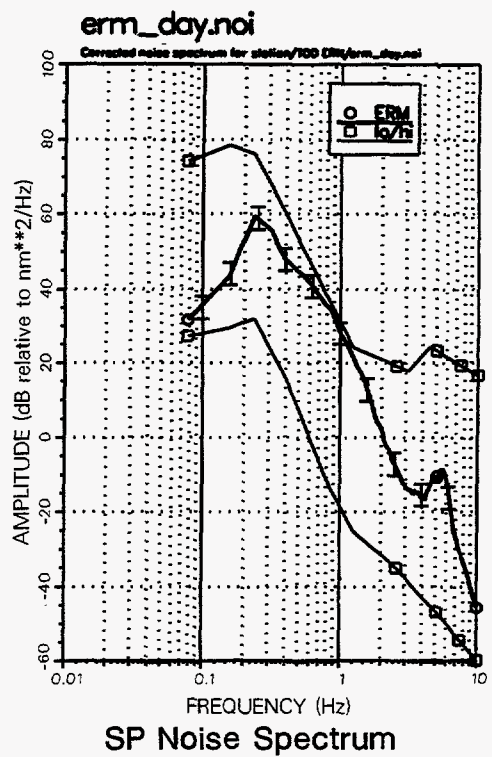
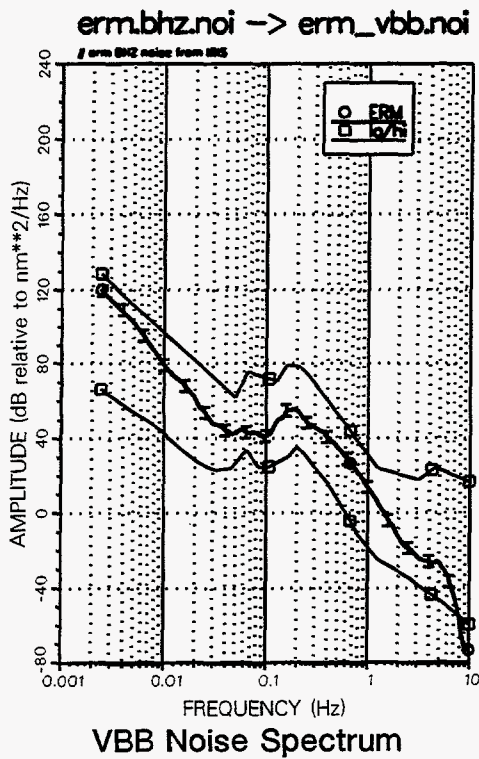


HF Noise Spectrum

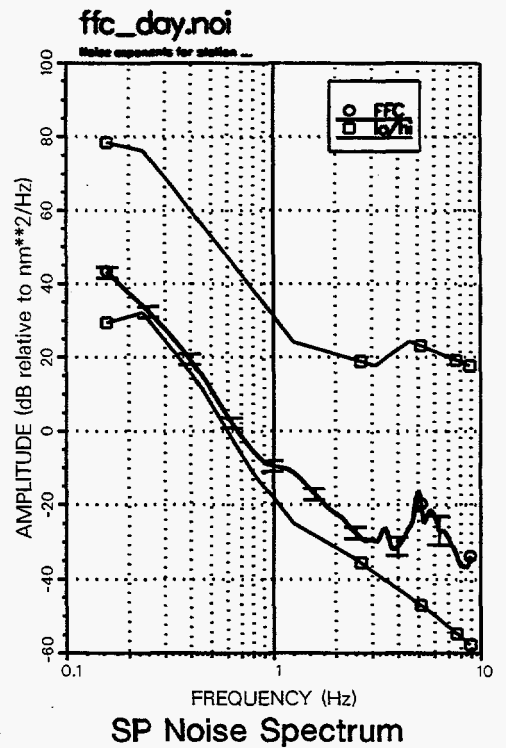
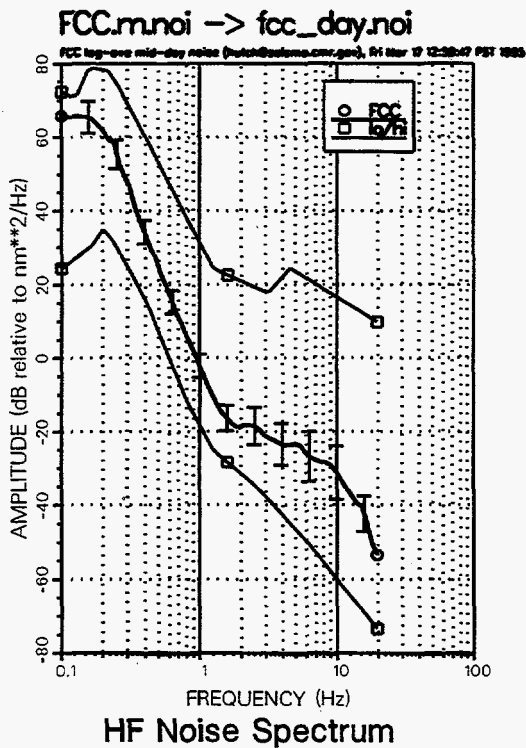
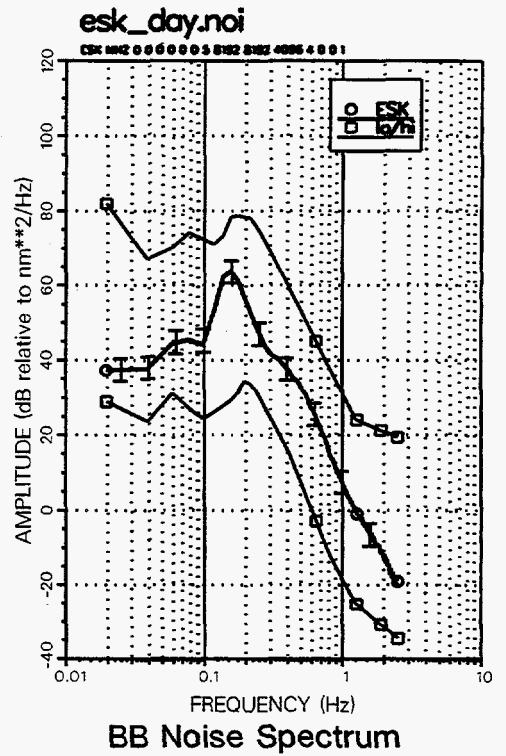
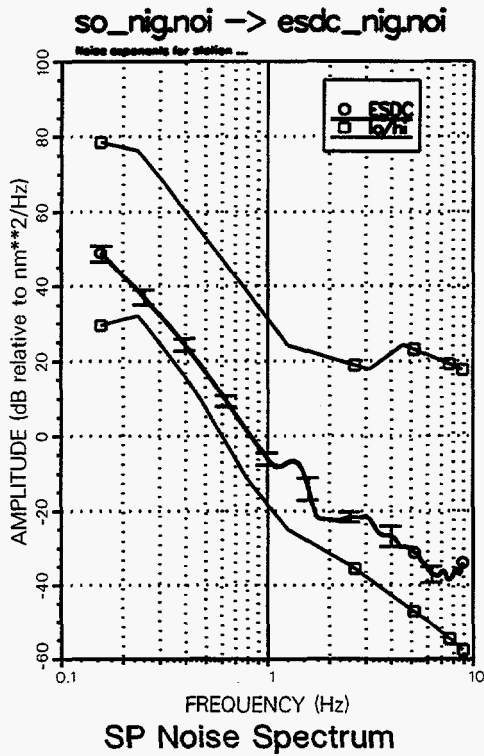


SP Noise Spectrum

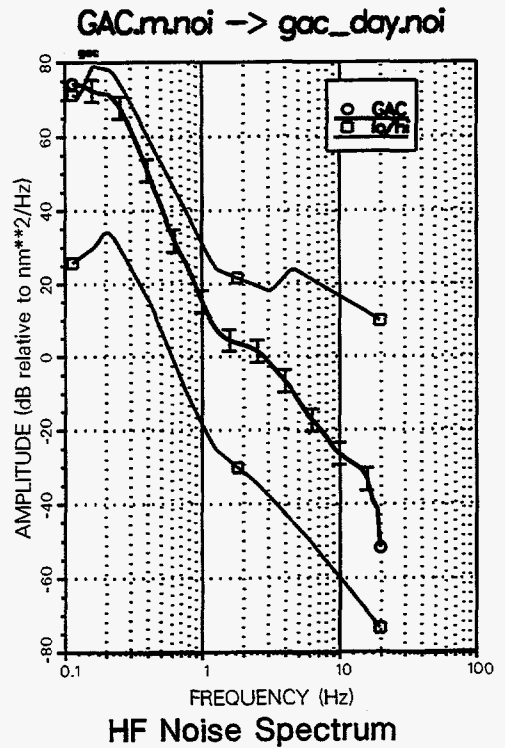
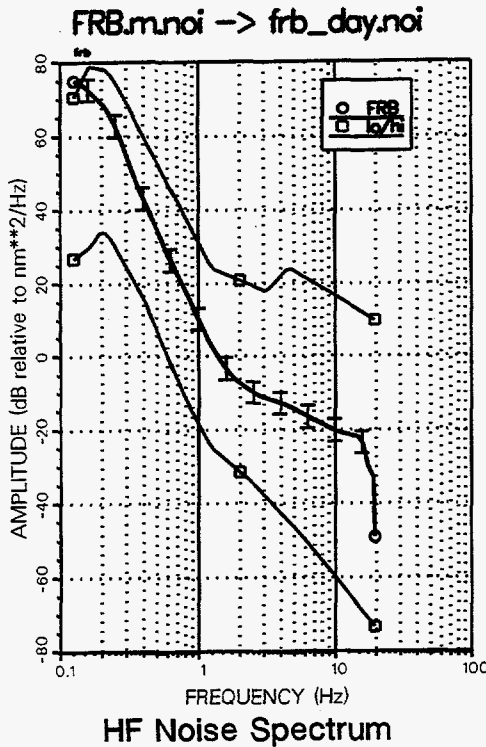
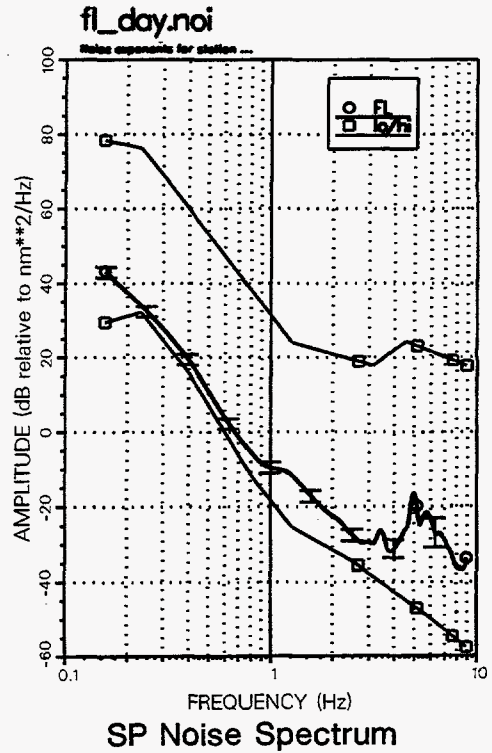
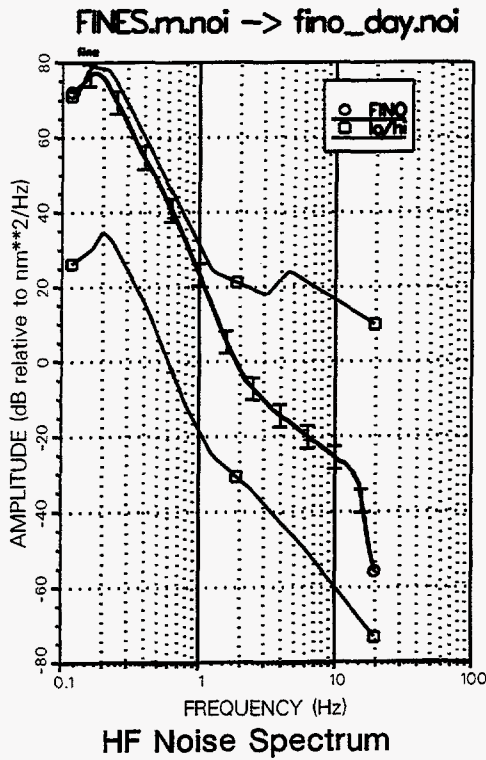
Station Noise Spectra



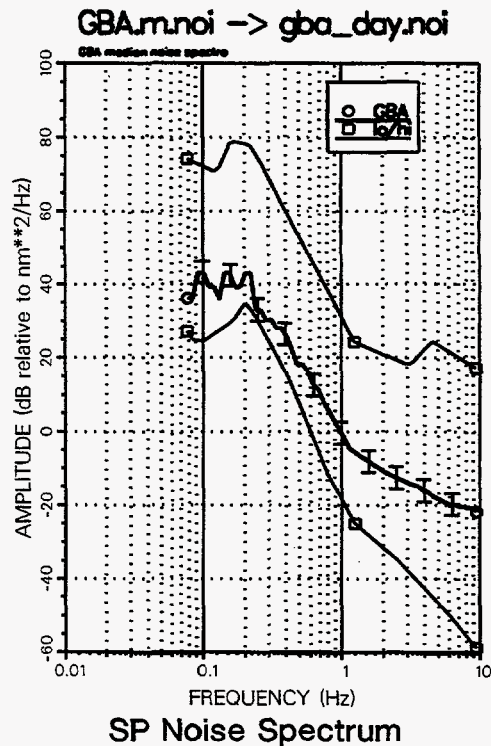
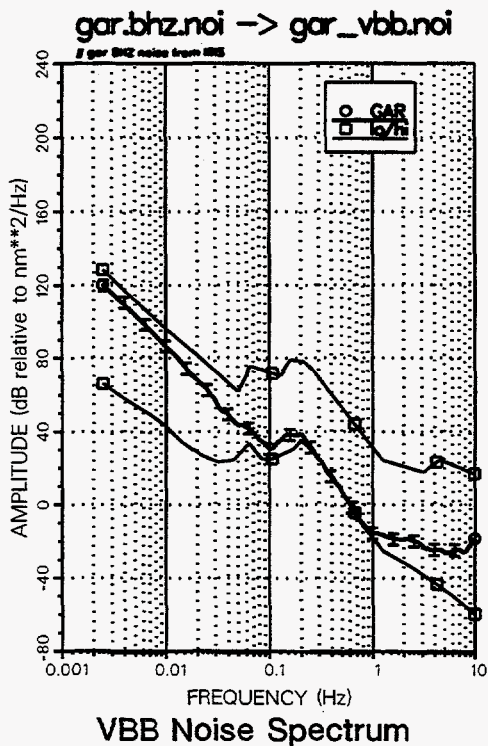
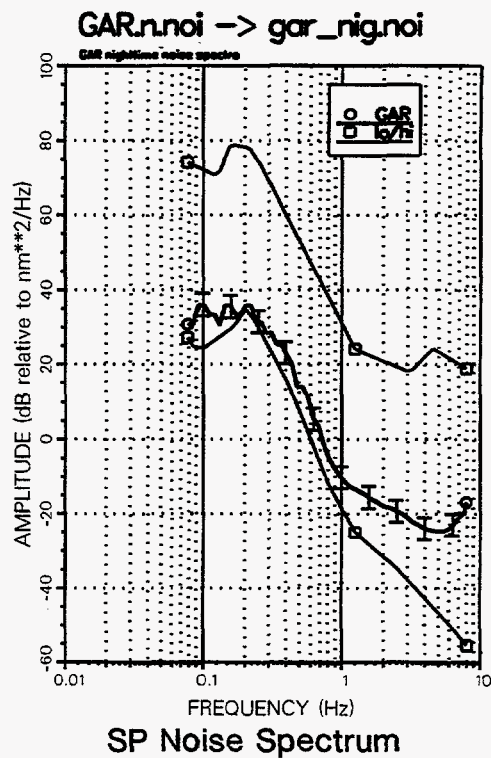
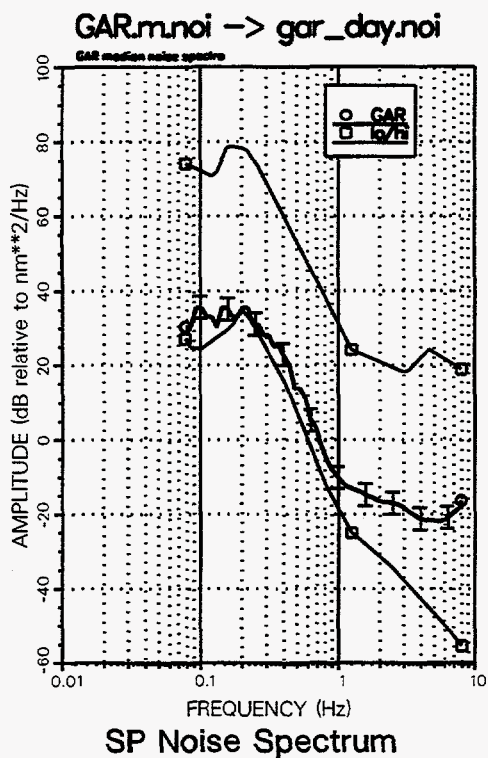
Station Noise Spectra



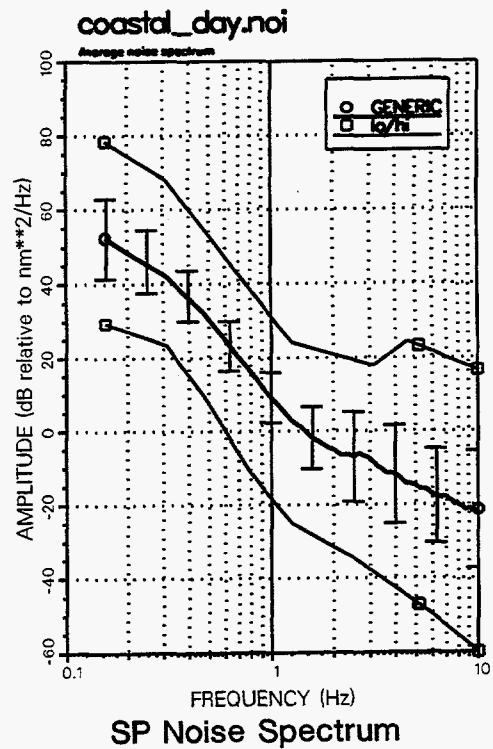
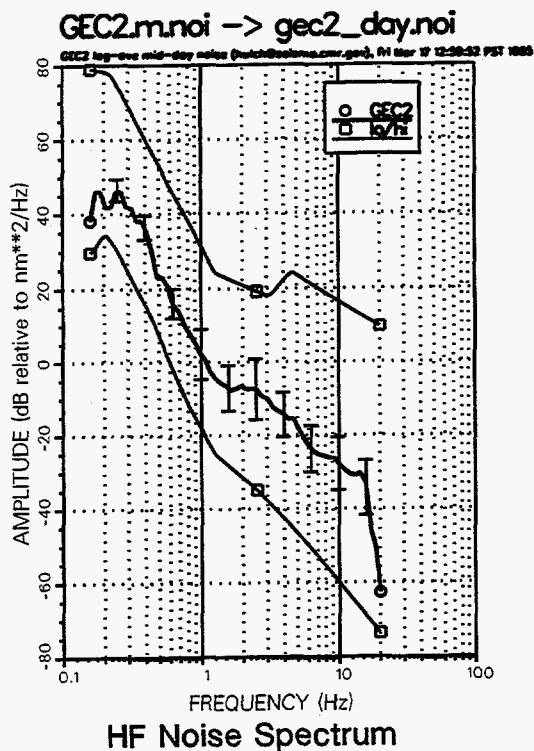
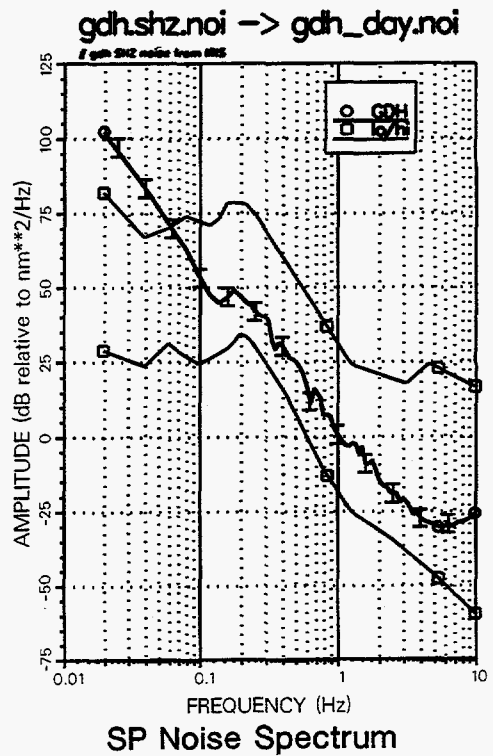
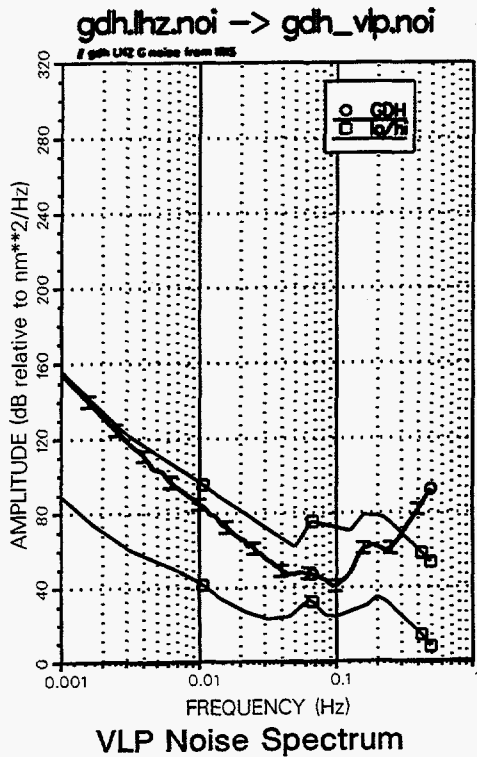
Station Noise Spectra



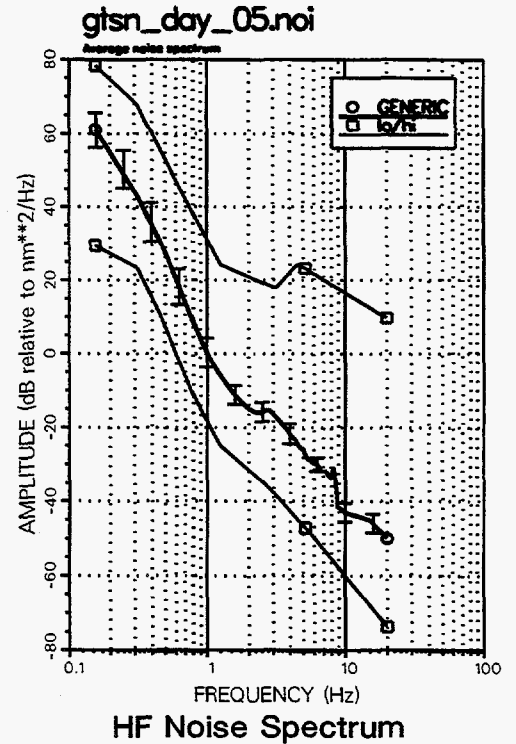
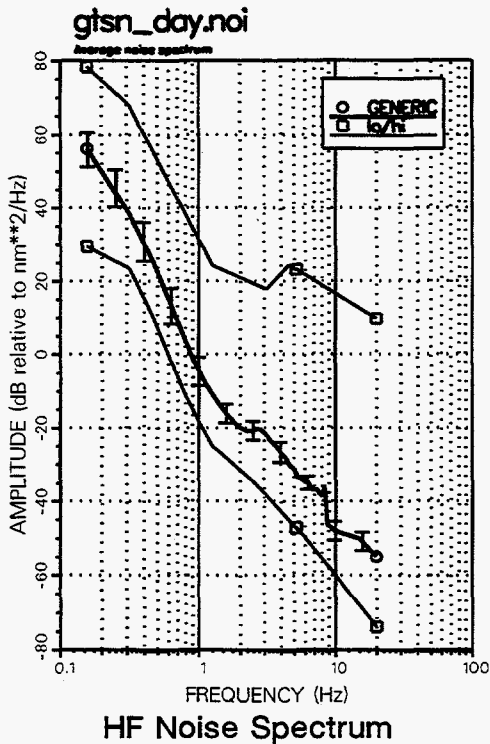
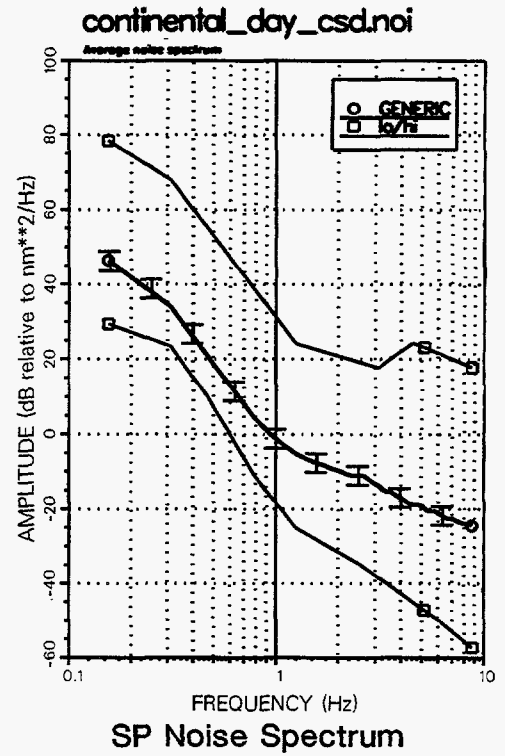
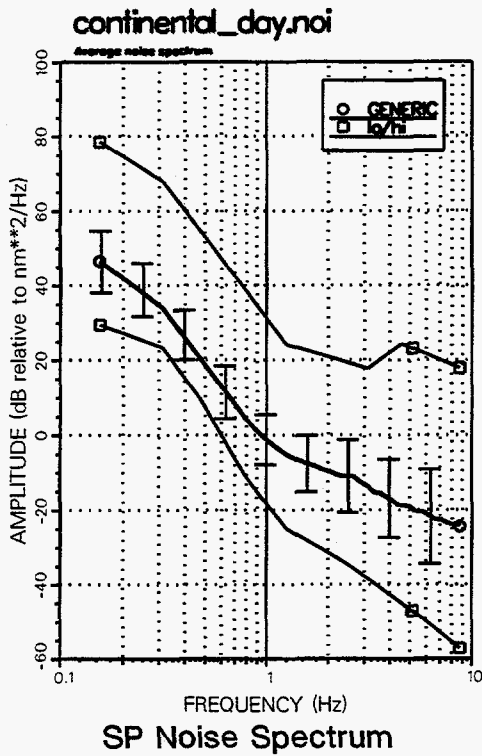
Station Noise Spectra



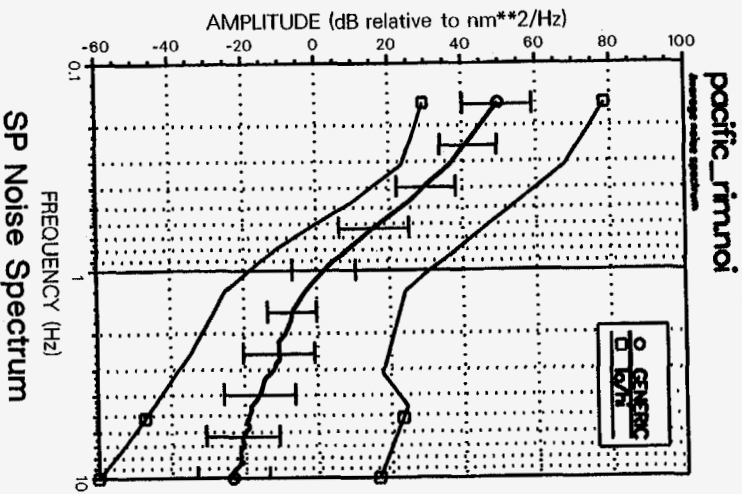
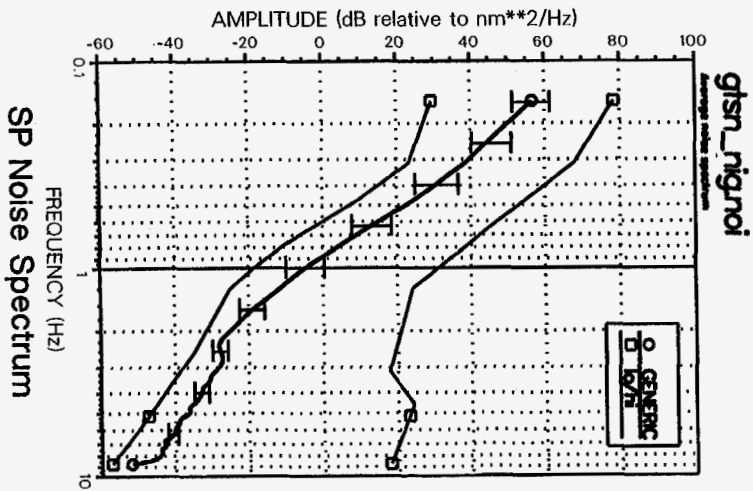
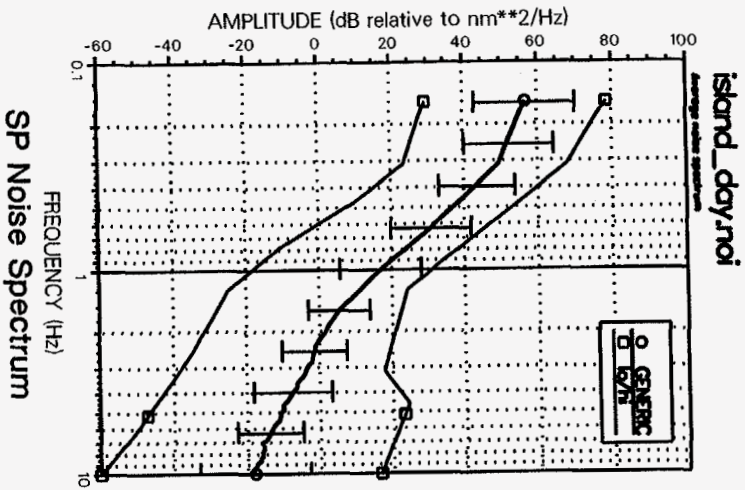
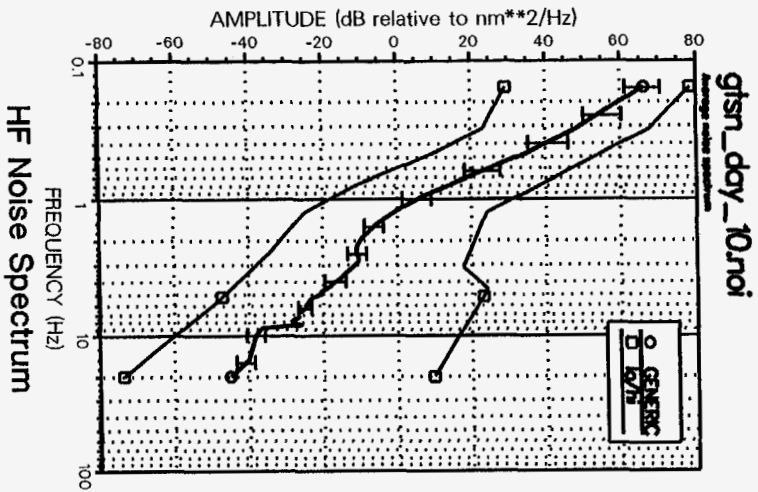
Station Noise Spectra



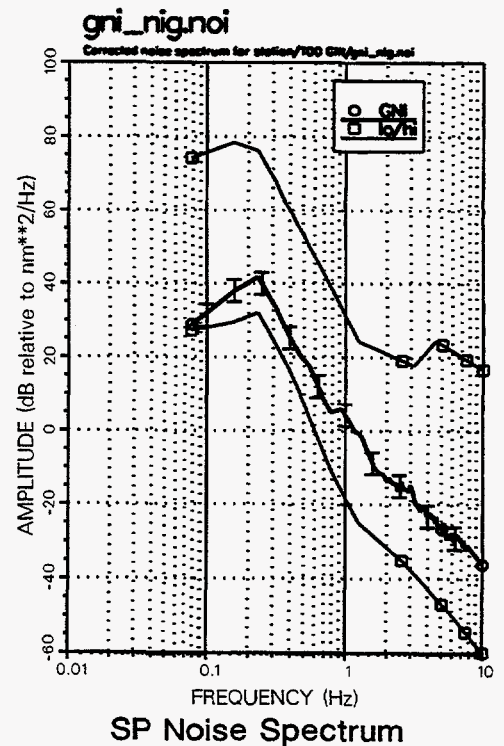
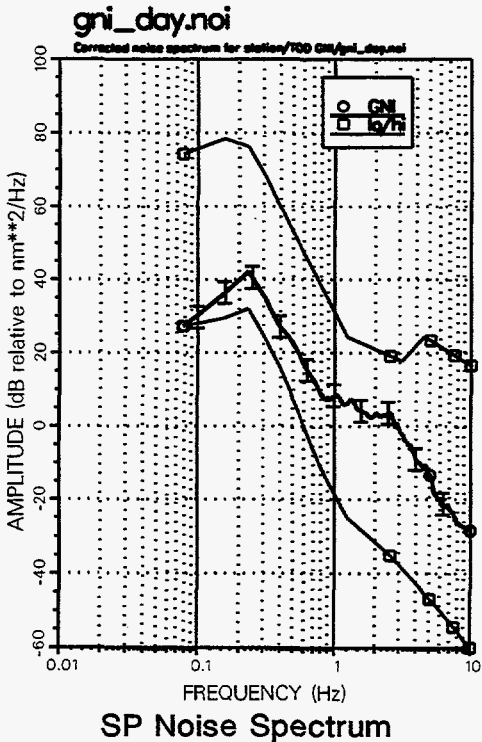
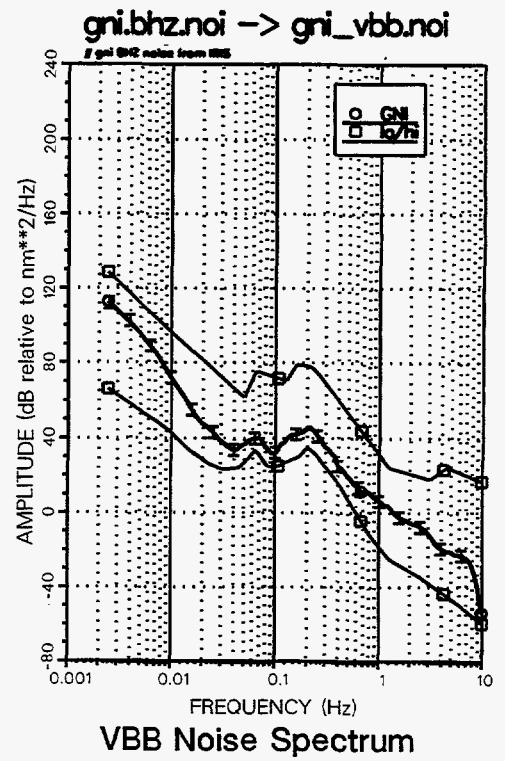
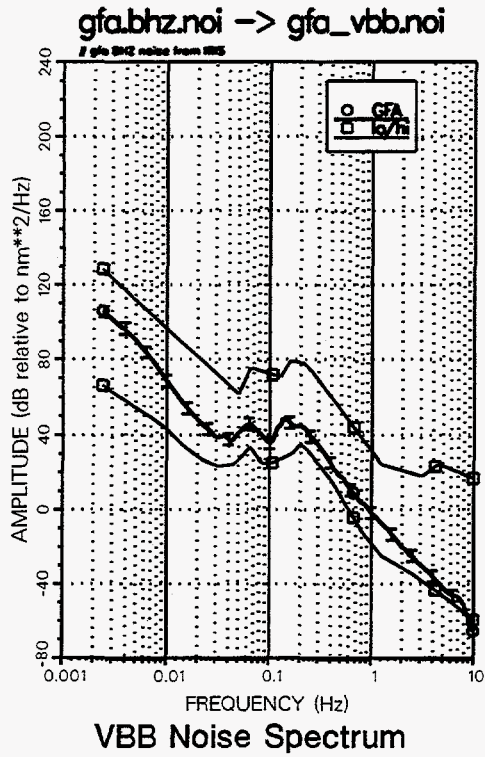
Station Noise Spectra



