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AN EVALUATION OF THE SEISMICITY OF THE NEVADA TEST SITE
AND VICINITY

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Abstract

Two USGS catalogs of earthquakes in the Southern Great Basin were edited to remove man-made seisms. Editing reduced 11,988 entries to 8,161. Known location of underground nuclear explosions provided an opportunity to assess location accuracy showing that accuracy differed according to the source of earthquake data. No evidence was found of explosions triggering earthquakes distant from the working points. Relationships are developed between earthquake magnitude and explosion yield for explosions at Pahute Mesa and Yucca Flat. Comparison of the number of underground nuclear explosions with the number of earthquakes of comparable magnitude shows the former exceeds the latter where magnitude is greater than four. Edited catalogs are recommended for hazard analysis relative to repository siting because unedited catalogs tend to greatly exaggerate seismicity of the region.

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PREFACE

The Yucca Mountain Site Characterization Project (YMP), managed by the Office of Geologic Disposal of the Office of Civilian Radioactive Waste Management of the U. S. Department of Energy, is examining the feasibility of siting a potential repository for commercial high-level nuclear wastes at Yucca Mountain on and adjacent to the Nevada Test Site. This work, intended to extend our understanding of the ground motion at Yucca Mountain from both earthquakes and the testing of nuclear weapons on the NTS, was funded jointly by the YMP and the Military Applications Weapons Test Program.

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INTRODUCTION

Nevada has a history of significant earthquakes, and as a consequence, its historic earthquake catalogue has received considerable attention (Townley and Allen, 1939; Slemmons et al, 1965; Wood et al, 1966; Ryall et al, 1966; and Gumper and Scholz, 1971). With the advent of underground nuclear testing, the area on and around the Nevada Test Site (NTS) has been subjected to even greater scrutiny (Hamilton et al, 1969; King et al, 1971; Hamilton et al, 1971; Fischer et al, 1972; Rogers et al, 1976; Rogers et al, 1977a; and Rogers et al, 1977b). At the beginning of the Yucca Mountain Site Characterization Project (YMP), an extensive net (the Southern Nevada Seismograph Network - SNSN) was installed on and around the NTS (Rogers et al, 1981; Rogers et al, 1983).

These and other sources have been used by the U.S. Geological Survey (USGS) to compile two catalogs of earthquakes in the NTS vicinity. In August 1986, USGS provided a draft of an open file report (Meremonte and Rogers, 1987) on the Southern Great Basin Historical Catalog (SGBHC) to Sandia National Laboratories. In January 1987, USGS also provided a tape of the SGBHC earthquakes and those from the more recent SNSN measurements. This report is the result of examining both catalogs.

Meremonte and Rogers were careful to acknowledge that many items in the SGBHC were man-made seisms rather than natural earthquakes. These included underground nuclear explosions, their collapses and aftershocks, chemical explosive detonations, mine blasts, and seisms resulting from the filling and subsequent level changes of Lake Mead. In order that these catalogs could be complete, USGS chose to retain the man-made events but to flag them where they could be identified. To retain the man-made events in using the catalogs for estimating seismic hazard with respect to Yucca Mountain results in an exaggeration of the hazard. While man-made events cause ground motion as do earthquakes, there are significant differences. UNEs are totally predictable in time and location, and quite predictable in energy release. HE tests, mine blasts have similar predictability and are small energy releases. Lake Mead events more nearly resemble natural earthquakes, but because they result from reservoir filling, they represent an unnatural perturbation on natural regional seismicity.

In this report, we have identified and deleted man-made events, examined the accuracy of hypocenter location, and considered the matter of triggering earthquakes with underground nuclear explosions. A tape of the edited version of the catalogs is available for further hazard analysis.

Not all underground nuclear explosions are announced to the public. Thus, the date, time, and names of unannounced events are classified. To avoid publication of classified information, dates and times of unannounced events have been omitted.

THE DATA BASE

The 28 source codes used in the SGBHC of Meremonte and Rogers have been retained and are reproduced in Appendix A. Some of the older sources gave locations only to the nearest degree of latitude and longitude. ALX, ISC, and KKG ordinarily have readings to the nearest 0.01 degree, and the balance to the nearest 0.001 degree. A difference of 0.001 degree resolves into a difference of about 110 m in latitude and 90 m in longitude. A later section of this report treats the accuracy actually achieved by some of the sources. The various sources differed in a number of ways in the amount of data provided and the detail in which it was presented.

Most, but not all, of the earthquakes in the RYC are listed in Slemmons et al (1965). The latter source lists many more earthquakes not shown in RYC, presumably because of more distant geographic locations. Earthquakes from HSF came from Hamilton et al (1969 and 1971), and those from ROW from Rogers et al (1977b). As would be expected from the titles, most of the events are aftershocks following underground nuclear explosions (UNEs).

Those events listed under KKG are not just from King et al (1971), but rather Bayer et al (May 1972), Bayer (July 1972), Bayer (September 1972), Bayer and King (October 1972), Bayer and King (November 1972), Bayer (December 1972), Bayer (January 1973), Bayer (February 1973), and Bayer (May 1973).

Man-Made Events

Five types of non-earthquake events were found in the catalogs: seisms induced by impoundment of Lake Mead, mine blasting and chemical explosions, UNEs, cavity collapses, and aftershocks following underground nuclear explosions. The numbers of these events deleted are listed by source in Table 1.

Lake Mead Earthquakes--When Lake Mead reservoir began filling in 1936, an increase in seismic activity was observed. Over a span of about 40 years, several efforts to measure the seismicity of the vicinity were made, including one during 1972 and 1973 (Rogers and Lee, 1976). It is to be expected that some of these earthquakes would find their way into the SGBHC. It is the position taken here that reservoir-induced earthquakes are not indicative of regional seismicity as it relates to a proposed repository at Yucca Mountain (unless, of course, a comparable reservoir is contemplated near Yucca Mountain.) Lake Mead events had M5 or less and were 160 km or more from Yucca Mountain, hence they do not add to the hazard there.

Accordingly, earthquakes which fell within 0.2 degree of the lake perimeter, according to the criterion used by Meremonte and Rogers (1987), were deleted. These numbered 428 and were distributed among the sources as shown in Table 1.

Table 1. Summary of Events Deleted

<u>Source</u>	<u>Total</u>	<u>Lake Mead</u>	<u>Blasts & HE Explosions</u>	<u>UNEs, Collapses, Aftershocks</u>	<u>Collapse*</u>	<u>Net</u>
ALX	66	6		2	2	56
BRK	168			2	1	165
BRP	395	294	1	17	1	82
CVH	1	1				0
ERS	3	2				1
FPH	18					18
GDY	226	11	2	59	4	150
HSF	2288			2159		129
ISC	83			19	12	52
KKG	1340	19	7	111		1203
PAS	1049	24		16	2	1007
PDX	66	1	1	31	13	20
PHM	33					33
ROW	519			498		21
RYC	107	47		1		59
RYN	241**			17	2	222**
SHJ	9					9
USE	1	1				0
Total SGBHC	6613	406	11	2932	37	3227
SNSN	5375 ⁺	22	26	392	1	4934 ⁺
<u>Grand Total</u>	<u>11988</u>	<u>428</u>	<u>37</u>	<u>3324</u>	<u>38</u>	<u>8161</u>

* Located outside aftershock criteria

** Includes one outside map boundaries

⁺ Includes two duplicates

High-Explosive (HE) Test Explosions--Fourteen high explosive tests were found in the catalogs. They were:

640206	16 17 49.54	Pre-Schooner A [Spruill and Paul (1965)]
640225	18 40 25.41	Pre-Schooner C [Spruill and Paul (1965)]
640227	18 17 54.60	Pre-Schooner D [Spruill and Paul (1965)]
710429	19 00 00.00	Mine Throw I [Carnes and Conway (1973)]
720510	12 00 00.00	Pre Mine Dust
720522	23 27 00.00	Post Mine Throw #1
720523	22 15 00.00	Post Mine Throw #2
720524	21 20 00.00	Post Mine Throw #3
720525	20 30 00.00	Post Mine Throw #4
720526	19 15 00.00	Post Mine Throw #5
800911	14 59 59.80	Nuclear Hardness & Survivability DH-1 [Swartz et al (June 1981)]
810213	18 00 00.70	Nuclear Hardness & Survivability D-1 [Noble et al (November 1981)]
810618	17 00 00.34	Nuclear Hardness & Survivability SH-1 [Noble et al (January 1982)]
820429	04 00 00.54	USGS Seismic Refraction [Hoffman and Mooney (1984)]

There were other man-made explosions associated with mining at Bare Mountain and construction and operation of an Air Force shock tube at Little Skull Mountain. These are difficult to identify positively because times of the explosions were not recorded. Some of these will be discussed in a later section.

Underground Nuclear Explosions--There were 85 nuclear explosions included in the catalogs that were identified by the same or nearly the same times as the recorded time of the explosions. Times for announced shots are in Table 2; unannounced shots are not identified. The difference in time between the UNE and the related catalog entry is given in the table.

Collapses and Aftershocks--As a routine part of the weapons test effort, cavity collapses are monitored by a geophone net or video camera focuses on surface ground zero (or both). Events concurrent (or nearly so) with the shot time plus the collapse time were identified as collapses and were deleted. Collapses have been observed as much as 2604 days after an event.

The rationale for deleting explosions and collapses is that they are man-made. That for deleting aftershocks may not be quite as obvious inasmuch as aftershocks could be considered small earthquakes occurring on pre-existing faults. The essence of whether they are man-made or natural is whether or not slippage would have occurred in the absence of the explosion. An hypothesis presented here is that tectonic stress is relieved by and concurrently with arrival of the UNE shock wave, and that UNE aftershocks are readjustments to the new stress field created by the UNE.

Table 2. Location Accuracy (UNE and HE data)

Index	Source	Event	Date hr:min	True Event Time hr:min	Time Diff	Lat.	Long.	Eqiv. RS Coordinates	Actual Hole Coordinates	Dist. View from No. about 20	Depth USCS ft.	Remarks	Time Probability	Spec Probability
1	ALX	Unannounced			-00:00:20	37.100	116.300	891985 606790	- 858092 592410	2.911	126.61		4.32+05	1.89+03
2	ALX	Unannounced			+00:02:00					10.807	45.15		4.32+04	2.83+02
3	REK	Unannounced			-00:00:20					4.562	116.38	(a)	4.44+05	5.29+02
4	REK	Unannounced			00:00:00					3.141	37.37	(a)	8.64+06	1.35+03
5	REK	Unannounced			+00:00:30					3.996	114.07	(a)	5.17+02	3.07+01
6	REK	Unannounced			-00:00:40					10.377	167.65	(a)	2.16+05	7.2+03
7	REK	Unannounced			+00:00:10					2.135	101.13	(a)	8.64+05	5.23+03
8	REK	Unannounced			-00:00:10					2.512	211.40	(a)	2.16+05	1.82+03
9	REK	Unannounced			+00:00:20					3.013	116.12	(a)	2.16+05	2.13+02
10	REK	Unannounced			-00:00:20					12.450	172.36	(a)	2.16+05	2.13+02
11	REK	Unannounced			00:00:00					3.465	193.54	(a)	8.64+06	1.37+03
12	REK	Unannounced			+00:00:10					1.684	255.84	(a)	8.64+06	1.37+03
13	REK	Unannounced			-00:00:10					1.810	213.83	(a)	8.64+06	1.37+03
14	REK	Unannounced			+00:01:00					19.695	290.76	(a)	8.64+06	1.37+03
15	REK	Unannounced			00:00:00					1.687	34.34	(a)	8.64+06	1.37+03
16	REK	Unannounced			-00:01:20					1.887	198.38	(a)	8.64+06	1.37+03
17	REK	Unannounced			+00:05:40					11.827	182.92	(a)	8.64+06	1.37+03
18	REK	Unannounced			-00:02:40					6.735	199.85	(a)	8.64+06	1.37+03
19	REK	Unannounced			+00:01:48					6.715	148.19	(a)	8.64+06	1.37+03
20	REK	Unannounced			-00:01:48					4.212	215.07	(a)	8.64+06	1.37+03
21	REK	Unannounced			+00:00:82					3.232	12.56	(a)	8.64+06	1.37+03
22	REK	Unannounced			-00:01:21					6.385	146.45	(a)	8.64+06	1.37+03
23	REK	Unannounced			+00:01:41					2.531	299.12	(a)	8.64+06	1.37+03
24	REK	Unannounced			-00:01:56					7.753	197.54	(a)	8.64+06	1.37+03
25	REK	Unannounced			+00:01:18					7.913	78.64	(a)	8.64+06	1.37+03
26	REK	Unannounced			-00:02:06					6.624	174.94	(a)	8.64+06	1.37+03
27	REK	Unannounced			+00:00:87					3.195	160.14	(a)	8.64+06	1.37+03
28	REK	Unannounced			-00:01:38					43.551	249.76	(a)	8.64+06	1.37+03
29	REK	Unannounced			+00:00:51					3.428	139.36	(a)	8.64+06	1.37+03
30	REK	Unannounced			-00:00:09					21.342	216.65	(a)	8.64+06	1.37+03
31	REK	Unannounced			+00:01:09					4.566	196.61	(a)	8.64+06	1.37+03
32	REK	Unannounced			-00:01:72					4.644	220.97	(a)	8.64+06	1.37+03
33	REK	Unannounced			+00:01:66					5.973	91.90	(a)	8.64+06	1.37+03
34	REK	Unannounced			-00:01:46					1.817	140.17	(a)	8.64+06	1.37+03
35	REK	Unannounced			+00:02:03					7.677	152.34	(a)	8.64+06	1.37+03
36	REK	Unannounced			-00:01:64					6.598	182.82	(a)	8.64+06	1.37+03
37	REK	Unannounced			+00:01:36					5.325	148.18	(a)	8.64+06	1.37+03
38	REK	Unannounced			-00:01:34					4.663	240.19	(a)	8.64+06	1.37+03
39	REK	Unannounced			+00:01:70					6.916	283.58	(a)	8.64+06	1.37+03
40	REK	Unannounced			-00:01:58					1.427	337.56	(a)	8.64+06	1.37+03
41	REK	Unannounced			+00:01:50					8.183	243.70	(a)	8.64+06	1.37+03
42	REK	Unannounced			-00:01:40					3.534	123.90	(a)	8.64+06	1.37+03
43	REK	Unannounced			+00:02:46					10.448	124.54	(a)	8.64+06	1.37+03
44	REK	Unannounced			-00:01:49					24.732	23.49	(a)	8.64+06	1.37+03
45	REK	Unannounced			+00:01:55					19.323	214.59	(a)	8.64+06	1.37+03
46	REK	Unannounced			-00:01:70					17.207	214.37	(a)	8.64+06	1.37+03
47	REK	Unannounced			+00:02:30					1.26	288	(a)	8.64+06	1.37+03
48	REK	Unannounced			-00:00:20					24.317	77.47	(a)	8.64+06	1.37+03
49	REK	Unannounced			+00:01:40					7.119	165.11	(a)	8.64+06	1.37+03
50	REK	Unannounced			-00:00:00					0.968	96.44	(a)	8.64+06	1.37+03
51	REK	Unannounced			+00:00:00					623156 597912		(a)	8.64+06	1.37+03
52	REK	Unannounced			-00:00:00					623156 635871		(a)	8.64+06	1.37+03
53	REK	Unannounced			+00:00:00					863230 597940		(a)	8.64+06	1.37+03
54	REK	Unannounced			-00:00:00					863230 597940		(a)	8.64+06	1.37+03
55	REK	Unannounced			+00:00:00					863230 597940		(a)	8.64+06	1.37+03
56	REK	Unannounced			-00:00:00					863230 597940		(a)	8.64+06	1.37+03
57	REK	Unannounced			+00:00:00					863230 597940		(a)	8.64+06	1.37+03
58	REK	Unannounced			-00:00:00					863230 597940		(a)	8.64+06	1.37+03
59	REK	Unannounced			+00:00:00					863230 597940		(a)	8.64+06	1.37+03
60	REK	Unannounced			-00:00:00					863230 597940		(a)	8.64+06	1.37+03
61	REK	Unannounced			+00:00:00					863230 597940		(a)	8.64+06	1.37+03
62	REK	Unannounced			-00:00:00					863230 597940		(a)	8.64+06	1.37+03
 

