Enclosure (2)

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

NOV 1 1983

MEMORANDUM FOR: Thomas H. Novak, Assistant Director for Licensing, DL

FROM: James P. Knight, Assistant Director for Components & Structures Engineering, DE

SUBJECT: DRAFT SAFETY EVALUATION REPORT - GEOLOGY AND SEISMOLOGY - WASHINGTON NUCLEAR PLANT PROJECT NO. 3

Plant Name: Washington Nuclear Plant - Project No. 3
Docket Number: 50-508
Licensing Stage: OL Review
Responsible Branch: Licensing Branch No. 3
Responsible Project Manager: A. Vietti

Enclosed are the geology and seismology sections for the WNP-3 draft SER. This input applies to the SRP sections 2.5.1, 2.5.2 and 2.5.3. The report was prepared by Richard McMullen, Geologist and Jeff Kimball, Seismologist.

As stated in the attached draft SER, there are a number of open items (staff questions) which fall into two broad categories. First is the possibility of a large or great earthquake on the subduction zone beneath the site. Second is the possibility of unrecognized low angle thrust faults in the site vicinity that could cause large close - in earthquakes or surface faulting at the site. We anticipate that when these significant issues are addressed, that new information may require the reinterpretation of some previous positions of the staff, the USGS, and the applicant.

Except for the above discussed open items, the staff reaffirms its conclusions stated in the SER-CP that the applicant has adequately investigated and characterized the seismic and geologic hazards at the site, and with respect to those hazards, the site is acceptable.

Robert E. Jackson for
James P. Knight, Assistant Director for
Components & Structures Engineering
Division of Engineering

Enclosure:
As stated

cc: See next page

8311140111 XA

cc: w/enclosure
G. Knighton
R. Jackson
L. Reiter
S. Brocoum
L. Heller
J. Kimball
R. McMullen
T. Sullivan
A. Vietti
D. Gupta
J. Rothberg
S. Algermissen, USGS
D. Perkins, USGS
J. Devine, USGS
R. Morris, USGS
R. Wells, USGS
A. Tabor, USGS
D. Slemmons

2.5 Geology and Seismology

The geology and seismology of the WNP-3 site were reviewed during the early and middle 1970's during the Construction Permit (CP) review.

As a result of the CP review the NRC staff concluded that:

(1) the inferred large deep seated fault blocks that have been associated with large earthquakes in the southern part of the Puget Sound are not present in the site area;

(2) movement of faults in the site vicinity most likely ceased in the late Tertiary, more than 2 million years before present (mybp), and are therefore not capable within the meaning of Appendix A, 10 CFR 100;

(3) there are no known structures in the immediate site vicinity that could be expected to localize earthquakes there;

(4) the applicant's assessment of the possible volcanic risks in the site region are adequate and that a problem of this type does not exist at the site; and

(5) the safe shutdown earthquake (SSE) with a maximum acceleration of 0.32, and the operation basis earthquake of 0.16g are conservative when applied to the foundation level.

During construction of the facility numerous minor faults were found in the excavation. The applicant investigated these faults and determined that they were at least 630,000 years old but most likely more than 2 million years old. The staff reviewed the applicant's data and made several visits to the site to examine the faults and concluded that the faults were not capable.

In 1974 through 1976, as a result of licensing activities for the Skagit Nuclear Power Plant, studies were initiated concerning the 1872 Earthquake

(MMI IX, magnitude 7.0). New data from these studies raised the question as to whether or not an event of that size could occur at the WNP-3 site. The applicant investigated that earthquake, mostly in regard to its Hanford sites, and determined that it was related to tectonic structure within a broad epicentral zone and therefore could not occur at the site. The NRC staff reviewed that data and data compiled by a panel of experts formed by Northwest US Utilities, and that of another panel of USGS and NOAA experts, and concluded that the 1872 Earthquake was centered in the region between Entiat, Washington and Chilliwack, British Columbia (NRC, 1978) and should not be expected to recur at the site. The most recent staff and USGS discussion of this earthquake can be found in the WNP-2 SSER.

