TECHNICAL REPORT 91-4

SEISMIC ACTIVITY NEAR THE V.C. SUMMER NUCLEAR STATION

FOR THE PERIOD

OCTOBER - DECEMBER 1991

BY

PRADEEP TALWANI
Principal Investigator

DEPARTMENT OF GEOLOGICAL SCIENCES
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COLUMBIA, S.C.29208

CONTRACT NO. N574984

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PRADEEP TALWANI

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and
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INTRODUCTION

Analysis of the seismic activity near the V.C. Summer Nuclear Station in South Carolina between October 1 and December 31, 1991 is presented in this report. During this period, 14 events were recorded in the vicinity of Monticello Reservoir, 6 of which were located. The largest magnitude recorded during this period was M_L=1.5. There was one other event of magnitude 1.4, located to the northwest of the reservoir.

A review of the seismic activity during the year 1991 is also presented in this report. The level of activity, and its spatial distribution are discussed in detail. The performance of various stations of the network during the past year is also presented in this report.

SEISMIC NETWORK

Earthquakes during this period were recorded on stations of Monticello Reservoir and South Carolina Seismic Network. The configuration of stations utilized to locate Monticello events is shown in Figure 1 and station coordinates are listed in Appendix I. The operational status of the network is given in Appendix II. The names of these stations have been changed in this quarterly report to conform with other Southeastern U.S. Network stations. Thus, the station previously identified as 002 is renamed MR02 with similar changes for all other stations. The network was fully operational during this period, though the records from MR02 were occasionally noisy and not usable in locating earthquakes.

DATA ANALYSIS

Hypocentral locations have been determined using the computer program HYPO71 (Lee and Lahr, 1972). The velocity model used in the earthquake locations is given in Appendix III. The format of the output is given in Appendix IV. The event magnitude was determined from the signal duration at JSC using the following relation:

$$M_L = -1.83 + 2.04 \text{ Log } D,$$

where D is the signal duration (seconds).

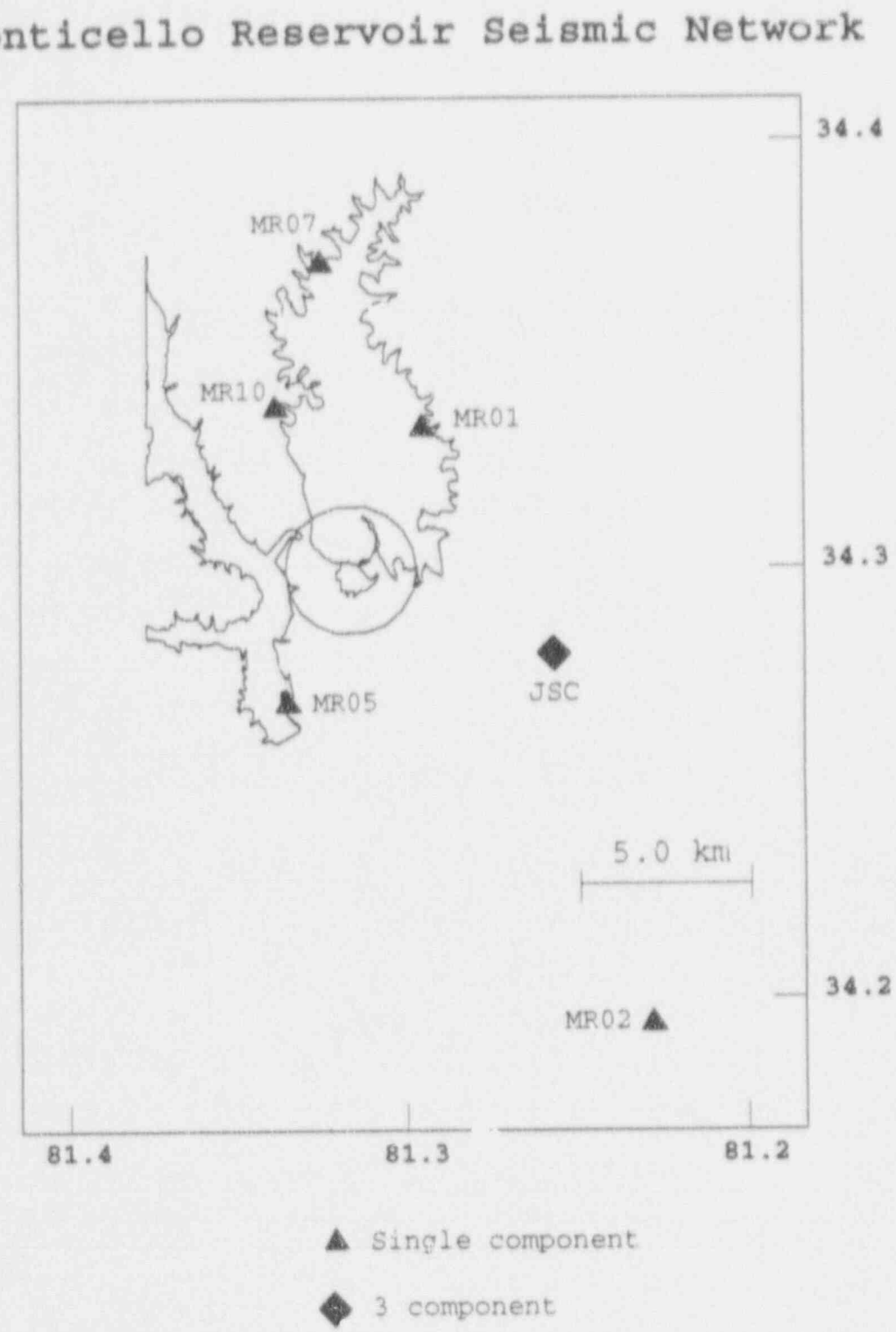

Figure 1 Location of Monticello Reservoir area showing seismic stations used in locating seismicity.

An estimate of daily energy release was determined using a simplified magnitude (M_L) . energy (E) relation by Gutenberg and Richter (1956):

$$\text{Log}_{10}\, E = 11.8 + 1.5\, M_L$$

OBSERVED SEISMICITY DURING OCTOBER-DECEMBER

During this period 14 earthquakes were recorded, of which 6 were located (Figure 2; Appendix V). The located events were of poor quality (C or D). The largest event was of magnitude M_L=1.5 which occurred on October 22 (17:48:08.31 UTC). There was one other event of magnitude M_L= 1.4 , which occurred to the northwest of the reservoir, outside the study area. This earthquake is listed in the study because of the activity in this area during the previous quarter. However, it is not included in the energy analysis. Blasting activity is being investigated to see if these events could be blasts from any of the nearby quarries.

Eight of the 14 events recorded during this period occurred in a swarm on November 16. These events were recorded first at station MR10 and were generally of short duration (Appendix VI). Only three of these events were large enough to be located (Appendix V; Figure 2). The largest event of this swarm occurred on November 16 (16 : 45 :14.22 UTC) and had a magnitude M_L = 0.5.

The long term decline in seismicity observed at Monticello is continuing (Figure 3). The seismicity at Monticello seems to have leveled off since 1985-1986 (Figure 4).