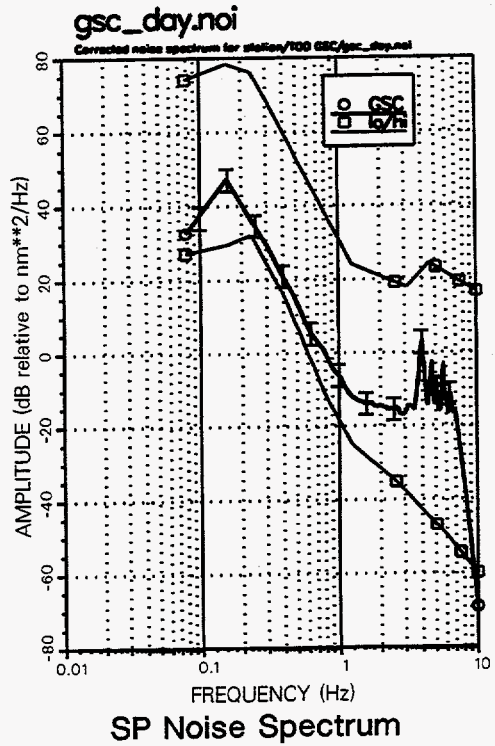
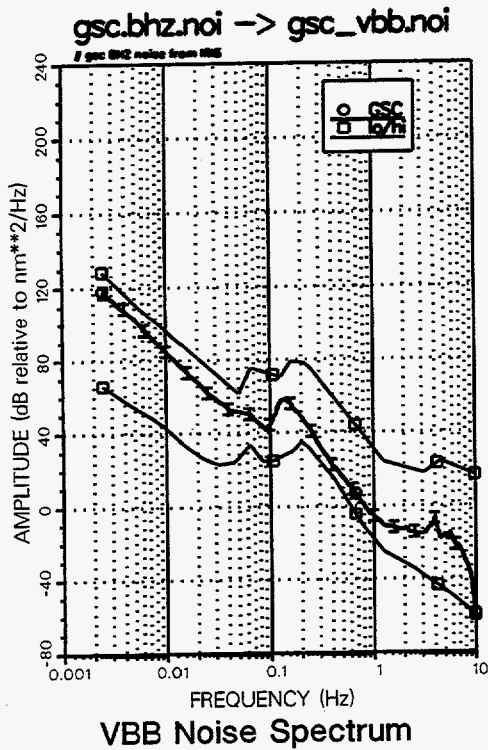
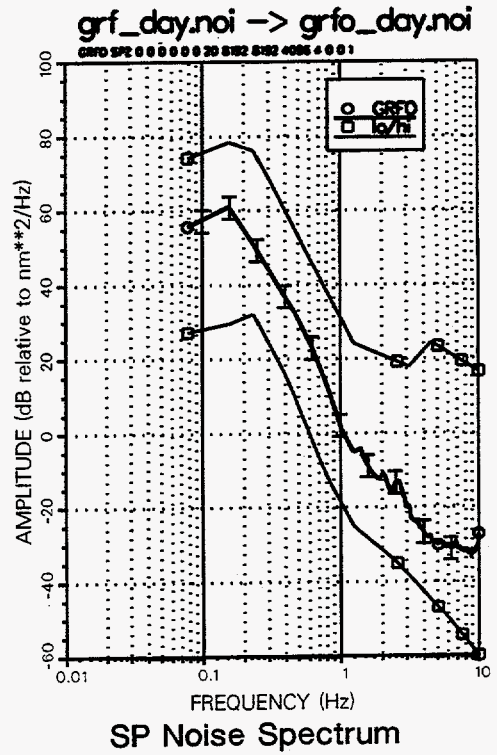
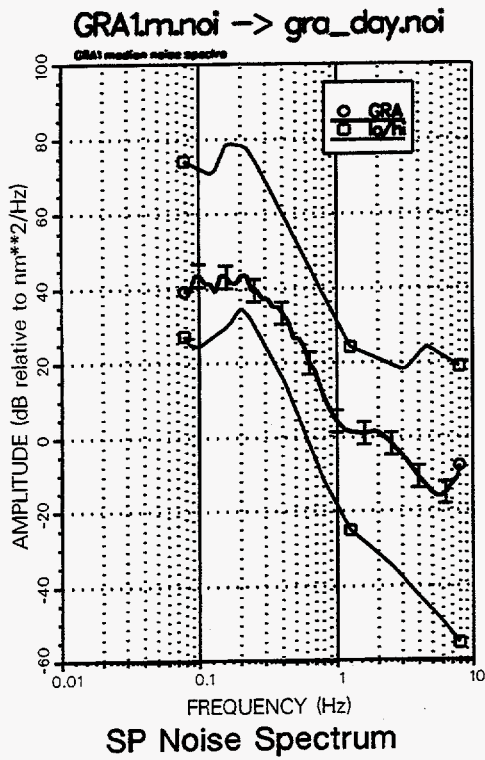
Station Noise Spectra



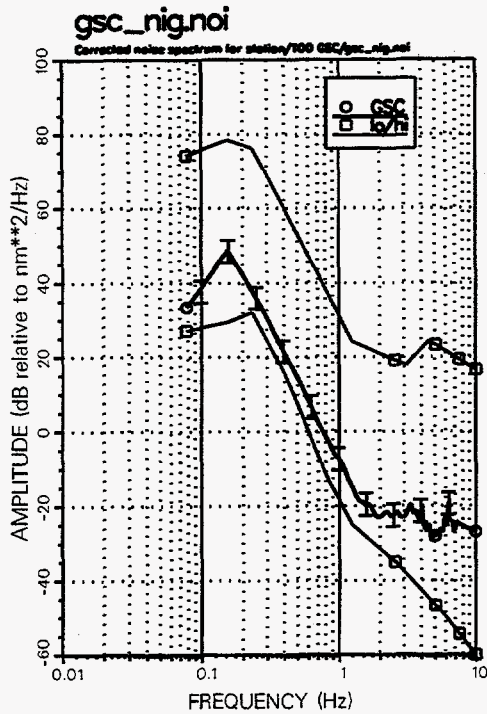
Station Noise Spectra



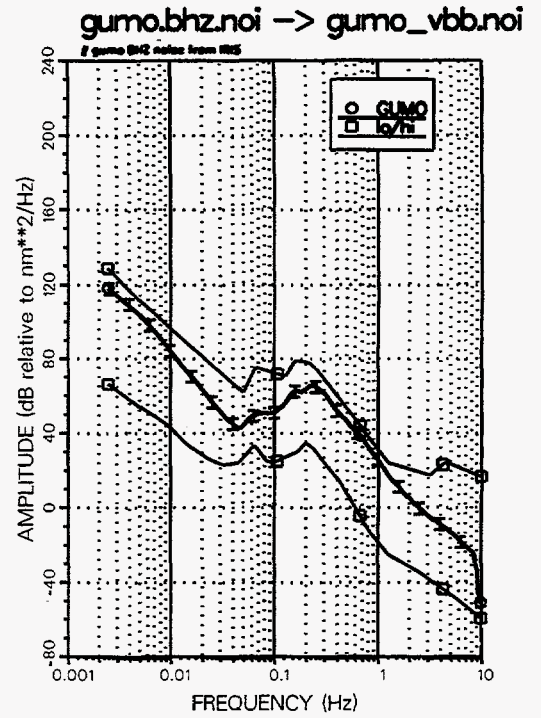
Station Noise Spectra



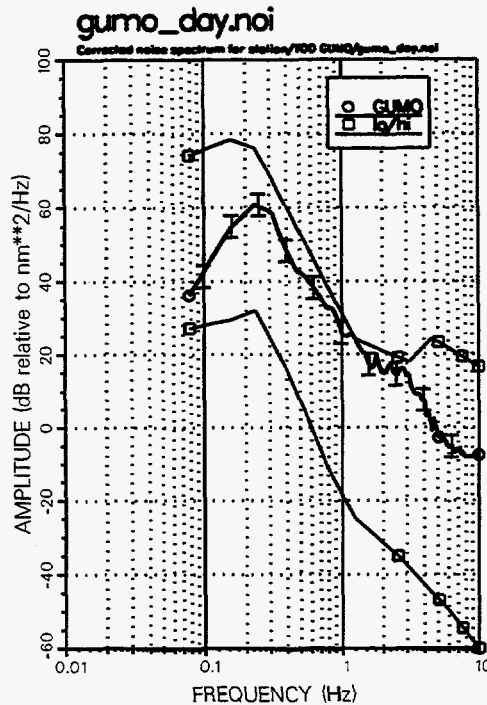
Station Noise Spectra



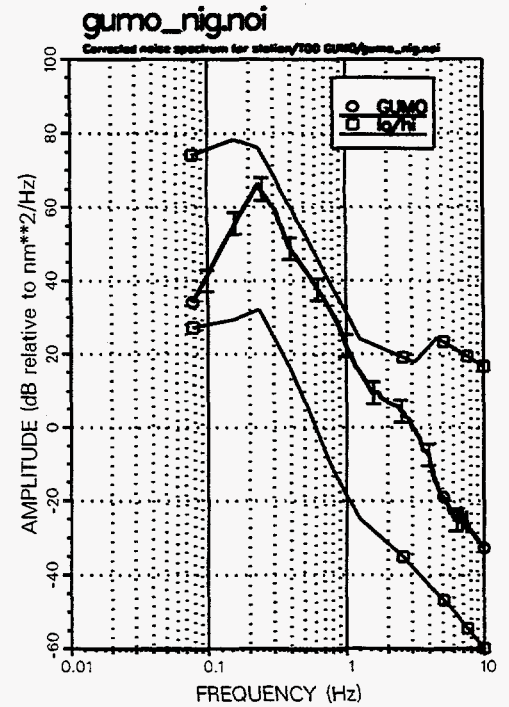
SP Noise Spectrum



VBB Noise Spectrum

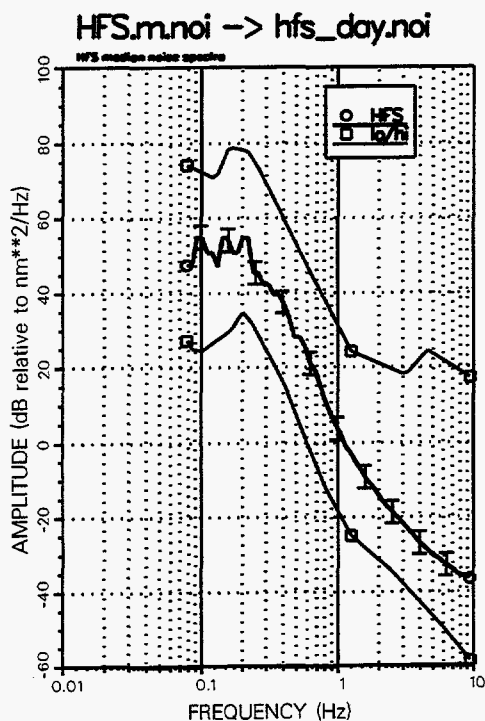


SP Noise Spectrum

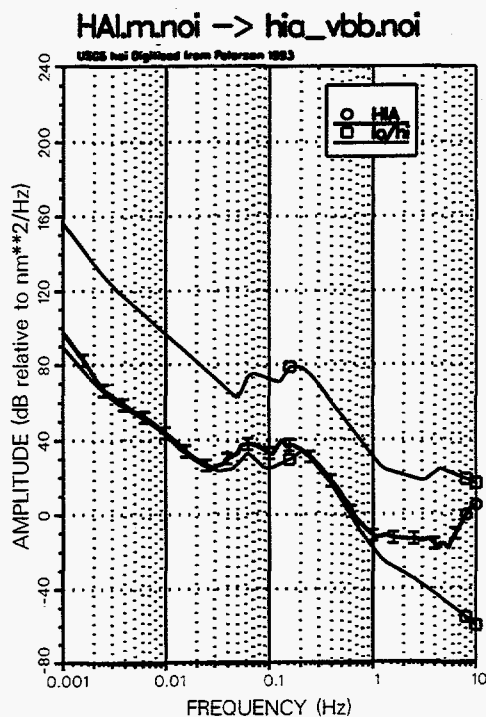


SP Noise Spectrum

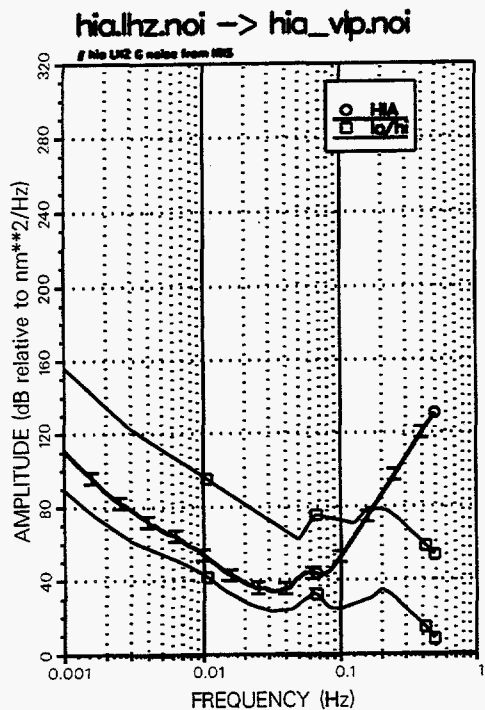
Station Noise Spectra



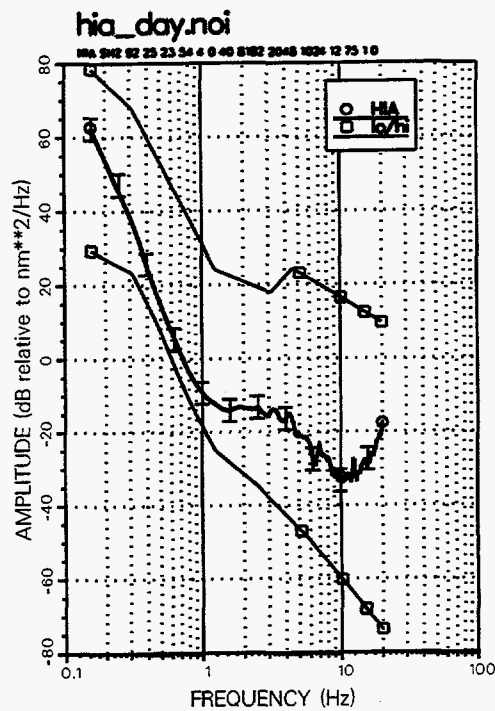
SP Noise Spectrum



VBB Noise Spectrum

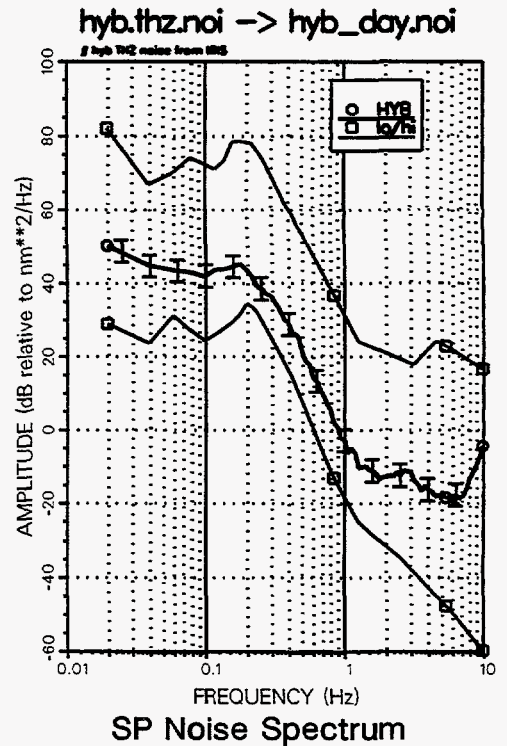
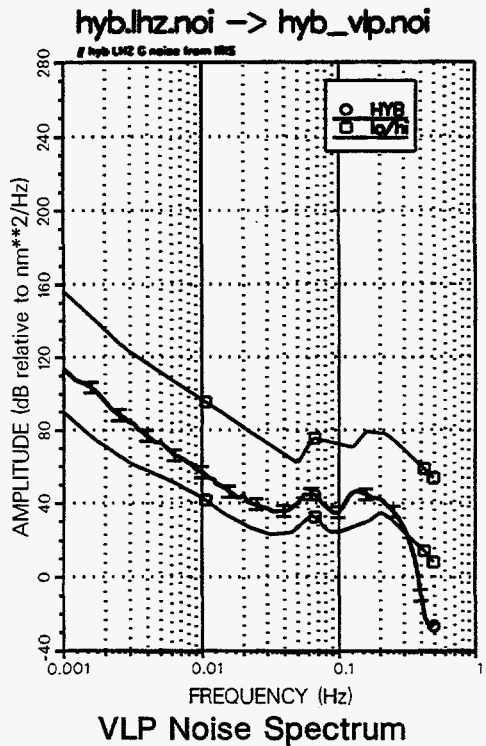
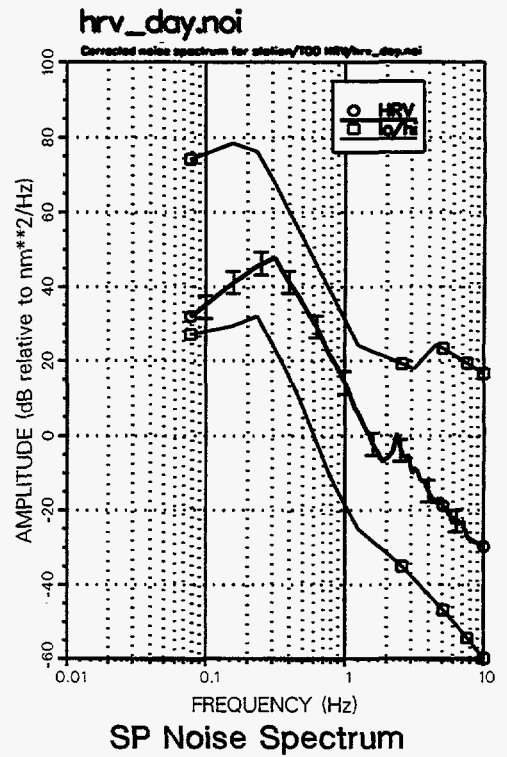
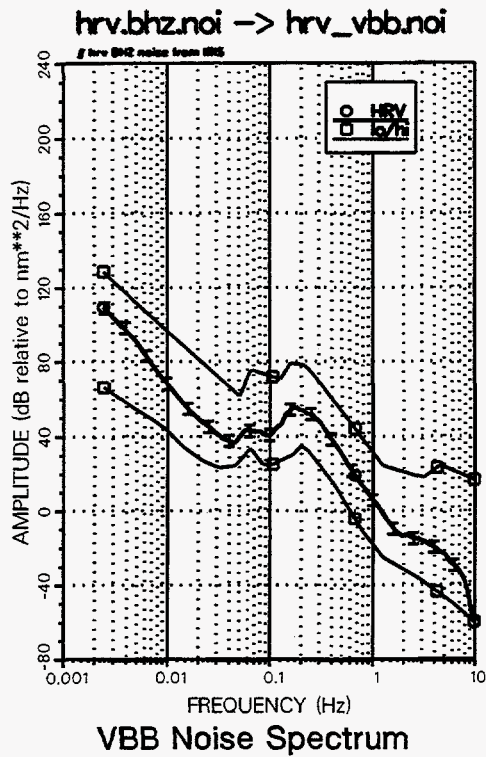


VLP Noise Spectrum

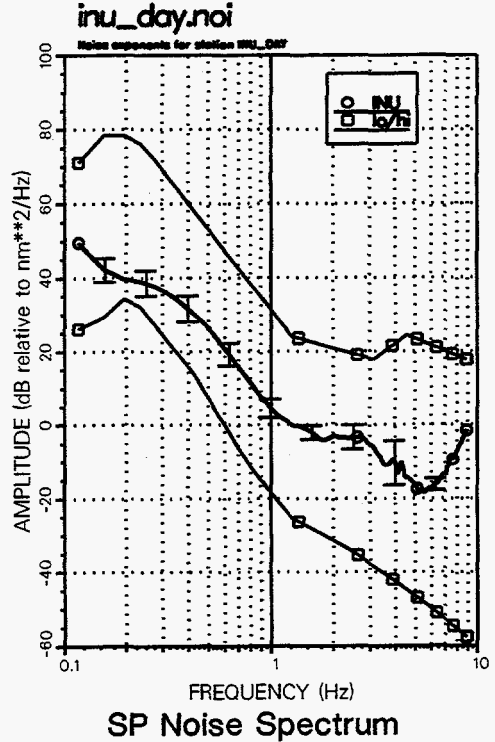
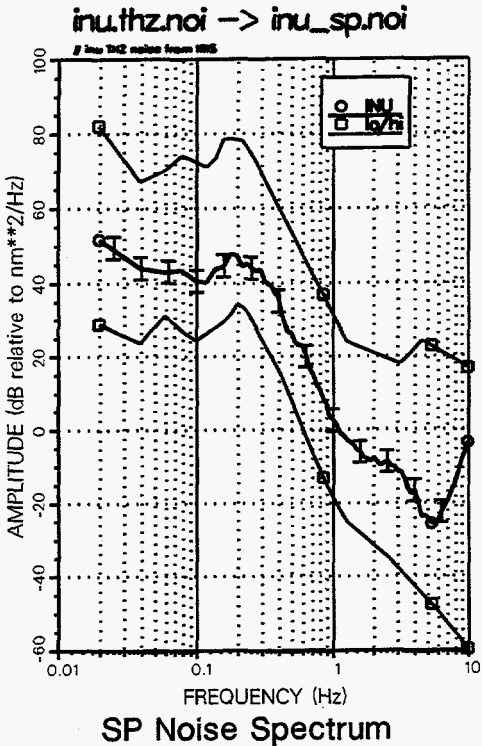
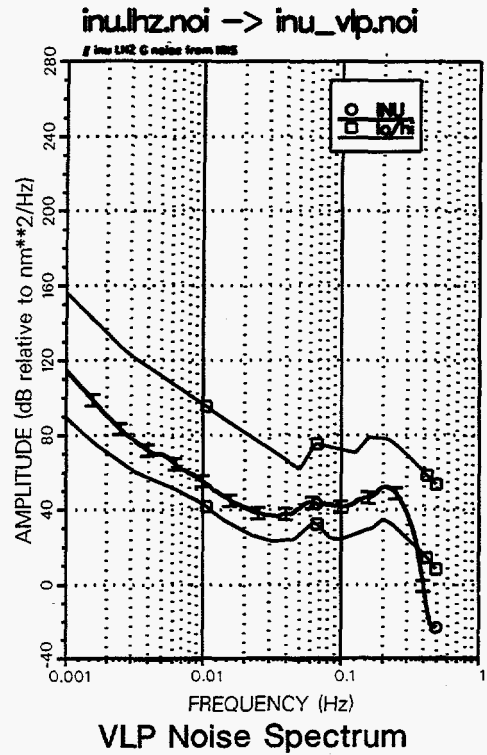
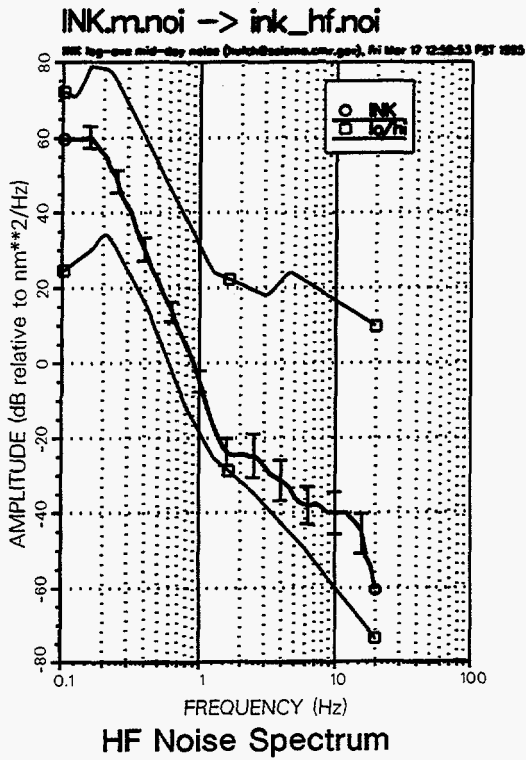


HF Noise Spectrum

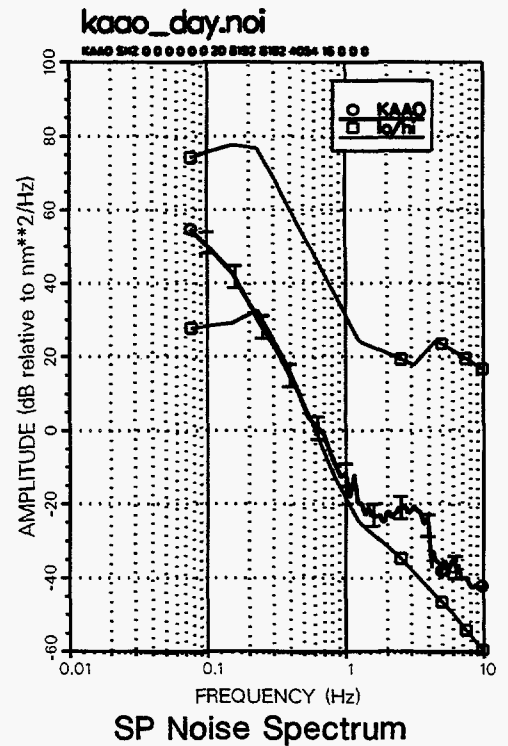
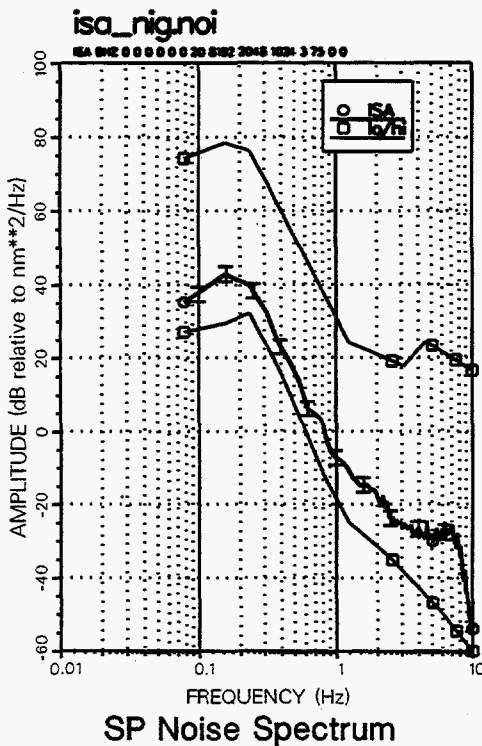
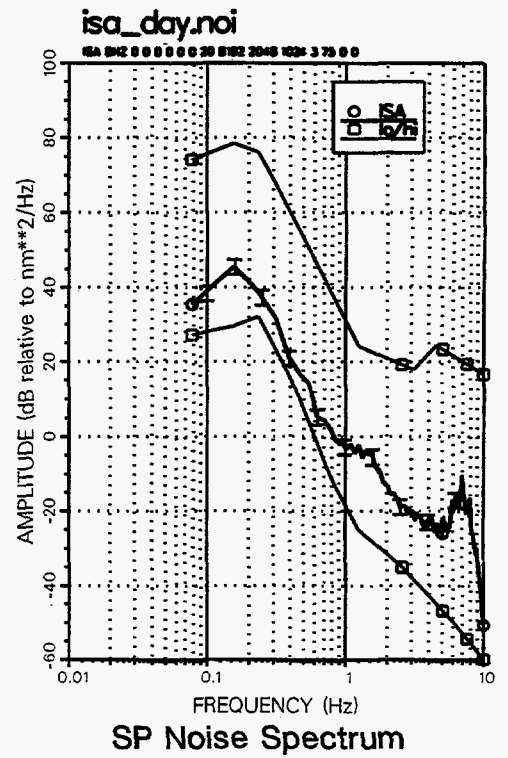
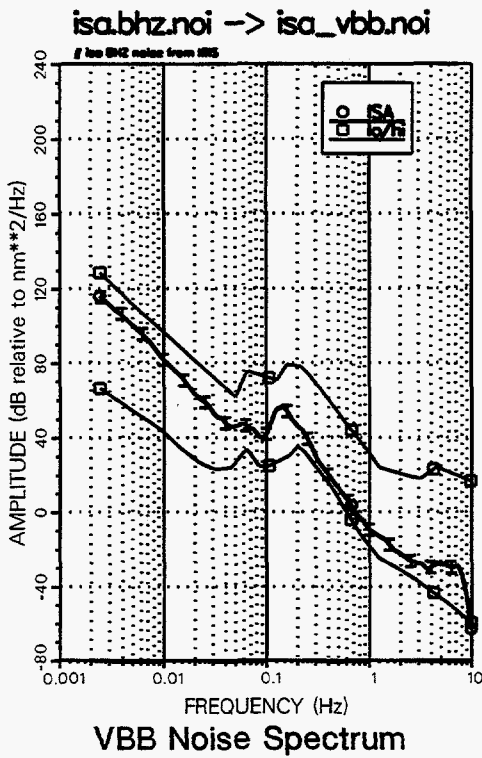
Station Noise Spectra



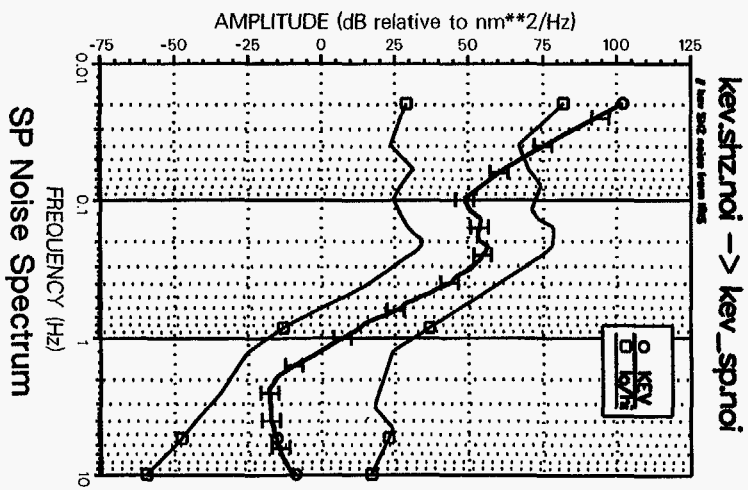
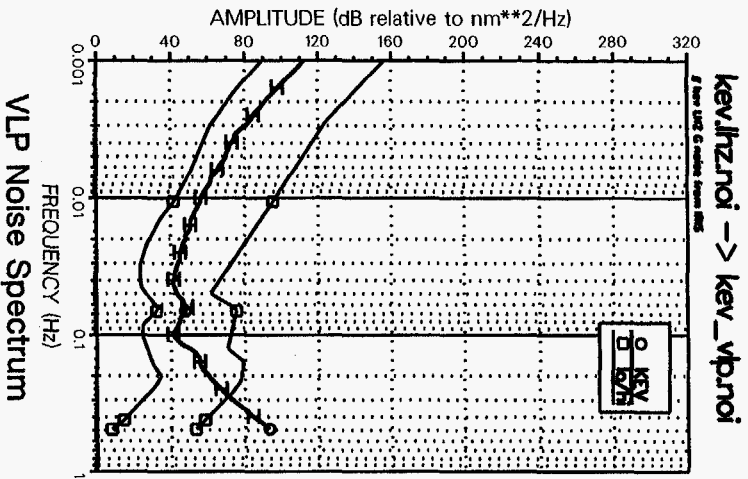
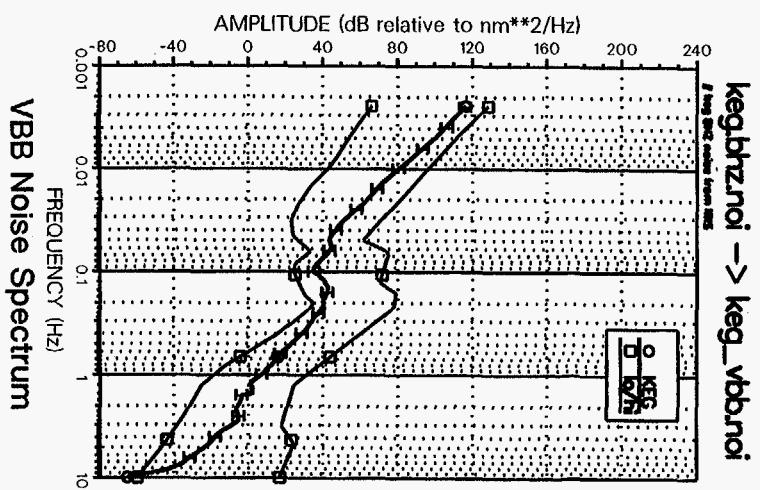
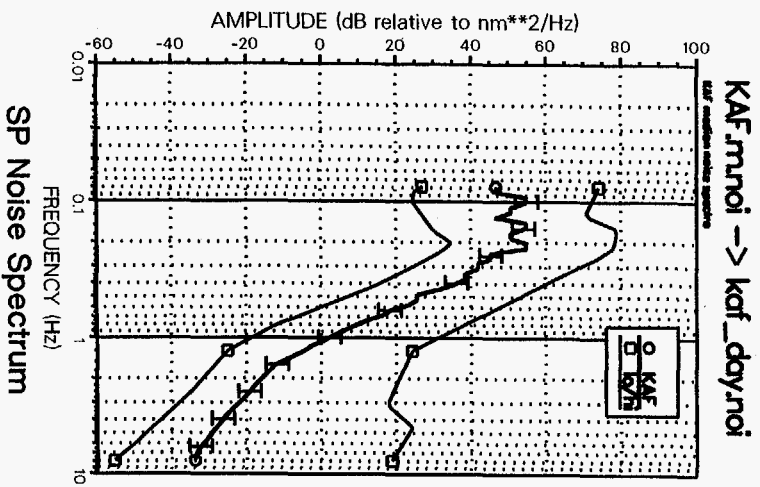
Station Noise Spectra



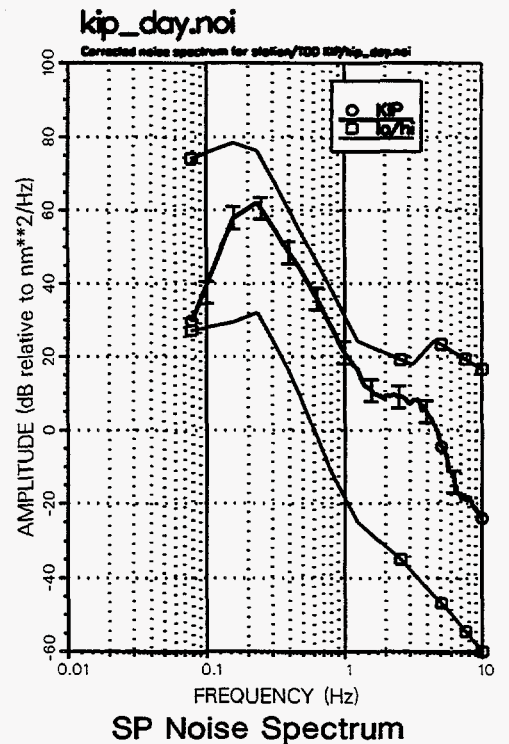
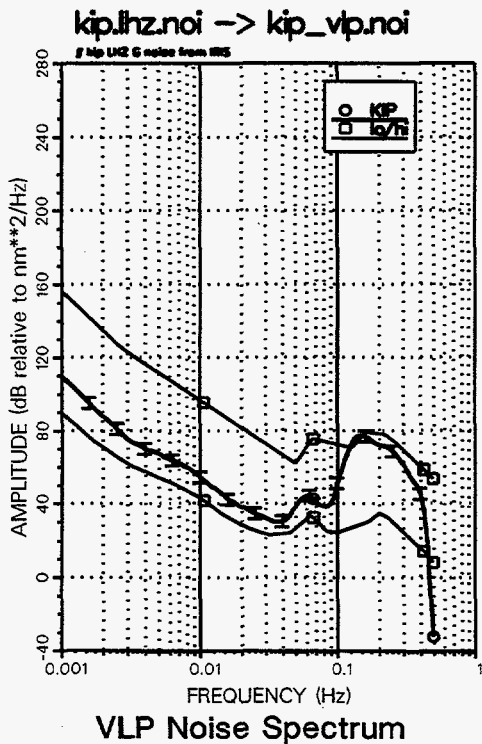
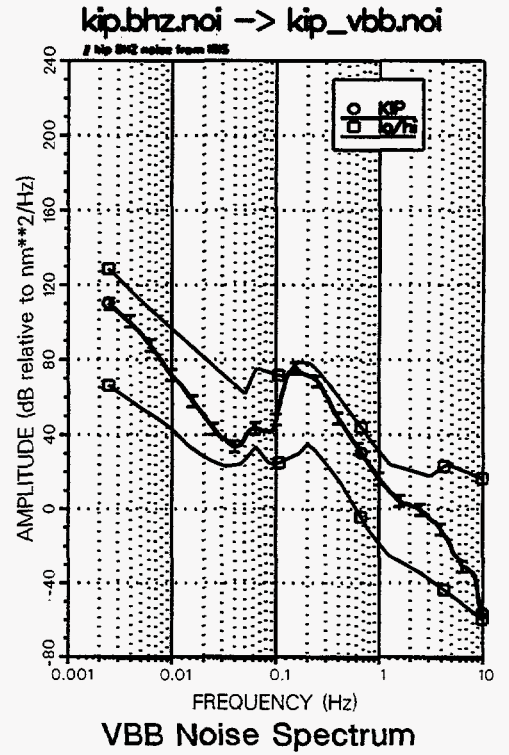
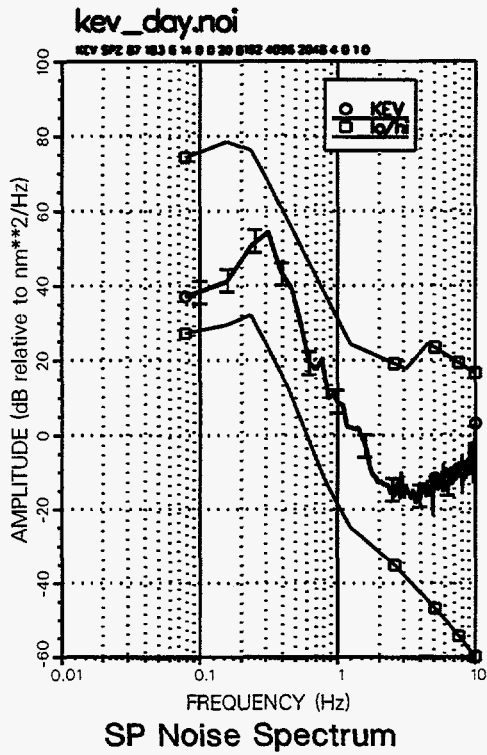
Station Noise Spectra