On May 18, 1980, after several weeks of resurgent activity, Mount St. Helens erupted violently sending large quantities of ash several hundred miles downwind to the east. The NRC requested the applicant to reassess the volcanic hazards to the site based on the new data. The applicant concluded, based on that assessment, that the maximum potential ashfall that could be expected from such an eruption from the closest volcanoes during the worst meteorological conditions, would result in a maximum of 1.75 inches of ash at the site. They stated that the plant design could accommodate that kind of ashfall. The NRC staff reviewed the applicant's data and USGS data collected with partial NRC funding and concurred with the applicant's conclusion, but requested additional supporting data.

The staff has completed its review of the FSAR. It has held several meetings with its advisors, the U.S. Geological Survey and its geological consultant, Dr. David Slemmons, two technical meetings with the applicant and its consultants, and conducted a geological reconnaissance of the site and region around the site. On April 28, 1983 we transmitted questions, including those of our advisors to the applicant. Because of the June 1983 postponement of the WNP-3 site construction, those questions or outstanding issues have not been responded to. These open topics will be presented in Sections 2.5.1, 2.5.2, and 2.5.3.

Because of the extensive geologic and seismic information (mostly about subduction zones) that has come out since completion of the CP review, new staff concerns have arisen; however, the following CP conclusions of the staff are still valid:

(1) the inferred large deep-seated fault blocks that have been associated with large earthquakes in the southern part of Puget Sound are not present in the site area;

(2) movement on mapped faults in the site vicinity, including those in the excavation are ancient and are not capable; and

(3) The volcanic hazard to the site has been adequately addressed even in light of the recent eruption of Mt. St. Helens and has been appropriately considered in the design.

Based on new data since the CP, the adequacy of the SSE is in question for the following reasons which reflect our general concerns:

(1) The possibility of a large or great earthquake on a subduction zone beneath the site;

(2) the possibility of unrecognized low angle thrust faults in the site vicinity that could cause large close-in earthquakes or surface faulting at the site.

These issues will be addressed in greater detail in the following sections.

2.5.1 Basic Geologic and Seismic Information

2.5.1.1 Regional Geology

The WNP-3 site is located in the Pacific Border Physiographic Province of Washington State, about two miles south of the town of Satsop and 16 miles east of the city of Aberdeen. The site area lies in the Chenalis Lowlands, which comprise a physiographic zone separating the northern termination of the Oregon Coast Range from the Olympic Mountains.

The site and its environs are largely underlain by Cenozoic strata. Relative to more northern areas of the region, rocks of the site area are not highly deformed. Igneous rocks of Mesozoic and Cenozoic age, however, are more abundant than either sedimentary or metamorphic units throughout the region. The nearest outcrops to the site of Mesozoic and Paleozoic rocks (metamorphic, igneous, and sedimentary types) are found in the highly deformed area some miles to the north and northwest of the proposed plant area. Lithologically, the Cenozoic strata consists predominantly of marine clastic sediments deposited on a basement of Eocene oceanic basalts.

The tectonic history of the site region is complex, with eastward and westward directed low-angle thrusts, grabens, granitic plutons, and stratovolcanoes being best displayed and developed in the Northern Cascades. In the Northern Cascades, the Paleozoic Era is characterized by metamorphic and eugeosynclinal rocks. Eugeosynclinal sediments, granitic plutons, low-angle thrusts, and grabens were formed throughout the Mesozoic Era. During Cenozoic time, the formation of grabens, granitic plutons and basalt flows predominated tectonic activity. These events were followed by several orogenic periods which caused folding and faulting of the older formed rocks and general uplift of the region, and the stratovolcanoes of the Cascade range began to form. The structural features that were formed during these orogenies, and the region, were subsequently eroded during the Quarternary to produce the present day topography. While it appears that the last major period of deformation in the region ended in the Late Tertiary (Pliocene), evidence from Pleistocene deposits in the coastal areas west of the site, from 1100 year old fault dates in the Puget Sound area to the north, and from three active stratovolcanoes in the central part of the state to the east of the site, show that tectonism continued on a more minor scale through the Pleistocene into the Holocene.