CORRELATION OF WATER LEVEL WITH SEISMICITY

Monticello Reservoir is a pumped storage facility. Any decrease in the reservoir level associated with power generation is recovered when water is pumped back into the reservoir. There can be normal variations up to five feet per day between maximum and minimum water levels. The water level has been monitored to see if there is any correlation between the daily or seasonal changes in the reservoir level and the local seismicity. Water levels are compared with seismicity in Figure 5. The top panel shows the average water level; the error bars show the maximum and minimum water levels each day. The second panel shows the change in

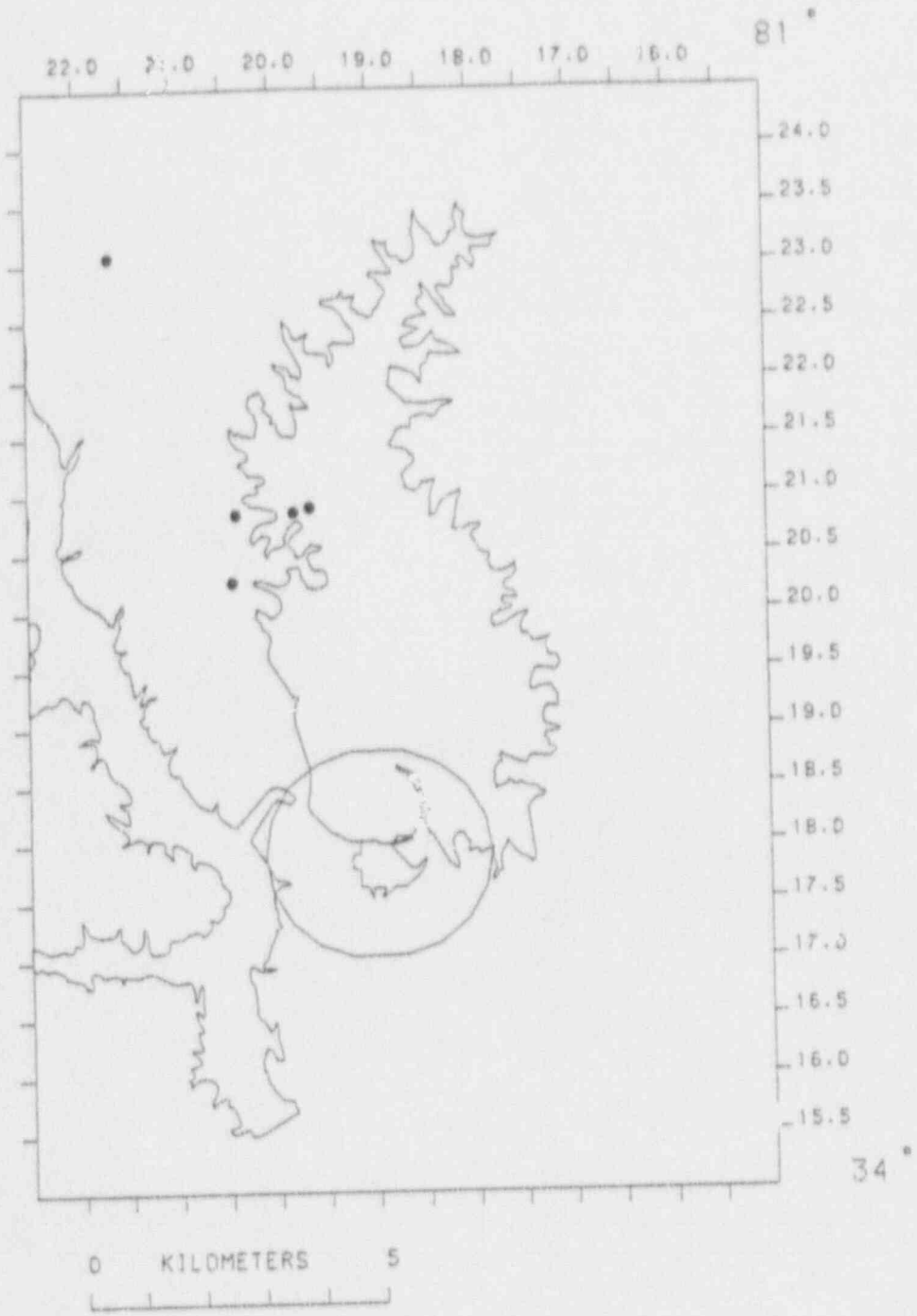

Figure 2. Earthquakes located near Monticello Reservoir during the period October 1 - December 31, 1991.

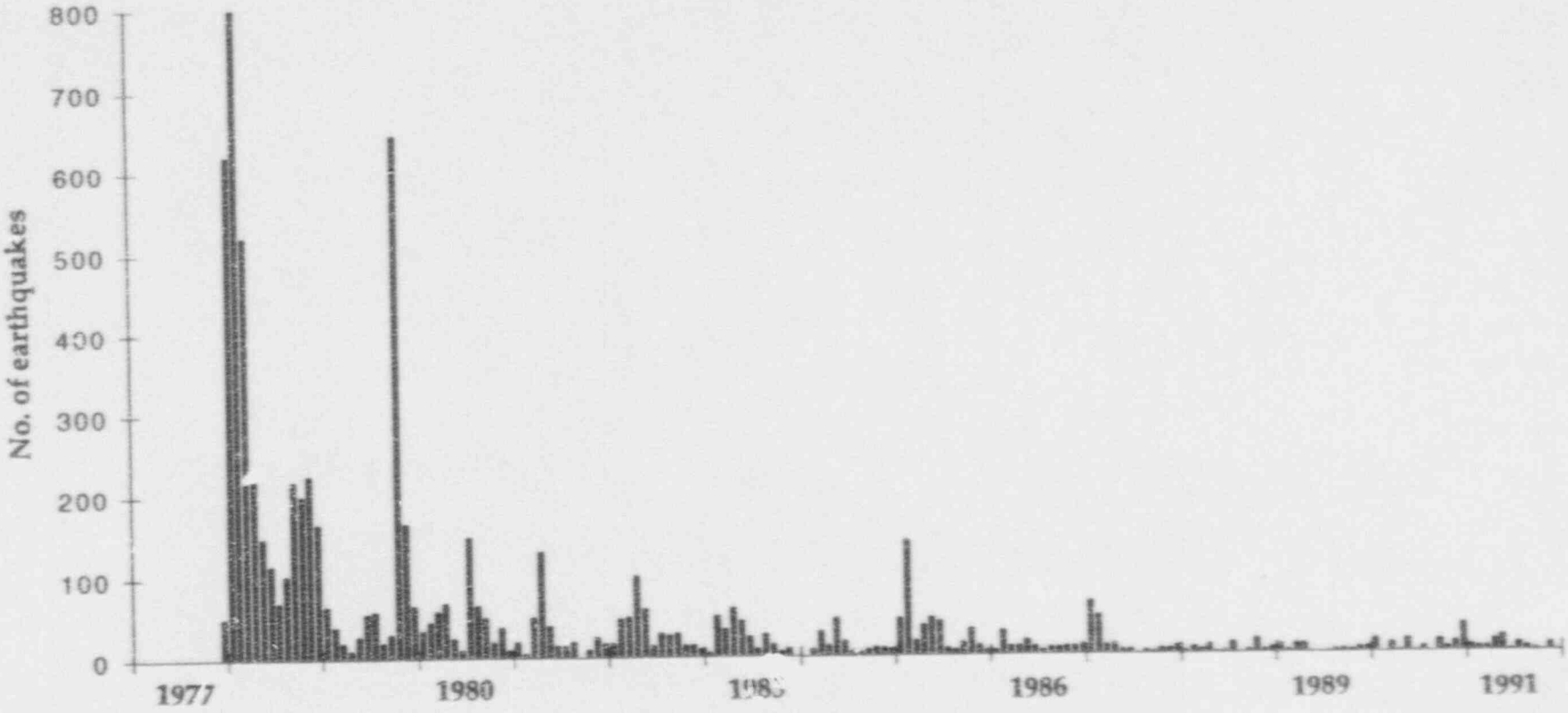

Figure 3. Earthquakes between impoundment and December 1991.

