The Hanford Nuclear Energy Center

A Conceptual Study

Harold Harty, Project Manager

September 1978

**Prepared for the U.S. Department of Energy
under Contract EY-76-C-06-1830**

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Pacific Northwest Laboratory
Richland, Washington 99352

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INTRODUCTION

The objective of the Hanford Nuclear Energy Center (HNEC) study is to develop an improved understanding of the nuclear energy center (NEC) concept and to identify research and development needed to evaluate the concept fully. A specific context was selected for the study--the Hanford site. Thus, the study primarily addresses the HNEC concept, but the findings are extrapolated to generic NECs where possible.

The impetus behind the NEC concept has changed with time. Presently it is seen as a means of solving pressing institutional problems including reducing licensing delays for nuclear facilities and providing safeguards for the use of plutonium as a reactor fuel.

An NEC is typically conceived of as a large number of closely sited nuclear power plants (10 to 20 or more) often near supporting fuel cycle facilities. This study assumed an HNEC comprising 20 nuclear power plants (five quads of four reactors each) that would be completed by about 2006. The HNEC would include interim fuel storage facilities or fuel reprocessing and fabrication facilities, assumed to meet whatever Federal requirements might be in place at the time of construction, and appropriate waste management facilities.

The major emphasis in the HNEC study was to explore potential technical and environmental problems in a specific context and in sufficient detail to evaluate potential problems and propose practical solutions. Earlier studies of the concept were not as detailed as this one. The areas of concern are typical of those considered in preparing environmental and safety analysis reports, including: topics dealing with engineering choices (e.g., site selection, heat sink management, electrical transmission, and reliability of generation); environmental matters (e.g., terrestrial and radiological effects); socioeconomic factors (e.g., community impacts);

and licensing considerations. The body of this report comprises summaries of these studies; the studies themselves have been published earlier and are collected and reprinted in the Appendix.^(a)

In the course of the study a conceptual layout was made of an HNEC. Its primary purpose was to provide a common basis for the various studies that were made. It should not be considered an optimum arrangement of facilities nor a selection of specific sites. A great deal more work would be required to make those kinds of judgments. In practice, an HNEC would probably be built by adding one or two power plants at a time with no specific capacity to be achieved in a given time. The siting of each new plant would draw upon previous experience, studies, and recent data to optimize site selection and minimize environmental and socio-economic effects. It is appropriate to note that no comprehensive comparison was made of dispersed siting of nuclear plants in the Pacific Northwest and siting at an HNEC. Such a comparison was not a part of the scope of this study. Generic comparisons are given in Reference 1.

BACKGROUND

The concept of a nuclear energy center (NEC) appears to have been conceived about 20 to 25 years ago. The basis for the concept at that time was to combine the fuel cycle facilities with the production of electric power. Flexibility in the fuel cycle and certain economic advantages were projected. This type of siting model did not present advantages to the electric utilities and the timing for implementation of the fuel cycle differed from that for generation of electric power. The concept was reviewed periodically as utilities and nuclear industry participants considered siting several or more nuclear plants at one location. The

(a) The appendix to this report has been published as a separate volume, PNL-2640 APP.

first major consideration of NECs resulted from Project Independence in 1973-4. The impetus of that project was to explore how quickly nuclear plants could be built in order to help free the United States from dependence upon foreign petroleum supplies. The studies made at that time speculated how rapidly nuclear plants could be built at a single location and assessed what the major problems might be.⁽²⁾ Project Independence studies did not treat any of the projected problems in depth. Problems thought to present potential barriers to the siting of a large number of nuclear plants at a single location included 1) atmospheric effects from massive heat releases, 2) coping with the overall waste heat problem, 3) the feasibility and reliability of electrical transmission systems from isolated centers to load centers, and 4) institutional problems arising from a new mode of siting electrical generating facilities. As the emphasis on Project Independence diminished, so did the interest in NECs.

The next major emphasis came as a result of the Energy Reorganization Act of 1974, which required the Nuclear Regulatory Commission (NRC) to make a nuclear energy center site survey. This study was made in 1975 and the results were published in January 1976.⁽¹⁾ There were several factors that provided the impetus for this study, including some residual aspects of Project Independence, a growing concern about nuclear safeguards and shipment of radioactive wastes, and the possibility of facilitating the siting of nuclear reactors and fuel cycle facilities. The study concluded that NECs would probably evolve in the course of nuclear industry development; that NECs containing 10-20 reactors could be feasible and practical; and that, from a safeguards/radioactive waste shipment point of view, there was no pressing need to move in the direction of the NEC concept.

More recently, factors such as the public's concern about nuclear power, the difficulty in obtaining sites for nuclear plants, licensing delays, plans to build up to four nuclear reactors at single sites, and greater regional planning of facilities for generating electricity have provided a continued basis for studying the NEC concept. The Department of

FIGURE 1. Conceptual Layout of Hanford as a Nuclear Energy Center

1933. Should Federal plans for that operation be delayed or discontinued, light water reactors (LWRs) would be substituted for LMFBs. This is not to say that decisions about these matters are of little consequence but only that they don't significantly affect the scope of the technical studies; changes in regional power projections simply change the date for completing a 20-reactor (or 40-reactor) HNEC. For this report the most recent projections are used. (For comparison, earlier projections are provided in the Appendix in BNWL-B-458, pages 7 to 18.) The major effects of changes in the growth scenario probably relate to socioeconomic factors and to plans for the electrical transmission system.

How an HNEC might develop could be significant. If an HNEC developed by adding one or several plants at a time--with different utilities and fuel cycle industrial firms building as they saw the need and factoring in the engineering, environmental, and socioeconomic climate that then existed at an HNEC--the whole process would not be unlike present siting methods. On the other hand, if an HNEC were planned as a major project, then a new licensing process might be created, environmental and safety analysis reports might be required for the entire project, and greater regional involvement would probably occur, to name a few likely changes. No evaluation was made of the impact such factors might have on costs and schedules.

The growth of the conceptual HNEC is keyed to the growth of nuclear generating capacity in the Pacific Northwest (PNW). Growth data applying to the Western Systems Coordinating Council (WSCC) (Figure 2) are also used to arrive at HNEC plant additions. This report assumes that from 20 to 40 nuclear power plants (up to 10 clusters of up to four plants each) would be built at an HNEC, together with an interim spent fuel storage facility and waste management facilities. It also assumes that all nuclear power plants in the Pacific Northwest coming on line after 1989 would be built at Hanford. All spent fuel, except Fort St. Vrain fuel, and nuclear-plant-generated

FIGURE 2. General Load Areas for the Western Systems Coordinating Council

nuclear-plant-generated wastes in the WSCC area would be shipped to the Hanford site for storage and, ultimately, for disposal or reprocessing.

In 1975 fuel cycle logistics were evaluated for an HNEC comprising 16 LWRs, 24 LMFBRs, reprocessing plants for LWR and LMFBR fuels, a refabrication plant, waste treatment facilities, and supporting facilities.⁽⁵⁾ If the Federal policy regarding reprocessing and the LMFBR were changed that study would need complete revision because the assumed growth rate for the WSCC is now much less and HNEC facilities would be delayed 5 to 15 years.

Nuclear Power Plants

For this analysis, the nuclear growth scenario is divided into three components: 1) nuclear power plants that are planned, specified, and scheduled (from the present to ~1987); 2) nuclear power plants that are planned, unspecified, and only tentatively scheduled (~1988 to 1997); and 3) nuclear power plants that are unplanned and unscheduled but are required to meet estimated electrical loads (~1998 to 2010). The projection for load growth through 1997 is based on the WSCC reply to FPC Docket R-362 dated April 1, 1978, in which generating facilities are projected through 1997.⁽²⁾ Some nuclear power plant startup dates have been modified based upon a report from the Subcommittee on Load and Resources to the Pacific Northwest Utilities Conference Committee.⁽³⁾ Table 1 shows the startup schedule for planned and specified nuclear power plants in the WSCC.

The WSCC has planned total additions of 58 GWe in the period 1988-1997, with 40% of the additions projected to be nuclear.⁽²⁾ This is assumed to be composed of 19 units of 1250 MWe each. For the purpose of this study planned but unspecified units have been scheduled as follows:

- Light Water Reactors - All 19 units are assumed to be light water reactors, and are assumed to be completed at the rate of about 2 per year. Table 2 gives the assumed startup schedule from 1988 through 1997.

TABLE 1. Planned and Specified Nuclear Power Plants in the Western Systems Coordinating Council

Principal Sponsor	Plant Name	Type	Vendor ^(a)	Startup Date	Capacity, MWe	
					Unit	Cumulative
Pacific Gas & Electric	Humboldt Bay	BWR	GE		63	
Southern California Edison	San Onofre 1	PWR	W		436	
Sacramento Municipal Utility District	Rancho Seco	PWR	B&W		903	
Public Service Company of Colorado	Fort St. Vrain	HTGR	GGA		330	
Portland General Electric	Trojan	PWR	W		1,130	2,862
Pacific Gas & Electric	Diablo Canyon 1	PWR	W	11/78	1,100	3,962
Pacific Gas & Electric	Diablo Canyon 2	PWR	W	05/79	1,100	5,062
Washington Public Power Supply System	WNP 2	BWR	GE	09/80	1,100	6,162
Southern California Edison	San Onofre 2	PWR	CE	10/81	1,100	7,262
Arizona Public Service Company	Palo Verde 1	PWR	CE	05/82	1,270	
Washington Public Power Supply System	WNP 1	PWR	B&W	12/82	1,250	9,782
Southern California Edison	San Onofre 3	PWR	CE	01/83	1,100	10,882
Washington Public Power Supply System	WNP 3	PWR	CE	01/84	1,240	
San Diego Gas & Electric	Sundesert 1	PWR		04/84	974	
Arizona Public Service Company	Palo Verde 2	PWR	CE	05/84	1,270	
Washington Public Power Supply System	WNP 4	PWR	B&W	06/84	1,250	15,616
Washington Public Power Supply System	WNP 5	PWR	CE	07/85	1,240	
Puget Sound Power & Light	Skagit 1	BWR	GE	07/85	1,288	18,144
San Diego Gas & Electric	Sundesert 2	PWR		01/86	974	
Portland General Electric	Pebble Springs 1	PWR	B&W	04/86	1,260	
Arizona Public Service Company	Palo Verde 3	PWR	CE	05/86	1,270	21,648
Puget Sound Power & Light	Skagit 2	BWR	GE	07/87	1,288	22,936
Arizona Public Service Company	Palo Verde 4	PWR	CE	07/88	1,270	
Portland General Electric	Pebble Springs 2	PWR	B&W	04/89	1,260	
Arizona Public Service Company	Palo Verde 5	PWR	CE	04/90	1,270	

(a) GE - General Electric
W - Westinghouse

B&W - Babcock & Wilcox
GGA - Gulf General Atomics

CE - Combustion Engineering

TABLE 2. Electrical Generating Capacity for Planned But Unspecified Nuclear Power Plants in the Western Systems Coordinating Council from 1988 to 1997

Year	BWR Capacity, MWe		PWR Capacity, MWe		Total Cumulative Capacity, MWe
	Add	Cumulative	Add	Cumulative	
1988		3739	1270 ^(a)	20,137	24,206 ^(b)
1989	1250	4989	1260 ^(c)	20,397	26,716
1990		4989	2520 ^(d)	23,917	29,236
1991	1250	6239	1250	25,167	31,736
1992		6239	2500	27,667	34,236
1992	1250	7489	1250	28,917	36,736
1994		7489	2500	31,417	39,236
1995	1250	8739	1250	32,667	41,736
1996		8739	2500	35,167	44,236
1997	1250	9989	1250	36,417	46,736

(a) Palo Verde 4

(b) Includes a 330-MWe high-temperature gas-cooled reactor

(c) Pebble Springs 2

(d) Includes Palo Verde 5

- High-Temperature Gas-Cooled Reactors (HTGRs) - Although this type of reactor appears to be ready to market, this study assumes that no additional units will be added to the WSCC because of a lack of commitment to the HTGR by industry and the utilities.
- Liquid Metal Fast Breeder Reactors - Based upon the current Federal policy to defer indefinitely the commercialization of this reactor type, no LMFBRs are assumed for the WSCC in this time period.

About 15% of the nuclear power plants that are operating, under construction, or ordered from vendors are located in the WSCC. It is therefore assumed that about 15% of those to be built in the United States after 1997 will be located in the WSCC. An addition rate of 10 to 15 nuclear power plants per year in the period 1998 to 2010 would be consistent with the national energy plan, ⁽⁴⁾ and thus, for nuclear power plants as yet unplanned and unspecified, an addition rate of two per year in the WSCC would be a reasonable assumption.

These growth projections for the WSCC call for the completion of about two nuclear power plants per year from 1989 through 2010. Table 1 indicated that about one half of the plants planned or under construction in the WSCC are in the Northwest. Thus, it is reasonable to assume that about one half of the WSCC nuclear power plants built after 1988 will also be in the Northwest. This study assumes that the nuclear power plant requirement for the Northwest for 1989 was satisfied with Pebble Springs #2 and that all additional plants would be built at an HNEC. This assumption points to a completion rate of one plant each year in 1990 through 2006 for a total of 20 units at an HNEC (3 now under construction plus 17 assumed).

Interim Spent Fuel Storage Facility

At the present time, the Federal government is planning to accept spent fuel for interim storage and disposal beginning in 1983. Such a facility would not be required for power reactors at an HNEC before 1990; however, to facilitate operating flexibility, shipment of spent fuel could start as early as 1986. Interim spent fuel storage might be required for other reactors in the WSCC by 1984. Spent fuel storage facilities were assumed to be located at the site set aside for possible future reprocessing plants. Spent fuel would then be shipped to a disposal site assumed to be available in 1988 or later. After the disposal site begins to receive spent fuel, spent fuel from most reactors would be shipped directly to the disposal site.

In the event of a change in the current Federal policy regarding reprocessing, the interim storage facility could be used as a receiving basin for the reprocessing plant. Based on the power reactor growth schedule presented, and assuming no spent fuel is shipped out of the WSCC or disposed of, there would be sufficient spent fuel to justify the start-up of a 1500-MT/yr reprocessing plant in 1993. The design of this plant and the composition of its product could be quite different from those previously considered, depending upon the outcome of Federal fuel cycle studies.

Fuel Refabrication

As presently envisioned, the HNEC will not contain commercial mixed-oxide fuel fabrication facilities. The power reactors at HNEC are expected to be fueled with slightly enriched uranium that has been fabricated off-site and shipped to the reactors. In the event of a change in the Federal policy on reprocessing, a fuel refabrication facility could be collocated with a reprocessing facility. These plant designs would be dependent upon the outcome of Federal fuel cycle studies; the fuel refabrication plant might be quite different from the one proposed by Westinghouse.⁽⁶⁾ It should be built concurrently with the reprocessing plant and have a capacity of about 300 MT/hr for LWR fuel or 60-70 MT/yr for LMFBF fuel.

If a change in Federal policy results in LMFBF construction, the reprocessing and refabrication plants would have the capacity to produce the first cores and all reloads for up to eight LMFBFs of the design assumed in Reference 5. Any LMFBF plant could be substituted for any one of the LWR plants in the 1998-2006 period. If more LMFBFs were desired, additional reprocessing capacity would be required. Based upon the assumed growth rate, a reprocessing plant with a capacity of 1500 MT/yr would result in excess capacity for WSCC needs if scheduled for operation before 2015.

Waste Management Facilities

The waste management facilities are assumed to handle all wastes generated by reactors other than HTGRs in the WSCC. The scope of these facilities is not treated in this study.

HNEC Electrical Transmission System

An electrical transmission system consisting of overhead-AC, single- and double-circuit 500-kV transmission lines was selected for a 20-reactor HNEC.⁽⁷⁾ An estimated 50,000 MWe could be transmitted from an HNEC to load centers having an 1100-kV system by using available cross-mountain rights of way (with widening in some places) assuming successful development and public acceptance of that technology and satisfactory reliability.

References for Introduction

1. Nuclear Energy Center Site Survey - 1975, NUREG-001-ES, Nuclear Regulatory Commission, January 1976.
2. Western Systems Coordinating Council, "Reply to United States Department of Energy Order 383-5 Docket R-362: 'Reliability and Adequacy of Electric Service,'" April 1, 1978.
3. Pacific Northwest Utilities Conference Committee, West Group Forecast of Power Loads and Resources July 1978 - June 1989, March 1, 1978.
4. The National Energy Plan, Executive Office of the President, Energy Policy and Planning, April 29, 1977.
5. Status Report -- Conceptual Fuel Cycle Studies for the Hanford Nuclear Energy Center, BNWL-B-437, Battelle, Pacific Northwest Laboratories, Richland, WA, November 1975.
6. Westinghouse Recycle Fuels Plant: License Application, Docket 70-1432, Westinghouse Electric Corporation, Pittsburgh, PA, 1973.
7. Electric Power Transmission for a Hanford Nuclear Energy Center (HNEC), BNWL-B-426-REV, Battelle, Pacific Northwest Laboratories, Richland, WA, June 1978.

Energy is now sponsoring several studies related to nuclear energy centers, including the Pacific Northwest Laboratory's study of Hanford as a nuclear energy center. (3,4)

DESCRIPTION OF THE HNEC CONCEPT - E. T. Merrill

A conceptual layout of an HNEC (Figure 1) has been prepared to provide a basis for analysis of the concept. The layout shows ten clusters, called quads, of four reactors each; the location of possible fuel cycle facilities; and an electrical transmission system as it might exist for an HNEC. The concept may not be an optimum layout of facilities, though efforts were made to keep it practical. Thus, the nuclear power plants are located near the Columbia River, the fuel cycle facilities are located on high ground away from the water table, and transmission lines use existing or planned corridors.

Initially, the HNEC study concentrated on a 40-reactor case, but following completion of a study by the Nuclear Regulatory Commission, (1) the 20-reactor case was emphasized. The quads selected for the latter case were south of the Columbia River; more is known of the geology and ground water in aspects of that portion of the Hanford site. But, to use sites north of the river or in other locations of the Hanford site would not have affected the basic conclusions of the study.

During the course of the study, an indefinite moratorium was placed on commercial fuel reprocessing, the development schedule for the liquid metal fast breeder reactor (LMFBR) program became uncertain, and regional power projections changed. These changes do not significantly affect those conclusions of the HNEC study that are primarily technical and not policy oriented, nor would renewed emphasis on reprocessing and the breeder or increased growth projections. The fuel site for the fuel reprocessing plant shown in Figure 1 could become the site for an interim storage facility for spent fuel or for whatever facility might result from present Federal studies on alternative fuel cycles. This also applies to the mixed oxide fuel fabrication plant. The waste management facility is presently undefined. Previously it was assumed that the LMFBR would be available for commercial operation in

CONCLUSIONS FROM TECHNICAL STUDIES

Concentration of a generating capacity in a limited area, as in an NEC, would be a new situation for most, if not all, electrical utilities in the United States. Typically, utilities avoid committing more than about 15% of their thermal generating capacity to one location. An NEC, and more specifically an HNEC, could represent about one-third of a region's generating capacity. Thus, the concept of an NEC pushes the technology of siting and may aggravate present environmental, engineering, and socioeconomic problems.

The approach taken in the HNEC study has been to explore potential problem areas in sufficient detail to make preliminary assessments. The topics that need to be addressed are similar to those that would be considered in preparing environmental and safety analysis reports. For this report we have divided these topics among: 1) engineering studies, including site selection, heat sink management, electrical transmission, and reliability of generation; 2) environmental studies, including terrestrial and aquatic ecology, meteorology, and radiological effects; (3) socioeconomic factors; and 4) licensing considerations.

A nuclear energy center at Hanford comprising 20 or more reactors and supporting fuel cycle facilities appears technically feasible without unacceptably degrading the environment, decreasing the reliability of electrical power supply to the Pacific Northwest (PNW), and compromising safety. Whether the HNEC approach is an optimal choice for the PNW from the standpoints of engineering, environment, and economics was not studied. However, data from some of the studies indicates that an HNEC does not appear to offer any significant cost advantages over dispersed siting.

A simple extrapolation of the HNEC study to generic NECs is not possible because the Hanford site is much larger than the sites for most projected NECs (570 sq mi versus 100 sq mi or less), because of its site-specific characteristics (primarily the proximity of the Columbia River), and because of regional factors (the large hydro base and the electrical

transmission system). Appropriate care should be taken in applying the results of the HNEC study to other NEC sites. Table 3 summarizes results of the HNEC study that have been extrapolated to generic NECs.

TABLE 3. Extrapolation of Findings for the Hanford Nuclear Energy Center to Generic Nuclear Energy Centers

Area of Study	Hanford Nuclear Energy Center	Generic Nuclear Energy Center
Feasibility of NECs	A 20-reactor or more HNEC with associated fuel cycle facilities is technically feasible on the Hanford site.	Other studies have shown that NECs of varying size are feasible at a number of sites in the U.S. HNEC studies support that conclusion.
Growth of NECs	A 20-reactor HNEC appears practical to achieve over a 20-25 year period. The growth of an HNEC would depend on subregional electrical demands, other siting opportunities, and other factors; thus an ordered construction of plants is unlikely. For this study it was assumed that one reactor per year from 1989-2005 is added to the three WPPSS plants currently under construction.	The number of reactor plants that can be accommodated and rate of buildup is site dependent. The frequently projected savings from "mass production" of power plants at an NEC are unlikely to materialize because of load growth variability. Some socioeconomic effects from a cyclic construction schedule are likely to continue.
Heat sink management	Consideration of environmental effects, economics, and resource utilization resulted in an HNEC heat sink management plan comprised of cooling towers and once-through cooling with Columbia River water for the 20-reactor HNEC. Less heat is released in the river than occurred with the Hanford Plutonium production reactors.	Heat sink management plans will be site specific. The environmental impacts from the heat release will probably be the limiting factor for an NEC.

TABLE 3. (contd)

Area of Study	Hanford Nuclear Energy Center	Generic Nuclear Energy Center
Electrical transmission	It is feasible to transmit more than 23,000 MWe with 500-kV lines from an HNEC; an economic penalty of about 5% of the unit power cost for generation is likely. Existing rights-of-way would need minor upgrading to handle 23,000 MWe.	The same conclusions as for HNEC probably apply, except that obtaining rights-of-way would be site dependent.
Reliability of generation	At full development (about year 2006) the HNEC would represent about 30% of the region's installed capacity. The probability of a significant interruption in electrical generation is greater for an HNEC than for equivalent dispersed siting. The probability level of once in 10,000 years is likely to be acceptable to the public based on related events involving power cutbacks. The unique characteristics of the hydro-thermal generating system in the PNW and the associated transmission system contribute to the ability of the power system to respond to massive interruptions.	The same general conclusion applies to generic NECs but will depend on generating and transmission characteristics of the region. To decrease the probability to acceptable levels may require one or more of the following: additional investment in plant construction, transmission system interties, or reserve margins.
Terrestrial factors	While an HNEC would alter the existing terrestrial ecosystem at the expense of certain native species, the overall terrestrial effects are probably not significant.	Terrestrial effects are site dependent.
Aquatic factors	Aquatic effects of an HNEC, assuming once-through cooling of about one-third of the 20 reactors, is not expected to be significant. This conclusion is substantiated by comparing the projected aquatic effects with measured effects resulting from the once-through cooling of Hanford plutonium production reactors.	Aquatic effects are site dependent. The use of once-through cooling with NECs is probably limited to large river sites and/or ocean sites.

TABLE 3. (contd)

Area of Study	Hanford Nuclear Energy Center	Generic Nuclear Energy Center
Meteorology	There are no overriding meteorological concerns for an HNEC with 20 reactors, though some weather modifications may be statistically significant. The most likely modifications include increases in cloudiness and fog and decreases in solar radiation, primarily in the vicinity of the reactor clusters.	Meteorological effects are site dependent. An equal number of plants on a smaller site could be expected to have a greater impact off the NEC site.
Safety	There is no apparent change in safety to the public from an HNEC compared to dispersed siting. Radiological standards for offsite and onsite persons can be met without use of special equipment.	This conclusion is probably valid for generic NECs, but there may be site-specific special requirements.
Socioeconomic factors	No significantly greater socioeconomic impact than that currently being experienced with the construction of WPPSS reactors (WNP 2, 1, and 4) is anticipated for an HNEC with 20 nuclear power plants, built at the rate of about one per year.	Socioeconomic factors are site and scenario dependent. Sites would tend to be chosen where socioeconomic impacts would not be great. Because NECs would probably be sited in isolated areas, the benefit of wider public familiarity with the nuclear technology and processes employed could be lost. This could represent a potential disadvantage for the concept.
Licensing	Examination of criteria in 10 CFR, Regulatory Guides, Work Plan Reviews, Standards, public correspondence of ACRS, and reviews of other NEC studies do not reveal areas where the NEC concept would be limited by technical concerns.	Same as for HNEC.

SITE SELECTION

There are adequate sites at Hanford for over 20 nuclear power plants and associated fuel cycle facilities without interruption of existing activities or processes, or infringement on other land commitments. Continuing geological and geophysical studies of the Hanford site in support of commercial nuclear power plant siting (by WPPSS) and radioactive waste storage (by Rockwell Hanford Operations) show no geologic structure on the site known to exhibit active faulting. An HNEC is not expected to interact significantly with the ground water regime on the Hanford site.

HEAT SINK MANAGEMENT

The major impact from an HNEC arises from the enormous amount of waste heat that must be dissipated -- about 50,000 MW for a 20-reactor HNEC. The impact can be divided between the atmosphere and the Columbia River, the two immediate heat sinks. The atmospheric impacts include increased cloudiness, ground-level humidity and fog, and decreased solar radiation. The Columbia River impacts are primarily related to fisheries. Studies indicate that a satisfactory balance among environmental effects, economics, and resource utilization (primarily land and water) can be achieved with 6 plants with once-through cooling using Columbia River water, 10 plants with tall, mechanically assisted cooling towers, and 4 plants with mechanical-draft towers (assumed to be the Washington Public Power Supply System site). Six plants with once-through cooling place less heat in the Columbia River than the Hanford plutonium production reactors did for eight or more years.

ELECTRICAL TRANSMISSION

Transmission of electrical power with single- and double-circuit 500-kV lines is practical for a 20-reactor HNEC. Existing rights-of-way are adequate (with minor widening in selected locations) and environmental effects are not significantly different for equal amounts of energy generated in dispersed plants. The increase in unit power costs that results from transmitting power from an HNEC is estimated to be about 5% greater than for dispersed sites.

RELIABILITY OF GENERATION

As previously stated, an NEC characteristically concentrates a large electric generating capacity in a relatively small geographical area. For an HNEC with 20 plants this could amount to 30% of the Pacific Northwest's total generating capacity. Thus, a PNW power system containing an HNEC (or any NEC) is potentially vulnerable to major interruption of power generation from a single natural event (earthquake, ashfall, etc.). Analysis of such a possibility, conducted on the basis of the probable state of capacity and energy reserves in the system, shows that there is little probability that a major power interruption at an HNEC would seriously affect Pacific Northwest power users. The characteristics of the PNW electrical generating system with its large hydro base and its transmission system are important factors in minimizing the effects of potential major electrical outages at an HNEC. A temporary loss of 20% of system capacity followed by a 16% energy deficit for about four months, for example, has a probability of occurring once in 10,000 years. Less serious outages, of course, have greater probabilities of occurring but with reduced consequences. Earthquakes are a major contributor to risk of loss of generating capacity; this risk could be reduced by an order of magnitude or more with the development of new seismic evaluation techniques, and/or the use of more rigid design criteria for selected portions of the generating plants. The above analysis did not include the risk of loss of transmission system associated with an HNEC.

TERRESTRIAL ECOLOGY

An HNEC would alter the existing terrestrial ecosystem at the expense of certain native species. No rare or endangered species would be involved in the land area, estimated at several percent of the total Hanford site, that would be affected by an HNEC. There would be no infringement on the Arid Land Ecology (ALE) reserve. Overall, the terrestrial ecosystem is unlikely to be significantly stressed by an HNEC.

AQUATIC ECOLOGY

Results of aquatic studies indicate that aquatic effects attributable to cooling towers for a 20- or 40-reactor HNEC are not significant. Based on analysis of Hanford production reactor data it is concluded that Columbia River water can be used to cool up to six nuclear power plants (~1250 MWe each) by a once-through system without producing significant changes in the river's ecosystem. For a period of eight years the Hanford plutonium reactors released quantities of heat to the river that were somewhat greater than that expected for six nuclear power plants without producing identifiable adverse effects to the river biota. Heat releases to other large rivers in the United States have typically shown, at most, near-field ecological impacts. The thermal release from once-through-cooled nuclear power plants at an HNEC might need to be curtailed or discontinued during periods of high ambient river temperature (August-October). Because most of the water removed from the river for once-through cooling is returned to the river, other downstream water uses would be preserved. Thermal additions to the river during the colder winter period might be beneficial to some river organisms by creating better conditions for growth.

METEOROLOGY

The results of the HNEC meteorological studies indicate that there are no overriding meteorological concerns associated with the heat sink management plan proposed. An HNEC may cause some weather modifications that would be statistically significant, however. The most likely modifications include increases in cloudiness and fog and decreases in solar radiation. These modifications would primarily occur in the immediate vicinity of the HNEC clusters. The magnitudes of the modifications could be controlled by optimization of the cooling system mix in an HNEC. The use of once-through river cooling and wet-dry or dry cooling towers tends to minimize increases in cloudiness and decreases in solar radiation, while the use of tall (or wet-dry or dry) cooling towers tends to minimize ground-level fogging. Enhancement of natural precipitation falling through moist plumes

is likely to occur over limited areas near an HNEC. An HNEC is not expected to cause convective vortices, such as large dust devils, or severe storms.

SAFETY

The concentration of nuclear facilities at an HNEC does not appear to affect public safety differently from dispersed siting. With present technology radioactive waste equipment, routine radiological releases from an HNEC would not exceed allowable radiation doses to construction workers or operating personnel at an HNEC or to people living adjacent to the Hanford site. Loss of all or a major part of HNEC generating capacity could have safety implications (as described in Reliability of Generation) but would not include loss of life.

SOCIOECONOMIC FACTORS

Construction of a 20-reactor HNEC by 2006 would require about 7,000 construction workers (craft and manual workers and engineering and administrative personnel) and the peak workforce would be maintained for about 12-14 years. This is similar in size to the number (about 6,000) which the community is presently accommodating for the construction of WPPSS's WNP 1, 2, and 4 nuclear plants at Hanford.

LICENSING

Examination of criteria in 10 CFR, regulatory guides, work plan reviews, standards, public correspondence of ACRS, and reviews of other NEC studies do not reveal areas where the NEC concept would be limited by technical concerns. Formal official guidance, rules or regulations that specifically address NECs, however, do not exist. The absence of criteria for siting or licensing NECs makes it difficult to assess the viability of some of the proposed solutions to significant problems that have been identified. Licensing the first NEC would probably be a lengthy process. Political or social pressures, which have not been evaluated in this study, could have a mitigating effect on the process.

FUTURE STUDIES

There are several activities that would be useful in further evaluating the NEC concept:

- licensing an NEC site.
- developing and validating models to predict atmospheric effects, especially those related to ground fog, cloud cover, humidity changes, visibility changes, and rainfall. Model development will be a much easier task than model validation because of the magnitude of energy releases and normal climatological variation.
- more detailed evaluation of unusual natural events that could cause extended outages in an NEC or in the associated transmission system. Most of these events would tend to be site dependent.
- An examination of how compatible the NEC concept may be with future trends in areas such as energy conservation and resource availability. Conservation of waste heat from an NEC is virtually impossible because of the extraordinary amount of it. An NEC could make heavy demands on a subregion's water resources. Most NEC-related studies have not addressed the potential effect of future trends on the desirability of NEC development.

ENGINEERING STUDIES

Engineering studies in support of the HNEC study addressed:

- site selection
- heat sink management
- electrical transmission and station service
- reliability of generation

The general objectives of the site selection and heat sink management studies were to provide a framework for other studies, particularly the environmental studies, and to identify significant siting or heat release problems. The approach taken in these two studies is typical of that used in dispersed plant siting studies. Electrical transmission, station service, and reliability of generation have not been analyzed in detail previously; the studies conducted for this report present significant new considerations.

No attempt has been made to optimize solutions; that would be done in subsequent phases if an HNEC were implemented. The assumptions made for the studies differ somewhat and simply reflect stages in the developing HNEC concept.

