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JOHN K. HARTSOCK 9/5/79
REVIEWED BY DATE

Ern Halzer, D.D., 50-10.23, 10/24/05

MANHATTAN DISTRICT HISTORY

BOOK IV - PILE PROJECT

X-10

VOLUME 3 - DESIGN

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31 December 1946

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EJ Thurin
2-17/57

FOREWORD

This volume of Book IV of the Manhattan District History presents a brief discussion of the design features of the Hanford Engineer Works and deals with the period between 1 February 1943 and March 1945, or between the initial statement of design requirements, as defined by research and development work, and the completion of final drawings and blueprints for construction. Minute details and highly technical discussions have been avoided, wherever possible, in an effort to present a clear, comprehensive history of the unique design problems.

Since it was often necessary to formulate plans for process equipment and buildings without the benefit of a sufficiently detailed research program, it has been necessary to include in this volume some material which might well have been included in Volume 2.

A rather detailed description of the design of Richland Village has been included in this volume. Photographs presenting a complete picture of the completed Hanford Engineer Works may be found in the appendix material of Volume 6.

The summary contains an abstract of every major subject treated in the main text, which is considered to be sufficient for the reader who is not interested in the actual design details. This summary is keyed to the text in such a manner that paragraph headings and numbers in the summary refer to the various sections in the text.

Supplementary material and references, necessary to a clear understanding of the narrative, are presented in four appendices bound in a separate cover. Appendix references have been made in the text as a

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combination of letters and numerals; the letters denote the appendix divisions and numerals refer to the position of the item in the particular appendix. Thus (See App. A 12) would refer to Appendix A, item 12 of that appendix.

Other phases of the history of the Pile Project are described in:

Book IV - Volume 1 - General Features
Book IV - Volume 2 - Research
Book IV - Volume 4 - Land Acquisition
Book IV - Volume 5 - Construction
Book IV - Volume 6 - Operation

[redacted]

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MANHATTAN DISTRICT HISTORY

BOOK IV - PILE PROJECT

VOLUME 3 - DESIGN

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SUMMARY

1. **Introduction.** - The Hanford Engineer Works for the production of plutonium and the separation of plutonium from uranium and fission by-product elements was designed by the E. I. du Pont de Nemours Company on the basis of information furnished by the Metallurgical Laboratory. The design proceeded generally abreast of process development and, in one case, permitted the use of either of two processes which offered the best prospects of successful operation. Production units were of unusual design since the processes necessitated remote operation and shielding of personnel from radioactivity. Although standard equipment was used wherever possible, much of the equipment was of original design. Changes in design were effected where necessary to facilitate operation.

2. **Site Criteria and Selection.** - Preliminary work on the production and separation of plutonium had shown that, because of the requirements of the most feasible manufacturing processes and the possible dangers accompanying the handling of large quantities of radioactive materials, the plant site must satisfy certain requirements:

1. A manufacturing site of approximately 12 miles by 16 miles.
2. No town having a population greater than 1,000 nearer than 20 miles, or public highway or railroad nearer than ten miles to the manufacturing site.
3. Available water supply of at least 25,000 gallons

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per minute.

4. An electrical supply of at least 100,000 kilowatts. Also to be considered were the load-bearing characteristics and value of the land, ease of access to railroad and highway facilities, and availability of fuel and concrete aggregates. Preliminary investigation by the Corps of Engineers and the du Pont Company showed that the large power requirement limited the site choice to the Pacific Northwest, or the Pacific Southwest. After inspection of the various proposed sites it was found that the region near Hanford and White Bluffs, in southeastern Washington, most nearly met the site requirements. This semi-arid region is located beside the Columbia River, one of the largest rivers in terms of water flow in the United States, and is near the Midway Station on the 230 kilovolt lines between Grand Coulee and Bonneville Dams. The manufacturing area is relatively level; the nearest community of any size is Yakima, about 40 miles to the west; and concrete aggregates are available on the site.

3. A Brief Description of the Operating Plant. - Because of the hazardous nature of the processes, the production areas of the Hanford Engineer Works were, of necessity, designed as independent units to be constructed in widely separated districts. This decision was made in order that accidents in any one area should not affect the operation of the remaining units. There are six areas in which these facilities are located. There is one Metal Fabrication and Testing Area where the uranium feed material is machined into slugs and canned for charging into the Pile units. This area also contains elaborate facilities for the testing of all materials and

instruments used in the transmutation and separation processes. The three Pile Areas contain the transmutation units, each of which is composed of carefully machined graphite blocks pierced by 2004 aluminum tubes, into which the canned uranium slugs are charged, surrounded by shielding to protect personnel from radioactive emissions. Cooling water is forced through the annulus between the aluminum tube and uranium slugs to remove the heat generated by the reaction. The water system is designed so that, should either the electricity or steam fail, pumping would continue at an adequate rate. To insure pure water and thus avoid corrosion problems, rather complete water treatment facilities are provided. A helium circulation system is used to remove air, moisture, and impurities from the Pile structure. The two Separation Areas contain three Separation Plants (each of which includes a Separation Building and a Concentration Building) and an Isolation Building. Elaborate shielding and remote operation and maintenance are necessary in the Separation Buildings because of the intense radioactivity encountered in this phase of the process. The Concentration Buildings and the Isolation Building are equipped for more direct operation and with less shielding. Storage has been provided for waste process solutions since their radioactivity precludes discharge into the Columbia River. Buildings for the storage of irradiated uranium intermediate to the transmutation and separation processes and a vault for the storage of the final product are included in the Separation Areas.

4. <u>Metal Fabrication and Testing Area.</u> - A Metal Fabrication and Testing Area was designed where the uranium metal could be machined

and canned by enclosing the short uranium segments in an aluminum sheath. In this area all the equipment could be of standard design with slight modifications because of the properties of uranium. Also included in the design of this area were: a test Pile, similar to those at Argonne and Clinton Laboratories; a semi-works Separation Plant, employing working models of actual production units; and a variety of shops and laboratories. Since none of these activities involved high levels of radioactivity, these facilities were grouped in this one area at a distance from the hazards of the other production areas.

5. Pile Area. - The problems that had to be solved in order to make the Pile Project feasible were:

1. To determine the conditions for a controlled, self-sustaining reaction.
2. To secure adequate amounts of primary materials of sufficient purity.
3. To develop methods for operating the reaction at high power levels, and to put these methods into operation.
4. To extract and purify the plutonium from the fission products.
5. To maintain health and safety during the process.
6. To produce useful bombs of plutonium.
7. To accomplish these results in time to be of military significance.

A self-sustaining, controllable reaction was established on 2 Decembe

1942 at the Metallurgical Laboratory. Procurement of materials was narrowed down to graphite and uranium and it appeared as if these two could soon be obtained in reasonable quantities. Although a graphite Pile with a uranium lattice and helium cooling appeared to be the most feasible, designs were drawn up for several other types, including a heavy-water plant, an enriched-uranium plant, a uranium hexafluoride-cooled plant, a molten bismuth-cooled plant, and a water-cooled plant. A heavy-water plant was eliminated from consideration as a manufacturing unit since no large quantities of heavy water would be available for some time. An enriched-uranium plant would have required something like 40 pounds of additional uranium-235 or plutonium-239, neither of which was available. Although it seemed as if a molten bismuth-cooled plant would operate at high power levels, the technical problems to be solved were much more complex than those involved in the design of other types of plants.

The du Pont Company originally accepted the helium-cooled plant as the one for which design could be carried through most quickly. However, after further study, this choice was abandoned because of the hazard of leakage of high-pressure coolant, the difficulty of procuring large blowers quickly, and other factors. Accordingly, the Metallurgical Laboratory submitted to the Prime Contractor a preliminary design suggestion for a liquid-cooled plant. Either water or diphenyl could be used as the coolant with only slight changes in design. After outlining the principal difficulties to be encountered in using diphenyl, e.g., polymerization and freezing, it was decided to proceed with design of a large-scale, water-cooled unit.

Decisions had to be made as to methods of cooling; whether the Pile should be a horizontal or vertical Pile; whether long uranium rods running throughout the entire length of the Pile should be used in preference to short segments; and whether the spacer ribs should be placed in the tube or on the rod sheath. Problems in the design of the Pile included chemical and electrochemical corrosion, the best form of Pile shielding, methods of handling the irradiated segments after discharge from the Pile, and control rods for keeping the Pile power level withim bounds. Originally it was felt that recirculati of water would be better than once-through passage of raw water. There was too much risk of contaminating the stream from which the water would be taken and it seemed likely that the amount of water required would be a large fraction of the stream. Consequently, pr visions were made for removing the gases evolved under radiation conditions; radiation shielding would be required; and corrosion of equipment would have to be considered. When the Columbia River sit with its dependable supply of large quantities of cool water, had been selected, all these designs had to be revised, since once-thro passage of raw water would not necessitate such extensive precautio

The final design of the Pile Areas as submitted by the du Pont Design Division to the Construction Division provided for a buildin housing a 250,000 kilowatt Pile, complete with accessories and controls and a complete cooling water system. A graphite structure, 3 feet by 36 feet by 28 feet, designed to be made up of approximately 100,000 graphite bars bored to receive 2004 aluminum tubes was decided upon. All materials of construction used in the Pile had to be chosen after their neutron absorption qualities and degree of purity had been determined, since impurities might have such high absorption capacities as to render the Pile useless for the nuclear chain reaction. Since investigation had proved that the optimum spacing required for the aluminum tube pattern was 8-3/8 inches, the cross-sectional area of the graphite bars chosen as the basis for the structure was one which could be finished to a 4-3/16 inch square. As in the case of the graphite, design of the Pile's aluminum tubes called for extremely close tolerances. This, combined with the fact that two longitudinal ribs were required on the inside of the tubes on which the uranium slugs were to rest, made their production difficult. The Pile structure would require unprecedented shielding to prevent the escape of radio-active emissions. Two shields were found necessary, an inner thermal shield, designed of cast iron blocks, which would absorb most of the thermal neutrons and gamma rays emerging from the Pile structure, while an outer biological shield would reduce the remaining radiation to a tolerable level. Thick concrete walls were also found necessary as an additional means of shielding for operating personnel. It was necessary that special instruments for the control of the Pile be provided to enable the system to respond to any variation in water supply and Pile activity, and to enable monitoring of the power level. Control and safety rods had to be designed to retard or check the Pile reaction, as the situation demanded, which could be activated by these instruments but could also be inserted manually if necessary. A borax solution, as an additional safety measure, was provided in case of failure of the rods to operate.

In order to insure continuity of water supply and to minimize corrosion during extended periods of operation, an elaborately designed system was not only necessary, but also essential. The average requirement of each Pile Area was estimated to vary from about 50,000 to 60,000 gallons of water per minute but only 30,000 gallons per minute of this total would be necessary for process cooling, requiring special treatment. A river pump house was designed for each area to meet these requirements as well as some Separation Area requirements, and each pump house, in addition, was to have a stand-by capacity for delivering 20,000 gallons per minute to the other Pile Areas in case of emergency. It was decided to use electrically driven pumps during normal operation but, to insure continuity of operation, steam turbine-driven pumps were also to be provided. Water from the pump houses was to be stored in 25-million gallon reservoirs. So that formation of film on aluminum tubes should be at a minimum, filtration plants, each of which was to have a capacity of 36,000 gallons per minute, were designed for filtering and treating process water. A demineralization plant was also thought necessary and was installed in one Pile Area to produce pure water but was later found to be unnecessary. Because of the presence of dissolved gases in the river water, a deaeration plant was designed for each area for the low-temperature removal of these gases, but these, like the demineralization units, were found to be unnecessary to successful operation. Refrigeration units were designed for two Pile Areas to prevent reduction of Pile production capacity during the warm periods of the year. Tanks, specially designed to prevent contamination of water during storage, were provided for the process water prior to its use. It was decided that each area should have twelve sets of pumping units, to consist of turbine driven pumps in series with electrically driven pumps. In normal operation both steam and electrical pumps could operate at partial load but each type was designed to supply minimum requirements in the event of failure of one source of power. A retention basin, of such proportions as to permit handling the large volume of water and allow a decay of radioactivity before discharge into the river, had to be designed.