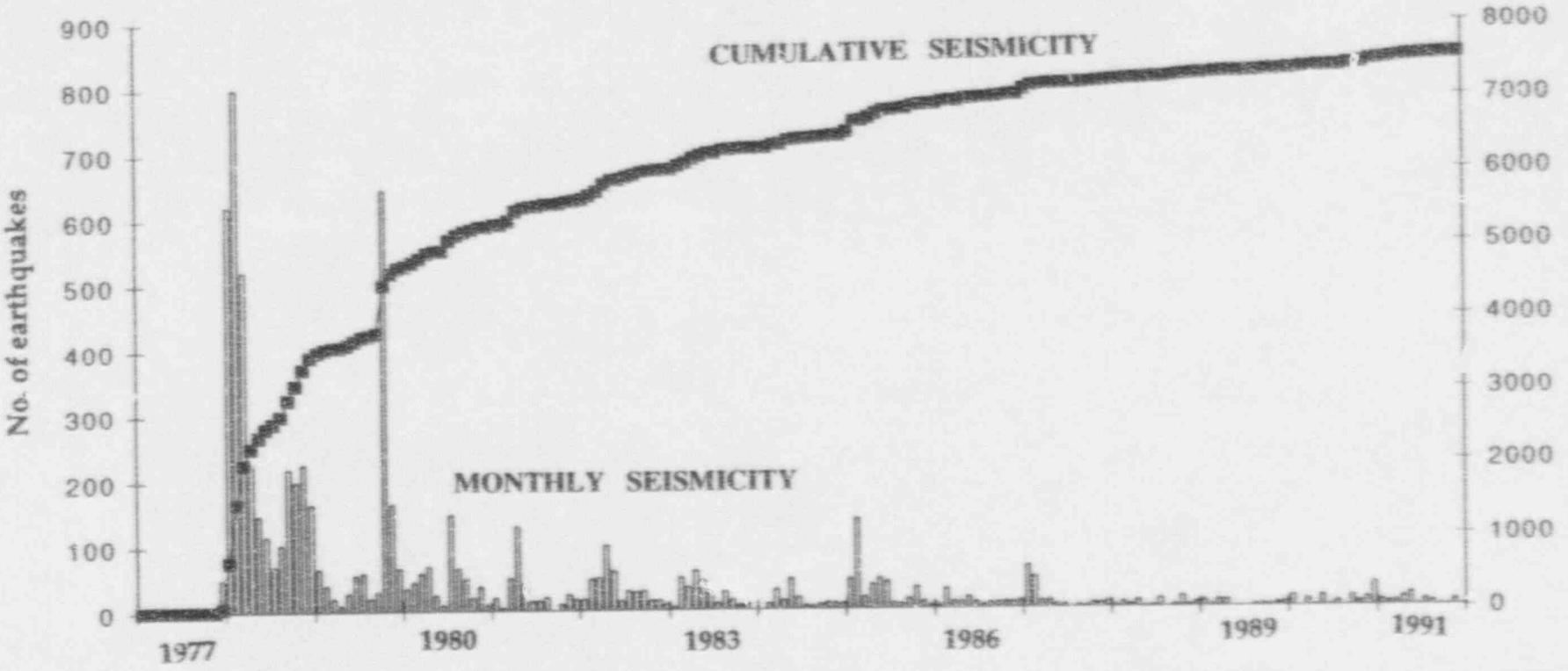

Figure 4. Monthly seismicity (bars) and cumulative seismicity (line) near Monticello Reservoir since impoundment.

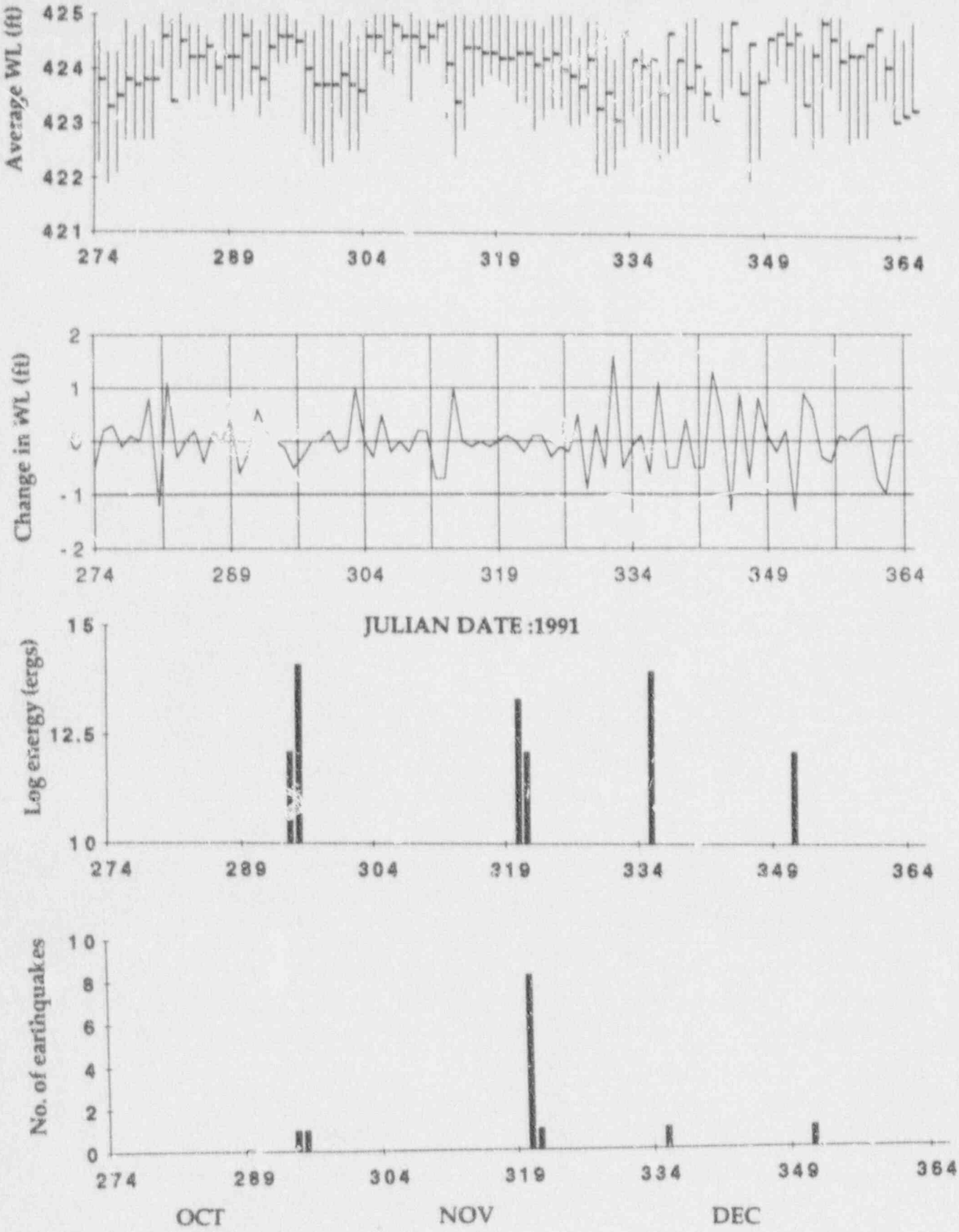

Figure 5. Comparison of daily reservoir level, changes in reservoir level, number of earthquakes and the log of energy release in ergs per day at Monticello Reservoir. Error bars in the top panel indicate daily fluctuations in reservoir level.

water level from day to day. The number of events per day and the log of energy released are shown in the lower histograms. These charts include all reported earthquakes listed in Appendices V and VI. The average water level, daily changes in water level, number of earthquakes and energy release are given in Appendix VII. No systematic correlation was observed between the seismicity and reservoir level fluctuations.

