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Reference

WPPSS (Washington Public Power Supply System), 1981a. Final Safety Analysis Report: WPPSS Nuclear Project No. 2, Richland, Washington, Volume 2, pp. 2.4-1 through 2.4-12, 2.5-114, 2.5-118, 2.5-119, and 2.5-131 through 2.5-143.

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magnitude, and focal depth if they were determined. Additional source parameters for selected earthquakes are discussed in Subsection 2.5.2.1.1.1, Appendix 2.5I, and in Appendix 2.5J.

For purposes of completeness, Table 2.5-5a supplements Table 2.5-5 and lists earthquakes reported in published and unpublished literature that have no reported intensity and for which data are very limited. These events occurred primarily during the early historical period. It is not known whether they meet the minimum magnitude or intensity criteria for Table 2.5-5.

Compared to coastal California or Alaska, the historical seismicity of the area within 320 km of the site is generally low to moderate in the frequency of occurrencc of felt events and in the frequency of earthquakes having magnitudus that exceed 3.0. The most active seismic zones in the area are associated with: 1) earthquakes inferred to occur within a subducted oceanic slab at depths of 40 to 70 km (Crosson, 1980) beneath the Puget Trough (Subsection 2.5.1.1.2.3); and 2) the crustal Puget Trough and Cascade Mountains (Subsections 2.5.1.1.2.3 and 2.5.1.1.2.8), where earthquakes occur in the depth range 0 to 30 km. Historical earthquake activity associated with the Columbia Plateau and adjacent provinces is summarized in Subsection 2.5.2.3. The current tectonic setting of these provinces is summarized by (Appendix 2.5N) and in Section 2.5.1.

Within the Columbia Plateau, historical earthquakes have been generally small and scattered, as shown in Figure 2.5-38. Relative concentrations of activity are noted between Wenatchee and Chelan (at a distance of 140 km from the site and discussed in Appendix 2.5I) and trending northeast and southwest from Walla Walla (at a distance of about 90 km from the site and discussed in Woodward-Clyde Consultants, 1980a). The areas of these two concentrations have been seismically active throughout the historical period, with the occasional occurence of felt earthquakes (Figure 2.5-38 and Table 2.5-5). However, felt events have been reported less frequently from within the Columbia Plateau than in these areas (Figure 2.5-52). Because the historical population distribution has been similar for these areas, the lower frequency of reported felt events within the interior of the Plateau appears real.

The operation of a seismic network at the Hanford Reservation since 1969 greatly increased the number of earthquakes detected in the area (Subsection 2.5.2.1.2.2) but the frequency of occurrence of felt events (MM IV) is

having magnitudes of (M_S) 6.9 to 7.1 that have occurred at focal depths of 60 to 70 km in Pacific Northwest have been devoid of significant aftershock activity.

Using the 1872 earthquake intensity data reported by the other workers (Washington Public Power Supply System, 1977p), Malone and Bor (1979) analyzed the location and size of the 1872 earthquake in terms of an attenuation model that accounts for local corrections to regional intensity attenuation. They tested several location assumptions; a location near Ross Lake was favored, but the data also fit the Milne (1956) location to the northeast. A location near Lake Chelan was definitely ruled out. Malone and Bor (1979) felt that the depth of focus could be 40 to 60 km, based on the known depths of other large earthquakes in the area, but the intensity data also allow a much shallower focal depth.

In summary, the comparison of the data from the 1872 event to modern data suggests that the 1872 earthquake had a magnitude of (M_S) 7 to 7-1/4 and probably occurred at a focal depth of about 20 km with an epicentral intensity (MM) VIII for structural response.

On July 16, 1936, the Milton-Freewater earthquake (M_S 5-3/4 reported Gutenberg and Richter, 1965; M_L 6.1 reported by Woodward-Clyde Consultants, 1980a) occurred 85 km southeast of the site. This earthquake, which was felt over an area of approximately 270,000 km^2, is the closest earthquake of maximum intensity (MM) VII or greater to have affected the site region. The isoseismal map for the earthquake is shown on Figure 2.5-41 and indicates an intensity (MM) IV level of shaking in the vicinity of the site. Estimates by observers for the duration of rapid ground motion in the epicentral region ranged from 10 to 30 seconds. The intensity effects of this earthquake have been described in detail by Brown (1937), USCGS, and Neumann (1938) and are discussed in Washington Public Power Supply System (1974).

Considerable property damage occurred but no serious injuries were noted in the area of highest intensity, particularly at Milton-Freewater, State Line, and Umapine in northern Oregon. Brown (1937) reported that, in the Milton-Freewater area, many chimneys were broken or shifted, plaster and windows were broken, several houses were moved off their foundations, a two-story concrete house lost part of the top of its second story, the ornamental railing on top of a cement block office building in Milton-Freewater

was greatly damaged, and many capstones in cemeteries were rotated. He also reported numerous changes in springs and water wells and some local ground cracking.

In the Pasco area, the shock was reported to have lasted for 30 seconds, causing dishes to rattle and pictures on walls to sway, but producing minimal property damage.

As discussed by Woodward-Clyde Consultants (1980b), the instrumental location for the Milton-Freewater earthquake was computed to be latitude 46°12.5' north, longitude 118°14.0' west, with an uncertainty of about 20 km. This epicenter is likely to be the point of initiation of rupture, and the aftershock reports and other intensity data suggest that the earthquake occurred on a buried fault surface that ruptured from the instrumental epicenter to the southwest, toward the area of highest intensity. This trend is parallel to the structural trend of the Blue Mountains anticline and to the trend of the Hite fault (Figure 2.5-38 and Shannon and Wilson, 1979b). The felt reports indicate that the zones of maximum structural damage during the main shock were also generally aligned along a northeast-southwest trend. Also, soil fissuring occurred at two locations in the maximum intensity region of the main shock. At the first location, the fissuring was aligned in an east-west direction along a highway cut; at the other, a railway cut, it occurred in an east-southeast direction. These cuts appear to have controlled the orientation and nature of the soils failures. Surface fault ruptures were not observed.

