APPENDIX D

U.S. GEOLOGICAL SURVEY REPORTS

United States Department of the Interior

GEOLOGICAL SURVEY
RESTON, VIRGINIA 22092

February 23, 1978

In Reply Refer To:
Mail Stop 905

Mr. Edson G. Case
Acting Director of the Office of
Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Mr. Case:

Transmitted herewith, in response to the request by your staff, is our review of the geologic and seismologic data relevant to the Skagit Nuclear Power Project, Units 1 and 2 (NRC Docket Nos. 50-522 and 50-523).

This review was prepared by William H. Hays and Stanley R. Brockman. Assistance was provided by Robert H. Morris and James F. Devine.

Sincerely yours,

[signature]

Director

Enclosure

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Puget Sound Power & Light Company
Skagit Nuclear Power Project, Units 1 and 2
Project No. 514
Skagit County, Washington
NRC Docket Nos. STN 50-522 and 50-523

Introduction

The U.S. Geological Survey (USGS) has reviewed the geologic and seismologic aspects of the Preliminary Safety Analysis Report (PSAR) for the Skagit Nuclear Power Project, including amendments 1-20 thereto.

The Skagit site is in the foothills of the Northern Cascades of Washington, 10 km (6 mi) east-northeast of the town of Sedro-Woolley and 35 km (22 mi) southwest of Mount Baker. The Devils Mountain fault zone is 21 km (13 mi) to the south. The site is on a glaciated bedrock bench on the north side of the Skagit River valley, 92 m (300 ft) above the floodplain of the river. Foundations of Category I structures will rest on steeply dipping beds of the Chuckanut Formation, which consists of interbedded sandstone, siltstone, mudstone, and subordinate coal of Cretaceous(?) and early Tertiary age. The sheared but essentially depositional contact between the Chuckanut Formation and the Shuksan schists and phyllites, of Paleozoic age, is within the site area. Glacial deposits mantle most bedrock at the site and crop out discontinuously along the Skagit River valley.

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Review of the PSAR involved a survey of much published and unpublished information on the region and consultation with many earth scientists associated with the USGS, the University of Washington, and Western Washington State College. Representatives of the USGS and the Nuclear Regulatory Commission (NRC) made several trips to the site and the surrounding area. They met with staffs of the Washington Division of Geology and Earth Resources and the Geophysics Department of the University of Washington; E. S. Cheney, representative of an intervenor; and, repeatedly, with the applicant and the applicant's consultants (Bechtel, Inc., and others).

Geology

The applicant's analysis of the site is based on published and unpublished information and original geological and geophysical field investigations. In the site area, the applicant carried out an extensive core-drilling program, logged and tested the core, trenched across the proposed sites of the reactors and other places where subsurface information was particularly needed, and carried out local seismic-refraction and magnetometer surveys. The applicant mapped the vicinity of the site geologically, investigated recent earthquakes near the site, studied the surface geology of parts of the Devils Mountain fault zone and the Chiwaukum graben, and obtained and analyzed magnetic and gravity surveys of much of the Devils Mountain fault zone and about 275 km (170 mi) of high-frequency seismic profiling in Puget Sound.

During review of the PSAR some topics were particularly stressed. These topics are discussed below:

1. The structure and stability of the immediate site area--The applicant studied the surface and near-surface rocks and

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surficial mantle of the site area by core drilling, trenching, surface observation, and supplementary geophysical techniques and compiled the resulting data on surface and subsurface geologic maps and cross sections. These illustrations and the text of the PSAR seem to adequately portray and describe the stratigraphy and geologic structure of the site.

2. The structure of the lower Skagit River valley--Because of the apparent offset of the Chuckanut Formation across the Skagit River valley, close to the plant site, the USGS and the NRC were concerned that a significant left-lateral fault might exist along the valley. The applicant has shown that folds in the Chuckanut Formation have a complex history and are commonly irregular, and has analyzed the constraints placed on faulting along the Skagit River valley by geologic features that cross it--particularly the Straight Creek fault and the Shuksan thrust. The applicant studied surface exposures of Quaternary sediments within the valley and photoimagery of the valley and of the lowland west of it. No substantial evidence for significant east-west faulting along the valley has been found.

3. Hazards of floods and mudflows along the Skagit River--The applicant considered the effects of the simultaneous occurrence of two catastrophic events upstream: a huge mudflow from Mount Baker, comparable to the Osceola flow from Mount Rainier (Crandell, 1971), and the failure of two dams that would be in the path of the mudflow. The applicant's calculations that all Category I

structures would be far above the crest of the mud and water appear to be valid.

4. Ash-fall hazard--The only form of eruption that poses a direct hazard to the plant site is the explosive eruption of ash into the atmosphere. The applicant assumes that a very large eruption of this type, comparable to the eruption of Mount Katmai, Alaska (Griggs, 1922), might occur at Glacier Peak, 90 km (56 mi) east-southeast of the site, which is the closest volcano with an explosive history. In view of available data on the distribution of ash from Mount Katmai and from Cascade volcanoes and the fact that the site is generally upwind from Glacier Peak, the applicant's conclusion that 15 cm (6 in.) of ash might fall on the plant site in 24 hours appears to be conservative.

5. The structural relationships of linear features (lineations) on the ground surface--The applicant made a comprehensive survey of lineations in the site region, using aerial photos and other imagery. Lineations identified within 56 km (35 mi) of the site were discussed with consultants knowledgeable of the region, and many lineations were examined in the field. The applicant concluded that most of the lineations are related to bedding or foliation of the rocks, glaciation, activities of man, or previously mapped faults. A few cannot be explained, but they do not appear to represent geologic features that could affect the plant site.

6. The Devils Mountain fault zone--The Devils Mountain fault zone bears west-northwest through the Devils Mountain-Lake Cavanaugh

region, south of and as close as 21 km (13 mi) from the site. Near Devils Mountain, this fault zone is about a mile wide and includes three faults that produce distinct photolineations. Eastward, these three appear to converge and form a single structure. The fault zone displaces the youngest Tertiary rocks in the Devils Mountain vicinity, which are of probable Oligocene age. Stratigraphic relations suggest large overall displacement in which the rocks south of the faults moved relatively downward (PSAR, p. 2.5-10e), but there may have been a substantial or even predominant strike-slip component (Hobbs and Pecora, 1941, p. 66-67; Loveseth, 1975, p. 16-17; J. T. Whetten, oral commun., 1976). Pleistocene glacial deposits overlie much of the Tertiary in the Devils Mountain region and cover much of the fault zone.

