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The Hanford Nuclear Energy Center

An Interim Conceptual Study

By the Staff
of Battelle, Pacific Northwest Laboratories

Harold Harty
Project Manager

November 1976

Prepared for the Energy Research
and Development Administration
under Contract E(45-1)-1830

Battelle
Pacific Northwest Laboratories

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BNWL-B-458-II

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By the Staff
of Battelle Pacific Northwest Laboratories

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Prepared for the U.S. Energy Research and Development Administration
under Contract E(45-1):1830

Battelle
Pacific Northwest Laboratories
Richland, Washington 99352

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INTRODUCTION

It is useful to review the history of the Nuclear Energy Center (NEC) concept to place the present study in perspective. The concept appears to have been conceived about 20 or 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 utilities and the timing for development of the fuel cycle differed from that for generation of electric power. Periodically the concept was considered as utilities and others thought in terms of siting several or more nuclear plants at one location. The first major consideration of NECs came as a result of Project Independence. The impetus here was to determine how quickly nuclear plants could be built in order to help free ourselves from dependence upon foreign petroleum supplies. The studies that were made at that time speculated on how rapidly nuclear plants could be built at a single location and made a preliminary assessment of what the major problems might be.(1) Project Independence studies, which were made in late 1973 and early 1974, did not treat any of the projected problems in depth. Those which were thought to present potential barriers to the siting of a large number of nuclear plants at a single location included meteorological effects from massive heat releases, coping with the overall heat sink management problem, reliability and capacity of electrical transmission systems from isolated centers to load centers, and institutional problems arising from a new mode of siting electrical generating facilities. As the emphasis on Project Independence decreased, so did the interest in NECs.

The next major emphasis on NECs 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 published in January 1976.(2) There were several factors which provided the

(1) Evaluation of Nuclear Energy Centers, WASH 1288, U. S. Atomic Energy Commission, January 1974.
(2) Nuclear Energy Center Site Survey - 1975, NUREG-0001-ES, Nuclear Regulatory Commission, January 1976.

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 facilities, including reactors and fuel cycle facilities. It was the conclusion of this study that NECs will probably evolve in the course of nuclear industry development, that NECs containing 10-20 reactors can be feasible and practical, and that from a safeguards/radioactive waste shipment point of view there is no pressing need to move in the direction of the NEC concept.

More recently the public's concern about nuclear power, difficulty in obtaining sites for nuclear plants, the fact that existing sites are already planned with up to four nuclear reactors, the tendency toward more regional planning of electric generating facilities, and other factors have provided a continued basis for studying the NEC concept. One of the ongoing studies of NECs is being performed by Battelle Pacific Northwest Laboratory under sponsorship of the Energy Research and Development Administration (ERDA). The Battelle study focuses on Hanford as a nuclear energy center. The objective of the study is to develop an improved understanding of the NEC concept, its advantages and disadvantages, and to identify research and development needed to evaluate the concept. A previous report on the Hanford Nuclear Energy Center (HNEC) concept was issued in mid-1975.[3] This report summarizes the status of the HNEC concept to the present and the studies made in support of the concept during the past year. Since the HNEC concept is based on incomplete studies, changes in the concept can be expected as the technical, socioeconomic, and institutional problems are investigated in greater detail.

(3) BNWL-B-458, The Hanford Nuclear Energy Center - An Interim Conceptual Study, October 1975.

SUMMARY

A conceptual layout of a Hanford Nuclear Energy Center comprised of 20 and 40 reactors with associated fuel cycle facilities has been developed (Fig. 1) based on limited technical studies. During the past year these studies have emphasized meteorological effects and heat sink management aspects of an HNEC, station electric power, and socioeconomic impacts. The studies to date have not revealed any insurmountable technical or socioeconomic problems, but areas of major uncertainty continue to relate to:

1. Changes in meteorological conditions caused by large heat releases, particularly those related to fog/humidity, rain/hail, ice, and wind generation.

2. Devising a heat sink management plan which results in an acceptable balance among environmental effects, economics, and resource (land, air, and water) utilization compared to dispersed siting.

Of the four meteorological aspects which must be analyzed -- changes in fog/humidity, rain/hail, ice, and wind -- only the fog/humidity aspect has been investigated for an HNEC. (Adequate analytical tools and supporting data for the others are not presently available.) This work indicates that extensive use of cooling ponds and mechanical draft towers* will be unacceptable because of increased ground-level fog and/or decreased visibility (though criteria are not available to judge this with certainty). Once-through cooling (to the extent it can be used) and tall mechanical draft towers appear to alleviate the ground-level fog situation. The cloud cover aspects of tall towers have not been examined. Dry or wet/dry cooling systems would probably be acceptable from both ground level fog and cloud cover aspects, but such systems would increase power generation costs 1-2 mills/kW-hr.

With these limited data and considering power generation economics, resource utilization and environmental factors, the following heat rejection systems for 20- and 40-reactor HNECs were tentatively selected for further evaluation:

*Several types of cooling towers are considered for an HNEC. They include mechanical draft towers (typically less than 100 feet high), natural draft towers (typically several hundred feet high), and tall mechanical draft towers (typically several hundred feet high but in which the draft is fan assisted).

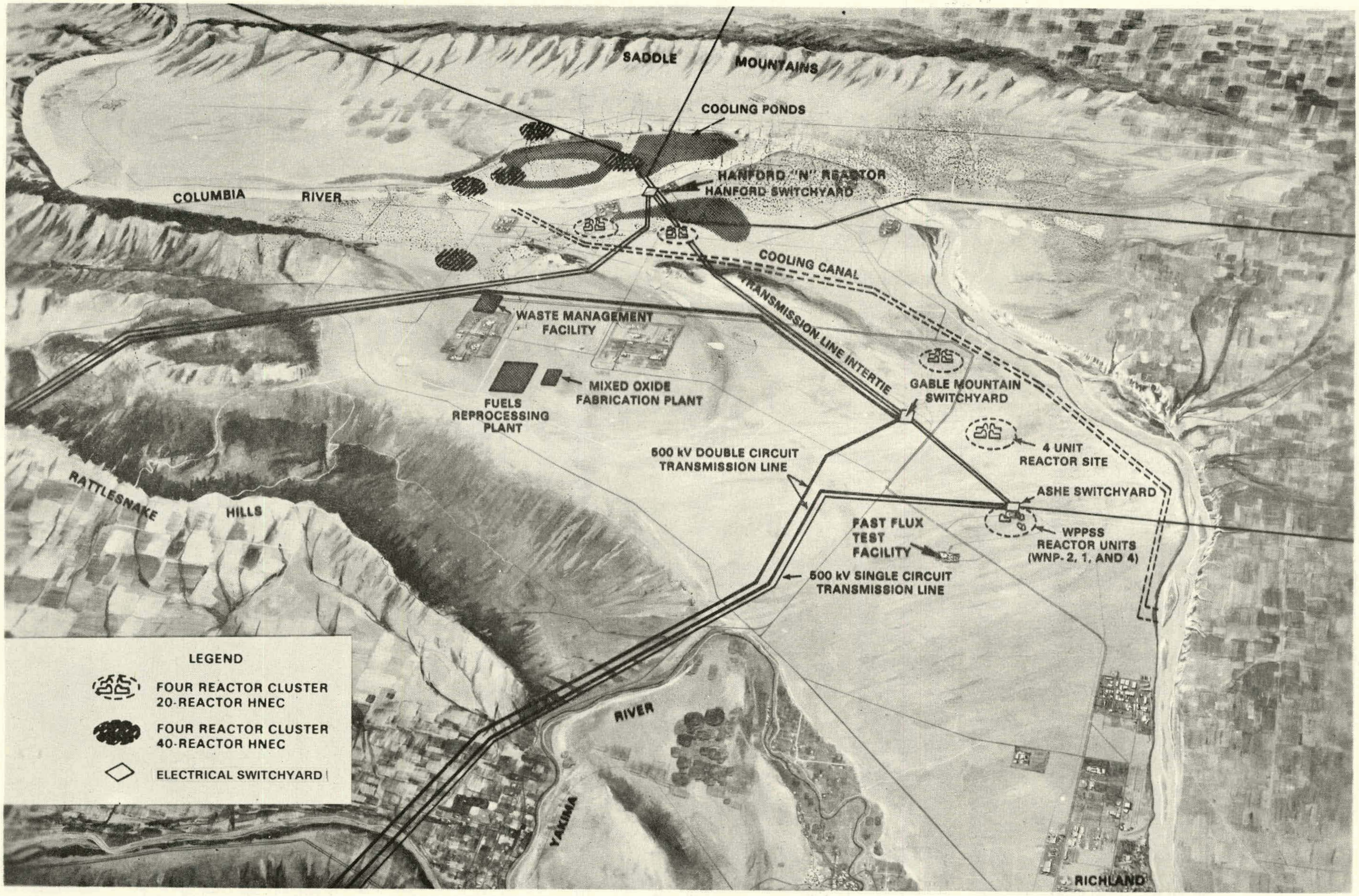

FIGURE 1. Conceptual layout of Hanford as a nuclear energy center

20-Reactor HNEC

6 reactors with once-through cooling
10 reactors with tall mechanical draft cooling towers
4 reactors with mechanical draft towers
(assumed to be the WPPSS site)

40-Reactor HNEC

10 reactors with once-through cooling
26 reactors with tall mechanical draft cooling towers
4 reactors with mechanical draft towers
(assumed to be the WPPSS site)

It must be emphasized that this mix of cooling systems may change as additional meteorological data on heat releases (and other data, including existing regulations) are considered. There is little indication that this amount of once-through cooling is presently acceptable to regulatory bodies. But for balanced environmental effects an HNEC may require that once-through cooling be used. In turn this might require that minimum river-flows be increased from about 36,000 cfs to 54,000 cfs, and that once-through cooled reactors be shut down for refueling for part or all of the period from September 1 to October 15, which is the longest period of time river temperatures exceed 68°F. Salmon spawning is impaired above this temperature and the environmental impact on them would be unacceptable. A further consideration is whether sufficient manpower would be available to maintain this many reactors shut down at one time. Increasing the minimum flow, while possible, would reduce the flexibility of the Columbia River to cope with changing water and power demands. Further study of these ramifications is required.