On April 29, 1965 a magnitude (M_b) 6-1/2 earthquake having an epicentral intensity of (MM) VII-VIII occurred near Seattle, 255 km west-northwest of the site. The earthquake was felt over an area of 335,000 km^2 as shown on the isoseismal map, Figure 2.5-42. The site, located on the higher side of the I-VI intensity (MM) zone, has been assigned an intensity (MM) IV.

In the Seattle-Tacoma region, damage effects of intensity (MM) VII and VIII are closely related to poor foundation conditions in the epicentral region (unconsolidated deposits characteristic of parts of the Puget Sound area). The effects at the Hanford Reservation are summarized in the following excerpt:

> Richland (Hanford Project). Motion rapid, lasted 45 seconds to 2 minutes. Felt by many in community. Hanging objects swung north-northeast. (USCGS)

source of the 1936 earthquake or other events in the area and a mapped geologic structure or fault (Subsection 2.5.2.1.1.1; Woodward-Clyde Consultants, 1980a). Additional small and generally scattered earthquakes occur within the province (Figure 2.5-39) with no apparent correlation to known geologic structures.

2.5.2.3.4 Other Provinces Adjacent to the Columbia Plateau

The Middle Cascade Mountains province, which is more than 110 km from the site, has generated scattered, small to moderate magnitude earthquakes, such as the September 16, 1961 event (Subsection 2.5.2.1.1.1) near Mount St. Helens. The Northern Rocky Mountains province, which is more than 160 km from the site, generated the August 17, 1959 Hebgen Lake earthquake (Subsection 2.5.2.1.1.1). Because of the distance of each of these provinces from the site, their earthquake potential is not considered further.

2.5.2.3.5 Columbia Plateau

The Columuia Plateau is characterized by small, scattered, infrequent earthquakes (Figures 2.5-38 and -52). Two concentrations of seismicity occur along the northwest boundary with the North Cascades (Chelan-Wenatchee area) and along the southeast boundary with the Blue Mountains (Walla Walla area) and are discussed in Subsection 2.5.2.3.3. Within 80 km (50 mi) of the site in the central Columbia Plateau, a minor concentration of earthquakes is located between Frenchman Hills and Saddle Mountains, and three additional events are located between Saddle Mountains and Gable Mountain (Figure 2.5-52). The December 20, 1973 Royal Slope and the November 1, 1918 Corfu earthquakes have been located between Saddle Mountains and Frenchman Hills (Figure 2.5-52). There is no well-defined correlation of this earthquake activity with the Frenchman Hills, Saddle Mountains, or Gable Mountain structures. However, because of the uncertainties in the epicentral location of the 1918 event (Subsection 2.5.2.1.1.1 and Appendix 2.5J) it is possible that this earthquake occurred on a fault associated with the Saddle Mountains anticline.

Analysis of microearthquake activity (M_L less than 3.0) for the data collected from 1969 through 1980 within the Columbia Plateau is discussed in Appendix 2.5I, Appendix 2.5J, and Woodward-Clyde Consultants (1980b), and is summarized in Subsection 2.5.2.1.2.2. The shallow, swarm-dominated microearthquake activity does exhibit some broad spatial trends, such as the northwest-southeast pattern lying between Frenchman Hills and Saddle Mountains.

The shallow activity appears to be associated with low-level deformation within the upper Columbia River basalts and to be triggered by the presence of high groundwater levels resulting from irrigation. However, no correlations between specific faults or fold structures and microearthquakes have been identified (as discussed in Appendix 2.5J). The microseismicity occurring beneath the flood basalt flows at depths from about 3 to 25 km appears to be distinct from the shallow activity (Woodward-Clyde Consultants 1980b; Appendix 2.5J). The deeper seismicity does not define any linear or planar patterns, nor is there any apparent association with the folds on other surface geologic structures of the Columbia Plateau.

2.5.2.4 Maximum Earthquake Potential

The maximum earthquake potential at the site was assessed based on the maximum historical intensity (Subsection 2.5.2.4.1). Recent investigations have indicated that the Central fault on Gable Mountain is capable according to U. S. Nuclear Regulatory Commission criteria (Appendix A, 10 CFR 100), and other studies have suggested that some of the fold structures of the Columbia Plateau may be associated with capable faults (Subsection 2.5.2.2.2.3). Uncertainties exist regarding the association of faults with known folds, fault capability, source geometry, and tectonic framework (Subsection 2.5.2.2). To account formally for these uncertainties, maximum earthquake magnitudes for potential fault sources were assessed probabilistically. The results of the maximum magnitude assessment are incorporated into a seismic exposure analysis (Appendix 2.5K) to evaluate the probability of exceeding the SSE design basis ground motion (0.25 g) that was based on the maximum historical intensity in the Columbia Plateau.

2.5.2.4.1 Maximum Historical Intensity

The potential vibratory ground motions that were used in the design of the WNP-2 and WNP-1/4 plants were based on the maximum historical earthquake intensity that has occurred in the Columbia Plateau (Washington Public Power Supply System, 1974), which is the July 16, 1936 Milton-Freewater earthquake. It had a maximum intensity of (MM) VII and occurred about 84 km southeast of the site. The December 14, 1872 earthquake had a maximum intensity of (MM) VIII and is thought to have occurred in the North Cascades province approximately 250 to 300 km from the site. The largest historical earthquake effects at the site are conservatively estimated to have been an intensity (MM) IV-V from the 1872 Northern Cascades earthquake, and an intensity (MM) IV from

the July 16, 1936 Milton-Freewater earthquake (Subsection 2.5.2.1.1). The closer (1936) earthquake probably produced a higher acceleration level at the site because of attenuation of the higher frequency wave components from the more distant event.

The 1936 Milton-Freewater earthquake epicentral region is near the intersection of the southeast extension of the Rattlesnake-Wallula alignment and the northeast-striking structures parallel to the Hite fault zone (Figure 2.5-52). There is no apparent correlation of seismicity with the Rattlesnake-Wallula alignment (Subsection 2.5.2.3). Nevertheless, for conservatism, it was postulated that an earthquake of intensity (MM) VII, similar to the 1936 Milton-Freewater event, could occur on the Rattlesnake-Wallula alignment, approximately 20 km from the site. If no attenuation is considered over the 20 km distance between the alignment and the site, such an earthquake would result in an acceleration of 0.125 g (Figure 2.5-54) at the site.