SITE SELECTION - R. W. Wallace

Sites for 10 four-reactor clusters and for supporting fuel cycle facilities have been tentatively selected for an HNEC (See Figure 1). Six of the ten nuclear power plant sites are located south of the Columbia River, and four north. Focusing on the 20-reactor case, five sites south of the river were selected. The primary reasons for emphasizing sites south of the Columbia are: 1) more is known about the geological/hydrological conditions south of the Columbia River; 2) the distance is greater between these sites and possible faults, such as Saddle Mountain and the Rattlesnake Hills; and 3) the sites are near existing or planned transmission systems.

An iterative process was used for selecting the sites. Some criteria were initially developed based on contributions from each of the disciplines involved in the study. The criteria addressed site safety, environment, reliability of generation, economic, and energy conservation considerations. As information was developed site locations were modified as required. Seven criteria have been developed and are discussed below.

1. *Sites should avoid areas on the Hanford Reservation committed to higher priority uses.* For the purpose of preliminary site selection, higher priority uses include those areas committed to existing facilities and those reserved for further activities. Among these areas are the production reactor plant areas and the production fuel fabrication and reprocessing areas, their associated controlled areas, the vegetative recovery areas, ecological study areas, dune study area, hot water irrigation site, isotopic uptake area, and the Arid Lands Ecology Reserve (Figure 3). These areas occupy a relatively small part of the Hanford site and the balance of the Reservation was considered as potentially usable for NEC sites.

Compared to other nuclear sites the Hanford site is very large--about 570 square miles. In other NEC studies the amount of land needed for the site has been estimated at one acre per MWe. For a 20-power-plant NEC the area required would be about 40 square miles based on this rule of thumb. Apart from the fuel cycle facilities, the area occupied by the nuclear power plants in the HNEC would amount to about 100-200 square miles.

2. *Sites should not be located where geologic faults are identified or postulated until appropriate geological and geophysical studies indicate site suitability.* Faults represent zones with relative movement between the rock or earth material on each side of the fault. The movement is a result of stress buildup within the rock and the fault is the rupture or yield zone. Earthquake activity is frequently associated with movement along faults, both first-time movement and renewed movement along existing faults. This criterion reflects not only the concern for earth movement because of faults in the vicinity of an NEC but also earthquake effects on design and safety.

FIGURE 3. Hanford Site Land Uses

Considerable effort is often required to determine earthquake loadings on which to base plant design characteristics. The design is usually based on the history of seismic activity, related geologic structures and faults, length of the structure or fault, and other considerations. The location of past earthquakes, geologic structures, and faults is vital to predicting the expected maximum effect from possible earthquake and fault activity.

The Washington Public Power Supply System (WPPSS) has recently released an extensive study and report concerning earthquake activity in the Columbia Basin.⁽¹⁾ Much of the study was devoted to determining the epicenter and magnitude of the earthquake of 1872 and its intensity in the region of the Hanford site. The study concluded that the earthquake's epicenter was in the northern Cascades-Okanogan area, an area of major mapped strike-slip faulting that run tens of kilometers in length. The magnitude of the quake was between 6 and 7 and the intensity was VII or VIII (MM), depending on the relationship of the "felt" area to the main earthquake and the reliability ascribed to the few reports available from persons in the epicentral region. The focal depth of the earthquake has not been determined although it is most likely to have been less than 25 km.⁽¹⁾ Geologic and aeromagnetic studies of the zones where Columbia River basalts overlap older basement structures indicate that none of the basement structures have been significantly affected since the mid-Pleistocene (1 million years ago). No evidence of faulting compatible with a shallow 1872-type event has been discovered on the Columbia Plateau or its boundaries since at least the beginning of Holocene time (11,000 years ago). It is further concluded that it is not geologically justified to judge that an earthquake of the magnitude of the 1872 earthquake is likely to occur in the Columbia Plateau. The current WPPSS projects on the Hanford site (WNP 1 and 4) are designed to withstand a lateral acceleration of 0.25 g, which could result from an earthquake in a nearby geologic feature (e.g., Rattlesnake Mountain) with an intensity of VIII and with no attenuation to the site. Design and construction for such an acceleration do not require significantly greater construction efforts and costs than normally required in building construction; thus, assumption of these seismic criteria for constructing HNEC plants is not an economic penalty.

The proposed HNEC sites lie entirely within the Hanford site located on the Columbia Plateau. There is no geologic structure on the Reservation known to exhibit active faulting. Faults several miles long are known to occur in the Olympic-Wallowa linear, which passes through Wallula Gap and Rattlesnake Mountains south and west of the Hanford site, and in Saddle Mountains to the north. Because of the geologic structure and the suggestion of a linear through Gable Mountain, Gable Butte, and into Umtanum Ridge, faulting may exist in these geologic structures. However, no faulting has been discovered by trenching in the area of Gable Mountain on the Hanford site and no active faults are considered to exist. Accurate knowledge of deep geologic and tectonic characteristics beneath Columbia Plateau basalts has not been gathered primarily because the overlying basalts mask features normally profiting geologic insight. Drilling the numerous wells required for investigating such characteristics is very expensive. Efforts toward complete characterization of the deep geologic and tectonic features are being supplemented by the DOE-sponsored program to determine the suitability of Hanford basalts for long-term storage of nuclear wastes (described later).

Tentative sites 4, 5, and 6 for the HNEC (see Figure 4) could be affected by potential faults in the Gable Mountain-Umtanum Ridge linear. Further field investigation in the region of the tentative sites should determine whether or not a fault exists and determines liquefaction potential. Even if a fault were discovered, minor relocation and seismic upgrading of construction techniques would probably satisfy site safety concerns. Upgrading seismic intensity above the presently accepted 0.25 g would require that demonstrated geologic instability exists.

The installation of networks of microseismographs--one in the Hanford area and one maintained by the University of Washington in eastern Washington--has enhanced the detection and location of small seismic events on and near the Columbia Plateau. The Hanford network (March 1969-December 1974) and the eastern Washington network (July 1975-March 1977) have recorded 1945 microearthquakes. Of these, only 62 measured 3.0 or greater on the Richter scale and only 3 measured 4.0 or greater (4.0, 4.1, 4.6). Ninety percent of the events to which a depth could be ascribed occurred at depths

FIGURE 4. Original Reactor Cluster Sites and Suggested Alternative Sites 7a and 9a. (Sites 1-5 comprise the 20-reactor HNEC; Sites 1-10 comprise the 40-reactor HNEC.)

less than 6 km and appeared in swarms representative of a number of shear planes within each swarm. The deeper earthquakes do not suggest any single deep faulting activity but appear to be distributed throughout the Columbia Plateau; some of these earthquakes occur at locations having few recorded shallow earthquakes.

Two locations on or near the Hanford site have experienced considerable shallow microseismic activity: Wooded Island and an area north of Gable Mountain. No widely accepted explanation exists for the concentration of shallow microseismic activity at these locations.

Potential for liquefaction and subsidence of soils on the north side of the Columbia River near the Vernita Bridge, particularly when potential future irrigation and hydrodynamic peaking effects are considered, suggests the possibility of relocating sites 7 and 9. Sites designated in Figure 4 as 7a and 9a could be appropriate replacements for 7 and 9, respectively. Subsidence may be a consideration in sites 8 and 10. For this study the original sites have been retained until foundation support materials can be suitably analyzed.

Another effort along these lines is planned by Rockwell Hanford Operations (RHO) in connection with the proposed Basalt Isolation of radioactive waste. This program is more a local one than that of WPPSS, but will be an intensive study of the Hanford site and its surroundings to determine the adequacy of basalt as a storage medium. The proposed study is to include extensive geological and geophysical investigation of the Hanford area to analyze structure and faulting.

The primary concern of these kinds of studies and of the seismic criteria for siting an NEC at Hanford is the future safety and integrity of any sites from the standpoint of the geologic setting. To determine this requires a detailed knowledge of the local and regional geology. While much of the work described is applicable to an HNEC, assessing the future stability for an installation of this size would require further efforts.

3. *The sites should be selected to permit the most flexible use of alternative cooling methods, such as wet towers, wet/dry towers, ponds, canals, once-through cooling, and combinations of these.* The Hanford Reservation lies along the Columbia River just north (upstream) of the Columbia's confluence with the Yakima River. In the northeastern two-thirds of the Reservation water drains directly into the Columbia River while water from the southwestern third drains into the Yakima River. The Yakima River, a major tributary of the Columbia River, is about 180 miles long and has a drainage basin of about 6,000 square miles. The river heads in the eastern slopes of the Cascade Mountains and flows southeastward into the semiarid region of central Washington. It joins the Columbia River a few miles north of the latter's confluence with the Snake River.

Direct precipitation over the Hanford Reservation mostly evaporates leaving a minimal amount of water as land runoff and for infiltration. The Yakima and the Columbia Rivers are the only two permanent streams in the area. Cold and dry creeks carry water only during the spring season. The natural ground water flow system underlying the Hanford Reservation has been influenced by three synthetic flow systems: 1) the 200 West Area, 2) the 200 East Area, and 3) Gable Mountain Pond. Approximately one-third of the liquid disposed at Hanford is received by each of the flow systems through disposal to ponds, swamps, and underground leach systems.⁽²⁾

The river reach from Priest Rapids Dam (river mile 397) to the head of the reservoir behind McNary Dam (approximately river mile 351) is the last free-flowing reach of the Columbia River within the United States. The main channel is braided around the island reaches and submerged rock ledges and gravel bars causing repeated pooling and channeling. The riverbed material is mobile and dependent on river velocities; it is typically sand, gravel, and rocks up to eight in. in diameter. Small fractions of silts and clays are associated with the sands in areas of low-velocity deposition, becoming more dominant approaching the upstream face of each river dam.

The flow rate for the Columbia River in this reach varies widely, not only because of the annual flood flow but also because of daily regulation by the power-producing Priest Rapids Dam just upstream. The flow rate during the late summer, fall, and winter may vary from a low of 36,000 cfs to as much as 160,000 cfs each day. During the spring runoff peak flow rates from 160,000 cfs to 650,000 cfs have been observed. A maximum discharge of 692,000 cfs was recorded on June 12, 1948 while the minimum discharge of 4120 cfs was recorded on February 10, 1932. Continuous flow data in the vicinity of Hanford are available from the gauging station maintained just below Priest Rapids Dam. Data from this station and its predecessor near Rock Island Dam⁽³⁾ show a 55-year average flow of 120,000 cfs, but during low flow periods daily flow rates sometimes average 80,000 cfs or less. The mean annual flow rate was 159,500 cfs.

The Yakima River, a small river with a flow rate between 1300 and 20,000 cfs, partially borders the Hanford Reservation on the southern side. This river is of minimal importance to the Hanford Reservation and its operation; i.e., no direct withdrawal or disposal is made to the Yakima River. Continuous flow data in the vicinity of Hanford are available from a water stage recorder located at Kiona (approximately 20 miles west of Richland). Data from this station show a maximum flow of 67,000 cfs on December 23, 1933 and a minimum of 105 cfs on September 11, 1906. For 1972 the maximum and minimum flows were 20,200 cfs and 1420 cfs, respectively; the mean flow was 6700 cfs.

The Hanford Reservation contains man-made ditches and ponds that are used for the disposal of liquid waste and cooling waters from various processes. There is also one natural pond whose ground water depends on elevation; its average size is about 10 acres.

The unsaturated (vadose) zone is the zone between the land surface and the water table (saturation zone). Characteristically, this zone contains liquid water under less than atmospheric pressure as well as water vapor and air or other gases usually at atmospheric pressure. In parts of this zone, interstices may be temporarily or permanently filled with water. Perched water, which is unconfined ground water separated from an underlying

body of ground water by an unsaturated zone, may exist within the unsaturated zone. On the Hanford Reservation, the thickness of the unsaturated zone varies from less than 1 ft to more than 350 ft.

The four distinct rock units in the Hanford region are, in ascending order, the Columbia River basalt, the Ringold Formation, the Palouse soil, and a thick deposit of fluvial and glaciofluvial sediments.

The Columbia River basalt forms the bedrock everywhere beneath the Hanford Reservation. The basalt rock lies within the unsaturated zone in several locations. In general, these areas are about one mile north and south of the 200 Areas and about four miles southwest of the 400 Area.

The Ringold Formation is a lacustrine and fluvial deposit overlying the basalt bedrock. This formation is composed of silt, sand, gravel, and clay, with some beds of volcanic ash. These sediments were deposited in a shallow lake formed during the period when the Columbia River was impounded by the uplift of the Horse Heaven Hills. The Ringold Formation is more than 1200 ft thick. However, south and west of the Columbia River more than 600 ft of these sediments have eroded away. In some locations, the surface of the Ringold Formation comprises a relatively thick accumulation of caliche (calcium carbonate). The Ringold Formation characteristically contains clays in the lower portion, locally consolidated and semiconsolidated silts, sands and gravels in the middle portion, and silts and sands in the upper portion. Sediments in all three zones of the Ringold Formation occur within the unsaturated ground water zone.

Overlying the Ringold Formation in the western part of the Reservation is a bed of fine sand and silt up to 600 ft thick. Believed to be of eolian origin (deposited by wind), this deposit is locally called Palouse soil because of its similarity in grain size and heavy mineral composition to the eolian Palouse soil of eastern Washington and western Idaho.⁽⁴⁾ The Palouse soil lies completely within the unsaturated zone.

Glaciofluvial sediments, deposited during late Pleistocene and Holocene, overlie the Ringold Formation and the Palouse soil. These materials are heterogeneous and range in size from clay to boulders, although lenses of

well-sorted materials are also present. When the glaciofluvial sediments were deposited on the Hanford Reservation about 18,000 years ago, the area was completely covered by a lake 700 ft deep at the southern boundary of the Reservation. Since the glaciofluvial sediments were deposited, the water table underlying the region has remained in essentially the same position as it is today. Most of the glaciofluvial sediments lie within the unsaturated zone.

The unconfined aquifer underlying the Hanford site is defined as the saturated sediment lying between the water table and the first thick impermeable bed below the water table. The saturated interval lies partly in sediments of the Ringold Formation and in other places in mostly fluvial and glaciofluvial sands and gravels. The Yakima River recharges the unconfined aquifer along its reach from Horn Rapids to Richland. The Columbia River forms a hydraulic potential boundary that is mainly a discharge boundary for the aquifer. The major source of natural recharge is precipitation on the Rattlesnake Hills, the Yakima Ridge, and the Umtanum Ridge, all of which outcrop to the south and west of the Hanford site. The water percolates underground near the base of the highlands and moves across the Hanford area to discharge into the Columbia River. The Rattlesnake Hills, Yakima Ridge, and Umtanum Ridge also act as the impermeable boundaries of the unconfined aquifer. Natural recharge due to precipitation over the lowlands of the Hanford site is minimal. A minor amount of recharge may occur where the water table is close to the land surface. The Hanford Reservation is in the rain shadow of the Cascade Mountains with average annual precipitation of 6.3 in. The primary return of rainfall to the atmosphere takes place almost immediately, before percolation can occur. Drying of the land surface by wind and low-humidity air produces a gradient of water potential toward the surface. Natural recharge of the ground water system is supplemented by large disposals of waste water near the 200 East and 200 West Areas. Disposals in those areas have gradually distorted the water table (upper surface of the aquifer) over the entire Hanford site.

A number of confined aquifers underlie the Hanford site. Relatively impermeable confining beds commonly include the individual basalt flows and the salts and clays of the lower part of the Ringold Formation. Within the basalt sequence, ground water is transmitted primarily in the interflow zones, either in sedimentary beds or in the scoria and breccia zones forming the tops and bottoms of the flows. In some locations the basalts are highly jointed and contain breccia, pillow, and palagonite complexes through which ground water can move. Data on the confined aquifers in the basalt flows are inadequate to fully characterize the confined aquifers. A possible recharge area for these aquifers is the Yakima River at Horn Rapids. Recharge is also possible from the upper Cold Creek Valley with flow toward a potential trough under the Columbia River. The Columbia Basin Irrigation Project to the northeast and east, and the Columbia River behind Priest Rapids and Wanapum dams to the northwest are recharge areas where basalt is exposed and covered by unsolidated deposits that are saturated perennially.

Disposal of blowdown or leakage of significant volumes of water (i.e., millions of gallons per day) to the ground from HNEC cooling systems (e.g., cooling ponds or canals) would have a significant impact on the subsurface hydrologic systems. The impact would be similar to that observed from the disposal of process cooling water from Hanford operations if the water were disposed of on the 200 Area plateau. Such a disposal would result in buildup of ground water mounds above the regional water table. If disposal is made at a lower elevation on the Hanford site, the increase in ground water level could result in production of ponds and springs.

Ground disposal of waste waters that contain deleterious substances could cause a detrimental change in ground water quality, as would discharge of water at elevated temperatures. Disposal of such waste water into the surface water systems adjacent to the Hanford site (i.e., the Columbia or Yakima Rivers) could cause a similar water quality problem.

Limited amounts of waste water could be disposed to retention ponds where evaporation could be relied upon to reduce the volume and concentrate the waste without impacting ground or surface water. Disposal of selected

waste water to either surface or ground water systems might be acceptable, depending upon type and volume of the waste and location of the proposed disposal site. Because of extensive research and investigations of the Hanford site hydrology, methods are available to quantitatively evaluate the effect of proposed waste disposal on the hydrologic systems.

Ancillary effects of HNEC operations, such as heat and moisture release to the air from cooling towers, are expected to cause little or no impact on the surface or groundwater systems.

4. *The sites should be spread out to minimize:*

- *the probability of a single natural event resulting in the loss of a significant number of reactors, switching stations, or transmission capabilities*
- *interaction of thermal plumes from plant cooling water discharges*
- *radiation dose to construction workers and operating personnel.*

As will be discussed in the section on reliability of generation, loss of generating capability from several plants probably will not affect the continuity of the electrical power supply in the PNW, whereas loss of most of the 20 plants could disrupt it. Siting and engineering features of HNEC plants may need to be jointly considered and upgraded to maintain generating reliability at the level of dispersed sites.

The concentration of heat releases that would characterize the HNEC raises special questions concerning effects on local meteorology. Analyses in support of HNEC studies have shown that:

- cooling systems used in an HNEC will be the primary factor in determining the fogging impact. Fogging is minimized if a combination of once-through and tall mechanical- or natural-draft towers are used. Dry cooling and hybrid wet/dry cooling also provide low fogging. Cooling ponds and short mechanical-draft cooling towers are the greatest sources of increased fogging.
- the predicted increases in fog are relatively insensitive to locations of the generating stations on the Hanford site.

- predicted increases in fog and reduction in visibility associated with dense fog are both statistically significant. An estimated increase from 34 hr. to 259 hr of fog per year would occur for a 20-reactor HNEC depending on the cooling options selected.

These findings indicated that sites should not be selected primarily because there was the potential for cooling ponds. Other cooling alternatives circumvent several problems created by cooling ponds. The use of cooling ponds on the south side of the river would require liners, which would increase construction costs significantly. Soils on the north side of the river may be subject to increased subsidence and potential liquefaction from increased irrigation north of the Hanford site. This could be cause for even greater concern if a cooling pond is installed. Further, economics of electrical generation on an HNEC do not support use of cooling ponds rather than cooling towers.⁽⁵⁾

Another HNEC-initiated meteorological study⁽⁶⁾ also provided information on plant siting. This study addressed contamination of generating sites resulting from accidental airborne releases of radioactive materials at adjacent facilities. Two conclusions of the study are of special interest for siting:

- Decreasing the spacing between clusters increases the potential level of contamination at down-wind clusters significantly; however, there are only small increases in the probability of contaminating a fixed number of other plants at any given level when spacing is decreased.
- Variations of a factor of three in the probability of multiple-reactor contamination following an accidental release can be obtained by changing the HNEC configuration and the orientation with respect to prevailing wind directions.

Configurations with reactor clusters in north-south or northeast-southwest lines had about half the probability of multiple-reactor

contamination compared with the present HNEC configuration. If multiple contamination proves to be of concern, the present siting should be altered to a more north/northeast-south/southwest line.

5. *The sites should disrupt arid lands as little as possible.* The Arid Lands Ecology (ALE) Reserve occupies the southwestern part of the Hanford site and is committed to studying impacts related to energy technologies and natural perturbations in shrub-steppe ecosystems. Because of the long-term nature of some of the studies, this area and its related project areas outside the ALE Reserve were considered unavailable for prospective NEC sites. Sites immediately adjacent to these study areas were also avoided.

6. *The sites should make use of existing transmission corridors.* As discussed later, transmission corridors and rights-of-way are considered available, assuming that present rights-of-way can be used and widened as needed and existing lines replaced with higher capacity lines.

7. *The sites should be located close to potential industrial sites.* It was assumed at the beginning of this study that significant industrial developments would be possible in the immediate vicinity (a few miles) of the HNEC because of the heat and electrical resources. Subsequent analysis suggested that the impact of industrial development would not be great at least in the early years of an HNEC. However, the availability of high- and low-temperature process heat might be attractive to specific industries that could use this heat if they were located near the heat supply. If, however, technology develops more efficient means of transporting and dispersing process or waste heat, siting the HNEC near industrial sites may not be necessary. While this criterion is maintained for the HNEC sites, it has had no significant impact on the siting process.

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HEAT SINK MANAGEMENT - L. D. Kannberg

The overall purpose of the HNEC heat sink management study was to identify the waste heat disposal method that gives an acceptable balance among environmental effects, resource (water and land) utilization, and economics. Five heat rejection systems were evaluated for transferring the waste heat from an HNEC to the environment: 1) once-through cooling with Columbia River water, 2) cooling ponds, 3) wet cooling towers, 4) wet-dry cooling towers, and 5) dry cooling towers.

A 20-reactor HNEC would release about 50,000 MWt of waste heat; a 40-reactor HNEC would release about 100,000 MWt. This is a much larger and more concentrated discharge of heat than has occurred from other industrial facilities.⁽¹⁾ The major environmental impacts from an HNEC (or any NEC) arise from the operation of the overall waste heat system.

Normally, waste heat is released to nearby water bodies or directly to the atmosphere by the use of cooling ponds or wet cooling towers. Whatever process is used affects the environment in some way. Cooling water withdrawals and releases to water bodies can affect aquatic life through physical damage in pumps and heat exchange systems or through changes in water temperatures or chemical composition. Construction of large cooling ponds can impact terrestrial life by reduction of habitat. Transfers of the

heat to the atmosphere either from ponds or from cooling towers may increase fog, create cloud shadowing, or modify nearby habitats as a result of icing in the winter. Release of blowdown streams containing high concentrations of dissolved salts, biocides, and corrosion inhibitors may adversely affect aquatic life in nearby water bodies.

For an NEC, the analysis of environmental effects arising from waste heat disposal is hampered by inadequate calculational tools and supporting data for massive heat releases. It is further complicated by the various state and Federal regulations governing heat releases. These regulations were prepared from a perspective of dispersed siting of power plants. In general they opt for heat releases directly to the atmosphere (via cooling towers) rather than directly to water bodies (via once-through cooling). In the interest of a balanced environmental impact from an NEC, both atmospheric and water body releases may be appropriate. Once-through cooling of some HNEC plants is addressed in greater detail later in this section of the report.

Assuming that environmental effects from waste heat disposal can be evaluated satisfactorily, two other factors need to be considered in arriving at a satisfactory heat sink management plan. The first is resource utilization--primarily the use of water and land. With an NEC life span of 75 or more years (about 35 years buildup with plant lifetimes of 40 years), thought must be given to the competing needs for these resources well into the future. Cooling systems that use small amounts of water, occupy small land areas, and don't place an unacceptable burden (humidity, temperature, or pollutant) on the atmosphere would tend to be favored.

The second factor is economics. In general, the electricity generation costs are lowest for once-through cooling, and about 10% to 15% higher for dry systems. The costs for wet-dry systems are from 5% to 15% higher depending on the portion of the heat transferred by the dry portion of the system. If environmental and resource utilization requirements demand a commitment to dry cooling (or wet-dry cooling) for substantial numbers of plants for periods of time, then projected cost advantages for NECs could quickly disappear.

In the case of an HNEC, it should be noted that the large land area at Hanford (~570 square miles) has essentially eliminated any constraint on land

resource availability, and the size of the Columbia River has eased potential problems related to water availability. Thus, in the HNEC study, the economics and the environmental effects of the disposal of waste heat become the major considerations.

If an HNEC (or any NEC) evolves on the basis of a few nuclear power plants at a time as opposed to being "licensed" as a 20- or 40-reactor NEC, the process of achieving an acceptable balance among the several considerations appears simpler. Monitoring programs would indicate changing environmental effects; current economics would permit more realistic choices of heat sink options; and competing uses for available resources could be more accurately assessed. While the evolutionary process may occur for NECs, some type of analysis similar to that presented in an earlier report⁽²⁾ and summarized here will probably be required for the heat sink options for the environmental reports and safety analysis reports. In general, there are 24 environmental interaction parameters to consider in evaluating heat dissipation facilities for an electric power generating system. Each of these parameters must be evaluated for each of the alternative heat dissipation methods. The sum of the effects of all parameters for each method is then compared to the sums for the other alternatives to determine the most desirable one. The environmental effects for once-through cooling are mostly aquatic in nature, while for dry-cooled systems they are almost entirely sustained in the atmosphere. For cooling ponds, wet cooling towers, and wet-dry cooling towers the environmental effects are combinations of both.

Considering the environmental factors, resource utilization, and economics the following tentative heat sink management plan was developed for 20- and 40-reactor HNECs:⁽²⁾

<u>20-Reactor HNEC</u>	<u>40-Reactor HNEC</u>
6 reactors w/once-through cooling	10 reactors w/once-through cooling
10 reactors w/tall, mechanical-draft-assisted cooling towers	26 reactors w/tall, mechanical-draft-assisted cooling towers
4 reactors w/mechanical-draft cooling towers	4 reactors w/mechanical-draft cooling towers
(assumed to be the WPPSS site)	(assumed to be the WPPSS site)

The maximum number of reactors with once-through cooling would depend partially on future decisions affecting the minimum river flow, but it appears to be about six reactors for a 20-reactor HNEC, given present river flows, and ten reactors for a 40-reactor HNEC given a Columbia River low flow rate of 54,000 cfs.^(a) The rest of the reactors (apart from the WPPSS reactors, which have conventional mechanical-draft towers) would be cooled by tall, mechanical-draft-assisted cooling towers. This combination would avoid significant increases in fog formation during the winter months and ground-level relative humidity increases in the summer. (Tall, mechanical-draft-assisted cooling towers have been operated in Europe.)

Because of the controversial nature of once-through cooling, an analysis was made of the effects on Columbia River biota of once-through cooling of the Hanford plutonium production reactors; the regulatory structure that deals with thermal discharges was also analyzed.⁽³⁾ The remainder of this section deals with once-through cooling. This information provides a basis for assessing aquatic effects described later. The Hanford production reactors discharged significant amounts of heat to the Columbia River in the period from the mid-1940s through 1970. Today N Reactor and the Hanford Generating Plant discharge nearly 3000 MWt to the river. The production reactors were once-through-cooled reactors, with cooling water passing through the following steps: shoreline intake, settling, water treatment (acid, alum, and chlorine), filtration, temporary storage, transit through the reactor core, retention, and single-port discharge to the center of the river. Coolant water flow rates were typically from ~180 cfs in reactors B, C, D, DR, H, and F to ~400 cfs in reactors KE and KW. Cooling water effluents from the reactors varied in temperature from about 75°C to 95°C^(b) during equilibrium operation.^(c) Of the thermal energy released to the retention basins, an estimated 3% to

(a) The minimum flow in the Hanford reach of the Columbia River is presently 35,000 cfs, as set by the license for Priest Rapids Dam. A higher minimum flow is possible. Changing the minimum flows would have several effects which would have to be analyzed. These include altering the power production profile in the PNW system and the planned future use of Columbia River flow for peaking purposes.

(b) Bulk temperature limit in the downcomers for coolant leaving the reactor.

(c) The higher range of temperatures occurred primarily after 1960.

10% was transferred to the atmosphere or ground water before release to the river. Figures 5 through 8 illustrate the total heat releases from the production reactors by month for the period 1951 through 1971.

For comparative purposes, a 1250-MWe nuclear generating station operating at 33% thermodynamic efficiency and with an annual plant factor of 0.7 including a one-month refueling outage would have a maximum average heat release rate of 2500 MWt, a mean monthly heat release rate of 1955 MWt, and a monthly integrated power of 58.7 gigawatt days thermal (GWDt). Six such once-through-cooled reactors would then produce 7500 MWe with a total maximum average heat release of 15,000 MWt, a mean monthly heat release rate of 11,730 MWt and a monthly integrated power of 352.2 GWDt. Figures 5 through 8 show that the production reactor heat releases exceeded those of six 1250-MWe reactors almost continuously for eight or more years. The peak heat releases occurred in December of 1964 when all the production reactors were operating. During this month the total maximum average heat release was 23,501 MWt, the mean monthly heat release was 19,490 MWt, and the integrated power was 604.2 GWDt. Mean monthly heat releases exceeded 15,600 MWt for 15 months between December 1963 and June 1965. Total maximum heat releases exceeded 20,000 MWt for 10 months between February 1964 and February 1965.

During the period of operation of the production reactors, numerous studies were performed to document the dispersion and mixing of reactor effluents in the Columbia. Many field measurement programs were conducted to measure the decay of temperature, radioactivity, and chemical concentration in the effluent plumes.⁽⁴⁻⁸⁾ Coincident with many of these physical studies have been studies of the aquatic biologic effects of the Hanford releases (see the section on Aquatic Studies). The results of both types of studies have been summarized elsewhere.⁽⁹⁾ The analysis of the hydrothermal characteristics of the river and the Hanford effluents provide the following conclusions:

- Although the effluents mix rapidly vertically (within 200-400 yd), lateral mixing is relatively slow and effluent channeling is evident until sharp curves and islands below 100-D Area cause rapid, nearly complete mixing.

FIGURE 5. Historic Hanford Heat Releases for March 1951 Through December 1956

FIGURE 6. Historic Hanford Heat Releases for January 1957 Through December 1962

FIGURE 7. Historic Hanford Heat Releases for January 1963 Through December 1968

FIGURE 8. Historic Hanford Heat Releases for January 1969 Through December 1971

- The Hanford reach of the Columbia responds more rapidly to environmental influences than impounded areas, as evidenced by an 0.7°C to 0.9°C July-August temperature rise between Priest Rapids and Richland resulting from natural heating. Therefore translation of the findings concerning persistence of Hanford generated thermal plumes to other locations on the Columbia River should consider this difference.
- Simulation of Columbia River hydrothermal dynamics with computer models has shown that in 1969, 65% of Hanford thermal additions had been dissipated to the atmosphere by the time the Washington-Oregon border was reached.
- Mixing coefficients range from about 2 to 7 ft^2/sec laterally and 70 to 4300 ft^2/sec longitudinally.⁽⁹⁾
- Temperature differences between Priest Rapids and Richland reflect the Hanford heat additions very closely when natural heating and cooling effects are considered.

The regulatory mechanisms having the greatest effect on the cooling system options possible for nuclear power plants on the Hanford site include: 1) effluent guidelines and 2) state water quality standards. Both of these mechanisms were established by the Federal Water Pollution Control Act (FWPCA), as amended by the Clean Water Act of 1977 (PL 95-217), and are implemented through the discharge permit required for every industrial discharger.

The objective of the FWPCA is "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters" [Section 101(a)(1)]. To achieve this end, the Act declared it a national goal to eliminate by 1985 the discharge of pollutants into "navigable waters", or "waters of the United States." The Act also declares an interim goal, to be achieved wherever possible by July 1, 1983, of "water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water" [Section 101(a)(2)].

The basic regulatory mechanism for achieving the above goals is the requirement that every industrial and municipal discharger be issued a permit

from the Environmental Protection Agency (EPA) or an EPA-appointed state government agency authorizing discharge and specifying the allowable amounts and constituents of the effluent and a schedule for compliance. One of the 27 categories of industrial facilities for which the EPA is required to issue effluent guidelines is steam electric power plants. The primary immediate water quality concern with regard to power plants to date has been the waste heat contained in the cooling water and the deleterious effects that it may have on aquatic life. Because of the potential ecological impact of waste heat, thermal discharges were defined as pollutants.

Section 402 of the FWPCA establishes the National Pollutant Discharge Elimination System (NPDES), which authorizes the issuance of discharge permits. The FWPCA has provisions whereby the permit issuance authority may be delegated to states satisfying various requirements. Washington is one of the 28 states that have been approved for participation in this program.

