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Annual Hanford Seismic Report - Fiscal Year 1996

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MASTER

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SUMMARY

Seismic monitoring (SM) at the Hanford Site was established in 1969 by the United States Geological Survey (USGS) under a contract with the U.S. Atomic Energy Commission. Since 1980, the program has been managed by several contractors under the United States Department of Energy (USDOE). Effective October 1, 1996, the Seismic Monitoring workscope, personnel, and associated contracts were transferred to the USDOE Pacific Northwest National Laboratory (PNNL).

SM is tasked to provide an uninterrupted collection and archives of high-quality raw and processed seismic data from the Hanford Seismic Network (HSN) located on and encircling the Hanford Site. SM is also tasked to locate and identify sources of seismic activity and monitor changes in the historical pattern of seismic activity at the Hanford Site. The data compiled are used by SM, Waste Management, and engineering activities at the Hanford Site to evaluate seismic hazards and seismic design for the Site.

The HSN and the Eastern Washington Regional Network (EWRN) consist of 40 individual sensor sites and 15 radio relay sites maintained by SM. Most stations and five relay sites are solar powered. The operational rate for stations in the HSN was 99.84% and 98.47% for stations of the EWRN.

A new data analysis system, both hardware and software, was installed in fiscal year (FY) 1996 to reduce maintenance cost and reduce analysis time. This system is fully compatible with archive files. After a three month data comparison period during which no significant differences were noted, the PRIME computer system was discontinued at the end of FY third quarter. Details involving changes in event identification, magnitude calculations and velocity models are provided within this report.

For FY 1996, 57 local earthquakes were identified: 28 occurred in the basalt, 15 in the prebasalt sediments, and 14 in the crystalline basement. Discussions of geologic structures and tectonic environments are provided within.

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Terms

BWIP	Basalt Waste Isolation Project
CAM	Coda Amplitude Magnitude
CRBG	Columbia River Basalt Group
CUT	Coordinated Universal Time
DOE	U.S. Department of Energy
EWRN	Eastern Washington Regional Network
FY	fiscal year
GBB	Gable Butte
GPS	Global Positions Satellite System
HHH	Horse Heaven Hills
HSN	Hanford Seismic Network
HTS	Hanford Technical Services
NEL	Nelson Butte
PNNL	Pacific Northwest National Laboratory
RAW	Rattlesnake Mountain-Wallula Alignment
RC1	Royal City
SMART	Seismic Monitoring Analysis and Repair Team
USGS	United States Geological Survey
WHC	Westinghouse Hanford Company

1.0 Introduction

1.1 Background

Seismic monitoring at the Hanford Site was established in 1969 by the United States Geological Survey (USGS) under a contract with the U.S. Atomic Energy Commission. In 1975 the University of Washington assumed responsibility for and expanded the network. In 1979 the Basalt Waste Isolation Program (BWIP) became responsible for collecting seismic data for the site as part of site characterization. Rockwell International Operations followed by Westinghouse Hanford Company (WHC), Geosciences Group, operated the local network and were the contract technical advisors for the Eastern Washington Regional Network operated by the University of Washington. Funding ended for BWIP in December 1988. Seismic Monitoring and the University of Washington contract were then transferred WHC's Environmental Division. Effective October 1, 1996, all of the Seismic Monitoring workscope, personnel, and associated contracts were transferred to the Pacific Northwest National Laboratory (PNNL¹).

Seismic Monitoring is currently assigned to PNNL's Applied Geology and Geochemistry Group. The Seismic Monitoring Analysis and Repair Team (SMART) operates, maintains, and analyzes data from the Hanford Seismic Network (HSN), extending the site historical seismic database and fulfilling U.S. Department of Energy, Richland Operations Office requirements and orders. The Seismic Monitoring Analysis and Repair Team also maintains the Eastern Washington Regional Network (EWRN). The University of Washington uses the data from the EWRN and other seismic networks in the Northwest to provide the SMART with necessary regional input for the seismic hazards analysis at the Hanford Site.

1.2 Purpose

The SMART is tasked to provide an uninterrupted collection of high-quality raw seismic data from the HSN located on and encircling the Hanford Site. These unprocessed data are permanently archived. The SMART is also tasked to locate and identify sources of seismic activity, monitor changes in the historical pattern of seismic activity at the Hanford Site, and build a "local" earthquake database (processed data). Local earthquakes are defined for this report and database as earthquakes that occur within 46 degrees to 47 degrees West Longitude and 119 degrees to 120 degrees North Latitude. The data are used by the SMART, Waste Management, and engineering activities at the Hanford Site to evaluate seismic hazards and seismic design for the Site. The processed database is also permanently archived.