The maximum earthquake potential from any other tectonic province within the site region was not considered high enough to be capable of exceeding the 0.125 g level of shaking at the site resulting from earthquakes originating in the site province.

2.5.2.4.2 Geologic Structure Approach

A geologic structure approach for assessing maximum earthquake magnitudes and the potential vibratory ground motions is appropriate for sites in the vicinity of capable faults. The 3 km-long Central fault on Gable Mountain is the only fault in the site vicinity that has been shown to be capable according to U. S. Nuclear Regulatory Commission criteria. Tectonic models proposed for thc Columbia Plateau postulate the presence of faults, both primary and secondary, associated with the major folds (Subsection 2.5.2.2). Although the capability of these mapped or inferred faults is uncertain, estimates of maximum earthquake potential can be made assuming that there is some likelihood both that the faults exist and that they are capable. Alternative tectoinc models and the associated geometry of the faults are considered in a probabilistic assessment of maximum earthquake magnitudes for each source.

Maximum earthquake magnitude on a fault is related to source geometry (rupture length, rupture area) and fault behavior (maximum and average displacemcnt per event, slip rate, and sense of displacement). Based on these fault parameters, empirical and analytical relationships can be used to

estimate maximum magnitudes. The use of a number of magnitude estimation techniques can result in more reliable estimates of maximum magnitude than the application of any single technique.

Alternative tectonic models have been proposed to account for the known and inferred structural elements of the Columbia Plateau; each model has implications to magnitude-related fault parameters (Subsection 2.5.2.2). Because more than one of these models may be compatible with the available data, the fault parameters associated with all possible models must be considered in the maximum magnitude assessment. As part of the probabilistic assessment of maximum magnitudes, the full range of possible fault parameters are considered. Degrees of confidence in the various tectonic models and parameters are assigned based on available data. In addition, the applicability of various techniques for estimating maximum magnitude is assessed for each tectonic model.

A discussion of the probabilistic methodology and the justification for decisions regarding tectonic models, fault parameters, and maximum magnitude assessment techniques are given in Appendix 2.5K.

2.5.2.4.2.1 Potential Seismic Sources Significant to the Site

The geologic structures that may be potential sources significant to assessing the probability of exceeding the SSE vibratory ground motions at the site are listed below and are shown in Figure 2.5-55.

Potential Seismic Sources	Closest Surface Distance to Site (km)
Umtanum Ridge-Gable Mountain Structural Trend	
Central fault	18
Gable Mountain-Southeast Anticline segment	7
Umtanum Ridge eastern segment	38
Umtanum Ridge central segment	63
Umtanum Ridge western segment	92
Rattlesnake-Wallula Alignment (RAW)	
Rattlesnake Mountain segment	20
Rattlesnake-Wallula segment	20
Wallula segment	53
Saddle Mountains	31
Rattlesnake Hills	27

Yakima Ridge	32
Horse Heaven Hills	30

All of the potential sources, except the Central fault, are structural folds. Observed or inferred faults of uncertain capability are associated with these fold structures. On the basis of the geologic and geomorphic data discussed by Woodward-Clyde Consultants in Appendix 2.5K, potential sources were segmented and in some cases, parts of structural trends were assumed to be separate potential sources.

2.5.2.4.2.2 Maximum Magnitude Assessment of the Central Fault on Gable Mountain

The Central fault on Gable Mountain is capable according to U. S. Nuclear Regulatory Commission criteria, and the maximum magnitude for the Central fault is assessed deterministically. Although some evidence supports non-tectonic hypotheses for the origin of the displacement along the Central fault, data gathered to date are insufficient to demonstrate a non-tectonic mechanism for the origin of the observed displacement. The magnitude assessment presented in this section is applicable only to the Central fault; magnitude estimates for the Gable Mountain-Southeast anticline segment of the Umtanum Ridge-Gable Mountain structural trend are made probabilistically and are summarized in Appendix 2.5K.

Magnitude-related data on the Central fault are presented by Golder Associates (1981a) and are summarized in this section. The Central fault is a northeast-striking reverse fault that dips to the southeast. The fault is interpreted to be the result of the interference of two en echelon folds, the east and west Gable Mountain anticlines. The maximim inferred length of the Central fault is about 3 km (2 mi). The fault displaces glaciofluvial deposits correlative with late-Pleistocene Missoula flood deposits that are between 13,000 and 19,000 years old. The glaciofluvial deposits are displaced up to 6 cm (0.2 ft).

Inferences based on the available data regarding the geometry and behavior of faulting on the Central fault can be made to estimate magnitudes. The east and west Gable Mountain anticlines are second-order folds that have wavelengths of less than 1 km; the folds may extend as deep as one wavelength but probably no deeper than three wavelengths. Because the Central fault is most likely secondary to folding, the down-dip width of the fault surface is probably no greater than the depth of the

en echelon folds. Therefore, the maximum width of the Central fault is estimated to be 3 km. The 6 cm (0.2 ft) displacement of the glaciofluvial deposits is the largest displacement that can reasonably be assumed to have occurred as a single event. In addition, the seismic moment can be estimated if the 6 cm (0.2 ft) displacement is assumed to be an average displacement over the fault surface.

The limited dimensions of the Central fault on Gable Mountain raise questions regarding its ability to generate significant earthquakes. However, assuming the Central fault is seismogenic, the following magnitudes are derived using the magnitude relationships presented in Appendix 2.5K:

Magnitude Relationship	Estimated Magnitude
Area vs M ($A = 9\ km^2$)	5.1
Displacement vs M ($D = 6$ cm)	4.4
Moment Magnitude ($A = 9\ km^2$, $= 3 \times 10^{11}\ dyn/cm^2$, $D = 6$ cm)	4.8
Lengths vs M ($L = 3$ km)	6.6

All of the magnitude estimates are subject to much uncertainty, primarily because the values of the parameters for the Central fault are smaller than those in the empirical data sets for the various magnitude relationships. The length-magnitude relationship is especially unreliable for short faults, such as the central fault, that have limited down-dip widths. The area-magnitude relationship accounts for the limited total size of the rupture surface available for energy release on narrow faults. On the basis of these assessments, the maximum earthquake magnitude for the Central fault is estimated to be magnitude 5. The ground motions that would be produced at the site by this earthquake would be less than 0.1 g, as discussed in Subsection 2.5.2.6.1.