Table 2. Location Accuracy (UNE and HE data - continued)

Remarks:

- (a) Reported by National Earthquake Information Service (NEIS)
- (b) NEIS gave location only to 0.1 degree
- (c) Event time not precise
- (d) Exact location not surveyed
- (e) NEIS quoted event location
- (f) NEIS location not used or substantially rounded
- (g) Depth with respect to mean sea level
- (h) Hoffman & Mooney, 1984

Thus, aftershocks are a result of the explosion rather than being triggered by it. The explosion alters the existing stress field, and adjustments are required to bring the field back into equilibrium. The 1.15 megaton test Benham (Hamilton, 1969) produced aftershocks until the Purse event 140 days later. (Using the criteria described below, aftershocks occurring more than four years later in precisely the locations Hamilton observed Benham aftershocks provides strong evidence that they are attributable to Benham.)

No aftershocks were observed below depths of 6 km. Aftershocks tended to delineate north-south faults, and migrated away from the area of the explosion with time following the event. This is consistent with strain release starting near the explosion and successively releasing with increasing distance. Hamilton (1971) noted that 95 percent of the Benham aftershocks were within 14 km from ground zero.

Stress produced by seismic waves is small compared with the lithostatic stress. At about 23 km from a 700-kt explosion, the P wave generates a peak stress of about 3.7 bars. A 700-kt explosion at 23 km has been judged the largest yield closest to Yucca Mountain if the Buckboard area becomes a future location for UNEs. This compares with a 71-bar vertical and 24-bar horizontal lithostatic stress at a depth of 564 m (Vortman, 1983).

Most earthquakes are at a considerably greater depth; thus, stress added by the UNE seismic waves are a small percentage indeed of the lithostatic stress. This substantiates Hamilton's observation and suggests that epicenters located more than 14 km from the explosion could be judged to be unassociated with it.

An explosion may be accompanied by tectonic release triggered by the shock wave passing through a fault under stress. The tectonic release may be determined from the effect it has on the signature of long-period P-waves (Wallace et al, 1983).

"The tectonic release time function has a short duration (less than 1 sec). A comparison of these results with well-studied strike-slip earthquakes on the west coast and eastern Nevada indicate that, if tectonic release is triggered fault motion, then the tectonic release is relatively high stress drop, on the order of several hundred bars. It is possible to reduce these stress drops by a factor of 2 if the tectonic release is a driven fault; i.e., rupturing with the P velocity. The region in which the stress is released for a megaton event has a radius of about 4 km. Pahute Mesa events which are detonated within this radius of a previous explosion have a substantially reduced tectonic release."

Thus, the energy from the tectonic release, sometimes combines with the energy of the explosion to produce the wavetrain observed at stations beyond a few kilometers. The above interpretation of aftershocks is in agreement with that of Ryall and Savage, 1969, who said "... we suggest that the stresses due to the (Boxcar) explosion may have been more significant than regional tectonic stresses in the generation of this aftershock sequence." The triggering of an earthquake at distances greater than about 10 km would be

separated in time from the explosion signal and is viewed as a relatively rare event. Possible triggering is discussed in a later section of this report.

The criteria for defining and eliminating aftershocks used here differ from those of Meremonte and Rogers (1987). Hamilton observed Benham aftershocks to 14 km. If aftershocks are a return to equilibrium from stress changes caused by the shock wave, the distance to a critical stress should scale as the cube root of yield. Since the Benham yield was 1.15 Mt, the scaled distance to the critical stress would be $d = 1.336 \text{ km/kt}^{1/3}$.

The procedure for defining aftershocks was as follows:

- a. The yield of the most recent UNE was used to determine a distance d.
- b. A circle about ground zero with a radius d was determined.
- c. All catalog listings subsequent to the time of the shot were scanned. If any had a location within the circle it was ascribed to that UNE and deleted from the catalog.

Attention was turned to the next earlier UNE and the procedure repeated until the earliest UNE was reached. This resulted in the determination and deletion of 3314 listings. A useful follow-on study would be to compare these results with results of other criteria and models for aftershock discrimination.

Since collapses occur below ground zero, they were also removed by this same procedure. However, there were 38 collapses (identified as such by temporal proximity to DOE determined collapse times) that fell beyond the circles as defined above (Table 1). These were the result of a location error in the catalogs which was large relative to the diameter of the circle for a given UNE yield.

There are three locations within the area of concern where natural earthquakes are known to occur: Thirsty Canyon, Massachusetts Mountain, and an area of about 3.6 km north of the common intersection of Areas 18, 19, and 20. Catalog listings falling within those areas were not deleted.

Location Accuracy

Slemmons et al (1965) divided their epicenters into two groups--pre-1932 and post-1932, "in order to distinguish between early historic events with poor epicentral locations, and modern events with better epicenters based on instrumental information." Entries in the SGBHC deserve the same division. There were 50 pre-1932 earthquakes listed in the SGBHC. Six are from the RYC source and are those of Slemmons et al. Thirty-four were attributed to BRP, but only 10 are among those published by BRP. The remainder are unpublished data. Twenty of the 50 had locations given only to the nearest degree, and 22 to the nearest 0.1 degree.

Location error estimates decrease as the number of stations is increases. These factors may affect latitude and longitude error estimates differently, depending on where the stations recording the signal are located with respect to the earthquake. There is some point at which the location error is so large that the data are of little value in assessing the seismicity of the

area as it relates to siting a waste repository. The selection of a cut-off is purely subjective. Opinions solicited from several people suggested that around 10 km would be a reasonable cut-off.

Only the data collected by the SNSN from August 1, 1978 to September 30, 1986 have calculated error estimates. There were 45 entries with error estimates from 10 to 20 km, 13 from 20 to 30 km, 5 from 30 to 50, 10 from 50 to 100, and 7 over 100 km.

Where the number of stations is 4 or fewer, the hypocentral solution is unique but not necessarily correct, and no error estimate is calculated. There are 3,239 such entries in the SNSN catalog. The location errors for these entries could range from small to very large. If they were over 10 km in the same ratio to the SNSN total as the 80 entries above, the number with error estimates greater than 10 km would be increased to 85. While no attempt has been made to delete entries with large location errors, attention should be called to these location uncertainties.

A 10 km cut-off approximates a 0.1 degree uncertainty in location. In the earlier years of the SGBHC, numerous locations were given only to the nearest degree and even more given only to the nearest 0.1 degree. It was noted that many of the early earthquakes located to the nearest degree were at 38° latitude and 118° longitude, the region attributed to the Tonopah Junction earthquakes. Thus, although earlier sources rounded latitude and longitude, by pure coincidence a significant portion of later earthquakes in that area appear to be close to 38°, 118°. However, this does not diminish uncertainty in the location of early earthquakes. Most of these events are of little consequence in assessing seismicity relative to siting the proposed repository since they are about 185 km from Yucca Mountain.

The fact that a number of UNEs were included in the catalogs provides a unique opportunity to assess the location accuracy published from the various sources.

The earthquake catalogs contain information on events that can be identified as UNEs or HE explosions. Most of the UNEs so identified are unannounced events. Those identified as explosions are listed in Table 2. The names, dates, and time of unannounced UNEs is classified data and have been omitted from the table. This information is available from Sandia National Laboratories for those who have access to classified information.

Listings are identified as UNEs or HE explosions by the closeness in time to the known time of the explosions. HE shots were reported only to the nearest minute, apparently from the experimenter's watch resulting in some large time differences (see lines 49, 50, 56, 58, 60, 61, and 62). The largest time difference for a UNE (line 63) appears to have resulted from a one minute error in the time of the earthquake, since it was the only event that day and the largest reported by KKG (M 4.8) during the month of June 1971.

The probability of a natural earthquake falling within the time difference between a UNE and a listed seism is

$$p = 1 / \frac{T}{n\Delta t} \quad (1)$$

where Δt is the time difference in seconds and n is the number of events listed in time T in seconds. If T is taken as one day, then the probability based on time is shown in the table. All identified UNEs show that the probability that the listing is a UNE is better than 1:9000.

The location of each specified UNE in the listing can be compared with the known location of the UNE to determine a location error. Some of the smaller errors result from listing seisms latitude and longitude to the nearest 0.1 or 0.01 degree. (Most were given to 0.001 degree.) This accounts for a portion of the distance errors. A large error such as line 53 in table 2 (109 km) is associated with a high time probability that it is a UNE (1:864,000). For line 29, the probability is 1:99,300. These high time probabilities that the listing is a UNE affirm that the large distance differences are a result of location errors.

Probability that an event falling within a distance r from a UNE location is a UNE is

$$p = 1 / (A / n\pi r^2) \quad (2)$$

where n is the number of events listed in time T defined as above and A is the area monitored for earthquakes. Here it is 103,690 km² for the area between latitude 35.5-38.5 N and longitude 114.5-118.0 W. This is the area covered by the USGS catalogs. These probabilities are also given in the table. The larger the r the smaller the probability that the event is a UNE. However, this must be weighed against the time probability that it is a UNE.

Table 3 is a comparison of the location accuracy by source for the explosion data. The table gives the number of events from each source, their largest and smallest errors, and a log average (average of logarithms) of the errors where the number of events is greater than 1. It was a judgment that an arithmetic average would have biased strongly those source sets with large miss distances. HSF, ISC, and PAS all have large log average errors, although HSF and PAS have only one event. The very small value for KKG is the result of small location errors or estimated errors for HE events. The one UNE shows the location error of 7.81 km. As would be expected, because of the greater sensitivity and larger number of stations, the log average error for SNSN is quite small.

Consideration of these errors is useful in assessing the location accuracy of other data from the same source. The location errors for UNEs and HES do not apply directly to data from events in other areas of the region since the station distribution around the events differs.