Previous studies[4] on transmission of electric power from an HNEC showed that 500 kV single or double circuit type of transmission was acceptable for at least 23,000 MWe. Additional studies of the HNEC station service power supply requirements show that with a possible connected station load of 1200-1500 MWe (about 75 MWe per reactor), the probability of the maximum exceeding 360 MWe was negligible. Thus, satisfactory alternate sources of electrical power are available from either 230 or 500 kV systems at Hanford.

(4) BNWL-B-426, Electric Power Transmission For An HNEC, May 2, 1975.

Evaluation of construction worker requirements for both a 20-and 40-reactor HNEC suggests that the buildup of reactors be more gradual than that assumed in this study, e.g., a 20-reactor HNEC by about 1998 or a 40-reactor HNEC by about 2008. In both cases 12,000 construction workers would be required. The peak would be maintained for about nine years in the 40-reactor case, and would only be reached in the 20-reactor case. This large swing in employment would be difficult for any area to accommodate. In another case, in which the employment was limited to 4,500 workers, a 20-reactor HNEC was achieved by about 2008. A more optimum case probably lies between these extremes.

An area of potential technical uncertainty which is being explored in greater detail arises at one point in which nuclear systems differ from fossil or hydro systems, i.e., under prescribed situations it is mandatory to shut down nuclear plants, for example, following an earthquake greater than an SSE (safe shutdown earthquake). The large commitment of generating capacity to an NEC could exceed a region's reserve capacity, making the system vulnerable to a single (albeit improbable) earthquake. While the probability of the event may be small, the consequences may be great. To reduce the risk (the product of probability and consequences) to an acceptable level may require development of new seismic evaluation techniques to pinpoint the probability more accurately or acceptance of higher SSE design criteria for NEC plants. The addition of more reserves in the region would reduce the consequences.

Current NEC studies are hampered by a lack of safety and environmental criteria for siting many reactors in close proximity. Studies tend to be guided by present practices for siting dispersed plants, and thus may either overstate or understate the difficulties in licensing NECs, which remains a major unknown. One of the ongoing HNEC activities is to develop bases for siting criteria for NECs. Those relating to safety of the public and reliability of electric service are being studied initially.

INTERIM DESCRIPTION OF THE HNEC CONCEPT

In a preceding report[3] of Hanford as a nuclear energy center, the scope and buildup of a 40-reactor HNEC was described. Sites for ten clusters of four reactors each were tentatively selected on the Hanford reservation (Fig. 1). It was assumed that all reactors in the Pacific Northwest beginning commercial operation after 1985 would be built at Hanford. This led to the construction of one or two reactors per year until 2008 (Table 1).

It was further assumed that all spent fuel and reactor-generated wastes from LWRs in the remainder of the Western Systems Coordinating Council area (WSCC) would be shipped to Hanford for reprocessing and waste management. Thus, an LWR fuel reprocessing plant of 1500 MT/yr size would be required in 1988, and an LMFBR reprocessing plant in about 2000. Also, in 1988 a mixed oxide fuel fabrication plant would be required with the assumption that all recovered plutonium would be used in HNEC LWRs or LMFBRs. Its size would increase from 140 to 300 MT/yr as the HNEC built up.

The first LMFBR at HNEC was assumed to begin commercial operation in 1993. All WSCC LMFBRs were assumed to be constructed at HNEC, resulting in 16 LWRs and 24 LMFBRs in the completed 40-reactor reactor development. The LMFBRs were assumed to have a larger electrical output (1500 MWe) compared to LWRs (1250 MWe) for the same thermal rating.

An electrical transmission system capable of transmitting 23,000 MWe from an HNEC to load centers was selected. The system consisted of overhead AC, single and double circuit 500 kV transmission lines. This capacity would be adequate until about 1997-98. An estimated 50,000 MWe could be transmitted to load centers with an 1100 kV system utilizing available cross-mountain rights of way (with widening in some places)[4], assuming successful development and public acceptance of that technology and satisfactory reliability.

It is this basic description of an HNEC that is used in the analyses that follow. In addition, a 20-reactor case has been added to the evaluation of an HNEC. These plants could be added as the first 20 listed in Table 1, or as every other one. The five clusters selected for the 20-reactor case

TABLE 1. Assumed Reactor Plant Additions at HNEC
(Megawatts)

	LWR[a]		LMFBR[a]		TOTAL	
CY	Incremental	Cumulative	Incremental	Cumulative	Incremental	Cumulative
1979	1100[b]	1100			1100	1100
1982	1250[c]	2350			1250	2350
1984	1250[d]	3600			1250	3600
1987	1250	4850			1250	4850
1988	1250	6100			1250	6100
1989	1250	7350			1250	7350
1990	1250	8600			1250	8600
1991	1250	9850			1250	9850
1992	2500	12350			2500	12350
1993		12350	1500	1500	1500	13850
1994	2500	14850		1500	2500	16350
1995		14850	1500	3000	1500	17850
1996	1250	16100	1500	4500	2750	20600
1997	1250	17350	1500	6000	2750	23350
1998	1250	18600	1500	7500	2750	26100
1999	1250	19850	1500	9000	2750	28850
2000			3000	12000	3000	31850
2001			3000	15000	3000	34850
2002			3000	18000	3000	37850
2003			3000	21000	3000	40850
2004			3000	24000	3000	43850
2005			3000	27000	3000	46850
2006			3000	30000	3000	49850
2007			3000	33000	3000	52850
2008			3000	36000	3000	55850
2009				36000		55850
2010				36000		55850

(a) LWR sizes are assumed to be 1250 MWe and LMFBRs are assumed to be 1500 MWE size.
(b) WNP-2, Washington Public Power Supply System
(c) WNP-1, Washington Public Power Supply System
(d) WNP-4, Washington Public Power Supply System

are shown in Fig. 1, and are all south of the Columbia River. This selection was made on the basis that (1) there is more information available on that portion of the Hanford Reservation, and (2) the transmission system studied thus far incorporates those sites.

In the earlier report on Hanford as a nuclear energy center there were several major conclusions. First, there are adequate sites for a large (40-reactor) nuclear complex at Hanford. Second, an electrical transmission system which will meet all the WSCC and BPA criteria for reliability results in an economic penalty of about 1 mill/kW-hr compared to dispersed reactor siting in the PNW. Third, potentially major meteorological and environmental impacts could result from the massive releases of heat and moisture from an HNEC. Acceptable impacts can probably be achieved through use of a variety of cooling methods which will distribute the environmental effects to both the atmosphere and the Columbia River. An overall heat sink management plan must achieve an acceptable balance among economics, environmental effects, and resource utilization. These conclusions are unchanged by more recent studies.

Using criteria set forth in reference 3 and data developed during current studies, the following tentative heat sink management plan was developed for 20- and 40-reactor HNECs:

<u>20-Reactor HNEC</u>

6 reactors with once-through cooling
10 reactors with tall mechanical draft cooling towers
4 reactors with mechanical draft cooling towers
(assumed to be the WPPSS site)

<u>40-Reactor HNEC</u>

10 reactors with once-through cooling
26 reactors with tall mechanical draft cooling towers
4 reactors with mechanical draft cooling towers
(assumed to be the WPPSS site)

Allocation of the several cooling methods to each of the reactor clusters has not been made.

It is appropriate to note several factors that are not a part of the scope of the HNEC study: an economic comparison between HNEC and dispersed sites in the Pacific Northwest (PNW); and a comparison of safeguards and transportation of radioactive wastes between HNEC and dispersed sites. Information on these factors for NECs is given in reference 2.

It has been assumed that HNEC plants would be owned and operated by investor-owned and public utilities in the PNW. If needed, some type of coordinating body, perhaps similar to the PNUCC, could provide a focal point for the coordinating activity at an HNEC.

Finally, because of several unique or almost unique characteristics of Hanford, compared to other NECs being studied, including its size, nuclear orientation, availability of water, etc., care should be taken in extrapolating the findings about Hanford as an NEC to other sites. Each of the reactor clusters at an HNEC could be spaced several miles apart, which may be atypical of most NEC sites. Thus, a problem may not exist at Hanford by virtue of its large land area, whereas it might at a smaller site. Where a problem does exist at Hanford, the problem might be more severe at a smaller site for similar numbers of reactor plants.

SUMMARY OF RECENT TECHNICAL STUDIES

Significant studies in support of the HNEC concept during the past year were made in the following areas:

- Heat Sink Management[5]
- Meteorology[6]
- Siting Selection
- Socioeconomic Factors
- Safety Analysis[7]
- Station Electric Power Service[8]

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(5) BNWL-2003, Selection Of Heat Disposal Methods For A Hanford Nuclear Energy Center, J. R. Young, et al., June 1976.
(6) BNWL-2058, Impact Of An HNEC On Ground Level Fog And Humidity, J. V. Ramsdell, September 1976.
(7) BNWL-2077, Safety Concerns Specific To HNEC, R. G. Clark, To Be Published.
(8) BNWL-2076, Station Service Power Supply For An HNEC, R. L. Richardson and W. J. Dowis, December 1976.

The results of these studies are summarized in the following sections.