CONCLUSIONS

The level of seismicity during the fourth quarter was lower, compared to the previous quarter. The largest recorded magnitude was M_L=1.5. Most of the seismicity during this quarter occurred in a swarm on November 16, located to the northern part of the reservoir. No systematic correlation was observed between the reservoir level fluctuations and the seismicity.

MONTICELLO NETWORK AND SEISMICITY DURING 1991

Station operational status

The operational status of the Monticello network during the year 1991 is given in Figure 6. Most of the stations have been operational during the second half of the year. Currently, all the stations of the network are working well. The quality of records from MR02 has not been good enough to be used in earthquake locations. Necessary steps are being taken to improve the operation of this station.

Seismicity

A total of 92 events were recorded around Monticello during January - December 1991, of which 54 were located (Figure 7). Seismicity level was highest during the first two quarters (Figure 8; Figure 9A,B).

The only event of M_L=2 in Monticello region during 1991 occurred during the second quarter (April 29, 18 : 41: 07.72). This event was preceded by seven foresnocks and 15 aftershocks during the period April 25- May 03 (Appendix VIII). There were six other smaller events which were not located (Technical report 91-2). The earthquakes during 1991 were scattered around the study region but there seems to be some

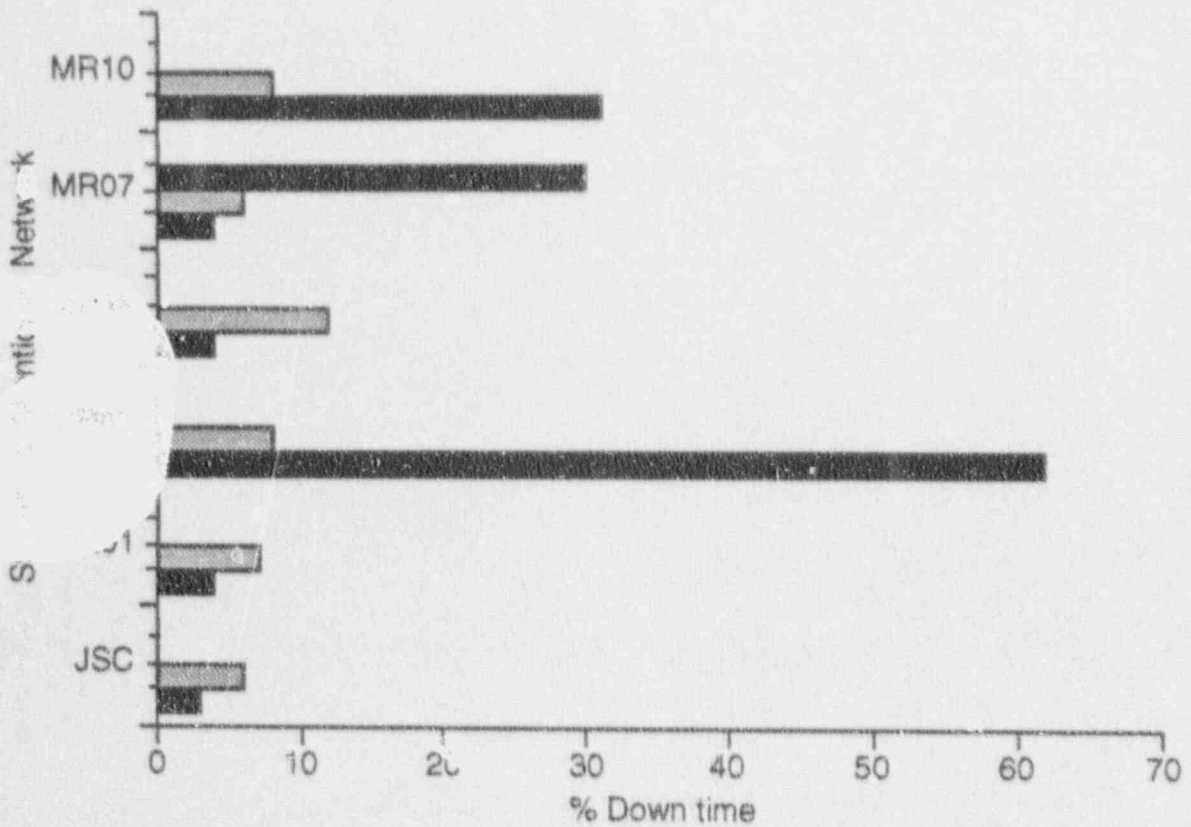

Figure 6. Operational status of Monticello Network during January 1- December 31, 1991. Quarters 1-4 are from bottom to top, for each station.

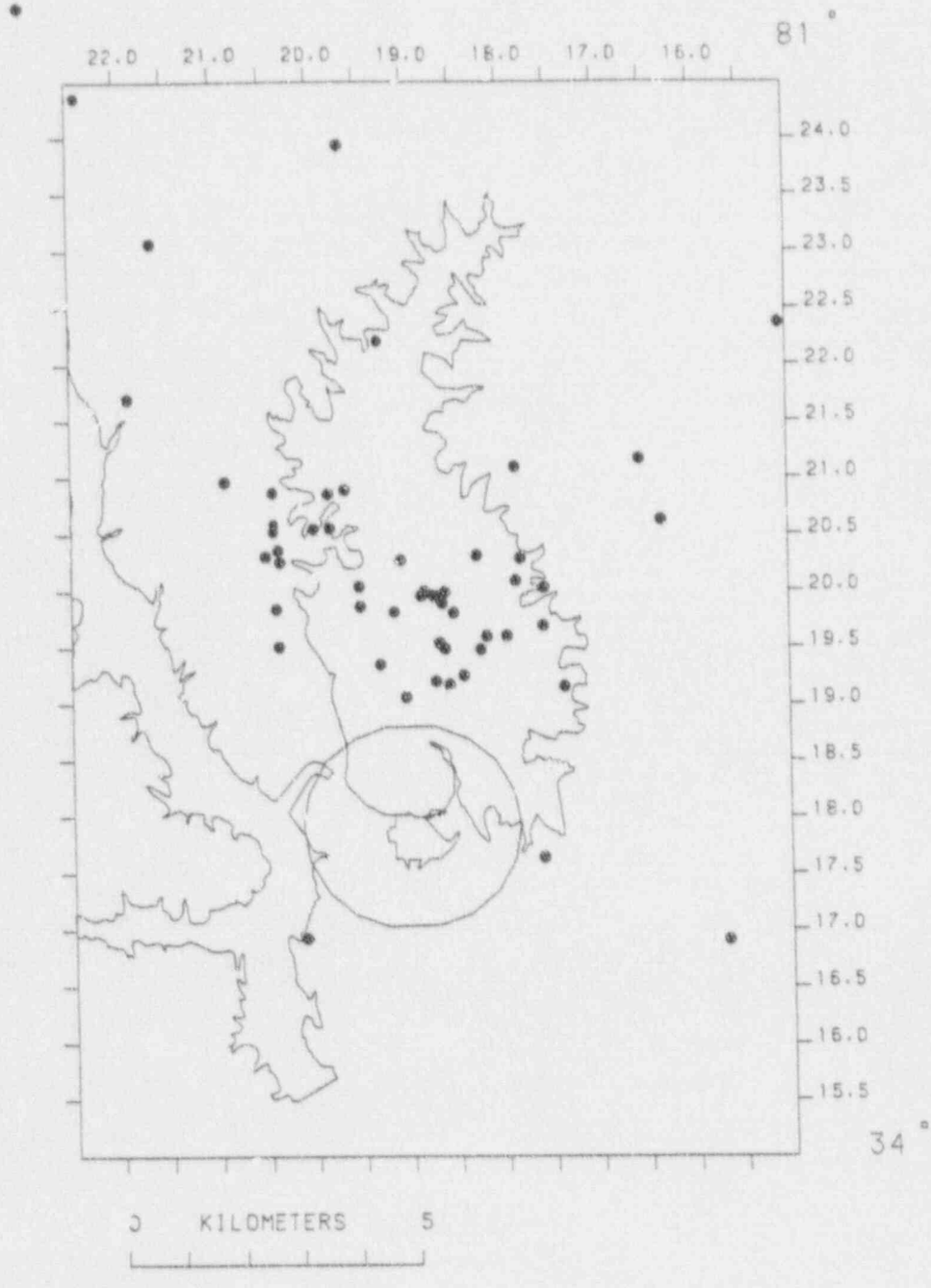

Figure 7. Earthquakes located near Monticello Reservoir during January 1 - December 31, 1991.

