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HANFORD AS A SITE FOR A CONTROLLED
THERMONUCLEAR POWER PLANT
PROTOTYPE

PREPARED FOR
THE UNITED STATES ATOMIC ENERGY COMMISSION
UNDER CONTRACT AT(45-1)-1830

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BATTELLE-NORTHWEST
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HANFORD AS A SITE FOR A
CONTROLLED THERMONUCLEAR
POWER PLANT PROTOTYPE

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December 1970

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HANFORD AS A SITE FOR A CONTROLLED THERMONUCLEAR POWER PLANT PROTOTYPE

INTRODUCTION

Recent advances in the field of controlled thermonuclear fusion plasma research indicate that the next generation of research machines may demonstrate controlled thermonuclear fusion. Briefly, current laboratory devices have, within the past two years, achieved a combination of confinement time, plasma density, and plasma temperature which is several orders of magnitude higher than the level which researchers had once postulated was a theoretical limitation. In addition, this recent breakthrough puts scientists within two orders of magnitude of a sustained reaction.

Fusion concepts operate on one or more of the following reactions:

The requirements in temperature are sufficiently lower for the $({}_1\text{H}^2, {}_1\text{H}^3)$ reaction that one could expect initial success with this reaction.

Certain basic characteristics of a Controlled Thermonuclear Power Plant (CTPP) can be envisioned. Large super-conducting magnets will be required for plasma confinement. There will be significant quantities of tritium to be separated and confined. The power plant size will be in the thousands of megawatt range. It will have a liquid metal or gas coolant operating at $\sim 1000^\circ\text{C}$ with perhaps a liquid metal topping turbine and a steam turbine.

Although it will be some time before a detailed design of a fusion reactor will be available, the general design criteria for a fusion reactor can be discussed. Experimental efforts to date have included work on toroidal and mirror (i.e., long straight tube with magnetic mirrors at the ends) machines. These current experimental machines are at a stage of development relative to actual power plants similar to what CP-1 was to the LWR. The center of the plasma region would consist of stripped deuterium and tritium atoms heated to millions of degrees and held in a vacuum. The plasma would be surrounded by a vacuum wall of niobium or molybdenum. This wall would be surrounded by a moderator/coolant region that could be made of graphite and liquid lithium. The lithium could act as a coolant and breeding ground for tritium and is followed by a combined heat shield and radiation shield. Surrounding the shield region, powerful superconducting magnets provide the magnetic bottle required to confine the plasma.

If controlled fusion is about to be a reality, one can make some guesses as to how the program might progress based on the previously successful fission reactor program. The results of an initial review are summarized in Figure 1. This timetable anticipates a prototype construction start in 1982. Initial site preparations might begin in 1980. Therefore, a site would have to be selected by the mid- or late-1970s. This report was developed on the basis of such a projected need.

There are two safety considerations of importance connected with a CTPP. They are:

- Tritium leakage to the environment.
- Energy release from liquid metal coolant.

The stored energy within the fusion core itself is so small that any sort of destructive run-away accident cannot be envisioned. Moreover, all deviations from normal operating conditions tend to depress the reaction.

Figure 1
Simplified Time Table
for
Controlled Fusion Development

Tritium release from a CTPP is likely to be significant. Current estimates show that the leakage can easily be within an order of magnitude of the federal regulations.

The potential energy release from a CTPP cooled by liquid metals is theoretically very large. Putting aside for the moment the difficulties in achieving these high theoretical energy releases in an accident situation, it can be readily shown for a 5000 Mwe plant cooled by liquid lithium that the potential energy release is of the order of 3×10^6 Mw-sec (700 tons TNT). Such an energy release could involve the subsequent release of significant radioactive material.

The implications of the above considerations on the siting of a prototypic CTPP are significant and are reflected in the parameters discussed in this report.