The studies that are undertaken are governed by two needs: to seek adequate solutions in problem areas that have been identified in previous studies, and to identify potential problem areas that NECs may face. The latter effort arises because there are no criteria for siting or licensing NECs. With the greater concentration of nuclear facilities in an NEC, it is likely that different criteria and/or standards will govern their siting as compared to present dispersed siting.

A difficulty in evaluating the NEC concept in a specific setting arises from the lack of adequate calculational models and site specific data to use in models. This is especially true in the meteorological effects area, which impacts directly on the heat sink management aspects of an NEC.

One of the possible limitations to the size of an NEC is the ability to dispose of the reject waste heat in an acceptable way. An acceptable way implies that it be environmentally and economically sound, as well as conserving of resources (land, water, materials, etc.). One of the major technical studies in support of the HNEC concept is an analysis of the heat sink management options.

A major input to the heat sink management studies is the analysis of meteorological effects arising from the waste heat. This constituted a second major study of the HNEC concept. It was limited, however, to an analysis of ground level fog and humidity changes due to an HNEC.

The third study is a preliminary evaluation of seismic considerations for an NEC.

The fourth study is a preliminary evaluation of socioeconomic impacts for an HNEC in which the size of construction work force is considered.

The fifth study is aimed at developing criteria and/or standards for an NEC. Initially two aspects are being examined--safety of the public and reliability of electric service.

The sixth study grows out of the latter, and is a detailed study of station electric power service for an HNEC. A number of topical studies similar to the station electric power study will be required to support the criteria/standards evaluation.

HEAT SINK MANAGEMENT

The environmental impacts sustained by an NEC may be significantly larger than that sustained in a single dispersed site, though studies[2] indicate that the total environmental effects could be less for an NEC than the aggregate of an equal number of dispersed reactor plants. As with dispersed plants, there will be a tradeoff among environmental effects, plant costs, and resource utilization for an NEC, and the problem is to devise an acceptable balance among them. As a limit is reached for any of these factors (e.g., environmental effects) the others (e.g., plant cost) assume an increasing burden. When all of them reach unacceptable levels, that will define the maximum size of the NEC in terms of number of reactors, or area.*

If the HNEC (or any NEC) evolved on the basis of a few reactors at a time as opposed to being designated as a 20- or 40-reactor NEC, as in this study, the optimization process would be 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 is likely for NECs, some type of analysis similar to that presented in reference 5 and summarized here will probably be required for the heat sink options for the environmental reports and safety analysis reports.

In the case of an HNEC, it should be noted that the large land area at Hanford (∿ 670 square miles) has effectively eliminated the constraint on land resource availability, and the size of the Columbia River has eased the problem of water resource availability. Thus, in the HNEC study the balance is mostly between economics and environmental considerations. One would expect the resource utilization aspect to become more important with time, however.

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 concentrated discharge of heat than has occurred from other industrial facilities. Special analyses are required to determine its effects.

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*There are other factors which could limit the size before any of the above factors would. Inadequate reliability in the electrical system might be one factor, for instance.

Normally waste heat is released to nearby water bodies or directly to the atmosphere by use of cooling ponds or wet cooling towers. Whatever process is used incurs some environmental effect. Cooling water withdrawals and releases to water bodies can affect aquatic life through mechanical abrasion 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. Transfer 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.

The analysis of environmental effects is hampered by inadequate calculational tools and supporting data for massive heat releases. As described in the following section on Meteorology, the effects of atmospheric heat releases of this magnitude might result in changes in (a) fog, humidity, and cloud cover, (b) precipitation, including hail, and (c) wind. In this heat sink management analysis only changes in fog (frequency and visibility) and humidity have been considered. It is possible that consideration of the other factors (which will be done as additional analytical tools are developed) will change the present heat sink management plan.

Another factor which complicates the heat sink management analysis is 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, both atmospheric and water body releases may be required. Such an approach may be permitted under the provisions of Public Law 92-500 concerning releases of heat. This law requires that by 1983 (1) the release of heat be made in accordance with the application of the best available technology economically achievable, and (2) the elimination of heat discharges when technologically and economically achievable. Further, in the case of waste heat discharges a waiver is permissible whenever it can be demonstrated that release will ensure the protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife in and on the body of water involved. The effect of Public Law 92-500 on NECs remains an unknown, however.

A second major consideration (in addition to environmental effects) is resource utilization, primarily water, land, and air (quality). Since the life span of an NEC is 80-100 years (a likely buildup over about 40 years with plant lifetimes of 40 years), thought must be given to the competing needs for these three resources well into the future at the location of an NEC. Cooling systems which consumptively use small amounts of water, occupy small land areas, and don't place an unacceptable humidity, temperature, or pollutant burden on the atmosphere, would tend to be favored.

The third major consideration for heat rejection systems is economics. It is at this point that major inroads might be made into the projected cost advantages of NECs. If the 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 fast disappear.

The overall purpose of the HNEC heat sink management study was to identify the waste heat disposal method which gave the best balance among environmental effects, resource utilization, and economics. The general criteria applied were: (1) there should be an acceptable level of environmental effects (and preferably no significant adverse effects); (2) resource utilization should be as low as practical; and (3) economic costs should be as low as possible.

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.

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, and then the sum of the effects of all parameters for each method is compared to the sums for the other alternatives to determine the most desirable alternatives. 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. The other three systems are combinations of both.

The most important environmental effects identified to date for the various HNEC cooling systems are alteration of the Columbia River aquatic life with once-through cooling and creation of more fog and higher relative humidity as a result of moisture releases into the atmosphere from cooling ponds and mechanical draft wet towers. At present only general estimates of the increases of fog and humidity increases can be made. Further, no quantitative evaluation has been made for changes in meteorological events such as icing, rain, and wind. Better methods for predicting the meteorological effects of wet cooling tower operation are necessary to assure that excessive adverse effects do not occur.

From a resource utilization point of view, the biggest effects occur with the wet towers (water use) and cooling ponds (land use), and the least effect for once-through cooling and probably dry towers.

In general, the electricity generation costs are lowest for once-through cooling, about 4% higher for ponds and wet cooling towers, 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.

Based on studies to date, the present "optimum" heat disposal method for an HNEC is a combination of once-through cooling and wet tower cooling. The maximum number of reactors with once-through cooling will depend partially on future decisions affecting the minimum river flow, but it appears to be about six reactors for a 20-reactor HNEC and ten reactors for a 40-reactor HNEC based on Columbia River low flow rate of 54,000 cfs.* The remainder

*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.

(apart from the WPPSS reactors which have mechanical draft wet towers) would be cooled by tall mechanical draft wet towers. This combination would avoid significant increases in fog formation during the winter months and relative humidity increases in the summer. Although tall mechanical draft towers have not been operated in the United States, they have been in Europe.

The impacts due to fog formation and humidity increases are essentially independent of the locations of tall mechanical draft towers on the Hanford Reservation. Consequently, locations would probably be based on other factors such as aesthetic impacts, proximity to water supply, and economic costs.

Once-through cooling probably will not be permissible during the late summer in some years because the river temperature at Hanford exceeds 68°F, temperatures detrimental to salmon. Scheduling the annual refueling outages for once-through cooled reactors during that time could avoid economic penalties. The number of reactors with once-through cooling may also be functions of the amount of generating capacity which can be shut down at one time and the number of personnel available for outage operations. These aspects have not been examined.

Future heat sink management studies will incorporate the findings of additional meteorological and environmental investigations. Significant potential problems exist for the heat sink plan presently selected, and modifications to it are likely. The acceptability of a given plan can probably be determined only by attempting to license an HNEC.

METEOROLOGY

The postulated atmospheric effects of heat rejection from nuclear energy centers include increases in humidity, cloudiness and fog, enhancement of precipitation and modification of precipitation patterns, triggering of more severe weather types such as thunderstorms, and the concentration of vorticity resulting in the formulation of large dust devils.[3]

The specific atmospheric effects* which might be associated with a particular energy center are generally related to the form of heat rejection,

*The atmospheric effects resulting from clusters of thermal power stations is being studied in detail under an ERDA program managed by Oak Ridge National Laboratory (ORNL). The program is planned to continue until 1980. It is expected that the ORNL program will provide analytical methods and data sufficient for the preparation of the meteorological portions of environmental reports for large clusters of thermal plants, including the NEC case.

the flux density and area of heat rejection, and the climate of the energy center site. For example, fog and humidity increases are associated with low level wet cooling systems, and the more spectacular effects are postulated for closely spaced cooling systems with a high energy flux.

The nuclear energy center being evaluated for Hanford (HNEC) consists of 20 to 40 power plants with associated switching and transmission facilities, a fuel fabrication plant, two fuel reprocessing plants, and a waste storage facility, as described earlier. Preliminary site evaluation indicates that the total area covered by the energy center will be between 100 and 300 square miles with the larger value representing the full 40-reactor case. These values are in contrast to the 75 square miles assumed for 40-reactor nuclear energy centers in the Nuclear Energy Center Special Study (NECSS).[2]

A preliminary study of heat sink management for the HNEC[5] has indicated that a variety of cooling systems are potentially suitable for handling the heat dissipation from an engineering standpoint. The selection of the cooling system mix to be assumed in evaluation of the HNEC concept has been a matter of study along with selection of specific locations for the clusters.

An attempt has been made to resolve both questions through the development of a comprehensive heat sink management plan which would result in the most favorable balance between resource utilization, economics, and environmental effects.

Rational evaluation of the significance of any effect of heat rejection requires that the extent and timing of the effect be estimated quantitatively, and that significance be defined in meaningful terms. Each of the effects postulated in the NECSS[2] has been considered in a cursory manner to screen out improbable impacts and those which cannot be adequately evaluated at this time.