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1.3 Reports

The SMART issues quarterly reports with discussions of local activity, an annual catalog of earthquake activity on and near the Site, and bulletins on special-interest local seismic events. The annual catalog includes the final quarterly report for the fiscal year. The SMART also provides information and special reports to other functions as requested.

This report is subject to revision. Some earthquake locations may be revised if new data become available.

2.0 Network Operations

2.1 Monitoring Stations

Combined, the HSN and the EWRN have 40 individual sensor sites. Sixteen sites are shared by both networks, so that the Hanford Seismic Network has 21 sites (Table 1 and Figure 1) and the Eastern Washington Regional Network has 35 (Table 2 and Figure 2). The networks have 44 combined data channels because Gable Butte and Royal City are three-component sites, each consisting of one vertical, one north-south horizontal, and one east-west horizontal data channel. Both networks use 15 additional telemetry relay sites. All station data links pass through at least one of these relay sites. Some data links cross as many as three relay sites. The last section of the data link for all channels is commercial telephone lines. Three to eight channels are multiplexed per telephone line.

Table 1. Stations Used for Location of Events

This table lists stations of the Hanford Seismic Network. The first column is the three-letter seismic station designator. This is followed by the latitude-north in degrees, minutes, and hundredth of minutes; the longitude-west in degrees, minutes, and hundredth of minutes; elevation above sea level in meters; and the full station name. An asterisk before the three-letter designator means it is a three-component station. The locations of the stations were derived from a Global Positions Satellite system (GPS).				
Station	Latitude Deg.Min.N	Longitude Deg.Min.W	Elevation (m)	Station Name
BEN	46N31.13	119W43.02	340	Benson Ranch
BRV	46N49.12	119W59.47	920	Black Rock Valley
BVW	46N48.66	119W52.99	670	Beverly, Washington
CRF	46N49.50	119W23.22	189	Corfu, Washington
ET3	46N34.64	118W56.25	286	Eltopia Three
*GBB	46N36.49	119W37.62	177	Gable Butte
GBL	46N35.92	119W27.58	330	Gable Mountain
H2O	46N23.75	119W25.38	158	Water
LOC	46N43.02	119W25.85	210	Locke Island
MDW	46N36.79	119W45.66	330	Midway, Washington
MJ2	46N33.45	119W21.54	146	May Junction Two
OT3	46N40.14	119W13.98	322	Othello Three
PRO	46N12.73	119W41.15	550	Prosser, Washington
*RC1	46N56.71	119W26.66	485	Royal City One
RED	46N17.92	119W26.30	366	Red Mountain
RSW	46N23.67	119W35.48	1,045	Rattlesnake Mt. WA
SNI	46N27.85	119W39.60	312	Snively Ranch
WA2	46N45.32	119W33.94	244	Wahlake Slope
WG4	46N01.85	118W51.34	511	Wallula Gap Four
WIW	46N25.76	119W17.26	128	Wooded Island WA
WRD	46N58.20	119W08.69	375	Warden, Washington

Figure 1. Locations of HSN Seismograph Stations.
(See Table 1 for exact locations.)

Table 2. Station Locations for the Eastern Washington Regional Network.

This table lists stations of the Eastern Washington Regional Network. The first column is the three-letter seismic station designator. This is followed by the latitude-north in degrees, minutes, and hundredths of minutes; the longitude-west in degrees, minutes, and hundredths of minutes; elevation above sea level in meters; and the full station name. An asterisk before the three-letter designator means it is a three-component station. The locations of the stations were derived from a Global Position Satellite system (GPS).

Station	Latitude Deg.Min.N.	Longitude Deg.Min.W.	Elevation (m)	Station Name
BRV	46N29.12	119W59.47	920	Black Rock Valley
BVW	46N48.66	119W52.99	670	Beverly Washington
CBS	47N48.26	120W02.50	1,067	Chelan Butte, South
CRF	46N49.50	119W23.22	189	Corfu
DPW	47N52.25	118W12.17	892	Davenport Washington
DY2	47N59.11	119W46.28	890	Dyer Hill Two
EII	46N54.58	120W33.98	789	Ellensburg
EPH	47N21.38	119W35.76	661	Ephrata
ET3	46N34.64	118W56.25	286	Eltopia Three
ETW	47N36.26	120W19.94	1,477	Entiat Washington
GBL	46N35.92	119W27.58	330	Gable Mountain
LNO	45N52.31	118W17.11	771	Linton Mt. Oregon
LOC	46N43.02	119W25.85	210	Locke Island
MDW	46N36.79	119W45.66	330	Midway Washington
MJ2	46N33.45	119W21.54	146	May Junction Two
MOX	46N34.64	120W17.89	501	Moxee City
NAC	46N43.99	120W49.42	728	Naches
NEL	48N04.21	120W20.41	1,500	Nelson Butte
OD2	47N23.26	118W42.58	553	Odessa Two
OT3	46N40.14	119W13.98	322	Othello Three
PAT	45N52.92	119W45.14	262	Paterson
PRO	46N12.73	119W41.15	550	Prosser
*RC1	46N56.71	119W26.66	485	Royal City One
RSW	46N23.67	119W35.48	1,045	Rattlesnake Mt. WA
SAW	47N42.10	119W24.03	701	St. Andrews
SNI	46N27.85	119W39.60	312	Snively Ranch
TBM	47N10.20	120W35.88	1,006	Table Mountain
TWW	47N08.29	120W52.10	1,027	Teanaway Washington
VT2	46N58.04	119W58.95	1,270	Vantage Two
WA2	46N45.32	119W33.94	244	Wahluke Slope Two
WAT	47N41.92	119W57.24	821	Waterville
WG4	46N01.85	118W51.34	511	Wallula Gap Four
WIW	46N25.76	119W17.26	128	Wooded Island WA
WRD	46N58.20	119W08.69	375	Warden
YA2	46N31.60	120W31.80	652	Yakima Two