The tectonic deformation of Western North America appears to be intimately related to the interaction of two major lithospheric plates, the North American Plate and the Pacific Plate. The interaction is principally along two major transcurrent faults, the San Andreas Fault in California and the Queen Charlotte Fault off Western Canada. However, in the area between Cape Mendocino in northern California and the southern extent of the Queen Charlotte Fault off the western tip of Vancouver Island, the two major plates named above are separated from one another by the small Juan de Fuca Plate.

The interaction between the Juan de Fuca Plate and the North American Plate is not presently understood. The magnetic anomaly pattern east and west of the Juan de Fuca Ridge indicates that part of the Juan de Fuca Plate has been subducted beneath the North American Plate. Also, the chain of stratovolcanoes which forms the axis of the Cascade Mountains is believed to have been produced by magma from a subducting plate (Atwater, 1970). Several other types of data indicate that an episode of late Cenozoic subduction occurred in this region of western North America. Seismic reflection surveys off the coast show a sediment-filled trench at the base of the continental slope (Hays and Ewing, 1970). Anomalously high gravity values on Vancouver Island are suggestive of a remnant subducting slab beneath the region (Stacey, 1973). Seismic wave velocities indicate that a high velocity slab exists beneath the Puget Sound Basin (McKenzie and Julian, 1971; Crosson, 1972) which is indicative of a subducting lithospheric plate.

The applicant has thoroughly reviewed the above-mentioned items and other types of data related to the current interaction of the lithospheric plate boundaries, including studies of plate kinematics (Silver, 1971; Atawater, 1970). While the available data are not clearly definitive, the applicant concludes that the data tends to support the interpretation that subduction is no longer occurring along the Juan de Fuca-North American Plate boundary or is occurring asseismically.

Available evidence examined during the CP review indicated that subduction along the Juan de Fuca Plate-North American Plate boundary was not currently occurring. In particular, earthquake activity indicative of a Benioff zone (a characteristic of subducting plates) was absent in this region. Also, the orientation of the present regional stress field was inconsistent with active subduction. Analysis of earthquake source mechanisms showed that the maximum principal stress is north-south compressional and the minimum principal stress varies from east-west to nearly vertical (Dehlinger and Couch, 1969; Couch and McFarlane, 1971; Crosson, 1972; Malone, et. al, 1975).

New information has been developed since publication of the CP SER and the FSAR, however, which may require a modification of the above conclusions. This new information may indicate that subduction is continuing and that the two plates may be coupled. That information and the NRC staff's concerns are presented in Sections 2.5.2 and 2.5.3.

Numerous reverse faults of a generally northwest or northeast trend, marking elongated basement uplifts, occur throughout the basaltic rocks of the region. These structural features are cut by east to northeast trending normal faults bounding areas showing different amplitudes of folding. Some of these faults significantly displace Tertiary strata in the region. The above described faults are thought to be the result of northeast compression of the crust, which was recurrent several times throughout the early Tertiary, until at least the middle Miocene. The basaltic basement complex shows the highest degree of faulting, with the intensity of faulting declining with the decreasing ages of the overlying rock units.

A line of stratovolcanoes extends along the Cascade Mountains from northern California to southern British Columbia. Eight of the valcanoes are within 200 miles of the Satsop site, the nearest being Mt. Rainier and Mt. St. Helens, each about 80 miles away. All of the volcanoes are believed to have been active within the past 15,000 years and three of them, Mt. St. Helens, Mt. Rainier, and Mt. Baker are considered active at the present time.

Prior to 1980 Mt. Rainier had received the most study. The studies show that it has been intermittently active during the last 10,000 years. This activity has been mainly of pyroclastic type, but includes at least one flow which extended nine miles from the mountain. Three of the tephra eruptions deposited about one inch of material up to 25 miles east of the mountain. The last major eruption occurred about 2000 years ago, but minor eruptive activity occurred 120 years and 150 years ago.

In addition to the eruptions of tephra, numerous mud flows have occurred at Mt. Rainier. The largest of these, the Osceola mud flow, occurred 5700 years ago. It extended about 70 miles down-valley from the volcano. None of the river valleys which could be potential mud flow pathways pass near the Satsop site. We conclude, therefore, that no mud flow hazard exists at the site.