The Department of Ecology (DOE) is the Washington State agency responsible for issuing industrial NPDES permits except for those for new power plants. For new energy facilities this responsibility has been vested with the State Energy Facility Siting Evaluation Council. An important point related to the cooling options available for a new power plant in the Hanford area is that State agencies have an unwritten policy^(a) of requiring closed-cycle cooling systems in any of Washington's waters. Pursuant to Section 316(a) of Public Law 92500, however, the EPA (or in this case EFSEC) can allow a relaxation of the thermal limitations in cases for which it can be shown that the limitations are more stringent than necessary "to assure the protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife in and on the body of water into which the discharge is to be made". Therefore, once-through cooling could be employed for HNEC power plants provided a convincing and defensible 316(a) exemption application could be presented.

(a) The policy has as its source a policy statement by the Northwest Pollution Control Conference (NWPCC) in February 1968 to permit the highest and best practicable technology providing complete offstream cooling.

Present environmental policy essentially prohibiting once-through cooling on the Columbia River appears to be unsupported by studies discussed earlier related to historic Hanford production reactor heat releases and their ecologic effects. Pending the outcome of the present review of effluent guidelines with respect to cooling of steam electric generating stations it is recognized that once-through cooling of any HNEC power stations might depend on special licensing provisions for an HNEC. The justification for such provisions would be that they permit a better balance in the environmental effects sustained by an HNEC.

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ELECTRICAL TRANSMISSION - R. L. Richardson, W. J. Dowis

The information presented here concerning electrical transmission is taken from three supporting studies.⁽¹⁻³⁾ Two aspects of electrical transmission were studied for an HNEC: 1) transmission of about 23,000 MWe from Hanford to load centers about 200 miles away, and 2) the requirements for station service to an HNEC. The transmission of this amount of electrical energy from a single generating center could be a significant potential constraint on an NEC. The supply requirements for station service to a large number of reactor plants represent a previously unstudied consideration. For the transmission study, four different cases were analyzed but only two are summarized here: one representing an HNEC case in which HNEC generating capacity builds to about 23,000 MWe^(a) by about 2002, and a distributed case (designated as DIST) involving the same amount of generation but originating from several sites closer to load centers. The DIST case selected for analysis was one of several conceived as comprising a number of clusters of thermal power plants located primarily in western Washington and Oregon.

The comparison of the DIST and HNEC transmission concepts considered the following major issues: 1) type of transmission to be employed and its state of technology, 2) availability of rights-of-way, 3) economics, 4) environmental impact, and 5) overall reliability of the transmission system.

(a) The difference between 23,000 MWe and the output of twenty 1300-MWe plants used elsewhere in this report results from the assumptions used in this transmission section of the report; i.e., four of the plants would be rated at 1250 MWe and only 18 plants were built. The conclusions of this section are unchanged for twenty 1300-MWe plants.

Description of the Transmission System for HNEC and DIST Cases

The power system of the Pacific Northwest may be characterized as having its major generating facilities east of the Cascade mountain range and its major markets west of the range. Power is transmitted westward and south-westward through seven mountain passes. A concentration of new thermal generating capacity at an HNEC would add to the present power flows through the passes.

Approximately 75% of Pacific Northwest loads are west of the Cascade mountain range and are now primarily served by hydroelectric plants east of the range (about 200 miles distant). In the future, energy will be increasingly supplied by thermal plants, with peaking capacity supplied by the present hydroelectric system. Based on load flow considerations, about 65% of the new thermal generating capacity installed between 1985 and 1995 should be sited west of the Cascade range and about 35% east of the range.^(a) Under the DIST concept the total cross-mountain power flow in 1998 from hydro and thermal plants is estimated to be 23,000 MWe. Under an HNEC concept, the flow in 1998 would be 31,000 MWe (including 14,400 MWe from an HNEC).

Growth of the existing transmission system as already planned to the year 1988 would precede any divergence in growth between the DIST and HNEC concepts. The initial divergence in the nature of the physical plant would begin to appear in 1989, to accommodate the first of the new nuclear plants (beyond the three units now planned for the Hanford location) that would begin the HNEC buildup in generating capacity. Differences in initial capital outlays between DIST and HNEC concepts would begin to occur about 1985 in the design and construction of transmission facilities that would go into service in 1990.

(a) The most recent estimate of generation to be installed east of the Cascades is greater than 35%, thus tending to decrease the HNEC-DIST transmission requirement difference. However, this shift was disregarded in Reference 3. Thus, the transmission penalty that accrues to an HNEC is somewhat less than calculated in Reference 1.

The divergence would be reflected not only in the transmission lines themselves, but also switching terminals at the sending and receiving points, voltage transformation, reactive supply, generating plant in-house service supply through transmission system branch lines, and subtransmission systems served from receiving points on the main transmission grid.

However, in this study no appreciable difference was found in the nature of, or costs of, subtransmission systems in the load areas. The principal reason is that the primary voltage for both the HNEC and the DIST concepts was 500 kV for the period studied. Therefore, conditions at the receiving terminals would be similar, and subtransmission systems would also be similar. Any underground subtransmission that would be required would arise from local conditions and not from the character of the main transmission grid.

The transmission system of the Pacific Northwest as planned to 1988 is shown in Figure 9 and includes major transmountain lines to be constructed between 1978 and 1988. These lines are characterized in Table 4. Additions and modifications to this base system to accommodate expansion through 1998 with dispersed generation (DIST) are summarized in Table 5 and shown in Figure 10 over the background of the 1988 system. Additions to accommodate the HNEC concept are shown in Table 5 and in Figures 11 (through 1998) and 12 (through 2003).

Figure 13 shows the onsite transmission lines proposed for a 20-reactor HNEC. The double lines represent double-circuit 500-kV transmission systems; the single line indicates single-circuit, 500-kV transmission systems.

Planning and construction of three nuclear plants by WPPSS in area No. 1 is in progress, with some switching station equipment now installed at the Hanford Station and some planned for the Ashe Station. A transmission line right-of-way is being established between the Hanford and Ashe Stations. The transmission plant to accommodate up to 23,000 MW at HNEC would be expanded from that already in place or planned.

As shown in Figure 13 the three switching stations are separated by distances of approximately 6 miles and 12 miles, with the end stations 18 miles apart. Separation of stations is an element considered in reliability analysis, which is discussed later in the section on reliability of generation.

FIGURE 9. Pacific Northwest Transmission System as Planned Through 1988

TABLE 4. Major Cross-Mountain Line Additions
Between 1978 and 1988

<u>Year in Service</u>	<u>Length, Miles</u>	<u>Description</u>
1980	71	Ashe-Slatt, 500-KV high-capacity double-circuit
1980	155	Slatt-Marion, 500-kV high-capacity double-circuit

Note: Several smaller system reinforcements are not included in this table.
The above additions are common to all cases.

TABLE 5. Major Cross-Mountain Line Additions
Between 1988 and 2002

<u>Year in Service</u>	<u>Length,^(a) Miles</u>	<u>Description</u>
Distributed Case (1988-1998)		
Late 1980s to early 1990s	180	Ashe-Portland Area, 500-kV high-capacity double-circuit
Mid-1990s	185	Grand Coulee-Snoqualmie, 500-kV high-capacity double-circuit
HNEC Case (1988-1998)		
Late 1980s to early 1990s	180	Ashe-Portland Area, 500-kV high-capacity double-circuit
Early 1990s to mid-1990s	185	Grand Coulee-Snoqualmie, 500-kV high-capacity double-circuit
Mid-1990s to late 1990s	180	Gable Mt.-Portland Area (No. 1), 500-kV high-capacity double-circuit
HNEC Case (1988-2002)		
		Same as HNEC Case for 1988-1998 plus the following:
2000-2002	180	Gable Mt.-Portland Area (No. 2) 500-kV, high-capacity double-circuit

Note: Several smaller system reinforcements are not included in this table.
(a) Approximate distances.

FIGURE 10. Pacific Northwest Transmission System for Additions for DIST Case

FIGURE 11. Pacific Northwest Transmission System for Additions Through 1998

FIGURE 12. Pacific Northwest Transmission System for Additions Through 2003

FIGURE 13. Electrical Transmission System for a 20-Reactor Hanford Nuclear Energy Center

Comparison of HNEC and DIST Electrical Transmission Cases

Based on the foregoing descriptions of electrical transmission systems for an HNEC and for an equivalent generating capacity distributed throughout the PNW, conclusions were made concerning the type of transmission to be employed, the availability of rights-of-way, economics, environmental considerations, and overall reliability of the transmission systems. These conclusions are summarized below.

Type of Transmission System. Transmission of up to 23,000 MW from an HNEC to load centers is considered feasible with 500-kV single- and double-circuit overhead transmission systems. Technology for the 500-kV concepts is now at hand except that breakers have marginal interrupting capacity. Technology for an alternative 1100-kV transmission system should be proven by the early 1980s. The DIST case would also employ 500-kV transmission systems.

System conditions are such that, from the 1988-89 base point when thermal generation not now committed to a particular site would begin to go into service (assumed to be in the HNEC), the major transmission system additions for each concept would be:

<u>Case</u>	<u>Number of Cross-Mountain 500 kV Double-Circuit Transmission Lines</u>	<u>Miles of Line Added</u>
HNEC	4	725
DIST	3	545

For the HNEC case two 1100-kV lines could be substituted for three of the four 500-kV lines.

Looking to the more distant future, about 50,000 MWe generated at the HNEC could be transmitted across the Cascades to load centers, assuming successful development of 1100-kV technology, by utilizing available cross-mountain rights-of-way with widening in some places. A transition from 500- to 1100-kV is expected to begin in the 1990s. An analysis of the economics of HNEC transmission with growing 1100-kV overlay was not made because there are too many uncertainties for such estimates to be significant.

Availability of Rights-of-Way. Rights-of-way, which are most critical in the mountain pass areas, are available assuming that present rights-of-way can be used and widened as necessary in localized areas. By replacing existing 230-kV and 345-kV lines with 500-kV and, later, with 1100-kV lines, the transfer capacity of the corridors could be increased up to 87,000 MWe should that be necessary. No significant amounts of underground transmission appear necessary. Conditions at the HNEC terminal switching stations do not require it, and throughout the system no right-of-way contingencies are indicated that would compel any more than localized undergrounding.

Economics. Capital investment for the HNEC and DIST concepts, including interest during construction before 1985, required for lines, switching stations, and series and shunt capacitors is estimated to be:

	Millions of Dollars		
	<u>Investment</u>	<u>Interest During Construction</u>	<u>Total Investment</u>
HNEC Case	655	200	855
DIST Case	458	140	598

The costs are in constant 1978 dollars and are for transmission facilities added after 1988. The total investment fixed charges, system energy losses, and costs of supplying reactive power to the system resulted in an added transmission cost burden of the HNEC case, estimated at 5% of unit power costs assuming generating costs of 20 mills/kW-hr.^(a) The effective added unit cost--i.e., the costs of added transmission plant going into service after 1988 divided by the capacity of, or energy from, HNEC generators coming on line after 1988--is estimated at:

\$6.80 per year per kilowatt of capacity, or
1.0 mill/kW-hr at 75% plant factor.

(a) The same percentage would probably apply over a range of unit power costs.

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	Millions of Dollars		
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HNEC Case	655	200	855
DIST Case	458	140	598

The costs are in constant 1978 dollars and are for transmission facilities added after 1988. The total investment fixed charges, system energy losses, and costs of supplying reactive power to the system resulted in an added transmission cost burden of the HNEC case, estimated at 5% of unit power costs assuming generating costs of 20 mills/kW-hr.^(a) The effective added unit cost--i.e., the costs of added transmission plant going into service after 1988 divided by the capacity of, or energy from, HNEC generators coming on line after 1988--is estimated at:

\$6.80 per year per kilowatt of capacity, or
1.0 mill/kW-hr at 75% plant factor.

(a) The same percentage would probably apply over a range of unit power costs.

As generating capacity increased from 15,000 MW to 23,000 MW at an HNEC, the estimate of transmission cost per unit of energy transmitted decreased, thus indicating that the 500-kV system is an attractive economic choice.

Environmental Considerations. Environmental differences between the HNEC and DIST cases can be summarized as follows:

- About 4800 acres in new rights-of-way are required for the DIST case versus about 5400 acres for the HNEC case. The HNEC case requires greater acreage in agricultural, range, and forest land than the DIST case, but somewhat less in residential/industrial land.
- The HNEC case involves more visual intrusion in one cross-mountain corridor caused by the use of an additional 500-kV line with larger towers replacing 230-kV lines.

The environmental effects are not greatly different, but on balance may favor the DIST case.

Reliability of the Transmission System. The heaviest power flow for the DIST and HNEC cases is in the corridor running south and west from HNEC, as shown in Figures 14 and 15. Reliability aspects of interruptions of flow in this and other corridors have been studied, and the results have been used in developing a transmission system concept for each alternative that would meet the Western Systems Coordinating Council and the Bonneville Power Administration's reliability criteria. Thus, with respect to internal failures and common hazards, even including loss of all lines in a corridor, the HNEC system could be designed to have a reliability essentially equal to that of the DIST system. A more detailed analysis is required to verify comparable reliabilities or reveal economic differences in the two systems. Unusual natural events such as a tornado or major earthquake could conceivably destroy one or more of the three switching stations at the HNEC. However, the risk of loss of generation because of station failure does not add significantly to the risk of generating plant outage or transmission line failure from the same event.

FIGURE 14. Peak Load Power Flows for DIST Case

FIGURE 15. Peak Load Power Flows for HNEC Case

Station Service Study for an HNEC

The second aspect of the electrical transmission study examined the requirements for station service for an HNEC. Designs have been developed in the United States for station electric power service systems for 4-unit nuclear plants. Some of these designs have been approved by the Nuclear Regulatory Commission (NRC) as complying with safety regulations, and have been accepted by utilities as providing for an adequate level of operating reliability and flexibility. No study has been made of the requirements for station service for a nuclear energy center. The requirements have been examined in the context of an HNEC of 20 units with a net capacity of 24 gigawatts (24,000 MW). The anticipated rate of load growth is such that an HNEC could have a total generating capacity of 24 GW by soon after the year 2000. The scope of the study included the station service transmission system from its offsite origin in the bulk power network to the station service buses in the plant. The internal redundant systems extending from those buses to the station loads would not be expected to differ because of the number of generating units in one complex.

An HNEC in the early 2000s can be envisaged as five groups of generating units with four units in each group, served by three 500-kV switching stations (Ashe, Gable Mountain, and Hanford as shown earlier in Figure 13). The power source for the station service circuits could comprise the 500- or 230-kV system or the 24-kV generator bus (Figure 16). The bulk power system for the Northwest Power Pool is a 500-kV system. A 230-kV system traverses the Hanford area; it will be interconnected with the 500-kV system at Vantage and Grand Coulee to the north and at McNary to the south of the Hanford Reservation. The 24-kV system, with a switch to isolate the generator, has both functional and economic merit. It was adopted in this study for the "normal" power source in all cases examined. It is equally attractive for dispersed plants or NEC plants.

The main task of the study, therefore, was to select the alternative station service supply system for multiple plants in the HNEC situation. The assumed grouping of plants is such that the problems of selecting an alternative offsite station service supply are similar to those of three-

EXAMPLE OF 500kV-230kV
SYSTEM INTERCONNECTION
THROUGH AUTOTRANSFORMER

PARTIAL DIAGRAM SHOWING POSSIBLE
CONNECTION POINTS BETWEEN GRID
AND STATION SERVICE CIRCUITS:

- N NORMAL CIRCUIT
- A ALTERNATE CIRCUIT-CONCEPT A (230kV SYSTEM)
- B ALTERNATE CIRCUIT-CONCEPT B (500kV SYSTEM)

- GENERATOR
- ⚡ TRANSFORMER
- 500kV SWITCHYARD
- ◻ 230kV SWITCHYARD

FIGURE 16. HNEC Transmission Systems and Typical Points of Power Supply for Offsite Station Service Circuits

and four-unit stations now being designed; nine of such groupings were reviewed for this study. The novel problem of a 20-unit station is to estimate coincidental peak loads on a system supplying all alternative station service circuits in common under normal and abnormal conditions. The Nuclear Regulatory Commission's restraints on the operation of a generating station when either of its normal or alternative station service circuits is not available, and the low failure rates of equipment in the normal supply circuits act to minimize the times when the load must be transferred to an alternative circuit. The study indicated that with a possible connected station load of 1200-1500 MWe (about 75 MWe per reactor times 20 reactors), the probability of a maximum load exceeding 360 MWe would be negligible. An analysis of loads under abnormal as well as normal conditions found the peak to be less than 360 MW. Load flow and economic data presented in Reference 8 are based on this finding. The data apply only if the station service for all plants is taken from the 230-kV system, designated Concept A (Figure 16). In Concept B, alternative circuit power is drawn from the 500-kV station bus, and the question of supply system capacity does not arise.

To demonstrate the engineering solutions to alternative methods of providing station service, certain assumptions were made with respect to the grouping, spacing, and orientation of the generating plant units, as well as their positions relative to the existing and anticipated main transmission line routes. In the southern part of the Hanford Reservation, where nuclear plants are under construction, the pattern already established was followed to a total of five generating units (WNP 1, 2, and 4, plus two other units). In the central and northern groupings, it was assumed that two-, three-, and four-unit stations would resemble those of the Catawba, Palo Verde, and Alan Barton designs. The relative positions of the 500-kV and 230-kV switching stations involved assumptions which affect not only the number of underground crossings but also other design features necessary to separate the offsite station service circuits. These assumptions, of course, influence the comparative cost estimates of Concept A and Concept B. Finally, the study assumed that the regulatory position now held on this topic by NRC would remain substantially as set forth in guides and standards now in effect or proposed.

Once these assumptions and base conditions were established with respect to the development of the HNEC and the development of transmission facilities in the vicinity of the Hanford Reservation, various means were considered of providing alternative circuits to serve the station loads of 20 units. The two most attractive concepts were:

- Concept A--Loop circuits from switching stations on the 230-kV system, serving three to five plants each, with 230/6.9-kV or 13.8-kV transformers (6.9 kV is used here as typical of intermediate voltage) at the station buses of each generating station unit.
- Concept B--Radial circuits from a 500/69-kV transformer fed from a 1-1/2 breaker position on the same 500-kV bus carrying the main generator output and having circuits to 69/6.9-kV transformers at each generating station unit.

The technical and operational merits of these two concepts were compared (Table 6). No major differences were found with respect to the potential effects of the circuit characteristics on generating plant availability or on continuity of service to safety-related plant loads. Significant differences were found in environmental effects, uncertainty with regard to regulatory aspects, and flexibility for sporadic growth.

The estimated capital cost for the normal and alternative circuit lines and equipment and grid reinforcements for 17 additional generating plants at the HNEC is \$78 million for Concept A and \$79 million for Concept B. A greater portion of the investment in Concept B comes early in the HNEC development; the discounted present worth of the required capital investment is from 10%-15% greater than for Concept A.

In addition to the specific combinations of Concepts A and B, other possible methods or combinations were considered, some involving three off-site circuits instead of two, and one having a separate generating source to provide an alternative supply for all plants. A plant design with a bifurcated main generator bus would provide a good opportunity for having both functionally and economically superior to most other designs; however, this design can only be used when the design of the major power circuits

TABLE 6. Comparison of Characteristics of Alternative Circuit Concepts

Characteristics	Concept A (230 kV)	Concept B (500 kV)
Equipment exposure to failure	More underground cable	More apparatus
Restoration of service within 72 hr	Ability to restore is facilitated by loop	Ability to restore is possible with spare 500-kV transformer
Exposure to natural hazards	No apparent difference	
System stability excursions	No apparent difference	
Potential power sources in the network	No apparent difference	
Relaying (electrical separation)	More protective zones separating the sources	Fewer protective zones separating the sources
Required system capacity	Estimate is based on probability	Ample capacity assured at no additional cost
Effect of human error	Slight disadvantage	Slight advantage
Adaptability for growth	No apparent difference	
Adaptability for early curtailment of program	Has advantage	Has disadvantage
Economics	No apparent difference	
Environmental effects	Additional transmission lines in and north of the reservation	Insignificant

is already a bifurcated system and very few plants have such systems. The other alternatives were not attractive, and any advantage they may have would not warrant the added cost.

In conclusion, the station power study indicated that there are acceptable methods of providing station service to a 20-unit HNEC. The choice of method would depend on the environmental, economic, social, and technical situation at the time that design of a new plant is committed, and on the preference of the responsible utilities. The study may be summarized as follows:

- No extraordinary engineering difficulties are expected in designing an HNEC's station service systems that will meet all utility and regulatory requirements.
- The major uncertainty involved with choosing the 230-kV system (Concept A) is whether the NRC would require full capacity in the BPA system for all possible connected loads. The capacity estimates herein are based on expectation of peak loads of only 24%-30% of possible connected load; this expectation is based on a study of the probabilities of the number of operating plants simultaneously transferred to the alternative system.
- Either of the two alternative circuit concepts, Concept A or B, studied in detail would be acceptable based on safety and operability.
- The estimated costs of the two alternatives are roughly equal for the set of conditions assumed in this study, but Concept A has a 10%-15% advantage in discounted present worth of required investment. Different geographical arrangements of plants and switching stations would affect the estimates, but not to the extent that one concept would have a marked economic advantage over the other.
- The principal advantage of Concept A, in which station service (alternative circuit) is taken from the 230-kV system, is that the method is flexible enough to accommodate sporadic growth of generating stations planned at an HNEC--that is, in the absence of a firm program for completion of a three- or four-unit group or for a full-scale HNEC development. This concept is already in use for plants planned in the vicinity of the Ashe switching station.
- The principal advantages of Concept B, in which the station service (alternate circuit) is taken from the 500-kV system, are that it does not require any added offsite transmission line construction, thus involving no added environmental effects, and that the inherent capacity is ample for any load combination, thus avoiding any uncertainty as to the position that may be taken by regulatory agencies.

- Other station service supply methods or combinations that would meet operational and safety requirements are possible but at higher cost and without substantial added benefits.

References for Electrical Transmission

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RELIABILITY OF GENERATION - R. G. Clark, W. J. Dowis

A nuclear energy center would have a large number of generating units that could be affected simultaneously by natural disasters or that could experience cascading failures triggered by a serious accident at one of the units. In the nuclear energy center concept, a number of generating units are relatively closely spaced, and the reliability of the generation as a result of their proximity could have an important bearing on the feasibility of the concept. The risk of forced outage^(a) of a large amount of capacity must be carefully assessed. Risk is a combination of the probability of occurrence of a causative event and the consequences of that event. The consequences of a forced outage comprise its impact on the Pacific Northwest generating and transmission system and on the power consumer if lost generation exceeds reserve capacity and loads must be dropped.

(a) A forced outage is defined as an unplanned loss of generating capacity that must be immediately replaced by reserve generating capacity.

These risks have been discussed briefly in prior studies on NECs.⁽¹⁻³⁾ In a Pacific Northwest Laboratory study comparative risks between an energy center at HNEC and at dispersed sites in the PNW have been analyzed in more detail⁽⁴⁾ and are summarized here.

The reliability of a nuclear energy center at Hanford was compared to that of a dispersed case (DS) consisting of six clusters of three or four 1300-MWe nuclear units at generalized locations in Washington and Oregon (Figure 17). The study assumes that load growth in the region to the year 2005 could be supplied by 26 GW of capacity at HNEC in addition to existing generating facilities at other sites. Thus, future thermal plants not now committed to other sites are assumed for this study to be located at HNEC. With these assumptions, the generating capacity in the HNEC case would be in five clusters with distances between adjacent clusters of 3 to 8 miles. In the DS case the capacity would be in six clusters, within a triangular area defined by Hanford, WA, Portland, OR and Eugene, OR.

FIGURE 17. General Locations of Dispersed Sites

Causes of forced outages in both cases may be categorized as internal or external and as man-made or natural. Failure from internal causes would be about equal for the two cases. With the exception of certain types of failure in a common switching station, a failure would affect only one plant at a time. However, if one unit fails within a cluster and the failure propagates to an adjacent unit in that cluster an internal failure could affect more than one unit. Whenever a failure is transmitted no farther than the confines of one cluster, exposure is the same for the HNEC and DS cases. If the event could affect adjacent clusters at the HNEC, a potential difference in risk between the HNEC and DS cases would result. Only one type of communicable failure for either case has been hypothesized, namely a class 9 accident in which radioactive gases and particulates are released and are carried through the air to plants in adjacent clusters causing them to be shut down for evacuation of personnel.

If disturbances from external causes are sufficiently widespread and if the conditions generated by them are beyond design levels, they obviously can affect more than one cluster in the HNEC case. For such causes to affect more than one such cluster in the DS case they would have to be extremely widespread. Severe earthquake, volcanic ashfall, and widespread floods are examples and are examined in the report.

A forced outage can occur through failure of either the nuclear or non-nuclear portions of the plant. For safety reasons, the nuclear portions are built to more rigid standards than are the nonnuclear portions, and can be expected to withstand greater stresses from external causes without failure than can the nonnuclear portions. However, after an earthquake exceeding the OBE (operating basis earthquake) level but less than the SSE (safe shutdown earthquake), shutdown for inspection is required whether the plant is damaged or not. This would constitute a forced outage and loss of generation as serious as any shutdown forced by damage to essential facilities.

The concern here is 1) the risk of losing the generating capacity of more than one cluster at one time thereby stressing the system, and 2) the risk of losing generating capacity for long periods of time thereby depleting the energy reserves of the system. The loss of one cluster of four units is

considered an acceptable (if undesirable) risk since it may have approximately equal probabilities of occurrence in either the HNEC or DS cases. Therefore, the difference in probabilities of concurrent outages of more than four units in either the HNEC or DS is the key element in the study. The average forced outage rate of all the units studied over a period of years may be essentially equal between the HNEC and DS cases.^(a) Further, if no single outage were greater than, for example, 5 GW from either case, the impact on the system would be manageable. If one single outage were to involve 15 to 24 GW, however, the impact would be serious. (In view of the consequences, the probability of the latter occurrence must be low for the risk to be acceptable.)

The consequences must be understood in the acceptance of even a very low level of probability of occurrence. The consequences of a forced outage of 15 to 24 GW on the PNW system were examined as of the year 2005, when total system generating capacity is expected to total more than 80 GW. Assumptions that are made regarding the state of the system at that time and the measures that might have to be taken to manage such an outage are discussed in Ref. 4.

Initiating Events

Events were screened that conceivably could cause forced outages at more than one cluster concurrently. Table 7 enumerates these events. The reasons for excluding certain of the events from consideration are developed in Ref. 4. Briefly, either the probability of the event was too low to have any significance, or the risks associated with the event were approximately equal between the DS and HNEC cases.

Reliability Standards

Reliability in the larger sense includes the effects of both scheduled and forced unplanned outages. Any difference in reliability between plants

(a) Any failures due to generic weaknesses in nuclear plant design or construction are assumed to involve equal capacities in the HNEC and DS cases.

TABLE 7. Events Considered for Analysis

<u>Natural</u>	
<u>Considered</u>	<u>Not Considered</u>
Earthquake	New volcano
Tornado	Meteorite
Ash fall	River channel blockage
Flood	Extremely low river runoff
<u>Man-induced</u>	
<u>Considered</u>	<u>Not Considered</u>
Release of airborne contaminants	Aircraft crash at generating plant
Aircraft crash (switching station only)	Explosion Industrial Sabotage Military action
Sabotage (switching station only)	Toxic gases Fires, including sodium fire Failure of offsite station service High-current faults

at these sites would be in the number and length of forced outages. Scheduled outages would be expected to be equal for a plant of the same design whether it was at a center or a dispersed site. Scheduled inspections and repairs might be accomplished in less time at a center because of the greater work forces that may be concentrated there, but in this report no differences were assumed to exist.

A nuclear generating plant with a 1200-MW capacity has an expected forced outage rate of 5.5%, or 482 hr/yr.⁽⁵⁾ (System reserve needs are determined in part by this rate.) Of that total less than two hours, on the average, are due to external events of the type of concern in this study.⁽⁶⁾ The major causes of forced outage are operator error and equipment failures and malfunctions. If HNEC outages from external events were to double or triple,

it would make little difference in the 5.5% outage rate since the doubling or tripling would apply to just the 2 hr. On the other hand, if on rare occasions 20 large generating units were to be affected by a single event, the temporary demand on system reserves could be enormous. The types of outages of concern here have very low probability but serious consequences. Adequate reserves for such contingencies cannot be maintained economically. The outcome of this study was to ascertain the extent to which normal reserves, based on conventional forced outages of lesser magnitude, could provide for system service and stability in the event of the rare HNEC outage involving more than one cluster. The major focus here is the loss of generation with its effect on the production of goods and services and the lifestyle of the power consumer.

Technique of Risk Assessment

A basic assumption in the assessment of difference in risk between HNEC and DS cases is that the risk of an outage of all units in one cluster is approximately the same in both cases. Any difference in risk arises from the effects of a single event on additional clusters at the HNEC, effects which are avoided in most DS cases because of the greater distances between sites. The risk of forced outage of all units at a single cluster at different sites may be somewhat different because of the site characteristics. However, these differences are sufficiently compensated for in the plant design and are not included in this analysis.

The causes of outages examined include those such as earthquake and ashfall in which the effects may be felt over wide areas, and those such as tornado and accidental radioactive release in which the effects are more localized. In all cases, however, the techniques employed are similar. Two sets of probabilities are developed: 1) the probability of the occurrence of the event and 2) the probability of multiple clusters being exposed to the event. These probabilities are combined to arrive at a cumulative probability distribution for the number of generating units at which design levels would be exceeded. A third set of probabilities is applied for earthquakes of various severity levels resulting in failure of essential equipment other than Category I; this set is used to examine the effect of

NRC postearthquake inspection requirements. Estimates are then made of the time required to inspect and/or repair the plants.

The probability of occurrence of the initiating event is taken from authoritative sources to the extent that such information is available for the PNW and specifically for the HNEC site in Eastern Washington. When such source information is too general or data are too sparse, the probabilities are modified through the use of records on local incidence, or through simulations based on available data.

Probabilities of exposure of multiple clusters to events are obtained by compiling all possible ways in which 1 to 20 generating units can be affected by a single cause, and by compiling a probability distribution of numbers of units forced out of service per event. The number of units exposed is a function of the configuration of clusters, the tendency of the disturbing force to move in certain directions, and the distance over which threshold intensity is exceeded at exposed sites. In all cases the probability of exposure of multiple units (sites) to an event is independent of the occurrence of that event.

Certain assumptions were required to develop probabilities of exposure. For example, it was assumed that attenuation of earthquake ground motion is uniform in different directions from the epicenter, that tornadoes move in a straight line, and that wind direction during an accidental release of airborne contaminants will not change during the release so that deposition will be within a 22.5° sector.

The results of developing the above probabilities are elements of histograms of $P(E)$, where E is relative exposure in terms of units exposed per event, and $P(F)$, where F is frequency of occurrence in terms of events per year. Combining these two elements gives $P(N)$ where N is number of units forced down in terms of units per year:

$$P(N) = P(E) \times P(F)$$

Values for $P(N)$ are generated for each kind of event affecting more than one cluster. For example, consider exactly 7 units affected by tornadoes, $[P(N)_1]$. This represents all cases of tornadoes of various wind speeds,

direction, and path widths acting on the HNEC and DS configurations of clusters to result in a forced outage of 7 units at either. All probabilities of $P(N)_7$ are added; similarly, probabilities of tornadoes forcing 2, 3, 4, 5, and 6 units out of service are discretely summed. These sums form histograms of numbers of units affected by an event with which cumulative probability curves are constructed.

The probability that a generating unit would be forced out of service when the design threshold conditions are encountered is taken as 1.0 for all types of events. For example, if an earthquake is at or beyond the OBE level, if flood waters reach a given level, or two in. of ashes have been deposited, it is assumed that there is a probability of 1.0 that the plant would have to shut down. However, in one case, that of earthquake, data are available on the probability of failure versus the degree to which the threshold has been exceeded. In the absence of current NRC inspection requirements applying in such cases, these data were used in supplementary calculations to illustrate the probabilities of given amounts of generating capacity being forced out of service by earthquakes.

Information on the extent of damage versus the intensity of an event was obtained partly from literature and from discussions with operators of facilities who had experienced such incidents, and partly from engineers, plant operators, and maintenance people with knowledge based on the vulnerability of plant structures and equipment. The estimate of repair time was approached by setting upper and lower bounds.

The above procedures are carried out for each of the events considered and the results added to arrive at the overall risk difference.