Figure 2. Locations of Seismograph Stations in the Eastern Washington Regional Network. (See Table 2 for exact locations.)

Most stations and five relay sites are powered by solar panels and batteries. A major outage is considered to be a failure of the HSN data recording computer or three or more data channels.

2.2 Station Maintenance

The HSN's maintenance records for the seismic sensor and relay sites are filed in the Seismic Monitoring office. Periods of major outage are addressed within this report. Table 3 shows the operational percentage time for each network. Winter conditions cause many malfunctions because of icing of antennas, snow on solar panels, or long periods of heavy overcast. Access to some sites within the EWRN may be impossible during some winter months because of travel restrictions or severe damage to access roads.

Table 3. Seismic Channel Operational Time (%).

Network	July	August	September	Fourth Quarter ^a	FY-96
Hanford	99.91	99.8	99.86	99.86	99.84
Regional	97.11	97.38	99.93	98.12	98.47

^a This column is the percentage for the fourth quarter.

Notes: The Hanford Seismic Network's goal is 98%.

The Eastern Washington Regional Network's goal is 97%.

The quarter period is July 1, 1996 through September 30, 1996.

Site Nelson Butte (NEL) was inoperative from February 28 to August 28, 1996.

3.0 Explanation of Magnitude, Velocity Models, and Quality Factors

3.1 Magnitude Calculation Method Change

An upgrade in the analysis hardware and software was made at the end of last quarter (June 25, 1996), which changed the method of calculation used for determining magnitude. All magnitudes given in this report with dates earlier than June 25, 1996 are Coda Amplitude Magnitudes (CAM). The CAM is calculated using an algorithm modified for very local earthquakes. All magnitudes given for June 25, 1996 and later are Coda-Length Magnitude M_c . CAM and M_c are the equivalent of Richter Magnitude M_L and apply only to local earthquakes.

A comparison of the data collected since January 1996 through June 24, 1996 revealed very minor differences between the results of the two methods. These differences are well within the acceptable error of the techniques.

3.2 Coda Amplitude Magnitude

The AUTOSEIS program (AUTOSEIS 1983) used before June 25, 1996 calculated the location, depth, and magnitude for earthquakes detected at the Hanford Site. This program used the basic decay of the S wave. By quantifying the expected decay of the average absolute amplitude as a function of time, any portion of the coda of an earthquake (coda segment) could be used to assign a magnitude. For the high-frequency earthquakes analyzed at the Hanford Site, the coda segment length was a 1-second sample. A number of coda segments of each record were averaged (or a median value selected) to produce a robust estimate of magnitude for each station. The average magnitudes for all stations was then averaged for an assigned CAM for that particular earthquake.

The CAM for each segment was computed from the following:

$$\text{CAM} = \text{Log } A + Q \text{ Log } (t-B)$$

where:

$$A = 1/256 \sum_{i=1}^{256} |S_i|$$

S_i = signal amplitude at sample

t = signal coda window in seconds = 1.0

Q describes the decay rate of the signal and B describes any DC bias for a particular station. Both parameters are station dependent.

3.3 Coda Length Magnitude

Coda-length magnitude M_c , an estimate of local magnitude M_L (Reichter 1958) is calculated using the coda-length/magnitude relationship determined for Washington by R. S. Crosson (1972).

3.4 Velocity Model

The velocities and layer depths presented in Table 4a were used by the AUTOSEIS program before July 25, 1996 to locate earthquakes on and near the Hanford Site. The velocities and layer depths presented in Table 4b are used by the program XPED, developed at the University of Washington. XPED is an interactive earthquake seismogram display and picking program providing a platform to analyze seismic events.