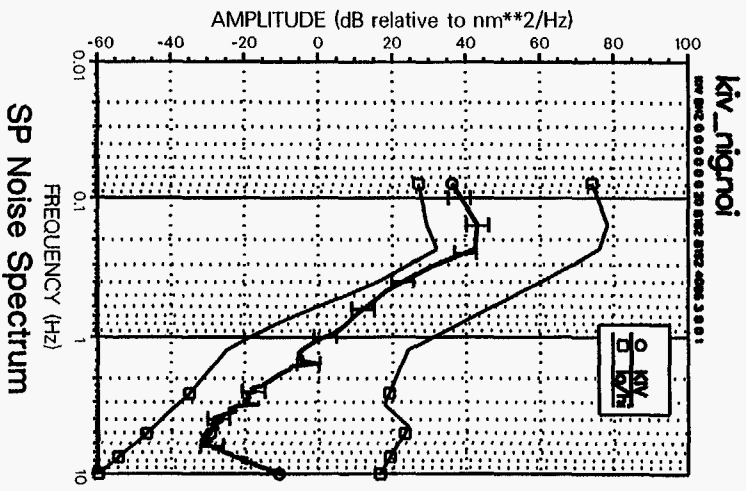
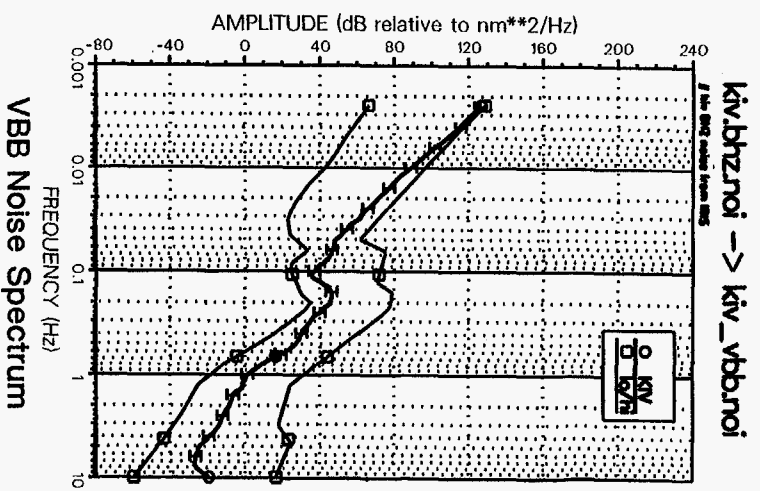
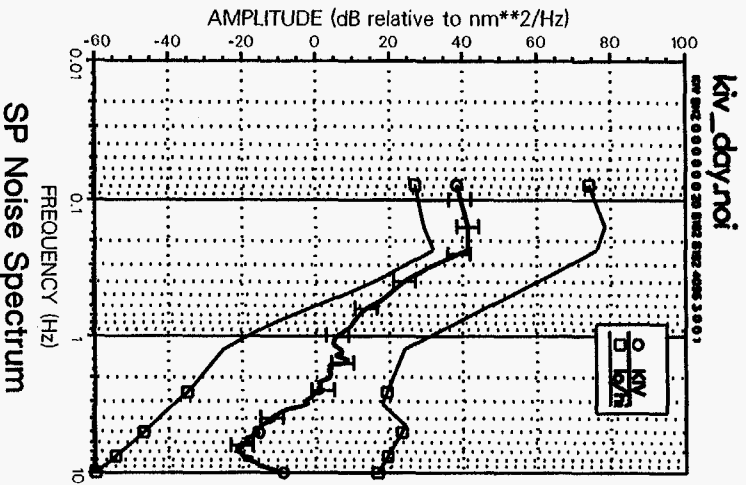
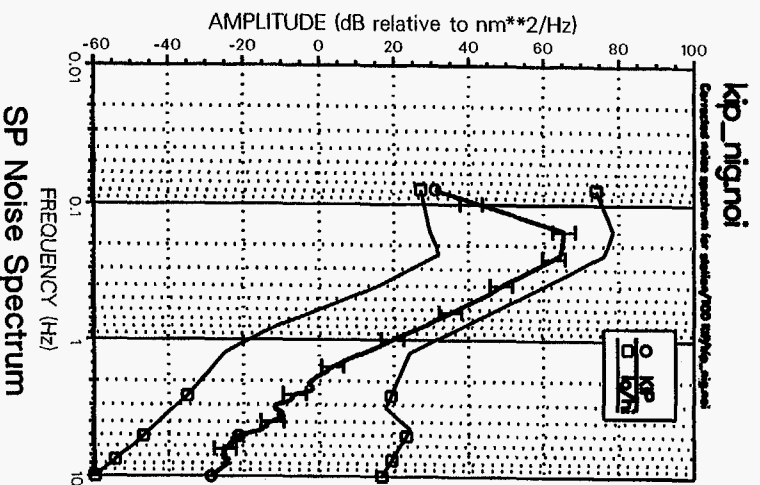
Station Noise Spectra



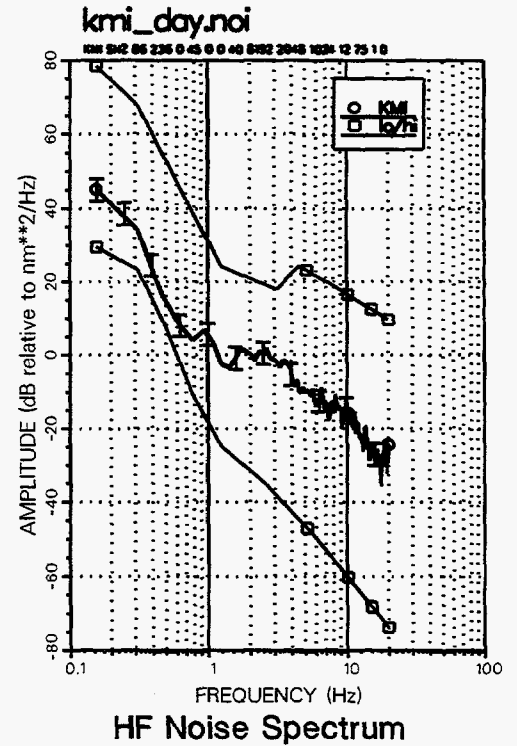
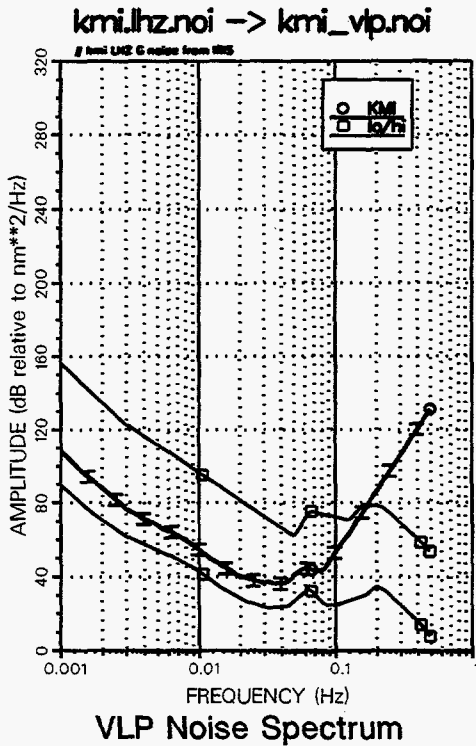
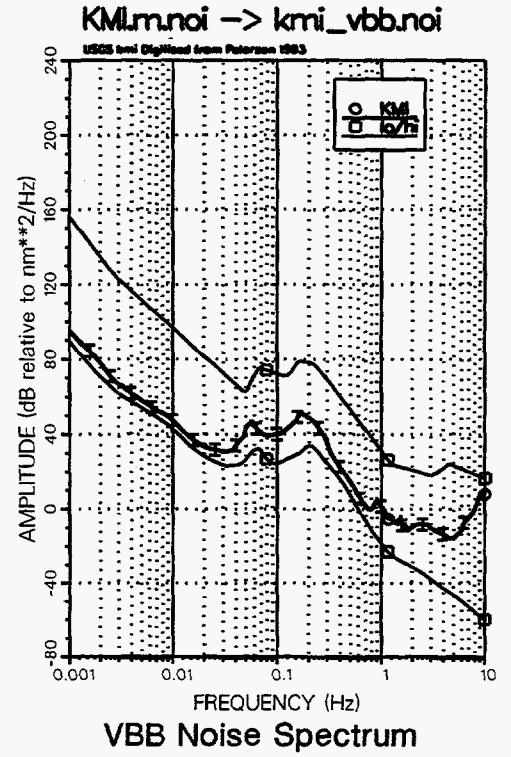
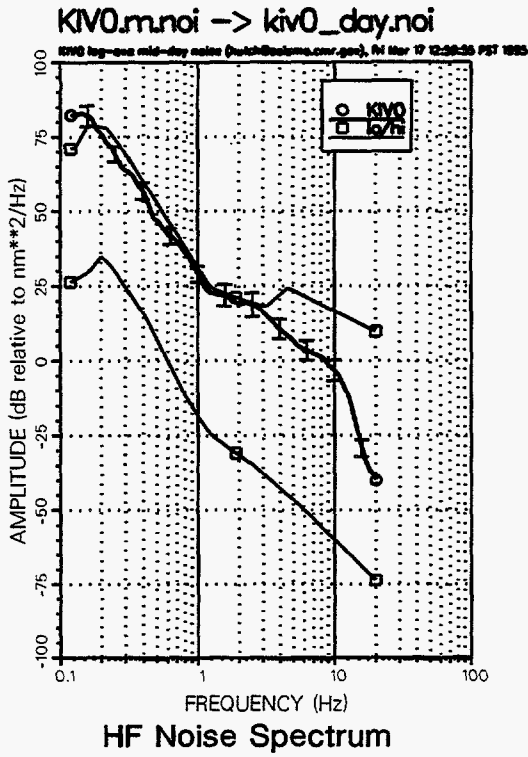
Station Noise Spectra



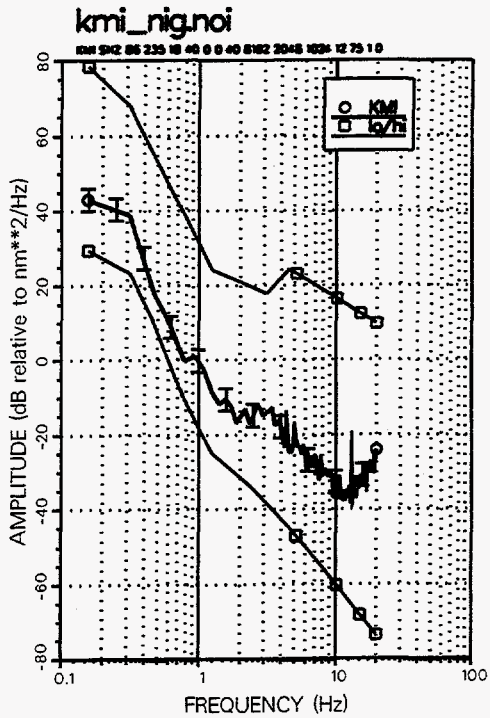
Station Noise Spectra



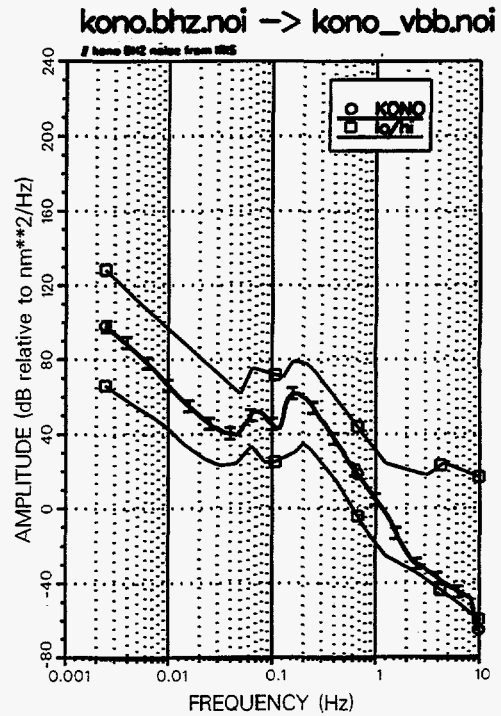
Station Noise Spectra



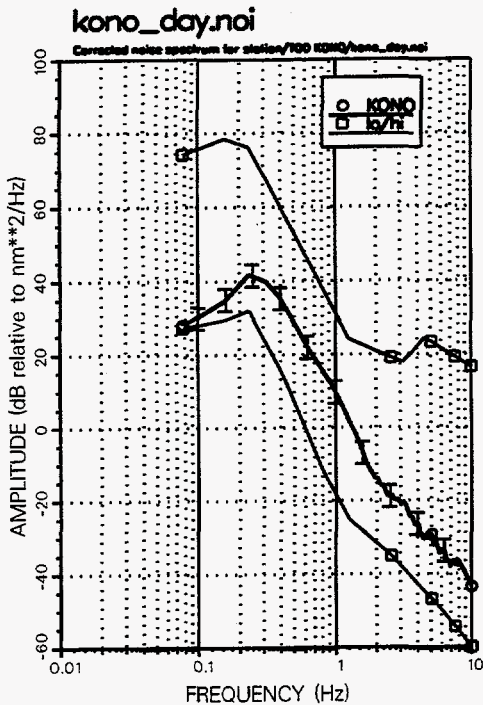
Station Noise Spectra



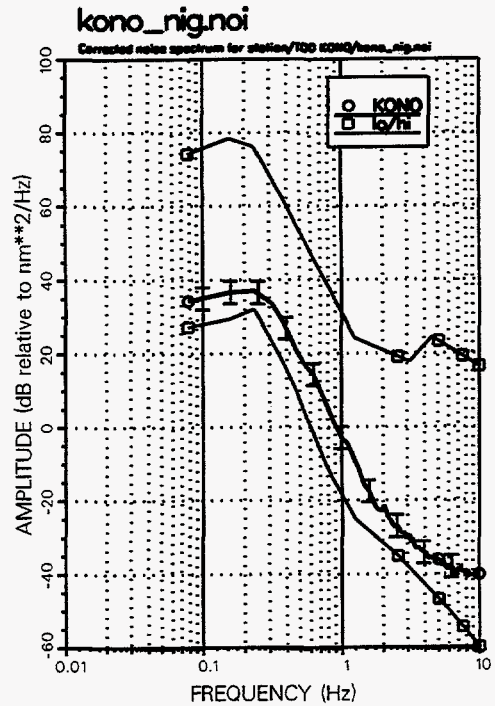
HF Noise Spectrum



VBB Noise Spectrum

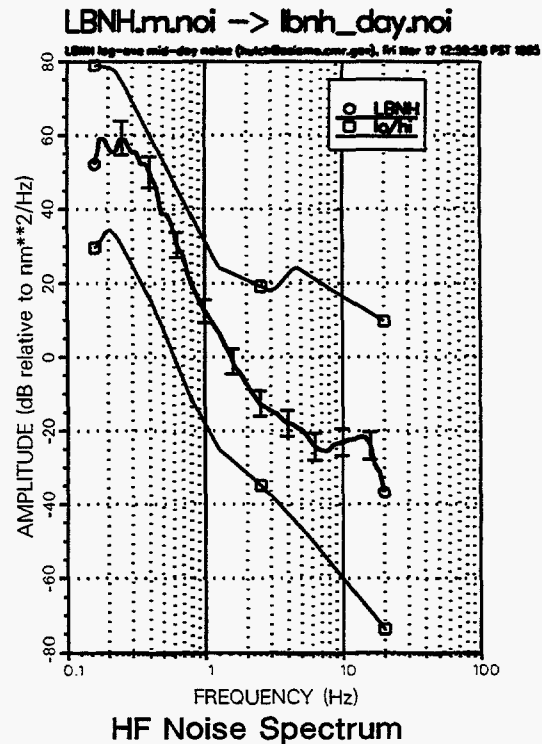
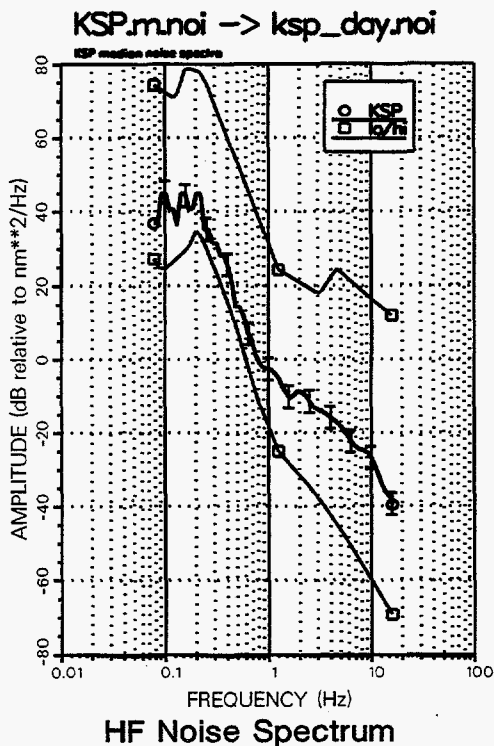
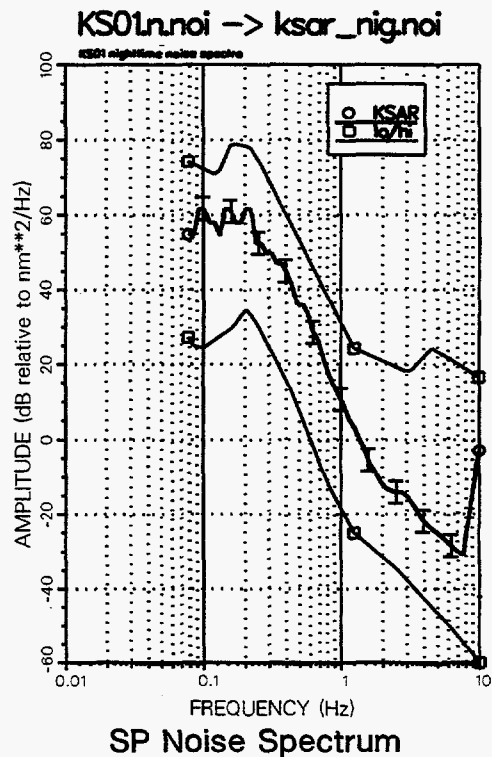
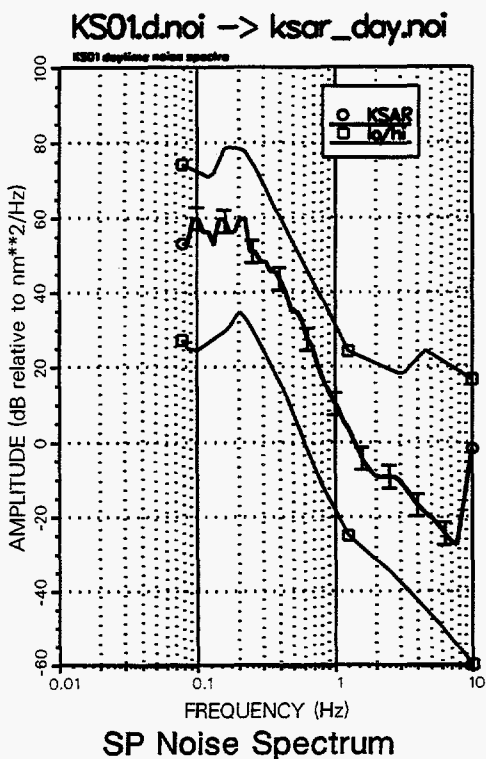


SP Noise Spectrum

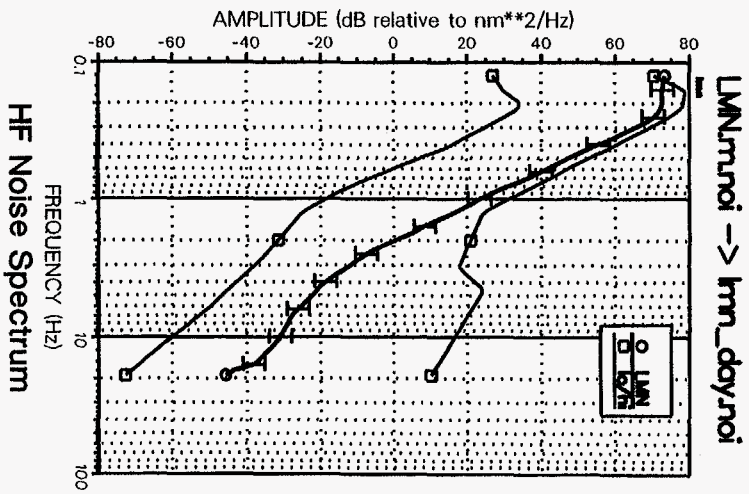
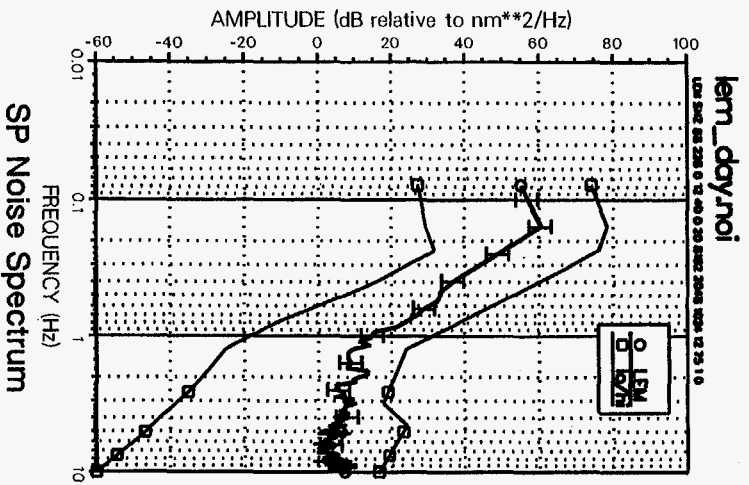
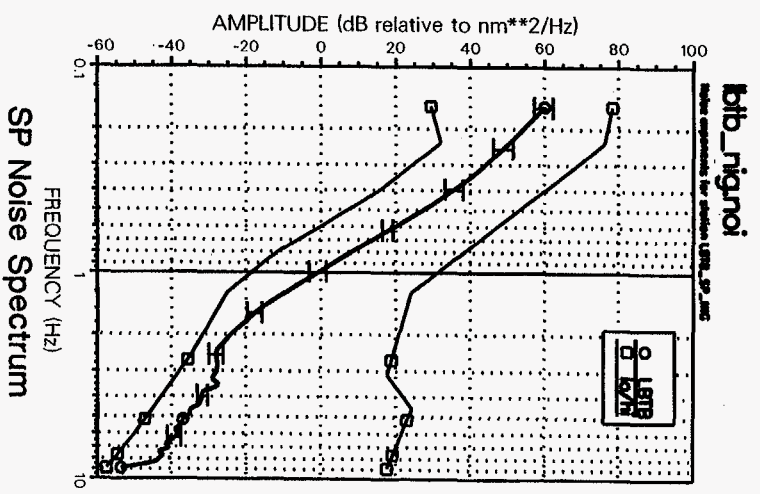
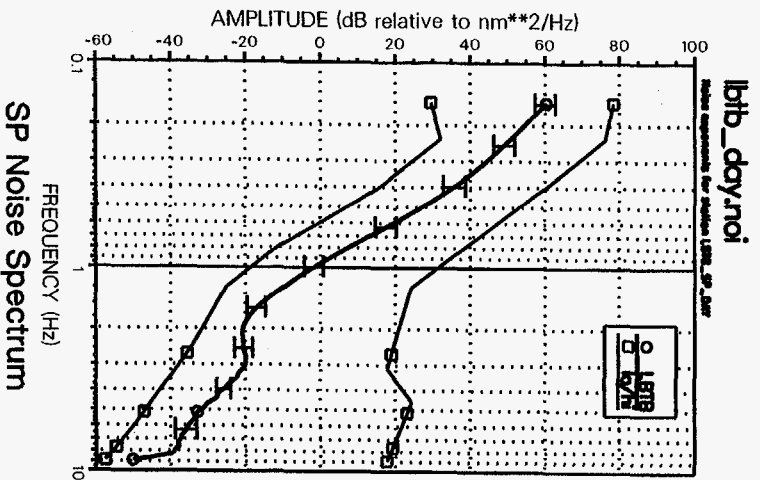


SP Noise Spectrum

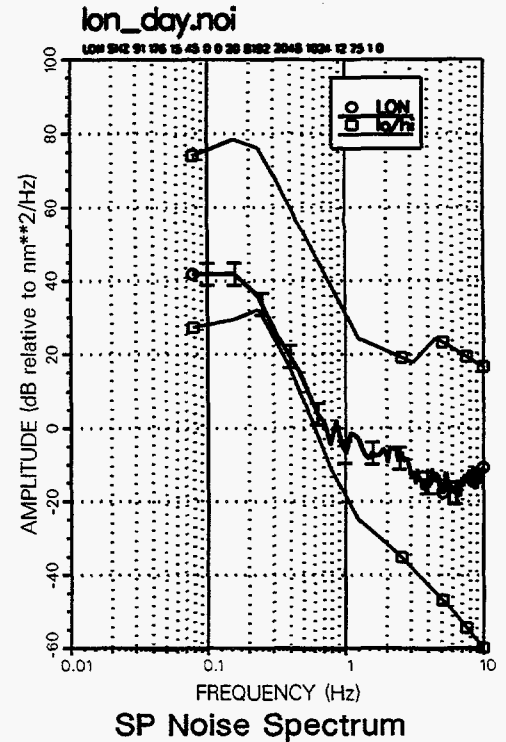
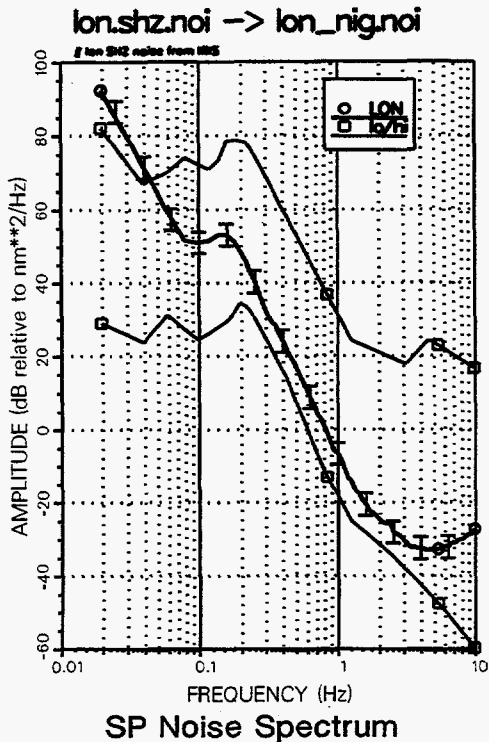
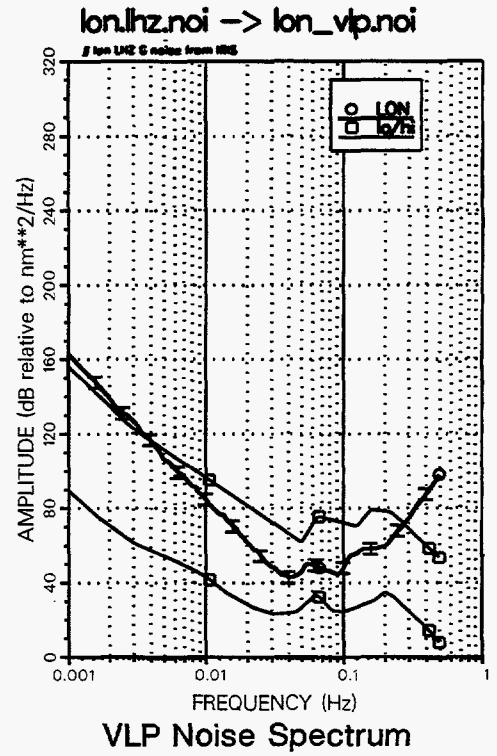
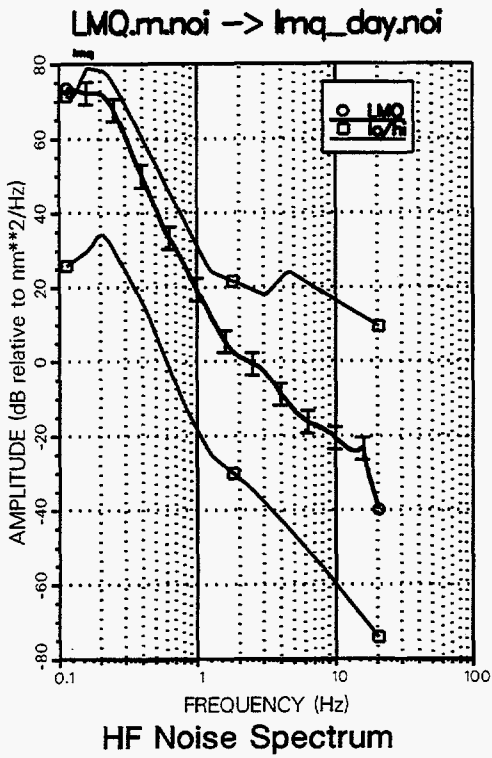
Station Noise Spectra



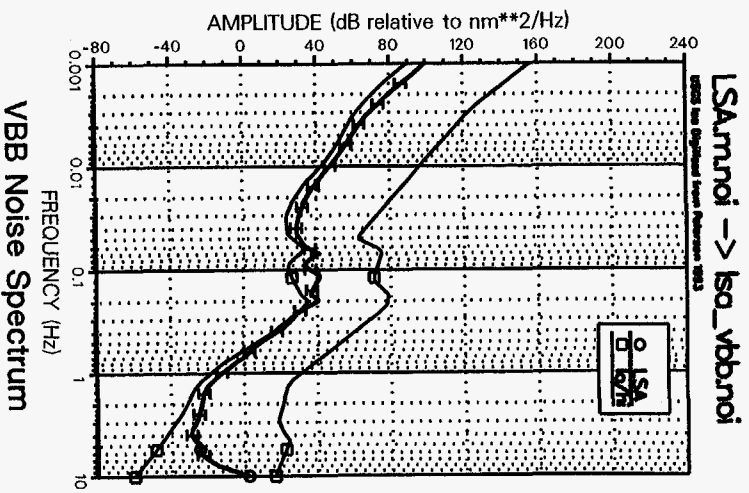
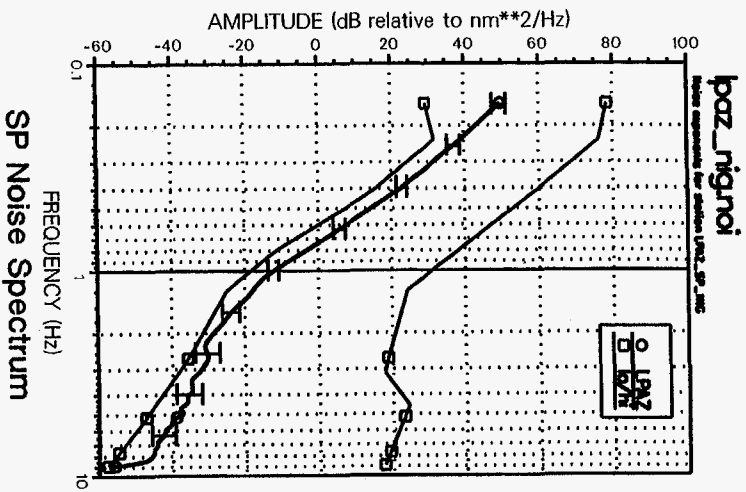
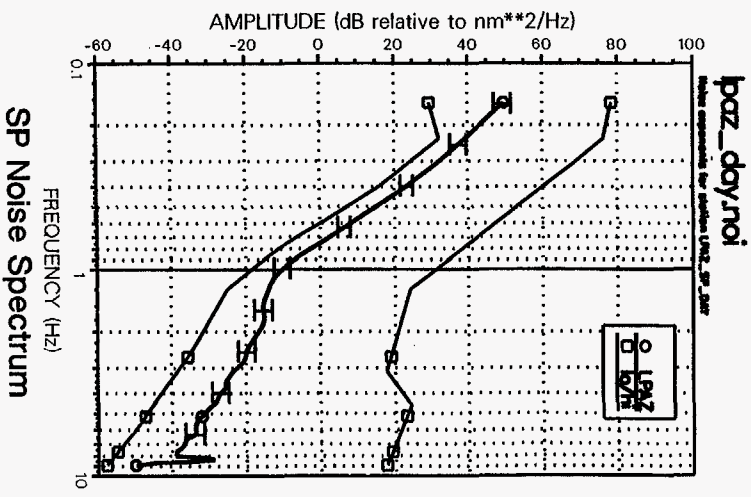
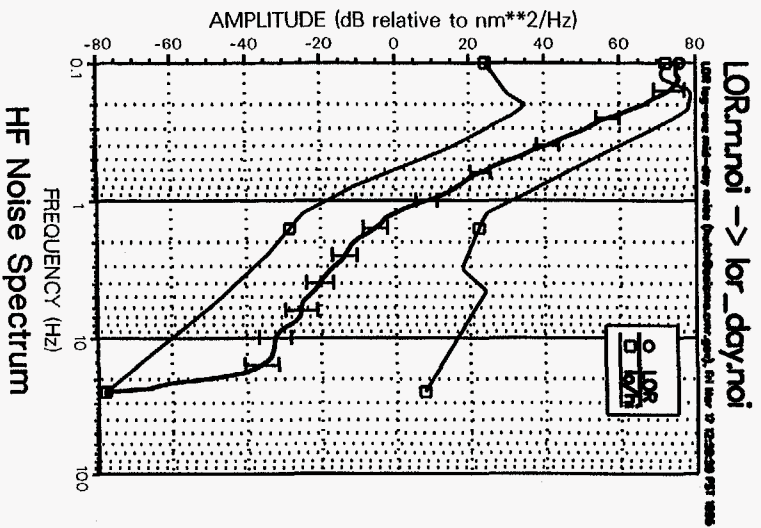
Station Noise Spectra



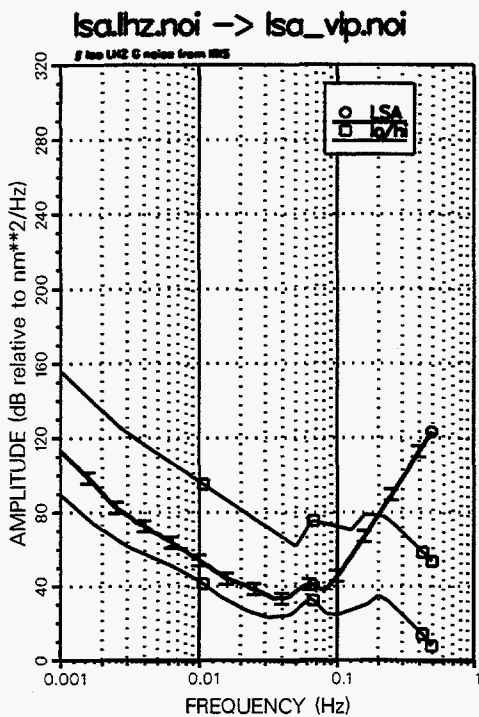
Station Noise Spectra



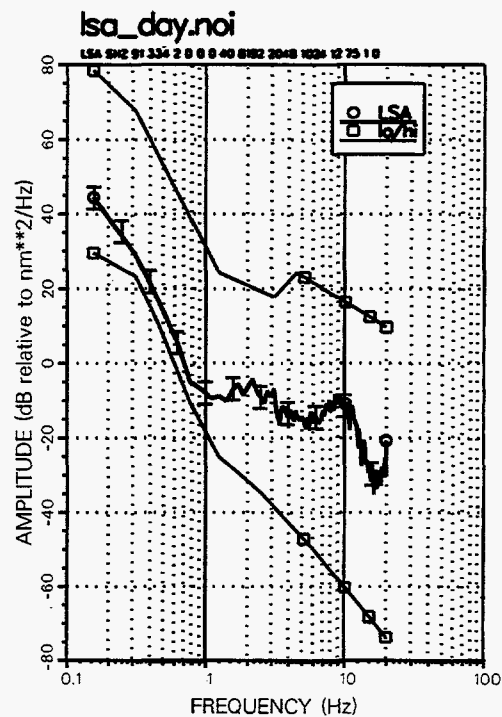
Station Noise Spectra



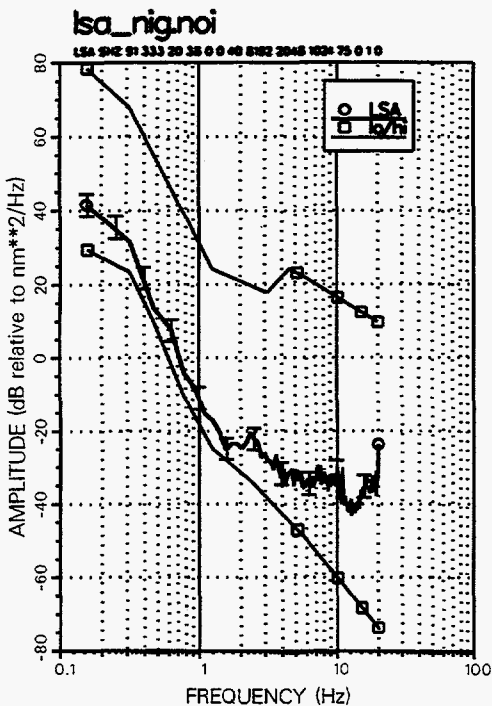
Station Noise Spectra



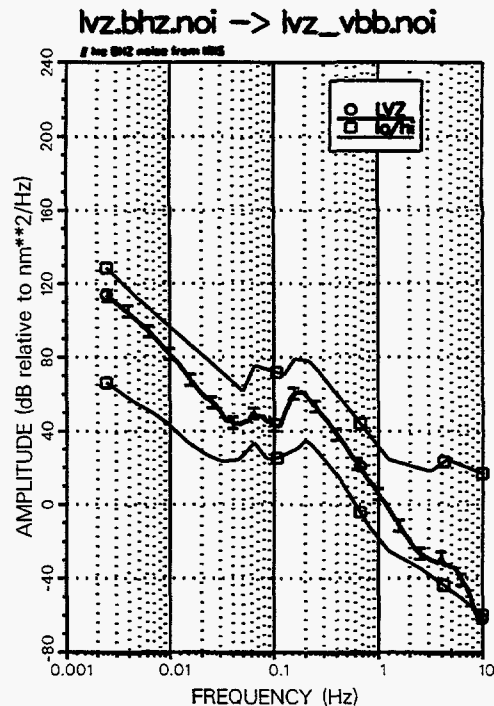
VLP Noise Spectrum



HF Noise Spectrum

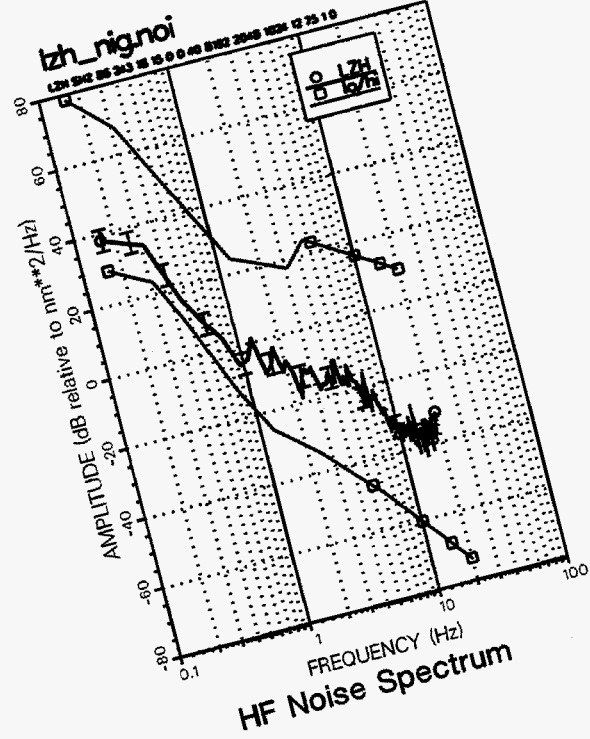
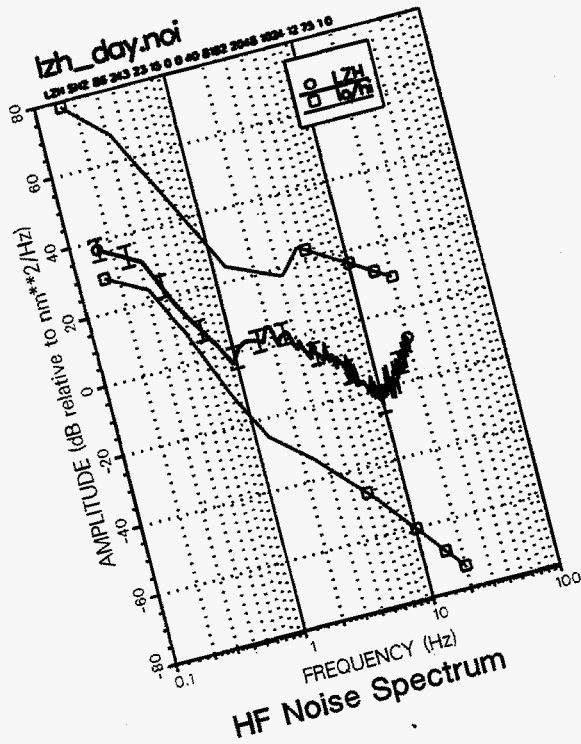
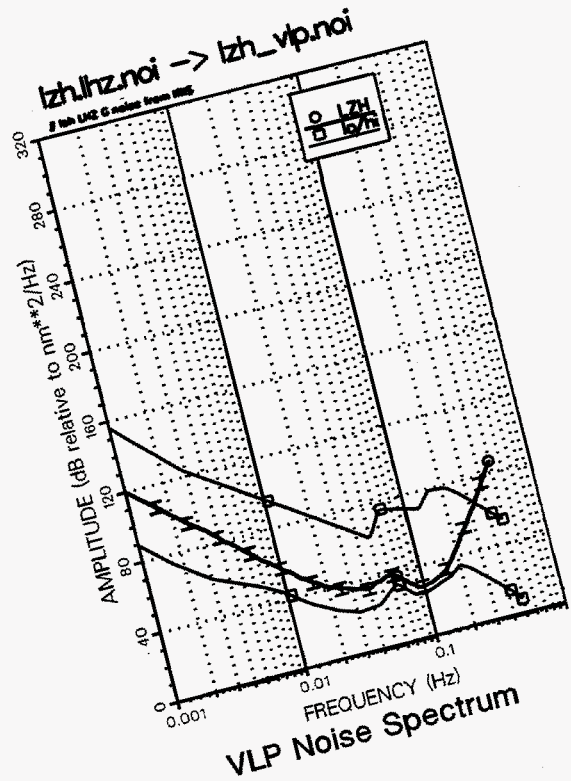
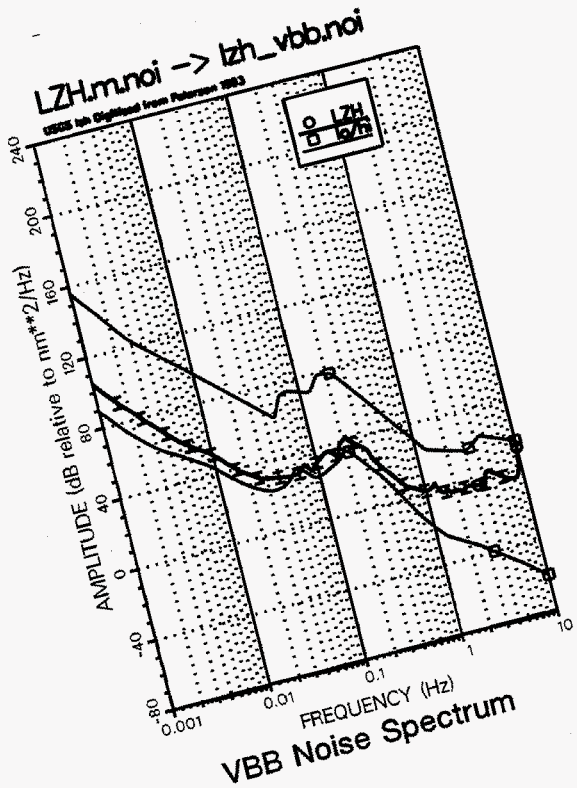