A reassessment of the volcanic hazard was made after the May 18, 1980 eruption of Mt. St. Helens. It was found that downwind of the prevailing winds from the volcano at about 80 miles (plant's distance) there was an accumulation of 6 inches of tephra. The applicant reduced that value to 1.75 inches because the WNP-3 plant is upwind from the nearest Cascade volcanoes. This is a reasonable assumption but we require more data about the maximum thickness of tephra landfall and maximum rate of ash fall to support it.

In summary, it can be said that, while the geologic conditions of the Satsop site and its environs are very complex, and the area is still tectonically active, based on our review of the applicant's work to date, there are no known faults or other structures in the immediate vicinity of the site which could be expected to localize earthquakes; however, because of recent findings about the tectonics of the region, we require additional information to support that conclusion. The outstanding items concerning faulting in the region are discussed more fully in Section 2.5.3.

2.5.1.2 Site Geology

The WNP-3 site is located on a ridge in the Willapa Hills, 1 miles south of the intersection of the Satsop and Chehalis Rivers. The site elevation was +595 msl prior to excavation. Elevations rise to +1,768 msl at Minot Peak, 4 miles to the south. The floodplain of the Chehalis River Valley is about 1 miles wide and has a general elevation of +25 msl. Drainage patterns in the site area form a modified dendritic pattern that is structurally controlled to some extent by the regional Tertiary folding and jointing. Slopes are generally moderate, but range from nearly flat to vertical. The abundant weathering profiles, relict erosion surfaces and Pleistocene terraces in the area were used extensively to determine an upper limit to areal tectonic events.

The site vicinity is underlain by Quarternary deposits which consist of weathered gravels of the Wedekind Creek and Logan Hill formations of early to middle Pleistocene age; glacio-fluvial sands, silts, and gravels of middle to late Pleistocene age; loess of late Pleistocene age; colluvium and landslide deposits of late Pleistocene to Holocene age; and Holocene colluvium.

Approximately 15,000 feet of Tertiary rocks are present in the site vicinity, the oldest of which is the middle Eocene Crescent formation, a submarine basalt. Late Eocene Skookumchuck and McIntosh formations siltstones, tuffs, breccias, and sandstones overlie the basalt. The late Eocene to early Miocene Lincoln Creek formation of tuffaceous siltstone overlies the older four formations and is overlain by early to middle Miocene sandstones of the Astoria formation. The uppermost rocks in the site area are siltstones, sandstones, and conglomerates of the Montesano formation of late Miocene to early Pleistocene age. The plant site is founded on massively bedded sandstone of the Astoria formation.

Structurally the site is located on the nose of a broad poorly defined anticline, which is an extension of one of the areas several uplifts, the Minot Peak uplift. Typical of other anticlines in the region, the Minot Peak uplift has the basaltic basement rocks exposed in its core. Several significant faults (some with several thousand feet of displacement) in the site area can be shown by various means (e.g., terrace dating, saprolitization rates, erosion rates) to be associated with deformations no younger in age than Middle Quaternary (more than 630,000 years ago). Thus, they are not considered to be capable faults within the meaning of 10 CFR Part 100, Appendix A.

Numerous landslides have been mapped on the site locality. Many of these, though not most commonly, have been identified in the Astoria formation, which is the foundation bedrock. These slides in the Astoria formation are related to slippage along weathered siltstone interbeds. Based on a detailed investigation of local landslides, the applicant determined the geologic and geomorphic conditions necessary for sliding to occur: strong weathering of the Astoria rock, the presence of siltstone beds in the Astoria, topographic slopes inclined in the direction of bedding dip, and undercutting of bedding beneath dip slopes. Site investigations showed that these conditions do not exist at the site. The staff concludes that landsliding does not represent a problem at the site.

2.5.2 Vibratory Ground Motion - WNP-3

As a result of regional and site investigations performed by the applicant and others since the issuance of the CP-SER for WNP-3 in February 1976, the knowledge of the area has been greatly enhanced. The applicant has, and is continuing to undertake numerous studies and investigations that will provide an extensive amount of new information and interpretation. The staff anticipates that our review of this new information will lead to an understanding and resolution of many issues relating to the site vibratory ground motion determination.