The length of the Devils Mountain fault zone was investigated by the applicant. Evidence of faulting of the discontinuously exposed bedrock was found from Deer Creek, on the east, to the hillfront south of Mount Vernon, on the west--a distance of about 31 km (19 mi). The applicant found much less shearing and secondary deformation in association with the fault at Deer Creek than farther west. According to J. T. Whetten of the U.S. Geological Survey (oral commun., 1976), the fault extends at least as far eastward as Boulder Creek valley. The westward extent as inferred from good aeromagnetic data (USGS, 1977) is at least as far as a point southeast of Lopez Island. In summary, the length of the fault zone has not been determined accurately by the applicant. It must be considered to be a minimum of 47 km (29 mi) long (the distance from where it has been traced near Boulder Creek westward to the hillfront south of Mount Vernon, along

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which the zone is discontinuously exposed). It is almost certainly 80 km (50 mi) long (the distance from Boulder Creek westward to the vicinity of Lopez Island), and it very probably extends farther both to the west and southeast.

The applicant's investigation of the age of the most recent movements on the Devils Mountain fault zone has included a search of the literature, considerable observation of parts of the zone in the field, the excavation of trenches at several locations along the southernmost fault in the zone, and core drilling in one area on this fault. (For comment on the applicant's seismic profiling in Puget Sound, see the discussion of profiling near the end of this review.) Neither the published and unpublished literature nor the applicant's original studies revealed any conclusive evidence that the Devils Mountain fault zone has displaced the widespread deposits of the last glaciation, which is presumably the Vashon glaciation (about 13,000-19,000 years ago). Radiocarbon dating of organic samples from trenches across the southernmost fault in the zone suggests, not entirely conclusively, that this fault has not moved in the last 37,000 years. There is no evidence in outcrops or trenches that the fault zone has or has not been active in the interval of 37,000-500,000 years ago. Owing to these uncertainties in age of movement the fault should be presumed to be capable.

7. The possibility of a continuous, northwest-bearing fault along the eastern site of the northern Puget Sound Lowland--A group called Skagetonians Against Nuclear Power (SKANP) was represented by E. S. Cheney who has suggested (1976a, b, 1977) that a continuous major fault zone extends from Lake Chaplain, east of the city of Everett, northwestward to Bellingham Bay--a distance of more than 96 km (60 mi)--and probably farther northwestward into the Strait of Georgia. Cheney has mapped a northwest-bearing fault at Lake Chaplain. He infers that there are major faults of similar trend east and west of Devils Mountain, that these faults are continuous with the Lake Chaplain fault, and that they extend northwestward along one or both sides of Lummi Island. Northwest-bearing contacts and structures are dominant in the Northern Cascades, and it is natural that there are some faults of this trend, such as the fault at Lake Chaplain, near the western front of the range. Neither Cheney nor the applicant, however, has reported good evidence for a continuous major fault or fault zone. Such a fault or fault zone was not observed on the applicant's BBN profiles. The west-trending steep linear gradient shown on the aeromagnetic map (USGS, 1977) appears to preclude extension of any such fault north of latitude 48°20'.

8. The local and regional structural relationships of the 1872 earthquake in central Washington, the 1946 earthquake near the northeast coast of central Vancouver Island, and the 1949 and 1965 earthquakes in southern Puget Sound--

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a. The 1872 earthquake--The applicant's regional analysis of the 1872 earthquake (intensity VIII MM, according to applicant) suggests that its epicenter is in the Wenatchee-Chelan area of central Washington. This location is in the general vicinity of the Entiat fault, a major early Tertiary structure that is truncated to the north by a Miocene pluton. The area east of the fault has experienced upwarping in post-Columbia Basalt (post-Miocene) time. The applicant's field investigations of the proposed epicentral area and investigations there or nearby by other geologists (for example, F. W. Cater, Jr., R. L. Gresens, S. C. Porter, J. T. Whetten, oral communs., 1975, 1976, and R. B. Waitt, Jr., and R. W. Tabor, written commun., 1976) have revealed no strong evidence for Quaternary deformation along these or other structures. On the other hand, Quaternary sediments are not ubiquitous in the vicinity, and minor local deformation could remain undetected.

The applicant proposes that the 1872 epicenter is in a different tectonic subprovince than that of the plant site and proposes that a north-bearing tectonic boundary, separating the two subprovinces, passes along the west sides of the Chiwaukum and Methow grabens. This boundary emphasizes what may be some real differences between Cretaceous and early Tertiary structures of the western and eastern sides of the Northern Cascades. On the other hand, the boundary transects

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the structural and metamorphic grain of the old core of the range, and, most importantly, has no clear relationship to the plate interaction that is generally accepted as having dominated Cenozoic tectonism in western Washington--neither to the subduction active until at least Pleistocene time, nor to the probably different but as yet uncertainly defined tectonic regime of the present. Thus there does not appear to be an adequate basis for establishing tectonic subprovinces.

On the basis of present evidence, it appears that the 1872 earthquake cannot be associated with any known tectonic structure and that it must be considered to have occurred in the same tectonic province as that of the plant site.

b. The 1946 earthquake--There does not appear to be a relationship between the 1946 earthquake and the surficial geology.

c. The 1949 and 1965 earthquakes--The largest historic earthquakes in the Puget Sound area were the 1949 event northeast of Olympia and the 1965 event south of Seattle, both of intensity VIII MM. Their hypocenters were apparently more than 40 km (25 mi) deep. The applicant attempts to associate the 1949 earthquake with a possible northwest-trending fault structure near Olympia and the 1965 earthquake with a strongly defined east-west fault structure near Seattle. The applicant recognizes that these structures are much shallower than the hypocenters of the earthquakes, that the Seattle structure is about 16 km (10 mi) from the 1965 epicenter, and that fault-plane solutions for the earthquakes do not appear to be consistent with the structures.

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The applicant's analysis of proprietary seismic profiles in northern Puget Sound led to recognition of an east-west fault that passes south of the central San Juan Islands and through northern Whidbey Island and probably turns southeastward on the mainland. This fault, which may be termed the "Southern San Juan Islands fault," appears to be subparallel to and south of the extension of the Devils Mountain fault that is inferred (above) from the aeromagnetic data. Largely because of the greater historic seismicity south of the Southern San Juan Islands fault than north of it and because the San Juan Islands and adjacent Cascades have apparently been elevated relative to the Puget Sound vicinity during most of Cenozoic time, the applicant proposes that the fault is the boundary between two tectonic subprovinces and suggests that the 1949 and 1965 earthquakes, if considered to be random, would be restricted by this boundary. It is generally accepted, as stated above, that the interaction between crustal plates and particularly underthrusting of the continental plate has dominated tectonism in this region in Cenozoic time. The Southern San Juan Islands fault is one of many geologic boundaries that may have had only minor tectonic significance within the large area controlled by the underthrusting.