Since a helium atmosphere would be effective in removing poisonous gases from the Pile structure, it was necessary to design a shielded purification and circulation system for the gas as well as ventilation of Pile buildings, removing the helium and other gases which would normally leak out of the Pile structure. Steam plants of simple design for maximum reliability were required, since, in case of electrical power failure, steam would have to be provided for the stand-by turbine driven pumps and generators as well as for the process water pumps.

6. Separation Area. - Having proved the feasibility of separating plutonium from the fission products and uranium, four processes presented the best possibilities for successful operation. These were the precipitation process, in which the separation of one or more substances from a solution is effected by the conversion of those substances to a solid state; the solvent extraction process in which certain substances are soluble in one solvent but not in others; the

adsorption process which permits the selective collection of some of the substances on the microscopic surfaces of a suitable adsorbent material; and the fractional volatilization process in which separati is effected by a distillation of a mixture of the substances and the separate collection of the distillates at each boiling point. Design proceeded concurrently on all these difference processes, but in the early part of 1943, all design work was concentrated on the precipitation process, with two possible carriers, bismuth phosphate and lanthanum fluoride. In June 1943, emphasis was placed on the bismuth phosphate process. Although bismuth phosphate is the poorer carrier of the two, the corrosion problems involved in using the fluoride wer more extensive.

Through a series of changes, the original number of Separation Plants was reduced from eight to three. There were to be two Separation Areas, containing these three Separation Plants, an Isolation Building, and facilities for the storage of irradiated slugs and of the final product. Each Separation Plant was designed to include a Separation Building, a Concentration Building, a Ventilation Building, and a Waste Storage Area. The procedure would involve removing the slugs from the Pile and carrying them in specially designed railroad cars to a Lag Storage Building where they would be stored under a shielding of 16-1/2 feet of water before use in the separation proces In the design of the Separation Buildings, in which the first phase o the separation process would be carried out, it was clear that, becaus of the intense radioactivity to be encountered, all the operations in this building would have to be performed by remote control in heavily shielded cells. A special type of stainless steel would be required in the design of process equipment and could be obtained only after extensive development work. A standard equipment group for this building would consist of a centrifuge, catch tank, precipitator, and solution tank, located in two cells. The cells were so designed that new units of equipment could be assembled and adjusted in another building, carefully disassembled, and reassembled in any cell by remote control. At least seven to nine feet of concrete would be necessary to seperate all process equipment from operating personnel. To eliminate the need for pumps and their subsequent maintenance problems, steam-jet syphons were designed to transfer solutions and slurries from any one piece of equipment to another. Remote operation of all process equipment was to be facilitated by the use of specially designed visual and audible aids as well as standard industrial control instruments. A special 75-ton bridge crane with a lead-shielded cab, equipped with periscopes to permit normal operation, for lifting and for manipulating the specially designed impact wrenches was designed for remote maintanance of cells and equipment. It was decided to locate operating galleries along one side of the building on three levels. A section of one of the Separation Buildings was to be used for process development.

The design of the Concentration Buildings and the Isolation Building, in which the process was to be further carried out, was similar to that used in the Separation Buildings. After leaving the Separation Buildings, however, the activity of the product solution would be sufficiently low that design of all subsequent equipment and shielding could be modified to permit more direct operation and maintenance. Since many of the process wastes would be intensely radioactive, it was necessary to provide storage space for these wastes for an indefinite period. Steel tanks, set in concrete and buried in the earth, to eliminate radiation hazards, were arranged in cascade to allow suspended solids containing the bulk of the radioactivity to collect in the first tank of each series and to permit emptying of subsequent tanks when the activity had decreased sufficiently. It was necessary that the Separation and Concentration Buildings also be carefully ventilated to prevent contamination of building air. Fans and steam-jet syphons were designed to exhaust ventilation air and waste process gases to a 200-foot stack. Since adequate dilution of stack gases was contingent upon weather conditions, a meteorological station was included in the design of the Separation Areas to permit scheduling of operations. Water for each Separation Area was to be supplied from the Pile Areas through reinforced concrete lines. The system included a storage reservoir and a small filter plant. A boiler plant was incorporated in the design of each Separation Area to provide steam for process and heating requirements.

7. Service Utilities. - The necessity for great quantities of uninterrupted electrical power required the strengthening and expanding of the Bonneville Power Administration's transmission and distribution system. Surveys were conducted, and the Corps of Engineers aided the Bonneville Power Administration in obtaining the necessary equipment. The main area transmission line is a 230 kilovolt loop, joining the five operating areas, which can be fed from either end.

The area communications system was designed by the Prime Contractor with the consultant services of the American Telephone and Telegraph Company and the collaboration of the Chief Signal Officer. A comprehensive road system was designed to expedite construction and to accommodate any emergency traffic during the operations period. The existing spur line of the Chicago, Milwaukee, St. Paul and Pacific Railroad was improved and approximately 100 miles of standard gauge, single-track railway was designed to serve the plant and housing areas.

8. Richland Village. - Since no community with facilities for housing the operating personnel of the Hanford Engineer Works existed near the site, it was necessary to build an entirely new community or to enlarge an existing one. The latter was to be preferred, as the existing buildings could be used to some extent and a minimum amount of grading would be required. It was necessary that the community be at a distance from the production areas both for the safety of the inhabitants and the security of the Project. Richland, an existing community of 250 persons in the southeastern part of the reservation, was selected and the design of a village to accommodate 6500 persons was begun. Most of the existing residences were not suitable for incorporation into a modern community and the commercial buildings were small, so that only a few of them could be incorporated into the new village although many were used during the construction period. The original population estimates made in March 1943 were based on an operating force of 4000 and the assumption that 40 to 50 per cent of them could find housing in nearby communities. As it was found that off-area housing was not available, as the need for a larger operating

force became apparent, and as it was found that there would be an overlap between construction and operating forces, Richland Village was finally designed to accommodate 17,500 persons. In addition to housing and commercial facilities, the administrative facilities for the Hanford Engineer Works were to be located in Richland Village. The number of housing units to be built in Richland Village was increased during the design period as the population estimates were revised upward. It was decided to utilize as many as possible of the existing houses and to build new houses, dormitories, and a hotel. Three classes of conventional-type houses would be provided and, with increased population estimates, contracts were let for more houses in each of the three classes. In November 1943, a study of prefabricated houses was undertaken and it was decided to erect them in the new (western) portion of the village. All prefabricated houses were furnished and 1175 sets of maple furniture are provided for the conventional-type houses. Lignite-burning hot-air furnaces were selected for heating the conventional-type houses and the prefabricated houses were equipped with electrical unit heaters. A total of 25 dormitories was provided for living quarters for approximately 1000 men and women and a hotel was designed to accommodate 150 guests in its 114 rooms.

Commercial facilities, grouped in the central portion of the village, with the exception of four food markets, two drug stores, and three service stations which were to be located in the residential district, were provided. Facilities were provided to supply all of the necessary merchandise and services. Educational facilities for approximately 1900 students were provided in the four conveniently located elementary schools and the high school. The high school was to have complete athletic facilities, an auditorium, and a cafeteria. A new 150-bed hospital and the Professional Building for private and clinical treatment were located near the Administration Area. New churches were provided for the Catholic and United Protestant groups and the Episcopal, Lutheran, and Mormon groups were to use one of the existing churches. An adequate fire protection system with three fire stations was also provided. The existing park along the Columbia River near the business section of the village was retained; open plots of land in the village were to be used as small neighborhood parks; and baseball and softball diamonds were established. In addition, the high school athletic field and the school gymnasiums were to be made available for village use. Two theatres and a recreation building with extensive facilities were to be furnished for indoor recreation. Electrical power would be distributed by three substations from a 66 kilovolt line running through Richland between Hanford and Pasco. A new sewage disposal system was designed for the village and a garbage collection system was established. Driven wells were chosen for the source of water but a river pump house was designed for construction should the water table become alarmingly low. The water would be treated at a small chlorination station before being fed into the two ground storage reservoirs. A small irrigation system existed in Richland but, as it was inadequate, the water supply system was used for irrigation during 1943 and 1944 and the water table dropped noticeably. The irrigation system was then expanded and placed in operation in the spring of 1945. Streets in Richland were to be of asphalt-stabilized macadam as were the sidewalks in the residential districts, whereas the sidewalks in the village center would be of concrete. A commercial bus depot was designed for use by all intercity bus lines. No railway passenger service was provided although a spur of the Project railway does extend to Richland for freight service.

9. Costs. - The cost of the design of the Hanford Engineer Works was $2,681,866.00. The break-down of design costs is made by areas. Other designations, by letters, signify temporary construction, commercial contracts, Hanford commercial contracts and general commercial contracts.

10. Organization and Personnel. - Design of the Hanford Engineer Works was performed by the du Pont Company in their Wilmington Office. All designs, however, had to have the approval of Metallurgical Laboratory and representatives of the Manhattan District. The Government Design Organization in the Wilmington Area, under Major W. L. Sapper, Area Engineer, consisted of one section, headed by B. Bowelle, who supervised the checking for approval of all plans and specifications. Heading the Contractor's Design Division was T. C. Gary, whose assistant was J. P. Martel. The Supervising Engineer was F. W. Pardee, Jr., and the Design Project (TNX) Manager was H. T. Daniels.

MANHATTAN DISTRICT HISTORY

BOOK IV - PILE PROJECT

VOLUME 3 - DESIGN

SECTION 1 - INTRODUCTION

1-1. Objectives. - The objectives of the phase of the work presented in this volume were the design of a large scale plant composed of Piles, each producing plutonium at a rated power level of 250,000 kilowatts, and extraction plants for the separation of the plutonium from uranium and fission by-product elements.

1-2. Scope. - The design of these large scale production and separation plants entailed consideration of the following factors:

1. Shielding of personnel from hazardous radiations.
2. Emergency provisions in case of power failure or other interruptions to smooth operation.
3. The development of high-grade materials, such as graphite and uranium, for use in the power unit.
4. Acceptable methods of handling and transporting radioactive materials.
5. Suitable and reliable means of removing heat from the production units.

1-3. Authorization.

a. General. - See Volume 1, paragraph 1-3, page 1.2.

b. Specific. - The original specific authorization for the design of the Pile Project is contained in a report to the President of the United States, dated 13 June 1942, by Dr. J. B. Conant, Chairman

NDRC, and Dr. V. Bush, Director OSRD. The report was approved by the Chief of Staff, the Secretary of War and the Vice President of the United States before it was transmitted on 17 June 1942 by Dr. Bush t the President, who also approved it.