Concentration of vorticity has been related to high density of the rejected heat and relatively large areas. This was a major concern for the energy centers considered in the NECSS where the flux density was about 0.5 kW/m^2. The flux density for the HNEC would be between 0.1 and 0.3 kW/m^2. In addition, there are no simple methods for quantifying the frequency, magnitude, or effect of vortices which might be generated. As a result, detailed consideration of vorticity concentration has been postponed until better tools are developed.

With respect to modification of precipitation patterns and the triggering of storms, theoretical and numerical models are being developed to provide insight into these postulated effects. Several investigators are currently pursuing this avenue of research. As results are achieved they will be applied to HNEC, although recently publicized problems in the National Hail Research Experiment[9] raise questions about the reliability of quantitative estimates for these effects.

The only atmospheric effects which are amenable to treatment at this time are those associated with the addition of moisture to atmosphere. Even in this case the treatment is semiquantitative at best. Thus, the effect of cooling systems on fog (and to a lesser extent humidity) became the atmospheric measure of heat rejection impact used in the initial selection of an overall HNEC heat sink management plan.

At the outset of the evaluation it was assumed that the addition of heat and moisture were not, in themselves, significant impacts. Similarly, it was assumed that a postulated small change in any naturally occurring atmospheric phenomenon would not be significant. Rather, significance must be achieved by meeting some specific criteria. Four criteria have been identified. These include: a statistically significant change in a meteorological variable, substantial adverse economic impact of a postulated change, initiation of an adverse environmental change, and adverse public reaction. Criteria other than that of statistical significance are not satisfactorily defined, but they provide guidance on the detail required in specification of a postulated impact. The environmental aspects will be discussed initially, followed by the statistical significance of the results, and some brief comments on economics.

The approaches used in the evaluation can be illustrated using fog as an example. In most cooling system evaluations fog is considered either

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(9) "Hail Suppression Up In The Air," Science 191, 932 (1976).

qualitatively or in terms of additional hours of fog. The effect of an additional hour of fog is indeterminate. If the visibility during that hour is 6 miles, the effect may be negligible or at most psychological. If, on the other hand, the visibility is 1/8 mile or less the effect can be evaluated in economic terms by considering its effect on transportation and other activities which require greater visibility.

With the criterion that the effect of fogging had to be estimated in terms of hours of specified visibility a multiple-source diffusion model was developed in which moisture releases from a variety of cooling systems could be simulated. The large number of possible cooling systems and reactor cluster locations placed a further constraint on model development, i.e., the model had to be economical as well as flexible. The Battelle Atmospheric Management model (BATMAN) was used. It is described in reference 6.

It is important to point out a difference in the definition of fog between climatological data and model predictions. In climatological data fog is a specific form of visibility restriction which occurs at high relative humidities. In models fog is assumed when the atmosphere becomes saturated. The two definitions are not equivalent.

A second important point is the fact that the increase in hours of reduced visibility may be greater than the increase in total hours of fog. It is possible that an insignificant increase in the total number of hours of fog may produce a significant impact when visibility is considered.

On a monthly basis relative humidities at Hanford range from a low of 30.5% in July to a high of 80.8% in December. High humidities (>90%) occur less than 1% of the time in the summer, about 9% of the time in the fall, almost 31% of the time in the winter, and slightly more than 3% of the time in the spring. These statistics are reflected in the occurrence of fog. Of the annual average of 278 hours of fog, 95% occurs from November through February. This percentage increases to 99.7% when the months of October and March are included. On the average, visibility is less than 1/2 mile for 101 hours per year.

Fog statistics indicate large natural variations in the occurrence of fog. Close examination of recent records does not indicate a change following deactivation of the plutonium production reactors at Hanford in the 1960s. In fact, January 1976 set a record for the most hours of fog in a single month, 257 hours.

More than 50 cases, ranging from a single 4-reactor cluster near the south side of the reservation to a full 40-reactor energy center, have been examined to evaluate the effects of energy center size, cluster locations and cooling system mix on fog and humidity. The initial test cases indicated the expected result that the most frequently impacted areas outside the Hanford Reservation would be the Tri-Cities and the region east of the Columbia River and north of Pasco.

A partial compilation of the results of the analyses conducted to evaluate the effect of various heat sink management options on fog is presented in Tables II and III. The increase in the range of hours of fog (Table II) for both the 20- and 40-reactor energy centers reflects differences primarily caused by changes in cooling system mixes; differences due to cluster location are secondary. The greatest effect was predicted for those cases with extensive use of cooling ponds and once-through cooling with helper ponds. Lesser effects were predicted for mechanical draft cooling towers and once-through cooling with mechanical draft helper cooling towers, and the least effect was predicted for natural draft cooling towers and (unassisted) once-through cooling. It should be noted that whenever the predicted increase of total hours of fog is less than 40 hours, the predicted increase of hours of visibility of less than 1/2 mile exceeds the increase of total hours of fog.

Three cases with wet/dry mechanical draft cooling towers were examined for both the 20- and 40-reactor energy centers (Table III). The fraction of wet cooling varies from 100% to 25%. These results indicate the fogging effect of wet/dry cooling system heat rejection at Hanford increases approximately linearly with the wet fraction for both the 20- and 40-reactor centers.

The need for considering the statistical significance of the model calculations is because of the large natural variations which occur, as

TABLE II. Frequency of fog and changes in visibility in the Tri-Cities due to an HNEC using evaporative cooling.

Case	Increase in total hours of fog	Increase in total hours of visibility < 1/2 mile
4-reactor cluster with mechanical draft cooling tower	15	28
20-reactor energy center	34-250	39-162
40-reactor energy center	90-288	71-184

TABLE III. Predicted increase in hours of fog in the Tri-Cities for energy centers using wet/dry mechanical draft cooling towers.

Wet Cooling Fraction	20-Reactor Center		40-Reactor Center	
	Fog (hours)	Visibility <1/2 mi. (hours)	Fog (hours)	Visibility <1/2 mi. (hours)
0%*	15	28	15	28
25%	37	40	63	55
50%	57	52	117	86
75%	74	61	164	113
100%	98	75	210	139

* Hours of fog for a single 4-reactor cluster using conventional mechanical draft wet cooling towers.

previously described. A small predicted change may take many years to verify statistically. Further, it should be remembered that (a) the model predictions are conservative, and (b) the results are predicted for the Tri-Cities area and not the Hanford Reservation itself. Thus, the determination that a predicted change is significant only indicates that further examination of the effect is warranted. A subsequent evaluation of an effect with more realistic models and assumptions may well show that a change is not significant.

The statistical significance of the postulated increase in total hours of fog and hours of visibility less than 1/2 mile can be assessed relatively easily using techniques for comparison of mean values. An appropriate null hypothesis for the evaluation of the increase in total hours of fog is that the difference in hours of fog before the start and after the completion of the energy center is zero. A similar hypothesis can be stated for the increase in frequency of visibilities less than 1/2 mile.

The results of such a statistical analysis are given in Table IV as a function of the number of years observation following completion of the energy center; a log normal distribution with Hanford fog and visibility statistics has been assumed. The minimum significant increases in the table decrease with increasing observation period, and approach limiting values which are a function of the pre-center climatological fog and visibility records. Comparison of these values with predicted effects given in Tables II and III shows that the use of evaporative cooling systems may lead to statistically significant impacts on fog and visibility.

An evaluation of the economic significance of the predicted effects has been initiated. As an initial step the effect of moisture on the frequency of five visibility categories (from 3 miles to 1/16 mile) has been estimated for the various cooling system combinations. Table V gives these estimates for current conditions and the three cases in which exclusive use of mechanical draft cooling towers was assumed.

The visibility categories chosen are directly relatable to activities which are important to public convenience as well as to changes which can be evaluated in economic terms. For example, reduction of prevailing visibility to less than 3 miles changes the rules governing flight from visual rules to

TABLE IV. Minimum statistically significant increase in hours of fog and visibility less than 1/2 mile at the 95% significant level for HNEC.

Years of Observation	Annual Increase in Hours of Fog for Statistical Significance	Annual Increase in Hours of Visibility of 1/2 Mile for Statistical Significance
2	101.5	58.2
4	82.9	39.8
6	68.3	32.6
16	45.9	21.7
36	36.4	17.1
∞	26.8	12.6

TABLE V. Predicted effect of development of a nuclear energy center using mechanical draft cooling towers on fog and visibility in the Tri-Cities.

Number of Reactors	Total Hours of Fog	Hours of Visibility (miles) <3	<1	<1/2	<1/8	<1/16
0	278	196	132	101	36	8
4	293	223	162	129	45	12
20	376	297	221	176	56	16
40	488	396	300	240	72	22

instrument rules. This has the effect of closing airports to pilots not qualified to conduct instrument flights. In addition to being an inconvenience to affected pilots this has a calculable economic effect on local airport and flight service operators. Further reduction of visibility in the Tri-Cities to less than 1 mile effectively closes the Richland airport to all traffic. When visibility becomes less than 1/2 mile, all air traffic to and from Tri-Cities airports is halted. Surface transportation is impacted as the visibility falls below 1/8 mile. Finally, when the visibility falls below 1/16 mile, surface traffic may be seriously impeded. The impact of reduced visibility on surface traffic can range from delays to an increase in traffic accidents.

In summary, the results of HNEC meteorology studies to date use simple atmospheric models which are conservative in the sense that they are biased toward over prediction of the effect of cooling system effluents on humidity and fog. Within this context the following conclusions have been reached:

1. The evaluation of any atmospheric impact postulated for heat dissipation must be conducted in quantitative terms which can be used to determine the significance of the effect.
2. Of the potential atmospheric effects of large heat releases from energy centers, the one most amenable to quantitative evaluation in meaningful terms is the increase in fog.
3. A postulated increase in frequency of fog can be translated into terms of visibility and both can be evaluated statistically.
4. The translation of an increase in fog to visibility terms permits economic evaluation of the effect.
5. The predicted effect of the HNEC on fog and visibility is statistically significant whether the energy center consists of 20 or 40 units.
6. Those heat sink management options which result in predicted effects near the low end of the ranges (Table II) are least likely to produce significant impact when examined in more detail. These systems are primarily tall cooling towers whether natural or mechanical draft and once-through cooling systems.