Overall Risk Assessment

Events that could cause greater and/or more frequent outages in the HNEC case than in the DS case include earthquake, volcanic ashfall, release of radioactive contaminants, flood, switching station failure from aircraft crash or sabotage, and tornado. Other types of external forces or internal failures (of which 12 were analyzed) would affect the HNEC and DS equally and were excluded from the risk comparisons. Figure 18 shows the relative contribution of the different types of events to the overall probability of loss

FIGURE 18. Probability of Forced Outage for All Causes at an HNEC

of various amounts of generating capacity at HNEC. Earthquake is the dominant contributor. Any effort to reduce overall risk should be directed to minimizing earthquake effects. A considerable reduction in probability of major generating capacity loss could be realized with modification of the single administrative requirement that a plant be shut down and inspected immediately after a ground-shaking corresponding to the OBE or greater, up to the magnitude corresponding to a SSE.

The combined risk from these causes is estimated in Table 8. The scenario considered a mature HNEC in the year 2005 with 20 units assumed in place.^(a)

TABLE 8. Risk of Forced Outage

Loss of Generating Capability, GW	Probable Duration of Loss, days	Probability of Loss, events/yr	
		For HNEC	For DS
5	7	1.1×10^{-2}	1.1×10^{-2}
12	8	6.0×10^{-3}	1.1×10^{-5}
24	40	1.6×10^{-3}	0

(a) No analyses of interim periods were considered.

From the above comparison, the risk of a 5 GW outage at single clusters is approximately the same for HNEC and DS, but the risk of simultaneous outages at two or more clusters (12 to 24 GW) is substantially greater for HNEC. Although the risk of forced outage is greater for HNEC it may nevertheless be acceptable from the standpoint of the power user because of the effectiveness of reserves in the PNW system as reflected in the risk of power shortage.

The greatest possible forced outage is one involving 100% of the HNEC capacity on line, or 30% of the operating capacity on the system in the year 2005. If such an outage occurred instantaneously, it could be partially offset by spinning reserves and inflow of power over tie lines to the south; but system loads would have to be reduced by shedding some industrial load and about 20% of the system commercial and residential load. Additional reserves would be brought on line immediately following the onset of the

outage, and a few hours later the system could enter a regime of management of an energy shortage of about 15% of normal usage, for a period of about four months.

The risk of user power shortage would be:

Probability: 1×10^{-4} per year; once in 10,000 years.

Consequence: Shedding of 20% of mixed loads for up to six hr followed by a 16% energy shortage for four months.

Instantaneous interruption of 30% of the system power flow would severely shock the system. If sufficient load were not shed, there would be substantial risk of system breakup, resulting in black-out pockets in the region for up to 12 hr. If blackouts did occur, they would threaten the health and safety of the public to some extent but probably not seriously if reasonable emergency procedures were in place and followed. Blackouts would not be a threat with instantaneous loss of 20% of the system capacity or less, or with a 30% loss in stages over an hour or more.

The impact of energy curtailment could be controlled by emergency measures now being put in place. With priority use of energy, the adverse economic effects of curtailment are not expected to be severe. Lifestyles would be affected and real hardships could be expected for some whose employment would be curtailed.

The risk described above is for the greatest possible outage. Lesser outages would occur more frequently but have diminished consequences. For example, the risk of interruption of half of the HNEC operating capacity, would be:

Probability: 9×10^{-4} events per year; once in 1100 years.

Consequences: Shedding of about 10% of mixed loads in PNW for tens of minutes until added reserves are placed on line, with no following load curtailment. (A 5% reduction in energy consumption resulted largely through conservation efforts as a result of the drought of 1976-77.)

Danger of blackouts under such conditions is virtually eliminated, and societal effects would be considerably reduced. Societal risks from

substantial generating loss at an HNEC are more meaningful when compared with those from natural disasters (rather than with DS risks).

Generally, society seems willing to accept accident probabilities of 10^{-7} or less per year where the consequences could be considerable loss of life, or a probability in the 10^{-4} to 10^{-6} range when some loss of life may occur along with extensive property loss. Somewhat greater risks are acceptable when the property loss would be moderate with little or no loss of life. For events of major magnitude, each case has to be examined separately in relation to the benefits of the endeavor versus its risks.⁽⁷⁾

Under these criteria the HNEC reliability risks described above may be acceptable. However, if they are not, the risk may be reducible by a factor of 10 or more. Earthquake is the predominant contributor to HNEC risk. Reduction of that contribution by a factor of 10 would result in an overall reduction of the risk by approximately the same factor. Modifications to the NRC inspection requirements, along with designing essential power handling structures and equipment outside the reactor facility to an earthquake resistance level somewhat above that of the operating basis earthquake (OBE), are two possibilities for reduction of the risk.

The results of this assessment are site dependent. The large available land areas at the Hanford Reservation and the hydroelectric component of the PNW power system tend to keep the risk of curtailment of service from outages at an HNEC relatively low.

Conclusions reached as a result of this study are:

- The risks of forced outage of generating capacity arising from the kinds of events analyzed herein are greater for the HNEC than for the DS case site configuration.
- With the HNEC, the probability of occurrence of the greatest capacity and energy shortages as felt by the power users is once in 10,000 years. The consequences would not be expected to include loss of life or great economic loss.
- If this risk is deemed unacceptable, it can be significantly reduced in ways now considered feasible.

- The reliability of energy centers relative to the risk of loss of power to users is definitely site dependent. The HNEC has space available for relatively wide separation of clusters within the Center to increase their reliability by increasing the independence of each from activities at another cluster. More importantly, the HNEC has the advantage of being tied to a hydroelectric system with a large amount of energy storage capacity, which lessens the consequences of large outages of thermal plants in the Pacific Northwest system.
- The major uncertainties in this assessment are due to: 1) sparcity of data concerning the risks from ashfall and 2) the lack of statistics for duration of outages from all catastrophic events because of the rarity of such occurrences at major thermal power plants.
- One of the potentially most productive areas for additional study is to find ways in which the safety of nuclear plants following an OBE that was less than an SSE could be assured without requiring immediate shut-down of operating plants for inspection. Permission to stagger the inspections following an earthquake less than an SSE would reduce the probability of the greatest HNEC power shortage from once in 10,000 years to once in 40,000 years (perhaps information from seismic instrumentation in the facility will become sufficiently acceptable to relieve the current regulation to shut down immediately to inspect). A second highly productive area for study involves estimating the monetary costs of designing those non-Category I portions of the plant that are essential to continuous generation according to earthquake-resistance criteria somewhat above Code levels.

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ENVIRONMENTAL STUDIES

Environmental studies in support of the HNEC study included:

- terrestrial ecology studies
- aquatic ecology studies
- meteorological studies
- radiological studies

The general objectives of these studies were to evaluate the basic HNEC concept and propose changes that reduce any adverse effects found.

TERRESTRIAL ECOLOGY ASSESSMENT - W. H. Rickard

An HNEC would remove about 2000 acres of shrub-steppe habitat from biological productivity during and, to a lesser extent, after the construction of 20 nuclear power plants. Similar amounts could be lost to fuel cycle facilities and to transmission switching stations. Other acreages would be lost to roadways, railroads, transmission lines, and similar construction and operational facilities. This section of the report examines the likely effects of facility construction and operation on 1) threatened and endangered species; 2) indigenous habitats useful for baseline and scientific purposes; and 3) the general terrestrial biota of the region.

It is concluded that an HNEC would alter the existing terrestrial ecosystem at the expense of certain native species. No threatened or endangered species would be involved in the land area affected by an HNEC, estimated at several percent of the total Hanford site. There would be no infringement on the Arid Land Ecology (ALE) reserve apart from transmission line construction in present rights-of-way. Overall, the terrestrial ecosystem is unlikely to be significantly stressed by an HNEC.

Figure 19 compares the plant and animal productivity for the world's various natural vegetation regions. The Hanford site, because of its climatic aridity, is at the low end of the world's plant productivity scale.

FIGURE 19. Plant and Animal Productivity for World Natural Vegetation Regions

Because of low plant productivity and the strong dependence of animals upon plants as a food base, the animal productivity of dryland habitats is also very low.^(1,2)

These basic parameters indicate that the biologic flow (transport) of environmental pollutants through Hanford site food chains will also be small compared to that of more productive regions. Historically, man's major biological use of arid lands has been through grazing livestock (cattle, sheep and goats) and producing meat for human consumption. In the absence of grazing livestock, as has been the case at the Hanford site for more than three decades, there are only a few wild game animals that can be used by man as food. This virtually assures the low transport of chemical contaminants to man via dry land food chain routes.

Game Birds and Mammals

Mammals

The most abundant big game animal on the Hanford site is the mule deer. Although the mule deer can be occasionally expected anywhere on the Hanford site, the greatest numbers are concentrated along the western shore of the Columbia River between the sand dunes and 100-B reactor areas. There are small deer populations in the Gable Mountain area and in the Rattlesnake Hills (ALE Reserve). The sand dune area, Columbia River islands, patches of trees and brush along the Columbia shore, isolated draws and canyons on Gable Mountain, and the Rattlesnake Hills are the fawning areas of most importance to Hanford mule deer. It is estimated that there are about 200 resident deer on the Hanford site. Automobile collisions are a source of mortality to adult deer, but coyotes are a major source of fawn mortality.⁽³⁾ A few deer are also killed each year for radiological monitoring and for other scientific purposes. Tagging studies show that fawns produced on the Hanford site at least occasionally do move long distances from the site.⁽⁴⁾

Small game mammals are not especially abundant on the Hanford site. Cottontail rabbits can be expected anywhere but are most plentiful in the vicinity of abandoned buildings and farmsteads and in the tree and brush habitats along the Columbia River.

Fur bearers are represented by the coyote, badger, bobcat, striped skunk, raccoon, mink, muskrat, beaver, and weasel. The coyotes are probably the most numerous of the fur bearers ranging throughout the Hanford site but are likely most numerous along the Columbia River.⁽⁵⁾ The badger and bobcat are much less abundant than the coyote. Mink, raccoon, muskrat and beaver are restricted to aquatic habitats of the Columbia River and ponds in the 200 areas. Only limited coyote control has been practiced on the Hanford site over the last decade and this has been aimed at protecting the nesting Canada goose population from coyote predation.⁽⁶⁾

The American elk (Cervus canadensis) is a permanent resident of the Hanford site and a small, wild herd is present in the Rattlesnake Hills on the ALE Reserve.⁽⁷⁾

Occasionally stray livestock, mostly cattle and horses, enter the fenced boundaries of the Hanford site where they can provide accident hazards to automobile traffic on unfenced interior highways.

Upland Birds

The most prevalent upland game bird on the Hanford site is the chukar partridge. The most dense populations are located in the Rattlesnake Hills (ALE Reserve). There are also scattered coveys in the Saddle Mountains and in the Gable Mountain areas. The gray partridge is present on the Hanford site, with the greatest population densities located in the Rattlesnake Hills. The California quail is at present mostly confined to the tree and brush habitats along the Columbia River. The Chinese ring-necked pheasant occurs on the Hanford site and is mostly restricted to tree and brush habitats along the Columbia River. Hunting is not permitted on the Hanford site but a few quail, pheasants, and chukars are killed for radiological monitoring surveillance purposes each year.

Historically, the sagegrouse probably occurred throughout the Hanford site, but today only a remnant population exists in the Rattlesnake Hills (ALE Reserve). The mourning dove is a migratory species that is distributed throughout the Hanford site mostly as a breeding summer resident. However, a few birds spend the winter on the site.

Waterfowl

The Columbia River on the Hanford site has served as an important fall-winter refuge for migratory waterfowl; however, its importance has diminished in recent years with the opening of the river between Richland and the Vernita bridge to public boat traffic. This will also probably make the river less attractive as a waterfowl refuge in future years unless action is taken to restrict waterfowl hunting.

Columbia River islands play important roles in providing safe nesting sites for a small resident Canada goose population.⁽⁶⁾ However, in recent years coyote invasion of the islands has caused serious damage to nesting geese, resulting in a dwindling population.⁽⁸⁾ Newly formed lakes and ponds on the Wahluke slope (Franklin County) under the supervision of the U.S. Fish and Wildlife service and the Washington State Game department in future years will probably be important nesting sites for certain species of waterfowl. Gable Mountain pond, a man-made pond about 20 years old, provides a nesting habitat for grebes, ducks and coots.⁽⁹⁾

Important Nongame Species

Because of its extensive area and semiwild status, the Hanford site provides a refuge for nesting birds that are not tolerant of human interference. For 30 years, the Hanford site has supported a relatively large nesting population of Swainson's hawks and a few red-tailed hawks.⁽¹⁰⁾ Other birds that have benefitted from this protection are the long-billed curlew⁽¹¹⁾ and the burrowing owl.

Threatened and Endangered Species

There are several species of plants growing on the Hanford site that are regarded as threatened or endangered. These plants are restricted to the thin, rocky soils of high elevation ridge crests such as the Rattlesnake Hills.⁽¹²⁾ Of special concern are Balsamorhiza rosea, Erigeron thymoides, and Talinum spinescens. Two species that are regarded as endangered may be on the Hanford site but have not been located. These are Astragalus columbianus and Allium robinsonii.

The American bald eagle is regarded as threatened in the state of Washington and endangered in many other states. About 15 bald eagles spend the winter on the Hanford site.⁽¹³⁾ The prairie falcon is rare on the Hanford site; a pair nests on Gable Butte. Falcons have also nested on the White Bluffs in the past but do not do so at present. Prairie falcons also nest on the steep cliffs near Priest Rapids Dam⁽¹⁴⁾ and along the Columbia downstream from the Wallula gap. The breeding ferruginous

hawk population in Washington is very low.⁽¹⁵⁾ There are no active ferruginous hawk nests on the Hanford site and the nearest breeding population is in the undeveloped sagebrush-juniper area northeast of Pasco in Franklin County.

There are two snake species on the Hanford site that are rare in Washington. These are the desert whip snake and the night snake.⁽¹³⁾

There are no mammal species on the Hanford site that are regarded as threatened or endangered at this time. However animals of relatively low population, the sagebrush mole, Merriam shrew and grasshopper mouse occur on the site and are protected on the ALE Reserve.

Indigenous Habitats

The pre-European-man habitats of the Hanford site, on the whole, have been less impacted by man's activity than the surrounding landscape. The surrounding lands have been planted in wheat, irrigated-row crops, and alfalfa. Uncultivated lands have been altered in species composition by years of domestic livestock grazing primarily through the invasion of alien weeds.⁽¹⁶⁾ Some of the best examples of native shrub-grass habitats in the Pacific Northwest are preserved for future generations and scientific study on the Arid Lands Ecology Reserve.

Terrestrial Effects

Impacts of Construction

The construction of 20 nuclear power stations on the Hanford site is expected to remove about 2000 acres of dry shrub-grassland (shrub-steppe) from biological productivity. Another 2000 acres will be usurped by switch yards. Biological productivity will be replaced by buildings, coolings towers, parking lots, and other structures. In addition, new roadways, railroads, and transmission line structures will remove additional acres from biological productivity.

The loss of habitat will be in areas of two of the most extensive types of vegetation--sagebrush-sandberg bluegrass and sagebrush-bitterbrush.⁽¹⁷⁾ The animal population losses are expected to be concentrated in the rodent population and especially in the pocket mouse population, which is

ubiquitously distributed throughout the Hanford site.^(17,18) Population densities for the pocket mouse can be 40-50 per hectare. The small breeding birds, the Western meadow lark and horned larks will probably be the most affected avifauna. Breeding population densities can be 270/km².⁽¹⁹⁾ It is not known if the loss of a fraction of the total pocket mouse population will have any appreciable impact on the food supply of hawks, owls, coyotes and snakes.

Construction activities are not expected to interfere with the avian use of the tree-brush riparian habitats important to many breeding birds. The noise, night lighting, and increased human traffic associated with construction activities could interfere with mule deer fawning, hawk nesting, and curlew nesting during the spring months of May and June.

High chain-link fences around inner security zones could isolate from mule deer acreage that provides forage and could affect daily movements of individuals and herds. The added miles of roadways will probably increase traffic mortality to nocturnal animals such as the mule deer and jackrabbit.

It seems feasible that if construction activities should destroy trees used for nesting by hawks or magpies these could be replaced in time by replanting and irrigation. It is also likely that loss of mule deer forage plants could be replaced or even enhanced by selective plantings and irrigation of selected browse species.

Impacts of Operation

Salt damage from cooling tower drift, especially in the high deposition zones close to cooling towers is the most likely source of damage to vegetation near operating thermal power plants. It is conceivable that in very dry areas such as the Hanford site, where evaporation rates are high, salts could build up in surface soil over a period of years and perhaps inhibit seed germination or damage young seedlings, thereby seriously affecting long-term soil stabilization.

In general, the annual precipitation of 7 in. is insufficient to leach deposited salts out of the root zone. As a worst possible case, high-level deposition zones could become devegetated and the soil then be subject to accelerated wind erosion.

A conventional agricultural method employed to mitigate excess soil salts is to leach the excess salts out of the root zone by adding copious amounts of fresh water to the soil surface.⁽²¹⁾ Using irrigation water drawn from the Columbia River and a sprinkler irrigation system, it is highly likely that a vegetative ground cover could be maintained around HNEC cooling towers, to prevent soil erosion by wind.

Such mitigation could be expected to greatly enhance the biologic productivity of the treated landscape. This would, in turn, be deleterious to native pocket mouse populations but would enhance the habitat for the California quail, Chinese ring-necked pheasant, mule deer and cottontail rabbits.

Another operational impact involves biocides in the cooling tower drift. Chemicals are added to coolant water to prevent the growth of algae and other organisms and to prevent or reduce metal corrosion. Some of these additives will likely be incorporated into drift droplets and become dispersed over the surrounding land. These droplets can be toxic to biota even in small amounts and can accumulate in soils where they may be taken up by plants and enter the food chain. It is not the purpose of this discussion to evaluate the impact of biocides in drift, only to indicate that this is an area under investigation.⁽²²⁾

Impact of Transmission Lines

The habitat disturbances created by transmission line construction are likely to be those associated with vehicular access to the sites for individual towers. Once native sagebrush-bunchgrass habitats have been destroyed it is virtually impossible to restore the indigenous species composition because of the invasion of the disturbed soil by highly competitive alien weeds, especially cheatgrass, which essentially occupies the invaded sites indefinitely.⁽¹⁶⁾

Sensitive habitats of concern are riparian habitats along the Columbia River, the ridge crest habitats of the Rattlesnake Hills, and all habitats on the ALE Reserve.

Little information is available in the published literature to judge the biological and ecological effects of magnetic fields, electric field strengths, noise, and ozone on Hanford site vegetation and animals. If 20 nuclear power stations are clustered on the Hanford site, the land area exposed to transmission line emissions will be substantial. Aesthetic values should receive some attention in terms of tower design and corridor routes.

Weather Modification

Postulated weather modification effects of large heat and moisture releases to the atmosphere are presented in a following section on Meteorological Studies. The weather modifications postulated there are not expected to have a significant effect on terrestrial habitats.

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AQUATIC ECOLOGY ASSESSMENT - D. G. Watson

Potential effects on the aquatic environment from the establishment of cooling systems for an HNEC are mainly those associated with the withdrawal of Columbia River water for power station condenser cooling and processing, and the discharge of station effluents to the river. The effects include loss of fish and other aquatic organisms resulting from:

- impingement on the water intake screens, causing physical damage from the impact or from subsequent screen cleaning operations
- passage through the station cooling system. Impacts may range from the death or injury of aquatic organisms because of thermal, chemical, and mechanical stress in once-through cooling systems to the removal of river plants and animals in the makeup water of closed-cycle cooling systems.

- discharge to the river of toxic chemicals and heat that may alter metabolic rates, reproductive cycles, behavior, disease resistance and food base, or cause mortalities as a result of rapid changes in temperature (i.e., heat and cold shock).

Many of the physical, chemical, and biological characteristics of the Columbia River have been summarized in an earlier document.⁽¹⁾ The primary biological systems that may be affected by an HNEC are the phytoplankton, zooplankton, benthic organisms, and fish.

River Biota

The phytoplankton originates in the impoundments behind the upstream dams and from the attached algae on the river bottom. Diatoms are the dominant algal group. Biomass of net phytoplankton range from a maximum of about 2.0 g dry wt/m³ in May to less than 0.1 g dry wt/m³ in winter.

Cladocerans and copepods are the dominant zooplankters. Numbers of zooplankters in the main river channel average 600/m³, with maximum of 12,000/m³ in summer and less than 30/m³ in winter.⁽²⁾ Both phytoplankton and zooplankton are nearly uniformly distributed throughout the river cross-section.

The principal benthic organisms include insect larvae, sponge, molluscs, flatworms, leeches, crayfish, and oligochaetes.⁽¹⁾ Sponge, caddisfly larvae and chironomid larvae make up the bulk of the benthic organisms.⁽²⁾ These organisms are most abundant near the shore. Maximum biomass ranges from 16 to 38 g/m² in the most productive riffle areas.⁽³⁾

There are over 40 species of fish in the Hanford section of the Columbia River.⁽¹⁾ About half of these are of no recognized direct value to man. Sturgeon, whitefish, catfish, perch, bass, sunfish and crappie are permanent residents of the area and provide recreational fishing; anadromous salmon, steelhead trout and shad are economically important to both commercial and sport fisheries. The latter group uses the local reach of the river as a spawning and rearing area and as a migration route to and from upstream spawning grounds. The extent to which the local section of river is used by adult anadromous upstream migrants is shown in Table 9, showing the passage of fish over Priest Rapids immediately upstream from

TABLE 9. Adult Anadromous Fish Passage at Priest Rapids Dam
for 1965 through 1975

<u>Chinook Salmon</u>	<u>April</u>	<u>May</u>	<u>June</u>	<u>July</u>	<u>August</u>	<u>September</u>	<u>October</u>
Mean	1,927	6,470	2,744	12,146	9,325	9,527	1,377
Max.	6,382	10,143	4,801	17,166	13,265	18,025	1,984
Min.	1	3,794	1,081	8,425	5,937	4,314	905
<u>Sockeye Salmon</u>							
Mean	0	3	1,669	69,576	4,250	117	18
Max.	0	9	5,020	158,352	10,210	315	54
Min.	0	0	96	32,933	1,195	19	0
<u>Coho Salmon</u>							
Mean	0	0	1	25	68	3,588	1,690
Max.	0	0	5	142	201	10,363	4,616
Min.	0	0	0	0	3	140	281
<u>Steelhead Trout</u>							
Mean	196	385	99	474	1,720	3,263	1,383
Max.	530	1,112	229	1,194	2,775	5,549	2,751
Min.	85	37	18	185	670	945	252
<u>Shad</u>							
Mean	0	16	734	2,901	435	6	1
Max.	0	172	5,843	6,648	1,405	39	11
Min.	0	0	0	147	32	0	0
<u>Total Mean</u>	<u>April</u>	<u>May</u>	<u>June</u>	<u>July</u>	<u>August</u>	<u>September</u>	<u>October</u>
	2,123	5,874	5,247	85,122	15,978	16,501	4,469

(a) Partial counts -- counting usually began April 15 or later.

the Hanford Reservation. Although chinook salmon and steelhead trout move up the Columbia during all months of the year, the greatest numbers are present during the period from April through November.

The Hanford section of the Columbia is one of the last mainstream river areas used for spawning by fall chinook salmon. Figure 20 shows the major sections of the river used for spawning. Most of the spawning takes place near the river islands in depths of approximately 3 to 12 ft in rapidly flowing water. Spawning begins about the middle of October and is concluded by the middle of November. Egg incubation and larval fish emergence from the redds (nests) in the river bottom takes place from February through April. The numbers of fall chinook salmon redds and estimates of the local spawning population are given in Table 10. Although there is considerable variability in the Hanford chinook spawning population, it represents a significant part of the adult fall chinook in the river, 15% of the escapement over Bonneville Dam, and about 30% of the fall chinook reaching the middle Columbia River.⁽⁴⁾

The average annual steelhead trout spawning population estimates near Hanford for the years 1962-1971 is estimated at about 10,000 fish⁽⁵⁾ and the spawning areas are thought to be generally similar to those used by the fall chinook salmon. Steelhead support a fairly intensive sport fishery between Ringold and Richland.

The juvenile chinook salmon pass through the Hanford section of the Columbia from March through July⁽⁶⁾ although there is some evidence that the young of populations spawning upstream of Priest Rapids may continue through August.⁽⁷⁾ There is a tendency for the young salmon to migrate downstream near the shore and near the river's surface.⁽⁶⁾ In addition to the salmon produced in the river, young are released to the river from the Washington Department of Fisheries artificial spawning channel at Priest Rapids Dam and from the rearing facility at Ringold (river kilometer 568). Steelhead young are also reared and released to the river at Ringold by the Washington Department of Game.

FIGURE 20. Hanford Chinook Salmon Spawning Areas

TABLE 10. Fall Chinook Salmon Redds (Nests) and Spawning Population Estimates for the Hanford Area

Number of Redds for Various Locations Along the Columbia River
(Locations designated as kilometers from the river's mouth.)

Year	560-570	586-592	597	600-608	618	633	Other	Total	Estimated No. of Salmon
1947	0	15	25	10	0	75	115	240	1,680
1948	120	330	38	219	0	25	53	785	5,500
1949	45	50	6	195	0	1	33	330	2,310
1950	24	43	38	151	3	46	11	316	2,210
1951	5	10	45	151	5	95	3	314	2,200
1952	73	101	40	221	3	78	23	529	3,770
1953	7	5	16	38	0	83	0	149	1,040
1954	4	5	8	127	0	6	7	157	1,100
1955	0	12	0	47	0	4	1	64	450
1956	0	3	7	59	0	17	6	92	640
1957	27	173	55	440	43	132	2	872	6,100
1958	49	249	133	520	192	258	83	1,485	10,400
1959	1	0	36	101	32	111	0	281	1,970
1960	0	31	22	99	38	105	0	295	2,070
1961	0	27	43	201	23	640	4	939	6,570
1962	6	195	66	456	1	635	2	1,261	8,830
1963	0	283	127	506	14	370	3	1,303	9,120
1964	5	163	111	510	37	624	27	1,477	10,300
1965	4	262	211	588	54	659	11	1,789	12,500
1966	10	279	267	1,206	37	1,300	2	3,101	21,700
1967	28	388	273	1,192	17	1,340	29	3,267	22,900
1968	117	595	188	1,069	52	1,520	39	3,560	24,900
1969	265	820	427	1,446	50	1,500	0	4,508	31,600
1970	107	615	302	1,180	72	1,528	9	3,813	26,700
1971	182	560	416	1,071	10	1,361	0	3,600	25,200
1972	88	247	147	259	4	131	0	876	6,130
1973	137	458	179	1,273	62	856	0	2,965	20,800
1974	164	156	49	238	5	173	3	728	5,100
1975	95	458	291	752	91	995	1	2,683	18,780

Food for the young salmon migrating through the Hanford section of the river consists almost entirely of aquatic insects (96% of diet), most of which originate in the river benthos.⁽⁸⁾

Thermal Impacts

The release of heat to the Columbia River from an HNEC may possibly affect the economically important fishes of the river, both resident and migratory, and other aquatic plants and animals including important fish foods. In addition to the discharge of heat to the river, such factors as condenser cooling water method (once-through or closed-cycle), location and design of water intake and discharge structures, and the chemical characteristics of the effluents will have a bearing on the environmental impacts.

Once-through-cooled power plants will have the largest use of river water, about 1500-2500 cfs/plant, and discharge the greatest heat load to the river. However, most of the once-through cooling water will be returned to the river rather than lost through evaporation, as is the case with cooling towers. The expected location of some of the power plants that could employ open-cycle cooling will probably be upstream from major salmon spawning areas. Careful design of the thermal discharge system will be required to minimize possible exposure of these breeding areas to heated effluents and the creation of a thermal block to the upstream movement of adult salmon and steelhead. The movement of adult chinook salmon and steelhead trout, and possibly of other salmon, is along the north shore in the Hanford reach of the river; there is a clear avoidance response by these fish to heated effluent discharged along the shore, but not to the main center-channel outfalls. Shoreline zones receiving heated water produced mortalities in juvenile salmon drifting slowly through these areas.⁽⁹⁾ Passage of young salmon through the midchannel thermal discharges resulted in no mortalities.

The most critical period for possible thermal effects on the local race of salmon is during the first three weeks in October at the start of spawning and continuing for about one month thereafter. River temperatures at this time average about 60°F (ranging from 56°F to 65°F).⁽⁴⁾ An

increase above these temperatures may delay spawning, cause deaths in the adult population, and reduce the survival of the spawn. The recommended optimum temperatures for certain stages of the salmon life cycle are as follows:⁽¹⁰⁾

Migration routes	45 ⁰ -60 ⁰ F (7.2 ⁰ to 15.6 ⁰ C)
Spawning route	45 ⁰ -55 ⁰ F (7.2 ⁰ to 12.8 ⁰ C)
Rearing areas	50 ⁰ -60 ⁰ F (10 ⁰ to 15.6 ⁰ C)

Temperatures of the Columbia historically have exceeded the desired temperature ranges, particularly for migration and spawning. In laboratory studies chinook salmon eggs were spawned in October at a base river temperature of 56⁰F and incubated at temperatures in increments of 2⁰F above the river ambient. These tests showed increased embryonic and larval mortalities at temperatures greater than 4⁰F above that of the river, as shown in Figure 21.⁽¹¹⁾ Thermal additions to salmon eggs that started incubation in late November and December, when river temperatures were 54⁰-48⁰F, resulted in a much lower increase in mortality. The fish hatched from these spawns had a much better growth rate when maintained at up to 12⁰F above ambient river temperatures. Warming the river during the winter may be beneficial to embryonic and early larval development.

In the past, the salmon spawning areas downstream from the proposed once-through-cooled power plants received the heated effluents from up to nine plutonium production reactors with no observed changes in the local salmon population or other river biota attributable to that discharge.⁽⁴⁾ Further, recent research on the ecological effects of the Hanford Generating Plant provides a basis for estimating possible changes that may be expected for once-through cooling. Some of the observed biological effects are listed below:

- Passage of phytoplankton through the cooling system reduced primary productivity within the system. No decrease in primary productivity downstream of the plant discharge could be measured.
- About half of the zooplankton were killed in passing through the cooling system.

FIGURE 21. Salmon Embryonic and Larval Mortalities

- Benthic organism production in areas receiving warm effluents increased and the organisms remained active longer into the winter.
- No fish survived after passing through the cooling system.

Particular care must be given to the design of the water intakes to reduce fish loss from impingement and entrainment. Studies of the shoreline water intake at the Hanford Generating Plant^(12,13) show that with some designs up to 18% of the juvenile salmon produced between the intake and Priest Rapids Dam are lost through impingement; and up to 9% are killed by passage through the cooling system. If proportionally similar losses, based entirely on water intake volume, are projected for six once-through-cooled plants, most of the salmon production between Priest Rapids and the power plants would be destroyed. This could be as much as 35% of the total salmon production in the Hanford section of the river. Resource loss of this magnitude could not be accepted without good justification. The intake structures for once-through systems should remove water only from the central portion of the river or other locations with low juvenile salmon populations.

Aquatic Effects of HNEC Cooling Systems

Based on the foregoing information and inputs from other studies,⁽¹⁴⁾ the effects of the HNEC cooling systems on Columbia River biota were evaluated. The HNEC proposed cooling system included both cooling towers and once-through cooling.

Total water intake and blowdown for 40 cooling towers is 1600 and 400 cfs, respectively; and the Δt of the blowdown is 12°F. Less than 5% of the minimum river flow would be used for cooling. Thus, no measurable aquatic effects are envisioned with cooling towers. Offshore water intake and blowdown discharges would have to be considered to reduce impingement-entrainment of river organisms in the cooling water system and to reduce exposure of the shoreline areas to undiluted blowdown discharge. The provisions of Public Law 92-500 probably can be met without blowdown treatment. The cases with less than 40 towers would have proportionately smaller effects.

To evaluate the aquatic effects of once-through cooling, data from the once-through-cooled plutonium production reactors have been examined in detail. The remainder of this section deals primarily with this subject.