1-4. <u>Statement of the Problem.</u> - Prior to the design of the Hanford Engineer Works, only laboratory production of plutonium in infinitesimal quantities had been demonstrated. Different processes ha been studied and enough research work had been conducted on the vario designs to indicate that the process was entirely feasible, although little knowledge of the design of large scale, production units was available. Several moderators had been considered, including heavy water and graphite. Several types of coolants had also been under co sideration and designs for several experimental Piles had been tentatively drawn up. Several processes for extracting the plutonium fr uranium and fission by-product elements had been investigated and developmental work was being concentrated on two of these. The probabl military importance of plutonium required that design proceed concurrently with selection and development of the process, and without benefit of the data which might have been obtained from full scale laboratory operation, much less pilot plant operation. Conceived by the Metallurgical Laboratory, the plant was designed by the du Pont Company, the Prime Contractor, on the basis of technical and process information, developed through research by the Metallurgical Laboratory and others, under War Department contracts (See Vol. 2). To insure that the plant, as constructed, would conform to the technical requirements, all final drawings dealing with process details were submitted to, and formally approved by, the Metallurgical Laboratory before release for construction. This was in addition to the usual approval of all drawings by the Manhattan District representatives. (Ref: design contract and contractor selection, see Vol. 1, p. 4.5.)

1-5. Design Considerations. - Preliminary design of a helium-cooled production unit had been started at the Metallurgical Laboratory and this design was carried somewhat further by the Prime Contractor during December 1942 and January 1943. Concurrent with work on design of the helium-cooled unit, an intensive study was being made comparing the possibilities of helium- and water-cooled production units, the possibility of water-cooled units having been suggested in the middle of January by the Metallurgical Laboratory. Plans for a helium-cooled unit for use at Hanford were abandoned in February 1943 because of extreme difficulties involved in handling and purifying the required large volumes of gas which would become contaminated with radioactive materials, making maintenance of circulators and other equipment difficult if not impossible. Moreover, it appeared impracticable to design, procure, and maintain the very large and heavy pressure-sustaining Pile enclosures which helium-cooling necessitated. Furthermore, the anticipated difficulties involved in loading and unloading the unit under gas pressure appeared to render the design of such a unit impracticable. The decision that the water-cooled unit offered greater possibilities of successful operation and appeared less hazardous and somewhat less costly to construct than the helium-cooled unit was concurred in by the Metallurgical Laboratory (See Vol. 2). Information on the details of the separation process had not been developed. Of necessity, design had to proceed generally abreast of, but in some cases ahead of, process development. Either of two separation processes (See Vol. 2) which offered the best prospects of successful operation could be used in the equipment and piping which was designed. The operation of the Clinton semi-works laboratories provided some experience applicable to Hanford design, but major design decisions for Hanford had to be made in advance of Clinton operation. Both the Pile and the Separation Plant processes presented problems that were most unusual. Not only did they involve nuclear physical principles, but both required elaborate methods of shielding to protect employees from radioactivity, and elaborate provisions for remote control. Process buildings, because of the shielding required, and the remote control features involved, were most unusual in design. Service buildings, however, were of a conventional type permitting the use, with minor changes, of designs prepared for other Government-owned plants. Standard equipment, although modified in some cases to meet the peculiar requirements, was utilized wherever possible; most of the equipment, however, was of original design. To meet the requirements for complete shielding and subsequent replacement of parts by indirect means, unusually close tolerances were required in building construction and in fabrication and installation of equipment. To insure safety and continuity of operation, it was necessary to incorporate special features even into such things as the railroad cars used for handling the irradiated uranium between the Piles and the Separation Plants, as well as the tracks over which the cars operated. A comprehensive testing program was necessary to demonstrate the practicability of many novel features before they were adopted for construction. Operation of all principal pieces of equipment was so proved on full plant scale, prior to actual installation in the plant. Designs were modified where necessary to insure maximum workability, continuity of operation, and ease of replacement, if replacement should prove possible. A variety of complex pieces of equipment required design and development work by established vendors.

SECTION 2 - SITE CRITERIA AND SELECTION

2-1. General. Research and pilot plant work on the Pile Project had shown that the production plant site would have to satisfy the general requirements for any large industrial plant site except that the singular characteristics of this process dictated some unusual features. These features would greatly limit the number of possible sites but the area near Hanford, in southeastern Washington, was found to best satisfy the requirements (See Vol. 4).

2-2. Criteria. Following preliminary discussions and studies by officials of the du Pont Company, the Metallurgical Laboratory at the University of Chicago, the Office of Scientific Research and Development, and the War Department, a meeting was held at Wilmington, Delaware, on 14 December 1942 to establish criteria for a site for the plant to manufacture plutonium. Each of the above agencies was represented at the meeting. Based upon technical information supplied by the representatives of the Metallurgical Laboratory, it was agreed that the major site requirements indicated that a large area, sufficiently isolated from centers of population, with readily available sources of water and power, would be necessary.

a. Area. The possibility of explosions of catastrophic proportions and the possibility of releasing to the atmosphere intensely radioactive gases would dictate the selection of a site of sufficient area to permit the several manufacturing areas to be separated by distances of several miles. The size of the manufacturing site required was based upon the tentative decision to construct six primary manufacturing areas separated by distances of not less than one mile, and four secondary manufacturing areas separated from each other and from the nearest primary manufacturing areas by not less than four miles (See Vol. 6). Moreover, it was decided that a boundary outside the manufacturing areas should be established not less than six miles distant from any area. A larger plant site would be demanded if it were determined subsequently that the most efficient space arrangement was not practicable because of considerations affecting the location of individual manufacturing areas. It was agreed that complete control would have to be exercised over not only the manufacturing site of 12 miles by 16 miles but also the six mile strip surrounding that area, with all persons other than plant employees excluded, and that residential occupancy should be prohibited within a larger area of about 44 miles by 48 miles, centered on the manufacturing site.

b. Isolation. The military importance of the Project and the potential hazards would demand the selection of an area of small existing population isolated to the maximum extent possible from any centers of population. It was agreed, therefore, that no large town or city should be less than 20 miles distant from the nearest manufacturing area and that housing for workers should be not less than 10 miles, preferably not less than 20 miles, from the nearest manufacturing area. Requirements were established to insure maximum safety to persons and security of the operating plants, and were based on estimates made by the scientific personnel present at the above mentioned meeting relative to the hazards inherent in the processes for manufacturing plutonium and preparing the finished product for shipment. Although access to railroad and main highway facilities was an essential requirement, it was determined, because of the possible hazards involved and the necessity of maintaining security, that no main line railroad or public highway should be less than ten miles from the manufacturing areas.

c. <u>Water</u>. A large and dependable supply of relatively pure water of reasonably low temperature would be necessary throughout the year in order to dissipate the enormous quantities of heat that would be released in the transmutation process. It was estimated that the minimum requirement would be approximately 25,000 gallons per minute. The distance the water would have to be pumped and the pumping head involved were also considered.

d. <u>Electric Power</u>. A dependable source of electric power capable of supplying at least 100,000 kilowatts would be necessary for driving the pumps required to circulate the large quantities of water and for the other necessary electrical equipment. A site near a source capable of supplying this added power to the production areas with a minimum of construction would be preferred in order to avoid unnecessary expense and use of critical materials.

e. <u>Secondary Considerations</u>. Although certain requirements were absolutely essential and were the criteria of site selection, a number of secondary factors were considered in the final selection. Preliminary studies indicated that certain of the main manufacturing buildings would present unusually high foundation loads introducing the practical factor that ground and subsurface conditions would represent an important economic consideration. Obviously, an area of land usable for no other purpose would be desirable from the standpoint of acquisition, to avoid taking fertile land out of agricultural production, and to avoid to the greatest possible extent the dislocation of inhabitants. Since large quantities of concrete were to be used in plant construction and powerhouses were to be constructed to insure continuous operation in case of failure of the regular power supply, local supplies of concrete aggregates and coal or oil would be desirable. The land in the manufacturing areas should be comparatively level for ease and economy of construction and operation. A region with comparatively mild climate would be desirable for speed and economy in construction. The prevailing wind direction and velocity were factors that would contribute to the location of the various manufacturing areas relative to workers' housing.

2-3. Preliminary Investigations. The site selection study was made jointly by the Manhattan District and du Pont, the Prime Contractor. Realising that the pressure of industrial war activities was creating shortages of electric power in many sections of the country, a survey was made to determine the areas where electric power capacity in the amount required would be available, preferably without additional plant installation (See App. C 1). It appeared that the Pacific Northwest would be the most desirable from the standpoint of existing electrical capacity and offered the further advantage of hydroelectric generation, eliminating the requirement for large quantities of coal or fuel oil. A second possibility was the Pacific Southwest where some hydroelectric generation was available, but it was doubtful whether the entire load could be absorbed without construction of additional generating facilities. Other areas served by hydro systems were possibilities but did not offer appreciable surplus generating capacity. The Tennessee Valley Authority area was considered, but the plants at the Clinton Engineer Works would absorb all of the available capacity of that system. The War Production Board informally concurred in these conclusions, and it was agreed that the initial search would be first in the Northwest, then in the Southwest, with additional search if a suitable site was not found in these areas. Consultation with officers of the Corps of Engineers in Washington, D. C., who were familiar with the Pacific area indicated that possible sites near Grand Coulee Dam would approximately meet the requirements.

2-4. <u>Field Study (See App. C 1)</u>. On the afternoon of 16 December 1942, a party of three men left Washington, D. C., to make field investigations leading to the selection of a site for the Project. Advance arrangements had been made with the District Engineers of the Corps of Engineers at Seattle, Portland, San Francisco, Sacramento, and Los Angeles. These arrangements included requests for information relative to possible sites based on criteria which had been furnished; for discussion of such information as was obtained in the limited time available; and the furnishing of transportation for the visiting group. During the period from 16 December 1942 to 31 December 1942, possible sites were physically inspected at two locations near Mansfield, Washington, in the vicinity of Grand Coulee Dam; one near White Bluffs and Hanford, Washington; one in the Deschutes

River Valley in Oregon; and two near the Colorado River in Southern California. These possible sites were suggested by the District Engineers responsible for the respective areas or by map and other study of basic data. Many other possible locations were considered in some detail but were eliminated from consideration without inspection because of failure to meet one or more of the specific requirements. These included locations near Odessa, Washington; Coeur d'Alene, Idaho; Priest River, Idaho; Bend, Oregon; and Umatilla, Oregon. In addition, a possible location approximately centered on Adin, California, on the Pit River in the northern part of the state was given thorough consideration, although it was not physically inspected. The District Engineers at Seattle, Sacramento, and Los Angeles prepared preliminary reports immediately on known site conditions at Mansfield and Hanford in Washington, at Adin, California, and near Needles, California (See App. C 2). These site reports included rough estimates of land values, the relative availability of water, power, concrete aggregates, transportation, and climate. It was clearly indicated that the White Bluffs-Hanford site in Washington was the most desirable and additional detailed land appraisals (See Vol. 4), subsoil investigations (See Vol. 5), labor studies, and other pertinent studies were initiated with respect to that site.