SUMMARY

Because of the speculative nature of the design configuration, site criteria for a controlled thermonuclear power plant (CTPP) have not been developed yet. However, based on experience with fission powered plants, one can develop site criteria which are probable for such a machine. These criteria are discussed below relative to the Hanford Site:

- ① Land--Hanford has available more than 150 square miles of government-owned land that readily meets probable topographic, geologic, and seismic criteria. There is also available ample room for cooling ponds. This huge section of land will probably meet any isolation criteria set. A large land requirement is generated by the possibilities of significant energy release or radioactive release during potential accidents.
- ① Power--Hanford has surplus electrical capacity already installed to meet the demands of the largest prototype--at the lowest rates in the U.S. The available power grid, because of its large hydro-generating capacity, is also ideally suited for maintaining its integrity in the face of the large transient behavior of prototype operation.
- ① Water--The Columbia River offers the largest supply of pure, cold water in the U. S.; there are excellent surplus reactor water plants available.
- ① Potential By-products--there are potential by-product concepts which would be uniquely applicable at the Hanford site. These concepts include fusion/fission, plutonium breeding and fission product destruction.
- ① Unique Site Capabilities--Hanford has a variety of unique capabilities available for application to CTPP siting problems. These characteristics include safety considerations and exploitation of existing facilities.

- Transportation--two major railroads have direct connections to the Hanford Project rail system; multi- 1000-ton barge service is also available. There is excellent highway access to the area.
- Manpower--a high level of scientific and technical personnel as well as construction and craft labor is already in residence.
- Services--complete support-type services, such as industrial shops, bus transportation, radiation protection, and plant security, are immediately available. There is available locally ample experience with large scale specialized construction.
- Community--the area has an exceptionally high education level, equal to the outstanding areas of the U.S.

In total, the many tangible assets of the Hanford Project offer potential dollar savings in the development of a prototypic power plant. Shutdown of the large production reactors makes many millions of dollars worth of excellent support facilities and manpower readily available.

INTRODUCTION TO THE HANFORD PROJECT

The Hanford Project is a complex of production, research and development, and supporting facilities; it covers a 575 square mile area of southeastern Washington (Figure 2). For more than twenty-five years Hanford was the chief producer of plutonium in the United States and was operated by the General Electric Company as prime contractor. In January, 1964, when a decision was made to curtail production and shut down three of the nine plutonium production reactors by mid-1965, a planned segmentation of Hanford to different contractors was begun. At present, Hanford contractors include Douglas United Nuclear as operator of the production facilities, Battelle-Northwest as operator of the

R&D laboratories, WADCO Corp. as contractor for LMFBF and related research, Atlantic Richfield as operator of chemical separation plants, J. A. Jones Co. providing construction services, Computer Science Corporation as contractor for data processing, and ITT providing general support services to the contractors.⁽¹⁾

SITE QUALIFICATIONS

Certain factors have been considered in developing the qualifications of Hanford as a potential site for a large Controlled Thermonuclear Power Plant (CTPP). The primary factors considered were:

- Land
- Power
- Water

Secondary factors considered include:

- Transportation
- Manpower
- Services
- Community

These factors are discussed in detail below.

Availability and Characteristics of Land

Land Areas and Potential Sites

The Hanford Project with three typical site areas shaded is shown in Figure 3. In each of the two northern areas, a 10 square mile land area is available which is level to within thirty meters. The shaded area to the south is approximately 130 square miles. Each of these shaded areas satisfy other land criteria discussed below. Therefore, there is more than sufficient land at the site for such a project.

Geological and Topographic Characteristics

The geology of the Hanford Project is characterized by three rock formations. The Columbia River Basalt series forms the bedrock of the region. The thickness of the basalt series is estimated at about 15,000 feet. The Ringold formation generally overlies basalt at a depth of about 500 feet. Gable Mountain (Figure 3) forms an anticlinal basalt ridge. Other local basalt out-croppings are found in the center of the northwestern shaded area (Figure 3). Late Pleistocene to recent fluvial and glacio fluvial sediments overlie the irregularly eroded surface of the Ringold Formation. The foundation materials are unconsolidated, but compact, sandy gravels and gravelly sands. They can be excavated at low-cost. The subsurface conditions in all three shaded areas (Figure 3) are indicated by representative sections at the indicated locations where wells were drilled to obtain geological and hydrological data. Bearing strengths of the undisturbed gravels and sands are consistently in the range of 6.5 tons/ft². Greater loadings may be possible but in any case could be provided by spreading the footing or localized use of piling.