3.5 Quality Factors (Q)

Before June 25, 1996 the AUTOSEIS program assigned a value based on results of events located with HYPO71 program module. The solution quality of the hypocenter is intended to indicate the general reliability of the solution (AUTOSEIS 1983). The quality is rated using characters A, B, C, and D.

Q	Error (km)	Epicenter	Focal Depth
A	≤ 1.0	Excellent	Good
B	≤ 2.5	Good	Fair
C	≤ 5.0	Fair	Poor
D	> 5.0	Poor	Poor

With the change to new hardware and software on June 25, 1996, XPED assigns two **Quality factors** (Table 5) that indicate the general reliability of the solution (A is best quality, D is worst). Similar quality factors are used by the USGS for events located with the computer program HYPO71. The first letter is a measure of the hypocenter quality base on travel time residuals. For example: a quality requires an **RMS** less than 0.15 seconds while an **RMS** of 0.5 seconds or more is **D** quality (estimates of the uncertainty in location also affect this quality parameter). The second letter of the quality code depends on the spatial distribution of stations around the epicenter; i.e., number of stations, their azimuthal distribution and the minimum distance (**DMIN**) from the epicenter to a station. Quality A requires a solution with 8 or more phases, **GAP** $\leq 90^\circ$ and **DMIN** $\leq$ (5 km or depth, whichever is greater). If the number of phases, **NP** is 5 or less or **GAP** $> 180^\circ$ or **DMIN** > 50 km the solution is assigned quality **D**.

Table 4a. Velocity Model for the Columbia Basin (AUTOSEIS software).

Depth to top of velocity layer (km)	Stratigraphy	Velocity (km/sec)
0.0	Suprabasalt sediments, Saddle Mountains Basalt and intercalated Ellensburg Sediments	3.7
0.8	Wanapum Basalt	4.7
1.2	Grande Ronde Basalt	5.2
7.5	Prebasalt Sediments	6.1
19.0	Crystalline Basement, Layer 1	7.2
28.0	Crystalline Basement, Layer 2	8.2

Table 4b. Velocity Model for the Columbia Basin (XPED software).

Depth to top of velocity layer (km)	Stratigraphy	Velocity (km/sec)
0.0	Suprabasalt sediments, Saddle Mountains Basalt and intercalated Ellensburg Sediments	3.7
0.4	Grande Ronde Basalt	5.2
8.5	Prebasalt Sediments	6.1
13.0	Crystalline Basement, Layer 1	6.4
23.0	Crystalline Basement, Layer 2	7.1
38.0	Crystal Lithosphere	7.9

Table 5. Seismic Event Data. (5 sheets)

- EVENT ID:** The identification number assigned by the AUTOSEIS program was used for events through June 24, 1996. Effective June 25, 1996, the identification number is created by the new analysis program, XPED, developed by the University of Washington. XPED uses the year, month, day and time to create a unique number.
- DATE:** The day of the year in Coordinated Universal Time (CUT).
- TIME:** The origin time of the earthquake given in CUT. To covert CUT to Pacific Standard Time, subtract eight hours; to Pacific Daylight Time, subtract seven hours.
- LATITUDE:** North latitude, in degrees and minutes, of the earthquake epicenter.
- LONGITUDE:** West longitude, in degrees and minutes, of the earthquake epicenter.
- DEPTH:** The depth of the earthquake in kilometers (km).
- MAG:** Before July 25, 1996, Coda Amplitude Magnitude (CAM) was used. Starting July 25, 1996, the method of calculating magnitude was changed to Coda-length Magnitude M_c , an estimate of local magnitude M^L . See page 7 of this report: Explanation of Magnitudes, Velocity Models, and Quality Factors.
- GAP:** Azimuthal gap. The largest angle (relative to the epicenter) containing no stations.
- NS/NP:** Number of stations/number of phases used in the solutions.
- RMS:** The root mean square residual (observed P-WAVE arrival time minus the predicted arrival time) at all stations used to locate the earthquake. It is only useful as a measure of quality of the solution when five or more well-distributed stations are used in the solution. Good solutions are normally characterized by RMS values of less than about 0.3 seconds.
- Q:** The Quality Factors indicate the general reliability of the solution/location (A is best quality, D is worst). See page 8 of this report: Quality Factors.
- TYP:** Events flagged in table 5 use the following code:
F - earthquakes reported to have been felt
P - probable explosion
S - Surficial event (e.g. rockslide, avalanche, sonic boom) not an explosion or tectonic earthquake
X - known explosion
*Denotes events that occurred during this quarter.