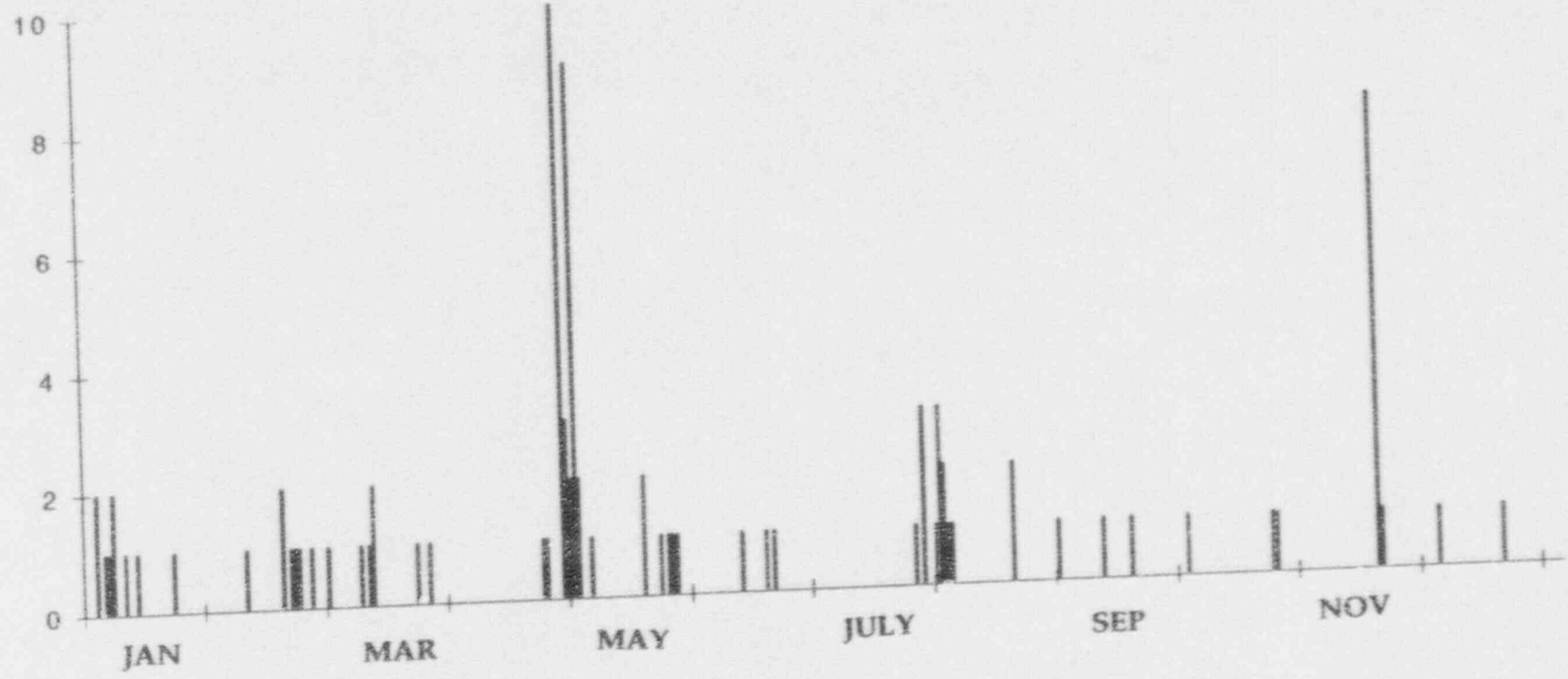

Figure 8. Number of events per day during January - December 1991.

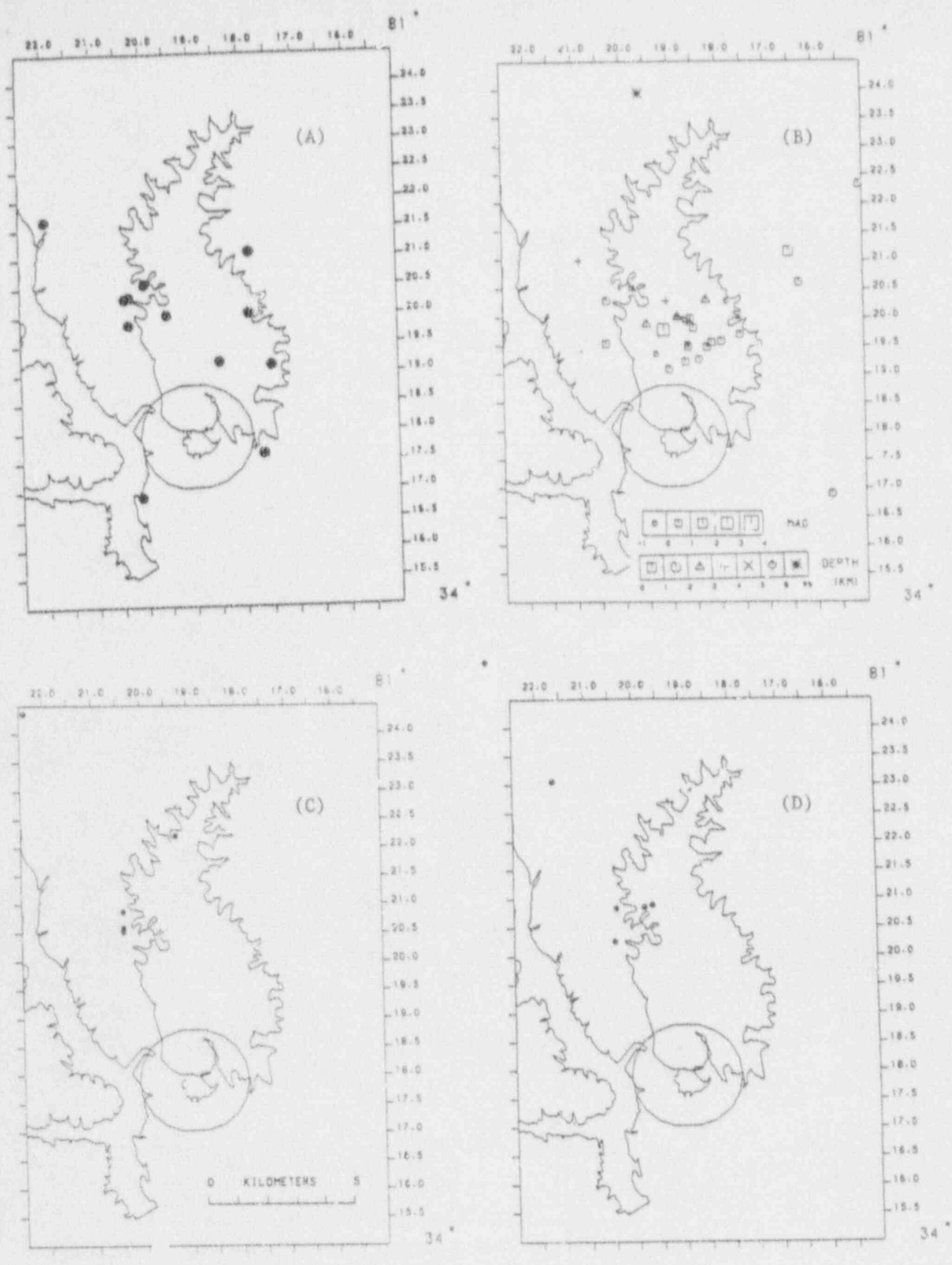

Figure 9. Earthquakes located near Monticello Reservoir during :
(A) January - March; (B) April - June (C) July - September and
(D) October - December 1991. Symbols (solid dots) used during different periods are not indicative of magnitudes or depths except in (B).