The increasing amount of new information, however, may require the reinterpretation of some previous positions of the staff, the USGS, and the applicant. Presently the open seismological items have been transmitted in the form of questions (0230.1 through 0230.6) to the applicant. The applicant and the staff have met to discuss these open issues, and it is anticipated that the applicant will undertake a rigorous program of investigations to collect the information which will allow the staff to resolve the open issues. A summary of these issues follows.

The most significant seismologic issue involves the seismogenic potential of the subducting Juan de Fuca plate beneath WNP-3. The staff concluded in the CP-SER for WNP-3 in February 1976 that "while the available data are not clearly definitive, we believe that they tend to support the interpretation that subduction is no longer occurring along the Juan de Fuca - North American Plate boundary." Since that time additional recordings of small earthquakes have revealed an inclined zone of seismicity dipping to the east-northeast (Crosson, 1980). In addition, based upon the work of Ruff and Kanamori (1980) and Kanamori (1983) regarding the seismogenic potential of subduction zones, a number of questions regarding the Juan de Fuca zone have been raised. It is the applicant's position as discussed in FSAR sections 2.5.1.1.4.2 and 2.5.2.4.2.2, that the interface between the Juan de Fuca and North American plates will not be the location of a large magnitude earthquake. The staff has indicated via the review questions that the applicant must document in greater detail their position.

In particular the staff has requested that the applicant document the following information regarding the Juan de Fuca plate. This includes the applicability of Kanamori (1983) relationship, and examples of aseismic subduction zones which share the same characteristics with the Juan de Fuca zone. The magnitude of the largest shock in the plate or along the plate interface that could occur without exceeding the SSE and ground motion attenuation from subduction zones that can be used for the WNP-3 site will also be documented. The magnitude of the maximum credible earthquake on the subduction zone, along with esitmates of vertical and horizontal response spectra, depth and configuration of the subducting plate based upon earthquake locations cross-sections, fault plane solutions, and historic earthquake re-locations will also be provided by the applicant and reviewed by the staff.

The staff has also requested that the applicant calculate site specific response spectra for the maximum historical earthquake, not associated with known geologic structure, in the tectonic province of the site, and for the maximum earthquake on the Olympia Lineament. The applicant has also been asked to estimate the annual exceedance probability for the SSE using all possible seismologic source including the subduction zone.

The staff, the USGS, and Dr. Slemmons will undertake and participate in meetings and probably several site visits to review the applicant's additional information and field investigations. Upon the applicant's submission and the staff's review of the new information, the staff will issue its Final SER. This SER will discuss in detail all the relevant geologic and seismic issues including the regional and site geology, capable faulting, seismicity, operating and safe shutdown earthquakes, and the vibratory ground motion. Reports by the USGS and Dr. Slemmons will be incorporated as appendices and will be discussed in the SER.

2.5.3 Surface Faulting

The applicant has determined that the structural geology of the site and region around the site is characterized by large uplifts and faults and folds related to those uplifts that were formed by regional northeast directed compression during the Tertiary period. Three of these uplifts are present within the site vicinity, the Minot Peak uplift, the Blue Mountain uplift, and the Black Hills uplift. The site is located on an anticline which is the northern extension of the Minot Peak uplift. All of the uplifts are bounded primarily on the southwest sides and southeast sides by high angle faults that strike north-northwest, and east-northeast, respectively, with offsets ranging from several thousand feet to several hundred feet. The closest faults of this kind to the site are the Weikswood fault on the southwest side of the Minot Peak uplift and the Gibson Creek fault on the southeast side of the uplift. Offsets on both faults exceed 2000 feet. The Weikswood fault is approximately 1 miles south of the site at its closest approach, and the Gibson Creek fault is about 5 3/4 miles south of the site.