From the evidence at hand, it must be considered that the 1949 and 1965 earthquakes were random events and that similar events could occur near the plant site.

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9. <u>The structural relationships of the 1974-1975 earthquakes in the Skagit River valley</u>--During a period extending from December 15, 1974, to at least May 1975, after which the temporary seismic net was removed, a few shallow earthquakes and numerous minor aftershocks occurred in a small area in the Skagit River valley, about 5 km (3 mi) southeast of the plant site. The largest event had a magnitude of 3 and produced local intensities on valley fill as high as VI MM. The University of Washington established a seismic net in the vicinity, to study aftershocks, and carried out gravity and earthquake-intensity surveys. The applicant sponsored a seismic-velocity survey, searched the ground and imagery for unrecorded surface faults, supplemented the earlier intensity survey, and made an additional gravity survey. Neither prior knowledge of the vicinity nor the investigations described above identified a structure with which the earthquakes can be associated, and the applicant concludes that the earthquakes are not a factor in plant design.

Recently three high-frequency seismic surveys were carried out near the eastern San Juan Islands that are relevant to some aspects of this review. In January 1976, the USGS surveyed various waterways between central Whidbey Island and the south end of Lummi Island as part of a larger marine-survey program. In March, the applicant sponsored a supplementary survey, mainly along the same lines as those of the USGS survey but employing different equipment. The techniques employed in

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IMAGE EVALUATION
TEST TARGET (MT-3)

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IMAGE EVALUATION TEST TARGET (MT-3)

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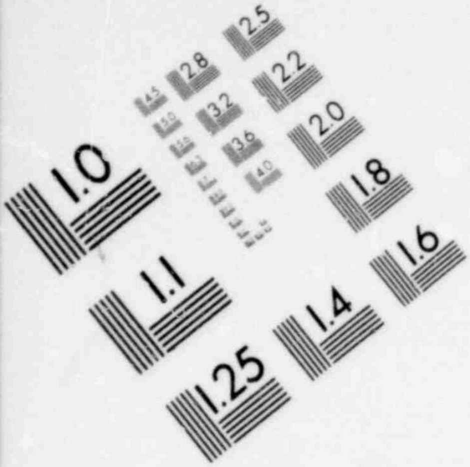


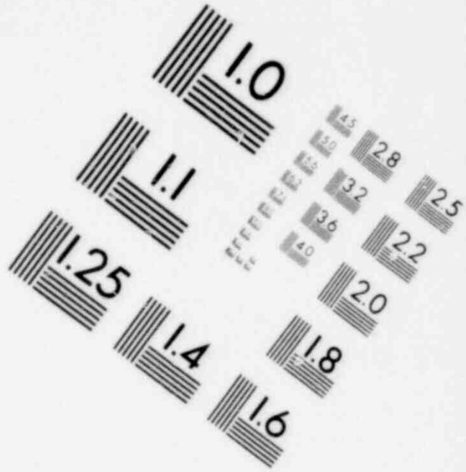
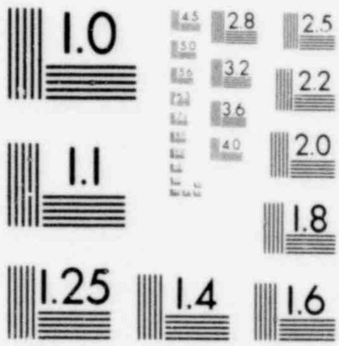


IMAGE EVALUATION TEST TARGET (MT-3)



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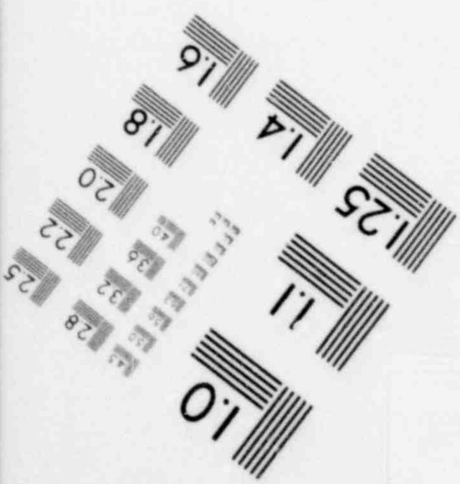

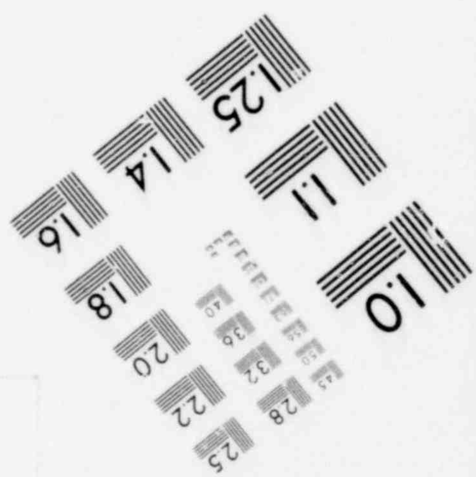

these surveys produced penetration of as much as 300 m (1,000 ft) of sediments (Quaternary but possibly including some pre-Quaternary) but not penetration of the underlying hard bedrock. The applicant analyzed the profiles produced by both surveys and found no clear indication of faulting of bottom sediments. Review of the applicant's profiles and analysis by the USGS does not alter any of the conclusions presented above. It does suggest the possibility of tectonic deformation of pre-Vashon(?) sediments near Fidalgo Island and northern Whidbey Island, as mentioned above, and the possibility of local minor faulting in sea-floor sediments farther north.

Seismology

Briefly, the Applicant has taken the positions that (1) the largest earthquakes in the site region had maximum epicentral intensities of VIII* and were located either on specific structures or in other tectonic provinces, (2) the highest intensity experienced at or near the site was VI, and (3) their chosen Safe Shutdown Earthquake (SSE) acceleration value of 0.35 g is sufficiently conservative.

During the course of this review the applicant has put forth considerable effort to document the location and intensity of several earthquakes, principally the December 14, 1872 event. The applicant has argued that it occurred between Wenatchee and Lake Chelan and had a maximum intensity of VIII.