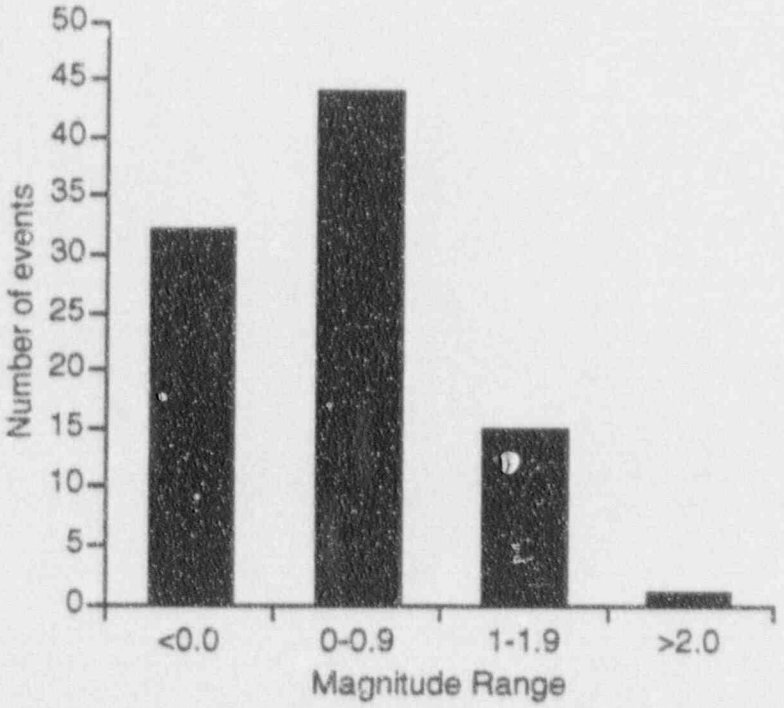

Figure 10. Magnitude range of earthquakes recorded during January - December 1991.

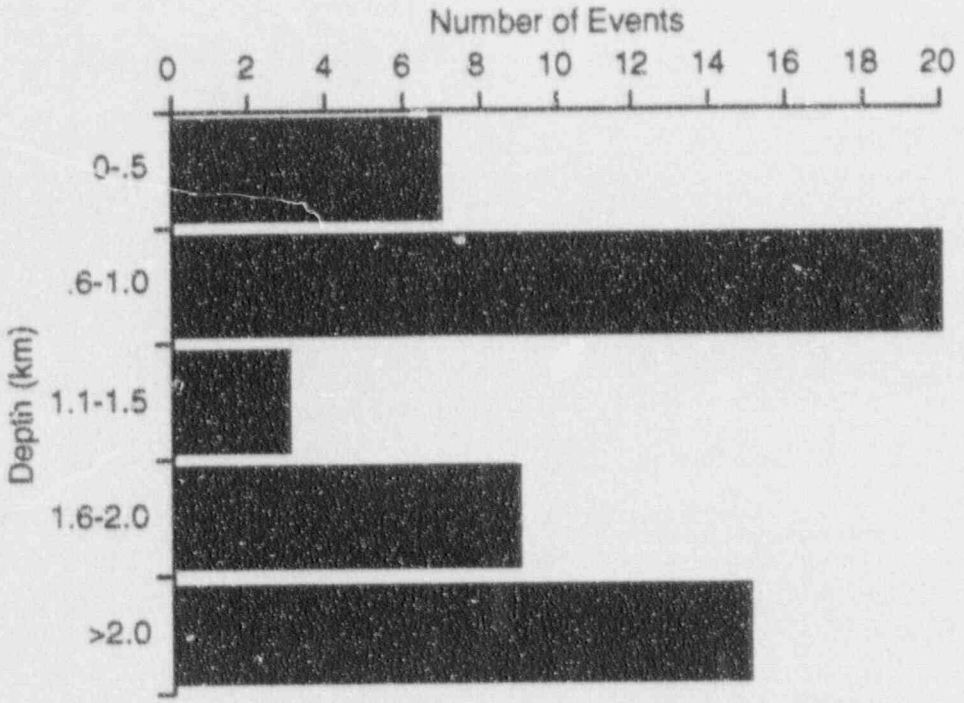

Figure 11. Depth distribution of earthquakes located during 1991.

concentrated activity in the middle of the reservoir (Figure 7). Activity in this zone was particularly dominant during the second quarter (Figure 9B).

The unlocatable events were generally of short duration and not recorded on more than one or two stations. The magnitude range of all the events recorded at Monticello is shown in Figure 10. The larger number of events recorded had a magnitude range between 0-1.0.

The quality of the located events was generally poor (C and D) and their depths are not considered very reliable. Out of the 54 located events, only 9 were of B quality. Maximum activity was observed in the focal depth regions of 0.5 to 1.0 km (Figure 11). This is not different from the previous periods of activity.

In conclusion, the activity during 1991 was not particularly different from the past several years. The long term decline in the seismicity at Monticello is continuing, with occasional short periods of seismic activity. Earthquakes occurred at shallow depths and were generally concentrated in the middle of the reservoir.

REFERENCES

Gutenberg, B. and Richter,C.F. (1956). Magnitude and energy of earthquakes, *Ann. Geof.* 9,1-15.

Lee, W.H.K. and Lahr, J.C. (1972). A computer program for determining hypocenter, magnitude and first motion pattern of local earthquakes, revisions of HYPO71, U.S. *Geological Survey, Open-File Report*, 100 pp.

Technical Report 91-2 (1991) Seismic activity near V.C.Summer Nuclear Station for the period April- June 1991.

APPENDIX I

STATION LOCATIONS

STATION	LAT° N	LONG °W
JSC	34°16.80′	81°15.60′
MR01	34°19.91′	81°17.74′
MR02	34°11.58′	81°13.81′
MR05	34°16.05′	81°20.05′
MR07	34°22.23′	81°19.50′
MR10	34°20.18′	81°20.25′

APPENDIX II

SEISMIC STATION OPERATIONAL STATUS
OCTOBER - DECEMBER 1991

STATION	PERCENT DOWNTIME
JSC	0
MR01	0
MR02	0
MR05	0
MR07	0
MR10	0

APPENDIX III

MONTICELLO RESERVOIR

VELOCITY MODEL

Velocity km/sec	Depth to top km
1.00	0.00
5.40	0.03
5.90	0.18
6.10	0.46
6.30	0.82
8.10	30.00

APPENDIX IV
MONTICELLO EARTHQUAKES
HYPO71 FORMAT

Column	1	Date
Column	2	Origin time (UTC) h.m.sec.
Column	3	Latitude (N) degrees, min.
Column	4	Longitude (W) degrees, min.
Column	5	Depth (km).
Column	6	Local duration magnitude.
Column	7	No. of station readings used to locate event. P and S arrivals from same stations are regarded as 2 readings.
Column	8	Largest azimuthal separation in degrees between stations.
Column	9	Epicentral distance in km to nearest station.
Column	10	Root mean square error of time residuals in sec. RMS = R_i^2/No, where R_i is the time residual for the ith station.
Column	11	Standard error of the epicenter in km*.
Column	12	Standard error of the focal depth in km*.
Column	13	Quality of the epicentral location.