Table 5. Seismic Event Data. (5 sheets)

EVENT ID	DATE	TIME	LATITUDE	LONGITUDE	DEPTH (KM)	MAG	GAP	NS/NP	RM _S	Q	TYP	LOCATION
96092814145*	09/28	14:14:54.67	46N51.44	119W34.41	14.64	1.4	147	22/26	0.06	AC		~ 19 km north of 100N area in the Saddle Mountains
96092502460*	09/25	02:46:07.47	46N27.57	119W34.76	15.60	0.5	78	14/22	0.03	AA		~ 10 km south of 200 East area in the Cold Creek Valley
96092209545*	09/22	09:54:55.81	46N30.30	119W41.45	8.21	0.5	155	7/10	0.03	AC		~ 6 km SW of 200 West area along Day Creek
96090717105*	09/07	17:10:51.06	46N40.19	119W37.24	6.89	0.8	144	6/10	0.04	AC		~ 3 km NW of 100K area
96090422121*	09/04	22:12:10.62	46N42.00	119W35.19	3.14	0.8	92	10/12	0.04	AB		~ 3 km NW of 100N area
96090222183*	09/02	22:18:35.34	46N13.50	119W36.93	7.00	0.9	239	6/7	0.04	AD		~ 12 km E of Prosser & 34 km S of 200W area along the Horse Heaven Hills
96082816142*	08/28	16:14:26.41	46N27.19	119W34.35	14.95	1.3	83	16/24	0.06	AA		~ 9.5 km S of 200 E area in the Cold Creek Valley
96081912180*	08/19	12:18:09.85	46N47.06	119W18.12	7.22	1.0	212	5/10	0.06	AD		~ 23 km NNE of Gable Mt.
96081223422*	08/12	23:42:21.11	46N50.89	119W46.38	1.67	1.4	182	18/30	0.02	AD		~ 26 km NNW of 100K area
96081214102*	08/12	14:10:28.03	46N22.82	119W15.01	0.05	0.7	225	9/13	0.05	AD		~ 2.5 km SE of Johnson Island
96081214032*	08/12	14:03:21.18	46N23.76	119W15.07	0.03	1.0	219	9/13	0.08	AD		~ 1.5 km E of the N end of Johnson Island
96080622361*	08/06	22:36:16.21	46N06.72	119W50.01	1.89	1.6	315	11/13	0.05	AD	X	~ 11.5 km SSW of Prosser along the Horse Heaven Hills
96072521443*	07/25	21:44:33.37	46N09.68	119W50.90	0.03	1.2	313	8/11	0.12	AD	X	~ 8 km SW of Prosser along the Horse Heaven Hills
96072218141*	07/22	18:14:17.08	46N09.08	119W49.00	6.18	0.00	284	14/16	0.06	AD	X	~ 7 km SW of Prosser along the Horse Heaven Hills
96071822011*	07/18	22:01:11.77	46N09.31	119W45.58	1.70	1.6	314	10/13	0.03	AD	X	~ 6 km S of Prosser along the Horse Heaven Hills
96071819094*	07/18	19:09:47.56	46N10.53	119W46.00	0.05	0.00	280	17/22	0.04	AD	X	~ 3.5 km S of Prosser along the Horse Heaven Hills
96071522082*	07/15	22:08:29.47	46N04.86	119W46.26	7.84	1.2	323	9/13	0.08	AD	X	~ 14 km S of Prosser along the Horse Heaven Hills

Table 5. Seismic Event Data. (5 sheets)