*All intensities are Modified Mercalli.

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The site lies within a region of only moderate seismic activity and numerous earthquakes have been felt at the site. Intensity VI, believed to be the highest intensity experienced at or near the site, was generated by the 1946 British Columbia, 1965 Seattle, and 1872 Wenatchee earthquakes.

The nearest non-instrumentally located event occurred April 15, 1931, 20 km from the site, had an epicentral intensity of VI, and may have generated intensity IV motions in the site vicinity. An intensity VI event oc rred December 15, 1974 which was instrumentally located in Skagit Valley within 6 km of the site and had a magnitude of 2.8 to 3.0. It was not reported felt at the site.

The largest earthquakes within 75 km occurred January 11, 1909 and January 23, 1920, 65 km of the site from the site. The applicant conducted a newspaper search for accounts of these events. Their investigation yielded new data which they feel indicates that the 1909 event may have been felt in the site vicinity with an intensity of V, while the 1920 event may have had a maximum epicentral intensity of only VI (instead of VII as reported in Earthquake History of the United States) and a site vicinity intensity no greater than IV. Since these events do not control the SSE, the conclusions regarding maximum intensities have not been critically reviewed for purposes of inclusion in the official record of historic earthquakes.

Other earthquakes having maximum epicentral intensities of VII and VIII and ranging in distances from 75 km to 300 km were felt in the vicinity of the site up to intensity V. Three distant earthquakes - 1949 Queen Charlotte Islands (975 km), 1958 Southeastern Alaska (1500 km), and 1959 Hebgen Lake (950 km) - were also felt in the site vicinity.

As mentioned earlier in this review, the nearest instrumentally located earthquake occurred December 15, 1974 in Skagit Valley. The earthquake was shallow, produced locally high intensities (VI) for its magnitude (2.8-3.0), and generated a number of aftershocks. Special studies were undertaken to locate the aftershocks refine the location of the main shock, to obtain focal mechanism solutions and to investigate the possibility that they were associated with a previously unrecognized earthquake generating structure. The results of the studies were mostly inconclusive. The events were accurately located but no generating structure could be identified nor could the focal mechanism solutions be sufficiently restrained. We believe the effects of this earthquake would be exceeded by the expected effects from the postulated maximum earthquakes described below.

Earthquakes considered significant in estimating the maximum earthquake are the 1872 Wenatchee(IX), the 1946 British Columbia (magnitude 7.3), the 1949 Olympia(VIII), and the 1965 Seattle(VIII) shocks. In addition, the Devils Mountain fault zone and its earthquake-generating potential have been examined. For the reasons given below, we feel that an event similar to the 1872 event represents the maximum earthquake for the Skagit site.

An independent study of the 1872 Wenatchee earthquake data as presented in the PSAR and its appendices was undertaken by a USGS/NOAA ad hoc working Group on Intensities of Historic Earthquakes. The consensus of the committee was that the maximum intensity probably was IX. They also concluded that the location of the epicenter has not been accurately determined (letter dated April 1, 1976). We recognize that the historic record contains equivocal data; however, for the Skagit application we recommend the use of the maximum intensity of IX as adopted by the ad hoc working group.

Hence, we believe the 1872 Wenatchee event can be characterized as a shallow-focus intensity IX (*) earthquake which (1) has not been associated with a known structure, (2) has not been located more precisely than within an area extending from Lake Chelan in central Washington to southern British Columbia, and (3) occurred in a tectonic setting and province that includes the Skagit site.

The term "shallow-focus" has been used in the traditional sense that the earthquake hypocenter was probably less than 70 km deep but the evidence for this is weak. That intensity IX was experienced over a broad area argues for at least some depth. The area of maximum intensity was probably quite small which suggests that the hypocenter couldn't have been very deep. No surface rupture along a fault has been identified that could be associated with the earthquake. That such a rupture has not been discovered is not considered

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surprising because of the large area and rugged terrain of much of the epicentral region. There is no reason to believe that a similar earthquake could not occur at some time in the future at shallow depths.

No new information pas been provided that establishes that the Skagit site is situated in a tectonic province distinct from that of the locale of the 1872 earthquake. The tectonic boundaries as they are related to the 1872 earthquake are discussed in paragraph 8(a) of the geology section of this report. We do not believe that the evidence that the 1872 earthquake can be associated with a tectonic structure such as the Badger Mountain Anticline is compelling. Although the concentration of earthquake activity in the Wenatchee-Entiat-Chelan area is suggestive of the presence of an earthquake-generating structure, no such structure has been demonstrated on the basis of geology or geophysics. We conclude, then, that a similar event could occur near the the Skagit site and that the site intensity would be greater than that expected to be generated by either the 1949 or the 1965 earthquakes.

The 1946 British Columbia earthquake was a magnitude 7.3 event which occurred June 23, 1946. The intensity reported in the United States was VIII; it is not certain what the maximum intensity was. Rogers (1976, personal communication reported in the PSAR, page 2.5-60n) calculated a depth of 30 km. The applicant has argued that it was associated with a northeast-trending structure which has not been recognized in

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the surface rocks but which has been inferred on the basis of tectonic and seismological considerations. The bulk of these considerations are presented in the PSAR (pages 2.5-60k to 2.5-61, 10 pages) and will only be summarized here. The seismological evidence includes [1] a diffuse band of earthquake epicenters southwest of the site which has a trend coinciding in general with the structure mentioned above and [2] similar focal mechanism solutions have been obtained for the 1946, 1957, and 1972 earthquakes (Rogers, 1976, as reported in the PSAR, page 2.5-60n). The epicenters of these events are coincident with the postulated structure.

A fault zone has been postulated on the basis of the tectonics of the region (ie, Barr, 1974; Riddihough, 1977). USGS geophysicists agree, in general, with the concept of a fault zone passing beneath Vancouver Island which would correspond to the applicants postulated structure. The sense of motion would be left-lateral, which agrees with one of the solutions obtained by Rogers (1976) for the 1972 earthquake.

The PSAR goes on to observe that Barr (1974) reports that the igneous basement (oceanic crust) is not involved in the deformation of the overlying sediments. The applicant concludes that if large earthquakes, such as the 1946 event, are associated with tectonic boundaries at depth, structure need not be expected to be visible at the surface.

In view of the foregoing discussion, the applicant then concludes that the 1946 earthquake can be reasonably correlated with a structure trending approximately N60E

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beneath Vancouver Island. The USGS concurs, hence the 1946 event is not considered significant in establishing the maximum earthquake.