Cavity collapse occurs at the shot location; hence, collapse signals are another means of judging location accuracy. The Weapons Test Organization records collapse time from geophone records or video coverage of SGZ, or both. Collapse times are quoted to the nearest 0.1 minute, although some of the longer collapse times appear to be rounded to the nearest minute. Table 4 lists the collapses identified with items in the catalogs. True event time is

Table 3. Comparison of Location Accuracy by Source (UNE and HE Data)

	Number	Distance Difference (km)		
		Smallest	Log Avg.	Largest
ALX	2	2.91	5.61	10.81
BRK	1		4.56	
BRP	15	1.06	3.06	19.70
GDY	32	1.84	6.21	43.55
HSF	1		23.90	
ISC	4	7.12	23.89	109.29
KKG	8	0.14	0.30	7.81
PAS	1		21.42	
PDX	5	0.26	4.73	16.25
RYN	6	1.32	7.91	15.74
SNSN	10	0.56	1.53	7.12

Table 4. Location Accuracy (Collapse Data - continued)

Remarks:

- (a) Reported by National Earthquake Information Service (NEIS)
- (b) NEIS gave location only to 0.1 degree
- (c) Event time not precise
- (d) Exact location not surveyed
- (e) NEIS quoted event location
- (f) NEIS location not used or substantially rounded
- (g) Depth with respect to mean sealevel
- (h) Hoffman & Mooney, 1984
- (i) Outside aftershock criteria
- (j) NEIS identified as an aftershock
- (k) NEIS identified as a collapse
- (l) Possible natural earthquake
- (m) Possible aftershock

detonation time plus the time to collapse. Only five collapse times are suspect. Those for Fontina (line 33) and Backbeach (line 37) may be associated aftershocks. Those for Cornice (line 3), Cup (line 10), and Asiago (line 34) are possibly natural earthquakes. Relatively low probabilities support this interpretation.

Three ISC listings (lines 18, 22, and 23) have small miss distances because the item was identified as a collapse by National Earthquake Information Service (NEIS). PDS has 19 items which NEIS identified as collapses, but it appears that the given locations were used in only six cases (lines 54-59).

Table 5 compares location accuracy by source. Use of announced locations of collapses and the possible natural earthquakes have been omitted in determining the distances given in the table. Comparison of the log average values in Tables 3 and 5 shows that only for GDY is the location accuracy about the same.

Entries from the SNSN after mid-1978 show calculated error estimates for both latitude and longitude. Table 6 lists the last 10 explosions from Table 2 together with the estimated errors. These in turn are compared with the actual error using the distance between the calculated and actual latitude and longitude. The next two columns are the ratio of calculated error to actual error. Error ratios range from 0.08 to 2.33 and have log averages of 0.52 for latitude and 0.31 for longitude. There is poor correlation between the ratios and the Quality HYP071 Estimate [Lee, et al (1975)]. These ten events, while a small sample, suggest that the estimated errors present an optimistic view of the accuracy of location.

Triggering Earthquakes

An argument could be made that the shockwave propagating outward from an explosion might trigger an earthquake on a fault at considerable distance, and that this might account for some of the larger miss distances. For this to be true, the earthquake would have to follow the explosion by an interval of time consistent with a propagation velocity appropriate for the distance between the two. There were only 7 candidates as shown in Table 7. Those on lines 1, 2, 3, 4, 5, and 7 had velocities greater than would be expected from velocities observed from nuclear explosions on NTS at the distances shown. That on line 6 fits the velocity criterion, but it also was from GDY, and well within the range of miss distances for that source (see Table 3). That on line 5 followed the UNE (line 16, Table 2) by 17.8 seconds. Event yield was small, and an approximation of strain at about 112 km is 1.9×10^{-8} --about that caused by earth tides. Since triggering is thus unlikely, (time probability is 1:809) the interpretation here is that the seism (M4.3, RYN) is a natural earthquake unrelated to the UNE.

The data suggest that it is unlikely that any of the reported events was an earthquake triggered by an explosion at a distance from the explosion.

Table 5. Comparison of Location Accuracy by Source (Collapse Data)

	<u>Number</u>	<u>Distance Difference (km)</u>		
		<u>Smallest</u>	<u>Log Avg.</u>	<u>Largest</u>
ALX	2	11.07	24.34	53.52
BRP	2	1.79	10.67	63.51
GDY	5	0.33	5.96	18.56
HSF	1		0.595	
ISC	20	0.54	18.82	124.82
PAS	2	9.92	16.50	27.42
PDX	17	2.81	7.56	26.01
RYN	2	18.53	31.08	52.13
SNSN	4	2.126	5.49	21.379

Table 6. Accuracy of SNSN Data

<u>Date</u>	<u>Time</u>	<u>Latitude</u>	<u>Longitude</u>	<u>Calculated Error (km)</u>		<u>Actual Error (km)</u>		<u>Ratio Calc:Act</u>		<u>Location Quality</u>
				<u>Latitude</u>	<u>Longitude</u>	<u>Latitude</u>	<u>Longitude</u>	<u>Latitude</u>	<u>Longitude</u>	
800911	14:59:59.70	36.974	116.170	0.5	0.3	0.300	3.488	1.67	0.09	B
810213	18:00:00.25	36.971	116.194	0.5	0.3	0.527	1.561	0.95	0.19	B
810618	17:00:00.34	36.987	116.175	0.4	0.4	1.093	0.180	0.37	2.22	B
811216	21:05:00.24	37.107	116.114	0.3	0.4	0.831	0.794	0.36	0.50	C
820429	04:00:00.54	36.874	116.777	0.2	0.2	1.677	1.041	0.12	0.19	B
841110	16:40:00.52	36.987	116.057	2.3	2.5	1.477	3.517	1.56	0.71	C
850817	16:25:00.05	37.006	116.049	0.2	0.1	0.407	0.533	0.49	0.19	B
860605	15:03:59.66	37.084	116.009	0.2	0.1	0.472	0.582	0.42	0.17	C
Unannounced				1.5	0.8	0.643	2.031	2.33	0.39	D
Unannounced				0.5	0.7	6.632	2.588	0.08	0.27	B
Log Average								0.52	0.31	

Table 7. Analysis of Possible Triggered Earthquakes

Number	Event	Date	Event Time	Time		Distance (km)	Expected		Time
				Earthquake Time	Difference (s)		Velocity (km/s)	Velocity (km/s)	
1	Bordeaux	670818	10:12:30.00	20:12:49.20	10.2	67.274	6.47	5.3 - 6.1	4.24 + 03
2	Diagonal Line	711124	20:15:00.20	20:15:20.00	19.8	155.481	7.85	5.2 - 6.6	2.18 + 03
3	Unannounced	Line 51, Table 2			3.7	23.897	6.46	4.6 - 5.4	1.17 + 04
4	Unannounced	Line 52, Table 2			2.2	17.207	7.82	3.9 - 4.8	3.93 + 04
5	Unannounced				17.8	111.944	6.29	5.0 - 6.1	8.09 + 02
6	Unannounced	Line 25, Table 2			1.96	7.753	3.96	3.2 - 4.2	2.20 + 04
7	Unannounced				3.6	26.152	7.26	4.7 - 5.5	1.20 + 04

Bare Mountain and Bare Mountain Fault

Bare Mountain fault has received considerable attention as a fault close to Yucca Mountain that conceivably could be active. Table 8 lists 45 entries from the SNSN catalog that fall within the boundaries of the Bare Mountain quadrangle (Map GQ-157, Cornwall and Kleinhamp¹, 1961). Of these, 16 fell within the vicinity of the Bare Mountain fault. Thirteen of these occurred on weekdays between 8 a.m. and 6:30 p.m. local time and were near the Sterling (Panama) mine. All occurred after 1980 when the mine resumed operations. The 14 we label as mine blasts (B) are shown in the next-to-last column of the table and can be compared with the last column which is the USGS notation. One at 9:29 p.m. could be either a blast or an earthquake. Nine have calculated depths above sea level. None of the 14 has a magnitude larger than 1.31. The remaining two, which are interpreted as natural earthquakes on or near Bare Mountain fault (labeled F in Table 8) have magnitudes of only 0.77 and 1.50. The SGBHC lists an additional M 3 event that occurred in August 1948 about 2 km from the Bare Mountain fault and the Sterling mine.

Deleting these mine blasts leaves evidence that the seismicity of Bare Mountain and the Bare Mountain fault is little different from the region around it.

Three listings in Table 8 in November 1985 are located at the north end of Bare Mountain. The three items have been retained, because they appear unrelated to the Bare Mountain fault and because mining activities there have not been confirmed.

Yucca Mountain Seismicity

Yucca Mountain is within the Tonopah Spring SW quadrangle (Map GQ-439, Lipman and McKay, 1965). There is only one M 3.6 earthquake in the SGBHC. This entry is from PAS and has an accuracy as indicated in Table 5; thus, it easily could have fallen outside the boundaries of the quadrangle.

The SNSN catalog has eight entries that fall within the Tonopah Spring SW quadrangle, five of which are identified as blasts, probably associated with construction activities. The remaining three had magnitudes of 0.63, 0.09, and 0.01. Thus, the Yucca Mountain area appears to be relatively quiescent.

Table 8. Entries Within Boundaries of Bare Mountain Quadrangle

Date	Time	RMS cf Error Sta.	No.	Lat.	N-S Error km	Epic. Error km	Long.	E-W Error km	Azim. Gap	ML Qual.	Depth. km	Depic.	No. ML Readings	ML Est.	Qual.	Comments
												Error km				
F790402	3 27	36.20	0.20	9	0.67	36.766	0.7	1.1 B	-116.672	0.8 124	0.7 B	1.03	0	0.0 B		default
F800704	8 21	39.38	0.0912	0.62	36.820	0.3	0.4 B	-116.685	0.3 97	0.6 B	4.19	3.3	0	0.0 B		Md recomputed
F800705	13 26	8.14	0.15	5	0.67	36.765	1.5	2.7 D	-116.627	2.3 106	0.7 C	8.25	0	0.0 D	F	Md recomputed
F800829	5 1	29.80	0.0917	1.12	36.989	0.2	0.4 B	-116.729	0.3 92	1.1 A	8.92	1.2	0	0.0 B		Md recomputed
F800918	11 13	46.80	0.0918	0.84	36.978	1.2	1.6 D	-116.559	1.0 211	0.8 C	7.81	6.7	0	0.0 D		Md recomputed
F801219	19 10	33.89	0.0516	1.12	36.939	0.1	0.2 B	-116.713	0.1 119	1.1 A	7.94	1.2	0	0.0 C		Md recomputed
F811212	0 19	48.92	0.1215	0.97	36.830	0.2	0.3 B	-116.635	0.3 129	1.0 A	-1.19	0.4	0	0.0 B		Md recomputed
F820213	0 7	17.31	0.0912	1.07	36.867	0.4	0.4 B	-116.647	0.7 148	0.4 C	-0.31	0.5	0	0.0 B	B	Probable blast
F820209	2 22	47.07	0.087	0.56	36.862	0.4	0.8 C	-116.647	0.7 148	0.4 C	-0.38	23.5	1	0.7 C	B	SGB defined ma
F820211	20 24	42.44	0.099	0.72	36.839	0.6	1.0 B	-116.650	0.8 135	0.7 B	1.06	4.5	3	0.7 B	B	Prob. blast
F820817	7 22	12.13	0.0820	0.87	36.903	0.2	0.3 B	-116.733	0.2 146	0.0 A	5.02	1.5	12	0.9 C	B	SGB defined ma
F820824	22 51	18.94	0.1318	1.00	36.825	0.3	0.5 B	-116.651	0.4 79	0.0 B	-0.48	0.7	7	1.0 A	B	Probable blast
F820914	20 49	27.61	0.1012	0.94	36.829	0.4	0.4 B	-116.648	0.3 110	1.0 A	-1.19	0.5	6	0.9 B	B	Prob. Bare Mtn
F821104	16 35	11.53	0.055	0.77	36.794	0.7	7.9 D	-116.614	7.8 193	0.0 D	1.87	6.2	3	0.8 D	F	SGB defined ma
F821227	23 22	25.09	0.034	0.66	36.822	0.0	0.0 C	-116.628	0.0 244	0.0 A	-0.54	0.4	2	0.4 D	B	SGB defined ma
F830201	23 24	9.25	0.056	0.71	36.815	0.3	0.6 B	-116.628	0.5 114	1.0 A	0.66	0.4	2	0.4 B	B	Prob blast
F830218	0 37	44.57	0.0810	1.18	36.825	0.5	0.7 C	-116.649	0.5 215	0.0 A	-0.94	0.5	4	1.2 D	B	Prob blast
F830414	18 56	16.75	0.1412	1.04	36.826	0.2	0.6 B	-116.627	0.6 116	1.2 A	-0.55	0.6	8	0.9 B	B	Prob blast
F830422	23 9	39.77	0.004	0.96	36.826	0.0	0.0 C	-116.657	0.0 282	1.0 A	-0.44	0.3	12	1.3 C	B	SGB defined ma
F830616	0 34	42.11	0.0619	1.30	36.882	0.1	0.2 B	-116.736	0.1 104	0.0 A	0.47	0.3	12	1.3 C	B	SGB defined ma
F830711	22 34	41.12	0.0815	1.00	36.826	0.2	0.3 B	-116.649	0.2 93	0.0 A	-0.72	0.3	9	1.0 B	B	Probable blast
F830718	20 33	9.66	0.054	0.50	36.980	0.0	0.0 C	-116.632	0.0 343	0.0 A	0.98	0.8	7	1.1 B	B	SGB defined ma
F831017	3 24	31.64	0.1123	1.12	36.780	0.2	0.3 B	-116.677	0.2 113	1.1 A	4.72	0.8	7	1.1 B	B	SGB defined ma
F831116	2 29	22.73	0.1610	0.29	36.837	1.4	2.4 C	-116.628	1.9 248	0.0 B	4.01	3.1	4	0.3 D	B	SGB defined ma
F831222	16 39	22.34	0.284	1.63	36.926	0.0	0.0 C	-116.518	0.0 237	0.0 B	34.47	2	1	6 D	B	SGB defined ma
F840103	0 13	18.46	0.1013	0.68	36.825	0.3	0.6 B	-116.634	0.5 127	0.0 B	0.90	0.8	7	0.7 B	B	1134
F840110	18 50	3.21	0.228	0.89	36.815	18.7	18.8 D	-116.704	1.4 317	0.0 D	0.44	15.2	4	0.9 D		1134
F840322	18 38	56.21	0.056	1.04	36.794	28.0	28.4 D	-116.723	5.0 333	0.0 D	0.04	23.4	3	1.0 D		1134
F841226	6 25	7.78	0.0413	0.63	36.827	0.3	0.4 C	-116.745	0.3 253	0.5 A	5.54	0.9	4	0.8 D		1134
F841227	16 37	27.86	0.1155	1.18	36.805	0.1	0.1 B	-116.736	0.1 58	1.1 A	0.58	0.2	26	1.3 B		1134
F841227	19 44	4.02	0.0852	1.22	36.800	0.1	0.1 B	-116.729	0.1 81	1.2 A	4.89	0.6	23	1.3 B		1134
F850203	21 33	38.78	0.0712	0.80	36.827	0.3	0.5 C	-116.728	0.4 240	1.0 A	2.07	0.7	3	0.6 D	B	Feb 85 digital
F850209	5 39	0.17	0.1714	1.31	36.828	0.6	1.1 C	-116.641	0.9 215	1.8 B	0.87	1.0	3	0.8 D		Feb 85 digital
F850213	8 24	23.65	0.0926	1.23	36.903	0.1	0.2 B	-116.654	0.1 134	1.5 A	0.87	0.3	6	1.0 C		Feb 85 digital
F850226	1 7	56.06	0.0914	1.21	36.951	0.8	1.2 C	-116.746	0.9 278	1.5 B	8.08	2.9	8	0.9 D		Feb 85 digital
F850313	22 31	43.54	0.087	1.30	36.754	49.7	349.6 D	-116.575	48.2 342	0.0 D	0.82	415.7	1	1.3 D		March 85 digital
F850519	11 15	24.50	0.0934	1.23	36.869	0.1	0.2 B	-116.691	0.1 95	1.5 A	2.57	0.7	11	1.0 C		uses Mca estim
F851011	11 13	36.86	0.1020	1.23	36.917	0.2	0.3 B	-116.726	0.2 96	1.3 A	1.71	0.9	5	1.1 C		1134 digital e
F851123	19 4	7.59	0.0915	1.08	36.888	0.3	0.4 C	-116.716	0.2 167	1.3 B	6.67	2.3	3	0.9 C		Prob Bare Mtn B
F851124	18 59	46.25	0.1311	1.23	36.902	0.5	0.7 C	-116.747	0.6 265	1.3 A	0.63	0.6	2	1.1 D		Prob Bare Mtn B
F851125	22 50	58.70	0.1612	0.61	36.898	0.8	1.2 C	-116.700	0.8 228	0.0 B	5.03	4.9	3	0.6 D		Prob Bare Mtn B
F851212	11 57	53.05	0.1030	1.68	36.860	0.1	0.2 B	-116.726	0.2 95	1.7 A	2.46	1.1	1	1.7 C		1134 digital eq
F860307	18 51	31.69	0.0714	0.82	36.814	0.4	0.5 C	-116.744	0.4 241	0.0 A	1.65	0.9	6	0.8 D		1134 eq
F860825	11 23	41.65	0.0414	0.22	36.851	0.1	0.1 B	-116.720	0.1 167	0.1 A	0.32	0.2	3	0.3 C		1134 data
F860924	2 41	39.98	0.0829	0.46	36.926	0.1	0.2 B	-116.712	0.1 129	0.0 A	7.22	1.1	13	0.5 C		1134 data