2-5. Site Selection. After personal inspection, the White Bluffs-Hanford site in Washington was approved by Major General L. R. Groves. The site selected (See App. A 1) almost uniquely meets the essential requirements. It is located principally in Benton County, Washington, in a semi-arid region beside the Columbia River, one of the largest rivers in terms of water flow in the United States. Above Vernita, just north of the proposed manufacturing area, the river drains an area of about 95,000 square miles, an area twice the size of the state of Pennsylvania. The average flow of the river at the site is 121,000 cubic feet per second with an average monthly minimum of 40,000 cubic feet per second in February, and a maximum of 334,000 cubic feet per second in June. The water is exceptionally pure and has an average temperature of 50° Fahrenheit for eight months of the year and 60° Fahrenheit for the remaining four months. Power is furnished by the Grand Coulee and the Bonneville Dams, located on the Columbia River above and below Hanford. Two 230 kilovolt lines connect to each of these generating plants at the Midway Station, in the northwest corner of the site, about six miles west of the westernmost manufacturing area. It is east of the Cascade Mountains in an unpopulated area where the low-lying Rattlesnake Hills, Saddle Mountains, and Yakima Range form the inland extremities of that system. The nearest community of any considerable size is Yakima, about 40 miles to the west, with a population of 30,000. The larger cities of Seattle, Tacoma, Portland, and Spokane lie well outside a 100-mile radius. The site itself lies largely, and the manufacturing reservation entirely, on the west bank of the Columbia River, which bounds the latter area on the north and northeast (See App. A 2,3). The manufacturing reservation is nearly level. It is broken prominently only by Gable Mountain which is an outcropping of the basalt that underlies the entire site. The overburden consists of shale and sandstone above which are deposits of sand and gravel. This ground is capable of sustaining high bearing loads and the material itself is suitable for plant roads, or, when screened and washed, for concrete aggregate. The total area amounts to approximately 670 square miles, of which 195 square miles comprise the manufacturing area. Details as to the acquisition of the site are presented in Volume 4.

SECTION 3 - A BRIEF DESCRIPTION OF THE OPERATING PLANT

3-1. Plant Layout. - The Hanford Engineer Works ~~are~~ is located in Southeastern Washington on a site of about 670 square miles on the Columbia River north of the junction with the Yakima River (See App. A 1). The production areas are, of necessity, constructed in six, independent, self-contained units located in widely separated districts (See App. A 2,4) because of the hazardous nature of the operations involved. With this plant arrangement, damage to any unit would not shut down the plant, since other identical units could be operated and the wide separation of the individual units would, therefore, prevent accidents in one unit from affecting the operation of another. The Metal Fabrication and Testing (300) Area provides facilities for converting the basic material, uranium metal, into a form suitable for charging into the Piles, as well as a wide variety of highly specialized testing, laboratory, and shop facilities. Three separate, almost identical plants, known as the B, D, and F Pile Areas, containing the Piles which produce the plutonium, were designed. The Separation Areas were designed to contain all the operating facilities used in the separation, isolation, storage and shipment of the product. Of three separation units constructed, two are located in the area known as the West (200) Area and one in the East (200) Area. The Separation Areas are placed approximately six to ten miles from the Pile Areas. A single "isolation"* unit is sufficient for the purification of the product after processing in the separation units, and is located in the West (200) Area. A third

Separation Area contains facilities for the lag storage of irradiated uranium after its discharge from the Pile, and in order to handle the production from the Pile units, three separate lag storage buildings known collectively as the North (200) Area are provided.

3-2. Metal Fabrication and Testing (300) Area (See Sec. 4). - The absolute purity and exact control of the graphite, the uranium, and all the other materials going into the Pile were critical to successful operations. Since their suitability had to be finally determined by functional tests, facilities were provided for testing all materials or samples thereof in a test Pile located in this area. Also located in the Metal Fabrication and Testing Area are facilities for the fabrication of uranium into rods, for cutting the rods into slugs, and for machining and canning the slugs. Included also are extensive laboratories and control facilities, and a semi-works separation plant for the study of the separation process, using tracer amounts of the radioactive substances. Complete instrument shops and laboratories are provided in this area for the assembly, calibration, and maintenance of the specialized instruments used for the control of the transmutation and recovery processes and for the determination of radiation levels throughout the entire reservation.

3-3. Pile (100) Areas (See Sec. 5). - The transmutation of the uranium to plutonium is carried out in three transmutation units or "Piles," each designed for operation at a level which will produce heat at a rate equivalent to 250,000 kilowatts. Each Pile is a structure consisting of approximately 1700 tons of carefully machined graphite blocks enclosing 2004 "aluminum"* tubes into which are charged between 250 and 300 tons of uranium in the form of small cylinders, each individually sheathed (canned) in aluminum. About 30,000 gallons per minute of cooling water per Pile is continuously forced, under pressure, through a small annular space between the canned uranium and the walls of the tubes. To prevent possible serious corrosion of the aluminum tubes and cans, it was necessary to provide elaborate purification facilities for the naturally pure Columbia River water. The seriousness of the effect of corrosion can be measured by the fact that failure of as few as ten of the 2004 tubes could cause complete failure of the Pile. In addition to the normal water treatment facilities, it was considered necessary to provide special equipment for each Pile to remove dissolved air and other gases completely from the water. Because water approaching the purity of distilled water might ultimately be required, there was installed in one Pile Area, D, special equipment for producing water equivalent to distilled water. Since speed of construction was essential, this feature was omitted in the design of Pile Area B, and was found unnecessary for Pile Area F, the third Pile Area to be completed. Because the ability to produce plutonium is limited by the ability to remove heat, refrigerating equipment having a total capacity of 25,000 tons of refrigeration was installed in two Pile Areas, D and F, to cool the river water during the summer months. Here, also, the design of Pile Area B omitted this feature in favor of completing the area in the shortest time possible. In order to insure continuity of water supply, complete, independent, and individual water facilities were installed; and all individual units were interconnected. Similarly, it was necessary to design water pumps, installed in series and driven by electric motors and steam turbines, respectively, so that, should either the electricity or the steam fail, the other source of power would continue pumping although at less than the normal total rate. In the Piles, the graphite structure is entirely surrounded by gastight steel, masonite, and concrete shields several feet thick, through which the 2004 tubes extend, to protect operating personnel from the radioactivity which accompanies the formation of plutonium. Because of the hazard, each Pile is located in a separate one square mile operating area (designated as a 100 Area) so arranged that the three Piles are separated from each other by at least six miles. Although early plans to cool the Piles with helium were abandoned, a low pressure atmosphere of helium is maintained inside the Pile structure. The helium is used to displace air, moisture, and other impurities from the Pile structure and provides for more efficient transfer of heat from the graphite to the cooling water tubes. Although the cooling water passing through the Piles becomes somewhat radioactive, this radioactivity is relatively short lived and, unless unexpected complications arise, retention for a few hours in a specially designed basin before release to the river avoids any difficulty. These conclusions were based upon an extended study of possible deleterious effects upon fish life carried out by various research groups cooperating with federal and state authorities and an ichthyologist familiar with the salmon industry (See App. C 3). Especially designed water inlet and outlet installations were provided to avoid physical injury to the salmon. Because the treated metal, containing highly radioactive by-products, must be kept under water continually, it is transported on special lead-shielded railway cars to an isolated storage area where it is stored under a minimum of 15 feet of water until the radioactivity has decayed to a level which will permit handling for chemical treatment to isolate the plutonium.

3-4. Separation (200) Areas (See Sec. 6). - There are a total of three Separation Plants, each designed to process one ton of irradiated uranium per day. There are two separate operating areas (designated as 200 Areas). The Separation Areas are separated from the Pile Areas and each other by four miles and the two Separation Plants in the one Separation Area are a mile apart. Each area is provided with its own water supply system, steam plant, and the other service facilities to permit independent operation. Each Separation Plant consists of a Separation Building and a Concentration Building in which the product is prepared for final treatment in the Isolation Building. The Separation Buildings are continuous concrete structures about 800 feet long, 65 feet wide and 80 feet high, made up of individual cells in which are installed large stainless steel tanks, centrifuges, and other process equipment. Because of the radioactivity present during the separation process, the concrete walls surrounding the cells are seven feet thick to provide the necessary shielding. Cell covers are removable, six-foot thick concrete blocks. Provisions must also be made for transferring solutions or slurries from one piece of equipment to another and for operating all equipment by remote control. Periscopes and television apparatus were provided to permit limited observation of the process equipment and to facilitate its operation. In use, the process equipment becomes radioactive and maintenance and repair work becomes difficult, if not impossible, to perform. For this reason it was necessary to make provisions for removal and replacement of equipment by remotely controlled cranes, and to provide much extra equipment and spare, unused cells for storage of the contaminated defective equipment. The corrosive nature of the solutions involved requires the use of special stainless steel process equipment throughout the Separation Plant. After removal of the product from the uranium and the removal of a large fraction of the radioactive material, there is a reduction in radioactivity making it possible to transfer the solution containing the product to the Concentration Buildings for further processing behind somewhat lighter shields and where less remote operation is possible. After further processing in these facilities, the product is removed to the Isolation Building where it is finally concentrated and prepared for delivery. Process solutions from the Separation Plant contain radioactive by-products which preclude their discharge into the ground or into the Columbia River. Accordingly, all process solutions are stored indefinitely in steel-lined, reinforced concrete tanks buried in the earth to protect personnel from the radioactivity. Many of these solutions, as a result of the decay of radioactive materials, will spontaneously evolve sufficient heat to cause the solution to boil and therefore, these tanks are equipped with a means to condense the vapors produced. A total waste storage capacity of approximately 25,000,000 gallons has been provided. The Magazine

Storage (213) Building is also considered a part of the Separation Area operating plant. It is a reinforced concrete, earth-covered building containing two ventilated vaults and is used for storage of the final product.

SECTION 4 - METAL FABRICATION AND TESTING AREA

4-1. Metal Fabrication and Testing (300) Area. - The Metal Fabrication and Testing Area (See App. A 7), as finally designed, was to comprise facilities for the fabrication of canned uranium slugs; a test Pile; a semi-works separation plant; special instrument shops and test facilities; and extensive technical laboratories. Since none of these activities would involve exposure to high levels of radioactivity and, therefore, would not involve the potential hazards to personnel to be experienced in the Pile and Separation Areas, it seemed practicable to bring these facilities together into a separate area, remote from the greater hazards of the operating areas and sufficiently removed from Richland Village and the Administrative Area to avoid any hazards to personnel located there.

a. Metal Fabrication Equipment. - Two buildings of conventional design were necessary for the extrusion of uranium rods from "billets"*; "outgassing"* and straightening the rods; machining them into short cylinders (slugs); canning the slugs; and testing the canned slugs preparatory to use in the transmutation process. The majority of the design of slugs and canning methods was performed by the Metallurgical Laboratory and by the Prime Contractor in the Wilmington laboratories and is discussed in Section 5 and in Volume 2. Equipment for these buildings was of a standard design, modified in some respects because of the characteristics of uranium metal (See Vol. 6).

b. Test Pile. - A test Pile to be used in determining the neutron absorption or emission properties of all materials such as graphite and uranium used in the construction or operation of the manufacturing Piles was necessary, in order that all slugs be as nearly perfect as possible before use in the Pile Areas. The basic design for the test Pile was similar to that of the graphite-moderated Argonne Pile (See Vol. 2) and the SMX Pile at Clinton Laboratories (See Vol. 2), modified somewhat to permit testing of graphite before using it in the manufacturing units. No provisions were made for cooling this Pile, and, therefore, it was to operate only at a very low power level.

c. Semi-Works Separation Plant. - A semi-works was designed for this area for investigating problems arising in the separation of plutonium from the uranium and fission by-product elements. In contrast to the semi-works located in the Separation Area, in which the equipment is similar to that used in the actual separation process, necessitating full-scale shielding, only tracer amounts of radioactive substances were to be used in this semi-works, so that shielding to protect personnel and remote operation and maintenance would be unnecessary. The equipment, however, would be of a design similar to that used in the actual production Separation Areas, but on a much smaller scale.

d. Special Instrument Shops and Test Facilities. - Facilities for the maintenance, modification, and calibration of the many types of electronic and other instruments required in the manufacturing processes and safety surveys were provided for in the design of this area. Radium and radium-beryllium sources required for calibration of special instruments were to be stored in a Standards Building, the design of which also provided for a small special Pile for calibrating the monitoring and control equipment.

e. Laboratories. - For further development in connection with the plant processes, laboratories for instrument design and analytical control and development had to be provided.