The Devils Mountain fault zone is believed to be at least 80 km long, may have had as much as 60 km of strike slip offset, and is considered to be capable. Much, if not all, of this displacement appears to have occurred prior to Quaternary time. According to Dobrin (page 2G-126, Amendment 19), Oligocene strata do not appear to be disrupted, within the limits of resolution of the geophysical data, along the trace of the fault where it is transected by the marine seismic reflection profiles (Figs 8-12, Amendment 19). Other evidence indicates that the strata identified as Oligocene by Dobrin may be younger than Oligocene in age. Considering that most of the strike slip component of displacement occurred in the Tertiary, strict application of fault length/magnitude relationships based upon California fault models does not seem to be appropriate. We believe, however, a magnitude 7.0 to 7-1/4 earthquake, which is consistent with other earthquakes of the region, could occur on the Devils Mountain fault zone.

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Summarizing, two earthquakes are postulated as the maximum earthquakes of the region:

1. an event similar to the 1872 Wenatchee (IX) event very near the Skagit site. "Very near" implies that attenuation of ground motion for distance not be considered.
2. a shallow magnitude 7.0 to 7 1/4 earthquake on the Devils Mountain fault, 21 km from the site.

It is the judgement of the USGS reactor site review team that the proposed use of a bedrock acceleration value of 0.35 g as the Safe Shutdown Earthquake for use with the Safety Guide 1.60 design spectrum is acceptable for nuclear power plant design.

On the other hand, the review team is not confident that all aspects of the geology and seismology leading to its position have been demonstrated and documented conclusively.

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*Reports prepared by E. S. Cheney for an intervenor group SKANP (Skagetonians Against Nuclear Power), Seattle, Wash.

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United States Department of the Interior

GEOLOGICAL SURVEY
RESTON, VA. 22092

September 17, 1979

In Reply Refer To:
Mail Stop 905

Mr. Harold Denton
Director of the Office of
Nuclear Regulations
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Mr. Denton:

Transmitted herewith, in response to the request by your staff, is a supplement to our review (February 23, 1978) of the geologic and seismologic data relevant to the Skagit Nuclear Power Project, Units 1 and 2 (NRC Docket Nos. 50-522 and 50-523).

This supplement was prepared prior to the completion of a review of certain proprietary seismic profiles which have not yet been received by the U.S. Geological Survey. Any impact of the review of these profiles will be transmitted at a later date.

This supplement was prepared by William H. Hays and Stanley R. Brockman. Assistance was provided by Richard J. Blakely, Robert H. Morris and James F. Devine.

Sincerely yours,

for Henry W. Coulter
H. William Menard
Director

Enclosure

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One Hundred Years of Earth Science in the Public Service

DUPLICATE

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Status Review
September 13, 1979

Puget Sound Power & Light Company
Skagit Nuclear Power Project, Units 1 and 2
Project No. 514
Skagit County, Washington
NRC Docket Nos. STN 50-522 and 50-523

Since submitting its last Status Review on the proposed Skagit Nuclear Power Project on February 23, 1978, the U.S. Geological Survey (USGS) has received and reviewed a major submittal from the Puget Sound Power & Light Company (PSPL) entitled "Report of Geologic Investigations in 1978-1979" and dated May 27, 1979. This submittal and a few new questions that have arisen from ongoing studies in the site region are discussed in this review.

Geology

The extensive investigations represented by the submittal of May 27, 1979, were stimulated by new ideas regarding the geology of the site vicinity that developed in the coarse of the long-term program of the USGS for mapping the geology of northwestern Washington. The new ideas concern a tectonic mixture of meta-igneous and metasedimetary rocks that is widely exposed south of the plant site in the Table Mountain-Haystack Mountain-Bald Mountain region. (These rocks are hereafter termed "CH/Ju rocks", a term coined from symbols for these rocks on the maps of the applicant and of J. T. Whetten.) In the Preliminary Safety Analysis Report (PSAR) of early 1978, the applicant identified these rocks as part of the Church Mountain thrust plate, dragged or pushed into this region from the east by the overriding Shuksan thrust, and as being generally correlative to the Chilliwack Group of largely Paleozoic age, which composes that thrust plate in the Cascade Range farther east (Misch, 1966, 1977, 1979). In identifying the CH/Ju rocks with the Church Mountain plate and the Chilliwack Group, the applicant was probably influenced by the fieldwork of G. M. Miller (1979, in press), who has sought to extend Misch's mapping westward into the Cascade foothills. At NRC-USGS meetings with the applicant in May 1978, and at the Atomic Safety and Licensing Board (ASLB) hearing in June of that year, J. T. Whetten of the USGS, who has been mapping in the San Juan Islands (Whetten and others, 1978) and was extending his work eastward into the mainland, proposed some markedly different relationships. He correlated the CH/Ju rocks south of the plant site with the Mesozoic Decatur Terrane (including the Fidalgo Ophiolite of Brown [1977] and Brown and others [1979]) that he had mapped as a thrust sheet in the e stern part of the islands--a correlation that is supported by petrologic and radiometric data. Whetten presented evidence that these rocks are not part of the Church Mountain thrust plate, structurally underlying the Shuksan thrust, but, rather, part of a higher plate that has been thrust over the Shuksan plate. These new ideas, later expanded in publications (Whetten and Zartman, 1979; Whetten and others, 1979; Whetten and others, in press) have produced uncertainty and division in the thinking of the geologic community regarding the basic structural framework of parts of the Cascade foothills. Such uncertainty is of significance to review of the site proposal in that it could limit identification and understanding of younger, post-thrust deformation of the rocks of the region.

In hope of resolving quickly the question of the basic structural relationship of the Shuksan thrust plate to the CH/Ju rocks and also more specific concerns regarding possible high-angle faults of post-thrust age, the NRC and USGS requested, on June 9, 1978, that the applicant make additional studies, including (1) core boring, to determine the orientation of the fault contact between the Shuksan and Ch/Ju rocks near Little Haystack Mountain; (2) aeromagnetic surveys, to help define the location and the attitude of the same contact regionally and to investigate an anomaly southeast of Butler Hill that had been revealed on an earlier, less detailed survey; and (3) further studies, including examination of Quaternary deposits, relative to the possible presence and significance of faulting in the vicinity of and parallel to Gilligan and Day Creeks.