2.5.2.4.2.3 Maximum Earthquake Magnitudes for Potential Seismic Sources

As part of the seismic exposure analysis, maximum magnitudes are estimated for potential sources. For the magnitude analysis, it is assumed that the structures are capable seismogenic sources. The actual asseesment of the

capability of the potential sources is considered probabilistically in the seismic exposure analysis (Appendix 2.5K).

As noted in Subsection 2.5.2.3, the shallow-focus microearthquakes that occur within the Columbia River basalts do not correlate with specific geologic structures. Based on the historical earthquake record and on associated detailed analyses of potential source characteristics within the Columbia River basalts, the maximum magnitude for the shallow focus earthquakes in the vicinity of the site is unlikely to be larger than M_L 4.0 Appendix 2.5J. Earthquakes of magnitude 4 or less are considered not to be of engineering significance to the plant because of the very short duration of vibratory motion associated with such earthquakes.

2.5.2.5 Seismic Wave Transmission Characteristics of the Site

At the site, about 14 m (to elevation 120 m) of glaciofluvial sand overlies the middle and lower members of the Ringold Formation. The middle member extends to a depth of about 76 m (elevation 58 m) and consists of dense gravel that contains relatively thin silt and sand zones at various depths. The lower member is predominantly a compact interbedded gravel, sand, and silt that extends to a depth of about 160 m (elevation -26 m) where it is underlain by basalt bedrock.

Compressional and shear wave velocities are based on geophysical surveys that are described in Appendix 2.5D. In the glaciofluvial sand, compressional velocities average 410 m/s and shear velocities average 200 m/s. In the upper part of the middle member of the Ringold Formation, compressional velocities range from 1,040 to 1,370 m/s and shear velocities from 520 to 580 m/s. A marked increase in compressional velocities (2,700 to 3,200 m/s) and shear velocities (1,280 to 1,370 m/s) was encountered at a depth of about 24 m (elevation 110 m) which is interpreted to indicate more compact material below this depth in the middle member of the Ringold. In the lower member of the Ringold, below 76 m depth (elevation 58 m), shear velocities range from 580 to 1,370 m/s. The seismic wave velocities at the site are summarized in Table 2.5-8. The dynamic properties of the materials are also described in Subsection 2.5.4.2.

Compressional and shear wave velocities of the soils above basalt bedrock have also been measured at WNP-1/4 (Appendix

2L of the WNP-1/4 PSAR). The changes in the wave velocities with depth at WNP-1/4 have a similar trend to those described above for WNP-2.

Because of the presence of relatively thick layers of soils above basalt bedrock, attenuation relationships applicable to soils rather than rock have been selected for use in the seismic exposure analysis. Attenuation relationships are described in Appendix 2.5K.

Available data describing material properties of the basalt flows, interflow materials, and deeper structures beneath the site have been reviewed for the purpose of evaluating the attenuation characteristics of the crustal structure. The best currently available information for characterizing the basalt-interflow materials has been obtained from logs of deep wells drilled in the area. The deepest of these is the Rattlesnake Hills No. 1 well, which extends to a depth of 3,230 m. The sonic log from this well indicates that the compressional-wave velocity is highly variable as a function of depth, with relatively high velocities of 5.0 to 5.7 km/s occuring in competent basalt flows and lower velocities of 4.0 to 4.5 km/s being typical of interflow materials. The lower-velocity materials were generally of lower density also. This variation in compressional-wave velocities in the basalt flows and interflow materials is also likely to characterize the shear wave velocities, although no direct measurements of the shear wave velocity at depth were made. Theoretical calculations, described in Woodward-Clyde Consultants (1981d), have indicated that this wave-velocity structure may substantially decrease peak strong ground motions at the site for earthquake sources beneath the higher-velocity layers in the basalt, relative to ground motions that would occur in the absence of these strong vertical material heterogeneities. The physical basis of this decrease in ground motions is known as the tunneling phenomenon; it is associated with waves incident from a relatively low to a relatively high velocity layer at angles from the vertical greater than a critical value that depends on the velocity contrast. The tunneling phenomenon has been modeled (Woodward-Clyde Consultants, 1981d) and found to decrease peak motions by 50 percent or more at epicentral distances of 6 to 15 km for source depths beneath the high-velocity layers. This conclusion is deperdent on several assumptions regarding kinematic descriptions of the seismic source, the relationship between shear and compressional wave velocities in the basalts, the source depth, and the nature of the crust beneath the basalts.

These theoretically predicted attenuation effects have been conservatively neglected in modeling attenuation in the seismic exposure analysis (Appendix 2.5K).

2.5.2.6 Safe Shutdown Earthquake

2.5.2.6.1 Vibratory Ground Motion of the SSE

The maximum vibration level at the site from historical earthquakes within the Columbia Plateau is estimated to have been 0.015 g associated with the site intensity (MM) IV from the Milton-Freewater earthquake (see Subsection 2.5.2.4 and Figure 2.5-54).

A peak acceleration of 0.25 g at ground surface in the site area has been assigned for the SSE. This value is consistent with the conservatism previously adopted for design criteria at the Hanford Reservation (Atomic Energy Commission, 1972) and is consistent with the vibratory accelerations associated with an intensity (MM) VIII earthquake (Figure 2.5-54), which is larger than any known earthquake east of the Cascades in Washington or Oregon. This earthquake was assigned to the Rattlesnake-Wallula alignment, which was considered to be the closest tectonic structure of significance to the site. The Rattlesnake-Wallula alignment is 20 km from the site. No attenuation was taken in the selection of the SSE.

As summarized in Subsection 2.5.2.4, the Central fault on Gable Mountain is capapble according to U. S. Nuclear Regulatory Commission criteria. Magnitude 5 is estimated to be the maximum magnitude, and the closest distance from the fault to the site is 18 km. Using the magnitude-distance-acceleration attenuation relationships given in Appendix 2.5K, the estimated peak acceleration at the plant site for this earthquake is less than 0.1 g.

The design response spectra for the SSE corresponding to the maximum vibratory acceleration of 0.25 g are shown on Figures 3.7-1 and 3.7-2.