Seismic Stability

The need for very good ground stability at a CTPP site is most obvious. The Hanford region is seismically a very stable area. This stability, which has been a significant safety and economic consideration in the continued location of large production reactors at the site, is most likely the result of the thickness of the basalt series. Tectonic stresses that develop appear to be relieved by basining and folding; hence, faults at the surface and at depth appear to be of minor significance. Interpretations of seismograph records have not indicated epicenters in the immediate Hanford area. Many earth tremors have been recorded by Hanford reactor instruments but in nearly all cases they have been correlated to known quakes throughout the world.

Figure 3

Hanford Project Showing Possible CTPP Sites

The potential of damage to substructures exists, but appears to demand earthquakes originating locally and emitting waves that are amplified as they pass through the basin-fill sediments. Such amplifications, by resonance, can take place with waves of about 0.2 second period. Waves of that period are normally damped out in passage through sediments, and only the longer-period waves are propagated. Therefore, a local source is required. If buildings with similar period of vibration lie in the wave path, they could suffer damage from a low intensity earthquake of this description. This vibration period should be avoided in Hanford site construction. More details of seismic investigation of Hanford are given in Reference 2.

For comparison of the seismic stability of the Hanford region, the expected probability of earthquake damage is about the same as that at the National Reactor Testing Station, and both probabilities are quite low. For building code purposes, the entire area east of the Cascade Mountains in Washington is in Zone 2 of the Seismic Probability Map.⁽³⁾ However, for construction of power plants, a horizontal acceleration of 0.3 g instead of 0.12 g as called for by Zone 2 should be used.

Water Table

Large construction items can require a stable water table at least 30 feet below the minimum ground level. This allows for construction of sub-basements with adequate foundation and, in addition, gives the flexibility to use underground construction for shielding purposes. The shaded areas in Figure 3, represent possible prototype sites which satisfy this criteria. Typical depths are shown in the indicated drillings. There has been discussions for many years of the addition of a dam (Ben-Franklin) on the Columbia River at a site a few miles north of Richland. Current plans make this unlikely. However, if it is built, the anticipated change in ground water table would mean only an insignificant part of the southernmost site would no

longer meet this criteria. Further details of ground water table at Hanford can be found in Reference 4.

Electrical Power

The electrical power requirements of a large prototypic fusion device can be discussed in two parts. First, there are general house load requirements whereby the prototype draws on the power grid for electricity to operate its systems during periods of testing and maintenance while the device itself is not operating. In addition, there are the transmission requirements of the prototype to be considered. These requirements include a system stable enough to withstand the potentially large transients resulting in the testing of the device and also the ability to transmit the large blocks of power to be generated at the site.

Prototype designs being considered in the literature are in the range of 5000 Mwe⁽⁵⁾ although the first prototype might be somewhat smaller. Typical values for a ratio of fusion power to injection power are of the order of 20. A 5000 Mwe device would then require 250 Mwe for injection power. This number could be considerably larger if the injection efficiency were appreciably less than 100%. In addition, one can estimate the power requirements of the conventional power plant to be of the order of 5% of the gross. This requirement would be 250 Mwe for a 500 Mwe prototype. Therefore, the total requirements for such a prototype could be at least 500 Mwe or larger.

The Pacific Northwest is unique in its ability to provide these large blocks of electrical power at the lowest possible cost and at high reliability. The power at Hanford is purchased from the Bonneville Power Administration, whose inter-connecting transmission system integrates with the Northwest power pool. Hanford is connected into the power pool through the Bonneville Power Administration Midway Switching Station located near the northwest boundary of the Project (Figure 4) and the N system 500 kv lines.

Three interconnected 230 kV lines from Midway form the primary power network serving the plutonium production areas. Because of the shutdown of seven Hanford production reactors by mid-1969, essentially the full power-carrying capacity of two existing lines would be available for power. There are also three 500 kV lines which have been installed to N-Area (See Figure 4). Additional lines are expected to be added with the construction of Hanford-2. A CTPP located in a northern site of the Hanford Plant would require essentially no construction cost for transmission lines. A CTPP site at the extreme southern end of the Plant would require at most 15 to 20 miles of installed line. Cost of construction for 500 kV lines would be of the order of \$125,000/mile which is quite low.