HF Noise Spectrum

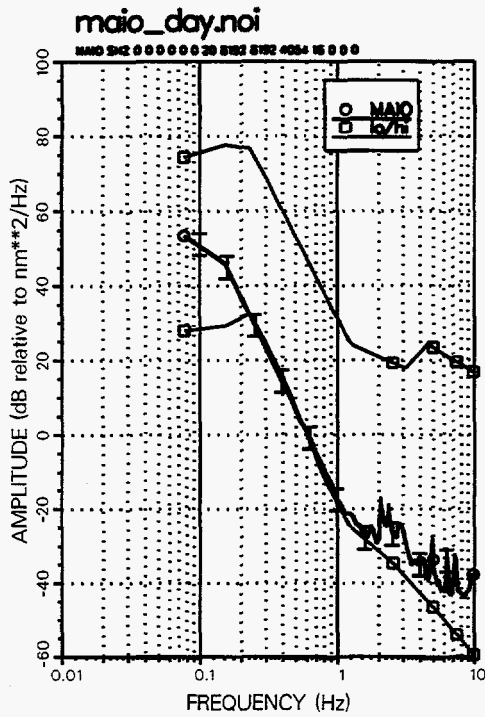


VBB Noise Spectrum

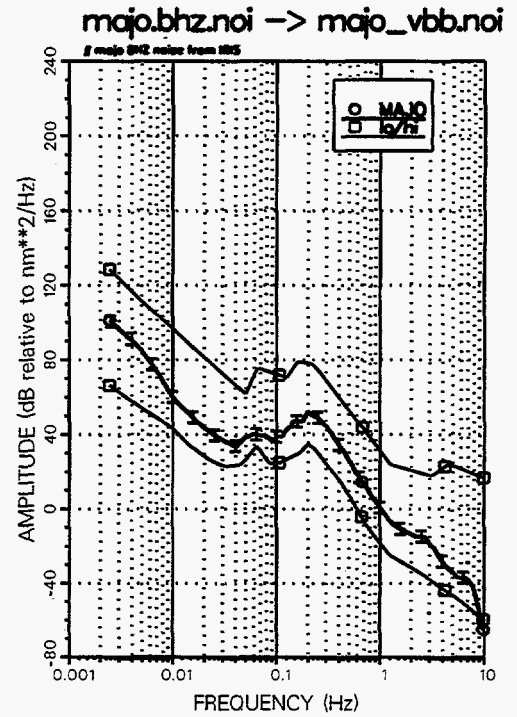
Station Noise Spectra



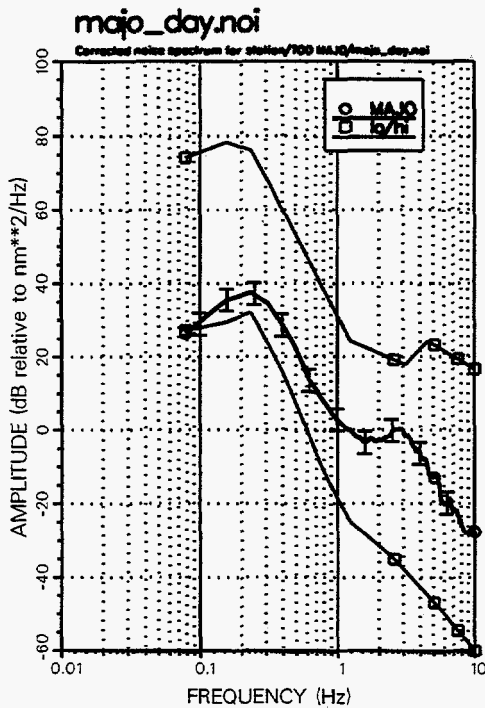
Station Noise Spectra



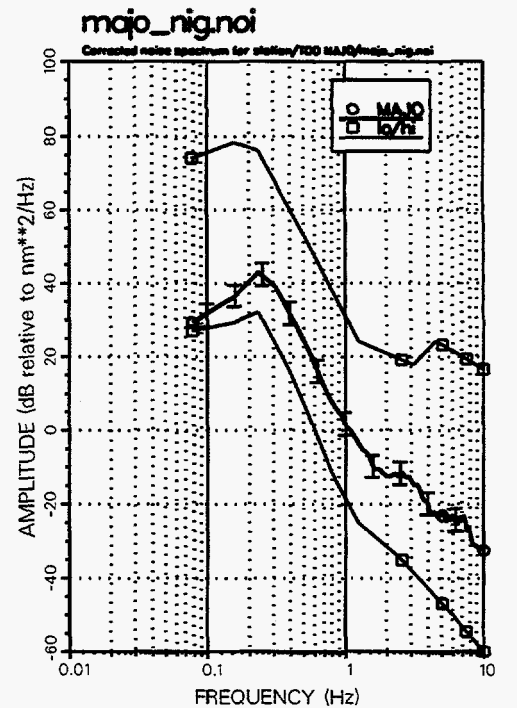
SP Noise Spectrum



VBB Noise Spectrum

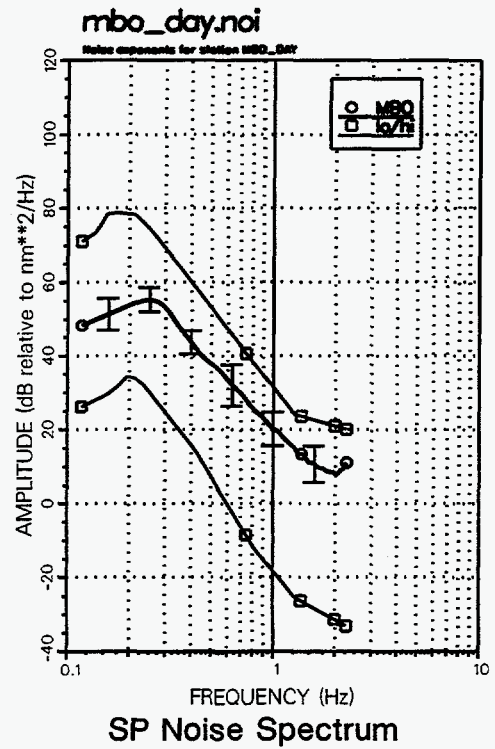
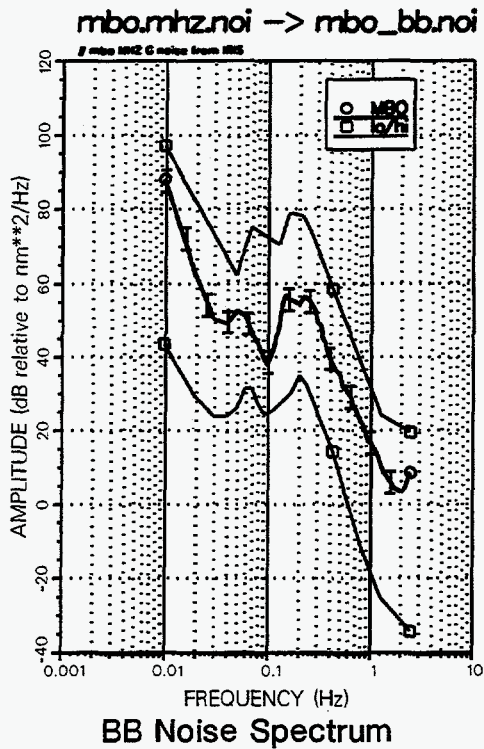
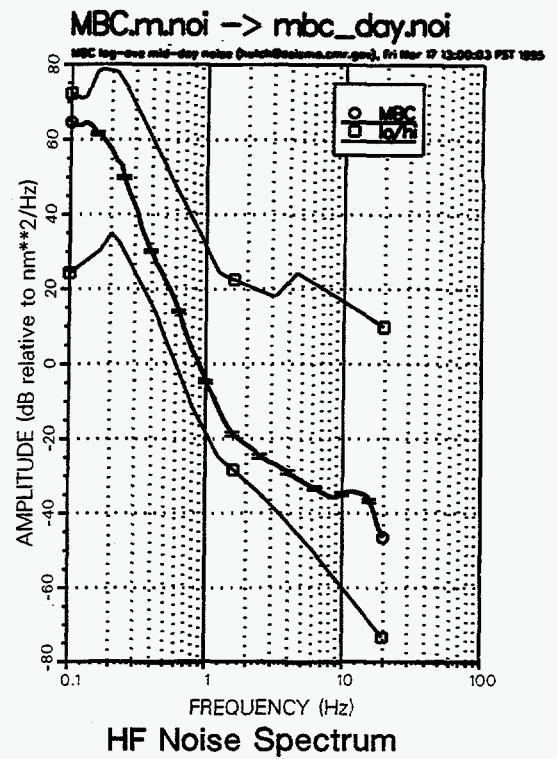
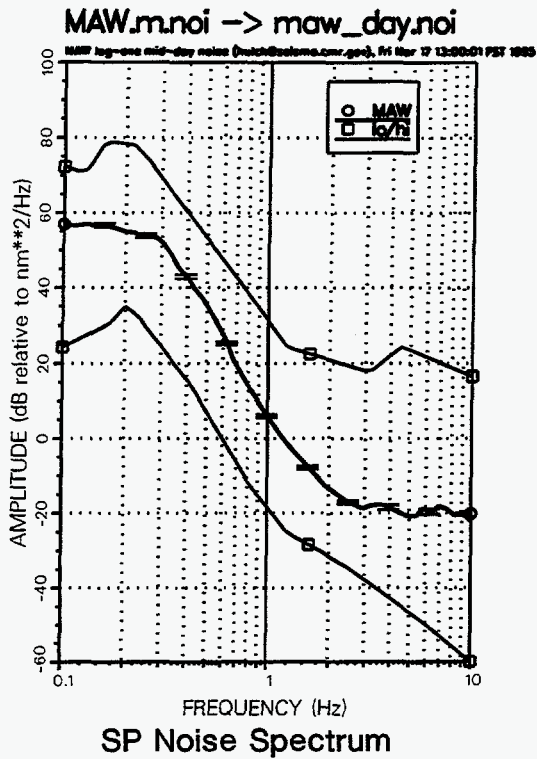


SP Noise Spectrum

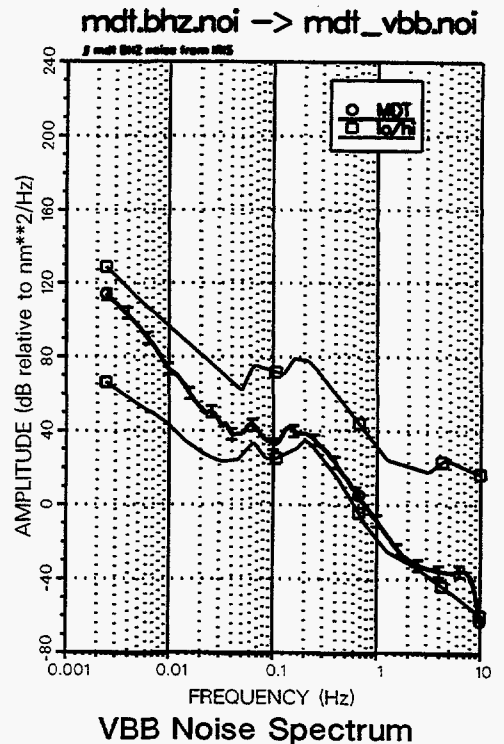
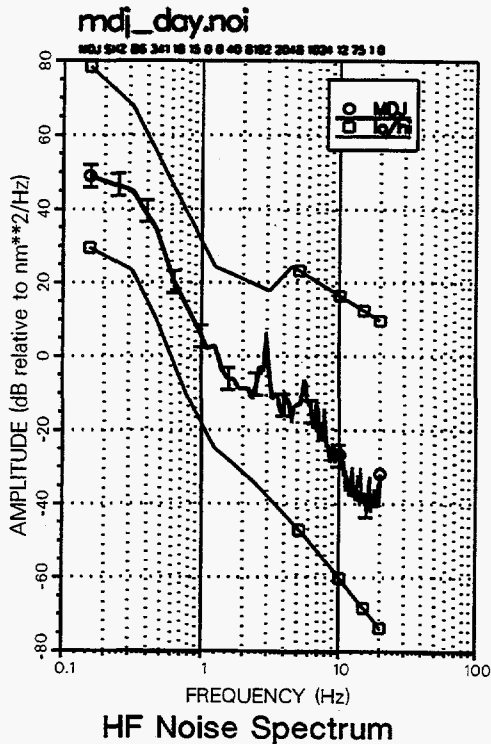
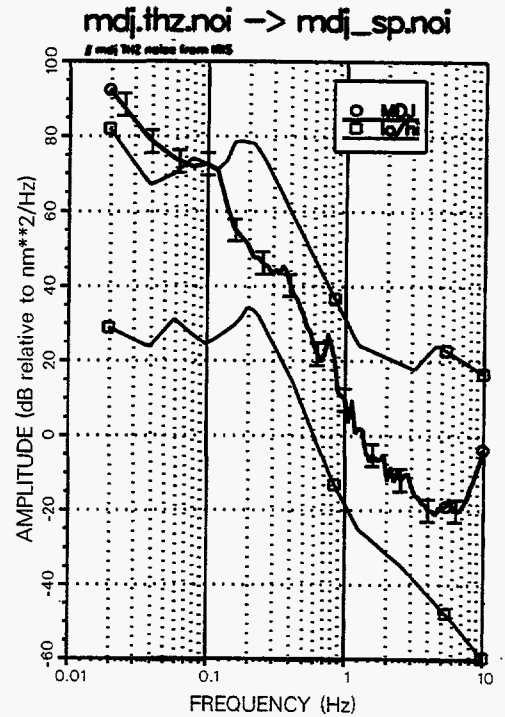
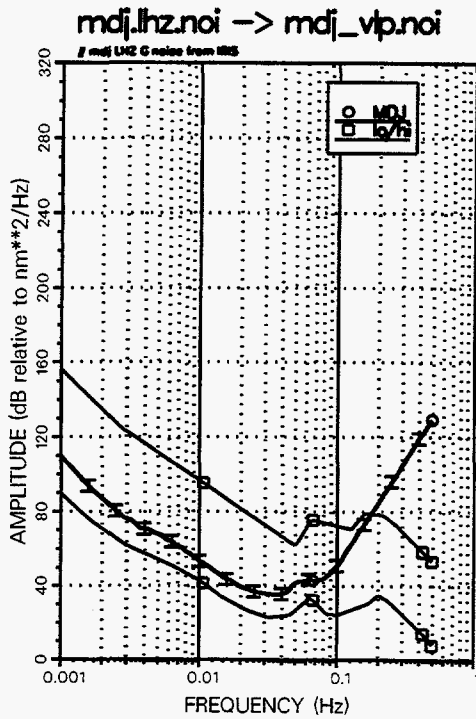


SP Noise Spectrum

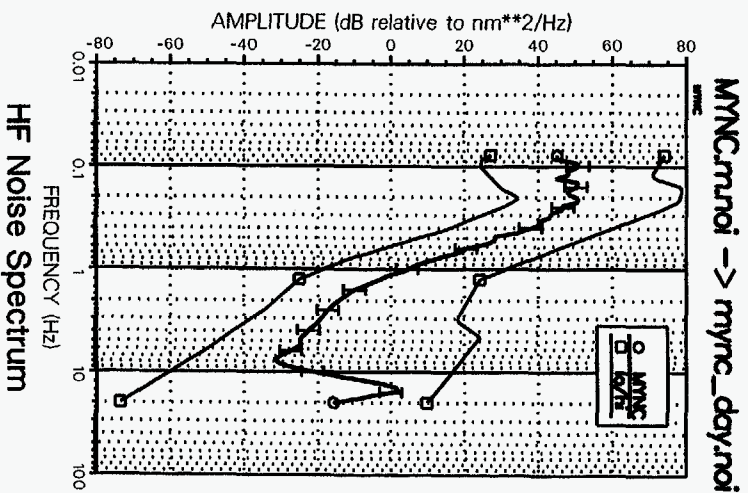
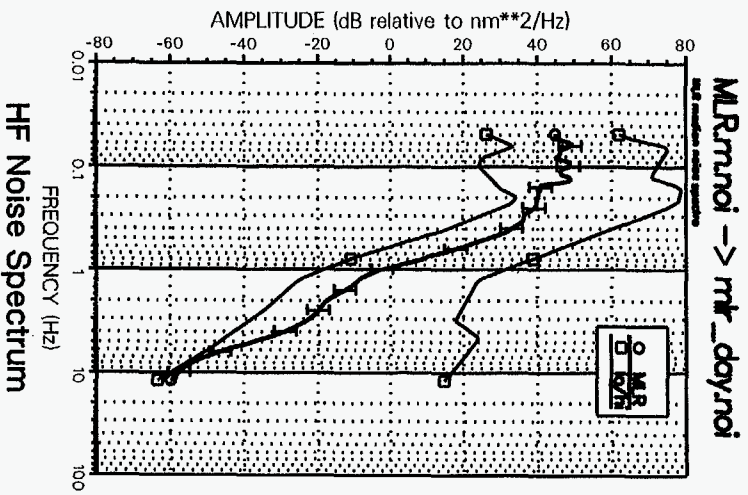
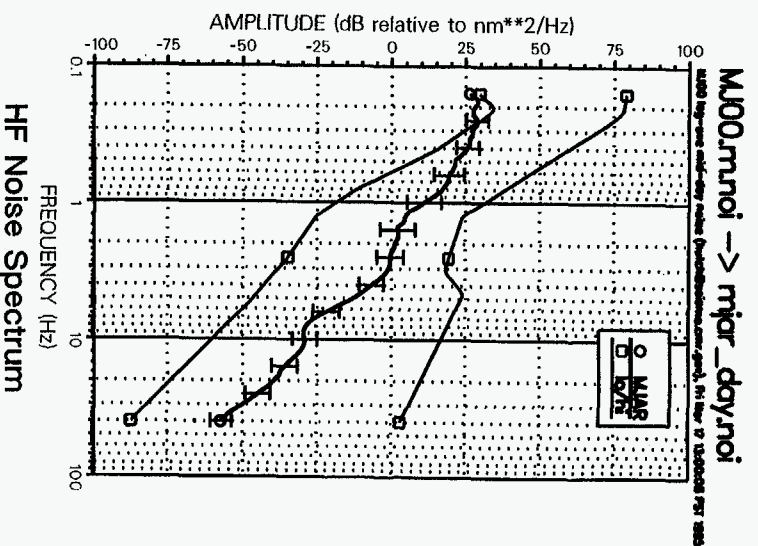
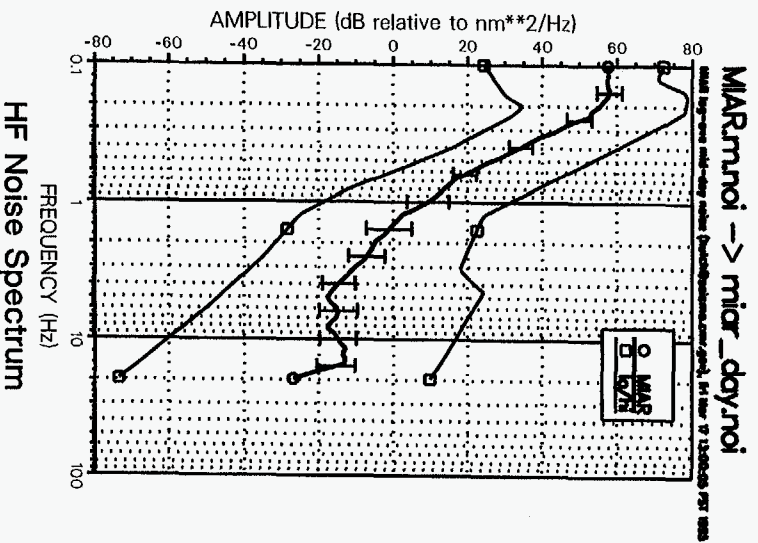
Station Noise Spectra



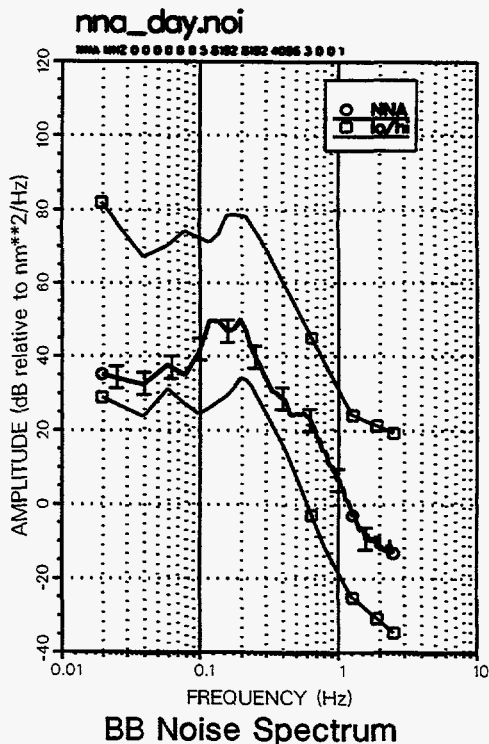
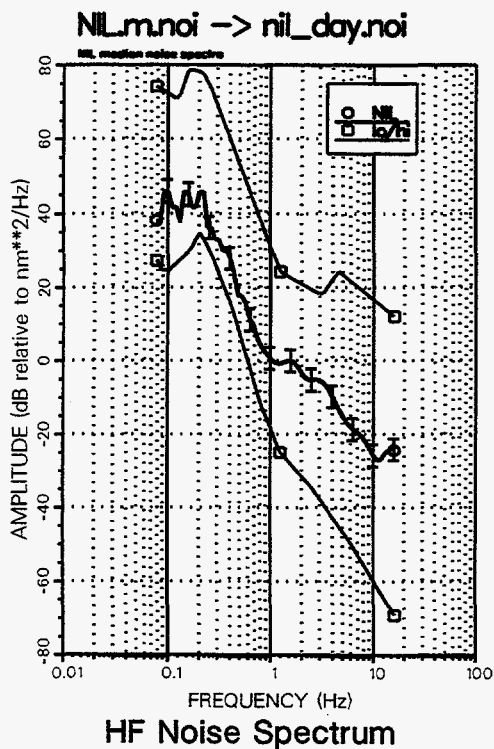
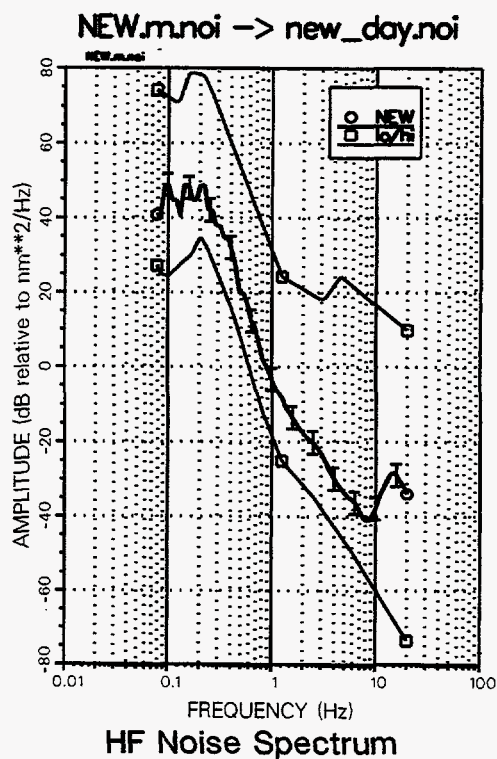
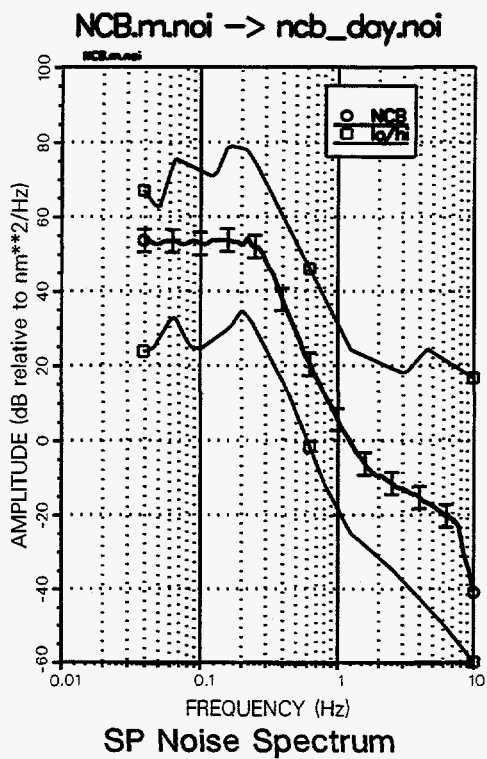
Station Noise Spectra



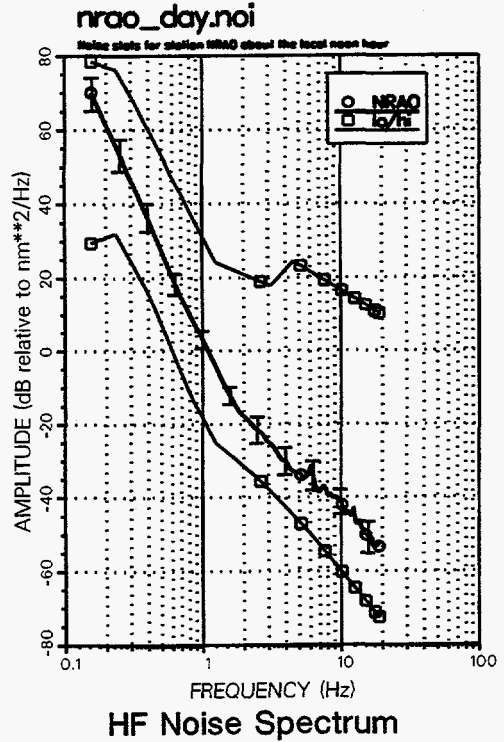
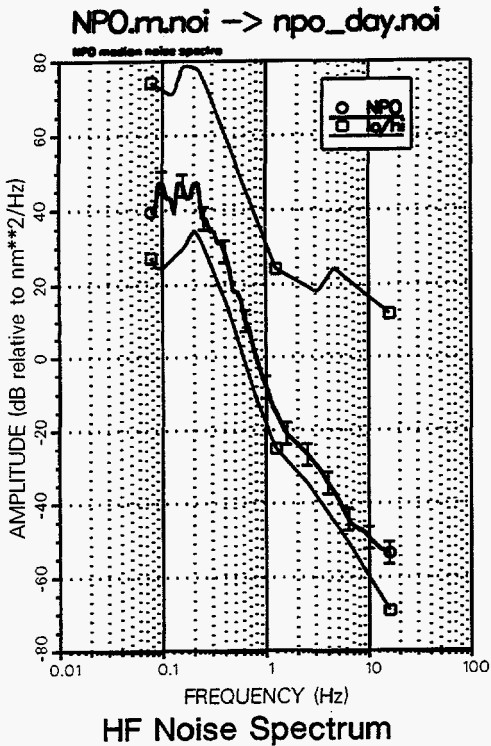
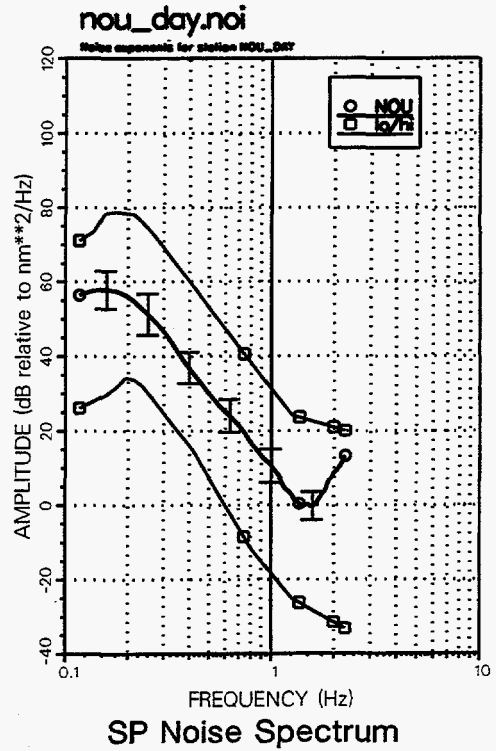
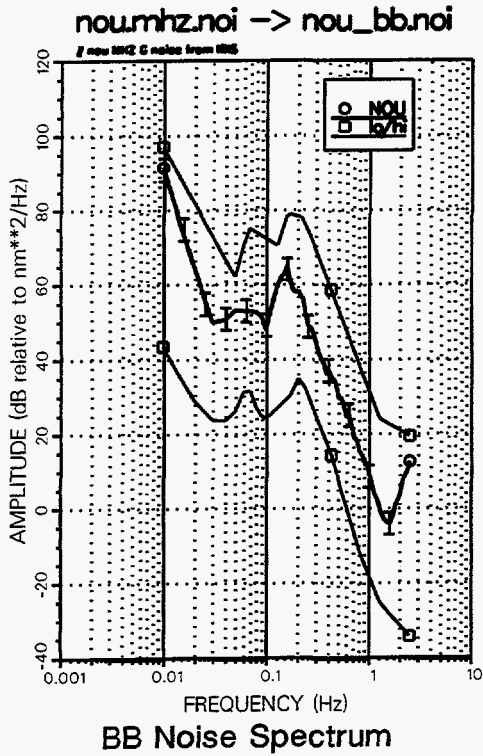
Station Noise Spectra



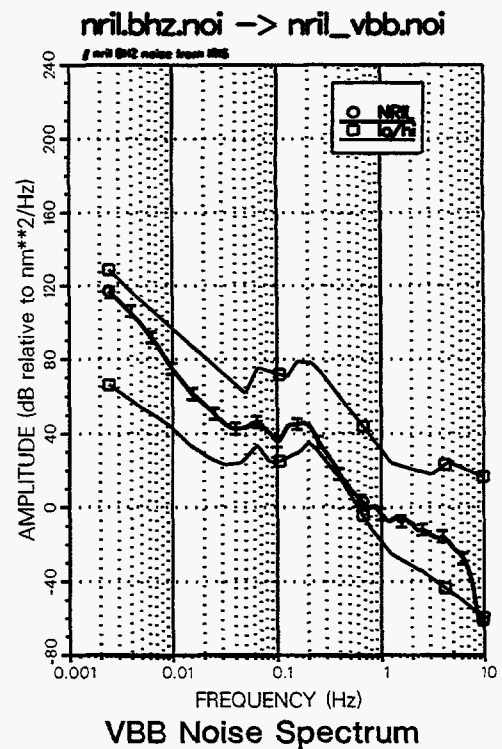
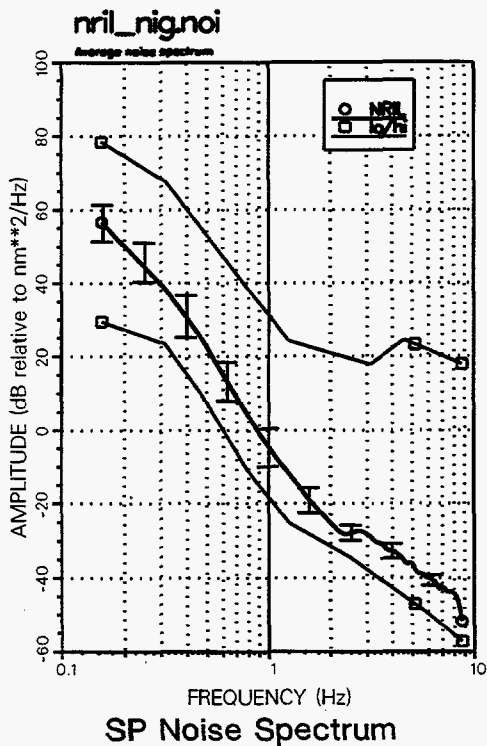
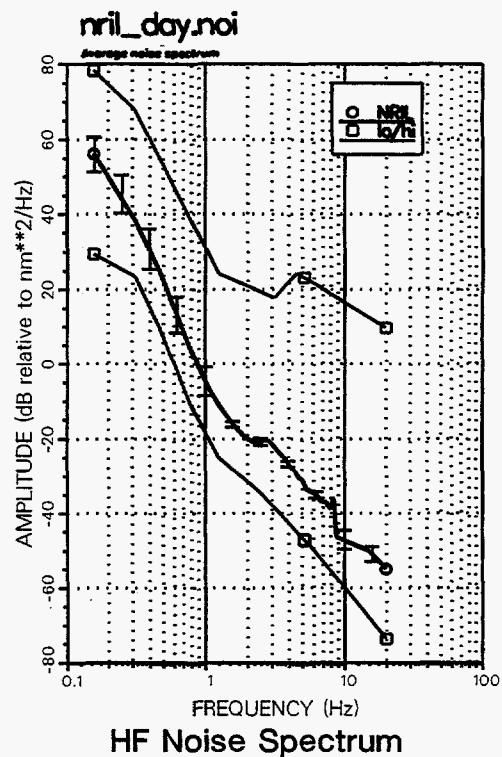
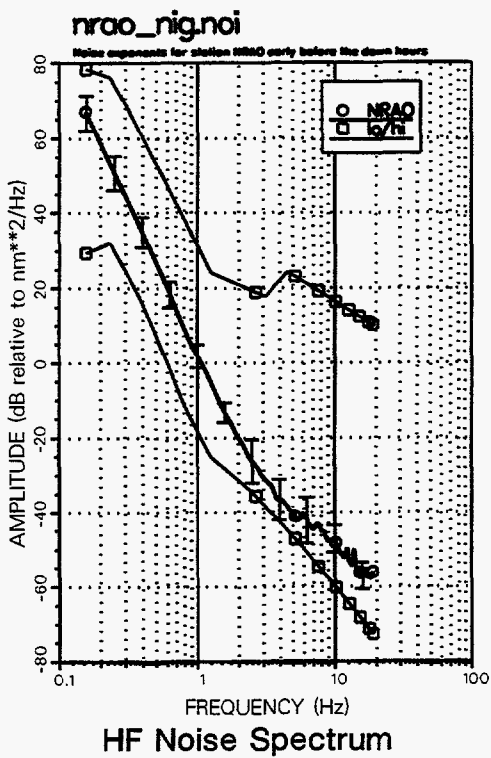
Station Noise Spectra