2.5.2.6.2 Evaluation of the Probability of Exceedance of the Vibratory Ground Motion of the SSE

A seismic exposure analysis has been performed to estimate the probability of exceeding the vibratory ground motions of the SSE. The uncertainties regarding fault segmentation, fault capability, fault geometry, maximum earthquake

magnitude, earthquake recurrence, and attenuation have been formally addressed and incorporated in the seismic exposure analysis.

The methodology and inputs for the seismic exposure analysis are described in detail in Appendix 2.5K. The methodology is shown schematically in Figure 2.5-56 and is briefly summarized below.

- All geologic structures that have the potential to be seismic sources (faults) of significance to the plant site are included in the analysis. These structures are identified in Subsection 2.5.2.4.2.1.

- Alternative fault segmentation models are defined, and the probabilities of each segmentation model representing the actual conditions are estimated.

- The conditional probabilities that each fault is a capable seismic source are estimated.

- Alternative tectonic models, described in Subsection 2.5.2.2, are defined for each fault. The conditional probabilities of each tectonic model representing the actual conditions are estimated.

- Alternative fault geometries (dips and widths of fault plane) are defined for each tectonic model for each fault. The conditional probabilities of each of these geometries being the actual geometry are estimated.

- Maximum earthquake magnitudes are estimated using different techniques for the geometries and tectonic models of each fault. The conditional probabilities of each maximum magnitude being the actual maximum magnitude are estimated.

- The recurrence of earthquakes of various magnitudes in the site region is evaluated based both on historical seismicity and geological evidence. Recurrence is distributed to the various faults in proportion to their lengths. The uncertainty in recurrence relationships is evaluated and included in the exposure analysis.

- Magnitude-distance-instrumental ground motion attenuation relationships are estimated. The uncertainty in predicted ground motion values

associated with these relationships is estimated and included in the exposure analysis. The selected attenuation relationships are judged to be conservative because they neglect the apparent highly attenuating effect of the basalt-interbed layering (Subsection 2.5.2.5).

- A seismic exposure analysis case is defined by each combination of segmentation, tectonic model, fault geometry, and maxiaum earthquake magnitudc for a given fault. These parameters are then combined with the recurrence and attenuation relationships to calculate the seismic exposure (probability of exceeding a certain ground motion value) for that case. Standard procedures for seismic exposure analysis are used for these calculations.

- The seismic exposure due to each fault is then calculated by appropriately combining the probabilities for each analysis case for that fault with the probabilities associated with maxumum magnitudes, fault geometry, tectonic models, fault capability, and fault segmentation. Then the total exposure for the plant site is obtained by combining the probabilities for all the sources.

From the results of the seismic exposure analysis, the estimated probability of instrumental ground motions exceeding the SSE peak ground acceleration (0.25 g), which is also the SSE design response spectral acceleration in the period range 0 to 0.03 second (Figure 3.7-1), is summarized below. Also summarized are the estimated probabilities of exceedance of SSE design response spectral acceleration at two other selected periods, 0.125 second and 0.40 second. These periods are selected because they correspond approximately to control points of the design response spectra in the low-period to mid-period range (Figure 3.7-1).

Ground Motion Parameter	Annual Probability of Exceedance
Peak ground acceleration of 0.25 g (zero-period response spectral acceleration)	1.1×10^{-4}
Response spectral acceleration at a period of 0.125 second (damping ratio of 0.02)	9.2×10^{-5}

Response spectral acceleration at a period of 0.40 second (damping ratio of 0.02)	2.9×10^{-5}

The values summarized above are the expected values, or best estimates, of the probabilities of exceedance. Confidence levels on the probabilities of exceedance have also been estimated in the seismic exposure analysis. At the 90 percent confidence level, the estimated probabilities of exceedance exceed the values tabulated above by a factor of about 2.5.

The analysis indicates that for peak ground acceleration and for response spectral acceleration at 0.125 second, approximately 70 percent of the exposure is due to earthquakes in the range of magnitude 4 to 5. For response spectral acceleration at 0.40 second, approximately 50 percent of the exposure is from the same magnitude range. These small-magnitude earthquakes are of less engineering significance than large-magnitude earthquakes due to their shorter duration and lower energy content. Consequently, this analysis is a conservative assessment of the probability ot exceedance (or ground motions of engineering significance.

2.5.2.7 Operating Basis Earthquake

A peak acceleration of 0.125 g, or one-half that of the SSE, has been assigned for the Operating Basis Earthquake (OBE). The chosen value for the OBE is consistent with the epicentral intensity of the largest historical earthquake that has occurred in the Columuia Plateau (Subsection 2.5.2.4 and Figure 2.5-54). The design response spectra for the OBE are shown on Figures 3.7-3 and 3.7-4.

The probability of exceeding the OBE ground motions has been evaluated from the seismic exposure analysis described in Subsection 2.5.2.6. The estimated probabilities of exceeding the OBE peak ground acceleration and selected spectral accelerations of the OBE design response spectrum (Figure 3.7-3) are as follows:

Ground Motion Parameter	Annual Probability of Exceedance
Peak ground accelerations of 0.125 g (zero-period response spectral acceleration)	4.6×10^{-4}

Response spectral acceleration at a period of 0.125 second (damping ratio of 0.02)	4.0×10^{-4}
Response spectral acceleration at a period of 0.40 second (damping ratio of 0.02)	1.7×10^{-4}

At the 90 percent confidence level, the estimated probabilities of exceedance exceed the expected values tabulated above by a factor of about 2.2. Similar to the results for the SSE described in Subsection 2.5.2.6, small-magnitude earthquakes are found to dominate the seismic exposure for the OBE. For peak acceleration and for response spectral acceleration at 0.125 second, approximately 70 percent of the seismic exposure is due to earthquakes in the range of magnitude 4 to 5. For response spectral acceleration at 0.40 second, approximateiy 60 percent of the exposure is due to earthquakes in the same magnitude range.

2.5.3 SURFACE FAULTING

Available geologic information, supplemented by geologic field mapping, aerial photograph interpretation, and subsurface data, were analyzed to determine whether the potential for surface faulting exisits within 5 mi of the site. This analysis which is summarized on Figure 2.5-30 and described in 2.5.1.2.7.4 indicated that there are no capable faults within a 5 mi radius of the site. Therefore, surface faulting is not a factor in the design of the plant.