EVENT ID	DATE	TIME	LATITUDE	LONGITUDE	DEPTH (KM)	MAG	GAP	NS/NP	RM S	Q	TYP	LOCATION
96071221493*	07/12	21:54:00.00	46N39.96	119W37.29	5.53	0.2	141	7/7	0.04	AC		~ 2.5 km N of the 100k area
96071221492*	07/12	21:49:29.20	46N40.17	119W37.01	7.16	0.5	141	7/8	0.06	AC		~ 2.5 km N of the 100K area
96071123085*	07/11	23:08:51.04	46N39.57	119W35.49	2.88	1.8	122	6/8	0.03	AC		~ 3 km N of the 100B area
96071120524*	07/11	20:52:41.95	46N00.08	119W48.16	10.90	1.9	305	11/15	0.05	AD	X	~ 23 km S of Prosser along the Horse Heaven Hills
96070503303*	7/05	03:30:35.78	46N18.47	119W43.39	7.06	0.7	267	5/8	0.05	AD		~ 14.5 km SW of Rattlesnake Mt. on the Hanford Site
96062523232	6/25	23:23:25.41	46N32.11	119W53.74	1.13	2.0	128	17/25	0.07	AB		~ 1 km W of the intersection of SR24 & SR241, Black Rock Valley
96676378	6/24	09:07:58.08	46N42.28	119N18.69	27.80	1.4			0.05	B		~ 12 km E of the S end of Locke Island
96670943	6/18	22:46:11.99	46N03.86	119N49.01	3.00	1.2			0.04	C		~ 16 km SSW of Prosser, WA
96662219	6/10	05:17:35.30	46N36.91	119N54.74	6.12	1.2			0.03	C		~ 4 km S of Priest Rapids Dam
96651021	5/30	00:30:25.89	46N13.43	119N18.51	16.26	1.7			0.05	C		SE flank of Badger Mountain
96647625	5/26	15:05:54.04	46N42.09	119N35.19	1.08	0.5			0.04	B		~ 3 km W of "D" Reactor
96645738	5/24	17:50:10.68	46N24.15	119N15.99	4.82	0.3			0.04	B		~ 1 km N of Johnson Island
96644274	5/23	06:36:39.63	46N24.11	119N15.47	0.06	1.7			0.04	B		North end of Johnson Island
96641811	5/20	19:35:24.81	46N24.19	119N14.83	0.05	1.5			0.05	B		~ 2 km NE of Johnson Island
96638157	5/17	03:47:41.00	46N23.95	119N14.55	1.38	1.5			0.04	B		~ 4 km E of the North end of Johnson Island
96636419	5/15	10:07:10.43	46N23.90	119N14.81	0.65	1.1			0.05	C		~ 3 km East of Johnson Island
96630310	5/09	07:29:02.16	46N50.90	119N25.47	17.12	1.4			0.05	A		~ 3 km NE of Corfu, WA
96609591	4/18	14:17:04.45	46N24.78	119N17.17	2.24	2.2			0.09	A		~ 1.5 km West of the South end of Wooded Island
96593615	4/02	14:51:11.69	46N47.14	119N28.52	0.72	0.00			0.02	B		~ 5 km SW of Corfu, WA
96590046	3/30	01:06:01.34	46N27.57	119N34.75	16.88	0.3			0.05	A		~ 3 km south of Goose Egg Hill or 9 km south of 200E on Hanford

Table 5. Seismic Event Data. (5 sheets)

EVENT ID	DATE	TIME	LATITUDE	LONGITUDE	DEPTH (KM)	MAG	GAP	NS/NP	RM _S	Q	TYP	LOCATION
96583601	3/23	14:30:43.04	46N24.32	119N16.33	0.68	0.7			0.06	B		North end of Johnson Island on Hanford
96581389	3/21	09:23:15.58	46N30.90	119N30.57	22.42	0.9			0.05	A		~ 3 km SSE of 200E & ~ 10 km NW of the LIGO vertex on Hanford
96567505	3/07	12:11:26.76	46N40.33	119N08.39	3.39	0.3			0.04	B		South end of Eagle Lakes, ~ 15 km east of the eastern Hanford boundary
96564061	3/04	01:28:56.80	46N24.11	119N16.11	1.09	0.5			0.40	B		North end of Johnson Island on Hanford
96555502	2/24	12:07:14.38	46N54.19	119N34.38	0.39	1.5			0.04	B		~ 4 km east of Royal City, WA & ~ 23 km north of "N" Reactor
96530902	1/30	21:46:53.28	46N24.01	119N13.13	0.95	0.7			0.03	C		~ 5 km east of the north end of Johnson Is. and 7 km east of the 300 Area on Hanford
96525666	1/25	16:04:45.77	46N49.01	119N22.83	1.11	1.1			0.03	A		~ 5 km east of Corfu, WA
96525032	1/25	00:47:01.15	46N35.24	119N40.40	9.57	0.7			0.04	A		~ 1 km NW of 200W on Army Loop road on Hanford
95851288	12/17	06:58:05.49	46N43.40	119N33.47	1.95	0.4			0.03	A		~ 5 km north of "N" reactor on Hanford
96844874	12/10	21:07:05.81	46N39.31	119N41.49	12.84	0.3			0.05	B		~ 13 km east of Priest Rapids Dam on Hanford
95822745	11/18	18:00:24.89	46N27.63	119N45.00	18.66	1.4			0.07	B		~ 2 km SW of Lower Snively Spring
95820872	11/16	21:04:06.58	46N38.92	119N46.39	1.02	1.3			0.05	C		~ 7.5 km east of Priest Rapids Dam at the Hanford boundary
95806888	11/02	21:26:28.86	46N30.37	119N37.37	8.71	0.3			0.02	A		@ SE corner of 200W, near Hanford Well # 699-29-70 on Hanford
95806600	11/02	14:30:14.44	46N09.00	119N34.55	18.17	3.3			0.08	C		~ 15 km ESE of Prosser WA
95806425	11/02	10:15:17.87	46N30.21	119N37.52	8.64	-0.3			0.01	B		@ SE corner of 200W, near Hanford Well # 699-29-70
95806068	11/02	01:39:10.02	46N30.29	119N37.40	8.45	0.00			0.01	B		@ SE corner of 200W, near Hanford Well # 699-29-70 on Hanford