SECTION 5 - PILE AREA

5-1. General. - As stated in the Metallurgical Laboratory's "Feasibility Report" of 28 November 1942 (See App. C 4), the critical problems that had to be solved to make the Pile Project feasible were:

1. To determine the conditions for a controlled, self-sustaining reaction.
2. To secure adequate amounts of primary materials of sufficient purity.
3. To develop methods for operating the reaction at high power levels and to put these methods into operation.
4. To extract and purify the plutonium from the fission products.
5. To maintain health and safety during the process.
6. To produce useful bombs of plutonium.
7. To accomplish these results in time to be of military significance.

a. Chain Reaction. - The determination of the conditions for a self-sustaining chain reaction was not primarily one of design but of research. But the determination of these conditions was essential to further progress. Although no self-sustaining, controllable reaction had been attained up to the end of November 1942, it had been demonstrated experimentally that suitable arrangements of uranium and graphite would give neutron reactions in which the number of neutrons would grow from generation to generation, and the development of controlling mechanisms adequate to keep the reaction within bounds had progressed considerably. An experimental Pile was under construction at the Metallurgical Laboratory and on 2 December 1942 was operated as a self-sustaining, controllable system.

b. Procurement of Materials. - Procurement of materials of sufficient purity was a major part of the problem of designing a Pile. It was clear that, however advantageous heavy water might be as a moderator, no large quantities would be available for months or years. Only a few pounds of heavy water were available in 1942. However, with increased production, it was hoped that as much as ten tons would be available by January 1944. Other materials needed in quantities were uranium, graphite, and possibly beryllium. Beryllium seemed the least advantageous of suggested moderators and about as hard to procure as heavy water. Therefore, procurement efforts for a moderator were centered on graphite. Procurement of uranium and graphite was not primarily the responsibility of the Metallurgical Laboratory but was handled through a planning board. Almost no uranium was available during most of 1942, but by November of that year, the production problems had been nearly solved. At the beginning of 1942, graphite production was also unsatisfactory, but was in quite a different condition from that of uranium since the industrial production of graphite had already been very large. The problem was mainly one of purity. By the middle of 1942 the purity problem was essentially solved and two companies were producing the highly purified graphite with a neutron absorption capacity some 20 per cent less than that of standard commercial types.

c. Health and Safety. - The main hazards to personnel in the plutonium production process were associated with intense radiation and radioactive materials. Hazards of this type and methods of protection from them were well known from experience with X-rays, radium, and cyclotrons. The present process differed from previous experience only in that the radiations would be of a higher order of intensity and, therefore, additional shielding would be required.

d. Military Usefulness. - The problem of producing useful bombs of the plutonium was later transferred to another laboratory located at Los Alamos, New Mexico (See Book VIII).

e. Time Element. - It was essential that these problems be solved in time to be of military significance.

f. Production and Separation Processes. - It is with these two problems that this and the next section are chiefly concerned.

5-2. Major Design Problems. - Some of the important general problems which had to be met in the design of a Pile were as follows:

1. The design of a Pile, through which the coolant could be circulated, which would meet the requirements of practicability for construction and very strict nuclear physics limitations.
2. Provision for circulation of the coolant at such rates and with such distribution as would permit removal of large quantities of heat from the unit without the development of excessive temperatures in any part of the system and still meet the nuclear physics

requirements.

3. Provision for adequate and dependable control of the reaction.

4. Protection of personnel and some types of material from intense radiation.

5. A dependable method for handling the intensely radioactive uranium.

6. Protection of equipment and, in particular, the uranium against corrosion or erosion.

7. The design of all mechanical equipment to operate with absolute dependability without maintenance or attention over long periods of time.

5-3. Merits of Different Types of Cooling. - Since production of substantial quantities of plutonium would necessarily liberate enormous quantities of heat (See Vol. 2), a means of dissipating this heat was essential. Many ways of accomplishing this were available, but studies carried out by the Metallurgical Laboratory indicated that the most practicable type of plant would be one in which a stationary lattice of uranium would be cooled by the circulation of a suitable coolant. Three types of coolants, gas, liquid, and metal, were considered. The advantages and disadvantages of these types seemed to be as follows:

a. Gas-cooling.

  1. Advantages.

    a. Relative simplicity of construction of the Pile Unit.

  - b. Less serious corrosion problems than in other types.
  - c. Relative simplicity of mechanical equipment for handling radioactive uranium.
- 2. Disadvantages.
  - a. Large quantity of equipment required for the circulating system.
  - b. Large amount of radiation shielding required.
  - c. Relatively low power output of the plant.
  - d. High gas pressure carried in system, increasing danger from escaping gas.

b. <u>Liquid-cooling</u>.

- 1. Advantages.
  - a. High power output relative to the gas-cooled plant.
  - b. Small consumption of power for circulating the liquid and, consequently, moderate cost of pumping equipment.
  - c. The probability that in normal operation the radioactivity in the circulation system would not be serious.
- 2. Disadvantages.
  - a. In one of the designs developed, the Pile Unit would have to be constructed with unusual precision. In an alternate design, difficult metal fabricating problems would have arisen.

b. The seriousness of the corrosion problem. This would demand protective coating on the uranium and the methods for accomplishing this dependably had not yet been developed. Likewise, it might have required that the circulating system be made of stainless steel or non-ferrous alloys.

c. The higher probability as compared to other types, that a mechanical failure within the Pile would prevent the operation from being carried to a successful conclusion.

c. <u>Metal-cooling</u>.

1. Advantages.

a. The possibility of developing plants of high power output. In view of the economy of uranium to be effected by high output, this advantage would be of importance.

b. Relative small size of circulating system.

2. Disadvantages.

a. The difficulty of handling molten metals which are intensely radioactive in the quantity required.

b. The fact that uranium carbide would have to be used instead of uranium in the Pile, since at that time the manufacture and fabrication of the carbide appeared to present a serious problem.

c. The increased difficulty of control of high power plants.

5-4. Sources of Operating Trouble. - A brief review of the sources of operating trouble in a power plant as seen from a pre-design point of view included the following:

1. The circulating system in both liquid-cooled and gas-cooled plants would be made up of conventional equipment which would in all probability operate satisfactorily over the period of a normal operating cycle. The failure of one or two units would probably cause no trouble more serious than a temporary reduction in power output of the unit. Repairs to the circulating system undoubtedly could be easily made in the liquid-cooled plant; and in the gas-cooled plant might be made after about a week of preparation. In the metal-cooled plant, the circulating system would probably not be so dependable, and repairs, if they could be made at all during operation, would involve difficult and hazardous operations.
2. Danger from radioactivity in the circulating system would be greatest in the gas-cooled plant, unless a successful method of coating the uranium could be developed. In the metal-cooled plant, the small size of the circulating system would facilitate shielding. In the liquid-cooled plant, the coating of the uranium would prevent the circulating water from becoming intensely radioactive. A failure of the coating,

however, would permit corrosion of the uranium and contamination of the coolant with the radioactive material, so that shielding of the circulating system would be necessary.

3. The most serious source of trouble to be expected was some sort of failure in the Pile itself. Completely satisfactory operation could be obtained only if the graphite Pile maintained its structure during the course of the run. There was the possibility that thermal or mechanical stresses, and erosion or corrosion would cause a shifting of the graphite. This would enormously complicate, if not prevent, successful unloading of the unit, and probably would prevent reloading of the unit. The danger of overheating would also be serious. This might be a general overheating of the Pile due to a failure of the controls to operate properly, or a local overheating due to faulty distribution of coolant in the unit. Failure of the mechanical equipment used in handling the radioactive material would also be a possibility, but it was believed that if the problems of maintaining a rigid graphite structure and of preventing overheating of the unit could be solved successfully, the task of designing practicable mechanical devices for this purpose could be accomplished.

5-5. <u>Early Considerations</u>. - After examining the principal factors affecting plant design, i.e., cooling, efficiency, safety, and speed of construction, the "Feasibility Report" (See App. C 4) suggested a number of possible Pile types. These types were, in order of preference:

- I. a. Ordinary uranium metal lattice in a graphite moderator with helium cooling.
  - b. The same, with water cooling.
  - c. The same, with molten bismuth cooling.
- II. Ordinary uranium metal lattice in a heavy-water moderator.
- III. Uranium enriched in uranium-235 using graphite, heavy water, or ordinary water as a moderator.

Each of these possibilities was discussed as to power output and plutonium formation. Plant principles and design were outlined. Types II and III were of no immediate interest since neither enriched uranium nor heavy water was available in sufficient quantities. Development of these two types continued, however, since if no other type proved feasible, they might have to be used. Accordingly, design principles were drawn up.

a. Uranium-Heavy-Water Plant. - Although the nuclear properties of heavy hydrogen were not sufficiently well known in November 1942, it was certain that heavy water would be superior to graphite as a moderator. As a preliminary estimate it appeared that an experimental Pile could be designed with a heavy water volume of about 1000 gallons and using approximately 1.5 tons of uranium. The size of the chain-reacting unit would be much smaller than that of a uranium-graphite Pile since the reproduction factor would be considerably higher. It was evident that the dissipation of heat would introduce difficulties. The inner temperature of the uranium lumps would soon rise far above 660° Centigrade which was considered a safe upper limit. One device considered would have involved constantly removing part of the metal and returning it into the Pile after having cooled it down outside the Pile, requiring much larger amounts of metal than the 1.5 tons given above. All cooling media used with a graphite Pile could be considered for a heavy-water Pile. Molten bismuth would present difficulties as a coolant because of the chemical decomposition of "deuterium"* compounds at the temperature of hot bismuth. Water could be satisfactorily used by increasing the heavy water volume to approximately 2000 gallons and the uranium charge to 7 or 8 tons. Helium seemed most promising since it would decrease the multiplication factor by so little. It was evident, furthermore, that all the above schemes would require considerable engineering development. To this, and the difficulty in obtaining heavy water, would have to be added the chemical decomposition of the heavy water which would have to be counteracted in some way. On the other hand, the principal advantages of a heavy-water Pile would be the elimination of graphite, the higher multiplication factor, and the small size of the units.