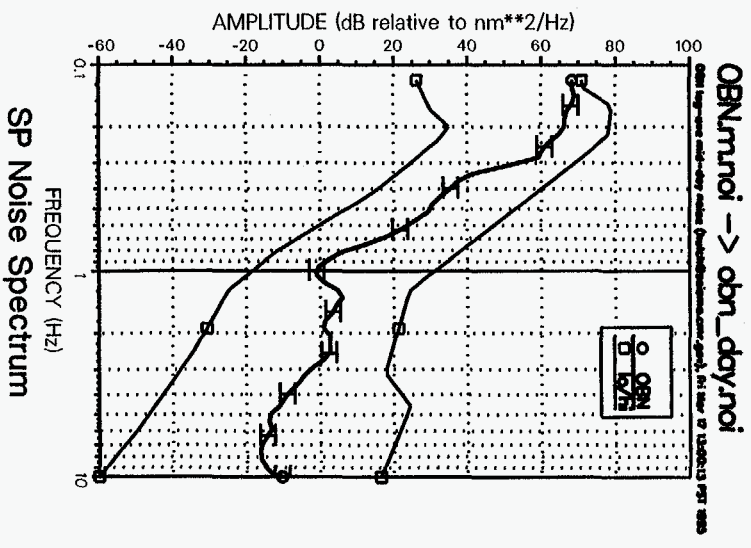
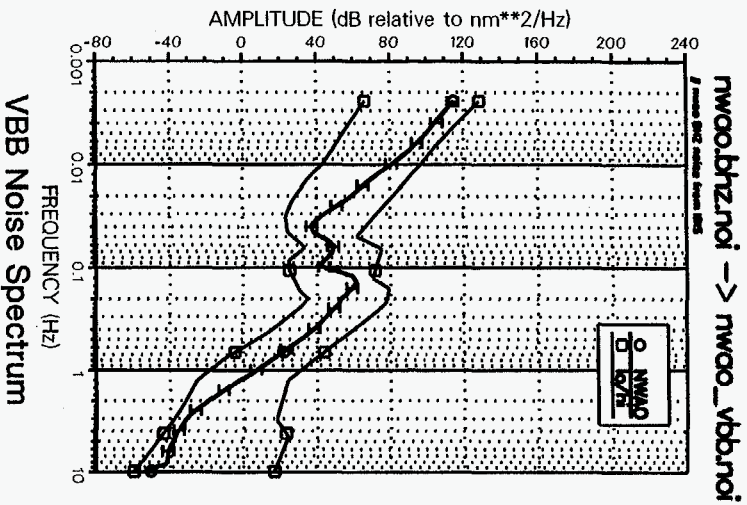
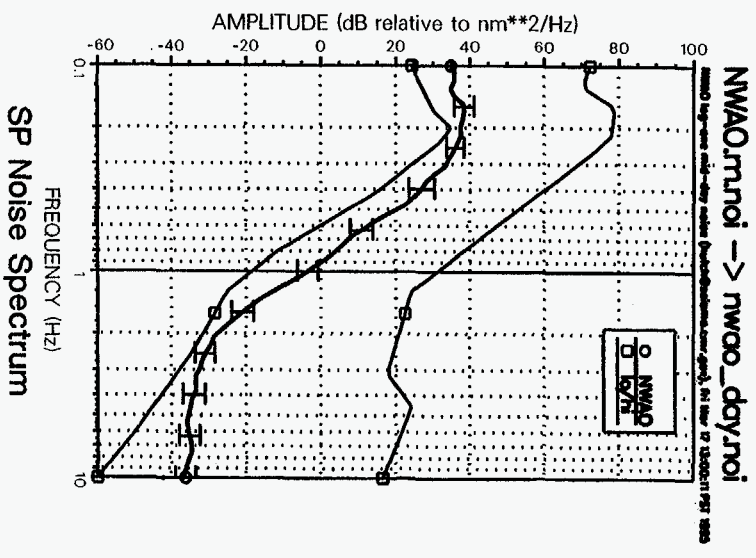
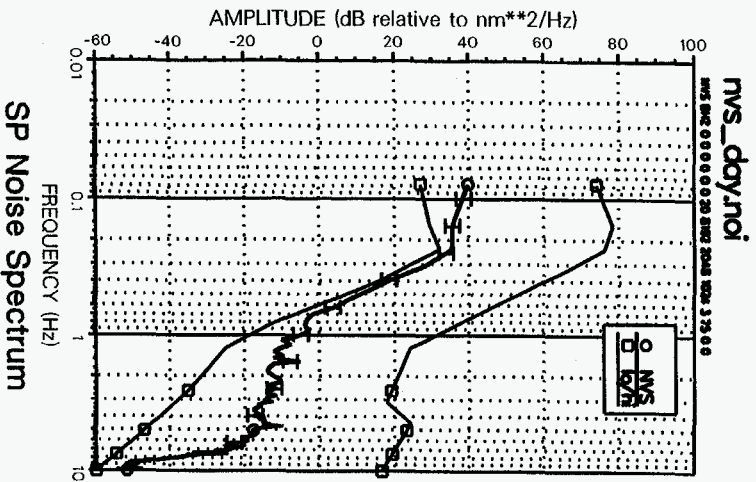
Station Noise Spectra



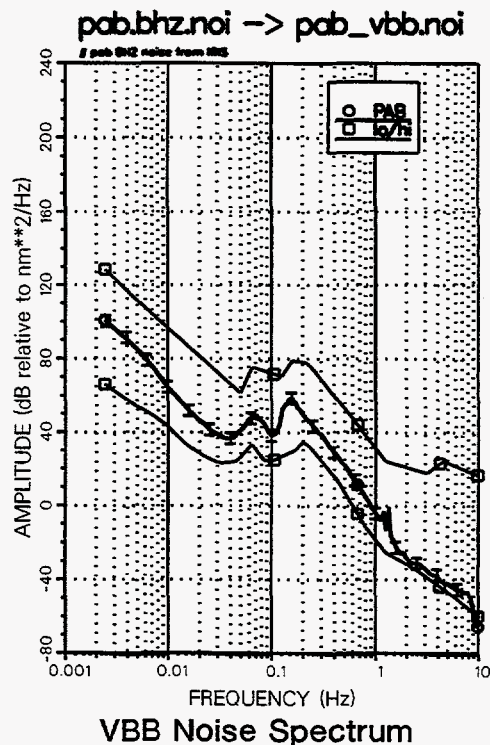
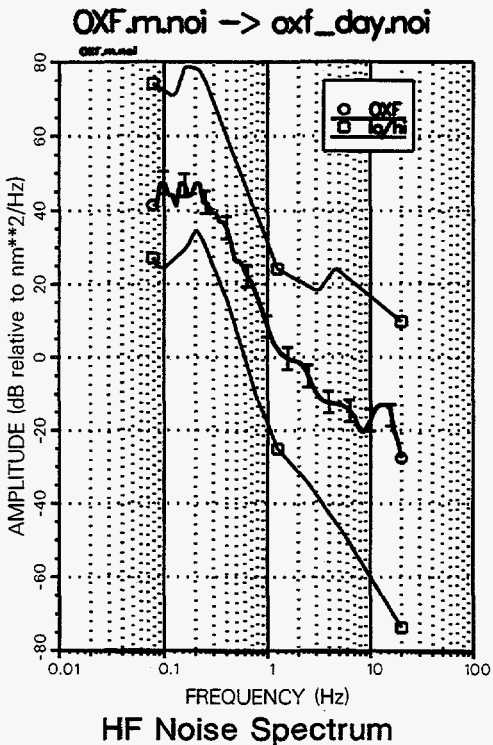
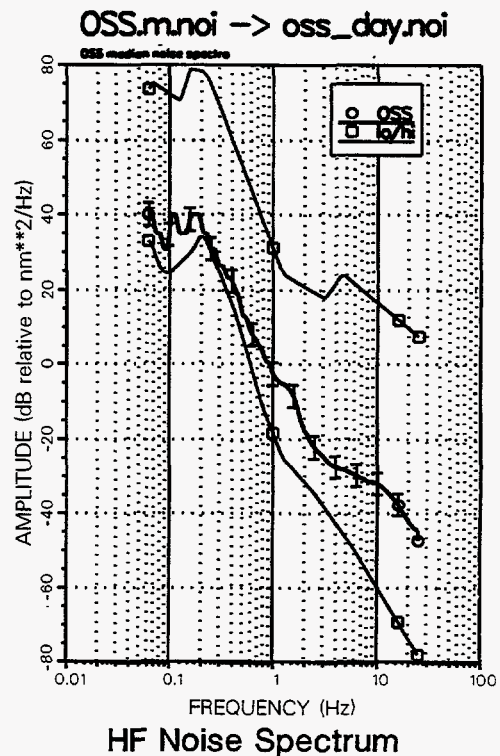
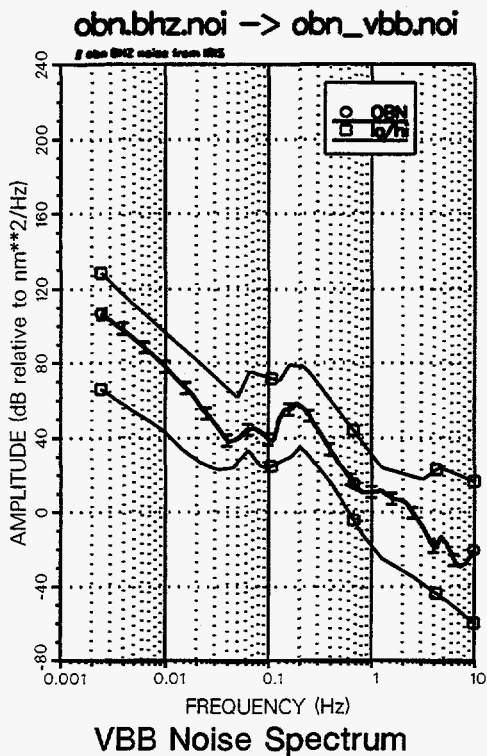
Station Noise Spectra



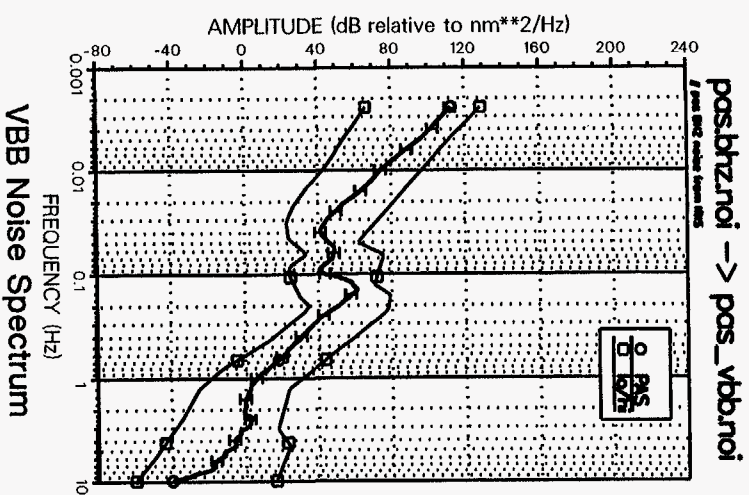
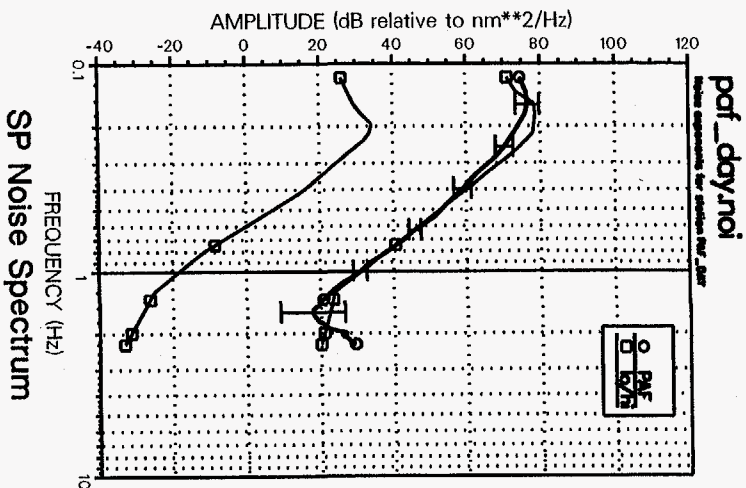
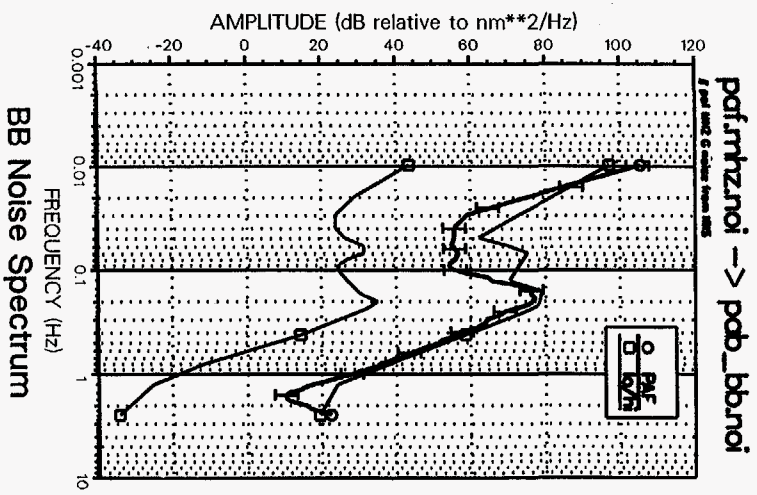
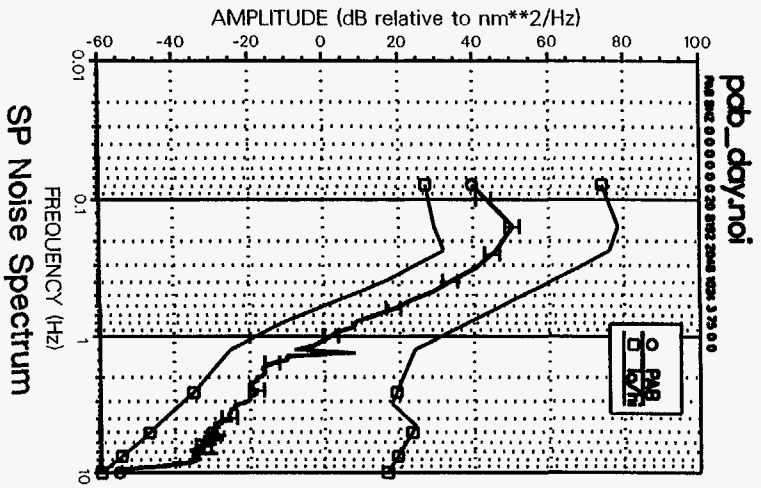
Station Noise Spectra



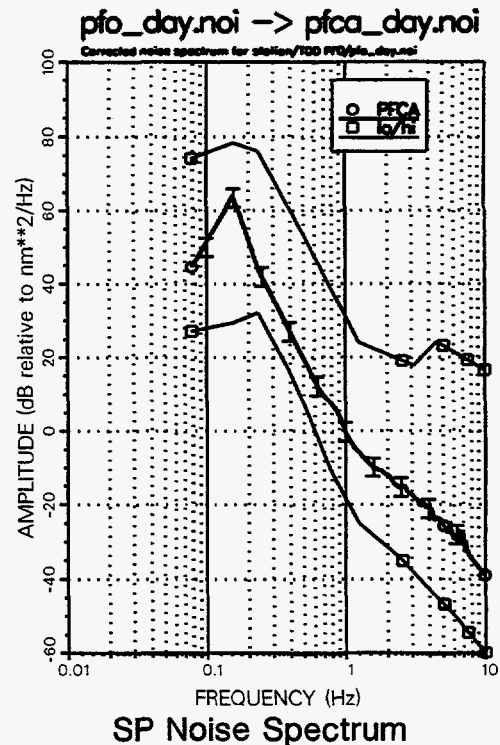
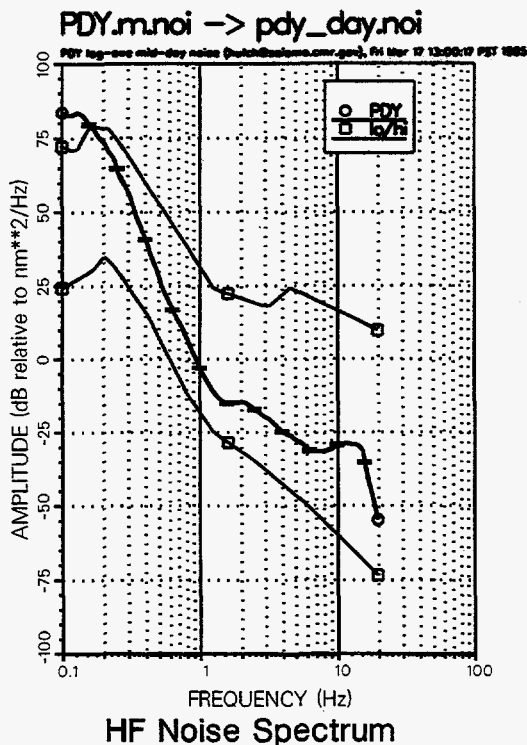
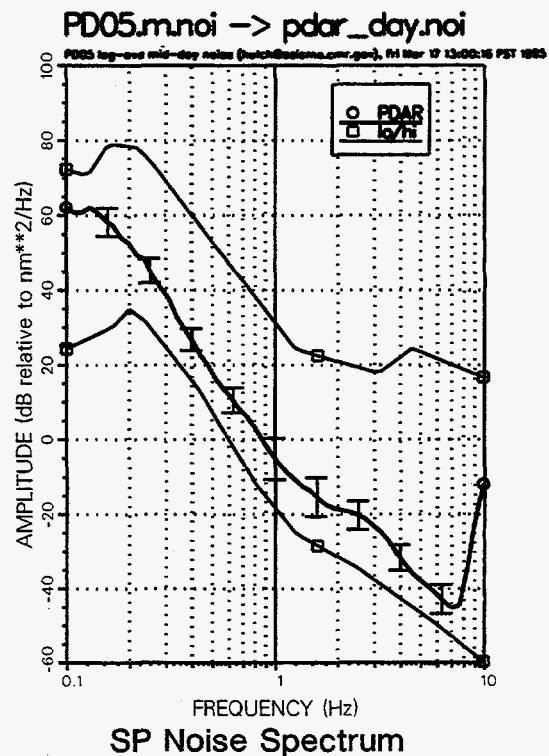
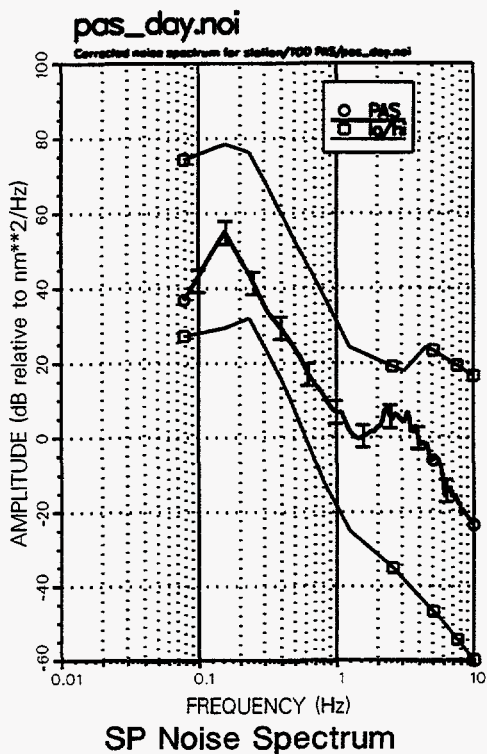
Station Noise Spectra



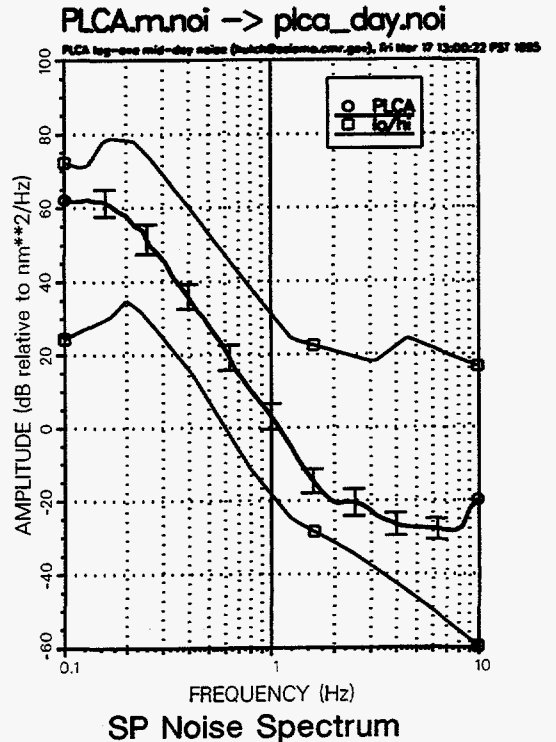
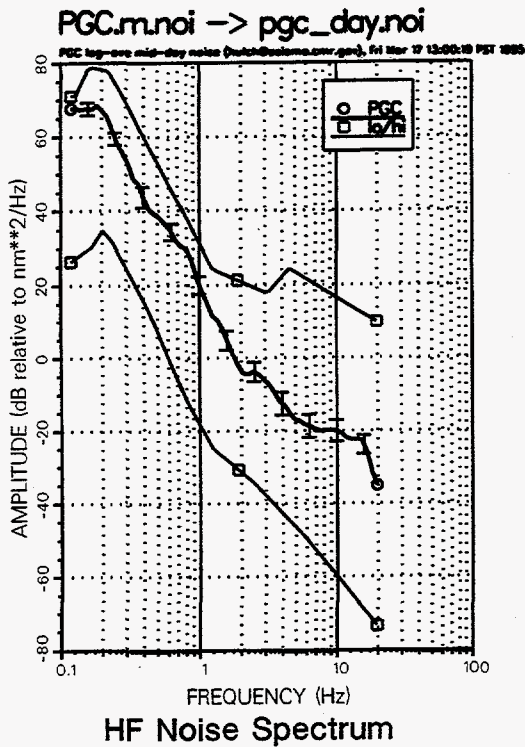
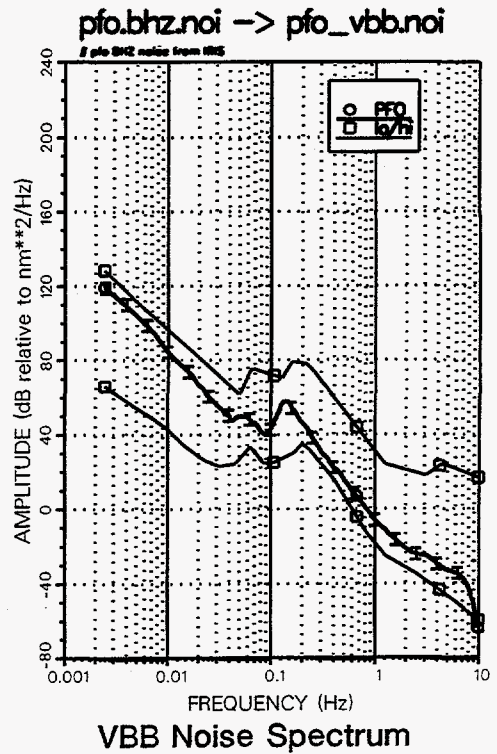
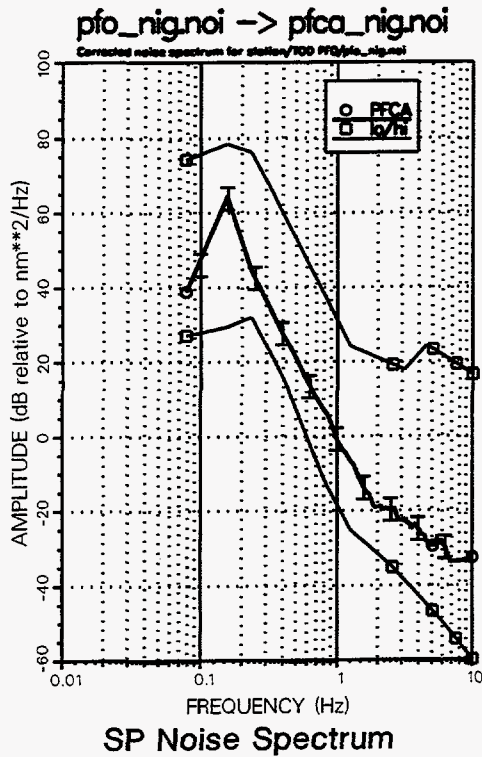
Station Noise Spectra



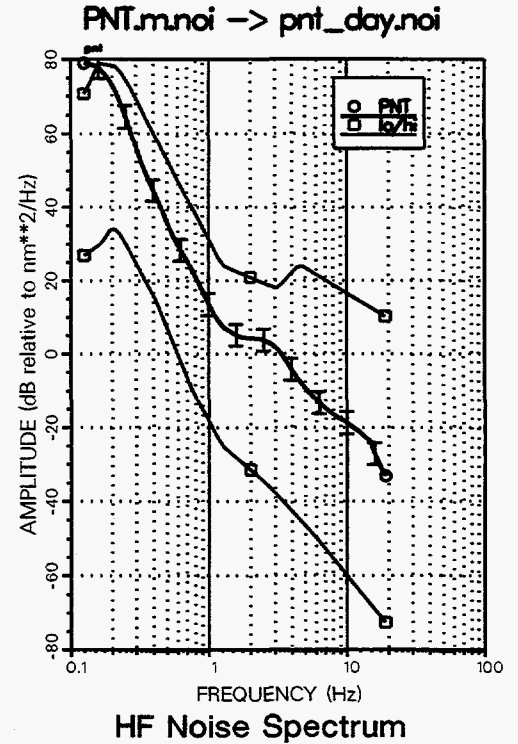
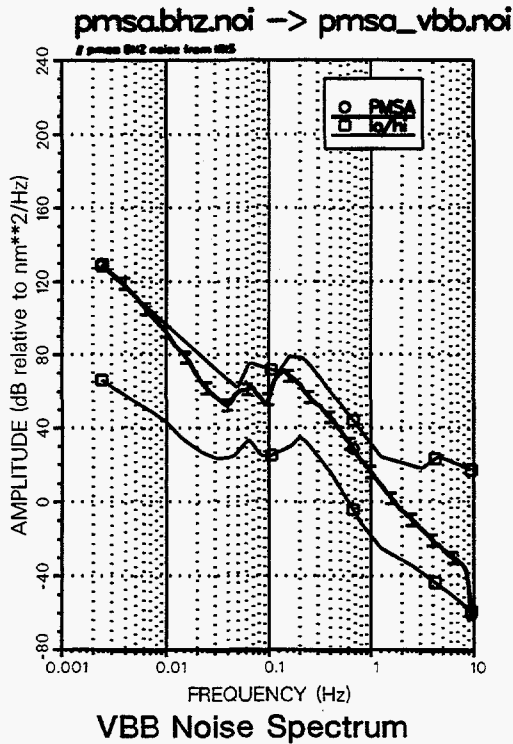
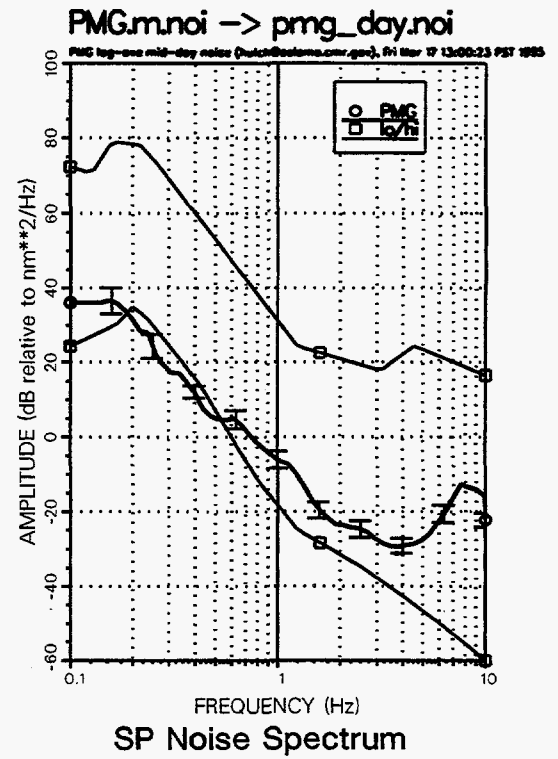
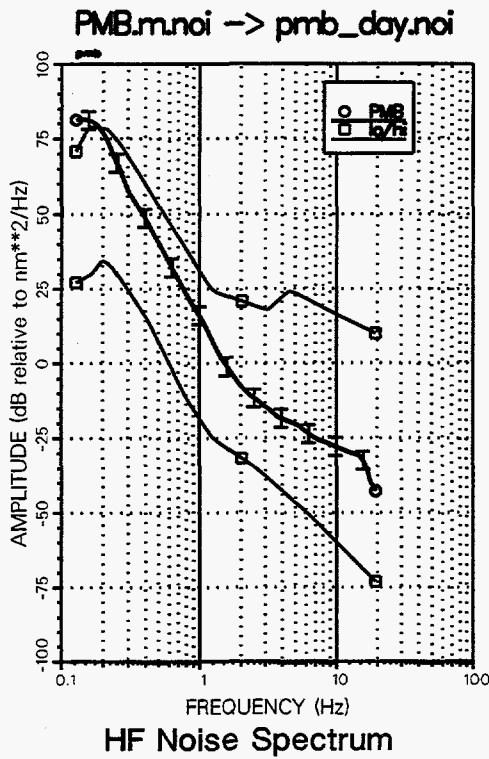
Station Noise Spectra



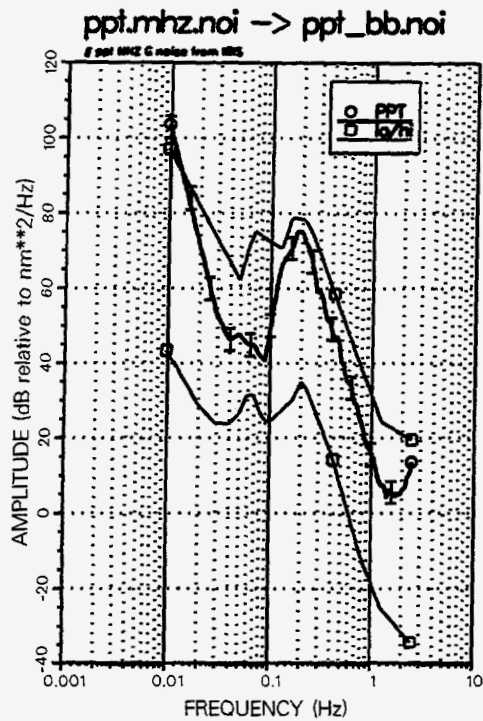
Station Noise Spectra



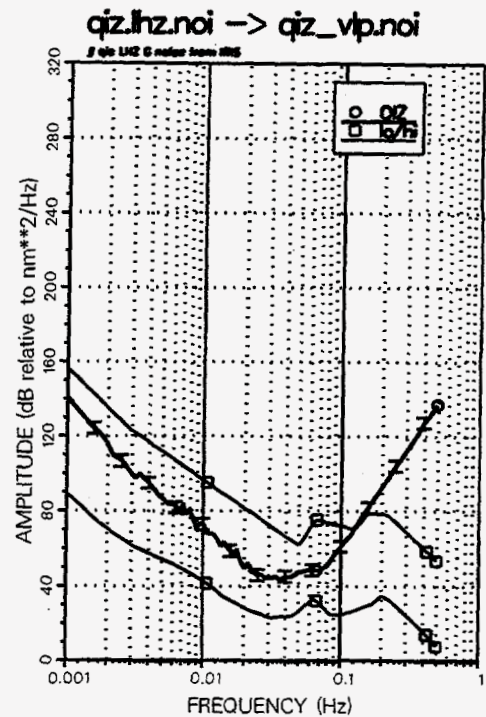
Station Noise Spectra



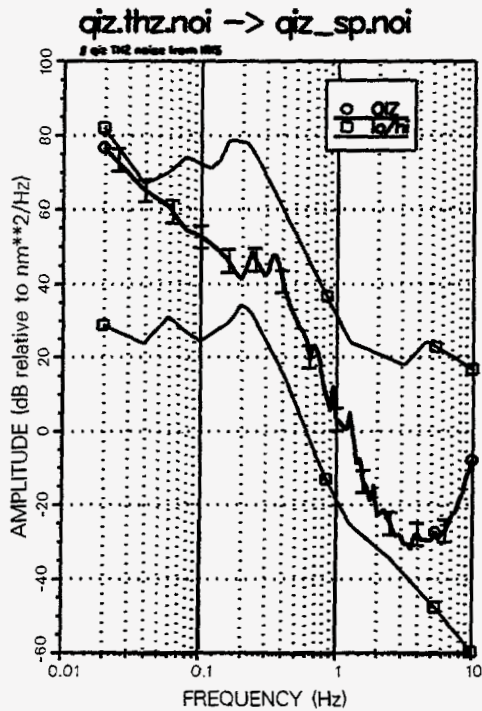
Station Noise Spectra



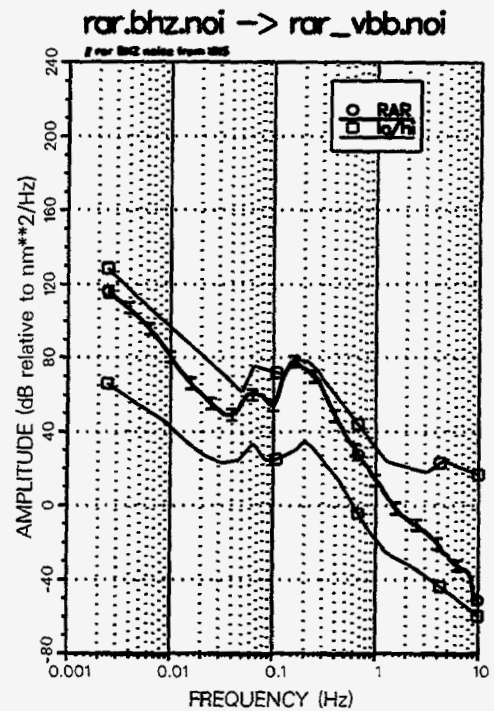
BB Noise Spectrum



VLP Noise Spectrum

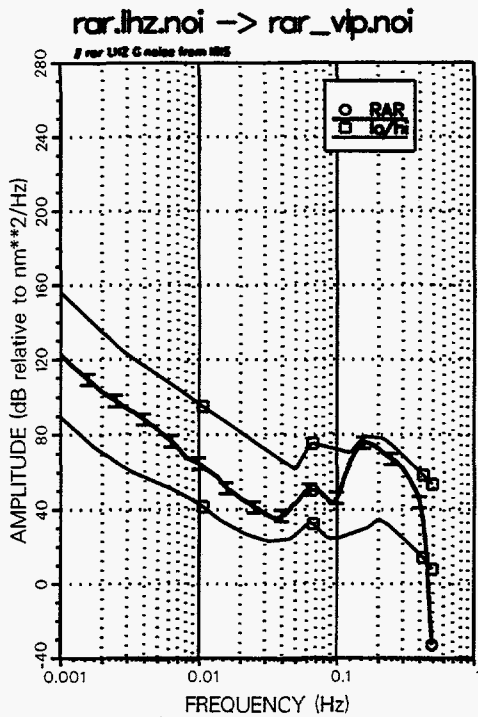


SP Noise Spectrum

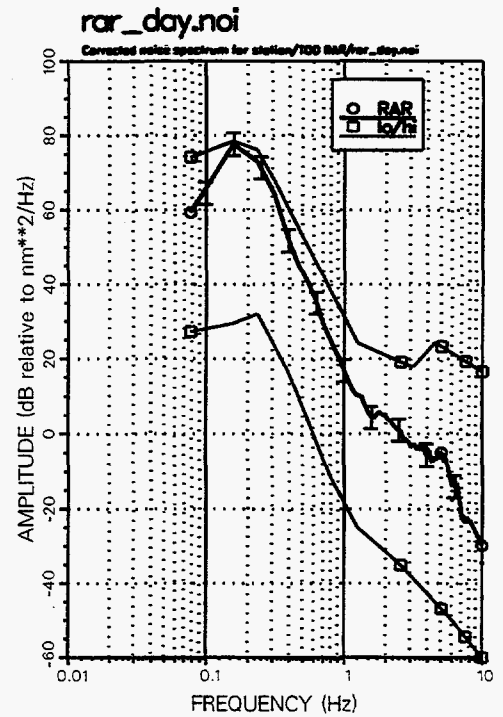


VBB Noise Spectrum

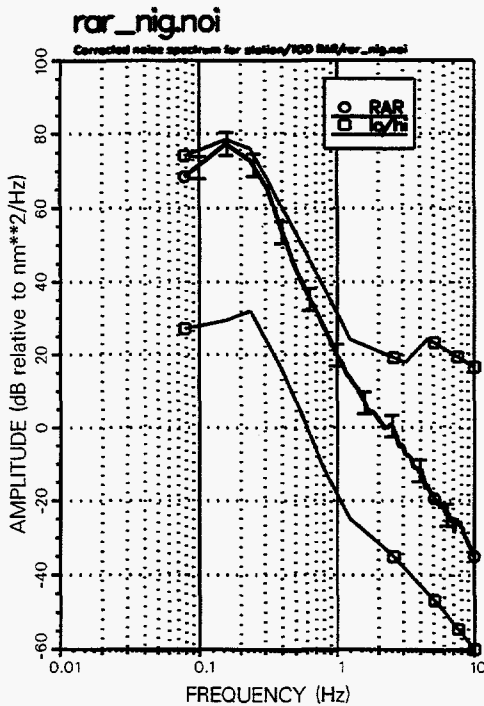
Station Noise Spectra



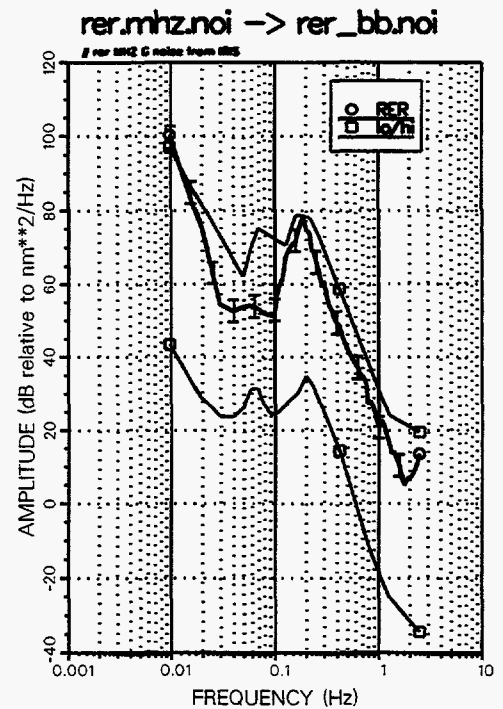
VLP Noise Spectrum



SP Noise Spectrum

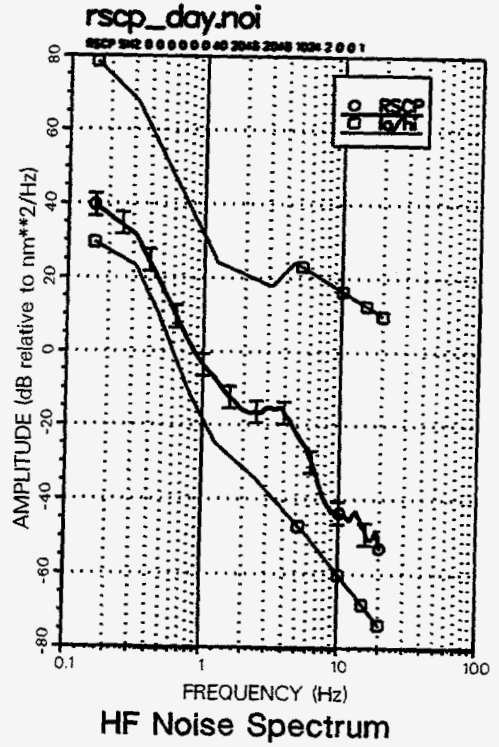
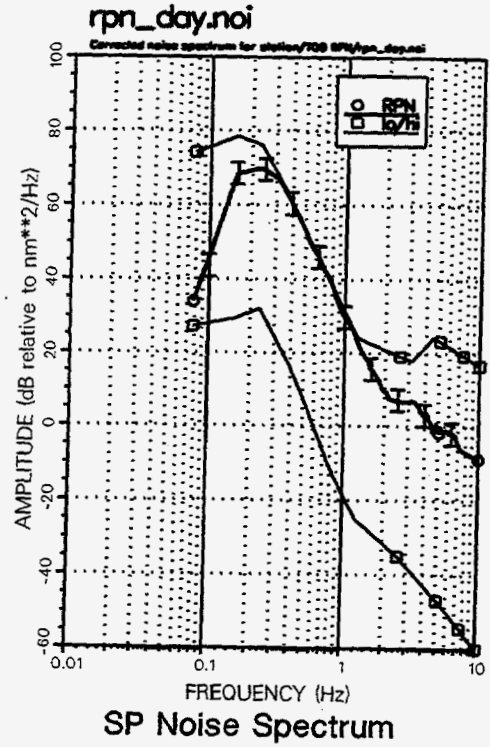
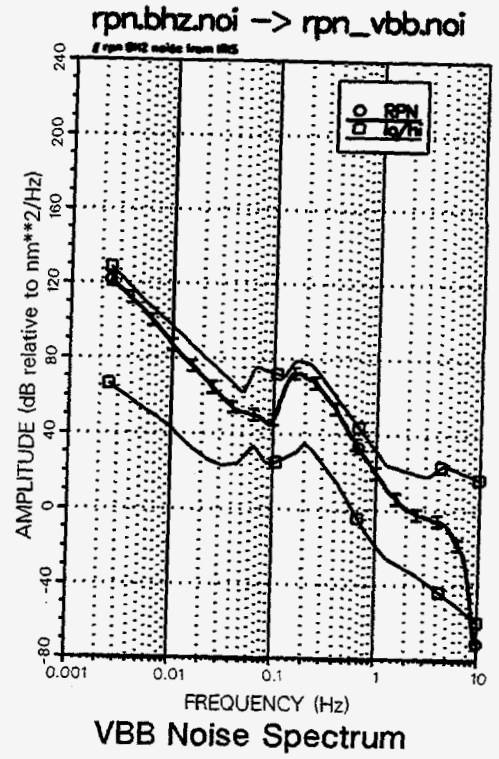
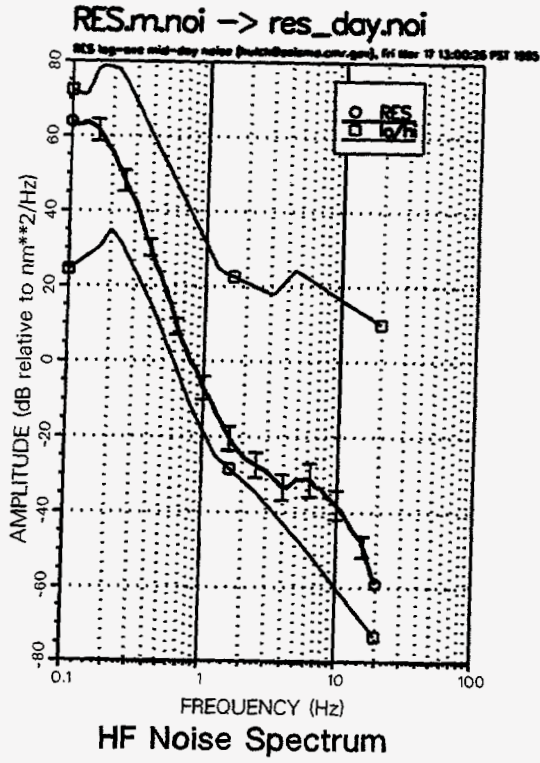