The applicant responded vigorously to the NRC-USGS requests and extended the scope of its studies slightly beyond the requests in order to address more fully concerns regarding the hypothesized "B and B Fault." The applicant was unable to carry out completely the requested drilling near Little Haystack Mountain, but drilled 11 core holes there and elsewhere; carried out an extensive detailed aeromagnetic survey and analysis thereof; markedly increased the density of data on its regional geologic map, including data near Gilligan and Day Creeks; carried out on-ground gravity and magnetic surveys across the lower parts of the two creeks; reexamined photographic and radar imagery; and studied Nanaimo-Chuckanut stratigraphy in the northern San Juan Islands.

In May and June 1979, the applicant distributed its report, "Report of Geologic Investigations in 1978-1979" (hereafter termed "RGI"), on the studies outlined above. The principal topics addressed by the applicant in this report and other aspects of regional and local geology that have seemed important in recent considerations of the proposed plant site are discussed briefly below:

1. <u>The basic tectonic framework of the region</u>--In its 1979 RGI, the applicant concludes that the controversial CH/Ju rocks south of the plant site and other exposures of similar rocks in the region are indeed parts of the Church Mountain thrust plate and structurally lower than the Shuksan thrust plate--a conclusion consistent with

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that in the earlier PSAR and in conflict with Whetten's model of the region. The applicant does modify its earlier position somewhat (p. 3.1-5) in stating that the CH/Ju rocks probably include some Mesozoic rocks similar to rocks in the eastern San Juan Islands, and the RGI includes (p. 3.1-4, 3.1-5) a brief description of a third structural model, that of Joseph Vance, which incorporates some features of the other two.

It seems clear, regrettably, that the issue raised by Whetten regarding the place of the CH/Ju rocks in the basic tectonic framework of the foothill region around the proposed plant site has not been resolved by the considerable new data acquired in the past 18 months and that no consensus on this problem can be expected until some future time when much more of the region has been mapped geologically in detail and more geophysical data have been acquired. The present situation of uncertainty in the geologic community is exemplified by recent studies in the vicinity of Little Haystack and Talc Mountains, where the aeromagnetic and core-hole data recently supplied by the applicant can apparently be accommodated both by the applicant's mapping and interpretation of the thrust and by Whetten, Dethier, and Carrol's (1979) very different mapping and interpretation. The most logical and responsible present course in the evaluation of the Skagit site seems to be acceptance of the existence of some major uncertainty among geologists regarding the geologic framework of the site region and recogition of this uncertainty in conservative evaluation of the bearing of specific geologic features on site safety.

2. High-angle north-trending faults near the plant site--The applicant has fairly conclusively demonstrated, by detailed observation and mapping supported by geophysical surveys, that no significant north-trending faults follow the valley floors of Gilligan and lower Day Creeks. The applicant has found little or no evidence for faults within the Shuksan metamorphic rocks on the slopes above the creeks, but it is prudent to bear in mind that such faulting might be difficult to detect.

In two localities in the vicinity of the plant site, on the south side of the Skagit valley, the strong possibility or likelihood of high-angle faulting younger than any regional thrusting is a present concern east of Gilligan Creek, along the contact between the Shuksan and CH/Ju rocks, and in the valley of Loretta Creek, at and near the Chuckanut-Shuksan contact.

The applicant's mapping (RGI, fig. 3.2-2 and Appendix H, sheet 1) of the fault between the Shuksan and the CH/Ju rocks in sections 12, 13, and 24 or T. 34 N., R. 5 E. accords closely with Whetten's mapping (1979), and all agree that the dip of the fault is steep there. In section 1 of the same township, bedrock exposure is commonly poor, and the contact can be less accurately located. Available outcrops and probable outcrops suggest that it continues, with a northerly trend, through about the center of the section. In the northern quarter of the section, the few outcrops may permit an inference that the contact turns abruptly east, so as to join the thrust contact between the same rock units in the northeast quarter of section 6, T. 34 N., R. 6 E. Even if the Shuksan-CH/Ju contact follows such a course, it seems likely that the semilinear high-angle fault that forms the contact for miles south of section 1 continues on across the section to the north. Rather than a steeply folded segment of a thrust, the fault east of Gilligan Creek (hereafter termed the "Gilligan Fault") is probably a younger fault that cuts across the thrust.

The extent of the Gilligan Fault to the north and south is unknown and perhaps almost indeterminable. If it extends northward beneath and beyond the Skagit valley, it enters a large mountainous mass of rather poorly exposed Shuksan metamorphic rocks; to the south, beyond upper Gilligan Creek, it is within the tectonically mixed CH/Ju rocks. In both the Shuksan and CH/Ju terranes, the identification and mapping of faults can be very difficult. South of upper Gilligan Creek, the fault is conceivably related to a discontinuous lineament, apparent on side-looking radar (RGI, p. 3.2-8 to 3.2-11), that extends south to a point near the west end of Lake Cavanaugh, but there is little or no evidence that this lineament is related to the Gilligan Fault or to any geologic structure. The offsets in glacial lake deposits about where this lineament crosses the Lake Cavanaugh Road (Bechtel, Inc., 1978) are probably nontectonic.

A second locality where there is concern regarding high-angle faulting, the valley of Loretta Creek (RGI, Appendix H, sheet 1; Whetten and others, 1979), was called to the attention of USGS reviewers by J. T. Whetten and P. R. Carrol. In the course of mapping geologically the lower part of the valley, Whetten and Carrol encountered an exceptionally good exposure of the Chuckanut-Shuksan contact in a small waterfall, at an elevation of about 1,250 feet. Here the contact consists of a near-vertical shear zone, at least about 6 feet wide, that appears to strike north-northwest. The zone very probably represents a significant high-angle fault of post-Chuckanut (post-Eocene?) in age. In the absence of strongly supportive data, the acceptance of any other interpretation here would be highly imprudent. The length of this fault (hereafter termed the "Loretta Fault") and the amount and exact sense of displacement on it are unknown. If it is present north of the Skagit valley, the difficulties in mapping it there would be similar to those described in the case of the Gilligan Fault. To the south, the fault may follow the Chuckanut contact or may take another course.