Controlling Federal and state agencies have not approved once-through cooling on rivers for nuclear power plants in recent years because of concerns over impacts to receiving waters. Since 1973, the effects of the Federal Water Pollution Control Act Amendment of 1972 have virtually eliminated once-through cooling at inland sites for new power plants.⁽¹⁵⁾ Washington State Water Quality Standards for the Hanford reach of the Columbia River prevent the addition of heat that will raise river temperatures about 20°C (68°F). State standards for heat releases are defined by the formula:

$$\Delta T = \frac{34}{T+9}$$

where ΔT is the permissible average daily temperature increase and T is the river temperature after all heat releases (°C). This limitation presumably "takes into account the normal water temperatures, flow rates, seasonal variations, existing sources of heat input and the dissipative capacity of the identified waters of parts thereof."⁽¹⁶⁾ Federal law⁽¹⁶⁾ also contains

language to the effect that discharge limits to public waters may be modified if it can be shown that the changes will not limit other desirable uses of surface waters, including protection and propagation of a balanced population of shellfish, fish and wildlife.

Governmental agencies responsible for managing Columbia River fishery resources have been reluctant to accept once-through cooling of nuclear power plants. This reluctance may stem from past experience in which fisheries resources have not fared well in competition with other river water uses. For example, the hydroelectric dams on the Columbia are usually operated to produce maximum amounts of electricity and not necessarily to keep fish passage mortalities at a minimum. By not permitting once-through cooling there is no risk of having to choose after the plant is operating between the economic benefits of the electricity produced and a natural resource (e.g., industrial production and jobs vs. preservation of a salmon run). The fishery resource managers understandably want to avoid the creation of possible competitive water uses that would work to the disadvantage of the resource they are charged with protecting.

Previous remarks concerning the possible effects of once-through nuclear power plant cooling were based in part on estimates of heat rejection to the river by the Hanford plutonium production reactors.⁽¹⁴⁾ In this report, calculated thermal releases based on actual plutonium reactor operating levels are compared with the possible releases from an energy center using once-through cooling for part of its heat rejection system. The plutonium reactors began operation in 1944 and all except one (100-N) were closed by January 1971 (Figure 22). A maximum of eight reactors were in operation between 1955 and 1964 and nine reactors were in operation for part of 1965. Our discussions consider only the five-year period from 1960 through 1964 and only monthly values for river flow, temperature, and reactor effluent discharge are used. Mean monthly river temperatures upstream from all reactor outfalls are given in Table 11. The maximum ambient daily temperature during 1960-1964 ranged from 17.9 to 19.4°C (64.2 to 69.9°F).

FIGURE 22. Hanford Plutonium Reactor Operation

TABLE 11. Average Monthly Temperature of the Columbia River

Month	Temperature, °C				
	1960	1961	1962	1963	1964
January ^(a)	3.7	5.4	4.1	5.3	5.5
February	3.3	4.7	3.6	3.8	4.6
March	4.1	4.7	3.6	4.6	4.7
April	6.9	7.4	6.5	6.5	7.2
May	10.6	10.4	10.0	10.4	9.7
June	13.6	13.7	13.2	13.9	12.8
July	17.1	17.3	16.1	16.6	15.3
August	18.2	18.9	17.4	18.4	17.1
September	17.5	17.8	17.1	18.3	16.3
October	15.0	14.9	20.3	16.3	14.6
November	11.2	10.4	11.9	11.9	10.8
December	7.3	6.6	8.9	7.7	6.3

(a) Temperatures for January through August 9, 1960 taken at 100-B reactor pump house; temperatures for August 10, 1960 through December 31, 1964 taken at USGS station below Priest Rapids Dam.

The rate of cooling water effluent discharge for eight to nine plutonium reactors ranged from 1900 to 2800 cfs (54 to 79 m³/sec), and the average ΔT was on the order of 70° to 89°C (158° to 192°F.) In comparison, a single 1250-MWe nuclear generating plant will have an open-cycle cooling-water throughput of about 1500 cfs (42 m³/sec) and a cooling-water temperature rise of approximately 14°C (24°F).

Calculated average heat release to the river ranged from about 10,800 to 19,500 MW (Table 12). The average maximum release was approximately 23,500 MW. These values do not take into account the loss of heat during holdup of the cooling-water effluent in the reactor retention basins. This amounts to about 3% in summer and 10% in winter.

TABLE 12. Average Monthly Release of Reactor Heat to the River

Month	Heat Released, MW				
	1960	1961	1962	1963	1964
January	13,926	15,041	13,041	14,070	11,035
February	13,103	15,496	14,097	13,005	13,848
March	10,837	14,022	14,874	15,945	16,741
April	14,103	15,094	13,661	16,754	13,982
May	14,672	14,618	14,056	12,420	17,491
June	14,506	14,490	13,588	15,249	16,692
July	13,196	13,780	12,396	14,948	16,160
August	13,507	12,797	13,764	12,350	15,747
September	14,180	12,755	13,060	13,523	16,508
October	13,567	13,788	12,707	13,333	13,098
November	15,209	14,428	12,875	14,677	17,889
December	15,208	14,007	24,194	15,872	19,489

Note: Calculated values based on average monthly river flow and average monthly heat release

The increase in river temperature attributable to the reactor thermal discharge is given in Table 13. These are calculated values for temperature in the river after complete mixing and do not consider heat loss to the atmosphere. Under 1969 conditions (three reactors operating), about 65% of the reactor heat in the river had been dissipated at the Washington-Oregon border about 74 miles (119 km) downstream.⁽¹⁷⁾ Complete mixing occurred approximately 22 miles (35 km) downstream of the effluent discharge.⁽¹⁷⁾ Table 13 compares the calculated increase in river temperature with the rise permitted by Washington State water quality standards. During the last quarter of the year, the input of heat from the plutonium reactors exceeded standards at the point of complete mixing, but was probably within standard limits near the Washington-Oregon border.

TABLE 13. Comparison of Actual and Permissible Average Monthly Increases in River Temperature Owing to Release of Reactor Heat

Month	Average Monthly Temperature Increase (actual/permissible), °C				
	1960	1961	1962	1963	1964
January	1.5 /2.2	2.1 /2.0	1.6 /2.2	1.4 /2.1	1.6 /12.0
February	1.5 /2.3	1.5 /2.1	1.6 /2.2	1.3 /2.2	1.6 /2.2
March	1.3 /2.2	1.3 /2.1	2.1 /2.2	1.8 /2.1	2.2 /2.1
April	0.72/1.9	1.2 /1.8	1.3 /1.9	1.4 /1.9	1.8 /1.8
May	0.67/1.6	0.55/1.6	0.67/1.6	0.72/1.6	0.89/1.6
June	0.44/1.4	0.27/1.4	0.42/1.4	0.47/1.4	0.36/1.4
July	0.44/1.2	0.61/1.2	0.54/1.3	0.56/1.2	0.36/1.3
August	0.94/1.2	1.1 /1.2	0.94/1.2	1.0 /1.2	1.0 /1.2
September	1.6 /1.2	1.2 /1.2	1.6 /1.2	1.6 /1.2	1.9 /1.3
October	1.7 /1.3	1.8 /1.3	1.7 /1.3	1.8 /1.3	1.8 /1.3
November	1.9 /1.6	1.9 /1.6	1.6 /1.5	2.2 /1.5	2.2 /1.6
December	2.2 /1.8	2.1 /1.9	1.5 /1.7	2.2 /1.8	2.4 /1.9

Note: Permissible values calculated from
Washington State Water Quality Formula: $\Delta T = \frac{34}{T+9}$

where ΔT = Average daily permissible temperature rise °C
T = River temperature after heat additions °C

No heat releases are permitted that will raise the river temperature above 20°C (68°F).

indicates values that exceed standards

Based on monthly mean values, the addition of heat from the reactors did not raise the temperature of the river above the 20°C (68°F) upper limit of the State standard. Priest Rapids ambient maximum daily temperatures only exceeded 20°C on 4 days--August 24, 1970 and August 18, 19, 20, 1977--during the 1960-1977 period (Table 14). The maximum daily temperature occurred most often in August, and August monthly river temperatures were usually the highest. However, a natural rise in river temperature of 0.5° to 0.75°C (0.8° to 1.2°F) occurs in the Hanford reach during August and September. ⁽¹⁸⁾ The addition of 0.67°C to the maximum daily temperatures listed in Table 14 would increase the expected temperature to above 20°C in the Hanford section during summer for seven more days.

The section of the Columbia River between Priest Rapids and Richland, the last free flowing stretch of the river, responds more rapidly to changes in weather and thermal modification from industrial effluents as compared to impounded parts of the river. ⁽¹⁸⁾ Water supply rather than weather is the principal factor in determining variations in river temperature. ⁽¹⁹⁾ This becomes of greater significance in changing the capacity of the river as a heat sink if out-of-stream uses of river water (e.g., irrigation, pumped storage power generation) increase. Reliance on the Columbia River for thermal power plant cooling cannot be exercised until an overall regional long-range water use plan is developed. Future demand for river water will exceed the supply, and the allocation of water rights among the several competitive uses, both in-stream and out-of-stream, will need to be made before development can proceed.

In an analysis of the heat-sink capabilities of the Columbia River, Jaske concluded that under average river conditions an incremental thermal addition of 19,300 MW in the Hanford reach would raise the river temperature to about 20°C (68°F), the upper limit for thermal additions, for 15 days per year. ⁽¹⁸⁾ He also concluded that most of the added heat would be released to the atmosphere before reaching Bonneville Dam, about 224 miles (358 km) downstream of Hanford.

TABLE 14. Maximum River Temperatures at Priest Rapids from 1960-1970

Year	Maximum Daily Temperature		Maximum Monthly Temperature	
	Day	Temp., °C	Month	Temp., °C
1960	September 15	18.4		
1961	August 16	19.4	August	18.9
1962	July 29, August 1	17.9	August	17.4
1963	August 13	19.5	August	18.4
1964	August 24	18.1	August	17.1
1965	August 16	19.5	August	18.4
1966	August 25	18.2	August,	
1967	August 16	19.3	September	17.5
1968	September 11	18.6	August	18.5
1969	August 20,21,23,24, September 11, 12	18.7	August	17.5
1970	August 24	20.2	August	18.2
1971	August 29,30	19.1	August	19.2
1972	August 29	18.3	August	18.4
1973	August 24	18.7	August	17.3
1974	August 31	19.7	August	18.7
1975	September 14,15	19.8	August	18.7
1976	September 5	19.4	September	18.5
1977	August 18,20,21	18.5	August	17.9
		24.3	August	19.2

In our earlier analysis⁽¹⁴⁾ it was estimated that six once-through-cooled 1250-MWe power reactors could be located on the Hanford reach of the river without severe impacts to the biota of the river. Table 15 gives a comparison of the river temperature after the addition of heat from the Hanford plutonium reactors with temperatures that would have been produced by the addition of waste heat from six nuclear power reactors under identical ambient river flows and temperatures. The resulting river temperatures

are very nearly the same. The calculated incremental increase in temperature attributable to heat from the power reactors is actually less than would be expected since power reactors seldom, if ever, operate at 100% of their rated power; 75% is more nearly the actual operating rate. If the heat additions to the river were reduced by 25%, then the estimated monthly temperature increases from the power reactors would be less than those calculated for the plutonium reactors. The point of making this comparison is to show that since no severe biological impacts were noted during the period of maximum plutonium reactor operation, one would expect a comparable amount of heat from once-through-cooled power reactors to be equally benign.

It has been assumed that some once-through cooled reactors would be preferentially shut down for maintenance and refueling during the August-October period, lessening the temperature burden on the river and the economic penalty of forced outages required by river temperature limits.

The effects of heat on aquatic organisms, particularly fish, have received a great deal of attention in recent years. Actual damage to fish has only been observed on a few occasions in the receiving body.⁽²⁰⁾ The absence of evidence of direct damage, however, should not be taken as conclusive evidence that detrimental effects are not produced by the addition of heat. The identification and measurement of possible long-term, subtle changes produced by thermal additions may be beyond our ability to distinguish from other environmental stresses.

Research reports have listed the thermal aquatic studies that have been conducted at Hanford.⁽²¹⁻²³⁾ Several review papers have also been published.^(10,24,25) Much of the reported research was conducted during the period of maximum plutonium reactor discharge. In general, the results of these investigations did not conclusively demonstrate a thermal effect on the biota of the Columbia River. In contrast, a more pessimistic conclusion with respect to thermal effects on the Columbia

TABLE 15. Comparison of Columbia River Temperature After Heat Additions from Actual Hanford Plutonium Reactors and Hypothetical HNEC Reactors for 1960 Through 1964

	River Temperature, °C									
	1960		1961		1962		1963		1964	
	Plutonium Reactors	HNEC(a) Reactors	Plutonium Reactors	HNEC Reactors	Plutonium Reactors	HNEC Reactors	Plutonium Reactors	HNEC Reactors	Plutonium Reactors	HNEC Reactors
Jan	5.2	5.3	7.4	7.4	5.7	5.9	6.7	6.8	7.1	7.7
Feb	4.8	5.0	6.2	6.2	5.2	5.3	5.1	5.3	6.2	6.3
Mar	5.4	5.8	6.0	6.1	5.7	5.7	6.4	6.3	6.9	6.7
Apr	7.6	7.7	8.6	8.6	7.8	7.7	7.9	7.8	9.1	9.2
May	11.2	11.2	10.9	10.9	10.7	10.7	11.1	11.3	10.6	10.5
Jun	14.1	14.1	14.0	14.0	13.7	13.7	14.5	14.4	13.2	13.1
July	17.6	17.6	17.9	17.9	16.7	16.8	17.2	17.2	15.6	15.6
Aug	19.1	19.2	19.9	20.2	18.3	18.4	19.4	19.6	18.1	18.1
Sep	19.1	19.2	19.4	19.7	18.7	18.9	19.9	20.1	18.2	18.0
Oct	16.7	16.9	16.7	16.9	16.4	16.7	18.1	18.3	15.9	16.1
Nov	13.1	13.1	12.3	12.4	13.4	13.7	14.1	14.1	12.9	12.6
Dec	8.9	9.5	8.7	8.9	10.4	10.4	9.4	9.8	8.7	8.1

Note: Temperatures calculated for HNEC reactors represent the addition of 15,000 MW of heat from six 1250-MWe power reactors under actual river flows and temperatures.

(a) HNEC reactors assumed to have a 100% plant factor.

River Salmon was reached by Davis and Snyder.⁽²⁶⁾ They predicted that the salmonid fishes would suffer serious damage if the heated effluents from once-through-cooled thermal power plants were discharged to the Columbia River. It should be noted that their review was conducted when seven plutonium reactors were still in operation.

Results of investigations of thermal discharges to other large streams in the United States are similar to those of the Columbia River. Studies on the effects of heated effluents from coal thermal plants on the Tennessee River showed no impact or some near-field reduction of periphyton and zooplankton, but no change in fish populations.⁽²⁷⁾ A rather intensive investigation of the impact of heat on the biota of the Connecticut River indicated fairly high mortality of organisms entrained in the condenser cooling water and some near-field loss of benthic organisms because of heat or scouring.⁽²⁸⁾ There was no evidence of a blockage of the movement of fish up and down the river, or changes in the size of the fish populations. The overall effects have been very small and confined to a limited area downstream of the power plant. In an NRC-sponsored analysis of ecological monitoring data from several nuclear power plants located on the Mississippi River⁽²⁹⁻³⁰⁾ and the Susquehanna River,⁽³²⁾ no thermal impacts of consequence were evident. This research also suggested that sublethal effects of heat were not easy to measure quantitatively from the collected monitoring data. In a comparison of thermal effects of British and North American rivers it was pointed out that there were few examples of real thermal damage in the streams of the United States and that there appeared to be room for greater release of thermal effluents before they would cause changes of the magnitude of those caused by discharge of other industrial wastes or by the impoundment of rivers.⁽³³⁾

Based on the examination of additional heat release data, it still appears that six 1250-MWe nuclear power reactors (or 10 reactors with Columbia River flows augmented to 54,000 cfs minimum) can be cooled by a once-through system that uses Columbia River water without producing great

changes in the river ecosystem. The justification and limitations for this conclusion are:

- For 10 years, the Hanford plutonium reactors released quantities of heat to the river that were a little greater than that expected for six nuclear reactors without producing identifiable adverse effects to the river biota.
- Heat releases to other large streams in the United States have shown no, or only near-field, ecological impact.
- The thermal release from once-through-cooled power plants at Hanford would need to be curtailed or discontinued during periods of high ambient river temperature (August-October).
- The addition of helper cooling towers to the once-through cooling systems would greatly increase their flexibility. This would be of particular benefit if anticipated future uses of the river will appreciably reduce river flow or increase temperature.
- Because most of the water that is removed from the river for once-through cooling is returned to the river, other water uses would be preserved. The consumptive water use for six power plants cooled by wet towers would be about 280 cfs (7.9 m³/S), or sufficient water to irrigate about 45,000 acres of agriculture land.⁽³⁴⁾
- Thermal additions to the river during the colder winter period may be beneficial to some river organisms by creating better conditions for growth.⁽²⁴⁾

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Thermal power plant cooling systems, including those that would be used in an NEC, ultimately release energy to the atmosphere. Concern has been expressed over potential atmospheric modifications that might result from the amount of energy that would be released at an NEC.⁽¹⁻³⁾ The modifications postulated generally fall into five categories: 1) concentration of vorticity and the formation of large dust devils, 2) increases in ground-level humidity and fog, 3) increases in cloudiness and associated decreases in solar radiation, 4) changes in precipitation patterns, and 5) initiation of severe storms.⁽¹⁻³⁾ Meteorological studies for an HNEC have examined potential effects on ground-level humidity, fog, cloudiness, and solar radiation.^(4,5) Generic meteorological effects of large energy releases are being studied in a Department of Energy program managed by Oak Ridge National Laboratory,^(6,7) and the Nuclear Regulatory Commission sponsored a study to place the postulated impacts in perspective.⁽⁸⁾ Results of these studies have been incorporated in the evaluation of the potential meteorological effects of HNEC heat rejection, and are summarized here.

CLIMATE

Any evaluation of the impact of heat sink management alternatives on the environment must consider the climate of the region under consideration. Thus it is appropriate to describe the climate of the Hanford area in some detail.

The basic reference on Hanford climate is Climatology of the Hanford Area.⁽⁹⁾ Temperature and precipitation data in this work indicate that the Hanford area borders between a steppe (BS) and desert (BW) climate using the Koppen classification scheme.⁽¹⁰⁾ This classification is confirmed by the vegetation types that occupy most of the Hanford Reservation.

Meteorological observations have been made at numerous locations in the Hanford vicinity, but the only extensive records for a single location are those for the Hanford Meteorological Station (HMS). The HMS is located on a plateau at about 750 ft above mean sea level and 300 ft above the Columbia River, which flows through the Reservation from the northwest to the southeast. There are several significant topographic features within 20 miles of the HMS that affect aspects of the Hanford climatology.

Prior to the establishment of the HMS in December 1944, meteorological measurements were made by U.S. Weather Bureau cooperative observers between 1912 and 1943, and by the U.S. weather Bureau in Richland for a short period at the end of 1943 and beginning of 1944. The climatological data from these sources are summarized in Table 16. This summary gives both monthly and annual statistics for a large number of climatological variables and includes extreme as well as mean values.

In addition to the month-to-month variation in the climatological statistics presented in Table 16, there are distinct daily cycles that are superimposed on the seasonal variations. These daily cycles are evident in temperature, humidity, wind speed, and sky cover. The range of the daily temperature cycle at Hanford is about 13⁰F in December and about 30⁰F in July and August. The daily cycle of relative humidity is inversely related to the temperature cycle; that is, when the temperature decreases, the humidity increases. Conversely, when the temperature increases, the relative humidity decreases. The daily relative humidity variation at Hanford is about 25% throughout most of the year. However, it decreases to about 15% in December and January. The daily wind speed cycle has a minimum during the morning hours and a maximum near sunset. It is most pronounced during the summer and almost imperceptible during the months of December and January. Sky cover diurnal variations generally parallel the temperature variations and are greatest during the spring and fall. The amount of sky cover (clouds) is at a minimum near midnight, increases following sunrise, and reaches a maximum in the

late afternoon. During the summer and winter, sky cover follows the same trend but the range of variation is comparatively small.

The most frequent restriction to visibility in the Hanford area is fog, which occurs on an average of 38 days per year. On 24 of these days the visibility is restricted to less than 1/2 mile. Fog is highly seasonal although it has occurred in every month. More than 95% of the occurrences are from November through February. If the months of October and March are included this percentage increases to more than 99.5%. Hanford fogs are generally associated with low wind speed conditions. More than 70% of the hours of fog occur when the wind speed is less than 3.5 mph; the average wind speed during fog is 2.5 mph.

Other relatively common obstructions to visibility include dust and smoke. Visibility is restricted by dust to 6 miles or less on an average of about 5 days a year and less than 3 days a year by smoke. Agricultural field burning and smudging have been major sources of smoke; however, smudging is no longer significant.

There are frequent, protracted periods of low wind speeds combined with strong, elevated temperature inversions during which there is a buildup of suspended particles in the atmosphere. On an average of once in two years one of these periods can be expected to persist for at least 10 days. During these periods there is a gradual decrease in visibility, which is evident through increasing haziness. With current particulate sources and humidities, the visibility generally does not decrease to 6 miles or less. As a result, the effect of humidity on visibility has not been documented in the records of the HMS meteorological observations.

The climatological data for the HMS are generally assumed to be representative of the entire region although local variations in the climate are known to exist. These associated with the Columbia River and the major topographic features which form the sides of the basin. Variations between the northern and southern portions of the Hanford site are primarily small differences in temperature, humidity and wind.

TABLE 16. Averages and Extremes for Climatic Elements at Hanford
(based on all available records to and including the year 1975)

	TEMPERATURE (°F)										DEGREE DAYS (BASE 65°F)										PRECIPITATION (INCHES)																			
	1912-1975 AVERAGES					1912-1975 EXTREMES					HEATING 1945-1975 TOTALS					COOLING 1960-1975 TOTALS					1912-1975 TOTALS					SNOW, ICE, PELLETS (SLEET)														
	DAILY MAXIMUM	DAILY MINIMUM	MONTHLY	HIGHEST MONTHLY	LOWEST MONTHLY	RECORD HIGHEST	RECORD LOWEST	YEAR	RECORD HIGHEST	RECORD LOWEST	YEAR	RECORD LOWEST	YEAR	MEAN MONTHLY	MAXIMUM MONTHLY	MINIMUM MONTHLY	YEAR	MEAN MONTHLY	MAXIMUM MONTHLY	MINIMUM MONTHLY	YEAR	MEAN MONTHLY	MAXIMUM MONTHLY	MINIMUM MONTHLY	YEAR	MEAN MONTHLY	MAXIMUM MONTHLY	MINIMUM MONTHLY	YEAR	MAX. IN 24 HOURS	YEAR	MEAN MONTHLY	MAXIMUM MONTHLY	MINIMUM MONTHLY	YEAR	MAX. IN 24 HOURS	YEAR	MAXIMUM DEPTH		
Jan.	37.0	22.2	29.6	42.5	1953	12.1	1950	72	1971	-2	1950	53	1932	23	1934	1085	1640	1950	694	1953	0	0	0	0	0.92	2.47	1970	0.13	1962	1.08	1948	5.1	23.4	1950	7.1	1954	12.0	1950	10.0	1950
Feb.	45.4	27.6	36.4	44.5	1946	21.4	1929	71	1924	3	1950	55	1932	23	1950	778	1147	1956	576	1958	0	0	0	0	0.60	3.08	1940	1	1967	1.74	1916	2.4	26.0	1916	5.6	1975	10.0	1975		
Mar.	56.5	33.7	45.1	49.9	1926	38.4	1955	83	1960	28	1960	54	1942	6	1955	641	794	1956	476	1947	0	0	0	0	0.37	1.86	1957	0	1942	0.59	1949	0.3	4.7	1951	2.2	1957	2.3	1957		
Apr.	66.1	39.9	53.1	59.6	1936	47.5	1955	95	1934	41	1945	80	1956	12	1935	386	522	1955	266	1947	1	5	1968	0	0.38	1.22	1969	0	1933	0.53	1951	1	1	1975	1	1975	0	1975		
May	75.9	48.0	61.9	68.5	1947	56.6	1933	103	1936	49	1918	70	1956	28	1954	154	255	1962	36	1947	49	99	1971	3	0.62	0.47	2.03	1972	0	1931	1.19	1972	1	1	1960	1	1960	0	1960	
June	83.2	55.4	68.4	75.4	1922	63.0	1953	110	1912	55	1966	81	1924	33	1933	36	90	1953	3	1956	192	310	1969	59	1971	0.56	2.92	1950	0	1919	1.50	1934	0	0	0	0	0	0		
July	91.9	61.1	76.5	81.8	1960	72.4	1963	115	1939	59	1966	82	1925	41	1935	3	22	1955	0	1975	408	518	1960	232	1963	0.15	0.91	1966	0	1939	0.73	1914	0	0	0	0	0	0		
Aug.	99.4	59.3	74.3	81.5	1967	66.9	1964	113	1963	63	1920	81	1961	40	1918	5	32	1960	0	1974	338	508	1967	171	1964	0.20	1.18	1920	0	1955	0.69	1975	0	0	0	0	0	0		
Sept.	79.6	50.7	65.2	71.7	1967	56.8	1926	102	1950	52	1934	72	1955	25	1926	71	179	1972	13	1967	107	216	1967	27	1970	0.30	1.34	1947	1	1961	0.92	1947	0	0	0	0	0	0		
Oct.	65.3	40.7	53.0	59.0	1952	48.8	1980	90	1933	31	1935	60	1945	4	1935	377	479	1966	200	1952	2	10	1971	0	1975	0.58	2.72	1959	0	1917	1.91	1957	4	1.5	1973	1.5	1973			
Nov.	48.6	31.5	40.0	46.0	1954	31.3	1955	75	1975	14	1955	52	1959	-1	1955	247	1008	1955	567	1954	0	0	0	0	0	0.86	3.05	1926	1	1939	0.78	1966	1.3	12.7	1955	4.8	1955			
Dec.	39.3	26.0	32.7	42.0	1933	18.5	1919	66	1933	-3	1919	56	1975	-27	1919	990	1224	1964	822	1957	0	0	0	0	0	0.99	2.53	1931	0.11	1946	1.00	1958	3.9	19.1	1964	5.4	1965			
Year	64.5	41.3	53.1	61.5	1960	12.1	1950	115	1939	-3	1950	82	1925	-27	1919	5271	1640	1950	0	1975	1093	518	1960	0	1975	6.28	3.08	1940	0	1955	1.91	1957	13.0	26.0	1916	7.1	1954	12.1	1954	

	WIND (mph)					RELATIVE HUMIDITY (%)					SKY COVER (SCALE 0-10)					SOLAR RADIATION (LANGLEYS)*																		
	1945-1975 AVERAGES					1946-1975 AVERAGES					1946-1975 EXTREMES					1953-1975 AVERAGES (SUNRISE TO SUNSET)					1953-1975 EXTREME DAILY TOTALS													
	PREVAILING DIRECTION	MEAN MONTHLY SPEED	HIGHEST MONTHLY	LOWEST MONTHLY	YEAR	SPEED	DIRECTION	MEAN	HIGHEST MONTHLY	YEAR	LOWEST MONTHLY	HIGHEST	YEAR	LOWEST	YEAR	MONTHLY	HIGHEST MONTHLY	YEAR	LOWEST MONTHLY	YEAR	MONTHLY	HIGHEST MONTHLY	YEAR	LOWEST MONTHLY	YEAR	MONTHLY	HIGHEST MONTHLY	YEAR	LOWEST MONTHLY	YEAR	HIGHEST MONTHLY	YEAR	LOWEST MONTHLY	YEAR
Jan.	NW	6.6	10.3	1972	3.1	1955	80	SW	1972	75.2	88.8	1960	80.0	1963	100	1975	13	1963	7.8	9.0	1969	4.3	1949	120	136	1973	88	1955	277	1969	16	1971		
Feb.	NW	7.1	9.4	1961	4.6	1963	65	SW	1971	70.0	86.9	1963	54.0	1967	100	1975	14	1962	7.4	8.9	1961	5.9	1964	202	238	1960	165	1954	422	1958	37	1970		
Mar.	NW	8.4	10.7	1964	5.9	1958	70	SW	1976	55.8	65.9	1950	44.0	1965	100	1974	12	1965	6.9	7.9	1950	4.9	1965	340	388	1965	304	1961	542	1968	47	1972		
Apr.	NW	9.1	11.1	1972	7.4	1958	73	SSW	1972	46.5	64.5	1963	36.9	1966	100	1973	9	1954	6.4	8.1	1963	3.7	1951	475	535	1973	374	1963	704	1972	75	1974		
May	NW	9.9	10.5	1965	5.8	1957	71	SSW	1960	42.3	61.0	1948	31.2	1966	100	1975	7	1953	5.8	7.7	1960	4.5	1949	576	634	1970	511	1962	782	1959	67	1962		
June	NW	9.2	10.7	1949	7.7	1950	72	SW	1957	39.5	51.5	1950	30.0	1949	100	1972	10	1964	5.3	7.0	1950	2.8	1961	628	698	1960	563	1953	821	1971	112	1965		
July	NW	8.6	9.4	1963	6.9	1955	95	WSW	1968	31.8	40.5	1955	21.9	1959	99	1972	6	1951	2.8	4.5	1974	0.9	1953	639	714	1973	568	1955	808	1974	118	1972		
Aug.	NW	8.0	9.1	1966	6.0	1956	66	SW	1961	34.9	43.9	1948	24.5	1967	100	1972	7	1951	3.2	5.9	1968	0.6	1955	558	631	1955	475	1968	721	1957	107	1959		
Sept.	NW	7.5	9.2	1961	5.4	1957	65	SSW	1953	40.6	55.1	1959	33.2	1974	100	1962	10	1962	4.0	6.1	1959	1.4	1975	423	463	1975	354	1959	591	1970	63	1957		
Oct.	NW	6.7	9.1	1966	4.4	1952	63	SSW	1950	57.0	74.2	1962	42.5	1952	100	1975	10	1952	5.9	8.0	1975	3.9	1962	262	299	1964	216	1975	362	1973	33	1974		
Nov.	NW	6.1	7.9	1945	2.9	1956	64	SSW	1949	73.5	88.1	1972	64.2	1963	100	1975	16	1959	7.6	9.1	1972	6.2	1957	132	180	1957	97	1964	295	1971	14	1969		
Dec.	NW	6.1	8.3	1968	3.9	1963	71	SW	1955	80.1	90.5	1950	60.0	1968	100	1975	26	1972	8.1	9.2	1962	6.8	1954	92	116	1970	57	1966	196	1972	9	1973		
Year	NW	7.7	11.1	1972	2.9	1956	80	SW	1972	53.9	90.5	1950	21.9	1959	100	1975	6	1951	5.9	9.2	1962	0.6	1955	372	714	1973	57	1969	821	1971	9	1973		

EXTREME AVERAGES OR TOTALS AND YEAR OR SEASON OF OCCURRENCE	
1912-1975 TEMPERATURE AVERAGES (°F)	
HIGHEST ANNUAL	56.2 1958+
LOWEST ANNUAL	50.2 1929
HIGHEST WINTER (D-J-F)	41.1 1933-34
LOWEST WINTER	24.2 1948-49
HIGHEST SPRING (M-A-M)	58.2 1947
LOWEST SPRING	48.0 1955
HIGHEST SUMMER (J-J-A)	78.2 1958
LOWEST SUMMER	70.3 1954
HIGHEST FALL (S-O-N)	56.6 1963
LOWEST FALL	49.6 1946
1912-1975 PRECIPITATION TOTALS (IN)	
GREATEST ANNUAL	11.45 1950
LEAST ANNUAL	3.26 1967
SNOW, ICE, PELLETS (SLEET)	
GREATEST SEASONAL	43.6 1915-16
LEAST SEASONAL	0.3 1957-58
1945-1975 WIND SPEED AVERAGE (mph)	
HIGHEST ANNUAL	8.3 1968+
LOWEST ANNUAL	6.3 1957
1946-1975 RELATIVE HUMIDITY AVERAGE (%)	
HIGHEST ANNUAL	57.9 1950+
LOWEST ANNUAL	49.4 1967
1946-1975 SKY COVER AVERAGES (SUNRISE TO SUNSET, SCALE 0-10)	
HIGHEST ANNUAL	6.4 1966
LOWEST ANNUAL	5.1 1949
1953-1975 SOLAR RADIATION AVERAGE DAILY TOTAL (LANGLEYS)	
HIGHEST ANNUAL	390 1973
LOWEST ANNUAL	357 1967

TABLE 16. (contd)