b. Enriched-Uranium Power Plant. - Since the maintenance of a chain reaction depends almost entirely on the presence of uranium-235 and plutonium-239 which readily undergo fission with slow neutrons, it was natural that the possibilities of a plant using metal enriched in uranium-235 or plutonium-239 should be considered. In general, an enriched power plant would be very much more flexible from an engineering viewpoint than an unenriched one. The reason for this is that enrichment would increase the neutron multiplication factor by an amount dependent upon the percentage of enrichment; consequently, the design of the Pile could be simplified without reducing the reproduction factor below the critical value. For example, the size of the Pile could be reduced, greater quantities of coolants could be used to extract heat, and larger spacings between the lattice elements could be provided. It was clear that enriched plants would be important as concentrated sources of high power, but there was some question as to the speed of production of plutonium, because, as the enrichment was increased, a relatively smaller percentage of the neutrons from the fission of natural uranium-235 would be used in the actual transmutation process. Since heavy, uniform enrichment would not be conducive to large chemical outputs, two alternatives were considered. All of the enrichment could be concentrated in a small seed in the middle of the Pile, or a low uniform enrichment could be used to make the chain reaction proceed in a Pile which was on the verge of operating by itself. The first alternative presented two difficulties: first, most of the heat would be produced in the small seed and it would, therefore, be hard to cool; secondly, the enrichment in the seed would be burned up too fast in comparison to the amount of plutonium produced in the materials outside the seed to make the plant a very efficient chemical producer. Whichever of these alternatives was accepted, it was evident that plants using uranium enriched in the 235 isotope could not be built unless much larger amounts of uranium-235 or plutonium-239 were made available quickly. Something like 40 pounds of uranium-235 or plutonium-239 would be required for each Pile.

c. Uranium Hexafluoride-Cooled Plant. - Although never carried beyond a design suggestion, serious consideration was given to "uranium hexafluoride"* cooling as a modification of the enriched uranium plant. The feasibility of such a Pile would depend upon several important conditions, such as the value of the reproduction factor of a uranium metal-uranium hexafluoride system or a pure hexafluoride system, heat transfer conditions, and the availability of uranium hexafluoride as a coolant. It was doubtful whether a plant with hexafluoride solution, acting as its own coolant, and no uranium metal, would be feasible. Although the chain reaction could be maintained with pure hexafluoride, the size of the plant would become excessive. Design would have required some 1700 tubes in a cylindrical graphite moderator weighing about 750 tons. Approximate metal requirements would be of the order of 50 tons and a total of 180 tons of hexafluoride would be required in the circulatory and Pile systems. Since about one-half of the heat generated would be in the liquid itself and since the metal tubes would not be very thick, the heat transfer problems would be comparatively simple. The output of the Pile would be limited chiefly by the pumping power which would have to be provided to circulate the hexafluoride. As far as the availability of uranium hexafluoride was concerned, several companies had had experience in its manufacture, so that it appeared that it could be classified as an available Pile material.

d. Molten Bismuth-Cooled Plant. - Molten metal plants appeared to be superior to gas-cooled or liquid-cooled plants in the matter of high power outputs, and, accordingly, the rate of production of plutonium in such plants would be high. The estimate of the power output per ton of uranium for a metal-cooled plant was 5000 kilowatts, while those for the gas-cooled and liquid-cooled were 1700 and 2500 kilowatts per ton, respectively. However, it was believed that the technical problems involved could not be solved for a long time. It was proposed to maintain a chain reaction in a cylindrical graphite Pile 26 feet high and approximately 31 feet in diameter, weighing about 1000 tons and containing about 150 tons of uranium in the form of uranium carbide. This graphite Pile would be enclosed in a hermetically sealed container filled with helium at normal pressure. Liquid bismuth would enter at the top of the Pile having a temperature of about 300° Centigrade and flow through grooves or bores in the graphite from top to bottom under the action of gravity, leaving at the bottom at about 600° Centigrade. The uranium carbide would be present in the form of aggregates weighing about 4.5 pounds, these aggregates resting one on top of the other in vertical columns through the Pile. The pumps lifting the liquid bismuth about 33 feet would require about 7000 kilowatts of power. Two possible designs for bismuth pumps were considered. One would be a centrifugal pump and the other an electrodynamic type, wherein the liquid bismuth would flow through the annular gap between a steel tube and an iron core under the electrodynamic action of windings which would be on the outside of the steel tube. At the bottom of the Pile a heat exchanger was to be provided in which the heat would be transferred to a bismuth-lead alloy having a melting point of 124° Centigrade. This alloy would then be pumped outside the Pile and would transfer its heat to water. It was proposed to control the Pile by means of automatically regulating the amount of a bismuth-lead-tin-cadmium alloy in the Pile by use of the above-mentioned electrodynamic pumps.

e. Helium-Cooled Plant. - None of the possible designs discussed in the preceding sections ever passed the research stage for one reason or another. In November 1942, as mentioned in the "Feasibility Report," the helium-cooled plant was the first choice of the Metallurgical Laboratory because it was believed that the design of such a plant could be carried through more quickly than that for a liquid-cooled plant. When du Pont entered the picture (See Vol. 1), it accepted the proposal of a helium-cooled plant. The Metallurgical Laboratory submitted to the du Pont Company a preliminary report, No. CE-277, dated September 1942 (See App. C 5), for the design of a helium-cooled plant. After further study of this report and modifications suggested in report No. CE-324 (See App. C 6), the Prime Contractor decided in favor of a liquid-cooled plant. The reasons for the change were numerous. Those most often mentioned were the hazard from leakage of a high-pressure gas coolant carrying radioactive impurities, the difficulty of getting large blowers quickly, the large amount of helium required, the difficulty of loading and unloading uranium from the Pile, and the relatively low power output per pound of uranium metal. These considerations had to be balanced against the peculiar disadvantages of a liquid-cooled plant, involving the large neutron-capture cross section of a liquid compared to that of helium, the increased complexity of the Pile itself, and the dangers of corrosion. The design of a helium-cooled plant, as taken from the above-mentioned reports and summarized in the "Feasibility Report," was as follows:

(1) Reacting Unit and Shell. - The "reactor"* proper would consist of a roughly cylindrical vessel approximately 90 feet high and 37 feet in diameter. Inside of this vessel the graphite-uranium lattice would be arranged in the form of a cylinder, 26 feet in height and 28 feet in diameter. Additional graphite would be included inside the reactor as a reflector for retaining stray neutrons within the unit. The vessel itself would be built up of spherical segments affording some economy in steel consumption. The lattice arrangement originally was fixed so that there would be 11 inches between adjacent rows of columns in both horizontal directions, as well as between adjacent layers of uranium lumps. In order to increase the amount of uranium in the Pile, these dimensions were changed to use a non-cubic cell having one side of 11 inches and the other two sides of 9 inches, one of these dimensions being the distance between adjacent uranium layers. This would probably require about 125 tons of metal and approximately 1500 tons of graphite.

(a) Uranium Elements. - It was planned that the uranium metal would be in the form of flat plates spaced apart from one another by lugs cast integral with the plates proper. The plates comprising each element would then be placed in graphite cartridges and be lowered into the vertical columns through the Pile, allowing the helium coolant to pass upward through the elements.

(b) Control Mechanisms. - The reaction would be controlled by means of rods, probably of mild steel, which could be lowered into the Pile to a sufficient distance to absorb excess neutrons. These rods could be cooled by the helium itself and would be actuated by a control mechanism which would respond to changes in neutron densities. In addition to the control rods, safety rods would be provided which would fall into the holes in the Pile in the event of power failure or excessive neutron density.

(c) Discharge Mechanism. - When the reaction was completed, a sliding trap door at the bottom of each column would permit the cartridges with their uranium lumps to drop into a conical receiving section below the Pile proper.

(d) Radiation Protection. - The problem of radiation from the Pile was to be met by building a concrete shield of one foot thickness around the shell and filling the intervening space with water which would cover the top of the shell to a depth of eight feet. An internal radiation shield would also be provided in an attempt to make possible the reloading of the unit after completing a run. This shield would be composed of three feet of "carbon" and 16 inches of steel, resting on a 3/4-inch steel floor.

(2) Cooling System. - The important units in the

circulating system would be the gas coolers, the gas cleaners, and the aftercoolers. The coolers would reduce the gas temperature from the Pile exit value of 800° Fahrenheit to about 120° Fahrenheit; the cleaners would remove the graphite dust and a part of the fission products in the gas; and the aftercoolers would reduce the temperature of the gas, after compression, from 160° to less than 120° Fahrenheit. The coolers would consist of shell and tube heat exchangers in which helium would pass through small tubes surrounded by circulating cooling water. Removal of the fission products would have been accomplished by passing the gas through activated charcoal which would have been discarded after it had become saturated. All units in the external system would have to be protected by radiation shielding. This would consist of concrete walls, three or four feet thick, or of earth shielding. Radioactive gases leaking from the system would be disposed of by means of a tall stack and dilution with air.

(3) Compressors. - Compressors would be necessary to return the helium to the required inlet pressure. For this purpose, centrifugal compressors were designed since the compressors should be capable of operating for extended periods without servicing or close attention, and should not contaminate the gas with oil. This was necessary because of the possibility that radioactive fission products would be deposited in the compressors and make it impossible for an operator to approach the compressors.

f. Liquid-Cooled Plant. - Having decided in favor of a liquid-cooled plant, the Metallurgical Laboratory submitted to du

Pont a preliminary process design of a liquid-cooled power plant producing 500,000 kilowatts. This suggested design is the subject of report No. CE-407, dated 9 January 1943 (See App. C 7), and proved extremely close to the final design adopted by the Prime Contractor.

(1) General Description of Pile (See App. B 1). - The Pile would be of the horizontal type--a large drum, in effect, lying on its side and supported in a graphite cradle formed by filling in the lower corner spaces between the cylinder and the enclosing parallelepiped with second class graphite or other suitable material. The active cylindrical Pile would be formed of first class, high purity graphite formed into blocks 8-3/8 inches square by 50 inches long, with all edges chamfered 1/4 inch. Each block would have a central hole throughout its length to accommodate the aluminum tubes. The rods and tubes (about 1695 in number) would be disposed in a square lattice arrangement with their axes all horizontal and parallel to the axis of the graphite cylinder. The square lattice spacing would be 8-3/8 inches, center to center horizontally and vertically, with the rods and tubes grouped symmetrically about the center of the Pile and located within the geometrical boundaries of an enclosing cylinder. The holes in the graphite would be lined with freely inserted, ribbed aluminum tubes. The uranium would be in the form of rods about two feet long, covered with an aluminum tube or sheath drawn tightly over the uranium. Surrounding the Pile would be a gastight shield, the ends of the shell being large, continuous, welded plates, having holes opposite the holes in the

graphite, and special nipples, welded gas-tight to the plate in the field, so as to be directly centered with the holes in the graphite. The Pile would be completely surrounded by shields. The shielding medium for the sides and top would be water retained in a concrete tank in which the Pile would be immersed. At the ends of the Pile, the shields would be sectional, interlocking steel tanks containing water and graded iron or steel shot. The tanks would each be divided by a partition, parallel to the tube sheet, to separate the water in the tank and prevent water circulation within the tank from carrying any dissolved radioactive materials from the Pile side of the shield to the outside face of the shield. In addition to the shielding tanks, a separate shield would be required at the water outlet end of the Pile, where the rods would be ejected, to protect against gamma-ray leakage while the rods were being pushed through the tube extension between the shield and the coffin (See Par. 5-7).