The applicant investigated all of the faults in the site vicinity by means of a literature search, mapping, borings, trenching, and remote sensing techniques. The applicant determined an upper limit of age of last movement on the faults by analyzing cross-cutting relationships between faults and stratigraphic contacts, relict erosion surfaces, Quarternary deposits, paleosols and weathering profiles. By determining the ages of these features the applicant was able to show an upper limit of movement on these faults of at least 630,000 years before present and more likely 2 million years before present. The staff has reviewed the data that is the basis for the conclusion and concludes that the faults mapped in the site vicinity are not capable within the meaning of Appendix A. Numerous minor faults were encountered in excavations for the plant. Most of these faults are northwest to northeast striking reverse faults. The applicant has made a good case in the FSAR for relating these faults to the regional faults and to the Late Tertiary northeast directed compression. NRC staff geologists examined these faults on several occasions. The NRC concludes that the faults mapped on and around the site are not capable (Appendix A).

On the other hand, considerable new geological information regarding the tectonics of the site region has been developed since the FSAR was published. Although we hold to our position that the faults in the site locality are not capable, some of the new data raises some concern. For example, it is not clear what happens to the faults at depth. If they are indeed related to Late Tertiary tectonics which are no longer in existence that is one thing, but if they are tied to large eastward dipping thrust faults that flatten downward (eastward), which are related to an active subduction tectonic style of the Juan de Fuca plate, then additional analyses and possibly investigations, will have to be carried out. A major northwest-trending fault in the Humptulips River area (Tabor and Cady, 1978) is a possible fault of this kind. It projects northwestward under Quaternary deposits to an outcrop of steeply dipping Pleistocene deposits (op. cit) on the west Fork of the Humptulips River. The capability of this fault may be important to the site in light of the following. Offshore studies by Silver (1972) and Snavely and Wagner (1982) indicate a subduction tectonic style characterized by eastward (landward) dipping thrust faults that generally steepen westward (upwards) and that have offset sediments as young as Quaternary. Considering this structural framework, we have asked the applicant to evaluate the possibility that the Humptulips fault, if capable, extends southeastward as a continuous fault or fault zone along the steepened west limb of the Wynoochee anticline (Rau, 1976) and on into the less well-defined Melbourne anticline (Gower and Pease, 1965) or alternatively to the southeast of these structures. We have requested the applicant to determine whether or not the Humptulips fault is throughgoing and capable, and, if so to evaluate the effects on the site.

Recent seismic reflection, remote sensing, and geophysical data covering the area has been gathered that post dates the FSAR publication and therefore has not been evaluated with respect to the site. We have recommended that the applicant assess these data with respect to the site.

Many of the natural drainage features in the site vicinity occur along projections of mapped faults although the faults are shown to terminate away from the stream valleys but along projections of their trends. Also many drainages are oriented in a pattern that is paralled to the north-northwest and northeast striking fault pattern, yet the streams are not considered to be fault controlled by the applicant. Evidence that supports the conclusion that the drainage features are not fault controlled is needed before the staff can complete its review.

The applicant has dismissed offset magnetic anomalies KK and HH on the Juan de Fuca plate as probably due to episodic jumping of short transform faults connecting offset segments of the spreading ridge as suggested by Hey (1977) (FSAR 2.5-44). Provided that successive jumps are in the same direction and occur after equal increments of spreading, the jumps should produce a V-shaped wake consisting of a pair of lineaments intersecting at the ridge. Although KK seems to form such a wake, mirrored in the Pacific plate, HH is less convincingly matched (c.f. Barr, 1974 and Elevers and others, 1973). Considering the difficulty of identifying the mirror image of HH, the applicant has been requested to evaluate the hypothesis that HH is a fault as suggested by Pavoni (1966), and that the on-shore subcrustal extension of HH could be the source of deep-seated major earthquakes in the Puget Sound region (Fox, 1983), and to evaluate the response at the site of a major earthquake on fault HH.

REFERENCES

1. Atwater, T., 1970, Implications of Plate Tectonics for the Cenozoic Tectonic Evolution of Western North America; GSA, 81, pp 3513-3535.

2. Barr, S. M., 1974, Sea Mount forméd near the crest of Juan de Fuca Ridge, NE Pacific Ocean; Marine Geology, vol. 17, p1-19.