EARTHQUAKE LOCATIONS

To better portray earthquake locations, maps were prepared with locations plotted. The maps are separated between original listing (all data) and after deletions (modified). There is a map with limits 35.6 to 38.5° latitude and 114.5 to 118.0° longitude and a close-up of NTS with limits 36.5 to 37.5° and 115.7 to 116.7°. There are separate maps for magnitude increments: 0 (no magnitude determined), 0 to 1 (read >0 to ≤ 1), etc. Maps for each source are in separate appendices as follows:

Source	Appendix
ALX	B
BRK	C
BRP	D
CVH	E
ERS	F
FPH	G
GDY	H
HSF	I
ISC	J
KKG	K
PAS	L
PDX	M
PHM	N
ROW	O
RYC	P
RYN	Q
SHJ	R
USE	S
Total SGBHC	T
SNSN	U

Table 9 summarizes the distribution by magnitude and source of the original (unmodified) listing of earthquakes as shown on the maps. Table 10 does the same for the modified listing after removal of man-made seismic events.

Page T-2 shows the locations of earthquakes for which no magnitude was determined. It also shows where UNE-related and Lake Mead seisms were deleted. Table 9 shows that most of the events with no magnitude came from KKG, and that contribution can be seen in Page K-2. Magnitudes were not determined for so many KKG events because instruments were set to a high sensitivity such that peaks were clipped and magnitude could not be determined from amplitude. Page K-2 shows that natural earthquakes on the NTS in the vicinity of Massachusetts Mountain, Frenchman Flat, and Ranger Mountain have been retained.

Figures T-4 and T-5 show that many small (0.01 to 1.0) magnitude events were concentrated on Pahute Mesa and were removed having been identified as UNE aftershocks. The same pattern follows for magnitudes 1.01 to 2.00 (Figures T-6 and T-7). The remaining figures in Appendix T exhibit a similar effect. Note in Table 9 that the majority of the earthquakes came with defined magnitudes came from PAS, HSF, and ROW. Note in Appendix L that most

Table 9. Distribution of Original Data by Magnitude

Source	Magnitude	0	0.01-1.00	1.01-2.00	2.01-3.00	3.01-4.00	4.01-5.00	5.01-6.00	6.01-7.00	Outside Map Boundaries	Total
ALX				9	53	4					66
BRK	23				12	109	24				168
BRP	35			17	167	147	22	5	2		395
CVH						1					1
ERS						3					3
FPH				9	7	2					18
GDY	51			3	37	86	41				226
HSF	50		448	875	837	74	4		8		2288
ISC	75					2	6				83
KKG	1224		1	10	47	54	4				1340
PAS	31		1	93	580	318	26				1049
PDX	23			2	3	18	19	1			66
PHM	12		16	4	1						33
ROW	4				242	264	9				519
RYC	44			1	10	35	16	1			107
RYH	22		1	53	97	61	6		1		241
SHJ			6	3							9
USE						1					1
Total SGEHC	1594	473	1079	2093	1179	177	15	2	1		6613
SNSN	28	1664	3209	346	8						5255
SNSN Outside map	9	60	45	6							120
Grand Total	1631	2197	4333	2445	1187	177	15	2	1		11988

Table 10. Distribution of Modified Data by Magnitude

Source	Magnitude	0.01-1.00 1.01-2.00 2.01-3.00 3.01-4.00 4.01-5.00 5.01-6.00 6.01-7.00							Outside Map Boundaries	Total
		0	0.01-1.00	1.01-2.00	2.01-3.00	3.01-4.00	4.01-5.00	5.01-6.00	6.01-7.00	
ALX				9	45	2				56
BRK	23				12	108	22			165
BRP	24				20	19	12	5	2	82
CVH										0
ERS						1				1
FPH				9	7	2				18
GDY	33			3	33	53	21	7		150
HSF	2		32	67	28					129
ISC	49					2	1			52
KKG	1100		1	10	40	49	3			1203
PAS	31		1	93	576	282	24			1007
PDX	5			2	3	8	1	1		20
PHM	12		16	4	1	7	2			33
ROW					12					21
RYC	12			1	6	25	14	1		59
RYH	20		1	52	94	50	4		1	222
SHJ			6	3						9
USE										0
Total SGHC	1311	57	253	877	608	104	14	2	1	3227
SNSN	27	1513	2965	307	6					4818
SNSN Outside map	9	60	43	4						116
Grand Total	1347	1630	3261	1188	614	104	14	2	1	8161

of the PAS earthquakes are in the Owens Valley vicinity (about 150 km from Yucca Mountain), with only an occasional UNE-related event included.

The seismic network employed for HSF was concentrated in Area 20 of Pahute Mesa with a few stations scattered out to about 30 km. Thus, as would be expected, the maps of Appendix L show few events away from the locations of the network.

ROW had 10 stations on NTS and 7 off-site--at Leeds, Utah, Darwin, California, and West Las Vegas, Angel Peak, Tonopah, Alamo, and Nelson, Nevada. The effort concentrated on UNE aftershocks on Pahute Mesa as shown on the maps of Appendix O; hence, most were deleted as UNE aftershocks. There were a few off-site earthquakes observed, most notably in the vicinity of the Rock Valley fault.

Most of the Lake Mead seisms removed came from BRP (Appendix D). Others came from RYC (Appendix P), PAS (Appendix L), KKG (Appendix K), and GDY (Appendix H).

Because the historical catalog contained data from sources which concentrated on Pahute Mesa UNE aftershocks, less than half the entries remain after editing out man-made events, as can be seen by comparing Tables 9 and 10. This is in contrast to the SNSN data where only about 8 percent of the entries were deleted. The effect of these deletions is shown on the maps in Appendix U.

Table 9 illustrates the effect of the sensitivity of the various seismic nets. The number of events observed by the SNSN has its peak for magnitudes 1.01 to 2.00 because of the sensitivity of the net. No event with a magnitude larger than 3.82 was observed, and that was 152 km from Yucca Mountain (shaft). For the historical catalog the largest number was observed for magnitudes from 2.01 to 3.00. Several of the individual sources peak at higher magnitudes. Only FPH, HSF, and PHM peaked lower.

The two largest earthquakes were magnitude 6.3. One, on September 4, 1868, is the earliest entry in the historical catalog. The location, given only to the nearest degree of both latitude and longitude, would be just east of Owens Valley, and about 140 km from Yucca Mountain shaft. The second, on November 21, 1910, also had location given only to the nearest degree, and was about 187 km from Yucca Mountain. (See Page D-14.) It was one of a series of Tonopah Junction earthquakes during that month, and warrants closer scrutiny.

Tonopah Junction Earthquakes

The M 6.30 and two M 5.7 earthquakes were located at latitude 38° and longitude 118°. There was one M 5.50 at 37.5° and 117°. Slemmons, et al (1965) list an additional nine in the same month at that location, which are included in the SGBHC. They cite the location as Tonopah Junction. That was a junction on the Tonopah & Goldfield and Carson and Colorado Railroads. The latitude and longitude are N38°16', W118°7', respectively. Slemmons et al (1965) cite the source of information as Townley and Allen (1939). Both show an intensity for each earthquake, rather than a magnitude, so a conversion has been made for entry into the SGBHC.

The following is quoted from Townley and Allen (1939):

- 1910 November 7 9:20 a.m. VII? This shock was felt from Goldfield, Esmeralda Co., to Rhyolite, Nye Co., a distance of about sixty miles. A few windows and dishes were broken at Goldfield.--Reid's Scrapbook, 3, 105.
- 1910 November 18 6:25 p.m. VIII? Tonopah Junction, Esmeralda Co. Reid assigns an intensity of VIII. The only other statements are that the duration was fifteen seconds and that the shock was accompanied by a loud rumbling noise. This information and that for the following shocks felt at Tonopah Junction was obtained from a letter from H. B. Vandersaal written November 29, 1910.--Reid's Card Catalog.
- 1910 November 19 9:57 a.m. III-IV. Tonopah Junction. Duration five seconds; rumbling sound.--Reid's Card Catalog.
- 1910 November 21 Tonopah Junction. The following shocks were reported by H. B. Vandersaal:

<u>Time</u>	<u>Duration</u>	<u>Intensity</u>
3:20 p.m.	5 sec.	---
3:23 p.m.		2 min. VIII
4:30 p.m.		15 sec. VI
10:00 p.m.		10 sec. ---
10:05 p.m.		25 sec. VII

The second shock broke window glass and threw the watchman's car from the track. There was a succession of shocks during the two minutes and loud rumbling noise. Rumbling sounds also accompanied the third and fourth shocks.--Reid's Card Catalog.

- 1910 November 23 10:50 p.m. III-IV. Tonopah Junction. Duration five seconds.--Reid's Card Catalog.
- 1910 November 24 8:30 p.m. III to IV? Tonopah Junction. Duration five seconds each. The vibrations of all the eleven shocks felt at Tonopah Junction, November 18 to 24 seemed to be north-south, according to Mr. Vandersaal.--Reid's Card Catalog.

About the source of the information, Townley and Allen say:

"Professor H. F. Reid of Johns Hopkins University very kindly loaned us his card catalog of earthquakes of the Pacific Coast and three scrapbooks of newspaper clippings. In using the information from these sources, we have sometimes given credit to the original source and sometimes to the card catalog and scrapbooks. In many cases there is no indication of the newspapers from which clippings were taken. Some of Reid's information came from the Lick Observatory and is marked 'L. O. Reports.' In such cases we have given Reid's Catalog rather than Lick Observatory as the reference."

For these earthquakes Slennons et al, use the intensities given by Townley and Allen, thus they were subsequently converted to magnitude.

Earthquakes as large as M 6.3 would be expected to attract considerable attention locally. The DOE/NVO librarian was requested to search for information in local newspapers during the period of the major earthquake activity at Tonopah Junction. The result of the search (personal communication, Cynthia Ortiz, DOE/NVO) was that no references to the events were found in the Tonopah Daily Miner, the Tonopah Daily Bonanza, the Goldfield Daily News, the Goldfield Daily Tribune, the Goldfield Weekly News, and The Rhyolite Herald. If correct, this implies a magnitude smaller than 6.3.