SP Noise Spectrum

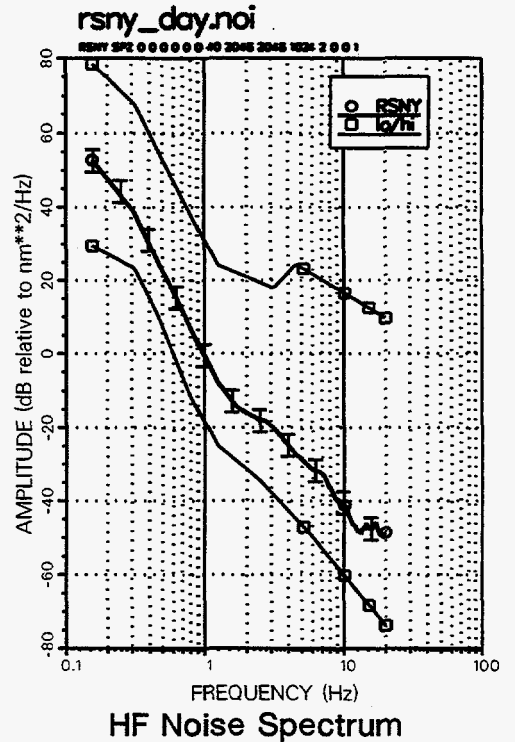
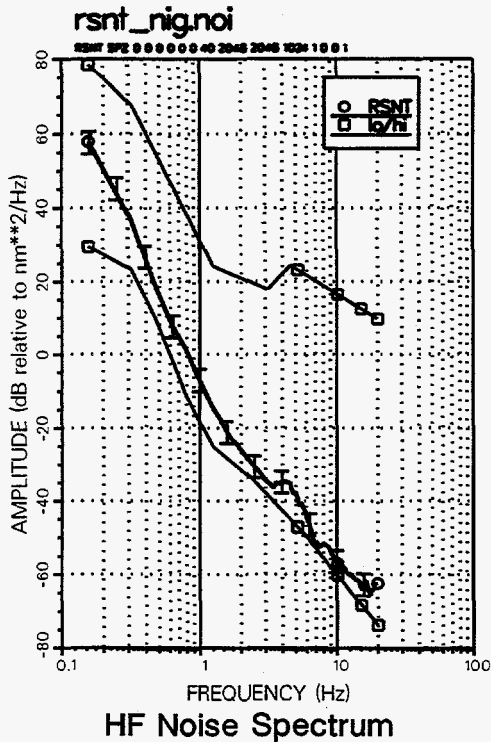
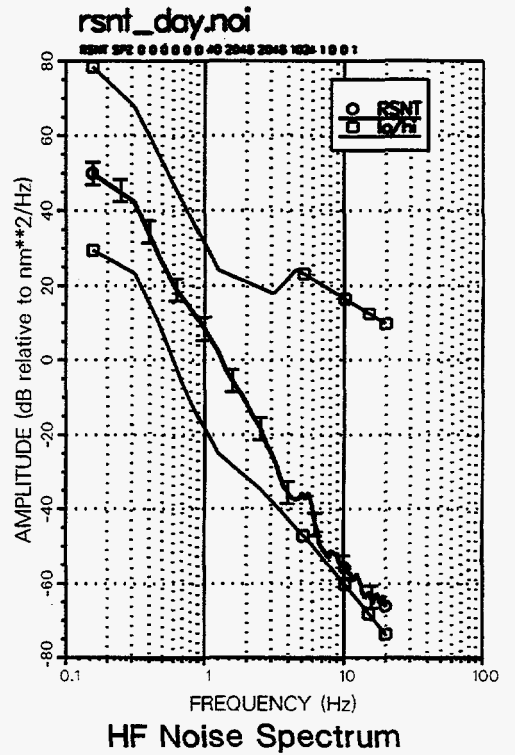
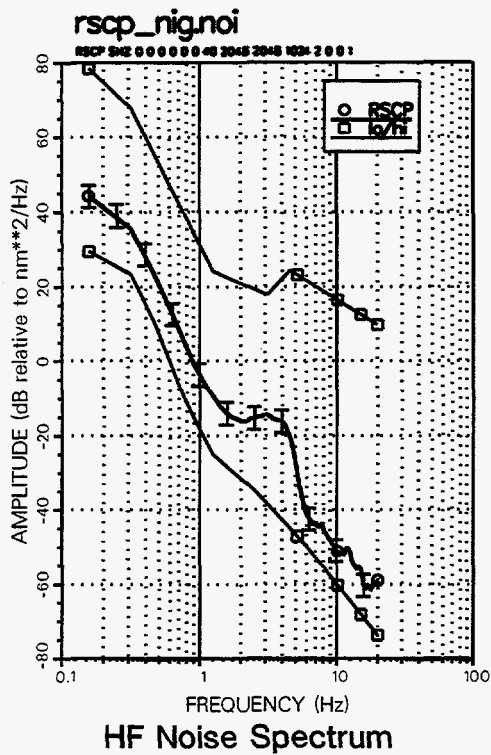


BB Noise Spectrum

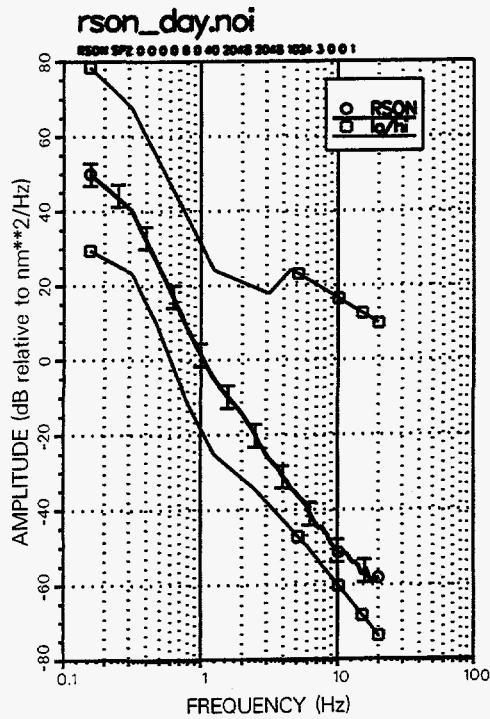
Station Noise Spectra



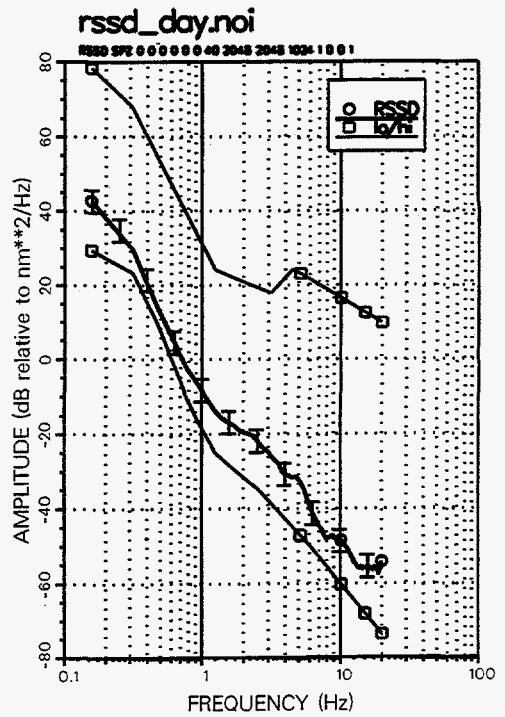
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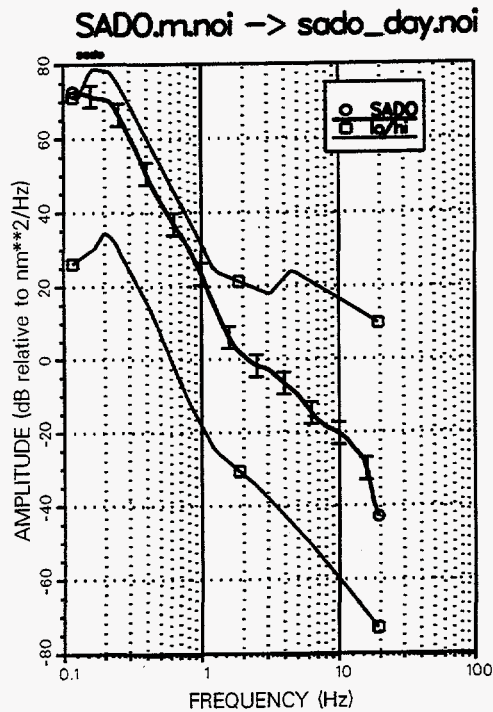
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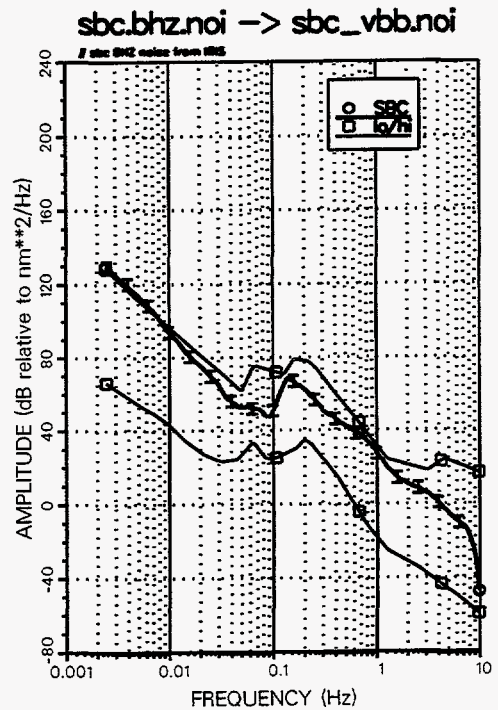
HF Noise Spectrum



HF Noise Spectrum

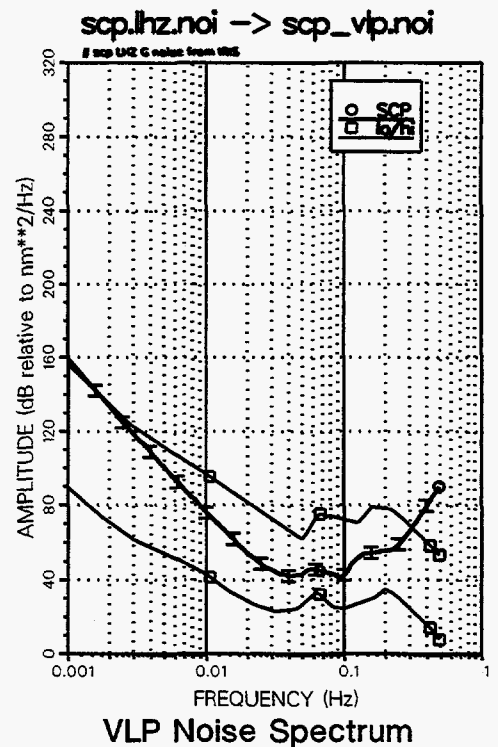
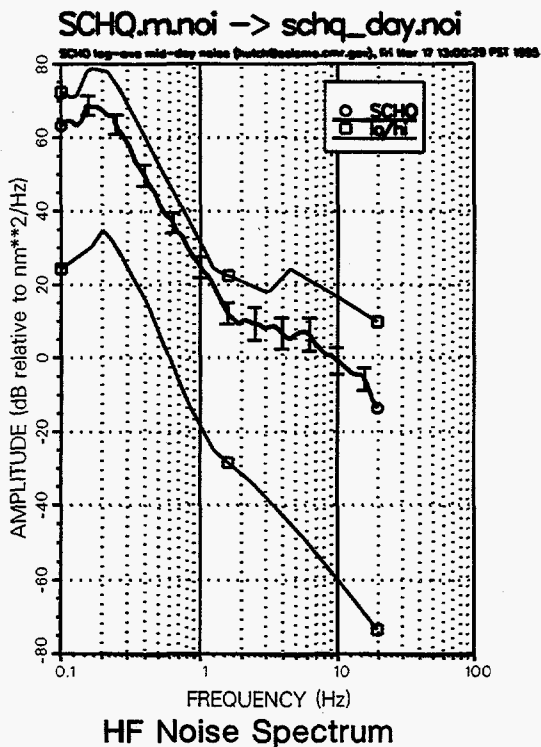
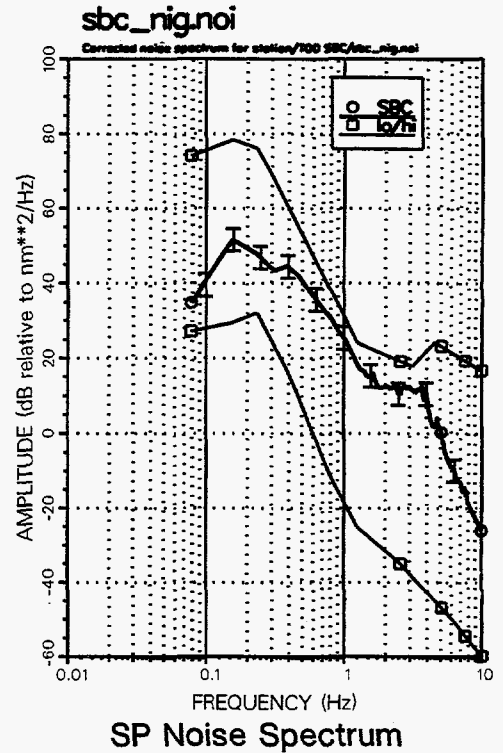
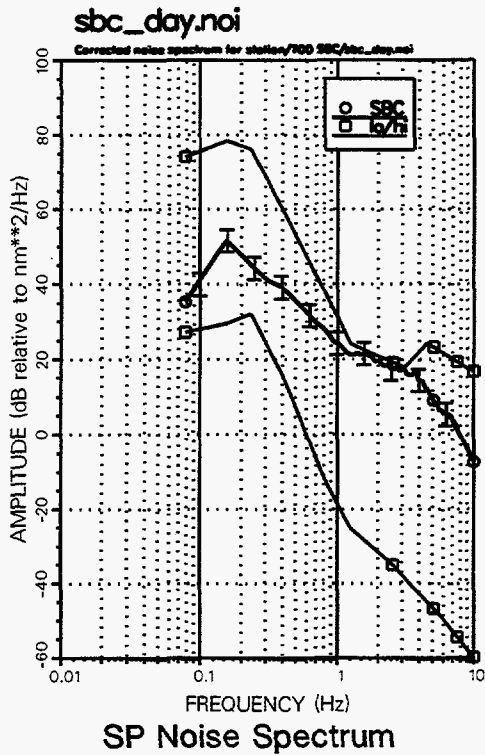


HF Noise Spectrum

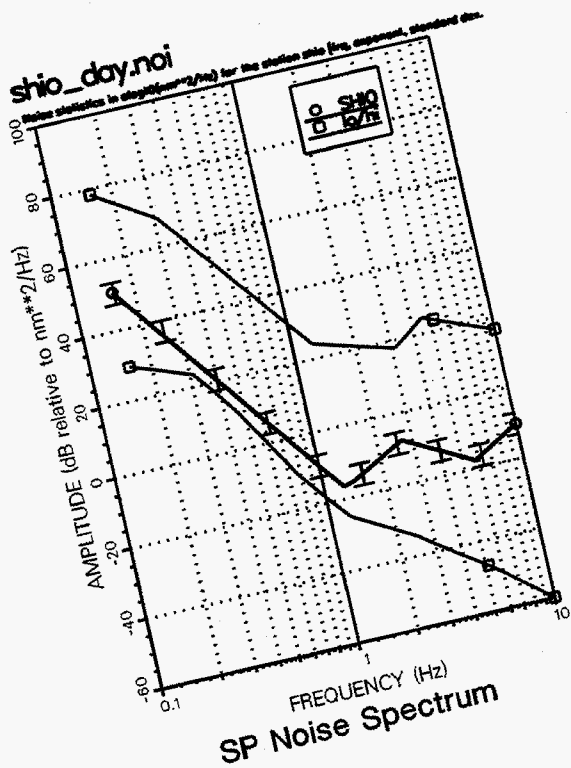
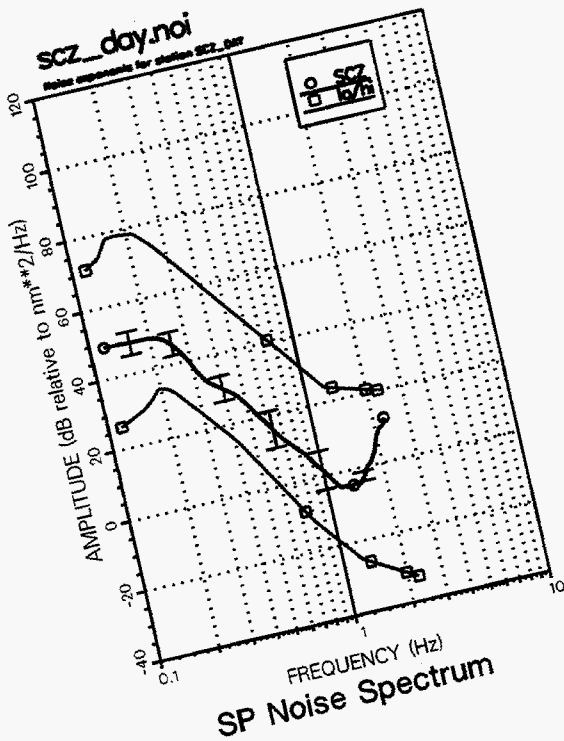
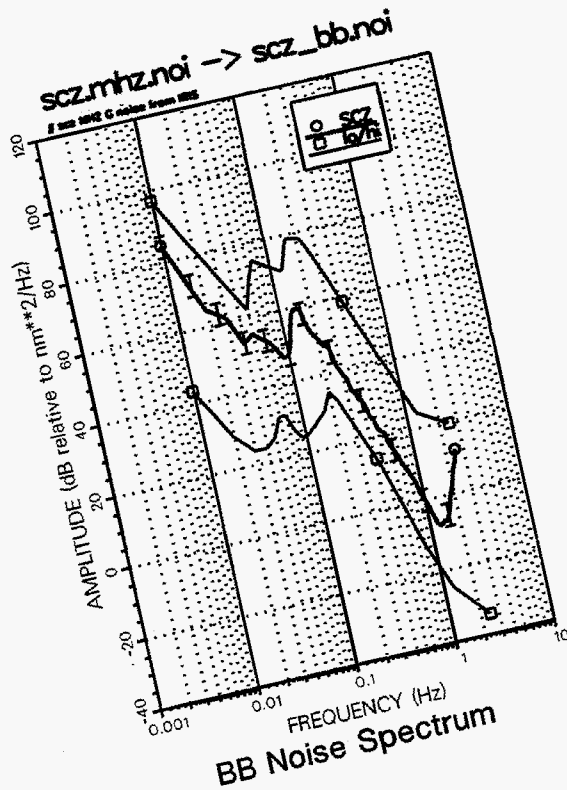
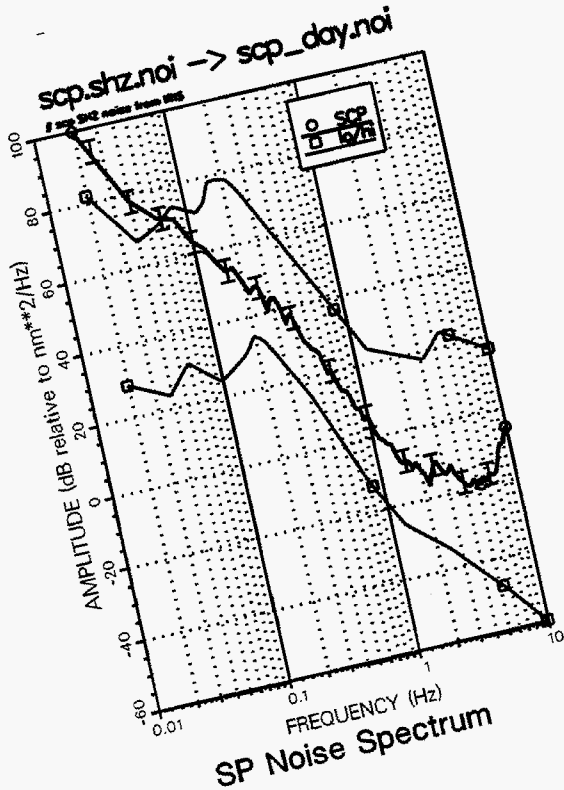


VBB Noise Spectrum

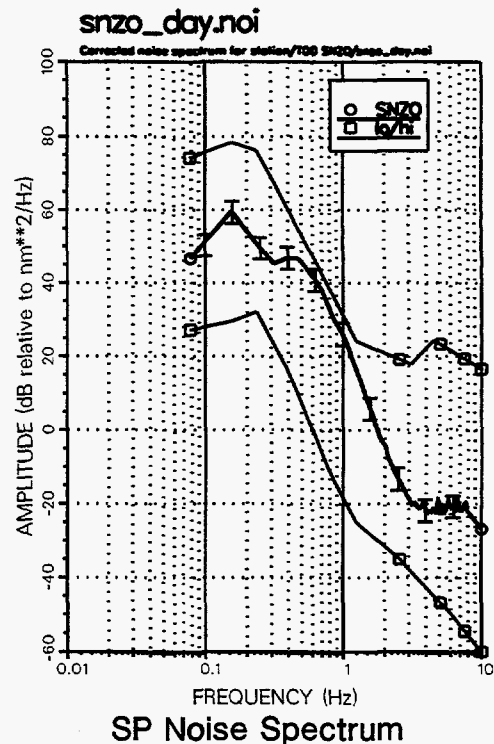
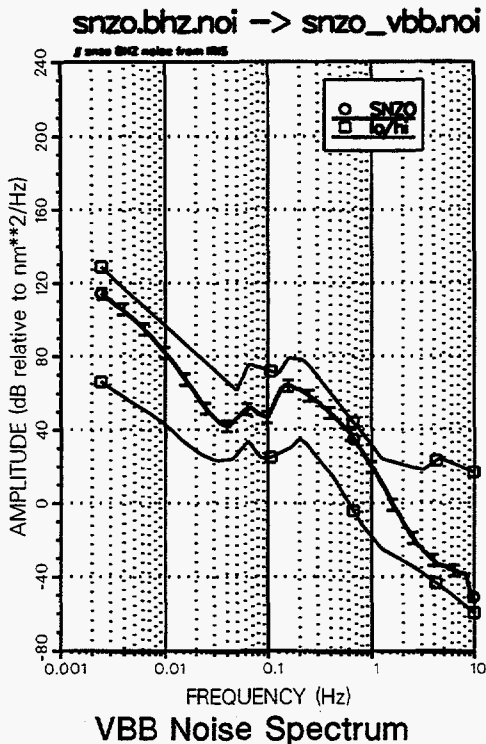
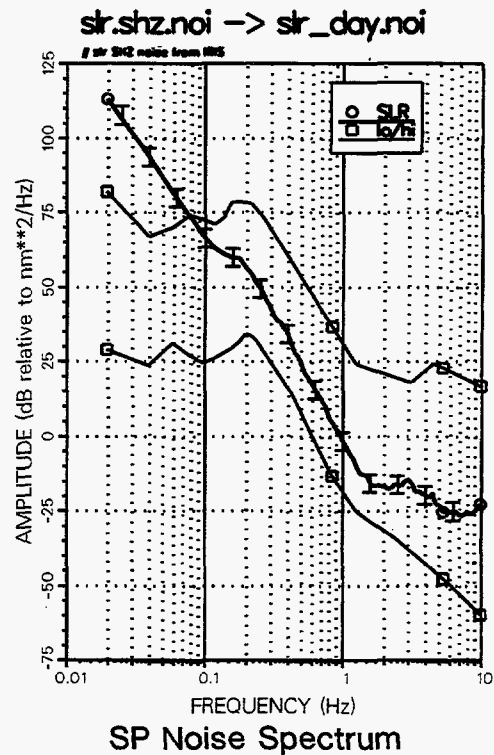
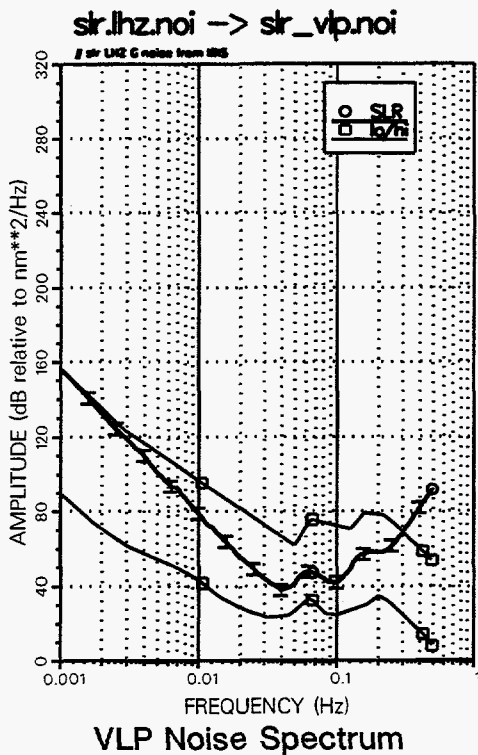
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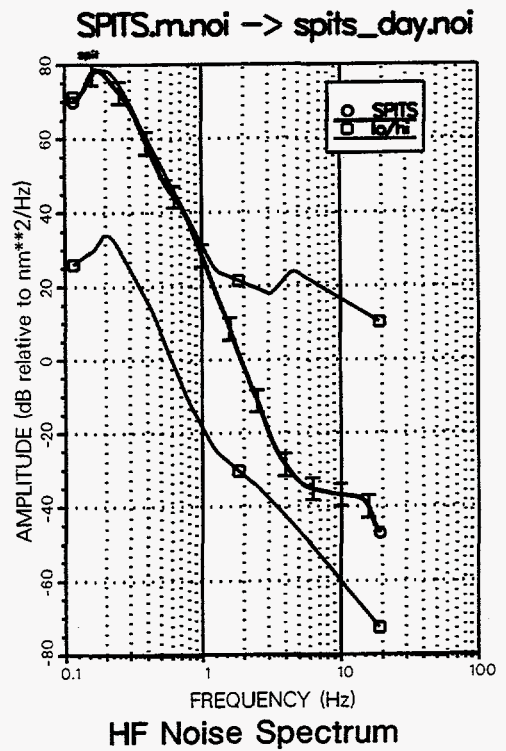
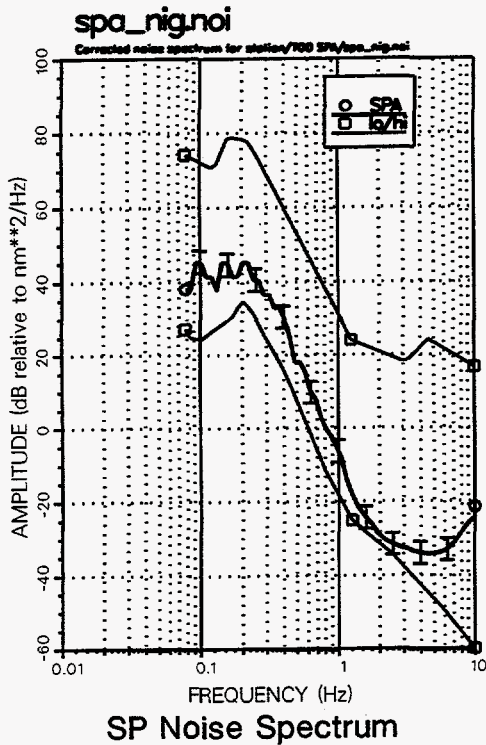
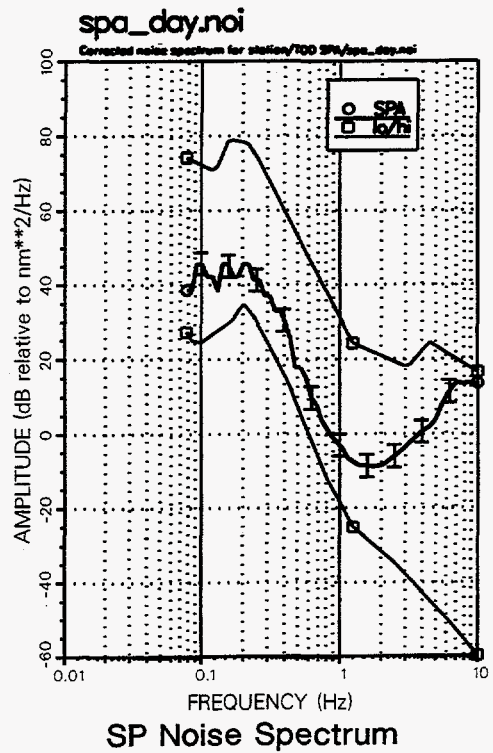
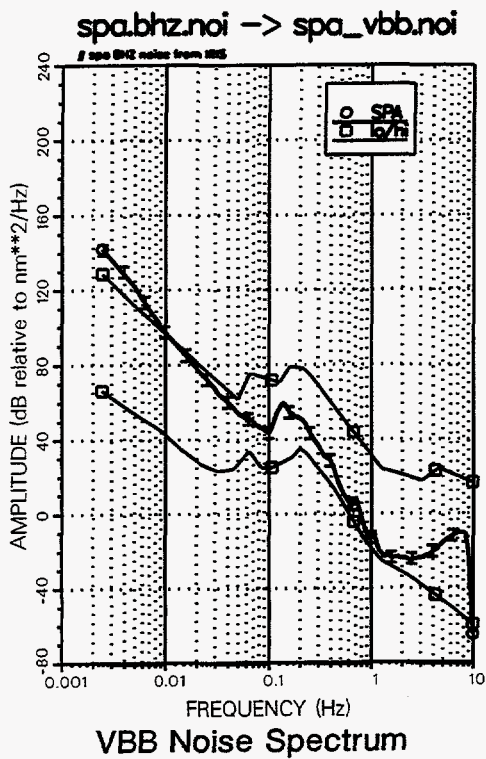
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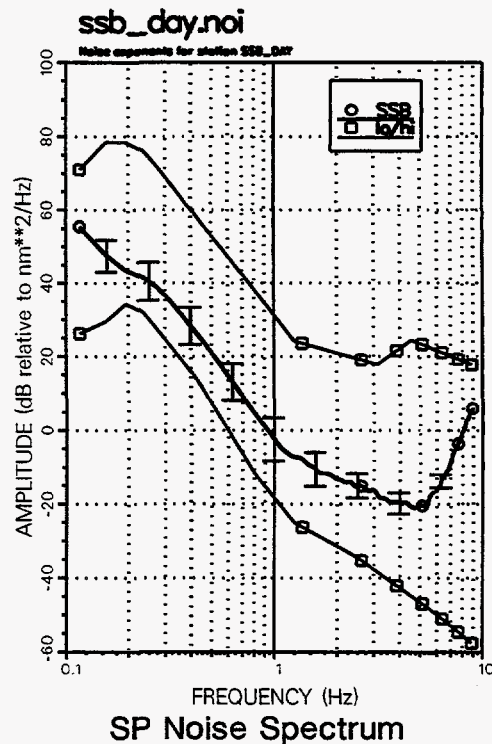
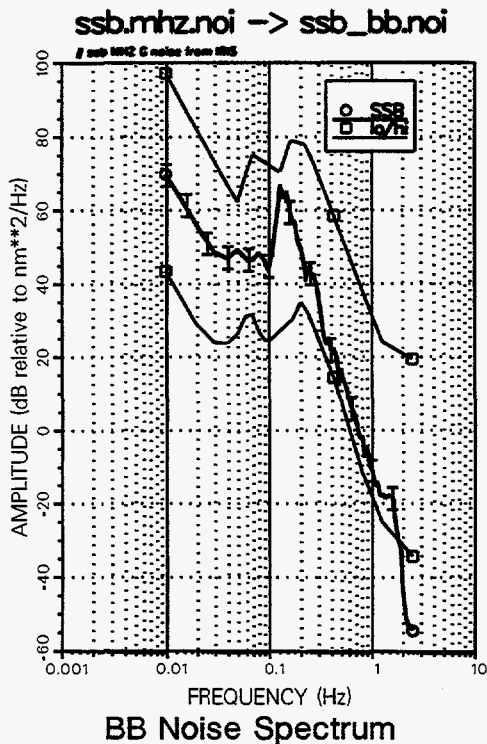
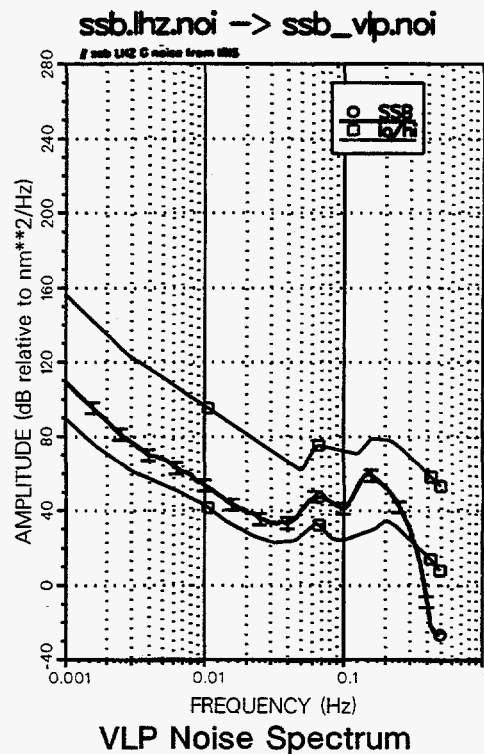
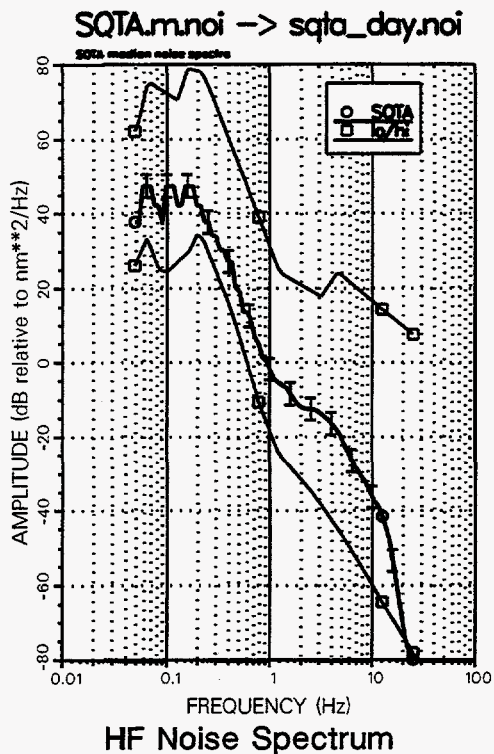
Station Noise Spectra