(2) Description of Cooling System. - After leaving the Pile at 2° Fahrenheit above its boiling point at atmospheric pressure and at a pressure of about 20 pounds per square inch, the water would pass through a throttling valve to reduce the pressure to near atmospheric. Part of the water would vaporize, most of the "hydrogen"[*] and oxygen being carried in the water vapor. The vapor-liquid mixture would then pass into a flash tank where it would be sprayed from a header pipe. This tank would be about 22 feet in diameter and 40 feet high with conical tops and bottoms. Water from the spray header would fall into the tank through a five foot spray space, and then pass through the filter, located 30 feet

below the surface of the water in the tank. The steam-hydrogen-oxygen mixture which would form in this tank would pass off through an opening in the top of the tank to a flash tank condenser, where the water vapor would mostly condense and run back into the flash tank. The remaining gases, hydrogen, oxygen, and some water vapor, would then be diluted with air to below the explosive limit and pass to the waste stack. This stack would be equipped with an induced-draft fan, located in its base and capable of handling 1400 cubic feet per minute. The hot, degassed water from the filter would pass then through the heat exchanger bank, where its temperature would be reduced to 95° Fahrenheit by counter current exchange against cooling tower water. These exchangers would be of the shell and tube type with the Pile water inside the tubes and the cooling tower water outside. The cooled Pile water then would pass to the Pile water pumps, and return to the Pile. These pumps would have to have a combined normal capacity of 28,700 gallons per minute. The proposal was that eight pumps be installed, any six of which would be capable of carrying the normal load. The cooling tower water would enter the heat exchangers at 85° Fahrenheit and leave at 130° Fahrenheit, pass over the cooling towers and enter a pit beneath them from which it would be picked up and recirculated through the heat exchangers by the cooling water pumps. Air would be blown through the cooling towers by motor-driven fans, and the evaporation of the cooling water into this air would cool the water from 130° to 85° Fahrenheit.

(3) <u>Sectional Model of Pile (SMX)</u>. - To minimize any

risk of delay through inadequate design, faulty or impossible assembly, or other unforeseen difficulty, a 16-tube section mockup of the Hanford Pile was designed and constructed at Clinton Laboratories (See Vol. 2). Here, graphite machining was proved on a practical basis, graphite laying procedures were developed, shield assembly procedure was established, and precision measurements were taken to forecast the allowance for machining tolerances, expansion effects, loading technique, and other factors.

5-6. Design Alternates and Decisions (See App. C 7).

a. Coolants. - The design of the Pile as drawn up by the Metallurgical Laboratory provided for two possible coolants, either one of which could be used with only minor changes to the plant. These were water and diphenyl, a colorless liquid above 160° Fahrenheit having a high thermal conductivity.

(1) Water Cooling. - Tests performed to determine the corrosion of aluminum by water under radiation conditions indicated that an average loss of less than 0.004 inch thickness of aluminum would result from 100 days of operation at the rated power level. The results with water inhibited against corrosive action proved more encouraging. Therefore, it was not indicated that a failure of the tubes should be feared. The chemical breakdown of water under radiation would offer no serious problem because water could be easily replaced and the products of disintegration (hydrogen and oxygen) could be easily eliminated.

(2) Diphenyl Cooling. - The only construction change that would be necessary in the Pile proper in going from water

cooling to diphenyl cooling would be to increase the thickness of the annular space from 0.086 inch to 0.158 inch. The disadvantages of using diphenyl as a coolant would be as follows:

1. The temperature rise would be about the same as with water. The highest temperature in the metal would be near or above the maximum allowable temperature, so that, if this were a limiting factor, the plant output would be smaller with diphenyl.
2. Diphenyl would offer the problem of chemical breakdown under radiation, known as "polymerization."* This breakdown would consist essentially of a change in the molecular weight of the diphenyl (say 320 instead of 150).

Advantages of using diphenyl would be as follows:

1. The temperature rise in the coolant would be about the same as with water.
2. Since diphenyl is not a conductor of electricity, no electrolytic action would have to be feared.
3. The elimination of corrosion due to diphenyl could be effected more easily than in the case of water.
4. The increased annular space of 0.158 inch thickness would bring about the same loss of

reproduction factor as that due to 0.086 inch of water.

From the engineering standpoint, the question of diphenyl versus water in the external system would seem to be better answered by choosing diphenyl. However, the use of diphenyl would create a few new problems. First, the radiation would cause polymerization of the diphenyl, probably with the liberation of hydrogen. The extent of polymerization was not definitely known at the time. A distillation unit of reasonable size would probably effect the separation of the higher polymers from the solution so that the purified diphenyl could be returned to the circulating system. A means of removing the dissolved hydrogen could probably be designed if the erosion due to the gas was found to be too severe. Secondly, if diphenyl itself were used, some freezing up in the external system due to its high melting point would have to be expected unless it were guarded against. Finally, it seemed likely that a diphenyl plant would require about 10 to 15 per cent more pumping power as well as more process steam, than a water plant. For these reasons water was accepted as the best coolant and all future discussion concerns water-cooled units.

b. Methods of Cooling. - Two methods of cooling presented possibilities between which a choice had to be made.

(1) External Cooling. - By far the more practicable from a design and engineering point of view, but with some doubt from the viewpoint of nuclear physics, external cooling would consist of passing water under pressure around and along the uranium

rods, between the rods and the tube. A modification of external cooling, double cooling, would be to use hollow uranium rods with the liquid flowing inside as well as outside the rods. This would allow high power levels, but because of the excess water there was some doubt as to whether a chain reaction could be sustained.

(2) <u>Internal Cooling</u>. - Here the cooling liquid would flow through a lined uranium tube inserted loosely in the graphite. This type of cooling, however, would present design and construction problems much more difficult of solution than those encountered in the external type of cooling. The greater expansion introduced by the hotter graphite, the more difficult uranium handling, and construction would be a few of the obstacles that would make internal cooling less attractive than external cooling. The only favorable aspect of internal cooling would appear to be from the standpoint of excess reproduction factor, due to the heating effect of the graphite. A modification of internal cooling considered involved so-called annular cooling, in which a solid uranium bar would be centered in the larger, hollow one, with the cooling fluid flowing between them.

c. <u>Horizontal and Vertical Piles</u>. - A Pile is referred to as vertical or horizontal according to the position of the rods and tubes. A horizontal axis would have the following advantages over a vertical axis and was therefore selected for design.

1. Easier to construct and operate.
2. Horizontal tubes would require only two ribs on which to let the rods rest. The vertical tubes

would require three ribs to act as spacers, which would give less play and more likelihood of binding. This would probably be the greatest advantage.

The vertical tube would have the benefit of gravity water flow at reduced or zero pressures.

d. Rods. - The graphite lattice, as originally conceived, would have consisted of lumps of uranium metal interspersed throughout the graphite in a regular pattern. Two difficulties would arise in the operation of such a Pile. It would be almost impossible to remove the processed metal without disassembling the Pile. Secondly, coolant would have to be concentrated around these lumps. This would involve certain design problems. It was obvious that if the uranium could be charged into the Pile in the form of rods parallel to the axis of the cylindrical Pile, they could be charged and discharged without removing any graphite. The design of a cooling system would be made simpler by adopting such a scheme. However, there was some doubt as to whether a chain reaction could be sustained with such a lattice. Three difficulties existed in following through with this type of design. First of all, discharging and charging, though easier than with a point lattice, would still be extremely difficult. There would also be the danger of long rods binding and warping in the tubes and the problem existed of designing a means of cutting off the rods, piece by piece, by remote control as they were being discharged. If the rods were unloaded without cutting them off, inordinately long casks or coffins would be required for their transfer to the Separation Area. A second difficulty foreseen lay in the fact of unsatisfactory bonding of the aluminum sheath and the long uranium rod, in order that the intense heat developed in the active metal could be removed into the coolant stream. A further difficulty lay in the fact that a long rod would not lend itself readily to dissolving at the Pile site. From a nuclear physics point of view, long rods would be desirable since more uranium would be present in the Pile. Long rods would also permit a more nearly streamlined flow of water and would eliminate the possibility of corrosion at the ends of segmental rods. But from the point of view of "canning" and handling the uranium, it was decided that short rods of arbitrary length should be designed. A length of approximately two feet was agreed upon. With rods of this length, handling would be made easier, and yet the amount of uranium in the Pile would not be too low to prevent production at the rated power level. This length was later reduced to eight inches.

e. Rod Spacing in the Pile. - Since there was no preference in lattice geometry from the standpoint of nuclear physics, a square lattice spacing of rods was adopted because of its easier adaptation to construction of the Pile shielding, piping, and valve arrangement.

f. Spacer Ribs for Rods. - A suggestion had been put forth that the spacing ribs be put on the outside of the uranium rod sheath. Since the tube would be relatively thin and subject to wear as rods were inserted or withdrawn, it appeared desirable to have the ribs on the tube to take the wear and save the tube itself.

g. Removal of Rods from Pile. - Since gripping a small rod in a small tube in order to pull it out would have presented a problem, and since, if each rod were made of several independent segments, the process of "fishing" through a long, small-diameter tube, gripping a segment, and withdrawing it, repeated about ten times for each of hundreds of tubes would have presented an unpleasant picture, the pulling of rods was abandoned as a possibility for Pile design, in favor of pushing them out.

h. Replacement of Air in the Pile with Helium. - By removing the impurities of air, with their large neutron-capture cross sections, and replacing the air with helium, having a negligible cross section, an increase in reproduction factor would be effected. It was thought best that this be accomplished by a simple gravitational displacement, with or without the aid of an intermediate displacement by carbon dioxide, requiring only a gas-tight shell around the Pile, rather than evacuating the air and then letting in helium, necessitating a shell capable of withstanding an atmosphere of external pressure.

i. Shipping to the Separation Area. - Several possibilities were considered in the design of a suitable means of transporting the irradiated segments to the Separation Area. Dissolving the rods at the Pile site would introduce the problem of disposing of large volumes of liberated gases containing "xenon"* and other radioactive elements and then pumping the solution and fission products over a considerable distance. Since the Separation

Area would already have the equipment designed to safely handle the xenon and fission products, it appeared more favorable to send the coated segments to the Separation Plant as solid rods.

5-7. Pile Design Problems and Solutions (See App. C 7). - In the discussion of corrosion, life of parts, shielding, control rods, and other parts of the Pile, it must be pointed out that the important consideration was the immediate production of plutonium and not the later construction of a plant for long time power production.

a. Chemical and Electrochemical Corrosion of Pile Materials under Radiation. - Since uranium is readily oxidized, it was necessary that it be protected from the water by a sheath or coating. This sheath would also serve to keep the fission products from contaminating the coolant. Also, for the external type of cooling, a lining tube would have to be placed in the graphite. With water as the coolant, these two (the sheath and tube) would have to be of the same material or of two materials close together in the "electrochemical series"* to suppress electrochemical corrosion. Of the few suitable materials which also are not attacked appreciably by hot water, the most promising were, in order, beryllium and aluminum. While the former was more desirable also for its hardness and resistance to wear, the limited supply of beryllium available plus the lack of commercial development made aluminum with its more extensive commercial production and development practically the only alternative, until such time as beryllium-aluminum alloys could compete with or surpass aluminum, or unless further corrosion tests should prohibit the use of aluminum and force the development of beryllium or beryllium-aluminum. A second danger point for electrochemical corrosion was at the junction of the aluminum and the steel which would comprise part of the water cooling system outside of the Pile. Tests on inhibitors and corrosion, however, indicated no great danger from corrosion at these junctions, if proper precautions were taken.

b. Pile Shielding. - Three types of shielding would be required for the Pile. All shields would have to be adequately cooled to eliminate the differential thermal expansion problems.