In view of the above it is in order to quote Townley and Allen concerning questionable information.

In a number of cases information furnished by the original observer, or, in the cases of published lists based on such information, the compilers' interpretations of the information, seems to the compilers of this catalog to be open to question. It has been the policy in such cases not to suppress what appears to be questionable observation, or inaccurate interpretation of observation, but to place a question mark following it, in some cases to remark upon the uncertainty, and in others to furnish only the additional information which makes the item questionable. Usually it is the observer's estimate of intensity which is questioned--almost always the observer had little training in estimating intensity--and often the report would furnish the information, which served to indicate the incorrectness of the estimate and to enable more experienced persons to make a better estimate; in some cases, however, the additional information was not furnished, and the possibility exists that the observer had good reason, which he failed to preserve in the record, for his estimate, questionable though it may appear in connection with other known facts.

These remarks apply to the one M 6.3 event and three 5.7 events appearing in the Townley and Allen catalog.

The earlier M 6.3, a M 5.7 in 1908, and a M 5.1 in 1933 must be equally questionable. It is not the purpose here to suggest that these items be deleted, but to emphasize the uncertainty in both location and magnitude of

the early entries. The closest M 5.7 event was 87 km and the next closest 107 km from Yucca Mountain shaft. Others were more distant.

GDY lists eight earthquakes with 5-plus magnitudes. One was UNE related and was deleted. The remainder (see Page H-12) were quite distant.

PDX shows one M 5.1 event (see Page M-13). It occurred 14 minutes 52 seconds after the Boxcar event in Area 20 of Pahute Mesa. Although not deleted, it is judged to be a Boxcar aftershock mislocated so as not to have been deleted by the criteria spelled out earlier.

RYC has one M 5.2 event (see Page P-12) at a distance of 2234 km from Yucca Mountain.

Thus, all events with magnitudes greater than 5 either have large uncertainties in magnitude and location and/or are distant from Yucca Mountain.

Earthquakes with No Magnitude Determined

Table 10 shows that there were 1347 earthquakes for which no magnitude was determined. Most were from KKG where no amplitude magnitude was determined because record peaks were clipped. Reasons for not determining magnitudes from other sources are not known. In some cases the seism may have been small enough to be identified as such but not large enough to permit a magnitude to be calculated.

The seismicity of an area is indicated by both location and magnitude. Without magnitude only the location is available to give some indication of where activity may be occurring. However, Tables 3 and 5 show that average miss distances for some of the sources are so large as to seriously degrade the usefulness of location data. Only for KKG and SNSN is the miss distance sufficiently small to enable seisms to be identified with a particular fault.

Although these have not been deleted for the purpose of this report, these seisms are of little use in hazard analysis, and it is strongly recommended they not be used for that purpose.

The Effects of Editing

In Figure 1 the magnitude versus distance from Yucca Mountain shaft for all entries in the unmodified historical catalog have been plotted (left) to compare with the modified (right). Those closest to Yucca Mountain are listed in Table 11. Figure 2 and Table 12 show the same for the SNSN catalog. Comparison of the two plots shows the effects of the deletions. Many of the larger magnitude entries between 40 and 60 km are UNE-related events that appear in the left of Figure 1 and are absent from the right. Also, the effect of removing blasting events at Yucca Mountain can be seen in Figure 2.

Figure 1 right shows a series of earthquakes at about 35 km and another at about 40 km. The first is from a series of apparently natural earthquakes on Pahute Mesa (see Pages I-7 and I-9). The second was from a series in the vicinity of Massachusetts Mountain (see Pages B-7 and B-9 and Pages G-3 and G-5).

Figure 1. Magnitude vs. distance for unmodified (left) and modified (right) historical data - Line represents 0.01 g acceleration.

Figure 2. Magnitude vs. distance for unmodified (left) and modified (right) SNSN data - Line represents 0.01 g acceleration.

7886 MODIFIED

E07886 ONLY

Table 11. List of Earthquakes Closest to Yucca Mountain from the Modified Historical Catalog

Date	Time	RMS No.	Error Sta.	M ₀	Lat.	Long.	Azim	Depth	M ₀	Source	Distance km
4810 1	1 11	21.00	0.00 0	3.60	36.833	0.0 0	0	16.00*	3.0	PAS	2.33103
72 926 17	15 59.11	0.00 0	0.00	0.00	36.900	0.0 0	0	15.00*	---	KKG	6.26789
73 419 10	24 36.39	0.00 0	0.00	0.00	36.920	0.0 0	0	20.00*	---	KKG	8.54619
48 829 11	25 57.00	0.00 0	0.00	3.40	36.800	0.0 0	0	16.00*	3.4	PAS	10.70284
73 218 1	18 6.84	0.00 0	0.00	0.00	36.870	0.0 0	0	15.70	---	KKG	11.78076
73 412 10	20 34.33	0.00 0	0.00	0.00	36.740	0.0 0	0	20.00*	---	KKG	12.76866
73 410 6	55 6.88	0.00 0	0.00	0.00	36.820	0.0 0	0	0.00*	---	KKG	13.09726
73 412 12	24 6.60	0.00 0	0.00	0.00	36.740	0.0 0	0	20.00*	---	KKG	13.13036
73 510 21	34 19.54	0.00 0	0.00	0.00	36.800	0.0 0	0	15.00*	---	KKG	13.90163
73 410 4	28 36.53	0.00 0	0.00	0.00	36.820	0.0 0	0	0.00*	---	KKG	13.95383
70 327 16	14 42.00	0.00 0	0.00	0.00	36.900	0.0 0	0	0.00*	---	ISC	14.26472
72 4 9	6 41	0.64	0.00 0	0.00	36.870	0.0 0	0	4.60	---	KKG	14.43106
681029 16	35 59.23	0.00 0	3.50	0.00	36.979	0.0 0	0	6.00*	---	GDY	14.58336
73 422 14	37 5.13	0.00 0	0.00	0.00	36.850	0.0 0	0	0.30*	---	KKG	15.22161
73 214 9	16 45.12	0.00 0	0.00	0.00	36.830	0.0 0	0	0.70	---	KKG	15.44843
73 410 18	37 13.21	0.00 0	0.00	0.00	36.830	0.0 0	0	0.00*	---	KKG	15.44843
73 321 21	44 3.23	0.00 0	0.00	0.00	36.790	0.0 0	0	5.00*	---	KKG	15.99242
73 4 8	5 21	59.95	0.00 0	0.00	36.790	0.0 0	0	5.00*	---	KKG	15.99242
72 214 12	5 52.06	0.00 0	0.00	0.00	36.860	0.0 0	0	7.80	---	KKG	16.11971
73 413 19	43 55.96	0.00 0	0.00	0.00	36.800	0.0 0	0	0.60*	---	KKG	16.35729
73 210 3	48 5.26	0.00 0	0.00	0.00	36.820	0.0 0	0	4.30	---	KKG	16.54608
74 312 16	53 8.19	0.00 0	3.00	0.00	36.934	0.0 0	0	11.10	3.0	PAS	16.66339
64 222 3	31 90	0.00 0	0.00	0.00	37.000	0.0 0	0	33.00*	---	BRP	16.78937
64 824 1	20 36.00	0.00 4	0.00	0.00	37.000	0.0 0	0	0.00*	---	ISC	16.78937
73 3 6	28 9.52	0.00 0	0.00	0.00	36.790	0.0 0	0	7.30	---	KKG	16.79650
72 8 3	15 34	5.64	0.00 0	0.00	36.840	0.0 0	0	8.20	---	KKG	17.07081
72 3 4	13 56	52.13	0.00 0	0.00	36.870	0.0 0	0	0.00	---	KKG	17.08914
73 128 19	6 26.78	0.00 0	0.00	0.00	36.780	0.0 0	0	0.00*	---	KKG	17.29586
570 319 16	29 19.95	0.00 0	3.70L	0.00	36.838	0.0 0	0	8.00*	3.7	PAS	17.58951
70 129 9	22 54.38	0.09 7	2.20	0.00	36.715	0.0 0	124	3.76	---	ROW	17.60663
72 719 17	1 34.23	0.00 0	0.00	0.00	36.770	0.0 0	0	0.00*	---	KKG	17.85032
72 926 12	55 14.41	0.00 0	0.00	0.00	37.010	0.0 0	0	0.00*	---	KKG	17.88924
50 113 5	7 19.00	0.00 0	4.10	0.00	37.017	0.0 0	0	0.00*	4.1	PDX	18.32182
75 1 9	12 15	40.36	0.00 5	2.90	36.798	0.0 0	0	5.92	2.9	PAS	18.38978
71 628 19	0 45.39	0.00 0	0.00	0.00	36.760	0.0 0	0	5.40	---	KKG	18.45491
72 819 10	28 7.86	0.00 0	0.00	0.00	37.020	0.0 0	0	25.00*	---	KKG	18.75307
72 3 3	13 57	51.23	0.00 0	0.00	36.830	0.0 0	0	5.00*	---	KKG	18.97289
73 5 3	13 22	1.49	0.00 0	0.00	36.690	0.0 0	0	10.10	---	KKG	18.98637
71 825 2	23 46.30	0.51 4	0.00	0.00	36.816	0.0 0	0	0.00*	2.5	RYN	19.06276
721023 2	13 48.26	0.00 0	0.00	0.00	36.760	0.0 0	0	5.00*	---	KKG	19.19770
70 928 8	0 23.00	0.00 5	0.10	0.00	37.022	0.0 0	262	3.00*	---	HSF	19.61416
72 618 19	23 43.98	0.00 0	0.00	0.00	37.030	0.0 0	0	9.90	---	KKG	19.70622
65 313 12	13 41.20	0.00 0	2.30	0.00	36.730	0.0 0	0	0.00*	---	ALX	19.87022
70 3 3	7 32	6.50	0.17 6	3.20	37.028	0.0 0	0	10.60	3.2	RYN	19.89904
72 516 15	36 37.33	0.00 0	0.00	0.00	36.760	0.0 0	0	15.00*	---	KKG	19.95274
701117 21	24 13.70	0.00 5	0.90	0.00	37.007	0.0 0	266	3.00*	---	HSF	20.14099
721130 19	57 41.30	0.00 0	0.00	0.00	36.850	0.0 0	0	7.40	---	KKG	20.57109
72 516 16	14 8.06	0.00 0	0.00	0.00	36.720	0.0 0	0	10.00*	---	KKG	20.65487
72 2 8	7 51	41.71	0.00 0	0.00	36.690	0.0 0	0	6.80	---	KKG	20.70536
1651225 18	59 53.80	0.00 0	3.00A	0.00	37.000	0.0 0	0	33.00*	---	BRF	21.03711
70 112 11	24 10.30	0.0011	1.40	0.00	37.043	0.0 0	240	9.80	---	HSF	21.11459
71 729 5	19 29.20	0.00 0	0.00	0.00	36.740	0.0 0	0	0.00*	---	KKG	21.19942
72 616 16	31 30.15	0.00 0	0.00	0.00	36.740	0.0 0	0	10.00*	---	KKG	21.19942
701114 2	43 34.00	0.0014	2.20	0.00	37.045	0.0 0	227	3.00*	---	HSF	21.20602
25 114 22	45 0.00	0.00 0	3.00	0.00	36.667	0.0 0	0	16.00*	3.0	PAS	21.21612
48 311 7	17 12.00	0.00 0	0.00	0.00	36.700	0.0 0	0	33.00*	---	BRP	21.67803
71 414 20	5 8.41	0.00 0	0.00	0.00	37.050	0.0 0	0	0.00*	---	KKG	22.03221
71 8 8	6 23 35.46	0.00 0	0.00A	0.00	37.050	0.0 0	0	0.00	---	KKG	22.21616

Table 12. List of Earthquakes Closest to Yucca Mountain from the Modified Snsn Data