7. Extensive use of wet/dry or dry mechanical draft cooling towers may reduce the probability of fogging impact to a level consistent with the lower ends of the ranges given in Table II. It should be noted that the single 4-reactor cluster is identified as having a potentially significant impact on visibility, although the impact on total hours of fog is not significant.

SITE SELECTION

As stated in BNWL-B-458[3] ten 4-cluster sites comprised the 40-reactor base case used in subsequent analyses of the HNEC. The initial selection of sites was based on the following criteria:

1. The sites should be selected to permit the most flexible use of alternative cooling methods, e.g., wet towers, wet/dry towers, ponds, canals, once-through cooling, and combinations of these;
2. The sites should be spread out to minimize (a) the probability of a single natural event resulting in loss of a significant number of reactors, switchyards, or transmission capabilities, (b) interaction of thermal plumes, and (c) radiation dose to construction workers and operating personnel;
3. The sites should be located above the highest credible flood level of the Columbia River;
4. For industrial benefits (e.g., the use of industrial heat) the sites should be located close to potential industrial sites (assumed to be near the edge of the Hanford Reservation);
5. The sites should avoid areas on the Hanford Reservation committed to higher priority uses;
6. The sites should be excluded from areas where faults are identified or postulated, at least until appropriate geological and geophysical studies indicate site suitability;
7. The sites should result in minimum disruption of arid lands;
8. The sites should make use of existing transmission corridors.

Further investigation of the ten sites has indicated that the eastern-most site north of the Columbia River might be subject to soil liquefaction during an earthquake. Fortunately, many alternative sites exist on the Hanford Reservation, and meteorological studies show that considerable flexibility exists in selecting site locations if cooling towers are used.

With the advent of a 20-reactor HNEC case, five sites south of the river were selected (Figure 1). The primary reasons for selecting these sites were (1) more is known about the geological/hydrological conditions south of the Columbia River, (2) the distance between the sites and sites characterized by possible faults, such as Saddle Mountain and the Rattlesnake Hills, is greatest, and (3) proximity of transmission systems.

One of the major efforts in the area of site selection is the delineation of seismic risk characteristics for large areas like Hanford. Earthquakes are one phenomenon that could adversely affect a sizable percentage and potentially all of the reactors at an NEC. Although there is only a very small probability that an earthquake at an NEC location would exceed the SSE (safe shutdown earthquake), if one did occur it would require all plants to be shut down for inspection. Such an occurrence could impair a region's ability to meet the electrical demand. For instance, a region such as the PNW might have generating reserves of 15-25% of demand. The reserves are used to cover scheduled outages of other plants, unexpected load demands, and unscheduled outages of plants. Electrical utilities typically refrain from concentrating in excess of about 15% of their system generating capacity in one station, because experience has shown that it is possible to lose the entire station to the grid (often because of transmission faults, but for other reasons too). Should the generating capacity at a single location approach or exceed the region's reserve, as could occur under the assumptions made for the HNEC study (Figure 2), the possibility of insufficient reserves could exist. The generation/reserve situation in the PNW may be unique with its large dams. For instance, the generating capacity of Grand Coulee Dam is about 15% of the PNW installed capacity, and may reach 18% for periods during the next few years. The combination of Grand Coulee and Chief Joseph dams reaches 22% of the installed capacity. Large concentrations of power are not new in the PNW. In part, this has been acceptable because the PNW has a

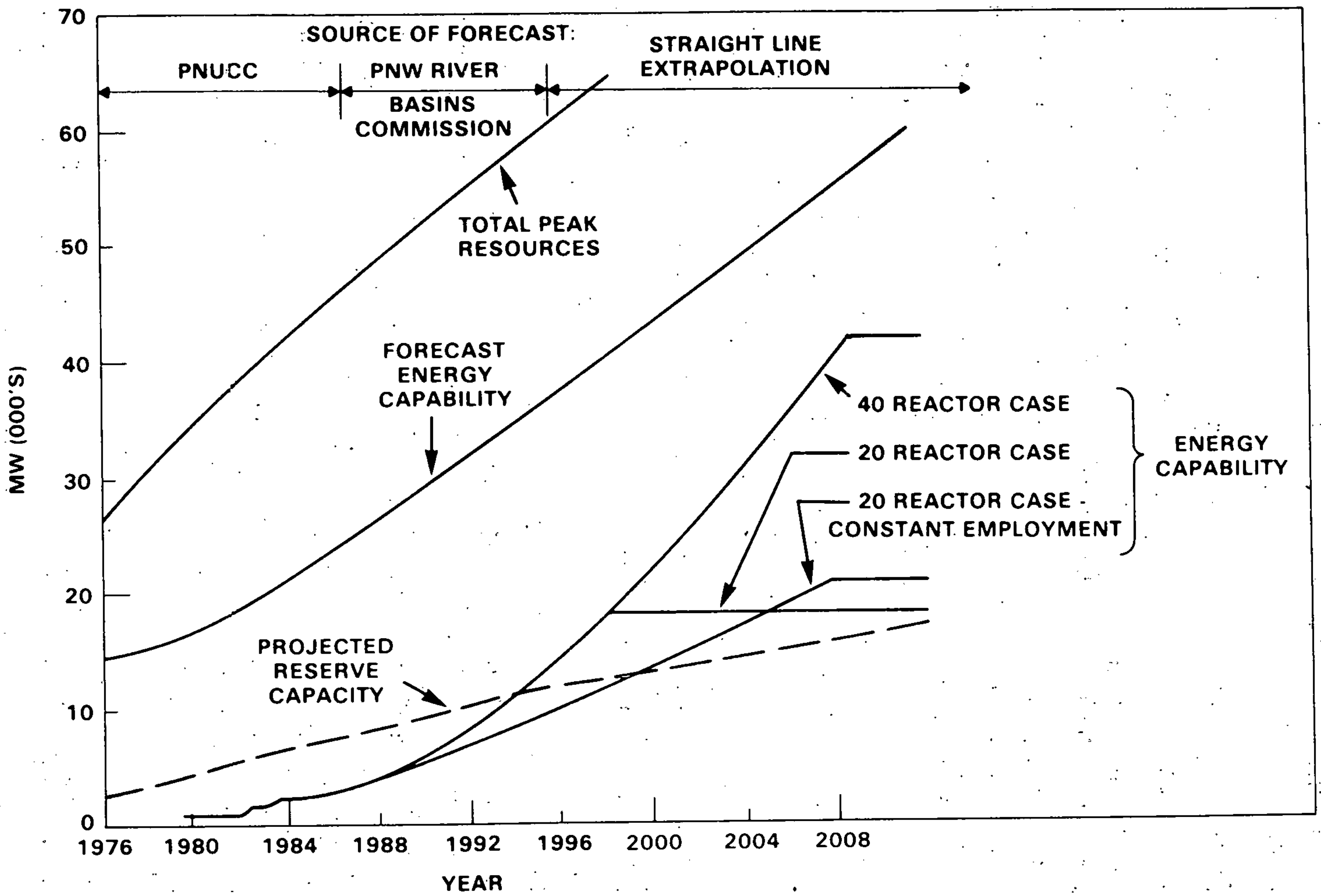

FIGURE 2. PNW Energy Capability

regional transmission grid which is more flexible and of greater capacity than that found in most regions.

What is new with the addition of nuclear units is that there exist situations which require nuclear generating capacity to be shut down promptly for safety inspection. An analogous situation does not exist for other electrical generating systems, e.g., hydro and fossil. These situations arise whenever the integrity of the nuclear system may have been compromised, e.g., earthquakes greater than the SSE. There are a number of possible options a region would have should it opt for concentrating on large blocks of generating capacity in one or a few locations, [e.g., a region could (a) have all the reactors designed for more stringent conditions, e.g., a higher SSE, (b) install additional reserve capacity, or (c) devise a plan for shedding loads so that higher priority demands would be sustained]. For the HNEC study we have tentatively assumed that the risk* of not meeting the region's electrical demand should be the same as for dispersed plants.**

One way to ensure the risk is the same for the HNEC and dispersed cases is to reduce the probability of a disabling event occurring, in this case an earthquake greater than the SSE. Nothing can be done about an earthquake per se, but an improved understanding of conditions at an HNEC (or any NEC) could reduce the probability of the SSE being exceeded. Thus, HNEC seismic evaluations have been directed toward this end.

There are at least two basic approaches to the problem. First, it is necessary to identify or detect faults and associated structures which can generate earthquakes. Second, it is necessary to understand the geologic processes and tectonic forces which have shaped the area to determine whether they are still active, and if so to determine event frequencies. These

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* Risk is defined as probability of occurrence times consequence. If the consequence of an HNEC interruption in generating capability is greater than an interruption at one or more dispersed sites, then the probability of an interruption must be correspondingly less in order that the overall risk remain constant.

** The Coordination Agreement in the PNW requires reserve capacity at a level to protect against the probability of load loss not to exceed more than one day in twenty years. (Ref. PNUCC West Group Forecast of Power Loads and Resources, March 1, 1976.)

processes and stresses are recognized as regional in scope, but it is necessary to understand them in order to determine the significance of the local features and adequately assess the level of seismic risk on a local scale.