Table 5. Seismic Event Data. (5 sheets)

EVENT ID	DATE	TIME	LATITUDE	LONGITUDE	DEPTH (KM)	MAG	GAP	NS/NP	RM S	Q	TYP	LOCATION
95797647	10/24	15:37:10.55	46N47.52	119N37.84	13.52	0.8			0.02	B		~ 5 km SE of Smyrna WA
95793510	10/20	12:19:53.79	46N38.84	119N46.70	0.15	0.9			0.06	B		~ 7 km NW of 200W, near Juniper Springs on Hanford
95793000	10/20	00:00:35.16	46N31.04	119N35.37	8.07	-0.6			0.01	B		@ SE corner of 200W, near Hanford Well # 699-29-70 on Hanford
95776509	10/03	12:17:49.16	46N20.91	119N38.96	21.52	2.4			0.06	B		~ 4 km WSW of McWhorter Springs

4.0 Geology and Tectonic Analysis

4.1 Depth of Earthquakes

Studies of seismicity at the Hanford Site have shown that the seismicity is related to the following crustal stratigraphy (layers of rock types) (DOE 1988).

- The Columbia River Basalt Group (CRBG) (approximately 0-5 km deep)
- The prebasalt sediments (approximately 5-10 km deep)
- The crystalline basement (greater than approximately 10 km).

Since the early 1980s deep boreholes have been drilled for hydrocarbon exploration. These boreholes have provided accurate measurements of the physical properties of the CRBG and the prebasalt sediments (Reidel et al. 1987, 1994). The thickness of the prebasalt sediments and nature of the crystalline basement, however, are still poorly understood. The difference between the thickness listed here and the thickness of the crustal layers in the velocity model in Table 4 reflect data specific for the Hanford Site rather than the University of Washington's crustal model for eastern Washington.

Since records have been kept, about 75 percent of the earthquakes at the Hanford Site have originated in the CRBG layer. The prebasalt sediments have had about 7 percent of the events and the crystalline basement has had 18 percent.

For fiscal year (FY) 1996, 57 events were located (Table 2); 28 events (49 percent) occurred in the basalt, 15 events (26 percent) in the prebasalt sediments, and 14 events (25 percent) in the crystalline basement.

For the current quarter, 22 events were located (Table 2); 9 events (41 percent) occurred in the basalt, 9 event (41 percent) occurred in the prebasalt sediments, and 4 events (18 percent) occurred in the crystalline basement.

4.2 Tectonic Pattern

Studies at the Hanford Site have concluded that earthquakes can occur in the following six different tectonic environments (earthquake sources) at the Hanford Site and in the Columbia Basin of eastern Washington (Geomatrix 1996).

- **Reverse thrust faults.** Reverse/thrust faults in the CRBG associated with major anticlinal ridges such as Rattlesnake Mountain, Yakima Ridge, and Umtanum Ridge could produce the largest earthquakes.
- **Secondary faults.** These are associated with the major anticlinal ridges.

- **Swarm areas.** Small geographic areas of unknown geologic structure produce clusters of events (swarms), usually in the CRBG in synclinal valleys. These clusters consist of a series of small shocks with no one outstanding principle event. Swarms occur over a period of days or months and the events may number into the hundreds and then quit, only to start again at a later date. This differs from the sequence of foreshocks, mainshock, and trailing-off aftershocks that have the same epicenter or are associated with the same fault system. Three principal swarm areas are known at the Hanford Site. One is the Wooded Island Swarm Area along the Columbia River near the 300 Area. The second area, the Coyote Rapids Swarm Area, extends from the vicinity of the 100 K Area north-northeast along the Columbia River Horn to the vicinity of the 100 N Area. The third major swarm area is along the Saddle Mountains on the northern boundary of the Hanford Site. Other earthquake swarm areas are present, but activity is less frequent.
- **The entire Columbia Basin.** The entire basin, including the Hanford Site, could produce a "floating" earthquake. A floating earthquake is one that, for seismic design purposes, can happen anywhere in a tectonic province and is not associated with any known geologic structure. It is classified as a random event by Seismic Monitoring for purposes of seismic design and vibratory ground motion studies.
- **Basement source structures.** Studies suggest that major earthquakes can originate in tectonic structures in the crystalline basement. Because little is known about geologic structures in the crystalline basement beneath the Hanford Site, earthquakes cannot be directly tied to a mapped fault. Earthquakes occurring in the crystalline basement without known sources are treated as random events for seismic hazards analysis and seismic design development.
- **The Cascadia Subduction Zone.** This source recently has been postulated to be capable of producing a M_c 9 earthquake. Because this source is along the western boundary of Washington State and outside the Hanford Array, the Cascadia Subduction Zone is not an earthquake source that is monitored at the Hanford Site, so subduction zone earthquakes are not reported here. Because any earthquake along the Cascadia Subduction zone can have a significant impact on the Hanford Site (Geomatrix 1996), the University of Washington monitors and reports on this earthquake source for the U.S. Department of Energy (DOE). Ground motion from any moderate or larger Cascadia Subduction Zone earthquake is detected by seismometers in the HSN.