Station Noise Spectra

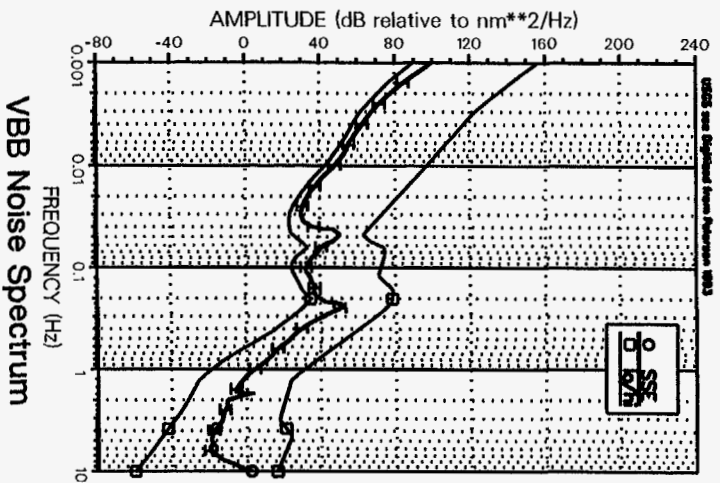


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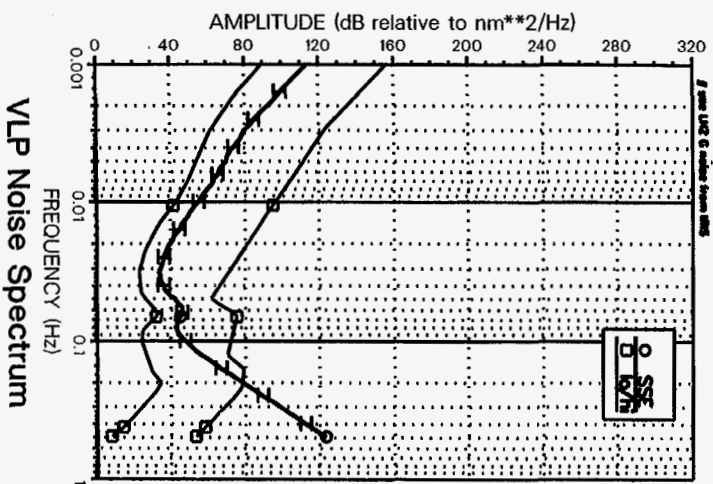


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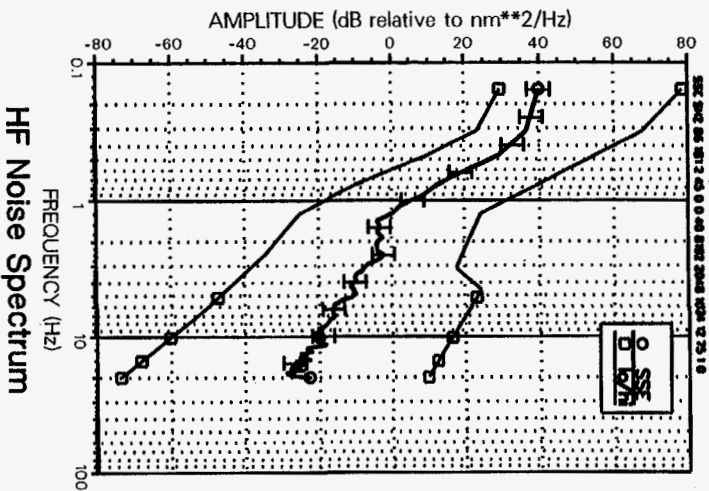
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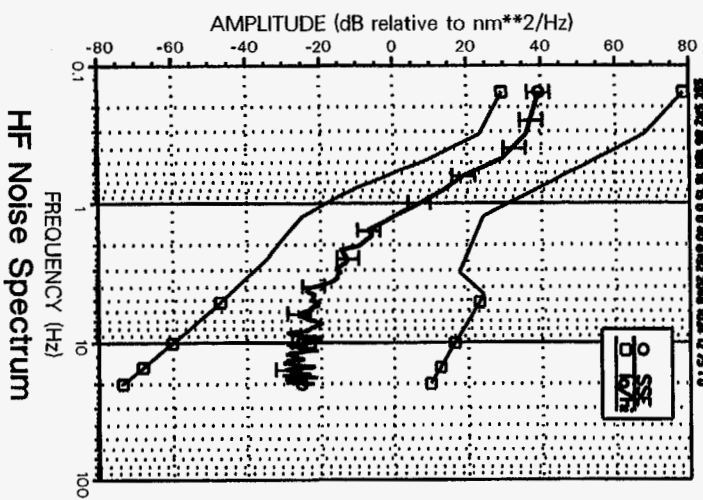
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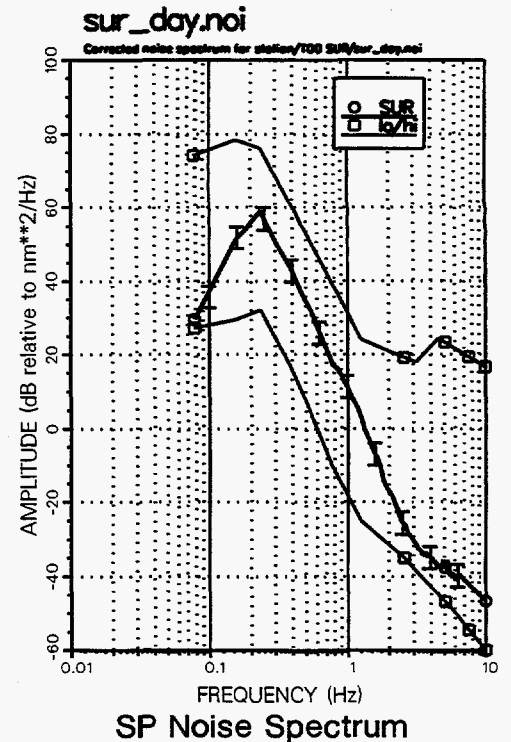
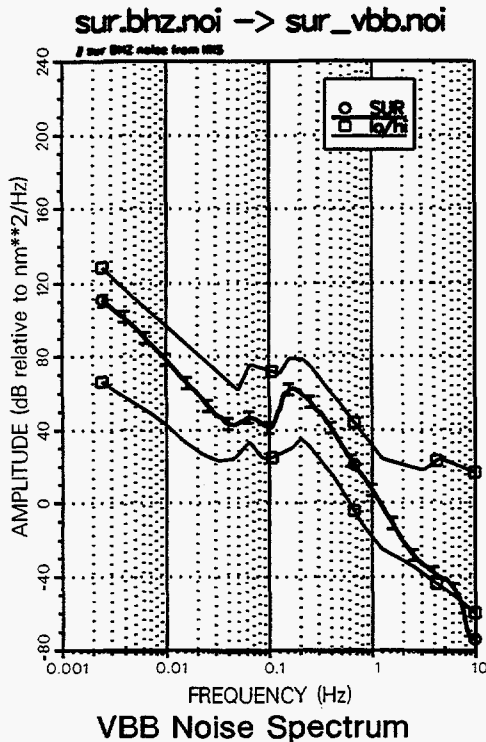
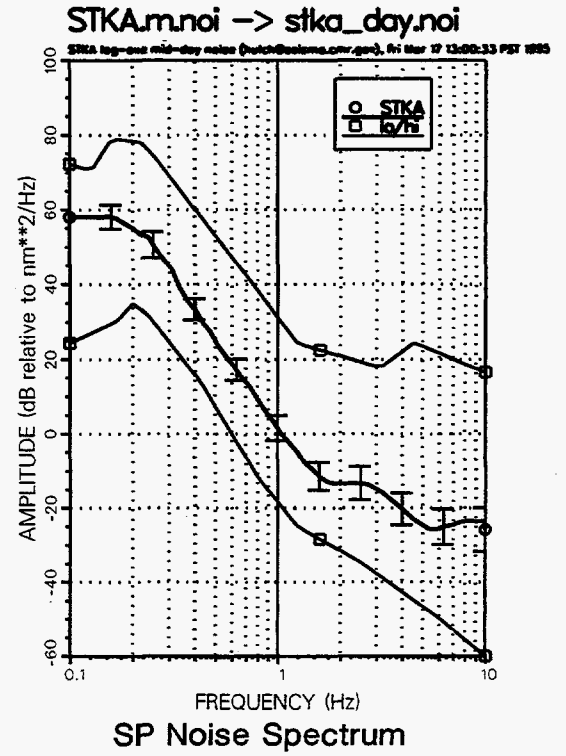
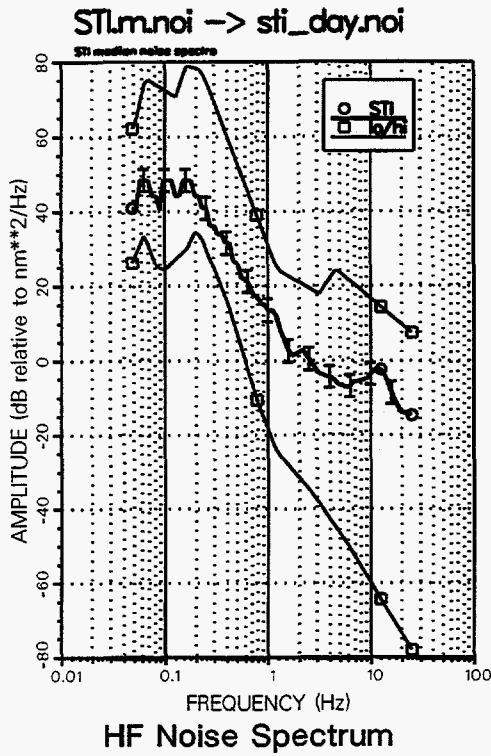
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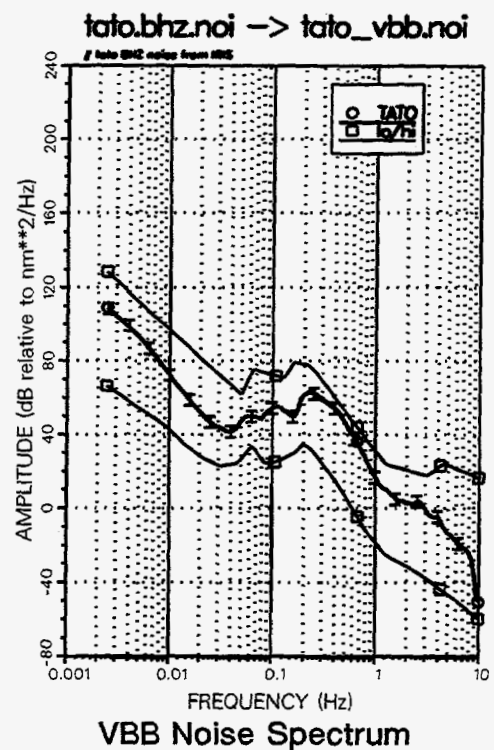
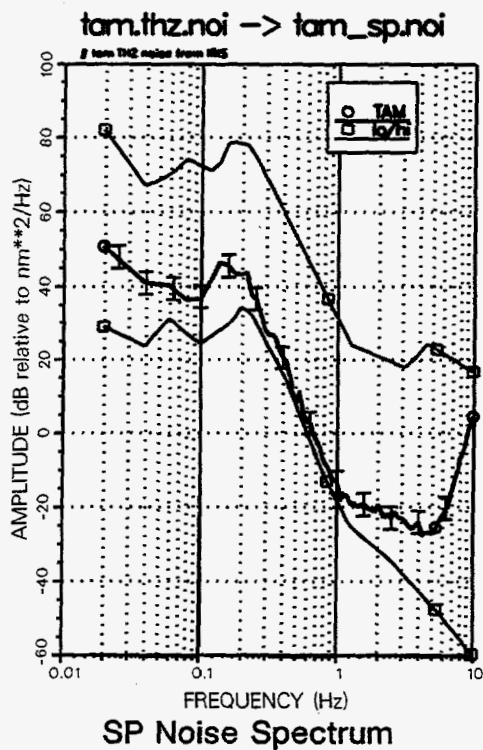
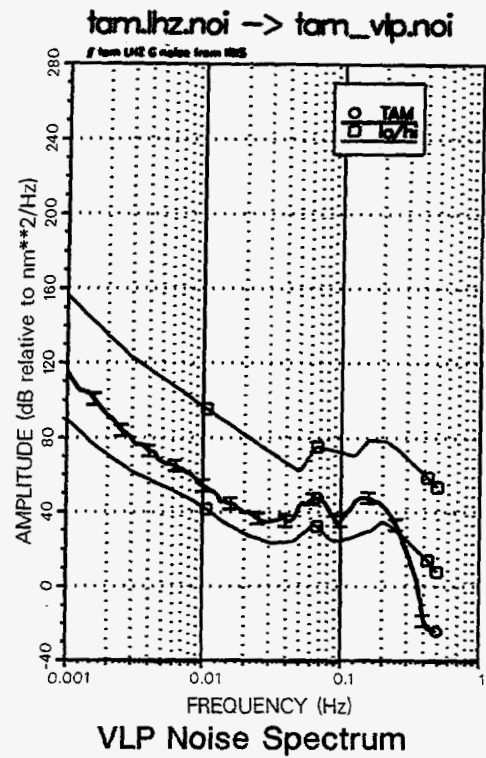
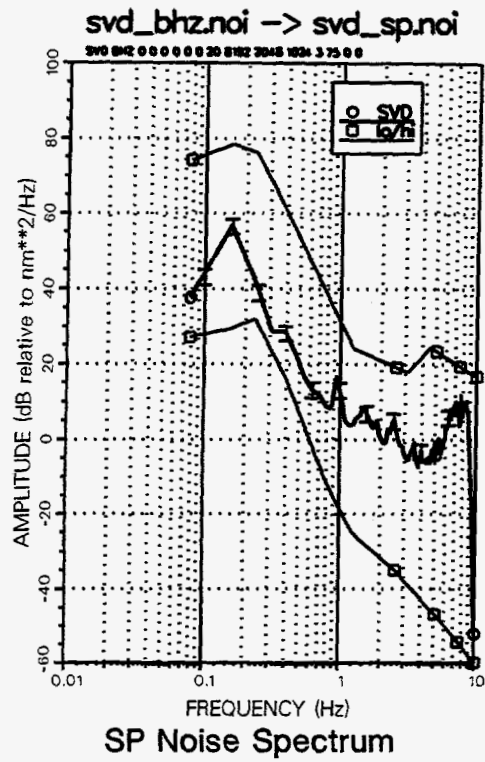
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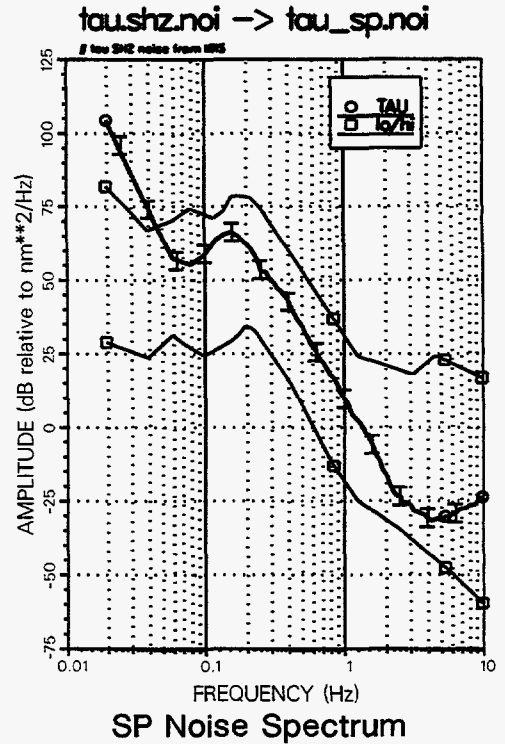
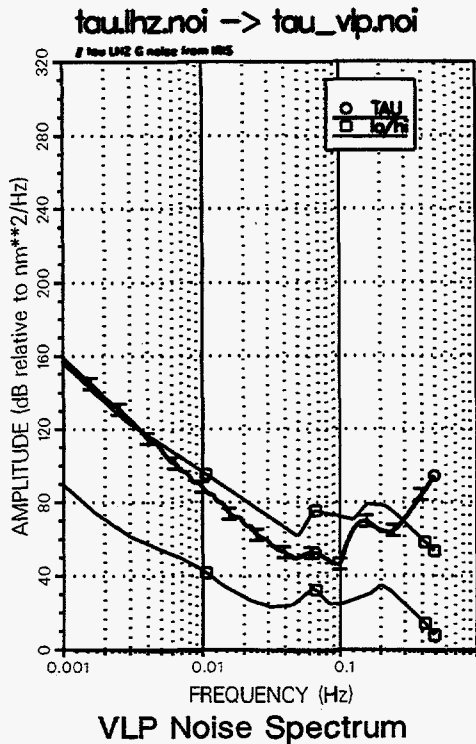
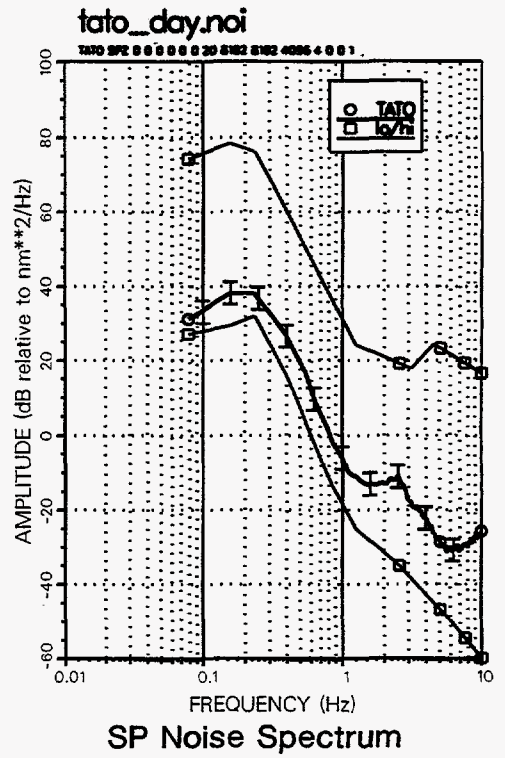
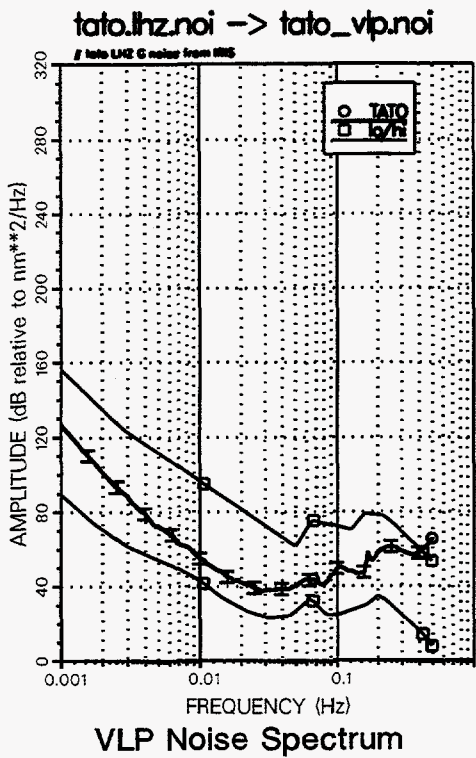
Station Noise Spectra



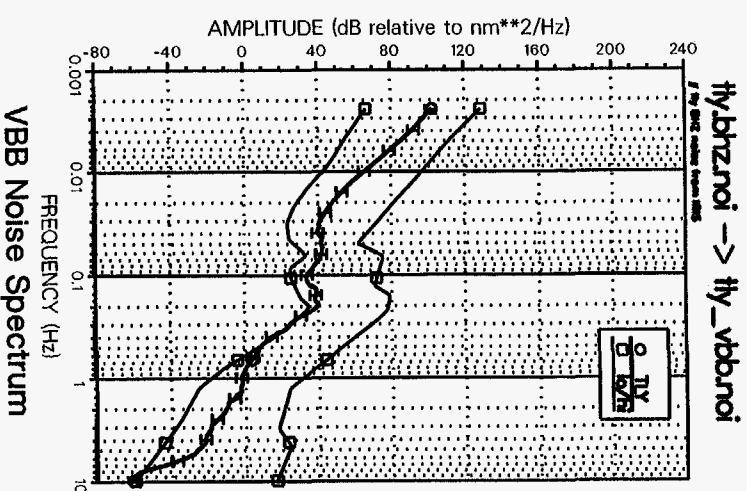
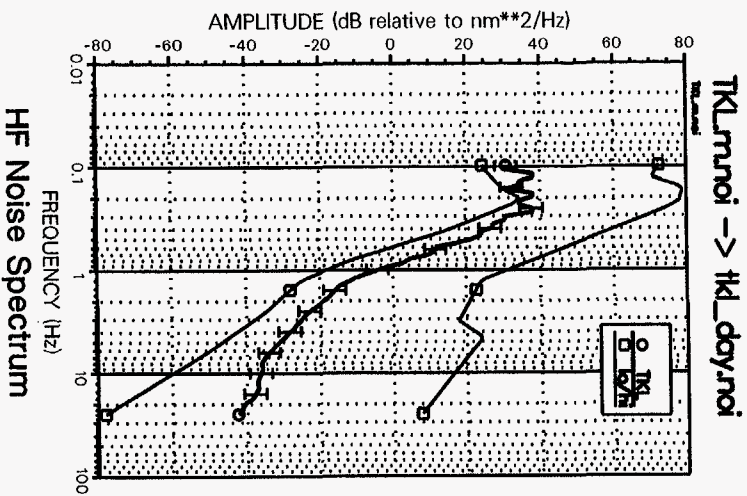
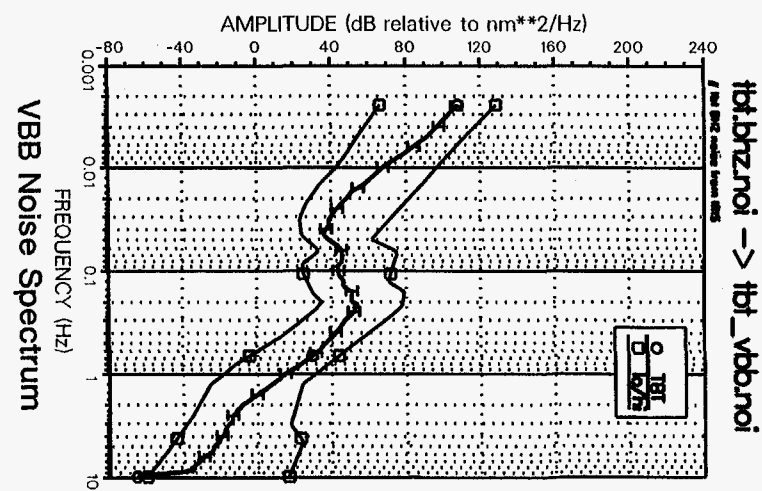
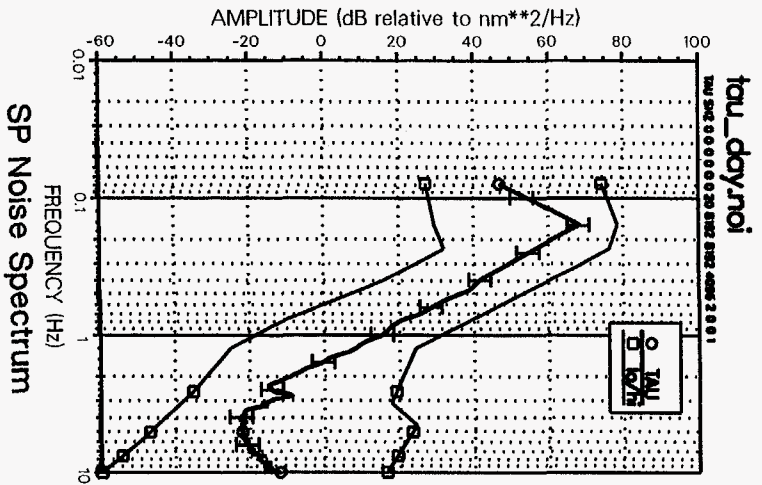
Station Noise Spectra



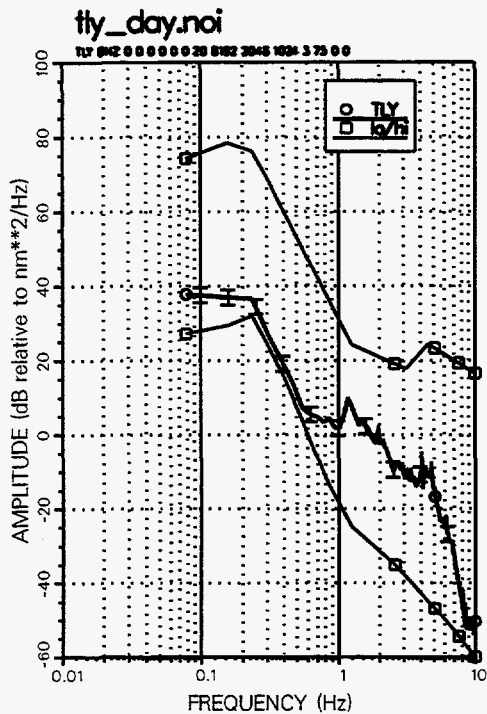
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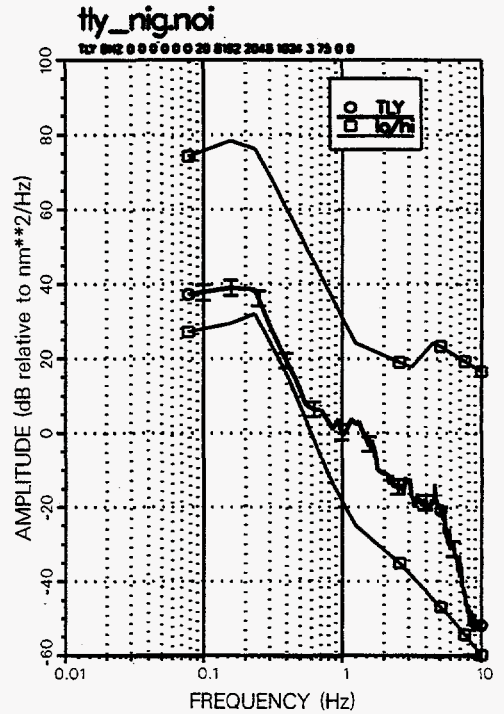
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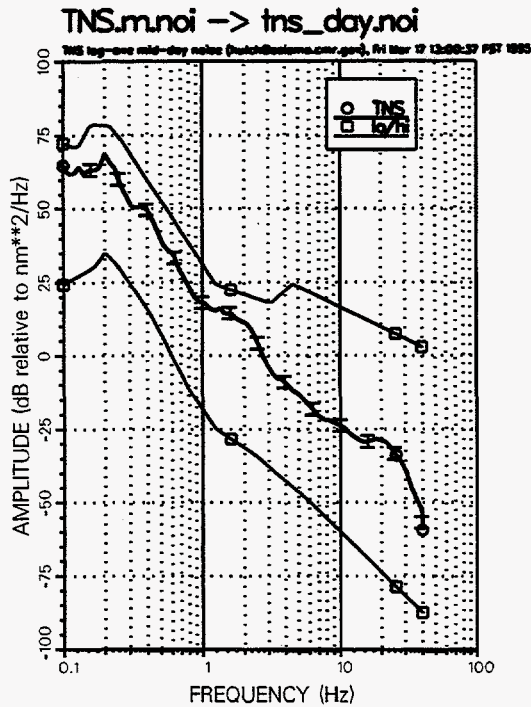
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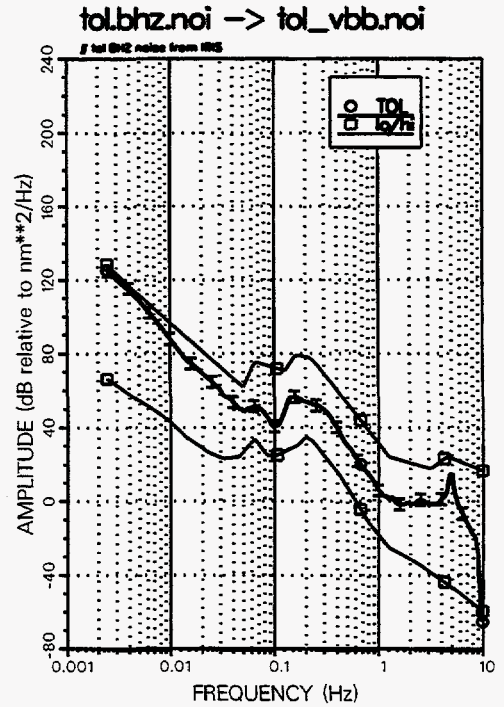
SP Noise Spectrum



SP Noise Spectrum

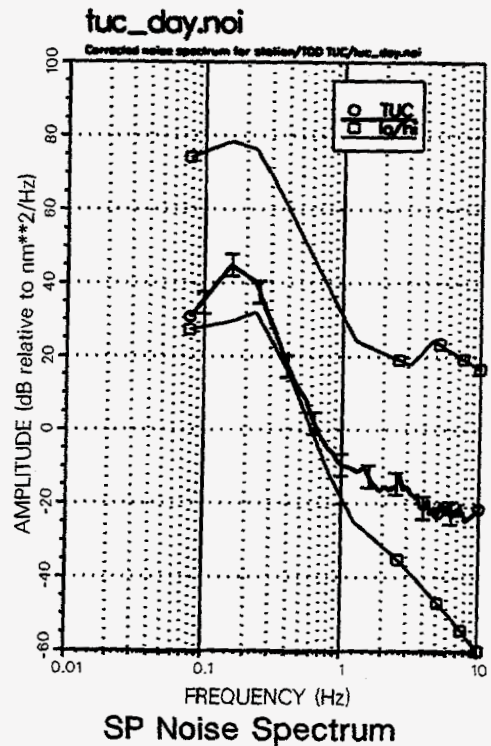
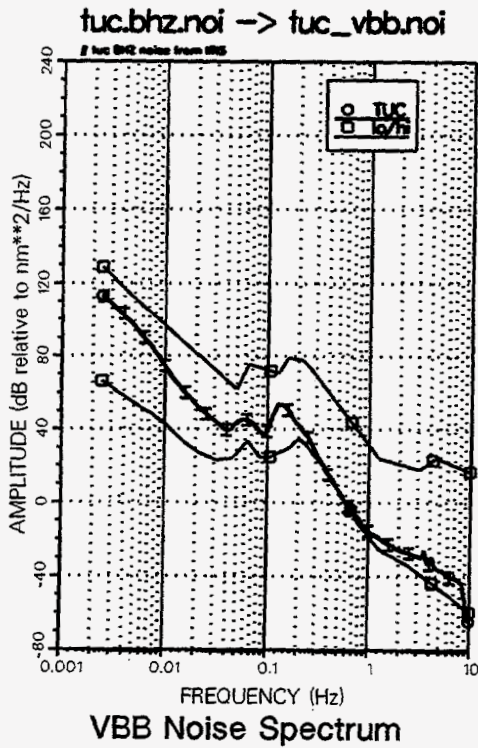
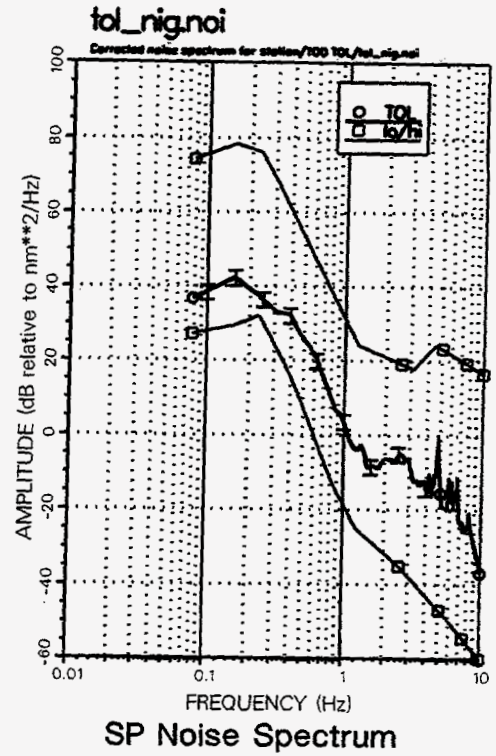
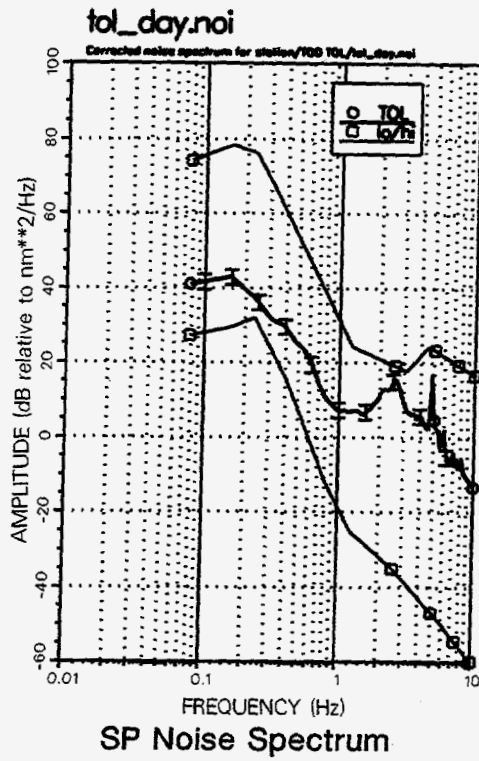


HF Noise Spectrum

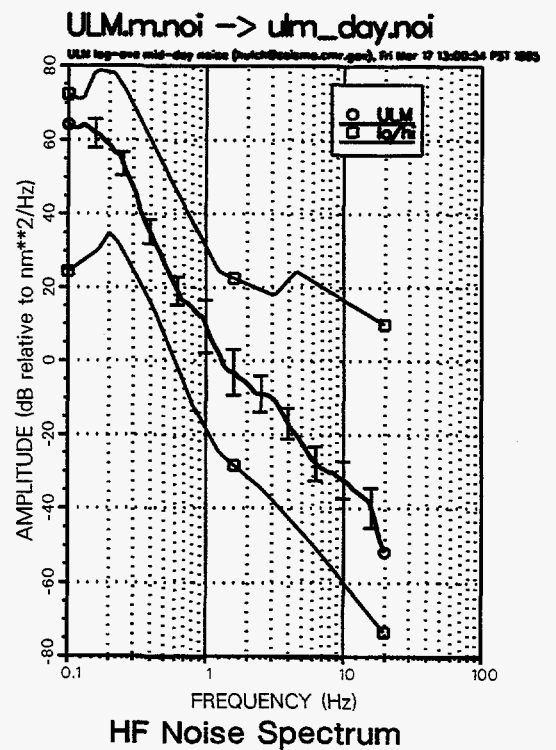
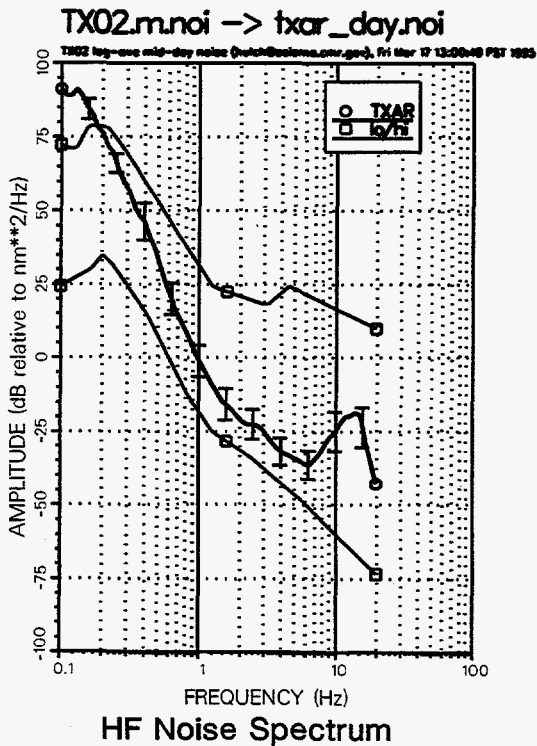
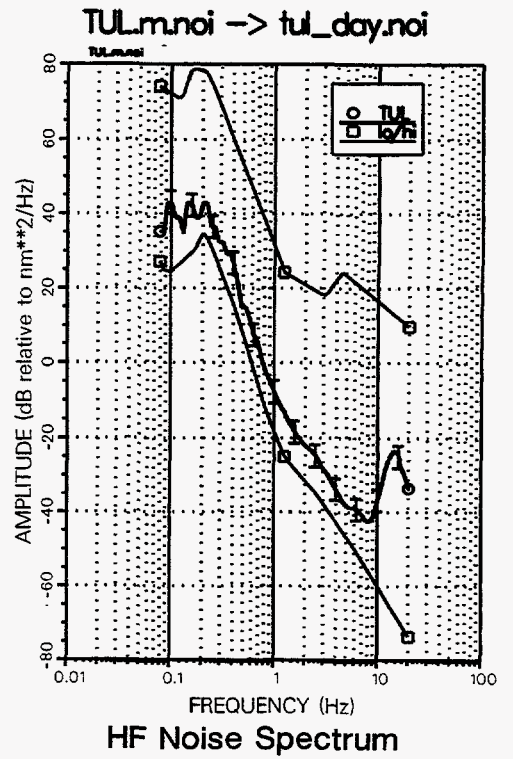
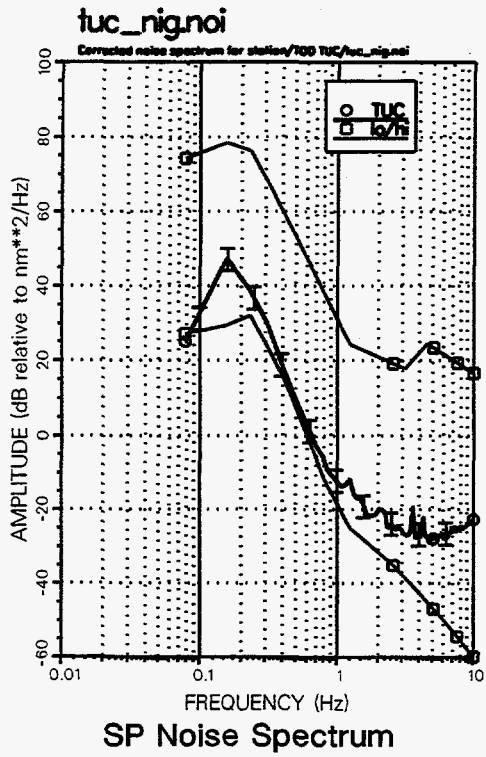