Seismic evaluations in the Columbia Basin are severely hampered by the presence of relatively young glaciofluvial and alluvial sediments. In addition, the Columbia Basin basalt flows which mask all features in the underlying bedrock are difficult to identify and to map, particularly in areas of poor exposure. Although in the Columbia Basin the surface geologic features including the structures are well known, the features at depth where earthquakes are most likely to originate are very poorly known, and are even less well understood. The tectonic processes which are responsible for the development of the area are also unknown, although hypothesized in part. Basining, folding, and faulting have occurred, and it is likely that these processes are continuing.

A credible analysis of the seismic risk for an HNEC (or any NEC) will require conducting extensive geological and geophysical investigations to identify regional concerns. These investigations will probably require a commitment beyond those which have been made to date in siting individual nuclear facilities.

A broad spectrum of advanced geologic and geophysical techniques will be required to provide the necessary data. In addition to conducting field surveys and studies utilizing available geological and geophysical techniques, investigations for the HNEC should include studies to advance the state of the art. Appropriate techniques would include:

- Geologic Mapping - Advanced techniques for accurately mapping large large areas and for verifying and integrating data obtained by other geophysical methods.
- Remote Sensing - Satellite and aerial imagery provide unique data for identification and analysis of geologic structures and fault patterns. Provides guidance for detailed ground-based studies.
- Geomagnetic and Gravity Surveys - Techniques utilizing high density aeromagnetic and gravity data for fault detection and subsurface mapping.

- Passive Seismic - Development and implementation of experimental and analytical techniques for seismic and structural analyses.
- Measurement of Tectonic Processes - Accurate measurements of distance and elevation to estimate rates of crustal movement.
- Land-Based Seismic Reflection Method - Detailed studies of faults, stratigraphic boundaries and other geologic features will depend on development of advanced survey techniques.
- Seismic Reflection Profiling in Inland Waterways - Techniques for adapting marine seismic subbottom profiling techniques for use in shallow inland waterways.
- Electromagnetic Exploration Methods - Electromagnetic methods (including theoretical studies) using a wide range of wavelengths to probe deep geologic structure.
- Deep Stratigraphic Correlation - Drilling of exploratory holes in key areas and the development of in-situ geophysical logging and drill core analysis techniques.
- Characterization of Sediments - Determination of physical and chemical characteristics of geologic materials.
- Age Dating - Development and application of geologic and hydrologic age dating techniques, including physical and paleontological techniques.
- Regional Tectonic and Structural Models - Development of models to study, describe, and predict large-scale crustal plant movements and regional and local faulting and folding.
- Aquifer Testing - Advanced techniques for accurately analyzing complex multidimensional aquifer systems.
- Hydrologic Modeling - Models to analyze complex hydrologic systems.

The foregoing geological and geophysical techniques are basically those which are needed for siting any nuclear facility. Advances in the state of the art which are needed for siting a nuclear energy center will also meet the increasingly stringent requirements for geologic investigations for the siting of dispersed nuclear plants. The geologic investigations for nuclear energy centers should be comprehensive enough to assure that subsequent geologic studies will not reveal significant hazards that were not identified in the initial siting studies.

HNEC SOCIOECONOMIC IMPACTS

Because they are large scale both in terms of construction workers and dollars of investment, NECs have the potential for considerable alteration of any area's economy and life styles. The construction phases of a nuclear center represent the greatest problem, facility operation phases are more of a routine and long-term addition to the area's economic base and job stability.

On the favorable side of an NEC will be the additional jobs and dollars of wages generated, the commercial expenditures and resulting sales taxes these wages represent, plus miscellaneous and property taxes attributable to construction and supporting workers moving into the project area. In addition to the economic benefits attributable to workers, there are, of course, substantial state revenues in the use taxes on purchases of materials going into the construction project.

The problems created by an NEC are the additional loadings placed on the infrastructure sectors of the area and the costs associated with their expansion. These sectors include such public services as school systems, municipal employment, municipal services, health and medical care, transportation facilities, etc. There are other problems which deal with quality of life.

Figure 3 presents the general research approach for evaluating the public service related problems. The impacts start with construction employment recruitment since few communities (and certainly not the Hanford area) can routinely provide the large number of building craft workers required in the construction of an NEC. Therefore, for most of these workers, along with the major part of the supporting workers they generate, must be recruited from outside the area. Some of these new workers will probably commute to their new jobs from their present residence but most of them will have to migrate

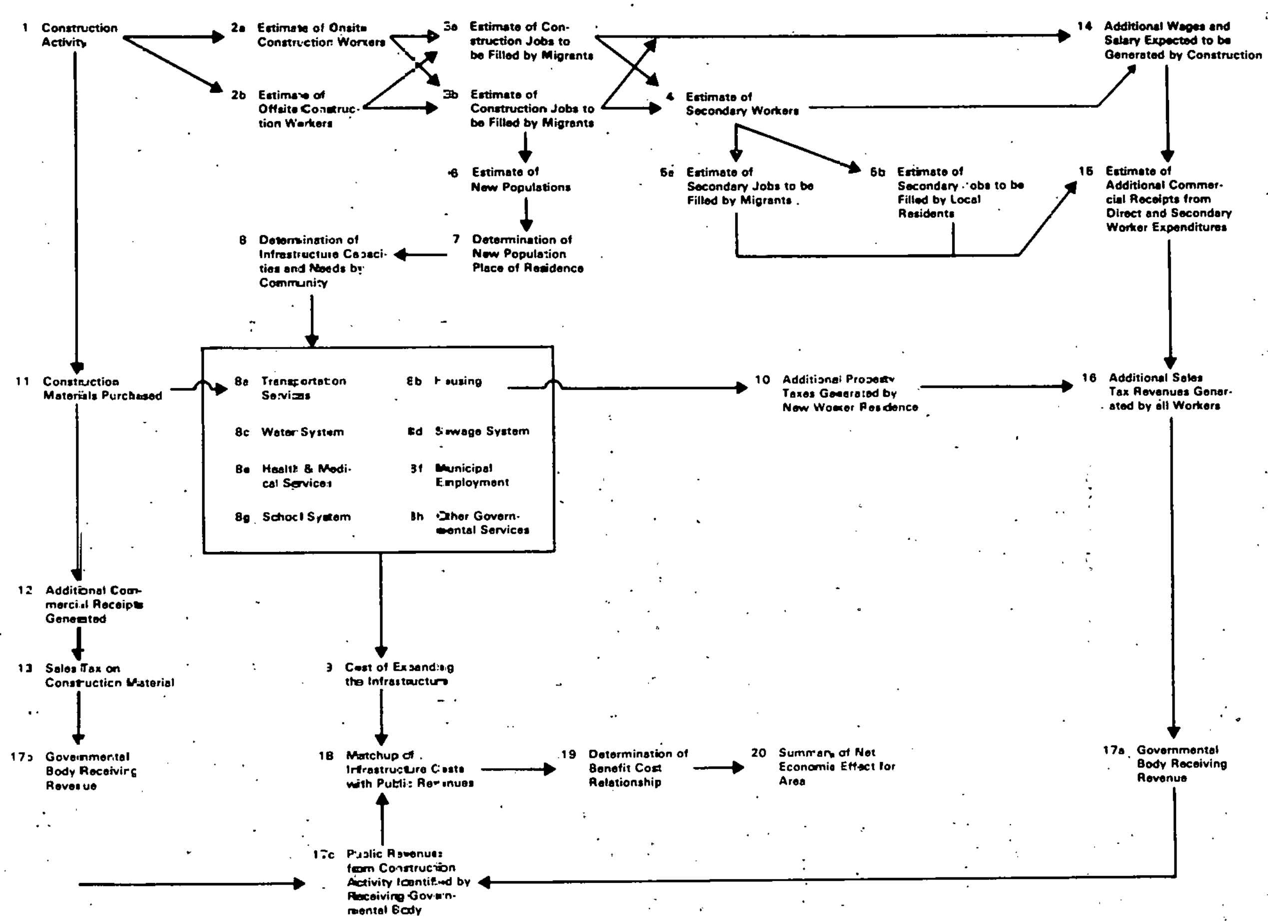


FIGURE 3. Outline of Research Steps for Assessing Socioeconomic Impact of Nuclear Construction

into the area and subsequently choose to reside at one of the several communities within reasonable driving range.

Typically, a 6-year period is involved in the construction of a single reactor which peaks in the neighborhood of 1500 workers for about half of the construction period. Table VI presents a typical work force profile by quarters of the 6-year construction period.

TABLE VI. Typical construction work force over a 6-year construction schedule

Time (in months)	Number of Construction Workers
3	120
6	245
9	370
12	540
15	700
18	850
21	1000
24	1150
27	1300
30	1410
33	1440
36	1460
39	1470
42	1475
45	1440
48	1410
51	1330
54	1250
57	1080
60	910
63	630
66	350
69	180
72	25

With the cumulation of a typical nuclear reactor center construction schedule dependent upon the load forecasts for the area, this worker peak could rise as high as 12,000 construction workers for a considerable period of years for a 40-reactor construction schedule (37 reactors plus WNP 1, 2, and 4). Figure 4 presents estimates of the cumulative work force as construction gets under way in accordance with the schedule shown in Table I. The figure also represents a hypothetical case wherein the construction work force is limited to a maximum of 4500 workers (about that required for WNP 1, 2, and 4 construction) in order that the economy of Hanford would not be so distorted as by a full-scale nuclear construction schedule. Under such constraints only 20 reactors would be constructed over the 30 year period. The numbers on the chart represent the cumulative number of reactors operative at that point in time.

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 is compounded by the uncertainties of estimating numbers of supporting workers plus trade service jobs required to accommodate the direct construction workers. The energy industry sector normally has an employment multiplier of about 2.3 as based on established national input/output tables. However, the construction industry, because of its temporary nature, has a multiplier of only about 0.5.