NUMBER OF DAYS (1945-1975) **																														
		CLEAR				PTLY CLDY		CLOUDY				THUNDERSTORMS				HEAVY FOG (VIS. 1/4 MI. OR LESS)				PRECIP. 0.10 INCH OR MORE				SNOW 1.0 INCH OR MORE						
		MEAN MONTHLY	GREATEST MONTHLY	YEAR	LEAST MONTHLY	MEAN MONTHLY	GREATEST MONTHLY	YEAR	LEAST MONTHLY	MEAN MONTHLY	GREATEST MONTHLY	YEAR	LEAST MONTHLY	MEAN MONTHLY	GREATEST MONTHLY	YEAR	LEAST MONTHLY	MEAN MONTHLY	GREATEST MONTHLY	YEAR	LEAST MONTHLY	MEAN MONTHLY	GREATEST MONTHLY	YEAR	LEAST MONTHLY	MEAN MONTHLY	GREATEST MONTHLY	YEAR	LEAST MONTHLY	
Jan.	3	7	1963	0	1975	6	22	27	1969	17	1963	0	0	1972	0	5	14	1965	0	1969	3	8	1970	0	1972	2	10	1950	0	1967
Feb.	5	9	1968	1	1972	5	18	26	1958	12	1964	0	1	1972	0	3	11	1963	0	1971	2	5	1961	0	1972	2	4	1975	0	1974
Mar.	6	12	1965	2	1961	8	17	22	1968	9	1965	0	1	1969	0	1	5	1951	0	1975	2	8	1961	0	1973	6	2	1957	0	1975
Apr.	6	12	1962	1	1963	10	14	21	1963	6	1956	1	3	1968	0	1	1	1975	0	1974	1	5	1968	0	1973	0	0	0	0	1975
May	9	14	1973	2	1960	10	12	19	1960	6	1958	2	7	1956	0	1	1	1958	0	1975	2	4	1967	0	1964	0	0	0	0	1975
June	10	21	1961	5	1972	10	10	15	1973	5	1960	3	8	1972	0	1	1	1971	0	1975	2	8	1950	0	1973	0	0	0	0	1975
July	20	26	1960	13	1974	7	4	9	1974	1	1961	2	7	1975	0	0	0	0	0	1973	0	0	1974	0	1973	0	0	0	0	1975
Aug.	19	30	1955	11	1968	7	5	13	1968	0	1969	2	8	1953	0	1	1	1959	0	1975	1	4	1975	0	1974	0	0	0	0	1975
Sept.	15	27	1975	8	1969	7	8	13	1969	1	1975	1	4	1959	0	1	1	1957	0	1975	1	5	1959	0	1975	0	0	0	0	1975
Oct.	9	14	1970	1	1975	7	15	22	1973	9	1970	0	1	1975	0	1	6	1962	0	1974	2	8	1950	0	1972	1	1	1973	0	1975
Nov.	4	10	1957	1	1975	5	21	25	1973	15	1961	0	0	1974	0	6	13	1965	0	1960	3	10	1973	0	1967	1	6	1955	0	1974
Dec.	3	7	1972	1	1967	5	23	28	1962	18	1967	0	1	1971	0	17	1950	2	1968	3	9	1964	0	1969	2	6	1964	0	1974	
Year	109	30	1955	0	1955	82	169	28	1962	0	1969	11	8	1972	0	26	17	1950	0	1975	23	10	1973	0	1975	6	10	1950	0	1975

		NUMBER OF DAYS (1945-1975)												NUMBER OF DAYS (1912-1975)																					
		3" OR MORE SNOW ON GND.				PEAK GUST 40 MPH OR GREATER				MAX. TEMP. 90 OR ABOVE				MAX. TEMP. 100 OR ABOVE				MAX. TEMP. 32 OR BELOW				MIN. TEMP. 32 OR BELOW				MIN. TEMP. 0 OR BELOW									
		MEAN MONTHLY	GREATEST MONTHLY	YEAR	LEAST MONTHLY	MEAN MONTHLY	GREATEST MONTHLY	YEAR	LEAST MONTHLY	MEAN MONTHLY	GREATEST MONTHLY	YEAR	LEAST MONTHLY	MEAN MONTHLY	GREATEST MONTHLY	YEAR	LEAST MONTHLY	MEAN MONTHLY	GREATEST MONTHLY	YEAR	LEAST MONTHLY	MEAN MONTHLY	GREATEST MONTHLY	YEAR	LEAST MONTHLY	MEAN MONTHLY	GREATEST MONTHLY	YEAR	LEAST MONTHLY						
Jan	5	23	1969	0	1975	3	11	1972	0	1973	0	0	0	0	0	0	0	11	29	1937	0	1967	28	31	1960	9	1953	2	14	1950	0	1975			
Feb	3	16	1950	0	1974	3	6	1961	0	1973	0	0	0	0	0	0	0	3	15	1956	0	1974	22	28	1964	5	1958	1	9	1929	0	1975			
Mar	0	0	0	0	0	3	9	1956	1	1973	0	0	0	0	0	0	0	4	2	1960	0	1975	16	25	1964	6	1968	0	0	0	0	1975			
Apr	0	0	0	0	0	3	7	1972	0	1967	4	4	1926	0	1975	0	0	0	0	0	0	0	5	13	1955	0	1974	0	0	0	0	1975			
May	0	0	0	0	0	2	6	1971	0	1965	3	11	1924	0	1974	0	1	1966	0	0	0	0	5	13	1938	0	1975	0	0	0	0	1975			
June	0	0	0	0	0	2	6	1973	0	1971	9	20	1960	0	1953	1	9	1970	0	1975	0	0	0	0	0	0	0	0	0	0	0	1975			
July	0	0	0	0	0	1	4	1962	0	1975	21	29	1961	8	1963	7	16	1971	0	1963	0	0	0	0	0	0	0	0	0	0	0	1975			
Aug	0	0	0	0	0	1	5	1951	0	1974	16	29	1915	7	1968	4	16	1962	0	1975	0	0	0	0	0	0	0	0	0	0	0	1975			
Sept	0	0	0	0	0	2	4	1966	0	1975	5	16	1938	0	1970	8	2	1955	0	1975	0	0	0	0	4	1933	0	1975	0	0	0	0	1975		
Oct	0	0	0	0	0	2	8	1967	0	1974	1	1	1933	0	1975	0	0	0	0	0	0	0	2	1935	0	1975	5	12	1916	0	1962	0	0	1975	
Nov	0	0	1955	0	1975	2	5	1973	0	1974	0	0	0	0	0	0	0	2	15	1955	0	1974	17	30	1936	4	1969	9	1	1955	0	1975			
Dec	2	14	1955	0	1975	3	8	1957	0	1960	0	0	0	0	0	0	0	8	19	1914	0	1974	26	31	1963	14	1933	1	14	1919	0	1975			
Year	10	23	1969	0	1975	27	11	1972	0	1973	56	29	1961	0	1975	12	16	1971	0	1975	24	29	1937	0	1975	119	31	1963	0	1975	4	14	1950	0	1975

REFERENCE NOTES

- * CALORIES/cm²
- * SKY COVER AND PRECIPITATION OBSERVATIONS NOT BEGUN UNTIL 1946
- # LESS THAN 1/2
- + ALSO ON EARLIER YEARS

LOCATION AND HISTORY

PRESENT LOCATION 25 MILES NW OF RICHLAND, WASHINGTON
 LATITUDE 46°34' N; LONGITUDE 119°36' W ELEVATION 733 FEET
 OBSERVATIONS FROM 1912 TO 1944 WERE BY UNITED STATES WEATHER BUREAU COOPERATIVE OBSERVERS AT A SITE ABOUT 10 MILES ENE OF PRESENT LOCATION. SINCE 1944 OBSERVATIONS HAVE BEEN MAINTAINED ON A 24 HOUR A-DAY BASIS BY THREE DIFFERENT ERDA CONTRACTORS.

NUMBER OF DAYS

CLEAR 10-3 TENTHS SKY COVER, SR TO SS1

GREATEST ANNUAL (1946-75) 141 1951
 LEAST ANNUAL (1946-75) 85 1966

CLOUDY (8-10 TENTHS SKY COVER, SR TO SS1)

GREATEST ANNUAL (1946-75) 181 1969
 LEAST ANNUAL (1946-75) 84 1949

THUNDERSTORMS

GREATEST ANNUAL (1945-75) 23 1968
 LEAST ANNUAL (1945-75) 3 1949

HEAVY FOG (VIS. 1/4 MILE OR LESS)

GREATEST SEASONAL (1945-75) 42 1950-51
 LEAST SEASONAL (1945-75) 9 1948-49

PRECIPITATION 0.10 INCH OR MORE

GREATEST ANNUAL (1946-75) 30 1950
 LEAST ANNUAL (1946-75) 10 1965

SNOW 1.0 INCH OR MORE

GREATEST SEASONAL (1946-75) 15 1955-56
 LEAST SEASONAL (1946-75) 0 1957-58

3 IN. OR MORE SNOW ON GROUND

GREATEST SEASONAL (1946-75) 40 1964-65
 LEAST SEASONAL (1946-75) 0 1966-67

PEAK GUST 40 MPH OR GREATER

GREATEST ANNUAL (1945-75) 41 1961
 LEAST ANNUAL (1945-75) 13 1958

MAX. TEMPERATURE 90 OR ABOVE

GREATEST ANNUAL (1912-75) 85 1960
 LEAST ANNUAL (1912-75) 31 1964

MAX. TEMPERATURE 100 OR ABOVE

GREATEST ANNUAL (1912-75) 32 1962
 LEAST ANNUAL (1912-75) 1 1954

MAX. TEMPERATURE 32 OR BELOW

GREATEST SEASONAL (1912-75) 53 1955-56
 LEAST SEASONAL (1912-75) 1 1917-18

MIN. TEMPERATURE 32 OR BELOW

GREATEST SEASONAL (1912-75) 141 1916-17
 LEAST SEASONAL (1912-75) 75 1957-58

MIN. TEMPERATURE 0 OR BELOW

GREATEST SEASONAL (1912-75) 18 1949-50
 LEAST SEASONAL (1912-75) 0 1974-75

The major impact of an HNEC on the atmosphere will come as a result of the release of waste heat. The extent of the impact will be further related to the ability of the atmosphere to disperse the heat. The primary factors that govern the dispersion or diffusion of the waste heat are atmospheric stability and the wind. The stronger the wind or less stable the atmosphere the more rapid the dispersion of the heat.

Results of numerous atmospheric diffusion experiments at Hanford indicate that four categories adequately describe atmospheric stability variations for the purpose of the diffusion modeling. Table 17 shows the joint frequency distribution of wind speed. Wind direction and atmospheric stability. The prevailing wind directions are clearly shown to be west-northwest and northwest, and the predominant atmospheric stabilities are moderately stable and neutral.

If the Hanford area had no significant topographic features, the major impact of an HNEC would be expected to occur to the east-southeast and southeast. However, the influence of the topographic features in the Hanford area alters this expectation. Airflow measurements made over the site in the past few years indicate there are frequent local circulation patterns that are not adequately described by the wind direction at the HMS. In some cases these circulations would act to increase the rate at which the waste heat is dispersed, and in other cases they would have the opposite effect.

Potential formation of convective vortices resulting from NEC heat rejection is postulated on the basis of the magnitude of heat release, the area of the heat release, and an analogy between plumes over cooling towers and plumes over large fires. In general, this impact is postulated only for energy centers using cooling towers for heat rejection; other cooling systems disperse the energy sufficiently prior to releasing it to the atmosphere to mitigate concerns in this area.

Orgill⁽⁶⁾ has examined the cooling tower-fire plume analogy in detail. Comparison of the observed behavior of plumes from single or small clusters of cooling towers and fires indicates that the analogy is inappropriate for current power generation facilities. For the cooling tower-fire plume

TABLE 17. Annual Joint Frequency Distribution of Wind Speed, Wind Direction and Atmospheric Stability for Hanford

Wind Speed, mph	Atmospheric Stability(a)	Annual Frequency for Various Wind Directions, %																		
		NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	N	VAR.	CALM	TOTAL
0 - 3	VS	0.06	0.06	0.04	0.06	0.06	0.12	0.07	0.07	0.06	0.05	0.06	0.10	0.08	0.10	0.11	0.09	0.08	0.09	1.37
	MS	0.29	0.30	0.24	0.29	0.40	0.55	0.32	0.29	0.23	0.26	0.25	0.44	0.41	0.56	0.48	0.49	0.25	0.66	6.71
	N	0.44	0.57	0.42	0.49	0.56	0.56	0.26	0.26	0.18	0.20	0.16	0.28	0.31	0.50	0.61	0.63	0.31	0.69	7.43
	U	0.37	0.44	0.25	0.30	0.25	0.26	0.13	0.11	0.08	0.10	0.08	0.10	0.09	0.19	0.22	0.38	0.30	0.06	3.71
4 - 7	VS	0.04	0.04	0.03	0.03	0.04	0.09	0.09	0.09	0.07	0.10	0.15	0.24	0.23	0.22	0.17	0.09	0.01	0.	1.75
	MS	0.28	0.21	0.18	0.21	0.30	0.50	0.34	0.32	0.29	0.39	0.52	1.02	1.21	1.35	0.94	0.54	0.03	0.	8.62
	N	0.35	0.38	0.27	0.32	0.36	0.47	0.27	0.26	0.22	0.31	0.29	0.39	0.56	1.04	0.72	0.56	0.08	0.	6.86
	U	0.77	0.71	0.44	0.46	0.44	0.52	0.29	0.33	0.33	0.36	0.26	0.28	0.33	0.75	0.78	0.86	0.23	0.	8.13
8 -12	VS	0.01	0.00	0.00	0.00	0.00	0.03	0.06	0.03	0.02	0.05	0.12	0.26	0.34	0.59	0.20	0.02	0.	0.	1.74
	MS	0.17	0.15	0.09	0.10	0.13	0.27	0.29	0.17	0.20	0.40	0.86	1.71	2.85	2.52	0.73	0.27	0.00	0.	10.94
	N	0.21	0.12	0.07	0.07	0.09	0.13	0.13	0.13	0.23	0.40	0.44	0.48	0.86	1.36	0.33	0.21	0.	0.	5.24
	U	0.40	0.29	0.11	0.08	0.07	0.14	0.10	0.11	0.25	0.41	0.38	0.22	0.43	1.01	0.39	0.36	0.00	0.	4.75
13-18	VS	0.00	0.00	0.	0.00	0.	0.01	0.02	0.01	0.01	0.01	0.04	0.10	0.28	0.81	0.07	0.00	0.	0.	1.38
	MS	0.10	0.06	0.03	0.04	0.02	0.10	0.18	0.12	0.17	0.42	0.86	1.25	3.45	2.66	0.24	0.11	0.	0.	9.80
	N	0.15	0.06	0.02	0.01	0.01	0.04	0.07	0.11	0.23	0.49	0.63	0.55	1.13	1.06	0.11	0.10	0.	0.	4.78
	U	0.21	0.11	0.03	0.01	0.00	0.02	0.03	0.04	0.13	0.40	0.49	0.19	0.51	0.79	0.07	0.12	0.	0.	3.16
19-24	VS	0.	0.	0.	0.	0.	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.04	0.12	0.00	0.	0.	0.	0.20
	MS	0.02	0.02	0.01	0.01	0.00	0.02	0.05	0.08	0.13	0.32	0.35	0.20	1.02	1.08	0.02	0.01	0.	0.	3.33
	N	0.05	0.04	0.01	0.00	0.00	0.02	0.03	0.07	0.20	0.46	0.45	0.22	0.84	0.81	0.02	0.04	0.	0.	3.26
	U	0.05	0.04	0.01	0.00	0.	0.00	0.01	0.02	0.08	0.26	0.31	0.09	0.29	0.59	0.01	0.02	0.	0.	1.79
OVER 24	VS	0.	0.	0.	0.	0.	0.00	0.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.	0.	0.	0.	0.01
	MS	0.00	0.00	0.	0.	0.	0.00	0.02	0.05	0.15	0.21	0.12	0.03	0.22	0.31	0.00	0.00	0.	0.	1.13
	N	0.02	0.01	0.00	0.00	0.	0.00	0.01	0.06	0.25	0.50	0.26	0.07	0.54	0.75	0.01	0.01	0.	0.	2.49
	U	0.01	0.02	0.01	0.	0.	0.	0.00	0.01	0.08	0.34	0.25	0.07	0.17	0.46	0.00	0.00	0.	0.	1.42
TOTALS	VS	0.11	0.11	0.07	0.10	0.11	0.25	0.24	0.20	0.16	0.22	0.39	0.71	0.96	1.85	0.56	0.20	0.09	0.09	6.44
	MS	0.87	0.75	0.55	0.65	0.85	1.44	1.20	1.02	1.17	2.01	2.96	4.65	9.16	8.49	2.41	1.42	0.28	0.66	40.53
	N	1.22	1.19	0.78	0.89	1.02	1.22	0.78	0.89	1.31	2.35	2.23	2.00	4.24	5.52	1.79	1.56	0.39	0.69	30.07
	U	1.82	1.62	0.84	0.86	0.76	0.95	0.56	0.63	0.95	1.87	1.77	0.93	1.82	3.77	1.48	1.74	0.53	0.06	22.96

(a) VS = very stable
MS = moderately stable
N = neutral
U = unstable

analogy to be strictly appropriate, however, several types of similarity are required. These include: geometric similarity, dynamic similarity, thermal and energy similarity, kinematic similarity, and boundary condition similarity. Orgill indicates that geometric similarity in the plumes is possible but that the other similarities are generally not found. Further, Hanna and Gifford⁽¹¹⁾ suggest that the separation of cooling towers to delay merger of their plumes until after the most active stage of plume rise can reduce the atmospheric impact of an energy center. Using a relationship suggested by Briggs⁽¹²⁾, it is estimated that merger of plumes from cooling towers serving a 4-reactor power-plant cluster located within 1 square mile would take place above 10,000 ft. This is certainly above the region of active plume rise. Merger of plumes from adjacent clusters would take place at a much higher level.

Applying these results to the conceptual HNEC, it is concluded that the HNEC heat rejection is not likely to cause a concentrated convective vortices. This conclusion is strengthened when the optimum cooling system mix suggested for the HNEC is considered.⁽⁴⁾

STUDY RESULTS

A detailed evaluation of the transport and diffusion of thermal effluents from a HNEC would be a complex and relatively expensive process because of these local circulations. Therefore a relatively simple dispersion model that uses HMS wind and stability data and assumes straight-line transport has been used to examine the previous potential atmospheric impacts of HNEC energy releases.⁽⁴⁾

Heat rejection through conventional cooling systems ultimately results in adding moisture to the atmosphere. Cooling ponds, low mechanical-draft cooling towers and to a lesser extent once-through cooling systems add moisture directly to the air near ground level. As a result these systems have a greater potential to increase ground-level humidity and fog than do natural-draft or tall mechanical-draft cooling systems. The diffusion model was used to evaluate the consequences of evaporation from cooling

systems on ground-level humidity and fog from the conceptual HNEC.^(a) The major conclusions of the study were: 1) the cooling system mix used in an HNEC will be a primary factor in determining the effect on ground-level humidity and fog; 2) the positions of the cooling systems within the HNEC will have only a secondary effect; and 3) the increase in both hours of fog and hours with visibility less than half a mile would be statistically significant.

For a 20-reactor HNEC the predicted increases in hours of fog in the Tri-Cities ranged from 15 hours for a center with four reactors using low mechanical-draft cooling towers and 16 reactors using dry cooling towers to 250 hours for a center with four reactors using low cooling towers and 16 reactors using cooling ponds. The conventional cooling system mix that gave the least increase in fog included four reactors using low cooling towers, eight reactors using tall cooling towers, and eight reactors using once-through river cooling. This combination gives a predicted fog increase of 34 hours per year. This combination is also predicted to increase: 1) the hours of visibility less than 1 mile by 42, 2) the hours of visibility less than 1/16 mile by 5. The increase in hours of low visibility may be more significant than the increase in total hours of fog.

The summertime increases in ground-level atmospheric moisture are small and would affect populated areas infrequently. A 20-reactor center using all low cooling towers would increase the moisture content in the Tri-Cities by more than 1 g/m^3 less than 50 hours per summer. A

(a) Model computations were performed for an HNEC with 1250-MWe power plants and operating factors of 1.0. Therefore, the results should be conservative for larger generating facilities as long as the product of the rated electrical output and operating factor is less than 1250 MWe.

1 g/m³ increase in moisture is equivalent to an increase of relative humidity of 2% to 3% at typical afternoon temperatures. In general an increase of this magnitude would be unnoticeable from a comfort standpoint. However, it might increase the haze. The effect of an increase in humidity on haze has not been estimated.

Expansion of the HNEC to 40 power plants would roughly double the magnitude of the predicted changes in ground-level humidity and fog. The increases could be controlled by selecting a suitable cooling system mix that incorporated both conventional cooling systems and dry or hybrid wet-dry cooling systems.

A modified version of the model was used to estimate changes in cloudiness and solar radiation.⁽⁵⁾ The primary conclusions drawn from the modeling results were: 1) the predicted change in sky cover (cloudiness) and solar radiation (insolation) would be statistically significant in the immediate vicinity of the energy center power plant clusters during the fall, winter and spring; 2) cooling system effluents are more likely to make a significant change in insolation than in sky cover; and 3) changes in sky cover and insolation would generally be small outside the immediate vicinity of the reactor clusters.

In the immediate vicinity of the HNEC the predicted increases in sky cover range from 0.4 to 1.6 tenths (sky cover is reported in tenths of the entire sky area). The smallest increases are predicted for summer months and are not statistically significant when compared with normal variability. During the remainder of the year the predicted increases are sufficiently large that after about 10 years of HNEC operation they could be distinguished from normal variations of average sky cover with 95% confidence. The predicted decreases in solar radiation are statistically significant for each month except August. Their magnitudes range from 15 ly/day^(a) in November to 62 ly/day in May. As a percentage

(a) ly stands for langley and is equal to 1 cal/cm².

of the current average solar radiation, the predicted decreases are about 20% for winter months, 12% for spring and fall months, and 5% for summer months.

Outside the immediate vicinity of the HNEC, the largest changes in sky cover and insolation occur over the agricultural region on the east side of the Columbia River north of Pasco. There, the increases in sky cover, which range from 0.1 to 0.6 tenths, are not statistically significant. The decreases in insolation in this area range from 6 to 25 ly/day; significant decreases are predicted for February, March and May.

In other areas surrounding the HNEC the largest increases in sky cover were 0.4 tenths for the Tri-Cities; 0.3 tenths for the Arid Lands Ecology Reserve (ALE) and the Wahluke Slope; and 0.2 tenths for the Yakima Valley in the vicinity of Sunnyside, Grandview and Prosser. None of the increases in these areas is statistically significant. In these areas the maximum insolation reductions predicted are 14 ly/day for the Tri-Cities; 10 ly/day for the ALE Reserve; 9 ly/day for the Wahluke Slope; and 7 ly/day for the Yakima Valley. The only statistically significant decrease is 14 ly/day in the Tri-Cities in February. This decrease is about 7% of the current average.

In the evaluation of potential changes in sky cover and solar radiation it was assumed that all reactors were operating simultaneously and that each used (standard or tall) mechanical-draft towers for cooling. In a practical sense it is unlikely that all reactors would operate at any time. Use of an environmentally optimized cooling system mix, such as that delineated in the section on heat sink management, would also reduce the magnitude of the predicted impacts. Thus the estimated changes tend to be on the high side.

The impact of a 36,000-MW energy center on precipitation was examined by Scott.⁽⁸⁾ Three processes by which an NEC could alter precipitation were identified. They were 1) formation of a "thermal mountain" that caused air passing over the center to rise as it does in passing over real mountains, 2) initiating convective activity with its buoyant plume, and 3) enhancement of natural precipitation falling through a moist plume.

These processes could increase the precipitation in the vicinity of the energy center; they might also result in decreases in precipitation further downwind.

To estimate the magnitude of the potential effect of an HNEC "thermal mountain" on precipitation an analogy is drawn with the effect of Rattlesnake Mountain, a ridge 1000 m high to the southwest of Hanford. On an annual basis Rattlesnake Mountain receives about twice as much precipitation as Hanford. Thus, it is assumed that an HNEC "thermal mountain" would continue to lift air passing over the region, or at least delay subsidence in the lee of the ridge. The result could be a 100% increase in precipitation between the ridge and the HNEC. The current gradient of precipitation on the lee slope of Rattlesnake Mountain ^(9,13) indicates that an increase in precipitation resulting from an HNEC thermal mountain would not extend very far beyond the edge of the HNEC.

Increased precipitation caused by an HNEC triggering a convective activity would occur primarily during the spring and summer and is estimated to increase annual precipitation by as much as 5% to 10%. ⁽⁸⁾ The time required for droplets to form, grow to precipitable size, and fall to the ground would result in augmenting precipitation 10 to 20 km downwind of the HNEC. Because of the prevailing winds during the spring and summer, these increases would be expected in a band of agricultural land across the Columbia River from the HNEC extending from Wahluke Slope to about Eltopia.

The final augmentation process, enhancement of natural precipitation falling through a moist plume, might increase precipitation rates by as much as 10% to 25%. ⁽⁸⁾ The amount of increase would diminish with increasing distance from the energy center, and meandering of the energy center plume during passage of rain storms would tend to limit the increase in total precipitation at any specific location. As a result, Scott concludes that increases resulting from this process would be nearly undetectable. ⁽⁸⁾

Evidence on potential triggering of severe storms by NEC heat rejection is inconclusive. Scott⁽⁸⁾ tentatively draws an analogy between energy center "thermal mountains" and urban "heat islands". Urban "heat islands" have been associated with increases in thunderstorm frequency of 25% to 40%.⁽¹⁴⁾ An increase of this magnitude in thunderstorms frequency could be expected to result in a similar increase in hail frequency. On the other hand, Wolf, Hane and Drake⁽⁷⁾ have used a numerical cloud model to examine initiation and enhancement of deep convective activity of the type associated with thunderstorms. When atmospheric conditions associated with thunderstorms were modeled, NEC heat rejection resulted in small increases (~10%) in vertical motion and precipitation. However, when conditions typical of Hanford were modeled NEC heat rejection caused small perturbations in the wind field but did not cause the formation of clouds or precipitation.

Climatology indicates that severe storms are relatively infrequent in the Hanford area.⁽⁹⁾ Thunderstorms occur an average of about 11 days a year and hail occurs an average of once a year. It is concluded that the region is not susceptible to the triggering of severe storms. Further, the HNEC is relatively dispersed compared to the typical energy center. As a result, the HNEC would not be expected to be a significant factor in initiating severe storms, particularly if an environmentally optimum cooling system mix were used.

In summary, the results of the HNEC meteorological studies indicate that there are no overriding meteorological concerns that would bar further consideration of an HNEC or prevent its operation. Specifically, the following conclusions were reached:

- An HNEC may cause some weather modifications that would be statistically significant. The most likely modifications include increases in fog and cloudiness and a decrease in solar radiation. The modifications would occur primarily in the immediate vicinity of the HNEC clusters.

- The magnitudes of the anticipated modifications can be controlled by optimization of the cooling system mix in an HNEC. The use of once-through river cooling and dry cooling towers would minimize the impact of an HNEC on cloudiness and solar radiation, while the use of tall rather than low mechanical-draft cooling towers would minimize the impact on fog.
- An HNEC, as described, is not expected to initiate the formation of either convective vortices such as large dust devils or severe storms.

If a decision is made to attempt to license Hanford as a nuclear energy center, more detailed evaluation of meteorological problems associated with heat rejection at Hanford will be required. It will also be necessary to assess the ecological and socioeconomic effects of any potential weather modifications.

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RADIOLOGICAL STUDIES - J. K. Soldat

This section discusses briefly the potential radiological impact of the conceptual Hanford Nuclear Energy Center (HNEC) on the environment. Principal attention is directed to the estimated radiation doses received by man. Experience at operating nuclear facilities has shown that, barring unusual circumstances, regulation of radiation doses received by man to levels consistent with currently accepted guidelines will ensure that the doses to other biota are inconsequential.

The discussion addresses, in a generic sense, the routine release rates of radionuclides from nuclear power plants and associated fuel cycle facilities at such an HNEC. The radiation doses resulting from such releases are summarized briefly, but details of the dose calculations are not presented. Further analysis of the potential radiological impact would have to be undertaken once specific sites and plant designs are chosen. Depending upon the actual plant characteristics, the radiological impact could be different than derived here for the generic site, but in all probability the net impact would not be significantly greater because of the conservative assumptions employed.

All industrial plants handling radionuclides have radioactive waste (radwaste) systems that treat the waste streams containing radionuclides. These systems are referred to as the liquid, gas, or solid radwaste systems in accordance with the physical form of the waste streams being treated. The purpose of the radwaste systems is to minimize release of radionuclides to the environment and the consequent radiation dose to the general public.

The radwaste systems can be designed for all degrees of treatment from essentially zero up to very sophisticated systems which result in virtually no release of radionuclides to the environment. The costs for operating these systems also have a broad range from a low value for minimal treatment up to high values for sophisticated treatment.

RADIOLOGICAL STANDARDS AND GUIDES

The NRC has a general policy that the radiation dose received by the general public shall be "as low as practicable," which was defined as "as low as is practicably achievable taking into account the state of technology and the economics of improvement in relation to benefits to the public health and safety and in relation to the utilization of atomic energy in the public interest."⁽¹⁾ This has been translated into design guides in Appendix I to 10 CFR 50,⁽²⁾ which defines the term "as low as reasonably achievable" (ALARA) in relation to radiation doses that the general public might receive as a result of radionuclide releases from nuclear power plants. Such design guides have not been issued for fuel cycle facilities by the United States NRC but only for light water reactor (LWR) power plants. New terminology, "as low as reasonably achievable" (ALARA) has since been adopted by the NRC.

Recently the EPA recommended radiation protection standards for limiting the exposure of the public from uranium fuel cycle operations.⁽³⁾ These standards are summarized below.

- The annual dose equivalent to any member of the general public from effluents or radiation from uranium fuel cycle operations shall not exceed 75 mrem to the thyroid and 25 mrem to any other organ (excluding skin and cornea).
- The total quantity of radioactive material discharged to the environment per gigawatt-year of electricity generated shall contain less than 50,000 Ci of ⁸⁵Kr, 5 mCi of ¹²⁹I, and 0.5 mCi combined of ²³⁹Pu and other alpha-emitting transuranic radionuclides with half-lives greater than one year.

The effective date for these standards is December 1, 1979 for all operations except milling of uranium ore, for which the effective date is December 1980. The EPA has examined the previously promulgated NRC Guidelines for individual light-water-cooled power reactors as contained in Appendix I to 10 CFR 50.⁽²⁾ They concluded that existing reactors licensed under the Appendix I Guides by NRC would have no difficulty complying with the new EPA standards even at sites with up to 5 LWRs, or at multiple sites each with one or two LWRs provided the sites were spaced at least 10 miles apart.

RADIATION EXPOSURE PATHWAYS

Each of the several types of nuclear facilities expected to be located within an HNEC will routinely release radioactive gases, liquids, and/or solids to the environment and must meet the ALARA guidelines and the EPA standards for total impact. In a general way, the total impact of the facilities is the sum of the impacts caused by each facility. However, the individuals receiving the highest doses will not necessarily be identical for each geographically separated facility and the doses to the maximum individual will not necessarily be completely additive, especially in the instance of gaseous effluents.

The radiation dose received by the general public, as a result of radionuclide release from a plant, depends primarily on the design of the radwaste systems, the distance between the plant and the nearest members of the general public, and the pathways for radionuclide travel to the public.

The composition of the radioactive effluents affects the organs which might receive the highest radiation doses as well as the pathways of exposure. At a fuel fabrication plant where actinide elements are released to the atmosphere, inhalation is the principal pathway and the lung, bone and liver are the organs receiving the highest exposure.

At nuclear power reactors and fuel reprocessing plants where tritium and mixed fission product radionuclides are released, ingestion of milk and produce are the pathways of interest and the thyroid (particularly of infants) is the organ of interest.

Several mathematical models developed for calculating radiation doses to man and other biota from radioactive materials released to the environs have been reported in detail in the literature. Some of these models were specifically designed to treat accidental or acute releases^(4,5) although they can be applied with modifications to chronic releases.^(6,7) Other models were designed to calculate radiation doses in a large region of the United States from chronic releases.^(8,9) Applications of these models to the estimation of radiological impact of nuclear facilities for inclusion in the Environmental Reports required by the National Environmental Policy Act (NEPA) have also been discussed in the literature.^(10,11) In addition, they have been applied to the

analysis of the radiological impact of large nuclear energy centers for an NRC study.⁽¹²⁻¹⁴⁾ Application of the results from these studies to the HNEC can be made by replacing the generic environmental conditions assumed in them with the specific conditions in existence at Hanford. The following discussions of the radiological impact of the various types of nuclear facilities at an HNEC are based upon such as application.