Because there are no known faults within 5 mi of the site, Subsections 2.5.3.1 through 2.5.3.8 do not apply.

2.5.4 STABILITY OF SUBSURFACE MATERIALS AND FOUNDATIONS

2.5.4.1 Geologic Features

The geologic features at the site are discussed in detail in 2.5.1.2.7.2 and 2.5.1.2.7.3, and significant subsurface features are summarized on Figure 2.5-64.

2.5.4.1.1 Areas of Potential Surface or Subsurface Subsidence

There are no areas of actual or potential surface or subsurface subsidence, uplift, or collapse at the site.

2.4 HYDROLOGY ENGINEERING

2.4.1 HYDROLOGIC DESCRIPTION

2.4.1.1 Site and Facilities

WNP-2 is located in the Hanford Reservation within Benton County, Washington, approximately three miles west of the Columbia River at River Mile 352, twelve miles north of Richland and 45 miles downstream from Grant County PUD Priest Rapids Dam. The site coordinates are approximately 46° 28' North Latitude and 119° 20' West Longitude.

The Columbia River is the predominant hydrologic feature of the area and provides principal drainage for the surrounding area and the site. The river bed is clearly marked in the terrain and at the proximity of the site the river flows between high banks. Other less important hydrologic features are the Yakima River to the south and Rattlesnake Creek on the west. The Yakima River at its closest point flows within eight miles of the plant site. The river system is shown in the Hydrographic Map, Figure 2.4-1. The approximate river bottom is at Elevation 328 ft. MSL; the ground elevation at the site is approximately 440 feet, based on USGS data.

All Seismic Category I structures are adequately protected against floods. For flood elevations refer to 2.4.3 and 2.4.4.

Cooling tower makeup water and plant service water are withdrawn from the Columbia River. The intake system is designed for a maximum capacity of 25,000 gpm (55.7 cfs). This amount of water is not significant when compared to the minimum flow of 36,000 cfs in the Columbia River. The makeup water intake system is made up of three parts: two offshore perforated pipe inlets supported above the bed of the river; two lead-in pipes; and the pump structure, almost fully buried in the river bank, located approximately three miles east of the plant. A secondary (standby) service water source is the ground water utilizing three wells as described in 2.4.13.1.

A topographic map and contour map of the region surrounding the site are shown in Figures 2.4-2 and 2.4-10. Figure 2.1-4 shows details of contours in the main plant area.

The natural drainage features of the surrounding area have not been changed by the construction of WNP-2.

2.4.1.2 Hydrosphere

The Columbia River, the largest river flowing into the Pacific Ocean from North America, is one of this world's greatest sources of hydroelectric power. Its annual discharge of 18,000,000 acre ft. (1 acre-ft = 43,560 cu ft) is exceeded in the North American continent only by the Mississippi, Mackenzie and St. Lawrence Rivers.

The Columbia River drains an area of approximately 258,000 square miles, lying to the west of the Continental Divide in the northwestern part of the United States (85%) and Southwestern part of Canada (15%). Major tributaries are the Kootenay, Snake, Pend Oreille, Spokane, Okanogan, Yakima and Willamette Rivers.

In determining the Standard Project Flood the drainage area was divided into subbasins. These subbasins can be grouped into six general areas with similar hydrometeorological characteristics.

The six (6) areas are: (1) upper Columbia, which includes the drainage of the area in Canada and the northern part of the United States above Chief Joseph Dam; (2) Middle Columbia, which includes the area between Pasco and Chief Joseph Dam; (3) Upper and Middle Snake River; (4) Lower Snake River, the area between Weiser and Ice Harbor Dam; (5) Lower Columbia, including the area between Bonneville Dam and Pasco; (6) the Columbia below Bonneville Dam, including the Willamette River.

The river basin has five (5) outstanding physical features: the Rocky Mountain System, the Columbia Plateau, the Columbia River Gorge, the Cascade Range and Puget Trough.

The Rocky Mountain System is the major range with elevations from 2,000 to over 12,000 feet. There are permanent glaciers and extensive snow fields at higher elevations and deep valleys that provide the principal drainage for the headwaters of the Columbia, Kootenay and other rivers.

The Columbia Plateau is a great, generally treeless, semiarid plateau covering over 100,000 square miles in the central portion of the basin. This plateau is in an area between the Cascade Range and the Rocky Mountains. The plateau was formed by successive flows of lava and filled to a general thickness of approximately 4,000 feet. The Columbia River flows 1,214 miles from its source in Columbia Lake (elevation 2,700 ft) in British Columbia, near the crest of the Rockies, to the Pacific Ocean at Astoria, Oregon. It sweeps around the north and northwesterly sides of the Columbia Plateau to central Washington to be joined by the Snake River. The Columbia River flows directly across the axis of the Cascades in a narrow gorge to the Pacific.

The Columbia Gorge is the gateway from the Pacific Ocean to the intermountain Columbia Plateau. Tide flows 140 miles upriver. For most of its length the river flows in deep valleys and canyons.

High flows occur in late spring and early summer with melting of snow on the mountainous watershed. Low flows occur in autumn and winter.

The Columbia River has been regulated by dams and reservoirs over the past thirty five (35) years. A large portion of the main stream and major tributaries is developed to meet various functional requirements, such as flood control, hydroelectric power, irrigation, municipal and industrial supply, etc. The regulation of Columbia River floods is accomplished by use of reservoir storage space provided primarily for irrigation or for hydroelectric power utilization. The volume of useable reservoir storage space is on the order of 20% to 25%.

There are seven dams upstream and four dams downstream of the site on the main stream of the Columbia River within the United States. These dams are listed in Table 2.4-1. Major hydrologic features are shown in Figure 2.4-4.

The Grand Coulee and Bonneville dams were put into operation prior to World War II and several dams were built after the war. The four downstream dams include large locks to permit the passage of river vessels. Several of the dams provide

emergency floodwater storage. Grand Coulee, the largest and most complex of the dams, augments the low winter flows for the entire system from its 9,402,000 acre-feet of available storage (of which approximately 5,100,000 acre-feet is active storage), and also pumps water to the Columbia River Irrigation Project.