Date	Time	PS of Error	No. of Sta	Lat.	N-S Error	E-W Error	Azim. Error	Cap	Depth	Qual.	Comments	Distance	
850209	11 39 30.72	0.16	9	36.888	0.6	0.9	C	-116.445	0.6	166	3 0.0 C	1134 eq	3.86596
850417	11 39 16.16	0.0614	0.01	36.856	0.2	0.3	B	-116.408	0.2	102	4.4	5 -0.2 B	3.82517
850418	11 39 16.16	0.0614	0.01	36.856	0.2	0.3	B	-116.408	0.2	102	4.4	5 -0.2 B	3.82517
850419	20 21 27.73	0.0918	0.07	36.882	0.2	0.3	A	-116.456	0.3	73	0.7	4 4.39	4.40809
850420	20 21 27.73	0.0918	0.07	36.882	0.2	0.3	A	-116.456	0.3	73	0.7	4 4.39	4.40809
850421	20 21 27.73	0.0918	0.07	36.882	0.2	0.3	A	-116.456	0.3	73	0.7	4 4.39	4.40809
850422	20 21 27.73	0.0918	0.07	36.882	0.2	0.3	A	-116.456	0.3	73	0.7	4 4.39	4.40809
850423	20 21 27.73	0.0918	0.07	36.882	0.2	0.3	A	-116.456	0.3	73	0.7	4 4.39	4.40809
850424	20 21 27.73	0.0918	0.07	36.882	0.2	0.3	A	-116.456	0.3	73	0.7	4 4.39	4.40809
850425	20 21 27.73	0.0918	0.07	36.882	0.2	0.3	A	-116.456	0.3	73	0.7	4 4.39	4.40809
850426	20 21 27.73	0.0918	0.07	36.882	0.2	0.3	A	-116.456	0.3	73	0.7	4 4.39	4.40809
850427	20 21 27.73	0.0918	0.07	36.882	0.2	0.3	A	-116.456	0.3	73	0.7	4 4.39	4.40809
850428	20 21 27.73	0.0918	0.07	36.882	0.2	0.3	A	-116.456	0.3	73	0.7	4 4.39	4.40809
850429	20 21 27.73	0.0918	0.07	36.882	0.2	0.3	A	-116.456	0.3	73	0.7	4 4.39	4.40809
850430	20 21 27.73	0.0918	0.07	36.882	0.2	0.3	A	-116.456	0.3	73	0.7	4 4.39	4.40809
850431	20 21 27.73	0.0918	0.07	36.882	0.2	0.3	A	-116.456	0.3	73	0.7	4 4.39	4.40809
850432	20 21 27.73	0.0918	0.07	36.882	0.2	0.3	A	-116.456	0.3	73	0.7	4 4.39	4.40809
850433	20 21 27.73	0.0918	0.07	36.882	0.2	0.3	A	-116.456	0.3	73	0.7	4 4.39	4.40809
850434	20 21 27.73	0.0918	0.07	36.882	0.2	0.3	A	-116.456	0.3	73	0.7	4 4.39	4.40809
850435	20 21 27.73	0.0918	0.07	36.882	0.2	0.3	A	-116.456	0.3	73	0.7	4 4.39	4.40809
850436	20 21 27.73	0.0918	0.07	36.882	0.2	0.3	A	-116.456	0.3	73	0.7	4 4.39	4.40809
 												

Table 11 lists the modified earthquakes from the historical catalog closest to the Yucca Mountain, with distance from the shaft in the far right column. The entry at 2.33 km from PAS could have a considerable location error (estimated at 16.5 to 21.4 km in Tables 3 and 5), which would move it to the right toward the other data in Figure 1.

Algermissen and Perkins (1976) determined the maximum acceleration versus distance and magnitude for stations on rock in the western region of the United States. The 0.01 g intercept from their Figure 3 is shown in Figures 1 and 2 by the solid line between magnitudes 4 and 6.6. A dashed line shows the extrapolation to smaller magnitudes. Thus, an acceleration of 0.01 g would be seen at Yucca Mountain for magnitude-distance falling along the line. With few exceptions the historical data fall below the 0.01 g line. The SNSN data fall more than one magnitude unit below the line. Considering the time span covered by the SNSN data (Figure 2), the probability of obtaining data from larger earthquakes between now and final siting decision must be especially small.

In Figure 1 (left) the plethora of nuclear test-related entries in the historical catalog is obvious. These have been deleted in the right side of Figure 1 as a result of editing. The deletions from SNSN data in Figure 2 are not as obvious.

Temporal Aspects of SGB Earthquakes

The earthquakes listed in the historical and SNSN catalogs reveal their episodic nature as well as manifesting the effectiveness of measuring programs. Table 13 shows the number of earthquakes in the modified catalogs by year and by month for each year. The SNSN started in August 1978 and measured an increasing number of events as more stations were added. The number of events for 1979 and subsequent years reflects that system's ability to measure a larger number of smaller earthquakes. Table 14 shows the same information for the modified catalogs. Comparison of the two tables indicates the number of deletions in each month and year. The deletions from the SNSN data were predominantly those related to nuclear tests. Note the large number of events in August 1979. Two swarms with large numbers of events were involved, one near Alamo and another in the Thirsty Canyon area.

An earlier version of the SNSN with 10 stations on the NTS and seven off-site was operated from October 1975 through June 1976 (Rogers et al, 1977b). The number in those years reflects a larger number of small earthquakes detected as a result of lowering the detection threshold, and is shown in Table 13. Most of the events were Pahute Mesa aftershocks which were deleted as shown in Table 14. The 18 remaining in June 1976 are the Rock Valley swarm.

A still earlier network was operated from March 1971 through June 1973. Again, the number of small earthquakes increased. Many were aftershocks following nuclear tests (KKG). Table 14 shows a number of months with larger activity. Those in August 1971 included the Massachusetts Mountain earthquake and its aftershocks. Forty-nine remaining in December 1972 included 19 in a swarm near China Lake, California, at a distance of 150 to 160 km.

Peaks in Table 13 in February 1964, December 1966, May 1967, May and December 1968, and January 1969 contained significant numbers of weapons test-related events as indicated by the reduced numbers for those months in Table 14. Deleted at Lake Mead were swarms in September 1936, May 1939, May 1944, May 1948, July 1949, July 1950, February 1952, October 1952, and November 1952. The reduced numbers in Table 14 reflect the deletions.

Table 13. Temporal Aspects of Earthquakes from the Unmodified Historical and SNSN Data

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
1868	0	0	0	0	0	0	0	0	1	0	0	0	1
1871	0	0	1	0	0	0	4	0	0	0	0	0	5
1872	0	0	1	3	0	0	0	0	1	0	0	0	5
1882	0	0	0	0	0	0	0	1	0	0	0	0	1
1885	0	0	0	1	0	0	0	0	0	0	0	0	1
1886	0	0	0	1	0	0	0	0	0	0	0	0	1
1887	0	0	0	0	0	0	0	0	0	0	0	0	1
1892	0	0	0	0	0	0	0	1	0	1	0	0	1
1894	0	1	0	0	0	0	0	0	0	0	0	0	1
1904	0	0	0	0	0	0	0	0	0	0	0	0	1
1905	0	0	0	0	0	1	0	0	0	1	0	0	1
1908	0	0	0	0	0	0	0	0	0	0	0	0	1
1910	0	0	0	0	0	0	0	0	0	0	1	0	1
1914	0	0	0	0	0	0	0	0	0	0	12	1	13
1916	0	0	0	1	0	0	0	0	0	0	0	0	1
1917	0	1	0	0	0	0	0	0	0	1	3	0	4
1918	0	0	0	0	0	0	0	0	1	0	0	0	2
1921	0	0	0	0	0	0	2	0	0	0	0	0	2
1928	0	0	1	0	0	0	0	0	0	0	1	0	1
1930	0	0	1	0	0	0	1	0	0	0	0	0	2
1931	1	0	0	1	0	1	0	0	0	0	0	0	3
1932	1	2	3	3	6	0	2	4	0	1	1	2	25
1933	5	6	3	1	3	1	5	0	0	2	1	0	27
1934	2	8	11	6	0	3	2	7	2	1	1	3	38
1935	3	8	2	5	2	1	0	0	0	0	0	0	21
1936	3	0	1	8	2	1	2	0	0	5	0	2	42
1937	1	7	1	4	1	4	1	1	14	0	3	4	39
1938	1	0	0	0	0	1	11	5	7	2	3	3	26
1939	11	3	3	0	14	9	0	2	4	4	1	3	59
1940	1	0	4	1	2	0	1	0	2	2	0	0	13
1941	0	1	2	2	0	2	1	1	5	3	0	0	17
1942	3	0	0	0	0	4	4	1	1	3	0	0	16
1943	2	4	8	7	4	4	2	5	1	2	0	0	49
1944	1	1	2	0	4	5	3	8	11	5	5	3	46
1945	4	5	2	0	9	1	3	1	1	1	3	2	23
1946	2	3	16	23	25	18	12	2	6	8	3	8	124
1947	4	4	4	0	3	4	5	3	7	3	1	2	40
1948	3	7	1	2	12	4	6	2	2	4	8	2	51
1949	5	4	0	2	6	2	10	9	0	3	1	9	51
1950	8	6	4	4	1	1	9	1	0	9	8	0	81
1951	4	7	1	1	0	17	7	6	2	13	7	1	76
1952	4	22	4	1	7	8	6	5	2	0	5	6	47
1953	1	1	9	2	8	1	5	1	3	0	4	0	30
1954	2	1	2	6	6	1	2	2	1	0	1	0	9
1955	3	0	1	0	1	0	0	1	1	1	1	0	10
1956	1	0	0	1	2	0	2	1	0	1	1	0	7
1957	0	0	1	3	0	0	0	1	0	1	0	0	9
1958	0	0	0	1	0	3	1	5	0	8	0	1	40
1959	0	2	2	2	0	0	2	1	0	1	1	0	9
1960	4	0	1	0	1	0	0	1	0	1	4	0	9
1961	2	0	2	3	2	0	2	1	1	11	2	3	29
1962	2	0	4	6	3	3	1	1	3	2	3	1	29
1963	4	1	2	10	12	2	9	4	2	4	11	1	62
1964	4	15	7	4	6	8	4	3	7	14	11	13	96
1965	7	5	6	4	8	4	4	1	1	0	2	15	57
1966	6	1	1	2	3	3	3	4	5	0	1	14	49
1967	5	5	7	3	11	6	2	6	3	3	5	3	59
1968	5	8	11	10	10	6	1	1	2	2	0	627	683
1969	280	110	33	12	88	22	38	89	200	82	32	39	983

Table 13. Temporal Aspects of Earthquakes from the Unmodified Historical and SNSN Data (continued)

1970	42	35	175	233	105	43	52	36	35	34	35	39	864
1971	12	10	22	17	20	10	18	84	20	18	17	53	301
1972	25	26	72	50	60	32	43	59	70	84	92	57	670
1973	57	209	78	65	54	49	5	7	4	5	2	8	543
1974	1	4	3	4	22	6	13	7	6	3	3	5	77
1975	8	7	6	4	4	12	12	7	8	83	62	18	231
1976	133	120	157	23	12	28	4	10	25	23	11	31	577
1977	4	6	16	6	0	4	10	24	1	7	9	11	98
1978	17	10	33	10	5	10	14	17	8	3	6	31	164
1979	10	9	25	25	15	24	33	166	26	33	45	29	440
1980	37	24	24	43	12	16	66	44	27	47	48	40	428
1981	21	9	8	31	29	39	27	18	22	82	75	51	412
1982	65	73	90	70	73	58	100	76	43	47	50	91	836
1983	57	112	29	51	55	44	56	72	41	63	55	52	687
1984	35	38	55	37	47	31	69	51	115	35	52	83	646
1985	104	60	44	84	147	83	120	220	65	48	53	44	1070
1986	88	98	82	2	65	138	103	98	115	0	0	0	789
TOTALS	1120	1094	1082	905	965	775	918	1185	949	809	767	1419	11988

Table 14. Temporal Aspects of Earthquakes from the Modified Historical and SNSN Data

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
1868	0	0	0	0	0	0	0	0	1	0	0	0	1
1871	0	0	1	0	0	0	4	0	0	0	0	0	5
1872	0	0	1	3	0	0	0	0	1	0	0	0	5
1882	0	0	0	0	0	0	0	1	0	0	0	0	1
1885	0	0	0	1	0	0	0	0	0	0	0	0	1
1886	0	0	0	1	0	0	0	0	0	0	0	0	1
1887	0	0	0	0	0	0	0	0	0	1	0	0	1
1892	0	0	0	0	0	0	0	1	0	0	0	0	1
1894	0	1	0	0	0	0	0	0	0	0	0	0	1
1904	0	0	0	0	0	0	0	0	0	1	0	0	1
1905	0	0	0	0	0	1	0	0	0	0	0	0	1
1908	0	0	0	0	0	0	0	0	0	0	1	0	1
1910	0	0	0	0	0	0	0	0	0	0	12	1	13
1914	0	0	0	1	0	0	0	0	0	0	0	0	1
1916	0	0	0	0	0	0	0	0	0	1	3	0	4
1917	0	1	0	0	0	0	0	0	1	0	0	0	2
1918	0	0	0	0	0	0	2	0	0	0	0	0	2
1921	0	0	0	0	0	0	0	0	0	0	1	1	2
1928	0	0	1	0	0	0	0	0	0	0	0	0	1
1930	0	0	1	0	0	0	1	0	0	0	0	0	2
1931	1	0	0	1	0	1	0	0	0	0	0	0	3
1932	1	2	3	3	6	0	2	4	0	1	1	2	25
1933	5	6	3	1	3	1	5	0	0	2	1	0	27
1934	2	0	11	6	0	3	2	7	2	1	1	3	38
1935	3	8	2	5	2	1	2	1	0	0	1	0	21
1936	3	0	1	8	2	1	2	1	5	5	2	0	30
1937	1	0	1	0	1	3	1	5	3	1	0	2	24
1938	1	0	1	0	0	0	9	0	4	0	0	2	17
1939	3	3	1	0	0	0	2	2	4	1	3	4	50
1940	1	0	4	1	2	2	1	0	2	2	0	0	13
1941	0	1	1	2	0	2	1	1	3	2	0	0	13
1942	3	0	0	0	0	3	4	1	0	2	0	0	13
1943	0	3	7	6	2	2	0	2	0	2	0	0	35
1944	0	0	1	0	0	0	0	5	9	1	0	3	13
1945	2	1	0	0	0	1	1	1	1	0	0	0	9
1946	0	0	0	1	1	15	9	2	6	4	1	7	101
1947	4	4	9	0	25	0	0	1	1	2	1	2	20
1948	2	3	0	1	1	0	0	2	1	2	1	0	17
1949	1	2	0	0	2	3	2	3	0	1	1	0	21
1950	7	5	3	4	0	0	0	0	4	6	8	4	41
1951	4	1	1	1	0	13	7	1	0	0	2	1	31
1952	3	6	1	0	0	1	1	3	0	2	0	0	17
1953	1	1	1	1	1	0	5	1	1	0	5	5	28
1954	2	1	5	6	0	0	4	2	1	0	4	0	27
1955	3	0	1	0	1	0	0	2	1	0	0	0	8
1956	1	0	1	0	0	0	0	2	1	1	0	0	8
1957	0	0	0	1	0	0	0	1	0	0	1	0	7
1958	0	0	0	0	1	0	1	1	0	0	0	0	3
1959	9	2	2	2	0	2	2	1	0	8	4	1	39
1960	4	0	1	0	1	0	0	1	1	1	1	0	9
1961	2	0	2	3	1	0	2	1	1	1	2	2	28
1962	2	0	0	6	3	3	1	1	2	1	3	1	28
1963	4	1	3	6	9	0	9	4	2	14	10	10	62
1964	1	6	6	1	4	5	3	1	1	0	2	14	64
1965	4	4	4	2	4	4	2	4	1	0	0	8	42
1966	5	1	0	2	1	2	1	4	5	6	0	3	35
1967	2	1	7	3	8	4	2	4	3	3	5	3	45
1968	5	8	9	5	3	3	1	1	1	1	0	9	46