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* Statistical interpretation of standard errors involves assumptions which may not be met in earthquake locations. Therefore standard errors may not represent actual error limits.

Note: If ERH or ERZ is blank, this means that it cannot be computed, because of insufficient data.

APPENDIX V

MONTICELLO EARTHQUAKES

OCTOBER - DECEMBER 1991

DATE	ORIGIN	LAT N	LONG W	DEPTH	MAG	NO	GAP	DMIN	RMS	ERH	ERZ	QM
911022	1748 8.31	34-22.91	81-21.14	1.75	1.54	8	314	3.5	0.07	1.1	1.4	C1
911116	15 2 28.12	34-20.78	81-19.78	1.00	0.40	7	156	1.3	0.08	1.1	2.2	C1
911116	1645 14.22	34-20.28	81-20.35	1.99	0.82	8	203	0.2	0.18	1.6	2.2	C1
911116	2317 36.30	34-20.81	81-19.63	0.61	0.21	8	145	1.3	0.12	1.1	2.5	C1
911117	014 26.20	34-20.77	81-20.35	0.17	0.21	5	209	1.1	0.08	2.5	1.4	D1
911119	1738 46.49	34-25.00	81-22.88	2.80	1.44	8	329	7.3	0.14	3.8	4.2	D1*

* This event is not included in the energy analysis.

APPENDIX VI

LIST OF EVENTS WITH (S-P)≤ 2.5 SEC RECORDED AROUND MONTICELLO RESERVOIR DURING OCTOBER-DECEMBER 1991

DATE	STATION	P-ARR.TIME	S-P(SEC)	EP.DIST (s-p)*8.5	DUR (S)	MAG
91 10 21	MR07	09 06 45.85	1.4	11.9	12	0.4
91 11 16	MR10	15 02 35.55	1.5	12.8	13	0.4
	JSC	15 02 37.00				
91 11 16	MR10	15 02 17.30	*	_	5	-0.4
91 11 16	MR 10	15 02 28.50	*	_	5	-0.4
91 11 16	MR10	15 03 24.15	*	_	4	-0.6
	JSC	15 03 25.65				
91 11 16	MR10	19 09 44.2	*	_	5	-0.4
91 12 01	MR10	21 43 01.0	0.55	4.7	5	-0.4
91 12 17	JSC	06 20 45.45	1.1	9.4	10	0.21

Maximum and minimum water levels, change in water level, number of earthquakes and energy release (ergs per day) at Monticello Reservoir during October 1 - December 31, 1991. Dates are given in Julian Calender.

DATE	WL(Max)	WL(Min)	WL(Avg)	CHANGE	# of Eqs	Log E
274	422.3	424.5	423.8	-0.5	0	0
275	421.9	424.3	423.3	0.2	0	0
276	422.1	424.3	423.5	0.3	0	0
277	422.7	424.9	423.8	-0.1	0	0
278	422.7	424.6	423.7	0.1	0	0
279	422.7	424.8	423.8	0	0	0
280	422.7	424.5	423.8	0.8	0	0
281	424	425	424.6	-1.2	0	0
282	424.1	424.9	423.4	1.1	0	0
283	424	425	424.5	-0.3	0	0
284	423.4	424.8	424.2	0	0	0
285	423.5	424.8	424.2	0.2	0	0
286	423.7	424.6	424.4	-0.4	0	0
287	423.3	424.3	424	0.2	0	0
288	423.5	425	424.2	0	0	0
289	423.2	425	424.2	0.4	0	0
290	423.4	425	424.6	-0.6	0	0
291	423.5	424.9	424	-0.2	0	0
292	423.1	424.7	423.8	0.6	0	0
293	423.4	425	424.4	0.2	0	0
294	424.1	425	424.6	0	1	12.11
295	424.1	425	424.6	-0.1	1	14.11
296	424.2	424.9	424.5	-0.5	0	0
297	422.8	424.7	424	-0.3	0	0
298	422.6	424.7	423.7	0	0	0
299	422.2	425	423.7	0	0	0
300	422.3	424.9	423.7	0.2	0	0
301	423.1	424.5	423.9	-0.2	0	0
302	422.5	424.9	423.7	-0.1	0	0
303	422.5	424.6	423.6	1	0	0
304	423.2	424.9	424.6	0	0	0
305	424.3	425	424.6	-0.3	0	0
306	424	425	424.3	0.5	0	0
307	423.9	425	424.8	-0.2	0	0
308	424.5	424.8	424.6	0	0	0
309	423.4	426	424.6	-0.2	0	0
310	424.1	424.9	424.4	0.2	0	0
311	424.1	424.9	424.6	0.2	0	0
312	424.5	424.9	424.8	-0.7	0	0
313	423.1	424.9	424.1	-0.7	0	0
314	422.4	425	423.4	1	0	0
315	422.9	425	424.4	0	0	0
316	423.5	424.9	424.4	-0.1	0	0
317	423.7	425	424.3	0	0	0
318	423.9	425	424.3	-0.1	0	0
319	423.8	425	424.2	0	0	0
320	423.7	425	424.2	0.1	8	13.33

321	423.4	424.9	424.3	0	1	12.11
322	423.4	424.9	424.3	-0.2	0	0
323	422.9	424.9	424.1	0.1	1	13.96
324	423.1	424.8	424.2	0.1	0	0
325	423.3	425	424.3	-0.3	0	0
326	423.3	425	424	-0.1	0	0
327	423	425	423.9	-0.2	0	0
328	423	424.6	423.7	0.5	0	0
329	423.2	424.9	424.2	-0.9	0	0
330	422.1	424.9	423.3	0.3	0	0
331	422.1	424.7	423.6	-0.5	0	0
332	422.2	424.2	423.1	1.6	0	0
333	422.6	424.3	424.7	-0.5	0	0
334	423.2	424.1	424.2	-0.1	0	0
335	422.7	424.4	424.1	0.1	1	13.96
336	422.7	423.9	424.2	-0.6	0	0
337	422.4	424	423.6	1.1	0	0
338	422.5	423.4	424.7	-0.5	0	0
339	422.6	424.2	424.2	-0.5	0	0
340	422.8	424.9	423.7	0.4	0	0
341	423.6	425	424.1	-0.5	0	0
342	423.1	423.9	423.6	-0.5	0	0
343	423.1	423.4	423.1	1.3	0	0
344	423.5	424.9	424.4	0.5	0	0
345	423.7	424.5	424.9	-1.3	0	0
346	423.7	424	423.6	0.9	0	0
347	422	424	424.5	-0.7	0	0
348	422.4	424	423.8	0.8	0	0
349	423.8	424.2	424.6	0.1	0	0
350	424.1	424.3	424.7	-0.2	0	0
351	423.8	425	424.5	0.2	1	12.11
352	422.8	424.9	424.7	-1.3	0	0
353	423.5	424.5	423.4	0.9	0	0
354	422.6	424.5	424.3	0.6	0	0
355	422.8	425	424.9	-0.3	0	0
356	423.7	425	424.6	-0.4	0	0
357	423.3	425	424.2	0.1	0	0
358	422.7	424.6	424.3	0	0	0
359	422.8	423.5	424.3	0.2	0	0
360	422.8	423.2	424.5	0.3	0	0
361	423.5	424	424.8	-0.7	0	0
362	423.5	424.3	424.1	-1	0	0
363	423.1	424.8	423.1	0.1	0	0
364	423.2	424.6	423.2	0.1	0	0
365	423.3	424.9	423.3		0	0