On this basis then, it is estimated that a peaking reactor work force of 1500 construction workers would generate another 700 to 800 supporting workers. Further, considering the proportion between single and married construction workers plus their supporting workers it can be estimated that construction of one reactor can result in a peak of about 5500 new persons residing somewhere in the construction area. For working convenience, it is assumed that the multiplier for basic construction workers to population is about 3.6. This population coefficient allows for single workers, both construction and indirect, family size, and direct-indirect multipliers.

Based on the assumed energy forecast in Table 1, construction of a 20- or 40-reactor HNEC would start in 1982 and peak about a dozen years later at a level of nearly 12,000 construction workers. If no other construction was scheduled, the peak of 12,000 workers would hold for about nine years for

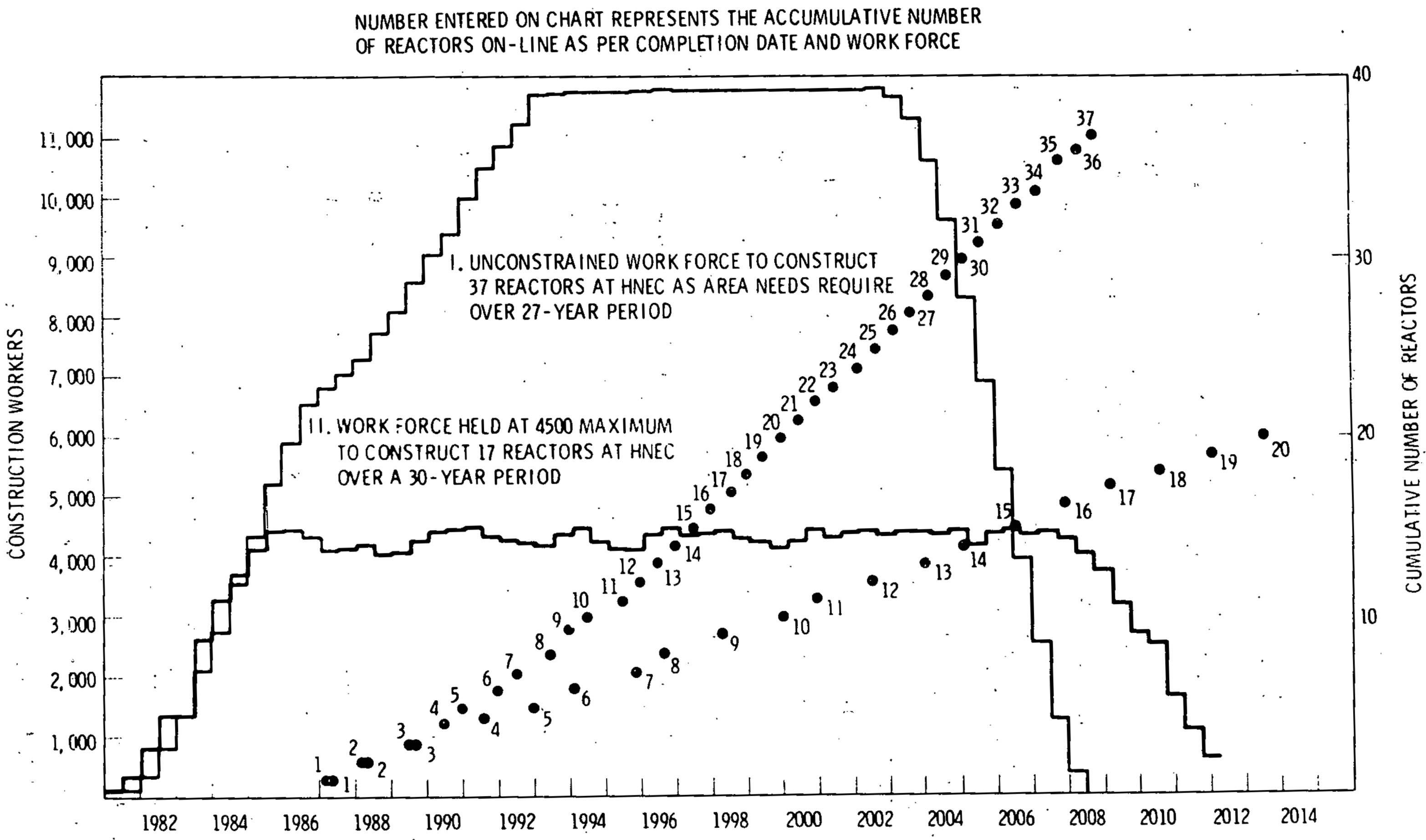


FIGURE 4. Estimate of Hanford Nuclear Energy Center Construction Work Force and Number of Reactors Operative

I. With Operational Dates as per Estimated Energy Demand

II. With Maximum of 4500 Construction Workers at Any One Time the 40-reactor case and for about one year for the 20-reactor case, and decline to 0 within another six years. In either case this job loss of 12,000 workers would be very difficult for any area to live with.

The 12,000 workers represent populations of at least 43,000 (including supporting and indirect workers) as potential out-migrants upon completion of the area's nuclear facilities. This potential drop of some 12,000 jobs and 43,000 persons over a six year period could be devastating to an economy unless the area's "natural" growth, including facility operations, was large enough to mitigate these adverse economic impacts.

Typically, with a project's completion, construction workers move on to new projects but some may choose to find jobs and remain in the area. It is not necessary, therefore, for the community to generate construction jobs for the peak 12,000 nuclear center project workers but rather to develop about an equal number of jobs for the area's total work force and population to remain about the same as during the nuclear center construction peak. Thus, the real crux lies in the timing and whether or not other job opportunities are increasing rapidly enough via natural growth to offset the construction worker loss without there being excess infrastructure capacity over a long period of time.

While the foreseeable problem would be lessened as the area's economy becomes more mature and self-sufficient as trade-service and other supporting activities take over, plus the 100-200 operational workers per reactor, etc., there would still have to be substantial increases in the area's "normal" economic base to offset a 12,000 construction worker job loss.

Among other problems to be faced in this transition period would be the decline in wages, income loss, public revenue declines, increased unemployment payments for those construction workers who chose to remain unemployed in the area, increased welfare costs, etc. An equally severe problem would be the investment costs in the excess capacity in municipal services which would remain unused until natural growth reaches these capacity levels. The public's investment in these infrastructures can be considerable.

An alternative to this problem and a reasonable means to mitigate the short-term construction impact could be planned scheduling of nuclear facility construction to stabilize construction employment at an acceptable level over a period of years consistent with the area's existing labor force size and normal development potential. In the light of Hanford current construction experience where worker totals will peak at about 4500 (for WNP 1, 2, and 4), this case was selected as being at the opposite end of the spectrum. The lower curves in Figure 4 present worker level and nuclear reactor construction for this case. Under the 4500 worker limitation about 20 plants could be constructed over a 27 year period. There are many other cases which could be examined. For instance, as the area's economy expands and becomes more diversified, the construction worker total might be increased from 4500 to 6000.

It is useful to examine some of the social impacts in terms of the economic consequences associated with a typical reactor project. Table VII presents estimates of economic benefit per reactor. When multiplied by the final number of those in an NEC, their totals become even more impressive. Most of the infrastructure costs have to be put in place far in advance of tax revenue generation. Under present conditions, there is no way for required public expenditures to be provided during the construction project. Governing bodies and utilities are becoming more aware of these unfunded costs. It is planned to examine the magnitude of these costs in future studies.

STATION ELECTRIC POWER SERVICE

The transmission of electric power from an HNEC is briefly described in the section titled "Interim Description of the HNEC Concept", and in greater detail in BNWL-B-426 Electric Power Transmission For A Hanford Nuclear Energy Center, September 1975. A second phase of the transmission study was undertaken to examine the requirements for station service to an HNEC.

TABLE VII. Secondary economic impacts associated with construction and operation of a typical nuclear reactor in Washington

Construction Item	Per Reactor
Construction Wages	$ 80,000,000
Indirect Wages	45,000,000
Commercial Receipts	
Construction Workers	36,000,000
Indirect Workers	20,000,000
Construction Materials	300,000,000
Tax Revenues	
Retail Sales	3,100,000
Use (Construction)	7,500,000

Operation	Annual
Operational Wages	$ 1,000,000
Indirect Wages	1,300,000
Commercial Receipts	
Operational Wages	450,000
Indirect Wages	580,000
Operational Materials	250,000
Tax Revenues	
Retail Sales - Workers	23,000
Retail Sales - Facility Purchases	12,500
Property	16,000,000[a]
Gross Sales (Revenue)	3,300,000[b]