VBB Noise Spectrum

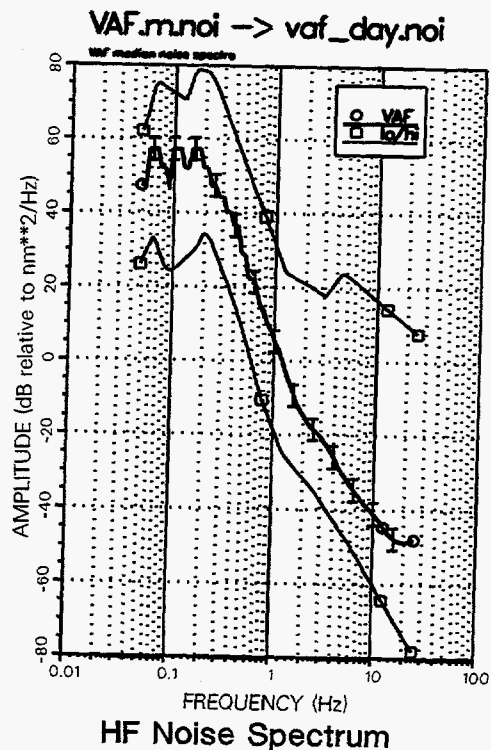
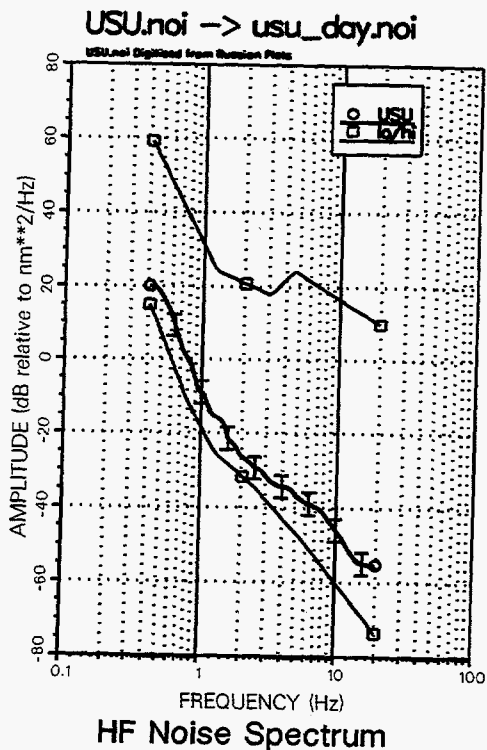
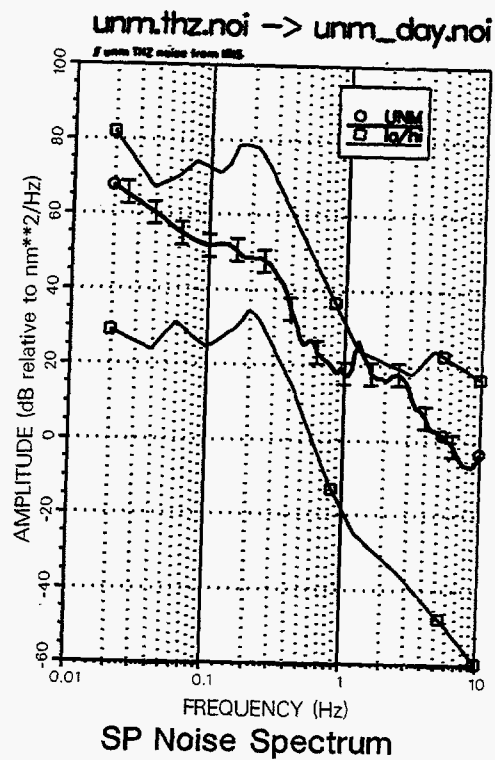
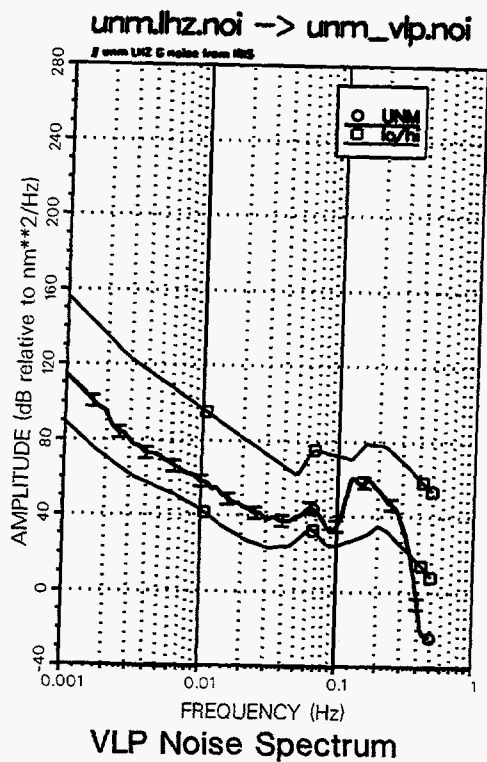
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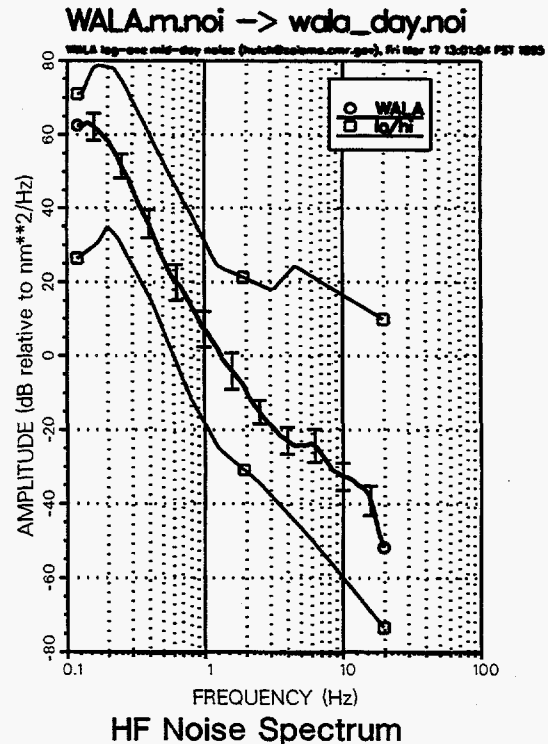
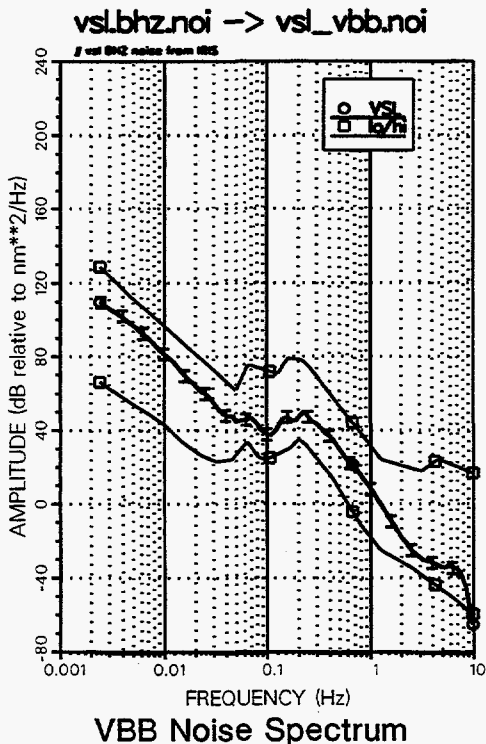
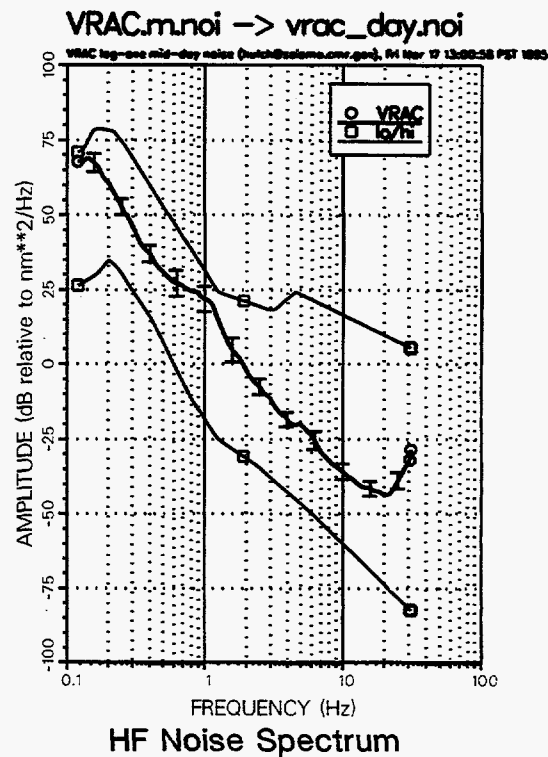
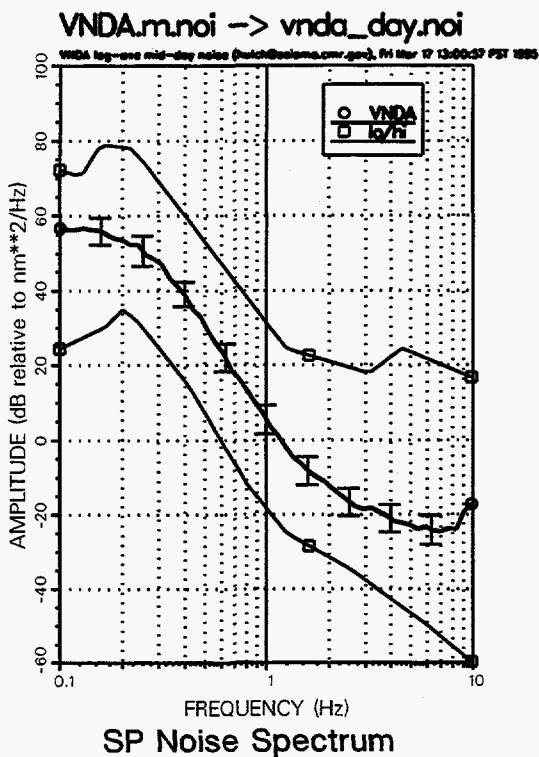
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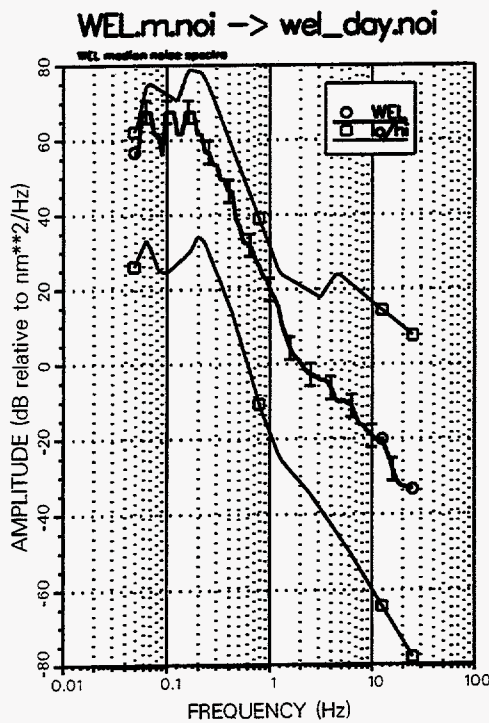
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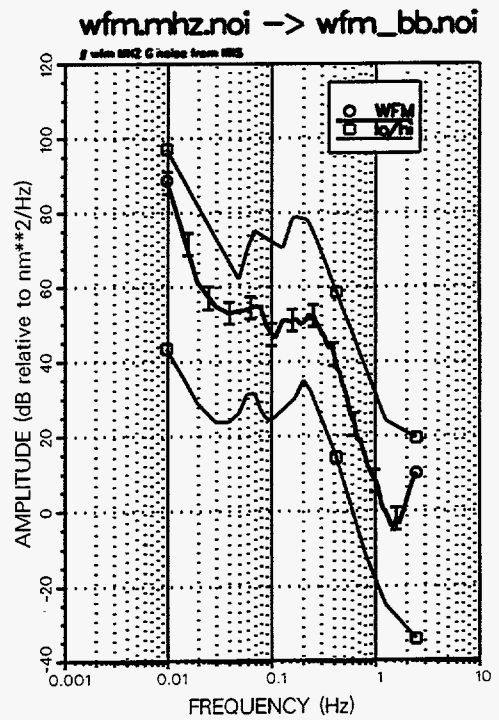
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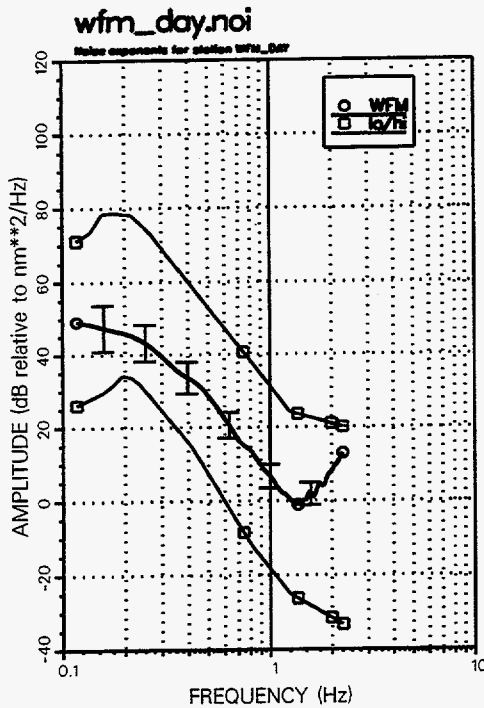
Station Noise Spectra



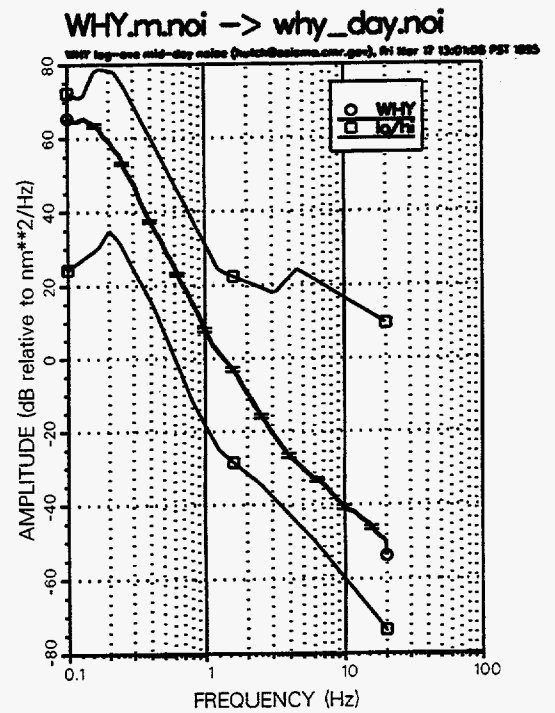
HF Noise Spectrum



BB Noise Spectrum

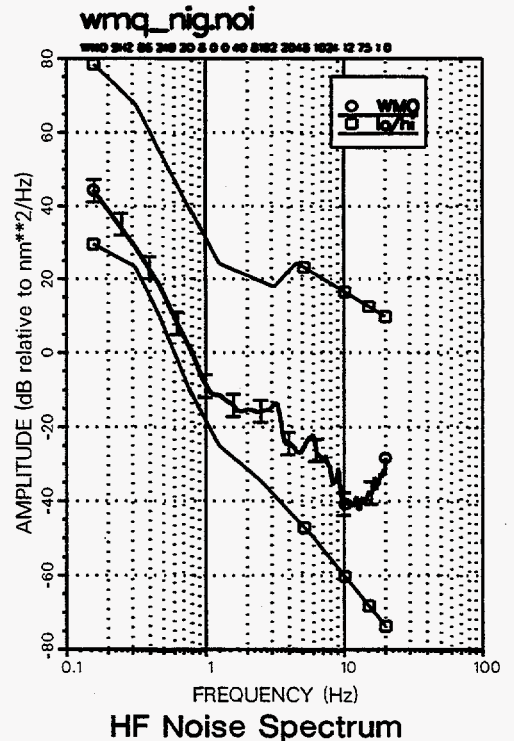
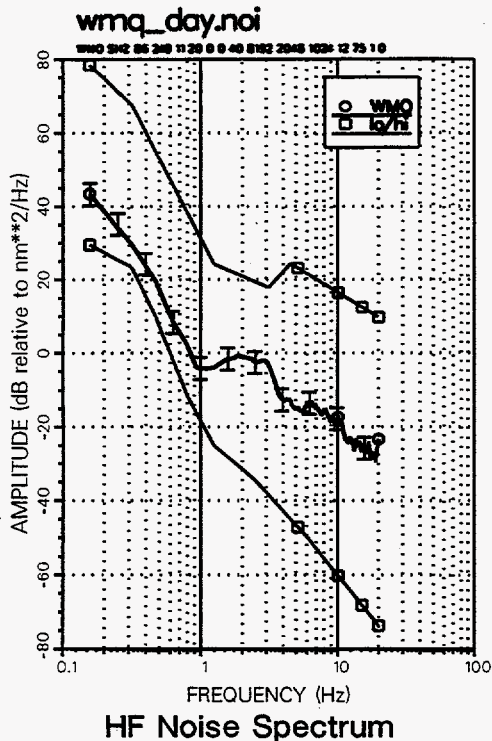
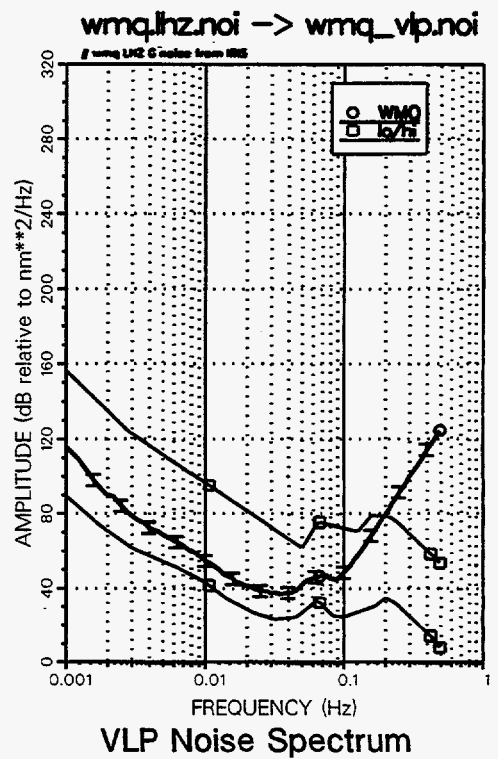
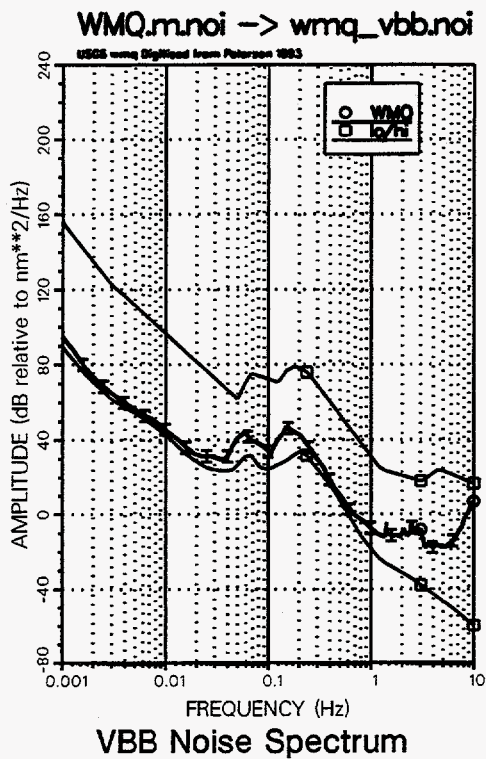


SP Noise Spectrum

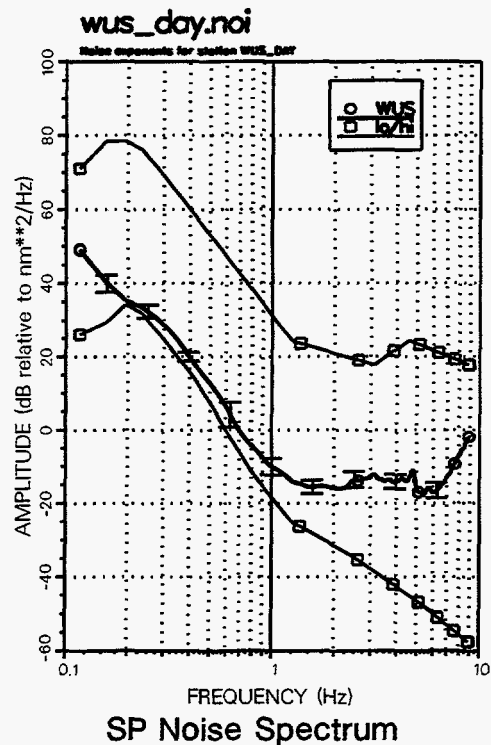
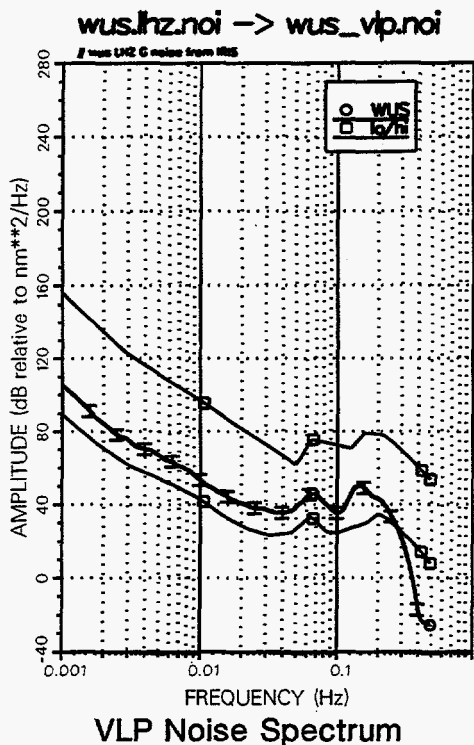
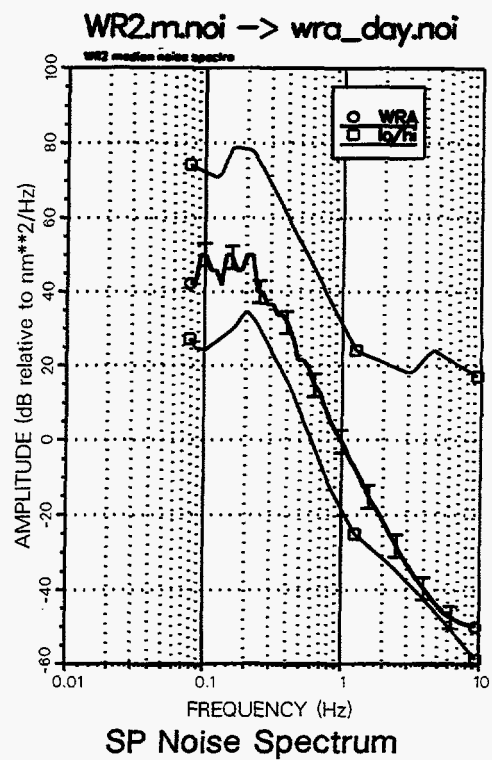
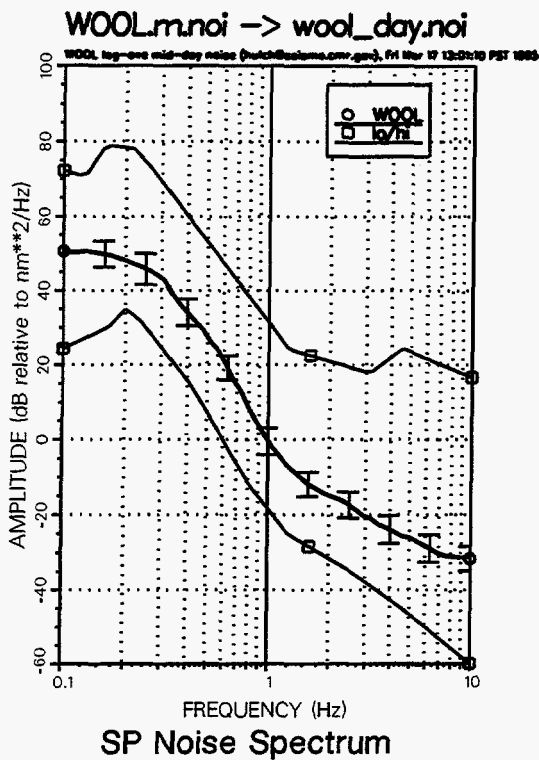


HF Noise Spectrum

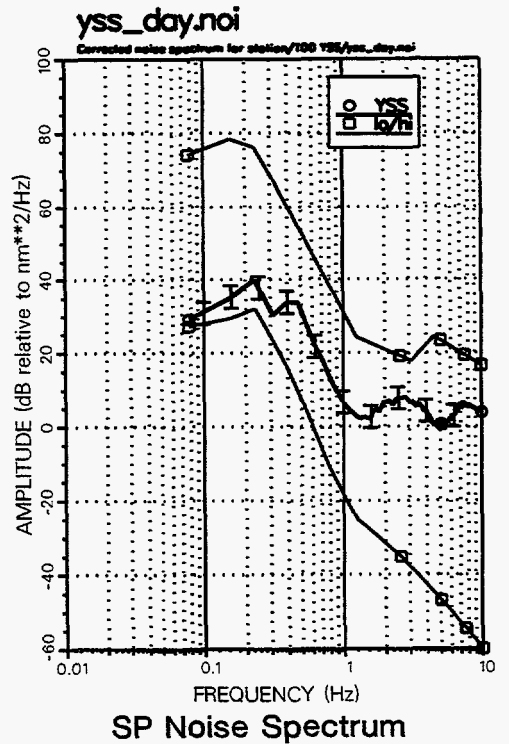
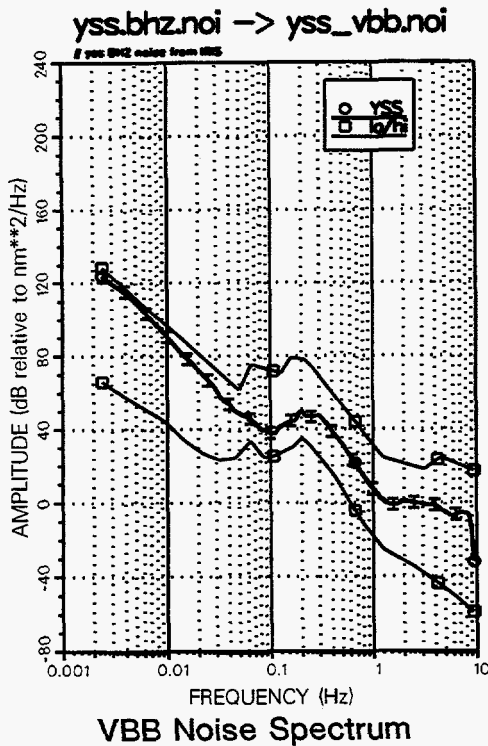
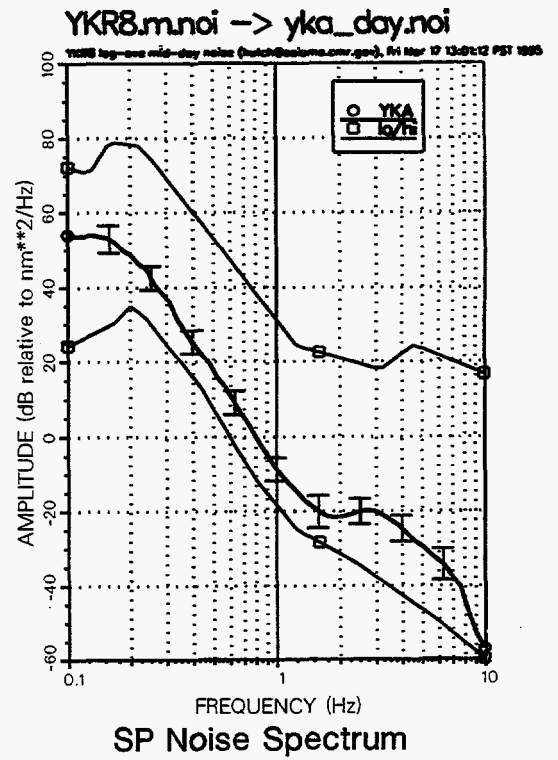
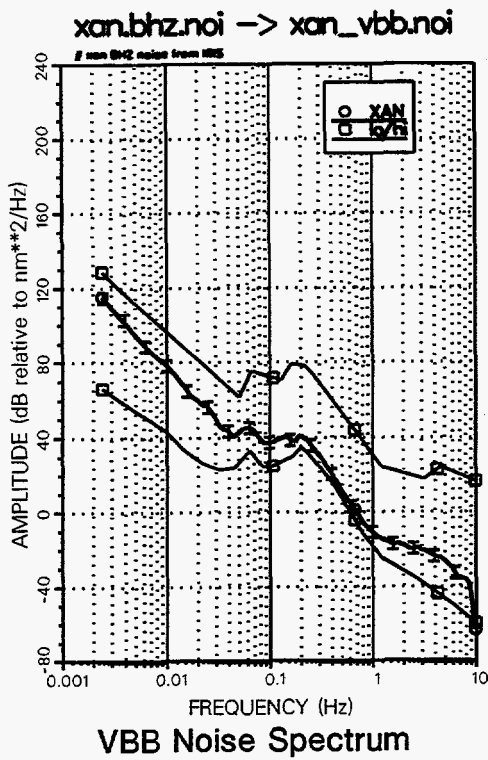
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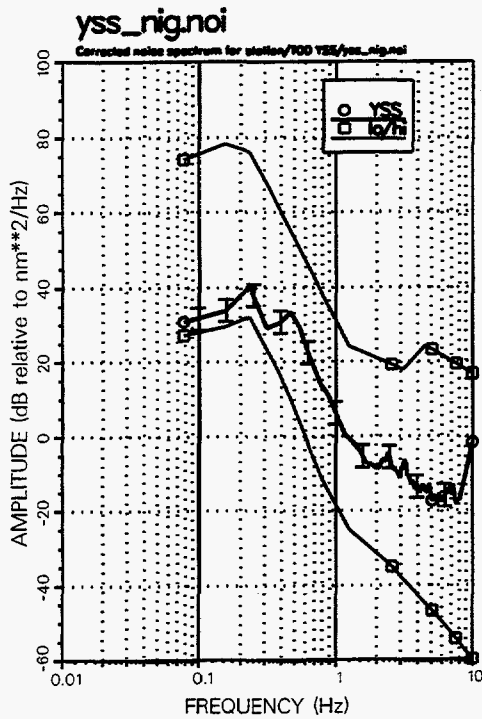
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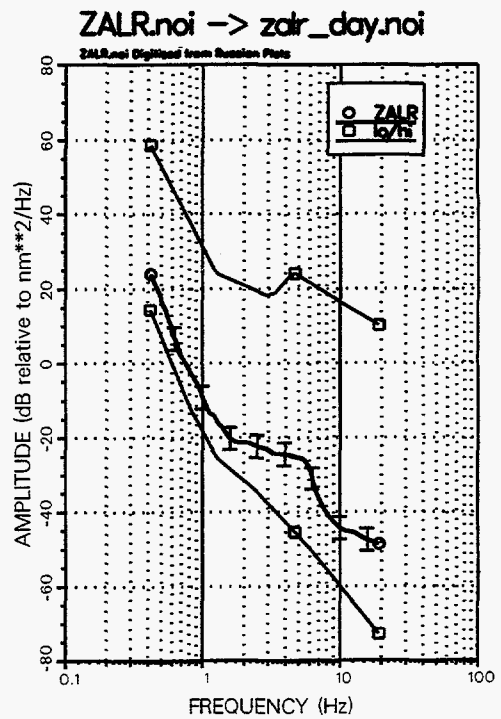
Station Noise Spectra



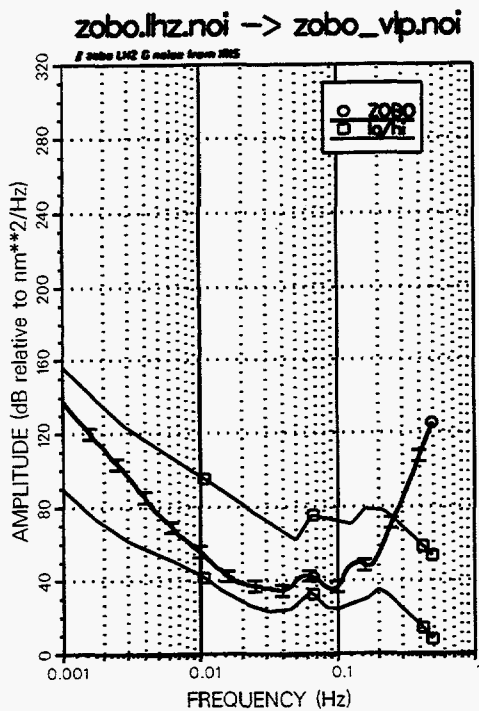
Station Noise Spectra



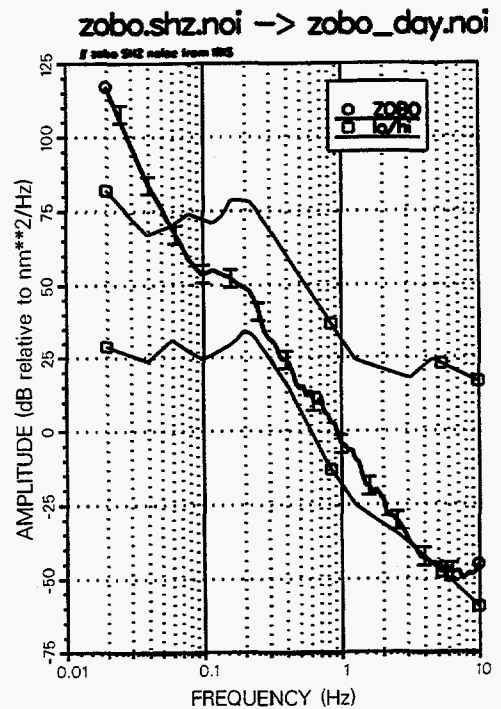
SP Noise Spectrum



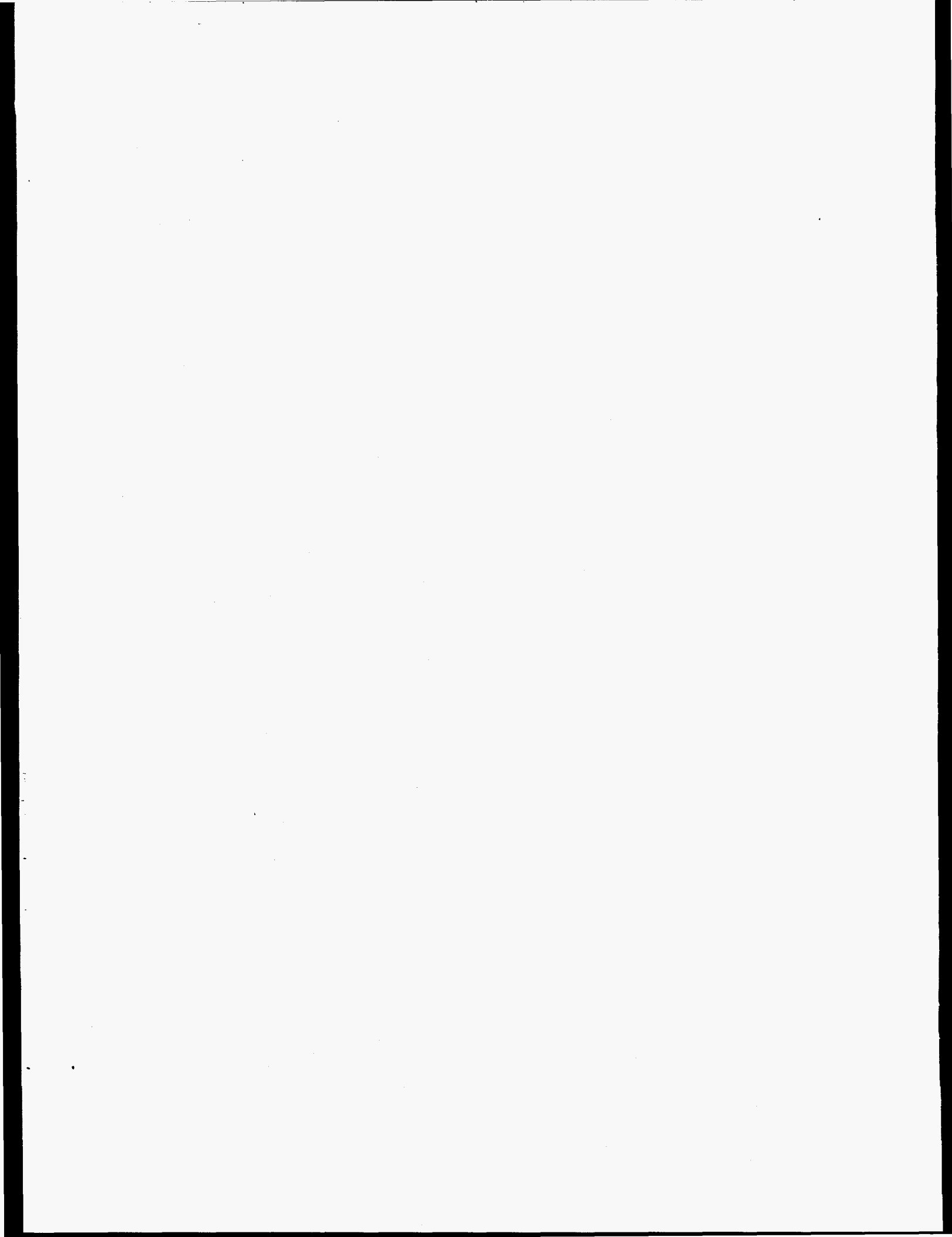
HF Noise Spectrum



VLP Noise Spectrum



SP Noise Spectrum



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