Electrical power distribution for the Hanford Project is administered by ITT, Federal Support Services. Partly because of the large load required at Hanford, electrical power costs are of the order of 2.4 mills/kw-hr. This rate is far below that available elsewhere in the U.S. (Table I). The electrical costs at other AEC sites as of 1965 are shown in Table I for comparison.

If the prototypes built are actually of the order of 5000 Mwe, the transient stability problems connected with the transmission system will be formidable. The Pacific Northwest power grid is perhaps unique in the U.S. in that a high percentage of its base power generating capacity will be of the hydro-electric form for some time to come. The hydroelectric plant is recognized to have the quickest response to system transients. The Pacific Northwest grid is thus admirably equipped to handle expected power transients developed by the prototypic nature of the device.

TABLE IELECTRICAL COSTS

<u>Site</u>	<u>Average Cost*</u> <u>Mills/kwh</u>
San Francisco	9.92
Brookhaven	11.05
Argonne	9.85
Idaho Falls	6.52
Oak Ridge	4.13
Denver	10.08
Albuquerque	12.0
Hanford	2.41

* As of Jan. 1965.

FIGURE 4
Existing Electrical Power

Finally, prototypes of this size require transmission systems capable of distributing and utilizing large blocks of power. With the advent of the California intertie, the Pacific Northwest transmission system will be more than adequate for this job.

Coolant Water

One consideration which led to the original location of the Hanford Project was the use of Columbia River water for reactor coolant. Columbia River water is relatively pure; it has the lowest silt rate of any major river in the U.S. The flow rate is high, ranging from about 35,000 to 430,000 ft³/sec and averaging about 120,000 ft³/sec. The water stays fairly cold throughout the year with maximums less than 70 F in July and minimums of about 39 F in January.

The above facts indicate that a more than adequate heat sink exists for a prototypic CTPP at the Hanford site. Cooling ponds, if required by changing environmental considerations, can be readily located in the area due to available land. Additionally, a potential agro-complex based on irrigation by waste heat water is possible in areas close to the site.⁽⁶⁾

POTENTIAL BY-PRODUCTS

One of the characteristics of the proposed CTPP is that it is a neutron-rich device. That is, it can have a potential breeding ratio of 1.3 or higher for the production of tritium. However, one would probably want to operate with a breeding ratio slightly in excess of 1 shortly after initial startup. Excess tritium would have limited usefulness and could constitute a hazards problem.

There are potential applications for this source of excess neutrons which would be particularly appropriate for the Hanford site. One of these potential applications would be as a fission product burner. There are stored at Hanford significant quantities of fission products which could be used to form the basis of an experimental program to develop means of burning stored fission products by neutron activation. If the process were developed sufficiently, there are significant quantities of fission products available on site for an extended program. It can be shown that only a fusion device will have sufficient neutron flux to even consider such an approach. This could prove more economical to the AEC than the current storage program. An associated potential by-product could be utilization of local R&D expertise in all phases associated with the project.

Another application could be in the production of cheaper plutonium. The 14 MeV neutrons, with a flux of the order of 10^{15} , generated by the device could be easily moderated to resonance energy neutrons with a corresponding high production of high grade plutonium. With the advent of the nuclear park concept at Hanford, there will be more than sufficient reprocessing capability on site to handle this plutonium. The combination would result in an extremely economical source of plutonium for fission reactors when coupled with other capabilities uniquely available at the Hanford site. It appears that, in principle, a CTPP could, in addition to carrying out its role as a power source, produce enough plutonium to service one or more fission plants.

UNIQUE SITE CAPABILITIES

Unique Hanford site capabilities can be discussed relative to two areas. These areas are:

- Safety considerations.
- Exploitation of existing facilities.

These considerations are discussed below in a summary manner. Additional information on these points can be made available.