APPENDIX VIII

MONTICELLO EARTHQUAKES: JANUARY-DECEMBER, 1991

DATE	ORIGIN	LAT N	LONG W	DEPTH	MAG	NO	GAP	DMIN	RMS	ERH	ERZ	QM
910104	2115 7.80	34-16.83	81-20.14	0.15	0.99	4	192	1.4	0.07			C1
910106	2132 37.41	34-20.01	81-17.84	2.78	-0.40	6	173	0.2	0.08	1.2	1.3	C1
910107	2053 27.74	34-19.16	81-18.43	0.95	1.02	10	101	1.7	0.09	0.4	2.4	B1
910108	326 9.76	34-19.13	81-17.48	0.10	0.01	4	186	5.2	0.08			C1
910219	10 0 29.17	34-19.94	81-19.54	1.15	0.73	9	106	1.2	0.07	0.4	0.9	B1
910219	10 2 45.46	34-20.28	81-20.35	2.60	0.82	9	203	0.2	0.09	0.6	1.0	C1
910223	315 4.79	34 21.03	81-17.84	1.00	-0.11	3	225	2.1	0.08			C1
910226	1735 31.97	34-21.59	81-21.98	1.68	1.15	8	269	3.7	0.08	0.9	2.1	C1
910312	1121 5.19	34-19.73	81-20.35	1.75	0.78	9	194	0.9	0.08	0.4	1.0	C1
910313	9 3 13.01	34-20.28	81-20.35	1.00	0.95	8	203	0.2	0.08	0.5	0.8	C1
910313	2259 34.17	34-17.58	81-17.55	0.87	1.02	5	203	3.3	0.03	0.7		D1
910327	1646 32.66	34-20.46	81-19.97	2.78	0.21	10	153	0.7	0.09	0.6	0.6	B1
910425	1416 41.31	34-19.53	81-20.37	0.23	0.21	5	244	1.2	0.06	0.1	0.1	C1
910429	1113 54.77	34-21.15	81-16.53	0.69	1.72	4	233	5.0	0.21			C1
910429	1251 50.15	34-19.70	81-17.57	1.93	0.82	7	183	4.2	0.07	0.5	2.2	C1
910429	14 3 31.91	34-19.58	81-17.95	0.23	0.44	8	171	3.7	0.10	0.7	2.7	C1
910429	1423 42.66	34-16.90	81-15.70	1.00	0.21	5	172	0.2	0.16	0.8	0.7	C1
910429	16 3 13.10	34-19.22	81-18.70	0.55	0.82	6	154	3.0	0.09	1.2	6.2	C1
910429	1614 51.45	34-19.26	81-18.42	1.11	0.57	9	153	3.3	0.12	0.8	5.0	C1
910429	1841 7.72	34-19.78	81-19.16	0.96	2.00	5	142	1.8	0.05	1.2	4.5	C1
910429	2012 19.31	34-19.49	81-18.64	0.81	0.82	7	151	2.8	0.10	1.1	2.1	C1
910429	2025 56.74	34-23.96	81-19.60	6.84	1.02	5	327	3.2	0.16			D1
910430	332 0.77	34-19.48	81-18.25	0.85	0.21	6	161	3.3	0.10	2.0		C1
910501	4 4 6.91	34-20.00	81-17.58	2.88	-0.24	6	188	4.1	0.10	1.7	2.7	C1
910501	13 5 55.63	34-19.53	81-18.66	0.63	-0.40	6	152	2.7	0.14	3.8		C1
910502	1035 18.94	34-19.88	81-19.51	2.94	1.18	10	110	1.3	0.10	0.6	0.7	B1
910502	1040 31.25	34-19.82	81-18.53	0.92	0.12	8	160	2.7	0.09	0.6	4.6	C1
910502	1222 55.71	34-20.01	81-18.86	2.60	1.02	12	110	1.7	0.09	0.5	0.6	B1
910502	1321 58.12	34-19.96	81-18.70	0.73	-0.60	7	157	2.4	0.12	1.5	3.2	C1
910502	1750 58.13	34-19.98	81-18.59	0.02	0.82	4	161	2.6	0.03			C1
910502	2339 52.38	34-20.31	81-18.26	2.84	1.54	11	161	1.1	0.19	1.3	1.7	C1
910502	2351 19.12	34-20.28	81-19.09	3.80	0.21	12	118	1.8	0.13	0.8	0.8	B1
910502	2351 35.81	34-20.28	81-17.84	1.00	-0.40	8	187	0.7	0.13	1.0	1.3	C1
910503	0 3 5.87	34-20.01	81-18.84	3.27	0.82	11	110	1.7	0.10	0.6	0.7	B1
910503	110 38.96	34-19.92	81-18.60	2.22	0.82	12	108	1.3	0.08	0.4	0.6	B1
910519	5 8 2.82	34-19.56	81-18.15	0.87	0.12	6	165	3.4	0.07	0.6	9.0	C1
910519	511 8.19	34-19.08	81-19.05	1.93	0.21	7	168	2.7	0.07	0.9	1.4	B1
910523	1546 16.35	34-22.33	81-15.07	1.85	0.68	5	266	6.8	0.11	4.7		D1
910526	23 3 46.60	34-20.50	81-19.81	0.28	-0.24	6	139	0.9	0.05	1.0	2.5	C1
910527	419 28.32	34-20.28	81-20.35	1.00	0.82	12	203	0.2	0.16	1.0	0.8	C1
910612	2332 26.38	34-19.35	81-19.32	1.52	-0.11	5	188	2.1	0.12	4.2	4.4	D1
910618	17 6 12.33	34-20.61	81-16.33	1.83	0.01	6	229	2.5	0.13	3.0	3.7	D1
910620	1919 23.83	34-20.99	81-20.90	3.35	0.37	9	231	1.8	0.11	1.0	0.8	C1
910727	2 3 10.49	34-20.83	81-20.35	3.18	0.82	8	214	1.2	0.09	0.9	0.8	C1
910727	751 47.88	34-20.64	81-20.35	1.75	1.02	8	214	0.9	0.16	1.6	1.4	C1
910727	752 43.49	34-20.62	81-20.35	1.00	0.73	5	214	0.8	0.12	2.3	3.2	C1
910801	20 0 9.89	34-24.36	81-22.44	2.10	1.54	5	337	8.4	0.04	2.2	4.6	C1
910909	1921 28.56	34-22.26	81-19.42	0.85	1.54	7	311	4.0	0.13	1.7		D1
911022	1748 8.31	34-22.91	81-21.64	1.75	1.54	8	314	3.5	0.07	1.1	1.4	C1
911116	25 2 28.12	34-20.78	81-19.78	1.00	-0.40	7	156	1.3	0.08	1.1	2.2	C1
911116	1645 14.22	34-20.28	81-20.35	1.99	0.82	8	203	0.2	0.18	1.6	1.2	C1
911116	2317 36.30	34-20.81	81-19.63	0.61	0.21	8	145	1.5	0.12	1.1	2.5	C1
911117	014 26.20	34-20.77	81-20.35	0.17	0.21	5	209	1.1	0.08	2.5	1.4	D1
911119	1738 46.49	34-25.00	81-22.88	2.80	1.44	8	329	7.3	0.14	3.8	4.2	D1