3. Couch, R. W. and MacFarlane, W. T., 1971, A Fault Plane Solution of the October 1969 Mt. Rainier Earthquake and Tectonic Movements in the Pacific Northwest Derived from Fault Plane and First Motion Studies; EOS, AGU Trans. 52, 428 p.

4. Crosson, R. S., 1980, Review of Seismicity in the Puget Sound Region from 1970 through 1978; Report presented at the Puget Sound Earthquake Hazards Workshop, University of Washington, Maple Valley Center, Lake Wilderness, October 1980.

5. Crosson, R. S., 1972, Small Earthquakes, Structure, and Tectonics of the Puget Sound Region BSSA, 62, 5, pp 1133-1171.

6. Dehlinger, P. and Couch, R. W., 1969, Synthesis of Geophysical Results in the Juan de Fuca and Gorda Ridge Areas (NE Pacific Ocean), EOS, AGU Trans, 50, 186 p.

7. Elvers, D., Srivastava, S. P., Potter, K., Moorley, J., Sdidel, D., 1973, A symetric spreading across the Juan de Fuca and Gorda rises as obtained from a detailed magnetic survey; Earth and Planetary Sciences Letters, vol. 20 p. 211-219.

8. Fox, K. F., Jr., 1983, Northeast-trending subcrustal fault transects western Washington; U.S. Geological Survey Open-File Report 83-398.

9. Gower, H. P., and Pease, H., Jr., 1965, Geology of the Monteseno Quadrangle, Washington; U.S. Geological Survey GQ Map 374.

10. Hayes, D. E. and Ewing, M., 1970, Pacific Boundary Structure; in The Sea, A. E. Maxwell (ed), 4, Part II, pp 29-72.

11. Hey, R., 1977, A new class of "pseudofaults" and their bearing on plate tectonics: a propagating rift model; Earth and Planetary Sciences Letters, v. 37, p. 321-325.

12. Kanamori, H., 1983, Global Seismicity; Preprint, California Institute of Technology.

13. Malone, S. D., Rothe, G. H., and Smith, S. W., 1975, Details of micro-earthquake swarms in the Columbia Basin, Washington, BSSA, 65, 4, pp 855-865.

14. McKenzie, D. and Julian, B. 1971, Puget Sound, Washington - Earthquake and the Mantle Structure Beneath the Northwestern United States; GSA, 82, pp 3519-3524.

15. Pavoni, N., 1966, Tectonic interpretation of the magnetic anomalies southwest of Vancouver Island; Pure and applied geophysics, v. 63. p. 172-178.

16. Rau, W. W., 1967, Geology of the Wynoochee Valley Quadrangle, Washington; Washington State Division of Mines and Geology Bulletin no. 46, 51 p.

17. Ruff, L., and H. Kanamori, 1980, Seismicity and the Subduction Process; Physics of the Earth and Planetary Interiors, v 23, p. 240.

18. Silver, E. A., 1972, Pleistocene Tectonic Accretion of the Continental Slope off Washington; Marine Geology, v. 13, p. 239-249.

19. Silver, E. A., 1971c, Small Plate Tectonics in the Northeastern Pacific; GSA, 82, pp 3491-3496.

20. Snavely, P. D., Jr., and Wagner, H., 1982, Geologic cross section across the continental margin off Greys Harbor, southwestern Washington; U.S. Geological Survey Open-File Report 82-459, 11 p.

21. Stacey, R. A., 1973, Gravity Anomalies, Crustal Structure, and Plate Techtonics in the Canadian Cordillera; Can Jour Earth Sci., 10, pp 615-628.

22. Tabor, R. W., and Cady, W. M., 1978, Geologic map of the Olympic Peninsula, Washington; U.S. Geological Survey Miscellaneous Field Investigations Man I-993.

23. US NRC, 1983, Geosciences Review Questions, Memorandum from R. E. Jackson to G. W. Knighton, Supply System Nuclear Project No. 3, April 28, 1983.

24. UN NRC, 1982. Safety Evaluation Report related to the Operation of WPPSS Nuclear Project No. 2, Docket No. 50-397, Supplement No. 1, NUREG-0892, August, 1982.