The primary safety consideration associated with the operation of a CTPP probably would be accidental release of significant inventories (10-200 kg) of tritium to the environment. The Hanford site has demonstrated proper and proven subsoil characteristics for dealing with inadvertent tritium release. As a result of the operation at Hanford over several years of fuel reprocessing facilities, there is a significant tritium deposit in the soil beneath the reprocessing plants on the Hanford site. This deposit has been extensively studied and found to have stabilized after 8-10 years from initiation. This stabilization in the growth of the deposit reflects the half-life of the isotope and also the soil and ground water characteristics of the site. The deposit stabilized long before it reached river water sources. It has, therefore, been adequately contained within the site. This capability should be a significant consideration on CTPP siting. The other safety consideration, liquid metal energy release with possible radioactive contamination is also compatible with the Hanford site.

The Hanford site is sufficiently isolated from large populated groups so as to make the operation of a CTPP at that site an extremely low risk venture for the general public almost independent of the particular hazard under consideration.

A substantial number of facilities at Hanford are now surplus due to the shutdown of seven production reactors. These facilities include large buildings that could be used for assembly and storage, steam-generating plants, water treatment plants, and others. For further information on this subject the AEC-GE Study Group has prepared a complete listing of available facilities. (7)

TRANSPORTATION

Freight

The CTPP construction would probably require the shipment of large equipment items weighing many tons. Again, Hanford has much to offer. At present two barge lines provide daily service from Pacific Coast ports to the Port of Pasco, 15 miles south of Area 3 (Figure 3). Loads of 1000 tons or greater can be barged into this area. With the John Day Dam on the Columbia River, slack water with a minimum depth of 15 feet exists between Hanford and the Pacific Coast and results in an extensive barge capacity.

Ground freight transportation is also good, both to the Tri-City area and within the Hanford Project. Hanford has 270 miles of primary roads, 175 miles of secondary gravel roads, and 225 miles of gravel and unimproved roads. It also has its own rail system with 150 miles of track. There are four major highways serving the Tri-City area; a new highway has been completed to provide better access to Seattle; and a new interstate highway from Seattle will go through, or near, the Tri-City area. The Tri-Cities is a major rail center. It is served by the Union Pacific and Burlington Northern railroads.

Personnel

It may be desirable for a project the size of a CTPP prototype to be near a major airline terminal. However, the distance from a metropolitan terminal to final destination may have little relation to the travel time required. Most remote potential power plant sites are 1 or 1-1/2 hours away from metropolitan terminals. Hanford is no exception. Major jet terminals for the Tri-City area are Portland, Oregon; Seattle, Washington; and less frequently Spokane, Washington. Air West Airlines provides jet connections from Pasco to these terminals in about an hour's flying time. It is possible that connecting services would be

improved if the demand associated with a CTPP were sufficiently large. In any case, it is usually possible to reach any destination within the United States within one days travel.

SUPPORTING SERVICES

Hanford is an industrial site with some 10,000 employees. Included in the complex are the J. A. Jones Co., which provides plant construction services and manages a large machine shop; the Battelle-Northwest and WADCO laboratories with many assorted fabrication and development shops; and other shop services in the Chemical Processing and Reactor Plants. In the segmentation of Hanford the supporting services were assigned to ITT Federal Support Services as a contractor. These support services include:

- ⑥ Fire Protection
- ⑥ Security Guards
- ⑥ Contaminated Laundry Facilities
- ⑥ Bus and Rail Transportation
- ⑥ Electrical Power Distribution
- ⑥ Plant-Wide Telephone System
- ⑥ Printing, Central Warehousing, etc.

The United States Testing Co. provides radiation film badge processing and other services. Electronic Data Processing service is provided to area customers by Computer Sciences Corporation. Extensive radioactive waste disposal services are available at Hanford. A large pipe-fabrication plant is operated in the Tri-Cities. Further information on these and other industrial activities in the Tri-City area can be obtained from the Tri-City Nuclear Industrial Council.

The Tri-City Community

Many of the readers of this report are undoubtedly without knowledge of the characteristics of the Hanford area. For those, we have summarized a few of the attributes which we feel would be of most interest.