FUEL FABRICATION FACILITIES

In an NEC fuel fabrication facilities might be required for both uranium and plutonium LWR fuels.

In the uranium plant, uranium is received as either the hexafluoride or oxide powder. It is converted to the oxide, formed into pellets, sintered, etc., and then placed in zirconium tubes. The tubes are sealed and then assembled into finished assemblies. The plant ventilation system employs adequate safeguards to prevent the release of significant amounts of particulate matter. The radiological impact of a uranium fuel fabrication plant would be much less than that of the mixed oxide (plutonium fuel fabrication plant) discussed below.

A safeguarded plutonium fabrication plant would have several additional steps in the process. Typically plutonium-bearing materials may have to be converted to an oxide, blended with uranium oxide and then formed into pellets. The pellets, after further treatment, would be placed in tubes and welded closed. Up to this point all operations have taken place in shielded glove-boxes because of the potentially highly radioactive nature of the safeguarded plutonium. The remainder of the process parallels the uranium assembly line equipment, so that both plants do not require significant controlled access or low population zones surrounding them.

The potential environmental impact of a 300-MT/yr mixed-oxide fuel fabrication (MOX) plant was addressed in document NUREG-001-ES.⁽¹⁴⁾ This size plant could provide the plutonium fuel for about 40 LWR power reactors. A safeguarded plant would probably not be significantly different. The release rates of transuranium nuclides from the postulated MOX plant given in Reference 12 are reproduced in Table 18.

TABLE 18. Estimated Release Rates of Radionuclides to the Atmosphere from a 300-MT/yr MOX Plant

Nuclide	wt%	mg/yr	Ci/mg	Ci/yr ^(a)
²³⁸ Pu	2.0	7.6×10^{-2}	1.7×10^{-2}	1.3×10^{-3}
²³⁹ Pu	45.5	1.7×10^{-0}	6.1×10^{-5}	1.0×10^{-4}
²⁴⁰ Pu	25.0	9.5×10^{-1}	2.3×10^{-4}	2.2×10^{-4}
²⁴¹ Pu	15.5	5.9×10^{-1}	9.9×10^{-2}	5.8×10^{-2}
²⁴² Pu	12.0	4.6×10^{-1}	3.9×10^{-6}	1.8×10^{-6}
²⁴¹ Am	-	$2.6 \times 10^{-2(b)}$	3.4×10^{-3}	9.0×10^{-5}
Total	100	3.8×10^0	-	5.8×10^{-2} 1.7×10^{-3}

(a) Released from roof vents.

(b) Assuming a 1-yr delay between reprocessing plant and fuel fabrication plant.

Siting such a plant on the 200 Area plateau in an HNEC increases the site boundary distance to nearly 20 miles. The maximum individual would probably be located in the direction of the prevailing wind (SE) where the annual average atmospheric dilution factor is $2.1 \times 10^{-8} \text{ sec/m}^3$.⁽¹⁵⁾ The radiation doses to the maximum individual were calculated using this dilution factor and the release rates in Table 18. The results are summarized in Table 19. Also included in Table 19 are the radiation doses to the population (290,000 persons) within 50 miles of the plant site using a population weighted average atmospheric dilution factor of $8.0 \times 10^{-9} \text{ sec/m}^3$.

The principal pathway of exposure is inhalation, with negligible contribution from external exposure or food consumption. The doses in Table 19 are certainly well below the EPA standards or any potential ALARA criteria for fuel fabrication plants. In addition, the projected release rate of less than 2 mCi of long-lived alpha emitters amounts to about 0.05 mCi/GWe-yr generated or about 10% of the EPA standard for such releases.

TABLE 19. Estimated Radiation Doses to a Maximum Individual and the Population Within 50 Miles of a 300-MT/yr MOX Plant at an HNEC Site

<u>Organ</u>	<u>First-Year Dose, mrem</u>	<u>Fifty-Year Dose Commitment, mrem</u>
Maximum Individual		
Total body	4×10^{-6}	1×10^{-3}
Bone	2×10^{-4}	4×10^{-2}
GI-LLI	6×10^{-6}	6×10^{-6}
Liver	2×10^{-5}	4×10^{-3}
Lung	8×10^{-4}	1×10^{-3}
Thyroid	5×10^{-7}	5×10^{-7}
<u>Population</u>	<u>First-Year Dose, man-rem</u>	<u>Fifty-Year Dose Commitment, man-rem</u>
Total body	4×10^{-4}	0.1
Bone	2×10^{-2}	4.3
GI-LLI	4×10^{-4}	4×10^{-4}
Liver	2×10^{-3}	0.4
Lung	8×10^{-2}	0.2
Thyroid	4×10^{-5}	4×10^{-5}

FUEL REPROCESSING PLANT

If fuel reprocessing were undertaken at an HNEC, then a plant with a 1500-MT/yr capacity would be sufficient for reprocessing the fuel discharged from about 40 operating light water reactors. The radwaste system postulated in Reference 12 assumed DFs of only 20 and 40 for ^{129}I and ^{131}I , respectively. By the time a fuel reprocessing plant (FRP) were constructed at the HNEC, DFs of 500 and 1000 for ^{129}I and ^{131}I , respectively, would be more realistic. Therefore the release rates of these two nuclides to the air from the FRP stack were assumed to be 1/25 of those given in Reference 12. The radwaste system DFs for the other nuclides were assumed to be the same. The revised list of release rates is given in Table 20.⁽¹²⁾

Siting this FRP at the 200 Area plateau of the Hanford project and utilizing a 60-m (200-ft) stack would provide an annual average atmospheric dilution factor of $4 \times 10^{-9} \text{ sec/m}^3$ at the location of the maximum individual

TABLE 20. Estimated Release Rates of Radionuclides from a 1500-MT/yr LWR Fuel Reprocessing Plant

Nuclide	Ci/yr	Nuclide	Ci/yr
^3H	1.2×10^6	^{134}Cs	6.0×10^{-1}
^{14}C	7.0×10^2	^{137}Cs	5.1×10^{-1}
^{85}Kr	1.4×10^7	^{141}Ce	1.3×10^{-1}
^{89}Sr	2.3×10^{-1}	^{144}Ce	2.2×10^0
^{90}Sr	2.0×10^{-1}	^{147}Pm	3.0×10^{-1}
^{90}Y	2.0×10^{-1}	^{154}Eu	2.3×10^{-2}
^{91}Y	3.9×10^{-1}	^{155}Eu	2.2×10^{-2}
^{95}Zr	7.2×10^{-1}	^{238}Pu	7.5×10^{-2}
^{95}Nb	1.4×10^0	^{239}Pu	3.6×10^{-3}
^{103}Ru	1.1×10^{-1}	^{240}Pu	7.5×10^{-3}
^{106}Ru	7.5×10^{-1}	^{241}Pu	$2.2 \times 10^{+0}$
$^{110\text{m}}\text{Ag}$	1.0×10^{-2}	^{242}Pu	6.0×10^{-5}
^{125}Sb	2.9×10^{-2}	^{241}Am	2.2×10^{-3}
^{127}Te	1.9×10^{-2}	^{243}Am	6.3×10^{-4}
$^{129\text{m}}\text{Te}$	6.6×10^{-3}	^{242}Cm	2.8×10^{-1}
$^{129}\text{I(a)}$	1.2×10^{-1}	^{244}Cm	1.5×10^{-1}
$^{131}\text{I(a)}$	1.4×10^0		

(a) These are 1/25 of the values given in Reference 12; see text.

(20 miles SE).⁽¹⁵⁾ The population-weighted average dilution factor for the 50-mile population (290,000 persons) would be 1.5×10^{-9} sec/m³. Combining these factors, the release rates of Table 20 and the radiation dose calculation models and parameters normally utilized for the Hanford project⁽¹⁵⁾ yield the radiation doses summarized in Table 21.

TABLE 21. Estimated Radiation Doses to a Maximum Individual and the Population Within 50 Miles of a 1500-MT/yr Fuel Reprocessing Plant at an HNEC Site

<u>Organ</u>	<u>First-Year Dose, mrem</u>	<u>Fifty-Year Dose Commitment, mrem</u>
Maximum Individual		
Total body	4.9	5.1
Bone	0.2	0.6
GI-LLI	4.9	5.1
Thyroid (adult)	5.1 ^(a)	5.3
Thyroid (infant)	13 ^(a)	-
Population	<u>First-Year Dose, man-rem</u>	<u>Fifty-Year Dose Commitment, man-rem</u>
Total body	410	430
Bone	13	32
GI-LLI	410	430
Thyroid	430	450

(a) 95% of this dose is from ^3H

The radiation doses in Table 21 are about 20% of the EPA Standards of 75 mrem/yr to the thyroid and 25 mrem/yr to any other organ. They also should be below any future ALARA guidelines that might be promulgated by the NRC for fuel reprocessing plants.

Table 22 lists the release rates of ^{85}Kr , ^{129}I and long-lived alpha emitters in units of Ci/GWe-yr generated. These values were obtained by dividing the corresponding values in Table 20 by the 40-GW equivalent represented by the FRP. Also listed in Table 22 are the EPA standards for release of these radioactive materials.⁽³⁾

It can be seen from Table 22 that release rates of ^{85}Kr and long-lived alpha emitters are each about a factor of 10 above the EPA standard. Improvement by a factor of 10-20 in the filtration efficiency of the particulate radwaste system over that employed in deriving the releases in Table 20 should be feasible. The values that were used in the NECSS-75 study for filter

TABLE 22. Comparison of Release Rates of ^{85}Kr , ^{129}I and Long-Lived Alpha Emitters from a 1500-MT/yr Fuel Reprocessing Plant with EPA Standard

<u>Radioactive Material</u>	<u>Ci/GWe-yr</u>	
	<u>Estimated Release Rate</u>	<u>EPA Standard</u>
^{85}Kr	4×10^5	5×10^4
^{129}I	3×10^{-3}	5×10^{-3}
Long-lived alpha emitters (a)	6×10^{-3}	5×10^{-4}

(a) Includes all TRU nuclides from Table 20 except ^{241}Pu and ^{242}Cm .

efficiency were conservatively low.⁽¹⁴⁾ Even if an extra bank of high-efficiency particle filters were required, they can be added at a small incremental cost.

The ^{85}Kr release rate however cannot be significantly lowered without the installation of a system for collection and storage of krypton. Such a system was proposed for the Nuclear Fuel Recovery and Recycling Center planned by Exxon Nuclear Co., Inc., for the Oak Ridge, Tennessee area.⁽¹⁶⁾ The projected overall ^{85}Kr recovery of that system was 95%, which would be sufficient for the postulated FRP.

NUCLEAR POWER REACTORS

Operation of a nuclear power reactor creates radioisotopes in the fuel elements, the fuel element cladding and end supports, the structural materials, and the coolant. Most of these radioisotopes are immobile because they are either encased in the fuel elements or are part of the permanent equipment. However, small amounts are created in or enter the coolant and travel throughout the coolant and the associated purification and waste systems. Small amounts also escape into other parts of the reactor building and eventually are transported to the radiation waste systems for appropriate treatment, storage and/or release to the environment.

Estimated release rates of radionuclides with liquid and gaseous effluents from BWR and PWR nuclear power reactors were given in reports of the NECSS-75 study.^(13,14) Guidance on the specific radionuclide content of liquid and gaseous wastes versus radwaste system complexity at LWRs can be found in WASH-1258.⁽¹⁾

Table 23 lists the estimated release rates of radionuclides with the liquid effluents from a 20-reactor HNEC. These values include the total contribution from 7 BWRs and 13 PWRs.

TABLE 23. Estimated Release Rates of Radionuclides with Liquid Effluents from a 20-Reacto HNEC^(a)

Nuclide	Ci/yr	Nuclide	Ci/yr
^3H	5.6×10^3	^{99}Mo	0.84
^{24}Na	4.7×10^{-3}	$^{99\text{m}}\text{Tc}$	0.77
^{33}P	1.8×10^{-3}	^{131}I	1.8
^{51}Cr	1.0×10^{-3}	^{132}I	3.2×10^{-2}
^{56}Mn	1.1×10^{-3}	^{133}I	0.62
^{55}Fe	4.6×10^{-2}	^{134}Cs	5.9×10^{-2}
^{59}Fe	1.4×10^{-2}	^{137}Cs	4.2×10^{-2}
^{58}Co	8.7×10^{-2}	^{140}Ba	8.4×10^{-2}
^{60}Co	1.0×10^{-2}	^{141}Ce	2.2×10^{-3}
^{89}Sr	7.0×10^{-2}	^{143}Ce	1.2×10^{-2}
^{90}Sr	4.2×10^{-3}	^{144}Ce	5.0×10^{-4}
^{90}Y	0.12	^{187}W	2.0×10^{-2}
^{91}Sr	2.5×10^{-2}	Total ^(b)	7.8
^{91}Y	3.2		

(a) Total release to the Columbia River from 7 BWRs and 13 PWRs based on the release rates given in Reference 13.

(b) Does not include ^3H .

Assuming that the entire annual release of radionuclides given in Table 23 is mixed into the average annual flow rate of the Columbia River (120,000 cfs) the radiation doses to a maximum individual and the 50-mile population^(a) were calculated. The results are summarized in Table 24.

TABLE 24. Estimated Radiation Doses to a Maximum Individual and the Population Within 50 Miles from the Liquid Effluents from 20 Operating Reactors at an HNEC

<u>Organ</u>	<u>First-Year Dose, mrem</u>	<u>Fifty-Year Dose Commitment, mrem</u>
Maximum Individual		
Total body	0.02	0.03
Bone	0.004	0.03
GI-LLI	0.02	0.02
Thyroid (adult)	0.06	0.07
Thyroid (Infant)	0.3	-
Population		
	<u>First-Year Dose, man-rem</u>	<u>Fifty-Year Dose Commitment, man-rem</u>
Total body	0.3	0.3
Bone	0.02	0.3
GI-LLI	0.3	0.3
Thyroid	1.2	1.3

Note: Values include contributions from external exposure to contaminated water and sediment and internal doses from ingestion of water, fish and irrigated farm products, conservatively assuming 30 years of accumulation of radionuclides in the environment from simultaneous operation of all 20 reactors prior to the first year of the dose period.

(a) Different numbers of persons are engaged in swimming, boating and fishing than consume water or eat irrigated produce (see Reference 15). It was conservatively estimated here that in the future as many as 20,000 persons could be ingesting irrigated farm products instead of the 2,000 persons quoted in Reference 15.

The doses in Table 24 include the conservative assumption that all 20 reactors were on line simultaneously for 30 years, during which time the released radionuclides were accumulating in river sediments and irrigated farmland, prior to initiation of the radiation exposure period.

Even though the NRC ALARA guidelines were not designed for large nuclear energy centers, the doses in Table 24 are below the guidelines for liquid effluents of 3 mrem annual dose commitment to the total body and 10 mrem annual dose commitment to any organ from each LWR. They are also well below the proposed EPA standards of 75 mrem to the thyroid and 25 mrem to other organs per gigawatt-year of electricity generated, since the 20 reactors would generate a combined total of about 25 GWe-yr per year of operation.

Table 25 summarizes the estimated releases of radionuclides with gaseous effluents from 7 BWRs and 13 PWRs at the postulated HNEC. The release rates are based on data from the NECSS-75 Nuclear Energy Study.⁽¹³⁾

The radiation doses from the releases listed in Table 25 were conservatively estimated by assuming one-half of the release occurred at the site of WPPSS reactors 1, 2 and 4, and the other one-half occurred at the site of the 100-N reactor. Appropriate meteorology for vent releases and population distributions were readily available for these two locations.^(15,17,18) It was also assumed that sufficient food was grown locally to provide for all of the 2×10^5 persons residing within 50 miles of either site. As was done for the liquid release, it was assumed that all 20 reactors had operated simultaneously for 30 years prior to the beginning of the dose period. The resulting doses are summarized in Table 26.

The principal pathway for all the doses listed in Table 26 is ingestion of foods contaminated with ^3H , ^{14}C , ^{131}I and ^{133}I . The principal contributor to total-body dose was ^3H with a small contribution from ^{14}C . As before, the doses are well below the EPA standard of 75 mrem/yr to the thyroid and 25 mrem to other organs. The thyroid dose to infant amounts to only about 0.5 mrem/GWe-yr generated. The ^{85}Kr release is about 950 Ci/GWe-yr compared to the EPA standard of 50,000 Ci/GWe-yr.

TABLE 25. Estimated Release Rates of Radionuclides with Gaseous Effluents from a 20-Reactor HNEC

<u>Nuclide</u>	<u>Ci/yr</u>
^3H	15,000
^{14}C	170
$^{83\text{m}}\text{Kr}$	90
$^{85\text{m}}\text{Kr}$	1.100
^{85}Kr	19,000
^{87}Kr	390
^{88}Kr	680
^{89}Kr	1,300
$^{131\text{m}}\text{Xe}$	1,300
$^{133\text{m}}\text{Xe}$	380
^{133}Xe	63,000
$^{135\text{m}}\text{Xe}$	440
^{135}Xe	4,000
^{137}Xe	2,200
^{138}Xe	1,800
^{131}I	1.2
^{133}I	0.82
Total ^(a)	110,000

(a) Total released from 7 BWRs and 13 PWRs with a combined capacity of 25,000 GWe

The doses listed in Table 26 do not exceed the ALARA guidelines specified for gaseous releases from each LWR at a site; viz., 5 mrem/yr to the total body and 15 mrem/yr to any organ (from radioiodine and particulates).

TABLE 26. Estimated Radiation Doses to a Maximum Individual and the Population Within 50 Miles from the Gaseous Effluents from 20 Operating Reactors at an HNEC

<u>Organ</u>	<u>First-Year Dose, mrem</u>	<u>Fifty-Year Dose Commitment, mrem</u>
Maximum Individual		
Total body	1.5	1.5
Bone	0.9	1.1
GI-LLI	1.5	1.5
Thyroid (adult)	2.7	2.8
Thyroid (infant	11	-
Population		
	<u>First-Year Dose, man-rem</u>	<u>Fifty-Year Dose Commitment, man-rem</u>
Total body	53	55
Bone	28	32
GI-LLI	53	55
Thyroid (adult)	84	87

Note: Values include contributions from external exposure to airborne and deposited radionuclides and internal dose from inhalation and ingestion of produce, meat, milk, and eggs. Conservatively assuming 30 years of accumulation of radionuclides in the environment from simultaneous operation of all 20 reactors, prior to the first year of the dose period.

WASTE MANAGEMENT FACILITIES

Waste management includes disposal of low-level solid wastes from all the nuclear fuel cycle facilities and either storage of spent reactor fuel elements or, if reprocessing and MOX fuel fabrication are undertaken, storage, solidification and ultimate disposal of high-level liquid waste. In addition, an incinerator for alpha wastes generated at the FRP and/or MOX plant would be required if these facilities were operated.

Low-level wastes from DOE facilities have been buried at the Hanford site for three decades and commercial low-level wastes for one decade. No indication of any offsite radiation exposure to man has been found from either of

these operations, and none is expected in the future from any waste burial operations associated with the HNEC.

Also, an alpha waste incinerator has been operated on the Hanford site with no offsite radiological impact. Based on this experience, the annual quantity of actinides potentially released from incineration of the wastes from a 300-MT/yr MOX plant and from a 1500-MT/yr FRP would be about 0.053 mg/yr and 0.023 mg/yr, respectively.⁽¹²⁾ Thus a total of 0.076 mg/yr of radioactive material is expected to be released. This is 2% of the release rate estimated for the MOX plant (Table 18). The composition of this material can be assumed to be similar to that given in Table 18, since most of the wastes would come from the MOX plant. Therefore, the offsite radiation doses from operation of an alpha waste incinerator would be about 2% of the doses from the MOX plant given in Table 19. The resultant doses are vanishingly small by any standard.

Waste management facilities were discussed in ORNL-4451⁽¹⁹⁾ and it was concluded that with proper design and siting any environmental radiological impact of such facilities would be minimal. Interim storage of high-level liquid wastes does not normally result in release of radioactive materials to the surface waters. Acceptably small releases of radionuclides to the atmosphere will occur routinely, and accidental leaks could release liquid material to the ground. For these reasons, careful design and judicious siting of high-level liquid waste storage facilities must be accomplished. Siting of these facilities within a nuclear center where the distance to the nearest population is relatively large would normally result in extremely low radiation doses to the offsite population.

Solidification of liquid wastes from the postulated HNEC reprocessing plant after a brief (3 to 5 yr) storage period would normally be done at the site of the FRP for economic and safety reasons. Properly encapsulated solidified wastes could be stored at an interim retrievable storage facility if necessary prior to shipment to an ultimate disposal site. It is also possible that the ultimate storage site might be on the Hanford reservation, eliminating the need for offsite shipment.

Neither the storage nor the solidification itself should impose an unacceptable environmental impact. According to the data provided

in Reference 12, the release rates of radionuclides during the HLW solidification process are, with few exceptions, less than 1% of the release rates expected during reprocessing of spent fuel. The exceptions include ^3H , ^{14}C , and ^{85}Kr for which the release rates during solidification are essentially zero. Hence, the radiation doses to the maximum individual and the population offsite resulting from solidification would be a small fraction of those previously calculated for the releases from the FRP. This is especially true since all ^3H , which is one of the principal contributors to offsite doses from the FRP, was assumed to be released during reprocessing operations.

The radiological impact of the ultimate disposal of either encapsulated HLW or spent fuel elements is the subject of a generic environmental impact statement being prepared by PNL for DOE. This statement is now nearing completion. The decision on exactly where and how solidified HLW or spent fuel would be disposed has not yet been made. But it appears that barring improbable accidents or a major natural catastrophe, no significant radiation doses from waste management operations or long-term storage of these radioactive materials is foreseen. Therefore, it is not expected that any of the waste management activities would lead to offsite radiation doses, which would be significant compared to either the existing NRC guide or the EPA standards.

OVERALL RADIOLOGICAL IMPACT ON MAN

Primary radiological safety advantages of siting all of the fuel cycle facilities at a nuclear power center include elimination of transportation over public highways of highly radioactive materials between the several process stages, and the increased distance between the facilities and the site boundary.

The disadvantages include the larger quantities of radionuclides discharged to air and water at one site compared to isolated facilities. There does not seem to be any insurmountable problems with the combined releases of 95,000 Ci of noble gases, 15,000 Ci of tritium, 200 Ci of ^{14}C , and 2 Ci of radioiodine to the atmosphere from 20 reactors, since the facilities would be well separated from each other and from the general public. Neither does the discharge of some 6,000 Ci/yr of tritium and less than 10 Ci/yr of other fission and activation products to one body of water from 20 operating reactors

seem to present any environmental impact problems. The estimated total radiation doses and release rates were all below those specified in the NRC guidelines for LWRs, and in the EPA fuel cycle standards.

Radiation doses from the postulated 1500-MT/yr fuels reprocessing plant are also well below the NRC and EPA standards. However, the release rates of ^{85}Kr and long-lived alpha emitting radionuclides from the FRP are about an order of magnitude higher than the EPA standards for these two sources. State-of-the-art radioactive waste systems can be installed to lower these releases to acceptable values.

The contribution to the total offsite doses from a 300-MT/yr MOX plant, an alpha waste incinerator and other waste management facilities which might be sited at the HNEC are negligible compared to those from the reactors and the FRP.

The estimated total combined radiation doses to the maximum individual and the population within 50 miles of all postulated HNEC facilities are summarized in Table 27. In view of the small offsite radiation doses listed in the table, it is apparent that no significant doses to construction workers or operating personnel should be present from routine releases of radionuclides from an HNEC. This is especially true since the majority of the offsite doses arise from locally grown foods, rather than external exposure or inhalation.

In summary, it appears that there are no insurmountable environmental impacts expected from the siting of 25 GWe of operating LWRs along the Columbia River plus associated fuel cycle facilities sited near the 200 Area's plateau within the Hanford Project. Continued monitoring of the environment and the radiation exposure pathways as the power reactors and fuel cycle facilities are added would test this conclusion and provide data to modify the dose estimates prior to completion of each new construction phase.

TABLE 27. Estimated Total Radiation Doses and Dose Commitments to a Maximum Individual and the Population Within 50 Miles from Operation of an HNEC

Organ	MOX ^(a)	FRP ^(b)	Reactors ^(c)	Total ^(d)	MOX	FRP	Reactors	Total
Maximum Individual	First-Year Dose, mrem				Fifty-Year Dose Commitment, mrem			
Total body	4×10^{-6}	4.9	1.5	6.4	1×10^{-3}	5.1	1.5	6.6
Bone	2×10^{-4}	0.2	0.9	1.1	4×10^{-2}	0.6	1.1	1.7
GI-LLI	6×10^{-6}	4.9	1.5	6.4	6×10^{-6}	5.1	1.5	6.6
Lung	8×10^{-4}	4.9	1.5	6.4	1×10^{-3}	5.1	1.5	6.6
Thyroid (adult)	5×10^{-7}	5.1	2.7	7.8	5×10^{-7}	5.3	2.8	8.1
Thyroid (Infant)	-	13	11	24	-	-	-	-
Population	First-Year Dose, man-rem				Fifty-Year Dose Commitment, man-rem			
Total body	4×10^{-4}	410	53	460	0.1	430	55	490
Bone	2×10^{-2}	13	28	41	4.3	32	32	68
GI-LLI	4×10^{-4}	410	53	460	4×10^{-4}	430	55	490
Lung	8×10^{-2}	410	53	460	0.2	430	55	490
Thyroid	4×10^{-5}	430	85	520	4×10^{-5}	450	88	540

(a) A 300-MT/yr MOX fuel fabrication plant.

(b) A 1500-MT/yr fuel reprocessing plant.

(c) Seven BWRs and 13 PWRs with total capacity of 25 GWe.

(d) Doses from other waste management facilities not listed are negligible.

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SOCIOECONOMIC STUDIES - K. E. Yandon

Socioeconomic implications inherent in the development of nuclear energy centers are many and complicated. Generally, the literature indicates that most adverse socioeconomic impacts are functions of the temporary in-migration of workers and their families into a project area and their subsequent emigration.^(1,2)

The impacts are reflected in the communities near the project area in two ways. First, the infrastructure of the community--its services and facilities--is overstressed during the period of immigration and peak employment and then is underused, as the temporary population moves out, leaving a tax burden on those remaining. Second, changes in lifestyle and quality of environment occur. These are typically reflected in traffic and recreational facility congestion and in crowding of schools and other public and private facilities. Economic perturbations also occur, such as increased labor costs for the area's permanent employers.

Favorable economic impacts associated with an NEC include the additional jobs and wage dollars, the commercial expenditures and resulting sales taxes these wages represent, and miscellaneous taxes and property taxes attributable to construction and supporting workers moving into the project area. In addition to the economic benefits attributable to workers, substantial state revenues are generated in the form of taxes on purchases of materials going into the construction project.

Both the adverse and favorable factors have been well studied.⁽¹⁻⁶⁾ In general, adverse socioeconomic impacts tend to be greater in rural and isolated areas than in more populated areas with reasonably large labor forces. They tend to be less if the area's permanent employment is increasing at a rapid enough rate to absorb infrastructure expansions required by the temporary demands of the construction work force.

The approach in evaluating the socioeconomic effects of an HNEC at Hanford has been to compare the temporary work force for an HNEC with that required for the WPPSS nuclear plants at Hanford, and then estimate the impacts based on what is occurring in the Hanford area now. Two HNEC cases are examined--a

20-reactor HNEC following the assumption of one reactor per year after 1989 and a 40-reactor HNEC following the schedule set forth in an earlier publication that has been included in the Appendix.⁽⁷⁾ Variations in in-migration rates, employment multipliers, and family sizes, coupled with uncertainties in construction schedules for the nuclear power plants and associated fuel cycle facilities, make a rigorous evaluation of socioeconomic impacts impractical.

ASSUMPTIONS FOR HNEC ANALYSES

For these analyses, a six-year period was assumed for the construction of a single nuclear power plant; manpower peaks at about 2000 workers for a period of one year (Table 28).

TABLE 28. Craft and Manual Workers for Nuclear Plant Construction

<u>Year</u>	<u>Number of Workers</u>
0.0-0.5	50
0.5-1.0	400
1.0-1.5	690
1.5-2.0	1000
2.0-2.5	1250
2.5-3.0	1600
3.0-3.5	1850
3.5-4.0	2000
4.0-4.5	1700
4.5-5.0	1100
5.0-5.5	350
5.5-6.0	100

Source: WPPSS manpower estimates for WNP-3.

Typically, about 20%-25% of the new construction workers would be single persons. The remaining 75% of the migrating workers would have 2+ family members per job holder. The problem of estimating immigration is compounded by uncertainties in estimating numbers of supporting workers plus trade service

jobs required to accommodate the direct construction workers. Past Pacific Northwest Laboratory studies as well as ongoing Hanford experience tend to indicate that each in-migrating NEC worker (both construction- and operations-related) would cause a population increase of 3.0 to 3.3. Each temporary employee leads to an increase in employment in the community (in home building, nuclear plant construction support services, service industries, etc.). Each permanent employee has a similar effect, but the multiplier is larger.

Tables 29 and 30 estimate the number of direct construction workers (craft and manual), engineers, and administrators required for a 40-reactor and 20-reactor HNEC, respectively. These tables detail the changes in worker force composition and job activity over time. With this information both the non-HNEC indirect construction and non-HNEC services-related employment generated by temporary workers is then estimated and the four categories which comprise the construction-related workers subtotaled. A similar approach is used for operations-related workers, except only two classifications--operation and maintenance and non-HNEC services-related--make up that subtotal. The total construction- and operations-related employment constitutes the total HNEC employment. Manpower totals do not include those for the fuel cycle facilities that might be constructed at an HNEC. The effect of adding them into construction totals for the reactor plant would be minor.⁽⁸⁾

Table 29 shows that for a 40-reactor HNEC the number of number of reactors under construction at one time peaks at 12 in the 23rd year and holds at that number for about eight years. All 40 reactors will be on line after the 37th year. A total work force of 22,000 will be reached in 23 years, varies between 22,000-26,000 for eight more years, and declines the next seven. For 34 of the 37 years of construction activity, craft and manual employment are the dominant source of employment with operational-related employment the next largest source. The former totals about 11,000 at its maximum. Changes in total employment beyond the 30th year are dominated by construction-related job losses. The impact will be somewhat cushioned by the increasing operations-related employment. Nevertheless, about 15,000 jobs are lost to the area over a period of about seven years.

TABLE 29. Estimated Manpower Levels for a 40-Reactor HNEC

Year	Reactor Status		Construction-Related Employment					Operations-Related Employment			Total Employment
	Under Construction	In Operation	Craft and Manual	Engineers and Administrators	Non-HNEC Indirect Construction (a)	Non-HNEC Services-Related (b)	Total	Operations and Maintenance	Non-HNEC Services-Related	Total	
1973	1	0	49	50	10	0	109	0	0	0	109
1973	1	0	303	50	35	0	388	0	0	0	388
1974	1	0	542	100	64	-	706	0	0	0	706
1974	1	0	721	100	32	0	903	0	0	0	903
1975	1	0	1,108	150	126	5	1,389	0	0	0	1,389
1975	1	0	1,389	150	154	23	1,716	0	0	0	1,716
1976	2	0	1,530	200	173	49	1,952	0	0	0	1,952
1976	2	0	1,806	200	201	772	2,279	0	0	0	2,279
1977	2	0	2,071	200	227	125	2,623	0	0	0	2,623
1977	2	0	1,847	200	205	169	2,421	0	0	0	2,421
1978	3	0	1,629	250	188	209	2,276	0	0	0	2,276
1978	3	0	1,946	250	210	265	2,574	0	0	0	2,574
1979	2	1	2,023	250	227	325	2,825	140	0	240	2,965
1979	2	1	2,224	250	247	315	3,036	140	0	140	3,176
1980	2	1	2,637	250	289	310	3,426	140	140	280	3,690
1980	2	1	2,515	250	276	369	3,410	140	140	280	3,690
1981	3	1	2,002	250	225	425	2,902	140	140	280	3,182
1981	3	1	1,963	250	221	490	2,924	140	140	280	3,204
1982	3	2	2,120	250	237	603	3,210	250	140	290	3,600
1982	3	2	2,150	250	240	608	3,248	250	140	390	3,638
1983	4	2	2,171	350	252	520	3,293	250	250	500	3,793
1983	4	2	2,570	350	292	535	3,747	250	250	500	4,247
1984	5	3	3,229	500	373	600	4,702	390	250	640	5,342
1984	5	3	4,219	500	472	634	5,825	390	250	640	6,465
1985	6	3	5,251	650	590	693	7,184	390	390	780	7,964
1985	6	3	5,763	650	641	835	7,889	390	390	780	8,669
1986	7	3	6,289	750	704	1,108	8,951	390	390	780	9,631
1986	7	3	6,588	750	734	1,453	9,525	390	390	780	10,305
1987	7	4	6,662	750	741	1,882	10,035	500	390	890	10,925
1987	7	4	6,702	750	745	2,116	10,313	500	390	890	11,203
1988	8	5	6,759	750	751	2,400	10,660	640	500	1,140	11,800
1988	8	5	6,628	750	738	2,583	10,699	640	500	1,140	11,839
1989	8	6	6,195	750	694	2,690	10,329	750	640	1,390	11,719
1989	8	6	6,077	750	683	2,787	10,297	750	640	1,390	11,719
1990	8	8	6,338	800	714	2,891	10,743	1,000	750	1,750	12,493
1990	8	8	6,891	800	769	2,922	11,382	1,000	750	1,750	13,132
1991	9	9	7,253	900	815	2,826	11,794	1,140	1,000	2,140	13,934
1991	9	9	7,726	900	863	2,854	12,343	1,140	1,000	2,140	14,483
1992	10	10	8,409	1,000	941	3,062	13,412	1,250	1,140	2,390	15,802
1992	10	10	8,738	1,000	974	3,384	14,096	1,250	1,140	2,390	16,486

(a) Workers supplying construction services to the HNEC but not employed by HNEC contractors.
(b) Employment induced by and/or generated by providing services and products to HNEC-related workers.