3. The "Loveseth" Fault--The "Loveseth" Fault, mapped as a fault by T. P. Loveseth (1975) and H. D. Gower (1978) is interpreted by the applicant (RGI, Section 3.4.2) and by G. M. Miller (RGI, fig. 3.1-3, sheet 2, and in press), a consultant to Bechtel, Inc., as the basal sedimentary contact of the Chuckanut Formation, disturbed only by local shearing associated with Tertiary folding. The applicant does not mention the existence of any clear exposures of the contact, and apparently its dip cannot be accurately measured anywhere. The geologic constraints on its location, though fairly tight in the northeast quarter of section 10 and perhaps in section 3, T. 33 N., R. 5 E., are commonly loose farther south. On the basis of evidence of strong shearing and of probable discordance of beds to the Chuckanut-CH/Ju contact, it seems most likely that the contact mapped in sections 3, 10, and 11 is a fault. The applicant's interpretation cannot, perhaps, be ruled out here, but it is surely not unique. Farther south, the most likely course of such a fault lies probably along the southwest side of the large volcanic body in section 14 and through the Chuckanut beyond, but other courses may be possible. The applicant's mapping, which established the presence of Chuckanut east of the large volcanic body in section 14, as well as west of it, suggests that the "Loveseth" Fault is not a major structure. The discordant dips in the Chuckanut in the northwest quarter of section 13 suggest that the contact there may be similarly faulted.

4. The "B and B Fault"--The possibility of a "B and B Fault" was discussed at the ASLB hearing in March 1978, largely as a result of USGS concerns regarding a letter received from Peter Ward, a stratigrapher who had been carrying on research in the northern San Juan Islands. Ward suggested that the Nanaimo and Chuckanut sedimentary rocks had been deposited in separate sedimentary basins and that their present juxtaposition across the strait between Barnes and Clark Islands and Lummi Island might be best explained by large-scale strike-slip faulting. The USGS had not fully evaluated Ward's suggestion at the time of the hearing and could only speculate regarding the proposed fault. In informal consideration of possibly permissible courses for the proposed fault south of Lummi and especially of such courses that were closest to the proposed plant site, it was thought that such a fault might possibly bend eastward and pass through the Table Mountain vicinity south of Cultus Mountain. It was this highly speculative, "worst-case" fault trace, between the vicinity of Samish Bay on the north and the vicinity of Lake Cavanaugh on the south, that W. H. Hays sketched on a map at the March 1978 hearing and that was there somehow christened the "B and B Fault."

Since that ASLB hearing, studies by the applicant and others have led to doubt regarding the possibility of large post-Chuckanut faulting west of Lummi Island, but seem to have established the presence of faulting near Table Mountain. In the northern San Juan

Islands, a major fault between Lummi Island and Orcas Island was first suggested by Misch (1966), and considerable evidence points to faulting there that has affected rocks as young as the Upper Cretaceous Nanaimo Group. The possibility of faulting younger than the Chuckanut Formaion on Lummi Island is, however, more difficult to evaluate. Stratigraphic studies by the applicant (RGI, section 3.4.1) suggest correlation of the Chuckanut formation on Lummi Island with strata on part of Sucia Island and on some other islands west of Lummi and thus support some of the earlier similar conclusions of Vance (1975, 1977). This correlation seems to lack the support of conclusive evidence for the various deposits being of the same age but, if valid, it would seem to preclude inference of large-scale faulting west of Lummi Island since Chuckanut (Eocene and older) time.

Another development since the March 1978 hearing has been increasing realization that the Chuckanut is probably younger than almost all, if not all, of the marine Nanaimo Formation on Barnes and Clark Islands and elsewhere west of Lummi and that the Chuckanut probably need not have been deposited in a basin distinctly separate from the Nanaimo basin, as Ward suggested.

Thus, while large-scale post-Chuckanut faulting west of Lummi Island cannot at present be ruled out, strong evidence for such faulting appears to be lacking. If there is no such faulting, there is, of course, no necessity of accommodating similar movement to the south, along some such structure as the "B and I Fault."

In the Table Mountain vicinity far to the south, which Hays speculated to be on one possible southerly course of the major fault suggested by Ward, continued geologic mapping has indicated the presence of a northwest-trending fault or fault zone (Whetten and others, 1979), an interpretation that is not necessarily inconsistent with the applicant's field studies (RGI, p. 3.4.1-4). Whetten (oral comm., 1979) believes that this fault or fault zone has near-vertical dip and has considerably disrupted the CH/Ju and Shuksan plate rocks in the Table Mountain-upper Nookachamps Creek vicinity. The age of this structure (hereafter termed the "Table Mountain Fault") and its extent to the northwest and southeast are unknown.

5. <u>The age of high-angle faulting in the site vicinty</u>--It seems clear that a conservative geologic analysis of the site vicinity must take into account the probable presence of fairly numerous high-angle Tertiary faults, one or two of which may pass within a few miles of the plant site. These faults include the Gilligan, Loretta, "Loveseth," and Table Mountain Faults discussed above; probably some of the faults mapped by Whetten, Dethier, and Carrol (1979) and the applicant west of middle and upper Day Creek; and perhaps the Shuksan-CH/Ju contact at "No Name Creek." All of these

faults should probably be presumed to be younger than latest Chuckanut deposition (Middle Eocene), though some may be older. Some probably formed during the ealy Tertiary (Eocene?) deformation that folded the Chuckanut, but the near-vertical dips of at least many of the fault surfaces and the linearity of the surface traces of the Gilligan Fault and probably other faults suggest that some of these structures formed after that deformation.

In discussing the possible age of this faulting, it may be instructive to consider the nearest faults that have, tentatively at least, been considered capable. The Devil's Mountain Fault, which passes 21 km southwest of the plant site, is considered capable by the USGS, largely on the basis of a lack of evidence that it could not be capable and of probable displacements as depicted in marine profiles located west of Whidbey Island. The Straight Creek Fault, 48 km east of the site, has probably moved a little since mid-Tertiary time and is "tentatively classified as capable" (McCleary and others, 1978, p. ii) in a study carried out by a consultant to the Washington Public Power Supply System. While it seems legitimate, in a conservative site analysis, to consider both of these faults capable, it should be remembered that both are very long, very large regional structures, which have doubtless moved many times; that displacement along the Straight Creek Fault was very largely, if not almost entirely, accomplished by Miocene time; and that there is no evidence that movement along the Devil's Mountain Fault was not also largely completed by that time. The capability of two master faults of the region does not logically establish capability for the many smaller faults. It seems likely that most, if not all, of the high-angle faults of the site vicinity have not moved in Quaternary time. There is no strong evidence of such movement on any of them. On the other hand, displacements, especially minor displacements, that might conceivably have occurred on these faults between 500,000 years ago and the end of the last glaciation (about 13,000 years ago) could have been covered or obscured by that glaciation; and the applicant has presented no strong evidence against such conceivable movement. In summary, it appears that the high angle faults of the site vicinity are very probably but uncertainly incapable.