Table 14. Temporal Aspects of Earthquakes from the Modified Historical and SNSN Data (continued)

1969	9	3	2	2	9	1	24	57	5	4	7	7	130
1970	6	8	27	9	6	6	10	10	14	11	17	10	134
1971	12	9	15	11	19	9	14	84	16	16	16	50	271
1972	22	24	37	45	48	30	40	53	66	79	92	49	585
1973	52	204	76	63	52	29	4	7	4	4	2	5	502
1974	1	3	3	3	21	5	11	7	4	3	3	4	68
1975	8	5	6	4	3	7	10	6	8	13	1	13	84
1976	13	15	17	14	2	25	4	10	26	21	10	27	183
1977	4	5	15	4	0	4	8	21	1	7	8	10	87
1978	17	9	32	8	5	8	13	11	5	3	4	24	139
1979	9	7	24	24	15	16	33	152	21	24	42	28	395
1980	35	23	24	34	11	16	57	30	22	30	40	36	358
1981	20	7	8	29	29	37	24	17	20	77	68	43	379
1982	59	64	87	63	69	57	99	67	41	45	47	85	783
1983	53	107	26	49	54	43	52	72	41	59	52	48	658
1984	31	35	51	36	45	29	65	49	99	32	46	71	589
1985	92	55	43	79	144	72	114	215	50	42	38	40	984
1986	75	91	76	0	60	134	97	93	113	0	0	0	739
TOTALS	617	752	670	590	692	613	773	1033	629	561	583	644	8167

Other swarms can be identified with Tonopah Junction, China Lake, Owens Valley, and Scotty's Junction. These remain in the edited catalog. Peaks in May 1974 were a swarm in the vicinity of China Lake. The large number in March through July 1946 can be attributed to a swarm in the vicinity of Owens Valley and China Lake.

A NOTE ON EARTHQUAKE MAGNITUDE AND EXPLOSION YIELD

There are nine Pahute Mesa tests for which yields have been announced (DOE/NVO 1985). These events and their yields are listed in Table 15. The table also shows the magnitude of each event as published by Rodean (1971). From the table, the yield-magnitude can be plotted as in Figure 3. Regression analysis gives the relationship

$$M = 3.603 + 0.3774 \ln W \quad r^2 = 0.97,$$

where M is Richter magnitude and W is yield in kilotons. The coefficient of determination, r^2 , is quite good. (Using classified yields changes the equation very little, although r^2 is smaller.) Perret (1972) shows that for the 1300 kt Boxcar event 2.86 percent, or 37.18 kt, of its energy was the seismic source. Using the seismic source energy in Bath's (1979) equation for energy and magnitude:

$$\log E = 4.78 + 2.57 M$$

and solving for magnitude gives $M = 6.37$. This compares with 6.29 given by Rodean (1971).

In Figure 4 the Pahute Mesa yield-magnitude relationship is extended to much smaller magnitudes. Burton, et al (1975), found that the kinetic energy into the ground from a 20-ton nuclear explosion was best matched by a 10-ton HE source. Thus, the upper scale of the figure shows the weight of HE in pounds matching the nuclear yields in kilotons in the lower scale. The USGS data base contains five HE explosions at locations other than Pahute Mesa for which magnitude was determined. For each, the charge weight versus magnitude as determined from the data base (Table 2) has been plotted on the figure.

Except for SH-1 the points fall near the line. That event had an ML 2.83; it also had a duration magnitude listed as M 1.7, which would make it fall within 0.5 magnitude also.

The U. S. Department of Commerce, Geological Survey, National Earthquake Information Center, publishes a monthly listing of "Preliminary Determination of Epicenters." It lists announced underground nuclear tests (and some unannounced ones) together with M_L from Berkeley and m_b from U.S. Geological Survey. When yields of the tests in Yucca Flat are compared with the published magnitudes, equations similar to that described above for Pahute Mesa can be derived. Separating the tests from 1972 through 1984 into two groups according to whether the working point was in alluvium or tuff gives the following results:

Alluvium

BRK	$M_L = 3.301 + 0.4158 \ln W$	$r^2 = 0.89$
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GS	$m_b = 3.546 + 0.3742 \ln W$	$r^2 = 0.77$
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Figure 3. Magnitude vs. yield of Pahute Mesa underground nuclear explosions

Table 15. Nuclear Explosion Yields and Magnitudes

<u>Event</u>	<u>Date</u>	<u>Yield (kt)</u>	<u>Magnitude</u>
Scotch	67/05/23	155 (a)	5.51 (b,d)
Halfbeak	66/06/30	365 (a)	6.04 (b,d)
Chartreuse	66/05/06	73 (a)	5.15 (b,d)
Duryea	66/04/14	70 (a)	5.17 (b)
Benham	68/12/19	1150 (a)	6.3 (c)
Knickerbocker	67/05/26	76 (a)	5.14 (b,d)
Greely	66/12/20	870 (a)	6.05 (b,d)
Rex	66/02/24	19 (a)	4.80 (b)
Boxcar	68/04/26	1300 (a)	6.29 (b,d)

(a) DOE/NVO (1985)

(b) Rodean (1971)

(c) C&GS (1969)

(d) Basham (1969)

Figure 4. Magnitude vs. charge weight and yield for five HE shots

Tuff

$$\text{BRK} \quad M_L = 3.623 + 0.3748 \ln W \quad r^2 = 0.86$$

$$\text{GS} \quad m_b = 3.618 + 0.4093 \ln W \quad r^2 = 0.73$$

The Berkeley equation for tuff is almost identical to the Pahute Mesa equation. The Geological Survey equation for alluvium parallels (has similar slope to the Pahute Mesa one) and is lower by about 0.06 magnitude units. Nearly all of the data fall within 0.5 magnitude units of the above equations.

Having established relationships between yield and magnitude it is in order to compare the number of underground nuclear tests and the number of earthquakes as a function of yield and magnitude. This comparison is made in Figure 5, where the number of tests is shown separately for Yucca Flat and Pahute Mesa and the number of earthquakes separately for the historical and the SNSN catalogs.

There are five times as many tests magnitude 6 and above as there are earthquakes. The factor is 3.8 for magnitudes 5.5 to 6. For magnitudes 5.0 to 5.5, the multiplier is 5.2; only for 4.5 to 5.0 is the number of earthquakes slightly greater than the number of tests. Note that there are no earthquakes in this magnitude range from the SNSN catalog. Consider further that all nuclear tests are within 50 km of Yucca Mountain, whereas earthquakes in the catalogs extend to 230 km. If earthquakes were uniformly distributed and only considered to 50 km, the number of earthquakes in Figure 10 would be 1/21 the number shown. Consider still further that underground nuclear testing began in 1957, but the earthquake catalog extends back to 1868 in the case of the historical and 1978 to 1986 in the case of the SNSN. Consider even further that no weapon tests with yields greater than M 5.5 have been conducted since March 30, 1976. As would be expected, only the largest earthquakes were observed in the early years when sparse population and dependence on sensory perception ruled out smaller quakes.

Figure 5 emphasizes that UNEs have, in historical times, subjected the area to more large magnitude disturbances than have natural earthquakes. If these large magnitude UNEs had been plotted in Figure 1 in the range from 40 to 55 km, they would be shown to have produced the largest motion closest to Yucca Mountain.

Figure 5. Comparison of number of underground nuclear tests and number of earthquakes

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Entries in the USGS SNSN and SGBHC have been scrutinized carefully. There was a combined total of 11,988 items listed making seismicity within about 200 km of Yucca Mountain appear to be a definite concern in the siting of a proposed waste repository. Table 1 summarizes the number of original entries, those which were selected for deletion for the reasons shown, and the balance remaining. The 8,161 entries remaining (68 percent of total) make it clear that the unedited catalogs tend to greatly exaggerate the seismicity of the region.

If one chooses not to use those events for which no magnitude was determined and those in the SNSN with large error estimates for purposes of hazard analysis, then the remaining number would be reduced by an additional 1,432, leaving 56 percent of the original number.

The inclusion of UNEs and HE detonations provided an opportunity to assess the accuracy of epicenter location. The miss-distances were quite small after May 1980 when DOE began announcing locations of UNEs and some announced locations are probably those in the catalog. The greater number of stations in the SNSN and the greater azimuthal distribution leads to small expected miss-distances. There were 10 explosions after installation of the SNSN, and miss-distances were from 0.67 to 7.12 km (see Table 2).

An hypothesis was presented that tectonic stress is relieved by and concurrently with the arrival of the UNE shock wave, and UNE aftershocks are readjustments to the new stress field created by the UNE.

Tectonic release may coincide with UNE. However, there was no information to support an explosion triggering an earthquake beyond 4 km from the explosion.

The view taken here was that listing an earthquake without determining a magnitude contributes little to understanding regional seismicity, especially as it relates to hazard analysis relative to repository siting.

NTS has maintained no record of non-test HE detonations. Consequently, there probably are still some HE detonations remaining in the catalog.

Most of the seisms located near the Bare Mountain fault appear to be man-made activity. With these removed, the seismicity associated with the fault appears to be no greater than at other locations within the Bare Mountain quadrangle.

An equation was developed to relate magnitude to yield of underground explosions at Pahute Mesa.

Similar equations are cited for UNEs at Yucca Flat.

The number of larger magnitude ground motions from underground nuclear tests exceeds by a large margin the number of earthquakes of comparable

magnitudes, in spite of the facts that the earthquake history is longer and the area sampled is larger than for weapons test explosions.

It would appear that the probability of large earthquakes between now and siting a repository is exceedingly small.

Recommendations

For assessing the regional seismicity for purposes of hazard analysis relative to siting a waste facility at NTS, the edited version of the USGS catalogs should be used.

Seismicity maps (such as Figure 3-9 of the Draft Environmental Assessment, DOE/RW-0012, 1984) should be redone using the edited (modified) versions of the maps contained in these Appendices. Since the SNSN catalog includes events as small or smaller than M 0.1, seismologists should agree on a magnitude threshold below which seisms have little or no significance in assessing seismicity as it relates to siting a waste repository, and discard those from the data base.

Cumulative and interval frequency of recurrence and estimates of return periods and yearly probability of exceedance used in YMP documents should be recalculated using the edited versions.

On the basis of the small sample used here, the epicentral location errors of HYP071 are significantly different from those determined from known locations of underground weapons tests. HYP071 locations and errors should be determined for a larger suite of weapons tests to determine whether there are systematic biases in the error estimates and to see if modifications could result in smaller error estimates.

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APPENDIX A

The data sources used in this study were those given in the reference listed below. The codes given below and used in this report are identical to those in that reference.

Codes for Data Sources Used in this Report

ALX
ANT
BRK
CGS
CVH
DMG
ERS
FPH
GDY
GPS
HSF
ISC
KKG
LLL
PAS
PDX
PHM
ROG
ROW
RWL
RYC
RYN
SPK
SHJ
USE
UTH
ZAK

REFERENCE

Meremonte, M. E., and A. M. Rogers, 1987. Historical Catalog of Southern Great Basin Earthquakes 1868-1978, USGS-OFR-87-80, Open File Report, U.S. Geological Survey, Denver, CO. (HQS.880517.1343)

UNMODIFIED ALX

9 MAGNITUDES 2.0 TO 3.0

MODIFIED ALX

7 MAGNITUDES 2.0 TO 3.0

SOURCE-ALX

4 MAGNITUDES 3.0 TO 4.0

117. 116. 115.

NTS-NEVADA TEST SITE

LM-LAKE MEAD

0 25 50 100 KM

MODIFIED ALX

2 MAGNITUDES 3.0 TO 4.0

117. 116. 115.