Population

- Adjacent to the Hanford Plant are the Tri-Cities of Richland, Kennewick, and Pasco, Washington. Each community is similar in population with a total of about 100,000. Many Hanford employees live in Kennewick and Pasco which are 8 to 10 miles further away from the Project than Richland. When all housing in Richland was government-owned many people moved to these communities to obtain private housing. Others continue to locate there for a variety of reasons.

Education

- The technical work force at the Hanford Plant has resulted in an educational level of the population of the Tri-Cities which is abnormal for a community of this size. There are some 3500 college graduates in the area representing over 2500 technical degrees. For comparison, the per capita ratio of professional people to total work force in the Tri-Cities is approximately equal to that of the Boston or San Francisco areas.
- The Tri-City schools are among the top in a state which consistently ranks among the top three in the nation by the standards of the National Educational Association. The State of Washington ranks ninth in expenditures per pupil. Each city has six or seven elementary schools, two junior high schools, and one or two high schools. There are Catholic parochial schools

for Grades 1 through 8 in each city, a Lutheran parochial school in Kennewick, and Seventh Day Adventist parochial school in Pasco. Libraries, cafeterias, gymnasiums, spacious outdoor playgrounds, and athletic facilities are to be found in nearly all schools. The excellence of the public school system in the Tri-Cities has always been an attraction to the scientists who have located at Hanford. Columbia Basin Junior College is fully accredited for freshman and sophomore work with both the University of Washington and Washington State University. The college accommodates more than 3000 students with day and night classes. Adult evening education classes offering extensive academic, vocational, and business training are conducted by the school systems in Pasco and Richland.

The need for continued association and participation in university research and course work is obvious both for the professional scientist and the scientist-in-training. The need has been recognized at Hanford. The AEC at Hanford has always sponsored graduate course work in arts and sciences. Some laboratory work has been provided but this has been limited. This graduate program is now administered by the University of Washington as the Joint Center for Graduate Study at Richland. Washington State University and Oregon State University also share in administering this activity. The lectures for the Center are provided almost exclusively from the professional staff at Hanford which includes some 140 Ph.D.s. In addition, regular lectures on topics of scientific interest are held in the Tri-Cities area under sponsorship of the ARCHO company. These lectures are given by experts from throughout the world. As an indication of

the effectiveness of this small graduate program, an incomplete survey indicates that some 18 former students and Hanford researchers in physics alone have subsequently received Ph.D degrees at universities throughout the country.

- Excellent library systems are operated in each city. These libraries are stocked and operated in keeping with the high standards of the area schools. Movies, recordings, and art works are loaned. Usage of the libraries reflects the high level of intellectual interests of area residents. For example, the use rate in Richland is three times the national average. The Hanford Project Library, administered by Battelle-Northwest, is one of the best-equipped technical libraries in the U.S.

Living, Recreation, Climate

- People living in the Tri-City area may choose between urban or rural living and may rent, buy, or build homes of their choice. Many residential districts with excellent new homes exist throughout the area.

- Each city has a community concert series with visiting artists. The area supports a symphony orchestra of community artists. There is a "little theatre" group which owns its own theatre, a number of choral groups, and an amateur light opera company.

- Mountain ranges on all sides of the Columbia Basin form a protective weather barrier which results in a mild, very dry climate with moderate winters and warm summers. The region is ideally suited for outdoor living more than six months of the year and visibility is seldom less than 10 miles.

CONCLUSIONS

Several conclusions can be made relative to siting a Controlled Thermonuclear Power Plant at Hanford and indeed, conclusions can be made as to the timing of

such a need. These conclusions, in summary form, are given below:

- A site should be selected for a CTPP probably before 1980.
- If the usual constraints on large prototypic power sources hold true for the CTPP, the Hanford site qualifications in terms of land, power, water, transportation and so forth are excellent.
- As far as the safety requirements can be defined, the Hanford site has a demonstrated capability for coping with them.
- The Hanford site has some unique features capable of enhancing such an undertaking which cannot be readily found at other sites. These include exploitation of existing facilities.
- The Hanford site has a large cadre of technologically trained personnel well versed in the problems of putting physical theory into engineering practice.

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