The surface water flow of the Columbia River in the reach of WNP-2 is, to a large extent, controlled by regulation of the upstream reservoir projects, which have a total usable storage capacity of approximately 35 million acre-feet. Some control of flow in the immediate vicinity of the site is by regulation of the nearest upstream hydroelectric projects, Priest Rapids Dam, at River Mile 397, containing about 45,000 acre-feet of active storage, and Wanapum Dam, at River Mile 415, containing about 161,000 acre-feet of active storage. Some minimal effect on the river flow in the vicinity of the site is caused by McNary Dam, at River Mile 292, approximately 60 river miles downstream from the site area.

Flows in the Columbia River during the summer, fall and winter vary from a low of 36,000 cfs to as much as 160,000 cfs. During spring runoff high flows ranging from 250,000 cfs to 450,000 cfs have been recorded. The average annual flow is 120,000 cfs; during low flow periods flows may average about 60,000 cfs (See Figure 2.4-5).

The river channel near the WNP-2 site varies between 400 and 600 yards in width for low water and normal high water level, respectively. The depth varies from about 25 feet to 45 feet for normal high water and flood high water levels, respectively. Velocities vary from 3 feet per second (fps) to over 11 fps depending on section and flow. Average water temperature is 51°F. Temperatures may reach a low of 32°F and a high of 68°F. (See Figure 2.4-5).

A list of water usage downstream of WNP-2, obtained from records of the Department of Ecology, State of Washington, for water rights as of February 1980, is presented in Table 2.4-2. The location of local groundwater users is discussed in 2.4.13.2.

2.4.2 FLOODS

2.4.2.1 Flood History

Floods in the Columbia River Basin are grouped as:

a. the interior basin east of the Cascades, caused by melting snowpack and occurring from May through June;

b. the Willamette and other basins, west of the Cascades, caused by direct runoff from intense winter rain occasionally augmented by snowmelt.

There is some overlapping effect within these two groupings. At certain elevations, basins in the interior Columbia drainage area occasionally have significant flood flows resulting from winter rain or snowmelt. These are local floods and do not usually contribute sufficient flow to cause flooding of the main Columbia River. Major floods on the Columbia River Basin result from rapid spring melting of the snowpack over a wide area, generally augmented by rain, or by above-normal precipitation in May, accompanied by a major chinook wind which causes rapid area temperature rise. The annual spring snowmelt flood of the main interior basin is characterized by relatively uniform distribution over the basin. The snowfall and individual snow storms may vary, but the integration of all storms over the winter period smoothes the irregularities, with the result that the distribution of the flood runoff is reasonably constant from year to year.

The maximum historical flood of record is that of June 7, 1894 which resulted from a combination of hydrometeorologic conditions, including heavy snowpack and rapid melt plus rainfall. The peak discharge at WNP-2 was 740,000 cfs for the Columbia River, as estimated from high water mark at Wenatchee, Washington (Reference 2.4-2). The largest recent flood, occurring in 1948, had an observed peak discharge of 690,000 cfs at Hanford. These floods were spring floods resulting from the melt of a large snowpack combined with the spring rains (Reference 2.4-3). Water surface profiles for the Columbia River in the vicinity of the site as derived by the Corps of Engineers (Reference 2.4-3) are given in Figure 2.4-8.

The plant site is located approximately 3 miles west of the Columbia River at River Mile 352 with reactor floor elevation of 441.0 ft. MSL, which is 68 feet above the water level estimated for the largest historical flood (approximately 373.0 ft. MSL). There is no record of flooding in the immediate site area.

2.4.2.2 Flood Design Considerations

Flood protection of safety-related components is based on the highest calculated flood water level including wave effects, resulting from intense local precipitation. Several different probable maximum events were considered, including the Corps of Engineers design-project flood considered to be "the most severe reasonably possible". Wave action caused by storm winds, the effects of failure of upstream dam surge flooding and ice flooding were also considered.

The results of these analyses (described in 2.4.3) indicate that the plant site for WNP-2, located 3 miles west of the Columbia River at a ground elevation of approximately 440 ft. MSL, the reactor first floor at Elevation 441 ft. MSL, and the spray ponds with a minimum wall elevation of 435 ft. MSL are safe-from-flood.

2.4.2.3 Effects of Local Intense Precipitation

Intense local summer thunder storms can produce short duration rains which have the potential for causing serious flood. The probable maximum precipitation event for the WNP-2 site has been determined using the methodology developed by the U.S. Weather Bureau and reported in Hydrometeorological Report No. 43, "Probable Maximum Precipitation, Northwest States" (Reference 2.4-4).

The plant area drains easterly to a broad channel which is adequate to store and drain the probable maximum precipitation construction contours of the WNP-2 site are shown in Figure 2.1-4. The reactor building and the spray ponds are located at elevations that are safe from the effect of any flood resulting from the maximum precipitation event.

Winter precipitation may occur as rain or snow. The winter season snowfall has ranged from less than one-half inch to a maximum of 12 inches in December 1964. There is no ice accumulation at the site.

Roofs of buildings are designed to take, with adequate drainage, any instantaneous or local intense precipitation. Discharge from roof drains is carried by means of a storm sewer system to a manhole located southeast of the reactor building. From that point a pipeline with a northeast alignment transfers the discharge to a low point of disposal about 1,500 ft. away from the plant site.

The roofs of safety-related buildings are concrete beam and slab construction except the high roof of the reactor building which is metal deck on steel framing. The minimum roof slope for all structures is 1/8-inch per foot for adequate drainage and the roof areas are encompassed by curbs or parapet walls up to 3 feet 6 inches high. Roof plans, including details of roof drains and overflow scuppers are provided in Figure 2.4-36. Assuming that the roof drains are completely blocked during the probable maximum precipitation (PMP) event, overflow scuppers limit the depth of water to within the design load carrying capability of the roofs. Those safety-related structures that do not have this relief capability structurally can carry the entire PMP accumulations.