NTS-NEVADA TEST SITE

LM-LAKE MEAD

0 25 50 100 KM

UNMODIFIED ALX

1 MAGNITUDES 3.0 TO 4.0

APPENDIX C

SOURCE - BRK

UNMODIFIED BRK

2 MAGNITUDES 3.0 TO 4.0

MODIFIED BRK

2 MAGNITUDES 3.0 TO 4.0

SOURCE-BRK

24 MAGNITUDES 4.0 TO 5.0

MODIFIED BRK

22 MAGNITUDES 4.0 TO 5.0

NTS-NEVADA TEST SITE

LM-LAKE MEAD

0 25 50 100 KM

NTS-NEVADA TEST SITE

LM-LAKE MEAD

0 25 50 100 KM

UNMODIFIED BRK

2 MAGNITUDES 4.0 TO 5.0

APPENDIX D

SOURCE - BRP

SOURCE-BRP
35 READINGS OF O. MAGNITUDE

UNMODIFIED BRP

8 READINGS OF O. MAGNITUDE

MODIFIED BRP

4 READINGS OF O. MAGNITUDE

UNMODIFIED BRP

5 MAGNITUDES 2.0 TO 3.0

MODIFIED BRP

2 MAGNITUDES 2.0 TO 3.0

UNMODIFIED BRP

MODIFIED BRP

UNMODIFIED BRP

2 MAGNITUDES 4.0 TO 5.0

APPENDIX E

SOURCE - CVH

APPENDIX F

SOURCE - ERS

APPENDIX G
SOURCE - FPH

UNMODIFIED FPH

2 MAGNITUDES 3.0 TO 4.0

APPENDIX H
SOURCE - GDY

UNMODIFIED GDY

5 MAGNITUDES 2.0 TO 3.0

MODIFIED GDY

3 MAGNITUDES 2.0 TO 3.0

UNMODIFIED GOY

MODIFIED GOY

SOURCE-GDY

8 MAGNITUDES 5.0 TO 6.0

117. 116. 115.

117. 116. 115.

NTS-NEVADA TEST SITE

LM-LAKE MEAD

0 25 50 100 KM

MODIFIED GDY

7 MAGNITUDES 5.0 TO 6.0

117. 116. 115.

117. 116. 115.

NTS-NEVADA TEST SITE

LM-LAKE MEAD

0 25 50 100 KM

UNMODIFIED GDY

1 MAGNITUDES 5.0 TO 6.0

APPENDIX I

SOURCE - HSF

SOURCE-HSF

875 MAGNITUDES 1.0 TO 2.0

117. 116. 115.

NTS-NEVADA TEST SITE

LM-LAKE MEAD

0 25 50 100 KM

MODIFIED HSF

67 MAGNITUDES 1.0 TO 2.0

117. 116. 115.

NTS-NEVADA TEST SITE

LM-LAKE MEAD

0 25 50 100 KM

UNMODIFIED HSF

74 MAGNITUDES 3.0 TO 4.0

APPENDIX J

SOURCE - ISC

UNMODIFIED ISC

25 READINGS OF O. MAGNITUDE

MODIFIED ISC

5 READINGS OF O. MAGNITUDE

SOURCE-ISC
2 MAGNITUDES 3.0 TO 4.0

117. 116. 115.
NTS-NEVADA TEST SITE
LM-LAKE MEAD
0 25 50 100 KM

MODIFIED ISC
2 MAGNITUDES 3.0 TO 4.0

117. 116. 115.
NTS-NEVADA TEST SITE
LM-LAKE MEAD
0 25 50 100 KM

SOURCE-ISC

6 MAGNITUDES 4.0 TO 5.0

MODIFIED ISC

1 MAGNITUDES 4.0 TO 5.0

APPENDIX K

SOURCE - KKG

UNMODIFIED KKG

641 READINGS OF 0. MAGNITUDE

MODIFIED KKG

535 READINGS OF 0. MAGNITUDE

UNMODIFIED KKG

14 MAGNITUDES 2.0 TO 3.0

MODIFIED KKG

8 MAGNITUDES 2.0 TO 3.0

UNMODIFIED KKG

19 MAGNITUDES 3.0 TO 4.0

MODIFIED KKG

14 MAGNITUDES 3.0 TO 4.0

4 SOURCE-KKG
MAGNITUDES 4.0 TO 5.0

3 MODIFIED KKG
MAGNITUDES 4.0 TO 5.0

UNMODIFIED KKG

2 MAGNITUDES 4.0 TO 5.0

MODIFIED KKG

1 MAGNITUDES 4.0 TO 5.0

APPENDIX L
SOURCE - PAS

SOURCE-PAS
MAGNITUDES 0.0 TO 1.0

NTS-NEVADA TEST SITE
LM-LAKE MEAD
0 25 50 100 KM

MODIFIED PAS
MAGNITUDES 0.0 TO 1.0

NTS-NEVADA TEST SITE
LM-LAKE MEAD
0 25 50 100 KM

UNMODIFIED PAS

MODIFIED PAS

SOURCE-PAS

26 MAGNITUDES 4.0 TO 5.0

NTS-NEVADA TEST SITE

LM-LAKE MEAD

0 25 50 100 KM

MODIFIED PAS

24 MAGNITUDES 4.0 TO 5.0

NTS-NEVADA TEST SITE

LM-LAKE MEAD

0 25 50 100 KM

APPENDIX M
SOURCE - PDX

UNMODIFIED PDX

18 READINGS OF 0. MAGNITUDE

SOURCE-PDX

3 MAGNITUDES 2.0 TO 3.0

117. 116. 115.

NTS-NEVADA TEST SITE

LM-LAKE MEAD

0 25 50 100 KM

MODIFIED PDX

3 MAGNITUDES 2.0 TO 3.0

117. 116. 115.

NTS-NEVADA TEST SITE

LM-LAKE MEAD

0 25 50 100 KM

SOURCE-PDX

18 MAGNITUDES 3.0 TO 4.0

MODIFIED PDX

8 MAGNITUDES 3.0 TO 4.0

UNMODIFIED PDX

11 MAGNITUDES 3.0 TO 4.0

MODIFIED PDX

1 MAGNITUDES 3.0 TO 4.0

UNMODIFIED PDX

18 MAGNITUDES 4.0 TO 5.0

MODIFIED PDX

1 MAGNITUDES 4.0 TO 5.0

SOURCE-PDX
1 MAGNITUDES 5.0 TO 6.0

NTS-NEVADA TEST SITE
LM-LAKE MEAD
0 25 50 100 KM

MODIFIED PDX
1 MAGNITUDES 5.0 TO 6.0

NTS-NEVADA TEST SITE
LM-LAKE MEAD
0 25 50 100 KM

UNMODIFIED PDX

MODIFIED PDX

APPENDIX N

SOURCE - PHM

APPENDIX O

SOURCE - ROW

UNMODIFIED ROW

4 READINGS OF 0. MAGNITUDE

SOURCE-ROW

242 MAGNITUDES 2.0 TO 3.0

117. 116. 115.

NTS-NEVADA TEST SITE

LM-LAKE MEAD

0 25 50 100 KM

MODIFIED ROW

12 MAGNITUDES 2.0 TO 3.0

117. 116. 115.

NTS-NEVADA TEST SITE

LM-LAKE MEAD

0 25 50 100 KM

UNMODIFIED ROW

241 MAGNITUDES 2.0 TO 3.0

MODIFIED ROW

12 MAGNITUDES 2.0 TO 3.0

UNMODIFIED ROW

264 MAGNITUDES 3.0 TO 4.0

MODIFIED ROW

7 MAGNITUDES 3.0 TO 4.0

UNMODIFIED ROW

9 MAGNITUDES 4.0 TO 5.0

MODIFIED ROW

2 MAGNITUDES 4.0 TO 5.0

APPENDIX P

SOURCE - RYC

UNMODIFIED RYC

1 READINGS OF 0. MAGNITUDE

SOURCE-RYC

35 MAGNITUDES 3.0 TO 4.0

117. 116. 115.

117. 116. 115.

NTS-NEVADA TEST SITE

LM-LAKE MEAD

0 25 50 100 KM

MODIFIED RYC

25 MAGNITUDES 3.0 TO 4.0

117. 116. 115.

117. 116. 115.

NTS-NEVADA TEST SITE

LM-LAKE MEAD

0 25 50 100 KM

SOURCE-RYC
1 MAGNITUDES 5.0 TO 6.0

NTS-NEVADA TEST SITE
LM-LAKE MEAD
0 25 50 100 KM

NTS-NEVADA TEST SITE
LM-LAKE MEAD
0 25 50 100 KM

APPENDIX Q

SOURCE - RYN

UNMODIFIED RYN

4 READINGS OF O. MAGNITUDE

MODIFIED RYN

2 READINGS OF O. MAGNITUDE

SOURCE-RYN
MAGNITUDES 0.0 TO 1.0

NTS-NEVADA TEST SITE
LM-LAKE MEAD
0 25 50 100 KM

MODIFIED RYN
MAGNITUDES 0.0 TO 1.0

NTS-NEVADA TEST SITE
LM-LAKE MEAD
0 25 50 100 KM

SOURCE-RYN

53 MAGNITUDES 1.0 TO 2.0

NTS-NEVADA TEST SITE

LM-LAKE MEAD

0 25 50 100 KM

MODIFIED RYN

52 MAGNITUDES 1.0 TO 2.0

NTS-NEVADA TEST SITE

LM-LAKE MEAD

0 25 50 100 KM

UNMODIFIED RYN

1 MAGNITUDES 1.0 TO 2.0

UNMODIFIED RYN

4 MAGNITUDES 2.0 TO 3.0

MODIFIED RYN

1 MAGNITUDES 2.0 TO 3.0

SOURCE-RYN

61 MAGNITUDES 3.0 TO 4.0

NTS-NEVADA TEST SITE

LM-LAKE MEAD

0 25 50 100 KM

MODIFIED RYN

50 MAGNITUDES 3.0 TO 4.0

NTS-NEVADA TEST SITE

LM-LAKE MEAD

0 25 50 100 KM

UNMODIFIED RYN

16 MAGNITUDES 3.0 TO 4.0

MODIFIED RYN

5 MAGNITUDES 3.0 TO 4.0

6 SOURCE-RYN
MAGNITUDES 4.0 TO 5.0

4 MODIFIED RYN
MAGNITUDES 4.0 TO 5.0

NTS-NEVADA TEST SITE
LM-LAKE MEAD

0 25 50 100 KM

117. 116. 115.

NTS-NEVADA TEST SITE
LM-LAKE MEAD

0 25 50 100 KM

117. 116. 115.

UNMODIFIED RYN

2 MAGNITUDES 4.0 TO 5.0

APPENDIX R

SOURCE - SHJ

SOURCE-SHJ

6 MAGNITUDES 0.0 TO 1.0

117. 116. 115.

117. 116. 115.

NTS-NEVADA TEST SITE

LM-LAKE MEAD

0 25 50 100 KM

MODIFIED SHJ

6 MAGNITUDES 0.0 TO 1.0

117. 116. 115.

117. 116. 115.

NTS-NEVADA TEST SITE

LM-LAKE MEAD

0 25 50 100 KM

APPENDIX S

SOURCE - USE

APPENDIX T

SOURCE - HISTORICAL

HISTORICAL ALL

773 READINGS OF O. MAGNITUDE

MODIFIED HISTORICAL

554 READINGS OF O. MAGNITUDE

HISTORICAL ALL

446 MAGNITUDES 0.0 TO 1.0

MODIFIED HISTORICAL

31 MAGNITUDES 0.0 TO 1.0

HISTORICAL ALL

886 MAGNITUDES 1.0 TO 2.0

MODIFIED HISTORICAL

77 MAGNITUDES 1.0 TO 2.0

HISTORICAL ALL

1136 MAGNITUDES 2.0 TO 3.0

MODIFIED HISTORICAL

79 MAGNITUDES 2.0 TO 3.0

HISTORICAL ALL

465 MAGNITUDES 3.0 TO 4.0

MODIFIED HISTORICAL

55 MAGNITUDES 3.0 TO 4.0

HISTORICAL ALL

2 MAGNITUDES 5.0 TO 6.0

MODIFIED HISTORICAL

1 MAGNITUDES 5.0 TO 6.0

HISTORICAL
2 MAGNITUDES 6.0 TO 7.0

MODIFIED HISTORICAL
2 MAGNITUDES 6.0 TO 7.0

APPENDIX U

SOURCE - SNSN

E07886 MODIFIED
27 READINGS OF O. MAGNITUDE

E07886 ALL
28 READINGS OF O. MAGNITUDE

E07886 ALL

15 READINGS OF O. MAGNITUDE

E07886 MODIFIED

14 READINGS OF O. MAGNITUDE

E07886 ALL
1664 MAGNITUDES 0.0 TO 1.0

E07886 MODIFIED
1513 MAGNITUDES 0.0 TO 1.0

E07886 ALL

831 MAGNITUDES 1.0 TO 2.0

E07886 MODIFIED

598 MAGNITUDES 1.0 TO 2.0

E07886 ALL

346 MAGNITUDES 2.0 TO 3.0

NTS-NEVADA TEST SITE

LM-LAKE MEAD

0 25 50 100 KM

E07886 MODIFIED

307 MAGNITUDES 2.0 TO 3.0

NTS-NEVADA TEST SITE

LM-LAKE MEAD

0 25 50 100 KM

E07886 ALL

66 MAGNITUDES 2.0 TO 3.0

E07886 MODIFIED

32 MAGNITUDES 2.0 TO 3.0

E07886 ALL

2 MAGNITUDES 3.0 TO 4.0

APPENDIX V

Information from the Reference Information Base Used in this Report

This report contains no information from the Reference Information Base.

Candidate Information for the Reference Information Base

This report contains no candidate information for the Reference Information Base.

Candidate Information for the Site & Engineering Properties Data Base

This report contains no candidate information for the Site and Engineering Properties Data Base.

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