TABLE 29. (continued)

Year	Reactor Status		Construction-Related Employment					Operations-Related Employment			Total Employment
	Under Construction	In Operation	Craft and Manual	Engineers and Administrators	Non-HNEC Indirect Construction (a)	Non-HNEC Services-Related (b)	Total	Operations and Maintenance	Non-HNEC Services-Related	Total	
1993	11	11	8,833	1,100	993	3,677	14,603	1,390	1,250	2,640	17,243
1993	11	11	9,272	1,100	1,037	3,985	15,394	1,390	1,250	2,640	18,034
1994	11	13	9,890	1,150	1,104	4,450	16,594	1,640	1,390	3,030	19,624
1994	11	13	10,241	1,150	1,139	4,713	17,243	1,640	1,390	3,030	20,273
1995	12	14	10,362	1,200	1,156	4,917	17,634	1,750	1,640	3,390	21,025
1995	12	14	10,398	1,200	1,160	5,248	18,006	1,750	1,640	3,390	21,396
1996	12	16	10,362	1,200	1,156	5,708	18,426	2,000	1,750	3,750	22,176
1996	12	16	10,398	1,200	1,160	6,014	18,772	2,000	1,750	3,750	22,522
1997	12	18	10,362	1,200	1,156	6,232	18,950	2,250	2,000	4,250	23,200
1997	12	18	10,398	1,200	1,160	6,379	19,137	2,250	2,000	4,250	23,387
1998	12	20	10,362	1,200	1,156	6,359	19,077	2,500	2,250	4,750	23,827
1998	12	20	10,398	1,200	1,160	6,379	19,137	2,500	2,250	4,750	23,887
1999	12	22	10,362	1,200	1,156	6,359	19,077	2,750	2,500	5,250	24,327
1999	12	22	10,398	1,200	1,160	6,379	19,137	2,750	2,500	5,250	24,387
2000	12	24	10,367	1,200	1,156	6,359	19,077	3,000	2,750	5,750	24,827
2000	12	24	10,398	1,200	1,160	6,379	19,137	3,000	2,750	5,750	24,887
2001	12	26	10,362	1,200	1,156	6,359	19,077	3,250	3,000	6,250	25,327
2001	12	26	10,398	1,200	1,160	6,379	19,137	3,250	3,000	6,250	25,387
2002	12	28	10,362	1,200	1,156	6,359	19,077	3,500	3,250	6,750	25,827
2002	12	28	10,398	1,200	1,160	6,379	19,137	3,500	3,250	6,750	25,387
2003	10	30	10,264	1,100	1,136	6,359	18,859	3,750	3,500	7,250	26,109
2003	10	30	9,792	1,100	1,089	6,379	18,360	3,750	3,500	7,250	25,610
2004	8	32	9,180	900	1,008	6,359	17,447	4,000	3,750	7,750	25,197
2004	8	32	8,350	900	925	6,379	16,554	4,000	3,750	7,750	24,304
2005	6	34	6,964	600	756	6,250	14,570	4,250	4,000	8,250	22,820
2005	6	34	5,572	600	617	5,991	12,780	4,250	4,000	8,250	21,030
2006	4	36	4,002	300	430	5,544	10,276	4,500	4,250	8,750	19,026
2006	4	36	2,566	300	287	5,088	8,241	4,500	4,250	8,750	16,991
2007	2	38	944	100	104	4,160	5,308	4,750	4,500	9,250	14,558
2007	2	38	314	100	41	3,395	3,850	4,750	4,500	9,250	13,100
2008	0	40	0	0	0	2,366	2,366	5,000	4,750	9,750	12,116
2008	0	40	0	0	0	1,577	1,577	5,000	4,750	9,750	11,327
2009	0	40	0	0	0	574	574	5,000	5,000	10,000	10,574
2009	0	40	0	0	0	228	228	5,000	5,000	10,000	10,228

(a) Workers supplying construction services to the HNEC but not employed by HNEC contractors.

(b) Employment induced by and/or generated by providing services and products to HNEC-related workers.

TABLE 30. Estimated Employment Effects from a 20-Reactor HNEC

Year	Reactor Status		Construction-Related Employment					Operations-Related Employment			Total Employment
	Under Construction	In Operation	Craft and Manual	Engineers and Administrators	Non-HNEC Indirect Construction (a)	Non-HNEC Services-Related (b)	Total	Operations and Maintenance	Non-HNEC Services-Related	Total	
1973	1	0	50	50	10	0	110	0	0	0	110
1973	1	0	400	50	45	0	495	0	0	0	495
1974	1	0	690	100	79	0	869	0	0	0	869
1974	1	0	1,000	100	110	0	1,210	0	0	0	1,210
1975	1	0	1,250	150	140	5	1,545	0	0	0	1,545
1975	1	0	1,600	150	175	30	1,955	0	0	0	1,955
1976	2	0	1,900	200	210	61	2,371	0	0	0	2,371
1976	2	0	2,400	200	260	97	2,957	0	0	0	2,957
1977	2	0	2,390	200	259	139	2,988	0	0	0	2,988
1977	2	0	2,100	200	230	192	2,722	0	0	0	2,722
1978	3	0	1,650	250	190	254	2,344	0	0	0	2,344
1978	3	0	2,100	250	235	343	2,928	0	0	0	2,928
1979	2	1	2,540	250	279	370	3,439	140	0	140	3,579
1979	2	1	3,000	250	325	354	3,929	140	0	140	4,069
1980	2	1	2,950	250	320	313	3,833	140	140	280	4,113
1980	2	1	2,700	250	295	414	3,659	140	140	280	3,939
1981	2	1	2,200	200	240	522	3,162	140	140	280	3,442
1981	2	1	2,100	200	230	643	3,173	140	140	280	3,453
1982	2	2	1,750	150	190	669	2,759	250	140	390	3,149
1982	2	2	1,500	150	165	649	2,464	250	140	390	2,854
1983	3	2	1,090	200	129	554	1,973	250	250	500	2,473
1983	3	2	1,500	200	170	557	2,427	250	250	500	2,927
1984	3	3	1,990	300	229	481	3,000	390	250	640	3,640
1984	3	3	3,000	300	330	436	4,066	390	250	640	4,706
1985	4	3	3,840	450	429	355	5,074	390	390	780	5,854
1985	4	3	5,000	450	545	486	6,481	390	390	780	7,261
1986	5	3	5,540	550	609	680	7,379	390	390	780	8,159
1986	5	3	6,100	550	665	1,016	8,331	390	390	780	9,111
1987	6	3	5,890	600	649	1,369	8,508	390	390	780	9,288
1987	6	3	6,200	600	680	1,798	9,278	390	390	780	10,508
1988	6	4	5,890	600	649	2,077	9,216	500	390	890	10,106
1988	6	4	6,200	600	680	2,341	9,821	500	390	890	10,711
1989	6	5	5,890	600	649	2,356	9,495	640	500	1,140	10,635
1989	6	5	6,200	600	680	2,543	10,023	640	500	1,140	11,163
1990	6	6	5,890	600	649	2,499	9,638	750	640	1,390	11,028
1990	6	6	6,200	600	680	2,693	10,173	750	640	1,390	11,563
1991	6	7	5,890	600	649	2,641	9,780	890	750	1,640	11,420
1991	6	7	6,200	600	680	2,842	10,322	890	750	1,640	11,962
1992	6	8	5,890	600	649	2,784	9,923	1,000	890	1,890	11,813
1992	6	8	6,200	600	680	2,992	10,472	1,000	890	1,890	12,362

(a) Workers supplying construction services to the HNEC but not employed by HNEC contractors.

(b) Employment induced by and/or generated by providing services and products to HNEC-related workers.

TABLE 30. (continued)

Year	Reactor Status		Construction-Related Employment					Operations-Related Employment			Total Employment
	Under Construction	In Operation	Craft and Manual	Engineers and Administrators	Non-HNEC Indirect Construction (a)	Non-HNEC Services-Related (b)	Total	Operations and Maintenance	Non-HNEC Services-Related	Total	
1993	6	9	5,890	600	649	2,927	10,066	1,140	1,000	2,140	12,206
1993	6	9	4,200	600	680	3,142	10,622	1,140	1,000	2,140	12,762
1994	6	10	5,890	600	649	3,070	10,209	1,250	1,140	2,390	12,599
1994	6	10	6,200	600	480	3,291	10,771	1,250	1,140	2,390	13,161
1995	6	11	5,890	600	649	3,213	10,352	1,390	1,250	2,640	12,992
1995	6	11	6,200	600	680	3,441	10,921	1,390	1,250	2,640	13,561
1996	6	12	5,890	600	649	3,355	10,494	1,500	1,390	2,890	13,384
1996	6	12	6,200	600	680	3,590	11,070	1,500	1,390	2,890	13,960
1997	6	13	5,890	600	649	3,498	10,637	1,640	1,500	3,140	13,777
1997	6	13	6,200	600	680	3,740	11,220	1,640	1,500	3,140	14,360
1998	6	14	5,890	600	649	3,570	10,709	1,750	1,640	3,390	14,099
1998	6	14	6,200	600	680	3,740	11,220	1,750	1,640	3,390	14,610
1999	5	15	5,840	550	639	3,570	10,599	1,890	1,750	3,640	14,239
1999	5	15	5,800	550	635	3,740	10,725	1,890	1,750	3,640	14,365
2000	4	16	5,150	450	560	3,570	9,730	2,000	1,890	3,890	13,620
2000	4	16	4,800	450	525	3,740	9,515	2,000	1,890	3,890	13,405
2001	3	17	3,900	300	420	3,515	8,135	2,140	2,000	4,140	12,275
2001	3	17	3,200	300	350	3,493	7,343	2,140	2,000	4,140	11,483
2002	2	18	2,050	150	220	3,080	5,500	2,250	2,140	4,390	9,890
2002	2	18	1,200	150	135	2,888	4,373	2,250	2,140	4,390	8,763
2003	1	19	350	50	40	2,310	2,750	2,390	2,250	4,640	7,390
2003	1	19	100	50	15	1,925	2,090	2,390	2,250	4,640	6,730
2004	0	20	0	0	0	1,210	1,210	2,500	2,390	4,890	6,100
2004	0	20	0	0	0	743	743	2,500	2,390	4,890	5,633
2005	0	20	0	0	0	220	220	2,500	2,500	5,000	5,220
2005	0	20	0	0	0	83	83	2,500	2,500	5,000	5,083
2005	0	20	0	0	0	0	0	2,500	2,500	5,000	5,000
2006	0	20	0	0	0	0	0	2,500	2,500	5,000	5,000

(a) Workers supplying construction services to the HNEC but not employed by HNEC contractors.

(b) Employment induced by and/or generated by providing services and products to HNEC-related workers.

In the case of a 20-reactor HNEC (Table 29), the number of reactors under construction at one time peaks at six in the 12th year through the 24th year. A total work force (including those jobs induced by the HNEC construction and operating jobs) totals about 14,000. The maximum craft and manual employment at a 20-reactor HNEC is about 6,200. About 10,000 jobs are lost to the area over a period of six or seven years as the full complement of nuclear plants is achieved.

Currently, WPPSS has three reactors under construction at the Hanford site. WNP-2 is scheduled for commercial operation in 1980, with WNP-1 and -4 in 1982 and 1984, respectively. Currently the three projects have generated about 6,000 construction-related jobs. The operations- and maintenance-related jobs are not included in this total, nor are those generated indirectly by the construction work force. The 20- and 40-reactor HNEC cases include the (computed) estimates of work force for WNP-1, 2, and 4. These computed estimates may differ from the actual requirements because of changes in construction schedules and manpower needs.

Ongoing WPPSS monitoring studies⁽⁹⁻¹¹⁾ indicate that the Hanford area has a relatively large and expandable reservoir of craft and manual workers with many employed elsewhere but returning to the Hanford area as additional WPPSS-related jobs become available. Monitoring studies indicate that WNP-1 and 4 have generated a population growth of only 1250 while craft and manual employment was nearing 2000. These studies suggest that since construction began, population growth attributable to WNP-1 and 4 accounted for 25 percent of the area's population growth and represented about 1 percent of the current total population.

Comparable data for WNP-2 are not now available but the 3100 craft and manual and engineering and administrative workers currently being reported for the project probably resulted in a population multiplier no higher than 0.64 (that for WNP-1 and 4). Most of those jobs came when the area's labor force was more elastic and expandable. If that multiplier is reasonable it can be anticipated that WNP-2 has generated an in-migrating population of about 2000.

Comparison of Socioeconomic Effects

The study of socioeconomic effects on the Hanford area resulting from construction of WPPSS's three reactors has not been completed by WPPSS. It is known that the effects being experienced in the Hanford area are a result of a number of factors including the other construction work, expansion of agricultural activities and industries, and lesser business developments. Overall, the infrastructure in the Hanford area has either accommodated the influx of workers, or plans are in place to do so. Quality-of-life issues are no longer as prominent as they were two years ago. Housing is available, though perhaps not in the price ranges required by lower-income families. The Hanford area appears to be achieving a temporary equilibrium.

It appears that the keys to minimizing socioeconomic effects of an NEC are 1) the availability of manpower for craft and manual construction jobs, and 2) a significantly growing community economy. The former reduces the influx of temporary workers, and the latter tends to reduce the effect of the loss of construction jobs.

With maximum utilization of locally available workers because of ongoing activities, the additional manpower requirements of an HNEC will have to be provided by in-migrants. In both cases the number of in-migrating workers will be the difference between WPPSS ongoing levels and the peaks shown in Tables 21 and 22. For the 20-reactor case about 700 more craft and manual workers will have to move into the area to meet HNEC requirements. For the 40-reactor case about 5500 more will be needed. Training and apprenticeship programs may lessen in-migration somewhat.

Additional population associated with the in-migrating workers will be represented by application of the 3.3 multiplier to the worker counts.

The continuing growth of the Hanford area economy will tend to cushion the socioeconomic effects suggested by the additional HNEC worker needs. Employment levels have been rising steadily for a decade. Official estimates of the Washington State Department of Employment Security show the following for the Hanford area (primarily Benton and Franklin Counties).

<u>Year</u>	<u>Labor Force</u>	<u>Yearly Percent Change</u>
1970	40,260	-
1971	41,240	2.4
1972	41,390	0.4
1973	42,180	1.9
1974	42,300	0.3
1975	45,500	7.6
1976	48,580	6.8
1977	53,440	10.0
June 1978	58,100	

Projected average annual growth rates based on Employment Security Department data and other official forecasts are shown below:

	<u>Percent</u>
1. Employment Security Dept. (8 year 1970-1977 average for Benton and Franklin Counties)	5.0
2. Employment Security Dept. [4 year 1970-1974 ^(a) average for Benton and Franklin Counties]	1.24
3. BPA 25-year 1970-1995 average for Washington State	2.2 ⁽¹²⁾
4. Washington State Dept. of Commerce 1972-1995 average, Benton and Franklin Counties	2.9 ⁽¹³⁾
5. Washington State Dept. of Commerce 1972-1990 average, Benton and Franklin Counties	2.5 ⁽¹³⁾

Applying these varying growth rates to the area's 1978 labor force without the WPPSS projects produces the following forecast of area employment:

(a) Prior to major construction on WNP-2.

	Average Annual Growth Rate, %	Forecast of Area Work Force Without HNEC	New Jobs New Jobs Created Annually
1.	1.24	69,240	750-900
2.	2.2	87,660	1,750-2,000
3.	2.5	94,050	2,400-2,800
4.	2.9	103,270	3,000-3,500
5.	5.0	167,700	8,000-9,000

Continued growth at any of the above percentages would essentially eliminate the perturbation caused by either a 20- or 40-reactor HNEC. It can be concluded that significant socioeconomic effects from an HNEC are unlikely, and certainly no greater than those experienced by the Hanford area over the past several years. If the 2.2 percent average annual growth rate is achieved (and this seems likely based on ongoing studies) the area's baseline economy will, on balance, be generating more new jobs annually than being lost by the HNEC project construction decline.

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LICENSING AND ACCIDENT STUDIES - R. G. Clark

The purpose of licensing studies for this report was to identify siting or other concerns that may affect the licensing of a nuclear energy center at Hanford. An examination of the criteria in Chapter 10 of the Code of Federal Regulation (10 CFR), the Regulatory Guides of the Nuclear Regulatory Commission (NRC), the Standard Work Plan Reviews, some specific standards and public correspondence of the Advisory Committee for Reactor Safety (ACRS), current proposed legislation, and reviews of several generic studies of nuclear energy centers⁽¹⁾ did not reveal any areas where the concept of a nuclear energy center at Hanford would be limited by technical concerns. There are, however, no rules, regulations, or formal official guidance specifically addressing nuclear energy centers.

The current status of regulations on nuclear energy centers is perhaps best summarized by a part of a recent revision to Regulatory Guide 4.11, dated August 1977. The introduction to this guide states that the guide is "intended to reflect current practice, i.e., the siting of up to several power plants at a single site" and that "prior consultation with the staff is recommended if larger-scale 'energy centers' are contemplated." Groups in the regulatory body, the Nuclear Regulatory Commission, apparently are not now considering the preparation of codes and guides directed to larger-scale energy centers.^(a) Such regulations and guidance will apparently be developed and promulgated following informal and preliminary petitions to the regulatory bodies requesting an energy center.

Codes and guides have increasingly noted siting several power plants at a single site. However, the approval of the NRC and others, such as state agencies, has not been sought for more than four units at one site. The regulations and guides do not specifically limit the number of units at a site to

(a) The Tyronne Energy Park in Dunn County, Wisconsin, that was recently issued a construction permit by NRC is not to be identified as an energy center. The park connotation results from the aesthetic features planned for this site, which is to contain one or perhaps eventually two power units.

four. Presumably, if all of the existing regulations and guides were satisfied more than four units might be acceptable.

Some preliminary plans have called for siting five units in two rather widely separated groups.^(a) These plans may be of interest in terms of a nuclear energy center at Hanford because of the distances at Hanford that are available to separate the sites. Regulations and guides that direct current practice in siting several units at one location may be adequate to address most if not all of the siting considerations for an HNEC with twenty units distributed among five sites, each of which would contain three to five power generating reactors.

The technical studies completed in support of such an HNEC concept have analyzed many of the key licensing issues that would normally be associated with the siting of several thermal nuclear power plants at one location. To contribute to these, PNL has analyzed how a class nine accident at one unit would affect the other power reactors at an HNEC. This analysis provided perspective concerning other similarly improbable events. Partly because of the distances between sites at Hanford, a class nine accident at an HNEC and its ensuing consequences onsite can be assessed to be less probable than ashfalls from volcanic activity in the Cascades and significantly less probable than earthquakes for which designs and procedures have been developed. Consequences here are defined as loss of electrical power generation.

A recent review examined the expansion potential for existing nuclear power station sites.⁽²⁾ The interesting concept of mini-NECs was developed in this analysis. It resulted from reviews of existing sites containing one or more thermal nuclear power plants and possessing some if not all of the essential features required to meet siting criteria for additional units. Thus, the potential for developing essentially a small NEC might exist utilizing the criteria in existing codes and guides. Hanford was rated as having the potential to expand from the existing three sites to a large nuclear energy center.

(a) Duke Power Company, Perkins and Catawba sites in South Carolina.

This back-door approach to an energy center was not defended in another recent review largely because it lacked the long-range planning that was deemed essential.⁽³⁾ The observation was also made, however, that presently organized utilities, institutions, and political entities are not capable of handling and evaluating the long-term planning and firm commitments of resources required for large (20-unit) NECs.

Whatever other reservations there may be concerning a 20-unit NEC at Hanford, siting criteria do not at this time appear to include limiting restraints.

REVIEW OF THE FEDERAL CODES

No regulations in the Federal code currently address nuclear energy centers per se. Limitations on annual dose equivalents from exposure to radiation and on quantities of radioactive material released from the entire fuel cycle have been imposed by the Environmental Protection Agency.⁽⁴⁾ These latter restrictions as they may affect an HNEC have been addressed earlier in this report.^(a) Regulations that bear on siting and safety where several thermal nuclear power plants may be located on one site are reviewed elsewhere.⁽⁵⁾ None appear to be limiting to the concept of an HNEC, but of course none specifically pertain to nuclear energy centers.

REVIEW OF THE REGULATORY GUIDES

By definition, regulatory guides "are issued to describe ... methods acceptable to the NRC staff implementing ... regulations ... to provide guidance to applicants."^(b) The guides are not substitutes for regulations (as contained in the Federal Codes for example) and compliance with them is not required. However, they are generally closely followed. More recent guides provide input relating to multiunit sites. None of the guides issued so far would appear to prohibit an HNEC. The results of this analysis are tabulated

(a) See "Radiological Studies."

(b) Introductory footnote, USNRC Regulatory Guides.

elsewhere.⁽⁵⁾ Two other documents reviewed for licensing criteria were the Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants, NUREG-75/087, and Draft Environmental Standard Review Plans for the Environmental Review of Construction Permit Applications for Nuclear Power Plants, NUREG-0158 Parts 1, 2 and 3. Both were prepared as internal working documents for the NRC staff for the purpose of improving the quality and uniformity of the reviews undertaken by NRC. They refer to the appropriate codes and guides where services are shared among units or where more than one unit may be located at a site. No additional insights or guidance on multi-unit siting is contained in these documents.

OTHER REVIEWS

In response to a request from the NRC staff, the Advisory Committee on Reactor Safeguards recommended in December of 1975 that several criteria in current siting policies be considered.⁽⁶⁾ One of the recommendations noted that studies may be needed on the short- and long-term consequences of a major accident at a nuclear installation, or other operations at a multiunit site such as a nuclear power park. Another recommendation was that attention should also be given to the development of additional criteria for sites containing more than one reactor or nuclear facility. Recent guides and regulations have noted criteria for multiunit sites. None are restrictive to the concept of HNEC.

RADIOLOGICAL CONSEQUENCES OF A CLASS NINE ACCIDENT AT AN HNEC

Our analysis of a class nine accident at an HNEC is based on a meteorological model applied in one of the HNEC conceptual studies.⁽⁷⁾ This model uses thirty years or more of meteorological records at Hanford from which some expectations of the frequency of occurrence (probability) of different meteorological parameters have been developed. These parameters include prevailing wind directions, average wind speeds, atmospheric stability, the height of the mixing layer, and others. To these parameters are added an expected plume width and deposition velocity for material released in the accident. The entire release is assumed to occur over a one-half hour period. The meteorological model is superimposed on a layout of the HNEC site, which comprises

five quads (multiunit stations). The model can then predict in a probabilistic manner how accidental releases from a unit in any one quad will affect the remaining quads at the site. The model thus yields the conditional probabilities of M quads being involved with different levels of normalized radioactivity concentrations in air or with surface depositions of radioactive material, given the occurrence of a class nine accident in one of the quads. Table 31 gives the resulting probability estimates. These probabilities assume that the release will contaminate the quad in which the accident occurs. The probability of contaminating two or more quads at some level is 0.194. The probability that only the source quad would be contaminated is therefore 0.806 (1.0-194). As expected, the probabilities decrease as either the number of quads or level of contamination increases.

The table does not indicate that it is possible for a single accidental release to contaminate all five quads. However, this reflects the limitations of the model, the orientation of the quad configuration and the wind direction classes in the climatological data summary. The contamination of all quads must still be considered possible.

Probabilities of surface contamination can be computed by multiplying the normalized activity concentrations in air given in Table 30 by 0.01 m s^{-1} , the deposition velocity. The left-hand column of the table then becomes the normalized surface concentration.

The full development of the consequences of a class nine accident requires the description of a source term and of a method to convert the normalized air and surface contamination values to corresponding levels of dose.⁽⁸⁾ Figure 23 illustrates the procedure that was used to do this. As indicated by Figure 23, the source term was taken from an earlier study.⁽⁹⁾ Any accidents involving the core that were identified in that study could be used to develop subsequent potential doses at other reactor sites from 1) the passing radioactive cloud immediately following the accident and 2) ground-level contamination during the period following deposition. The accident selected as the source term represented the greatest impact (worst case) of any in which there was a ground-level release.

TABLE 31. Conditional Probabilities of Involving
at Least the Given Number of Quads

Normalized Radioactivity Concentration in Air, sec/m ³	Probabilities for Number of Quads		
	≥2	≥3	≥4
1.000 x 10 ⁻⁵			
4.6 x 10 ⁻⁶	0.006		
2.15 x 10 ⁻⁶	0.021		
1.00 x 10 ⁻⁶	0.046		
4.64 x 10 ⁻⁷	0.069	0.011	
2.15 x 10 ⁻⁷	0.126	0.030	
1.00 x 10 ⁻⁷	0.158	0.066	0.018
4.6 x 10 ⁻⁸	0.172	0.085	0.023
2.15 x 10 ⁻⁸	0.182	0.090	0.024
1.00 x 10 ⁻⁸	0.188	0.095	0.025
>0	0.194	0.108	0.030

Note: Involvement is defined by normalized concentrations of radioactivity in air equal to or greater than tabled value.

FIGURE 23. Schematic of Procedure for Determining the Consequences of Radioactivity Release at an HNEC

Air submersion during the half-hour passage of the radioactive cloud results in different levels of dose in control rooms; Table 32 gives the probabilities for the involvement of M or more quads at these levels. The probability per reactor-year of this class of accident is given as 1.6×10^{-4} [$8 \times 10^{-6(7)}$ x 20 reactors]. The probability of reactors in the same quad as the accident having the developed exposure would be the same as the probability of the accident itself; namely, 1.6×10^{-4} . The probabilities that reactors in other quads would receive these doses, are progressively less than the probability of the accident (see Table 31) as determined by meteorological conditions and distance.

Emergency plans that include immediate communications and evacuation of personnel from nearby plant sites will be required. All reactors can be expected to shut down, perhaps some only to the point of hot standby. The effects of this event on the northwest power grid have been addressed elsewhere.⁽¹⁰⁾

For deposition (fallout), the probability of M or more quads being involved depends (in addition to meteorology and deposition with distance) upon the half-lives of the radioactive species. Different shielding factors are also applicable. Table 33 summarizes these results.

TABLE 32. Actual Probabilities of M or More Quads Receiving the Computed Radiation Dose from a Passing Cloud Following a Class Nine Accident

Normalized Air Concentrations, sec/m ³	Radiation Dose, rem(a)	Probabilities per Reactor- Year, units of 10^{-4}		
		≥2 Quads	≥3 Quads	≥4 Quads
1×10^{-6}	28	0.04	-	-
2.15×10^{-7}	6	0.14	~0.04	-
4.6×10^{-8}	1.3	~0.22	~0.14	0.03
1.0×10^{-8}	0.3	~0.25	0.17	0.04

(a) Assuming a building shielding factor of 0.2.

TABLE 33. Actual Probabilities of M or More Quads Receiving the Computed Radiation Dose Rate from Ground Deposition for Various Times Since Accident

Normalized Surface Concentrations, sec/m ³	Dose Rate, mrem/hr	Probability per Reactor-Year, units of 10 ⁻⁴		
		<u>≥2 Quads</u>	<u>≥3 Quads</u>	<u>≥4 Quads</u>
<u>0 days</u>				
1 x 10 ⁻⁸	97	0.07	-	-
2.15 x 10 ⁻⁹	21	0.20	0.04	-
4.64 x 10 ⁻¹⁰	4.5	0.28	0.14	0.04
<u>7 days</u>				
1 x 10 ⁻⁸	80	0.07	-	-
2.15 x 10 ⁻⁹	17.2	0.20	0.04	-
4.64 x 10 ⁻¹⁰	3.7	0.2	0.14	0.04
<u>30 days</u>				
1 x 10 ⁻⁸	40.5	0.04		
2.15 x 10 ⁻⁹	8.7	0.14	0.04	
4.64 x 10 ⁻¹⁰	2	0.22	0.14	0.04

Low radiation levels can be expected within some reactors for most weather conditions and to persist unless efforts to decontaminate are undertaken. In a quad adjacent to the quad containing the involved reactor, extensive decontamination efforts are predicted in order to return the reactor facility to operating status.

The class nine accident is a serious incident with the potential for significant exposure to operating personnel from the radioactive cloud unless time is available for successful evacuations. The dose inside the facilities are not estimated to be lethal, however, and the contamination levels in most instances are manageable. As serious as it is, this accident was shown in another report to have a lesser probability per reactor-year of creating a loss of generation capacity than an ashfall from volcanic eruption in the Cascades, or from an operating-basis earthquake.⁽¹⁰⁾

CONCLUSIONS - ACCIDENT REVIEW

The results are given in terms of the most probable involvements based on several assumptions in meteorology.⁽⁴⁾ For the dose within buildings due to a passing cloud, lethal doses are not predicted for any who remain inside during the passage; but these doses are, however, for the reactors in the same and next quads as the accident, substantial. If any are caught outside and remain submersed in the cloud for the time estimated for it to pass, a lethal dose is predicted. Emergency procedures for this low probability event, once about every 6000 years, can be expected to be in place to prevent this. These procedures would be essentially the same as required for other accidents involving a reactor core. Most of these would not result in accidental releases, but full-scale emergency procedures would be constantly available if needed. For the reactors more distant from the accident, the times available to take proper action prior to arrival of the cloud and the much lower doses that occur, result in no real threat to personnel assuming proper actions are taken. From contaminated ground from fallout at reactor sites near the accident, the dose rates are predicted to be significant for the greater releases. Substantial decontamination efforts are predicted to be required to restore nearby reactors to operating status. For example, surface dose rates of about 75 mrem/hr outside (7.5 mrem/hr inside) are estimated to be possible for at least fifteen reactors although 50 times less probable than the accident itself. Manageable dose rates however result even in the worst predicted case. Some reduction will occur as the radionuclides decay with time, but the real reductions in dose rates in reasonable time periods will result only from decontaminating each affected site.

The risk of this event when the consequences are loss of generating capability, compare favorably with rare natural events. It was shown that a loss of generating capacity from a class nine accident at an HNEC is less likely than a loss of generating capacity from an ashfall from volcanic activity in the Cascades and significantly less likely than a loss of generating capacity from an Operating Basis Earthquake.⁽¹⁰⁾ See Appendix D.

In this review, numerically conservative values of dose and dose rates were developed and meteorology parameters specific to Hanford were used. This

analysis, while adequate to indicate probable exposures and consequences, is not a detailed safety analysis. Such an analysis would be a subject for further development of the HNEC concept.

Finally, the probability of occurrence of the accident selected as the example in this review from the reference report;⁽⁸⁾ namely, the PRW-2, is used throughout as single value. At best, it is an estimate with some error bounds which if developed in the reference report were not given. Knowing the conservatism that was used in that report to develop the estimate, it seems plausible to accept it as a reasonable approximation. As such, it is utilized here to make comparisons with estimates of the frequency of occurrence of other rare events to provide perspective among them. This procedure was used knowing that estimating the frequency of occurrence of any rare event is an uncertain process.

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