6. The 1946 earthquake near the northeast coast of central Vancouver Island--Several papers dealing directly or indirectly with the 1946 earthquake have been published since submittal of the last USGS Status Review in February 1978. Rogers and Hasegawa (1978) recompute the epicenter of the earthquake and place it on Vancouver Island near its northeast coast, rather than under the Strait of Georgia. They favor a fault-plane solution calling for a northwest-striking fault surface, possibly in close proximity to the similarly striking Beaufort Range Fault, but they do not rule out a northeast-striking surface. Riddihough (1978) relates the 1946 event to a northeast-trending fault in the subducting plate

beneath the crust of Vancouver Island. Slawson and Savage's (1979) resurvey of an old triangulation network revealed distortions consistent with movement on the Beaufort Range Fault, but association of the earthquake with surface geology appears to remain doubtful.

Aeromagnetic Data

The USGS has reviewed the analysis of aeromagnetic data by Exploration Data Consultants, Inc. (Edcon) and found it to be generally satisfactory. Alternative interpretations are possible in some cases, however, and the data do not unambiguously establish the correctness of the applicant's mapping and tectonic model. The following are several general conclusions arising from our review of these data and the Edcon report:

(a) Aeromangetic anomalies help to define the shape and location of highly magnetic rock types, which are probably serpentinites in this area. In particular, aeromagnetic data were used to deduce the nature of the contact between Shuksan metamorphic rocks and the CH/Ju rocks. However, the dips of the surfaces of the serpentinite bodies may be unrelated to the attitudes of the thrust because (1) the serpentinite may not be originally associated with thrusting; (2) serpentinite is a highly mobile rock when subjected to stress; and (3) serpentinites possess highly variable magnetic properties.

(b) Concern regarding an abrupt change in trend of the aeromagnetic contours southeast of Butler Hill, on small-scale USGS aeromagnetic maps (see RGI, fig. 3.3-2), was expressed in the NRC-USGS request to the applicant of June 1978. The additional more detailed aeromagnetic survey data provided by the applicant indicate that there is no magnetic basis for a fault with an east-west trend along Skagit Valley south of Butler Hill.

(c) Anomalies along the thrust contact in the vicinity of Talc Mountain are caused by rock bodies (probably serpentinite) which appear to have northeast-dipping northeast faces. However, these bodies extend to only about 2,000 feet below ground surface and could, therefore, be confined within a thin thrust sheet.

(d) The absence of fault-related aeromagnetic anomalies near the mouth of Gilligan Creek, south of Butler Hill, and elsewhere does not necessarily preclude the existence of faults in these areas.

(e) Aeromagnetic maps show that anomalies characteristic of CH/Ju rocks usually terminate at the thrust contact between Shuksan and CH/Ju rocks. This suggests that if CH/Ju rocks underlie Shuksan, as the applicant has suggested, they lie at depths in excess of 10,000 feet. As CH/Ju frequently crops out in small areas surrounded by Shuksan and away from the thrust (e.g., at Butler Hill), this lack of anomalies over Shuksan terrane forces a rather complicated geologic model.

Seismology

A detailed discussion in the ~~Geology and aeromagnetic data sections~~ of this review is presented concerning the existance and age of numerous high-a e faults in the site vicinity. The conclusion offered there is that these faults are "very probably, but uncertainly, incapable."

On the other hand, there have been numerous small earthquakes in the area containing the site. Their magnitudes range from 1.2 to 3.3 and several have been felt locally. An alignment of epicenters has been noted in the Skagit River Valley but there are doubts about the absolute accuracy of their locations. The stated accuracy of events located by the University of Washington-operated seismic network is 1 to 2 km (Crossen, 1974). However, the seismograph stations in the Skagit Valley vicinity are fewer and more widely spaced than those further to the south and because the locale is near the northern limit of the network coverage, the accuracy is not likely to be that precise. The remaining epicenters appear to be essentially random in the site vicinity. None of the small earthquakes have been associated with identified faults. It is possible that these earthquakes are associated with structures that are sufficiently small that no surface expression has been recognized by the geologic investigations.

Consequently, it is our judgment that for purposes of nuclear reactor design it should be assumed that earthquakes as large as magnitude 4.0 could originate on any of the identified faults or an unmapped fault in the region of the plant site. However, it is our judgment that even if an earthquake of this size were to occur on one of these structures, its consequences at the plant site would be less than that already postulated to result from the two much larger earthquakes discussed in our previous reviews (Jan. 30, 1978 and Feb. 23, 1978).

Since our last review, other articles relating to the tectonics of the Pacific Northwest, in general, and the Vancouver Island vicinity, in particular, have been published. They reinforce the concept that the 1946 earthquake was related to the present-day subduction regime of the region rather than regional north-south compression (Rogers and Hasegawa, 1978). Rogers (1979) suggests that the occurrence of earthquakes having a northeast alignment across Vancouver Island are related to differential movements of the Explorer and Juan de Fuca plates. Two interpretations of the tectonic settings are presented; his preferred setting suggests that the subducted Nootka fault zone (named by Hyndman, et al, 1978) would represent, in effect, a tectonic boundary, north of which earthquakes would occur because of intense local north-south compression resulting from the Explorer-America plate interaction. To the south of the Nootka fault zone, subduction of the Juan de Fuca plate beneath the America plate would proceed in a normal but aseismic fashion. In view of these considerations, we believe that the constraints on the locus of an event similar to the 1946 earthquake would make its significance less than the two postulated controlling earthquakes (USGS Jan. 30, 1978, and Feb. 23, 1978).

In summary, there is a recognition that there has been a large amount of new geological and geophysical data provided by the applicant and others since the preparation of our last review. However, there remains a major uncertainty as to the completeness, significance, and proper interpretation of both the new and previously discussed data. Consequently, it is still our jugment that for purposes of nuclear reactor design the following two earthquakes should be considered as controlling:

1. an earthquake simila to the one that occurred December 15, 1872 but having its epicenter sufficiently close to the site that no attenuation effects be considered, and

2. a shallow magnitude 7.0 to 7 1/4 earthquake on the Devils Mountain Fault 21 km. from the site.

The USGS reactor site review team agrees with the applicant's proposed use of a bedrock acceleration value of 0.35 g as the Safe Shutdown Earthquake for use with the Safety Guide 1.60 design spectrum for nuclear power plant design.

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