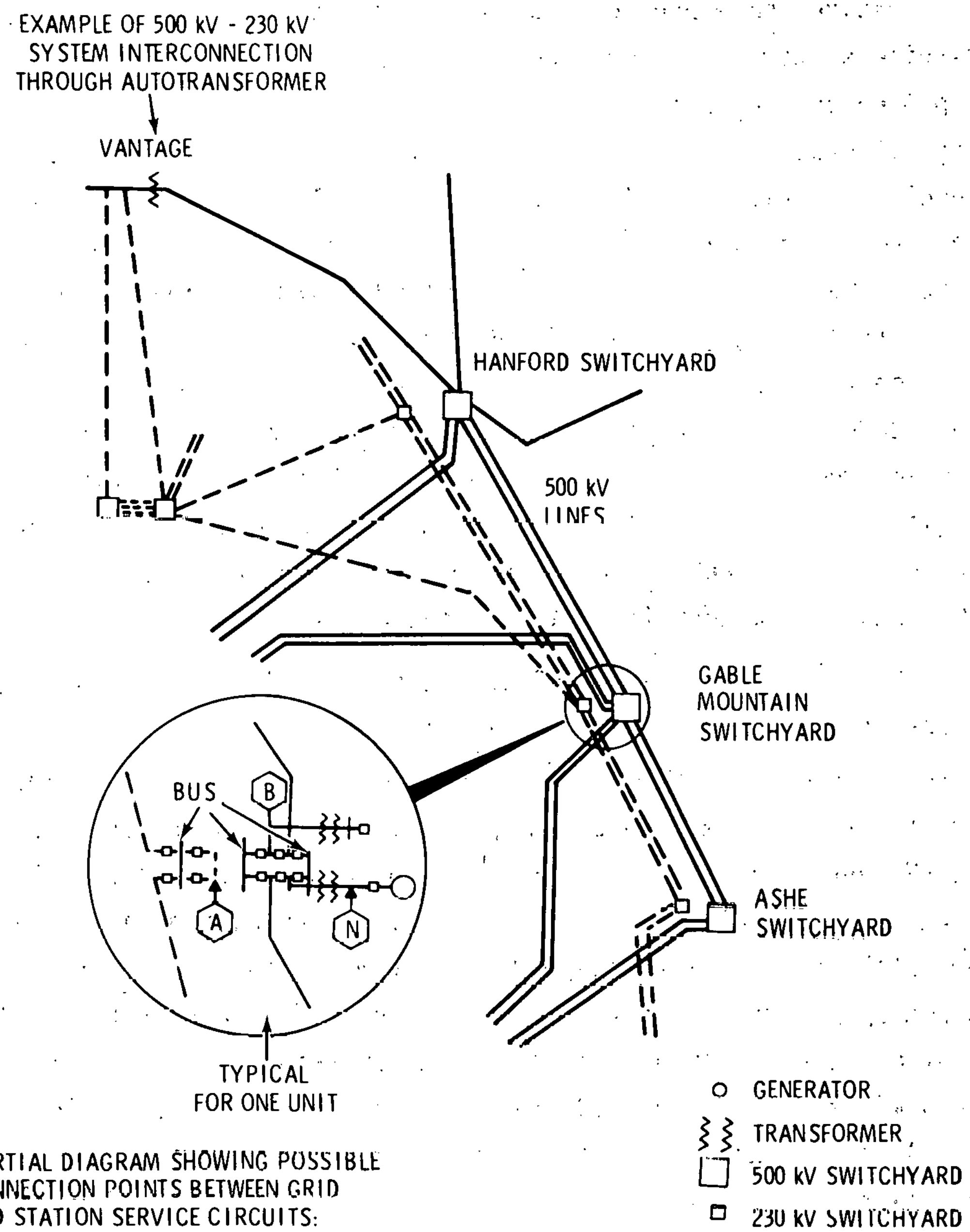
[a] If investor-owned

[b] If public operated

Designs have been developed in the U.S. 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 a 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 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 year 2000 can be envisaged as five groups of generating units with three to five units in each group, served by three 500 kV switching stations (Ashe, Gable Mountain, and Hanford in Figure 1). The power source for the station service circuits could be the 500 or 230 kV systems or the 24 kV generator bus (Figure 5). The bulk power system for the Northwest Power Pool is 500 kV. 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 "alternate" station service supply system for multiple plants in the HNEC situation. The assumed grouping of plants is such that the problems of selecting an "alternate" offsite station service supply are similar to those of three- 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 alternate



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

N NORMAL CIRCUIT

A ALTERNATE CIRCUIT - CONCEPT A (230 kV SYSTEM)

B ALTERNATE CIRCUIT - CONCEPT B (500 kV SYSTEM)

FIGURE 5. HNEC Transmission Systems and Typical Points of Power Supply for "Offsite" Station Service Circuits.

station service circuits in common under normal and abnormal conditions. NRC's restraints on the operation of a generating station when either of its normal or alternate station service circuits is not available, and the low historical failure rates of equipment in the normal supply circuits act to minimize the times when the load must be transferred to an alternate circuit. The study indicated that with a possible connected station load of 1200 to 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 5). In Concept B alternate 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 alternate circuits to serve the station loads of 20 units. The two most attractive concepts were:

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 (6.9 kV is used here as typical of intermediate voltage) transformers at the station buses of each generating station unit.

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 Concepts A and B were compared (Table VIII). 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 alternate circuit lines and equipment and grid reinforcements for 17 additional generating plants at 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 offsite circuits instead of two, and one having a separate generating source to provide an alternate supply for all plants. A plant design with a bifurcated main generator bus would provide a good opportunity for having both offsite station service supply circuits on the generator bus. This combination appears to be 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 VIII. Comparison of characteristics of alternate circuit concepts

Characteristics	Concept A (230 kV)	Concept B (500 kV)
Equipment exposure to failure	More UG cable	More apparatus
Restoration of service within 72 hr	Ability to restore is facilitated by loop	With spare 500 kV transformer, restoration would be possible
Exposure to natural hazards	---equal---	
System stability excursions	---equal---	
Potential power sources in the network	---equal---	
Relaying (electrical separation)	More protective zones separating the sources	---
Required system capacity	Estimate is based on probability	Ample capacity assured at no added cost
Effect of human error	---	Slight advantage
Adaptability for growth	---equal---	
Adaptability for early curtailment of program	Had advantage	---
Economics	---roughly equal---	
Environmental effects	Added 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 load. 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 alternate system.
- Either of the two alternate 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 (alternate 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 which would meet operational and safety requirements are possible but at higher cost and without substantial added benefits.

SAFETY AND RELIABILITY ANALYSIS

As previously stated, the HNEC concept is being studied to develop an improved understanding of nuclear energy centers, their advantages and disadvantages, and to identify research and development needed to evaluate the concept. One aspect of the study is to determine whether there are any added or different concerns for the safety of the public resulting from an HNEC compared to dispersed siting. The analysis applies the many considerations relative to the safety of the public in siting and operating single or multiple nuclear units in dispersed sites to an HNEC. A second aspect of the study -- how the reliability of electric service might be affected by an HNEC -- will be addressed in a subsequent phase of the HNEC study.

It is important to recognize that there are no licensing or reliability criteria governing NECs. Such criteria may not be developed until there is a serious effort to license an NEC. Thus, in considering these two aspects of NECs, it is sometimes necessary to develop the bases for criteria before considering appropriate approaches or solutions to potential NEC problems. In the absence of specific criteria, two general criteria have been used. First, there should be no greater risk to the public with an NEC than with dispersed plants. Second, there should be no decrease in reliability of electrical service from an NEC compared to dispersed siting.

The safety review attempts to identify differences in the consequences to the public resulting from the analyses of accidents from natural and man made events that would presumably be conducted for an HNEC when compared with the normally required analyses for dispersed sites.

In this development, the following were reviewed in considerable detail: The Regulatory Guides including the appropriate Work Plan Reviews, the Design Criteria (Appendix A, 10 CFR 50), Seismology Criteria (Appendix A 10 CFR 100), and the available appropriate standards. Regarding the last item, namely the appropriate standards, some were not available for review and these are noted in reference 7.

Lastly, recommendations from ACRS on siting and safety that might impact safety reviews for an HNEC were reviewed. Included in this were the appropriate responses from NRC.

During the review, it also become apparent that some new considerations result as a consequence of a large concentration of electrical generating capacity at any site. These become added considerations to a generic overview on safety.

One such consideration is the element of time. Normally 20 or 30 years of plant life are accepted when considering dispersed sites and if multiple siting is approved, up to 40 years is reasonable for the site. For an energy center where upwards of 20 large generating facilities are planned, a time interval probably greater than 100 years must be considered. It will probably be a time span of this amount from the time the first unit is considered until the last unit approaches decommissioning. This assumes that none of the original units are replaced along the way.

A 100-year (or more) time span can create different parameters for long-term meteorologic effects or population density studies, for example. In fact, wherever the frequency of occurrence parameter is a factor in an accident or safety analysis, the long-term time consideration for an HNEC or any energy center may be an input unique to the analyses completed for an HNEC.

Also to be included now as factors are safety concerns resulting from LMFBRs eventually becoming part of the generating system and facilities supporting other parts of the fuel cycle being located at the HNEC.

Another general parameter specific to an HNEC is the relatively long distances (several or more miles) possible between quads (four generating stations). This results from the relatively large area available at HNEC with relatively extensive portions of it as yet uncommitted to any other activity. Thus, the quads may be considered as separate entities because of the distance between them, in which case existing guides and siting requirements may be applicable, at least for smaller, 20-reactor HNECs.

To support this observation, some additional specific analyses may be required. These may include, for example, both long-and short-term effects of a significant accident at an operating reactor, the potential on an HNEC of a serious release from activities of the nearby weapons waste management program, the acceptance of a long-term commitment of the Columbia River as a coolant, the potential for releasing radioactivity to the Columbia River as a result of an accident concurrent with flooding, security measures at an HNEC, and the decommissioning requirements.

Thus far, there appears to be no evidence that the safety of the public will be affected more by concentrating reactors at an HNEC than dispersing them throughout the region they would serve. This conclusion is similar to other conclusions reached in other NEC studies. At Hanford as at other nuclear energy center sites the safety impact on the public by siting 20 reactors in the area will perhaps be even less than if dispersing them throughout the region. This would result from the greater land area available at Hanford, the added distance from population centers and the sparseness of population.

Some design criteria, regulatory guides and other nuclear standards recognize and include multiple siting of reactors. Grouping nuclear generating facilities in units of four (or five) has been addressed. However, locating four or five such groupings in the same locale such as at Hanford can be expected to receive special attention of regulatory bodies. But, because of the size of the area that permits several miles between quads, plus the remoteness of the area from population centers, no limiting features or excessive design requirements have been established to date.

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