4.3 Current Tectonic Activity

The locations of all events with M_c greater than 1.0 for July 1, 1996 to September 30, 1996 are shown on Figure 3. The locations of all seismic events for FY 1996 are shown in Figure 4. Figure 5 is a tectonic map of the Yakima Fold Belt and Hanford Site. The Yakima Fold Belt is the main tectonic province of concern for the Hanford Site. The figure shows all the major mapped ridges and faults that are potential seismic sources. These figures should be referred to for the following discussions.

Figure 3. All Located Earthquakes: July 1, 1996, and September 30, 1996. (Coda Length Amplitude (M_c) Scale is shown at the side of the Map.)

Figure 4. Locations of All FY 1996 Events: (Coda Length Amplitude Magnitude (M_c) Scale is shown at the side of the map.)

H95110224.10

Figure 5. Structural and Tectonic Map of Columbia Basin Showing Major Seismic Source Structures.

4.3.1 Reverse/Thrust Faults on Major Anticlinal Ridges

During the period from July 1, 1996 to September 30, 1996, no events appear to have occurred on one of the major anticlinal ridges.

4.3.2 Secondary Structures on Main Anticlinal Ridges

During the reporting period from July 1, 1996 to September 30, 1996, no events appear to have occurred on any secondary structures on any major anticlinal fold in the area.

4.3.3 Swarm Area Activity

During this same reporting period, 13 events (59 percent of all events located) were located in earthquake swarm areas. The swarm areas are discussed in Sections 4.3.3.1 through 4.3.3.4.

4.3.3.1 Saddle Mountains Swarm Area. The Saddle Mountains swarm area experienced three small (< 1 CAM) event during the reporting period. These events occurred on August 12, August 19, and September 28, 1996. The first event occurred in the basalt, the second event occurred in the prebasalt sediments and the third event occurred in the crystalline basement. The August 19th event occurred near the Saddle Mountains fault but was too deep to be caused by the fault. The fault plane dips to the south and this earthquake would be located in the footwall, north of the fault. The two other events occurred several kilometers north of the Saddle Mountains structure.

4.3.3.2 Coyote Rapids Swarm Area. Five earthquakes occurred in the Coyote Rapids swarm during this quarter. The events occurred on July 11, July 12 (a double event), September 4, and September 7, 1996. These were a small-magnitude earthquakes (< 2 CAM). Four events occurred within 3 km of the 100 B and 100 K areas and the fifth event, September 4, 1996, occurred within 3 km of 100 N area. The events near 100 B and 100 K areas occurred both in the basalt and prebasalt sediments while the event near 100 N Area occurred in the basalt.

4.3.3.3 Wooded Island Swarm Area. Two events occurred in the Wooded Island swarm area on August 12, 1996. These events occurred near Johnson Island, one near the east end and one near the southeast of the island. All events were less than 1 CAM and occurred in the basalt at very shallow depths.

4.3.3.4 Other Swarm Areas. The Benson Ranch earthquake swarm area appears to have been active during the reporting period. Three small magnitude (< 1.5 CAM) events occurred there: August 28, September 22, and September 28, 1996. All events were deep (> 8 km); one event occurred in the prebasalt sediments and two occurred in the crystalline basement. The events are interpreted to be too deep to have occurred on the Yakima Ridge anticline.

4.3.4 Random or Floating Event Areas

Nine events that occurred during this reporting period (40.9 percent of all events located) are classified as random events.

One event occurred on July 5, 1996 in the Yakima Valley syncline between the Horse Heaven Hills and Rattlesnake Mountain. This event occurred in the prebasalt sediments and had a magnitude less than 1.0 CAM. There is no known structure near the hypocenter.

Eight event occurred in the Horse Heaven Hills (HHH) between July 11 and September 2, 1996 in a small geographic area south of Prosser, Washington. These events are just beyond the monitoring array. Blasting by the Benton County Highway Department accounts for seven of the events. The remaining small (2.0 CAM) event (September 5, 1996) is classified as an earthquake. It occurred near the crest of the HHH at a depth of 1.1 km.

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