2.4.3 PROBABLE MAXIMUM FLOOD (PMF) ON STREAMS AND RIVERS

Analyses for Probable Maximum Flood (PMF) and Standard Project Flood (SPF) on the Columbia River done by the Corps of Engineers (Reference 2.4-3) are consistent with the requirements of Regulatory Guide 1.59, Rev. 2. The SPF for the Mid-Columbia Reach of the highly developed and regulated Columbia River has been defined by the Corps of Engineers (Reference 2.4-5) as 570,000 cfs. The unregulated Standard Project Flood for the same reach is 740,000 cfs. The unregulated PMF at the site was derived (Reference 2.4-6) by the North Pacific Division, Corps of Engineers (Reference 2.4-3). The adjusted flow for the Hanford region is given in Reference 5 as 1,600,000 cfs, for the unregulated PMF.

The methods of estimating peak flow rate and the controlled PMF hydrograph above Pasco are given in the above referenced report. Adjustment of the flood profiles for the Hanford region reported in Reference 2.4-5, results in a regulated PMF of 1,440,000 cfs and a water level of 390 feet at the Seismic Category II makeup water structure. This structure is not designed to function throughout the PMF but is designed on the basis SPF (unregulated) of 740,000 cfs. The water level at the intake structure (R.M. 351.7) was derived by interpolating the Corps of Engineers drawing dated November, 1970, titled "Columbia River Washington Water Surface Profiles, RM 323 to RM 395", sheet 2 of 2, and is given in Figure 2.4-8.

Although assumed to exist for the purpose of flood hydrograph calculations, the Corps of Engineers states (Reference 2.4-7) that the Ben Franklin dam is not a federally authorized project but as originally planned it would have been a low head dam which would have had only a negligible effect on extreme flood flows.

Presently there are no authorized river projects which affect the water level at the site.

The design basis flood for the WNP-2 site area results from the probable maximum precipitation event on the adjacent drainage basin and not from flooding of the Columbia River.

2.4.3.1 Probable Maximum Precipitation (PMP)

The Probable Maximum Precipitation (PMP) event which was presented in the WNP-2 PSAR was subsequently reevaluated in the preparation of the PSAR for WPPSS Nuclear Project No. 1 (Docket 50-460). The analysis presented here is consistent with the latter document.

Precipitation in the vicinity of the site has been classified by the U.S. Weather Bureau, Reference 2.4-4, as convergence precipitation, orographic precipitation, and thunderstorm precipitation. The methodology for predicting the total amount of precipitation from each of these events, as given in Reference 2.4-4, requires the adding together of the convergence PMP and the orographic PMP to obtain a single precipitation for a general storm. A separate analysis is then required for thunderstorms. Thunderstorms in the vicinity of the site can be locally very intense for short periods of time and hence, have the potential for causing serious flooding. The PMP for both a general storm and a thunderstorm were analyzed as given in Chapters 6 and 5, respectively, of Reference 2.4-4 for a 38.5 square mile basin at the site. This basin is shown in Figure 2.4-9 and is described in 2.4.3.3. The calculated general

storm PMP results in a 24-hour and 48-hour precipitation of 7.9 inches and 10.1 inches, respectively. A thunderstorm PMP yields 9.2 inches in a 6-hour period. Therefore, the thunderstorm is considerably more severe. The thunderstorm PMP hydrograph is:

Hour	Inches of Rain
1	0.6
2	1.6
3	5.2
4	0.9
5	0.5
6	0.4
Total	9.2

2.4.3.2 Precipitation Losses

Infiltration losses have been estimated in the vicinity of the sites as 1.5-2 inches/hour (Reference 2.4-7a). However, for the analysis below, an average antecedent moisture condition (Condition II as defined in Reference 2.4-51) was assumed. As explained in the following section, the 60-minute retention loss rate is 0.15 in/hr.

2.4.3.3 Runoff and Stream Course Models

The drainage basin common to the reactor building and spray ponds is shown in Figure 2.4-3. The entire area drains to a broad channel that extends in a north-south direction for about seven miles, and ranges from about 2,000 feet to over a mile wide. All plant structures are located on high ground to the west of the channel. At a point about 2.8 miles south of the reactor site, the four-lane DOE highway crosses the drainage basin. The area above this section is 33.2 square miles.

To evaluate the effect of the PMP event on the plant area, the peak discharge at the highway crossing, 2.8 miles downstream of the plant, was calculated using the U.S. Bureau of Reclamation procedure for computing design floods on ungaged basins from thunderstorm rainfall in the Western U.S. (Reference 2.4-51). Important assumptions used in the triangular hydrograph procedure of Reference 2.4-51 are:

a. Hydrologic soil group B

b. Land use and treatment class - poor pasture or range

c. Thunderstorm cover-index is brush-sage-grass combination with 50% or less cover density

d. Thunderstorm minimum 15-minute retention loss rate of 0.06 in/15 min. and 60-minute retention loss rate of 0.15 in/hr.

Additionally, no credit was taken in the hydrograph analysis for potential storage in the stream channel or upstream subbasins.

The time of concentration, T_c, for the watershed above the highway crossing was computed to be 7.5 hours. The PMF hydrograph is shown in Figure 2.4-9 for the 33.2 square mile drainage basin. A peak discharge of 21,400 cfs was determined.

Based on this PMF, an upstream water surface profile was determined using the Corps of Engineers HEC Standard-Step Procedure (Reference 2.4-52). A total of eleven cross-sections were used (7 downstream, one at the plant, and 3 upstream as shown in Figure 2.4-10). Details of the channel cross-sections are shown in Figure 2.4-11. The Manning roughness coefficient was conservatively taken as n=0.035 in the main channel sections, and n=0.05 in the overbank areas.

Using the computational procedure of Reference 2.4-52, it was determined that the channel restrictions at cross-sections 5 and 7 (Figure 2.4-10) do not control the flow. The stillwater elevation at the plant site (cross section 8) was determined to be 431.1 ft MSL. The water surface profile is shown in Figure 2.4-12.

2.4.3.4 Probable Maximum Flood Flow

The PMF runoff hydrograph produced by the PMP at cross-section 1 (Figure 2.4-10) is shown in Figure 2.4-9. The peak discharge at this location is 21,400 cfs.

2.4.3.5 Water Level Determinations

As discussed in 2.4.3.3, the water elevation of a flood at the plant site generated by the PMP event is 431.1 ft MSL. This flood condition is more severe than any flood of the Columbia River.