(1) Side Shields. - These could be of the simplest type such as a water tank around the Pile.

(2) End Shields. - These shields would have to be as thin as possible, and permit the insertion or withdrawal of rods without permitting the escape of the helium at any time. They should, however, be adequate to permit the proximity of workmen during Pile operation, absorbing fast and slow neutrons and primary and secondary gamma radiation. Since water or concrete alone would require so thick a shield, a shield composed of iron shot and water in tanks could be used.

(3) Shielding during Removal of Rods. - A shield would have to be provided to protect against the lateral gamma-ray leakage from the rods during withdrawal through the unshielded space between the Pile end shield and the coffin. This would have to be easy to open at any point for access to piping.

c. Coffins for Handling Rods. - Because of the intense radioactivity of irradiated segments and the natural radioactivity of unprocessed uranium, it was essential that some means of handling the rods be designed.

(1) Charging the Pile. - The coffin or chamber used to hold a new rod to be inserted into the Pile would not need to have a cooling system of its own. It would merely need adequate material to shield against gamma rays and a seal to prevent leakage of water from the Pile during the insertion of the rod. With aluminum-sheathed rods these precautions were found unnecessary, since the aluminum sheath provided sufficient shielding to reduce gamma radiation to safe levels.

(2) Discharging the Pile. - If it was decided that the new rod should be used to push out an active rod from the Pile, no other coffin would be needed at the entry end. If the active rod were to be removed without replacement, a separate flexible or ramrod plunger in a coffin would have to be provided, similar to the charging coffin. The coffin for receiving the discharged rod from the Pile could be one of several types depending on Pile design. The type preferred would consist of a short cartridge holding several rod segments and mounted on a small car.

(3) Handling Coffins. - At the Pile site, cartridge-type coffins could be handled by a small elevator tower on a crane traversing the face of the Pile. In turn, these cartridges would be handled on railroad cars to and from the "extraction"* plant, where facilities would be provided for dumping the contents of the coffins into storage and solution vats.

(4) Cooling Rods after Discharge. - The best method

of cooling the discharged rods while in the coffins was to allow the water in the coffin to boil away. This would require no more than a reservoir to replace the water as it boiled away. A second way of performing this operation was to circulate water in the coffin with a pump and drive, reservoir, and heat exchanger.

d. Control Rods. - The design of control rods suitable for a chain-reacting Pile was a problem of major proportions. Although design of these rods was not complete at the time the Metallurgical Laboratory submitted its design suggestion to du Pont, nevertheless, the engineering problems were already clear. It was believed that 9 rods would be required; 4 of them safety rods, to be used for stopping the reaction completely in emergencies; one of them, centrally located, the operating control, to be automatically moved by changes in the neutron density; and 4 of them "shimming rods," to be manually adjustable and to serve to control the effective size of the Pile.

(1) Safety Rods. - The safety rods were to be so designed that they could be driven into the Pile very quickly, by some means other than gravity, such as a fast acting pneumatic-driving device. These rods were to be designed to act in response to the following events:

1. 5% too high neutron density.
2. Excessive coolant outlet temperature.
3. Failure of plant power supply.
4. Excessive radioactivity in the coolant issuing from the Pile.

5. Inadequate back-pressure on the Pile.

(2) Size of Control Rods. - The rod would probably be about four to six inches in diameter, depending on the fraction of the neutrons in the Pile which it was intended that the rod should absorb.

(3) Cooling of Control Rod. - This could best be accomplished with water, possibly containing a dissolved "boron"* compound. This procedure would have the advantage that the rod itself could be made of any structurally convenient material, since the bulk of the neutron absorption would occur within the liquid itself. Connections to the cooling rod could be made by flexible metal hose. The idea of using a boron solution was later eliminated because of the possibility of leakage into the graphite causing the Pile to cease operating.

(4) Actuation of the Control Rod. - This would depend somewhat on whether the rod was horizontal or vertical. The vertical case would be a little easier from the engineering standpoint since no supporting horizontal track for the rod would have to be built into the Pile. In the vertical case the rod would either be suspended by a cable passing over a motor-driven drum, counter-weighted and fitted with a stuffing box, or it could be hung from a vertical rack and fitted with a counter-weight pinion-gear drive and a stuffing box. In the horizontal case the rack-and-pinion drive would undoubtedly be preferred, and the rod would have to travel on a graphite or water-cooled aluminum track in the Pile. The cooling solution probably would be introduced through a central tube running through the ~~cooling~~ control rod, and would return through the annulus to an external cooler.

e. Control of Helium through the Pile. - In order to detect water leakage into the graphite and to hasten its removal from the graphite, it was desirable to circulate helium in the Pile continuously. This would require an external helium purification, storage, and circulation system.

5-8. Cooling System Design Problems and Solutions (See App. C 7). - The function of the external system was to cool the water circulated through the Pile and partially to remove from it the hydrogen and oxygen formed in the water under the strong radiation in the Pile. A number of cooling schemes were suggested.

1. Once-through passage of raw water, discarding the hot water into the cold stream from which it was taken. Numerous objections to this procedure could be raised, among them the facts that the quantity of water required would be a considerable fraction of the river from which the water would have to be taken, that scale formation in the Pile would undoubtedly occur, and that a coating failure would result in contamination of the stream and thereby constitute a health hazard.
2. Cooling of the water after its passage through the Pile by pumping it over a cooling tower and thus evaporating a portion of it.
3. Cooling of the water after its passage through the Pile by countercurrent exchange against water, in turn cooled by passage over a cooling tower.

4. Cooling of the water after its passage through the Pile by "flash vaporization"* of a part of it at a lower pressure.

5. Cooling of the water after its passage through the Pile by countercurrent exchange against cooling tower water, with the addition of a distillation column for removing the dissolved gases from the hot water.

Scheme 3 was selected for preliminary design because the engineering problems for such a system should have straightforward answers, adequate Pile cooling should be provided without the considerable amount of equipment required for types 4 or 5, and excessive water requirements of types 1 and 2 could be avoided.

a. Dissolved Gas Removal. - In order to avoid erosion by liberated gas, it was desirable to keep the dissolved gas content of the Pile to a minimum. However, in this case there was reason to think that no extraordinarily complete separation of the dissolved hydrogen and oxygen from the water would be necessary. Therefore, it was believed that a single flash vaporization would be adequate.

b. Radiation Shielding. - One of the attractive features of the water-cooled plant was the fact that in its simplest conception the fluid would not become dangerously radioactive. As a practical matter, however, it would have been extremely foolish not to provide for the installation of substantial shielding. Earth, concrete, and water were the most economical shielding materials and, since bulk was no objection, these were to be used, although selection of shield thicknesses was difficult because there was no good approximation of the upper limit of the gamma ray energies to be expected.

c. Corrosion of Equipment. - The results of tests on 1020 type steel indicated that some type of corrosion protection would be necessary for steel of this kind. Several possible solutions of this corrosion problem were suggested. These included:

1. Use of inhibitors.
2. Cathodic protection.
3. Catalytic decomposition of "hydrogen peroxide."*

Consideration of the facts after considerable experimentation led to the conclusion that a sodium phosphate and sodium silicate inhibitor and the scrap iron reduction of the hydrogen peroxide appeared to offer the best probabilities for solving the corrosion problem.

5-9. Pile (100) Areas (Final Design). - When it was decided that the production plants were to be constructed near a large supply of water so that once-through passage of water could be used instead of recirculation, considerable change in design was necessary, simplifying the design problems of a recirculation system, such as gaseous waste removal, cooling, and radiation protection. The Columbia River site provided an adequate supply of cool, pure water. Whereas it was originally considered safe to allow the exit water temperature to rise above the boiling point of water, this value was later reduced to 130° Fahrenheit to provide a factor of safety. Consequently, the power level of the Pile would have to be lowered. Each Pile Area would then include a building containing a 250,000 kilowatt Pile complete with accessories and controls (See App. A 10, 11); a complete cooling water system; a retention basin for effluent water control; a helium gas purification building; service buildings for administration, security, fire protection, first aid, communications, and maintenance; and a power plant, the primary function of which was to maintain uninterrupted operation of critical process equipment (See App. A 8). There were to be three Piles similar in size, capacity, method of operation, and control. Because of the necessity of speed in construction, only Pile Areas D and F, containing the second and third Piles to be completed, were designed to include refrigeration equipment to cool the water during the summer, and only Pile Area D was to be provided with "demineralization"* equipment to further purify the water. In order to protect the demineralized water from contamination, it was decided to use stainless steel and rubber-lined water piping and rubber-lined water tanks. This feature was incorporated in the design of Pile Area D only. This was done in order to provide every means possible to insure continuity of operation of the second Pile should initial operating difficulties cause abandonment of the first Pile. There was little doubt that further experience gained from operation of the first two Piles would indicate any additional, but necessarily delayed, features requisite for the third Pile. The three outstanding characteristics of a Pile which were to be controlling factors affecting every consideration in the arrangement and design of each Pile Area were:

1. The hazard to life and health, prevalent during operation, if leakage of radioactive gases should occur, or if shielding should fail mechanically, thereby exposing

the area to radioactive emission.

2. The amount of heat liberated at capacity operation plus the risk of a spontaneous rise in temperature beyond controllable limits if pulsations or interruptions in cooling water flow should occur.
3. The specific materials of construction within the Pile and the dimensional tolerances dictated by the process, which would demand cooling water and all other materials to be of the highest attainable quality and of such a character that the absorption of essential radioactivity would be at an absolute practical minimum.

Using the Pile Building as a nucleus, the location and arrangement of the other buildings and facilities within each Pile Area could be determined from the operating requirements and the topography of the site.

5-10. Pile Units (Final Design). - Early start-up and reliable operation of the Pile Areas were of paramount importance. The main process unit in each of these areas was to be the transmutation unit or Pile (See App. A 12-14). From the beginning, Pile design consisted of a series of difficult problems wherein ordinary materials were converted into multiple unusual shapes, having extremely fine dimensional tolerance for the size or mass involved, and requiring unconventional assemblies, careful planning, and diligent inspection of every minute detail. As the scarcity of high-grade carbon eased somewhat, and in view of the problems encountered in designing a domelike Pile (See Par. 5-5), it was decided to design a graphite structure (See App. A 15, 16), approximately 28 feet deep by 36 feet high by 36 feet wide, built up from over 100,000 graphite bars to be bored to receive special aluminum tubes oriented in a special pattern on accurate centers, retaining the original active cylindrical arrangement for aluminum tubes. Originally 1695 tubes were to be incorporated in the design of the Pile. However, after a square-faced Pile had been adopted, this number was increased to 2004 in view of the unpredictable possibility of loss of Pile reactivity through formation of high "neutron absorbers"* among the fission products. This was a fortunate decision because it permitted charging extra metal to overcome the poisoning effect of fission products which did occur and to reach and surpass the rated power level (See Vol. 6). Measuring and control devices, discussed later, would require other openings to be provided in the horizontal and vertical directions. From a nuclear physics point of view, the highest obtainable purity of all materials of the Pile structure was essential since the materials of construction would be chosen as to their low neutron-absorbing properties. Plans had to be drawn for enclosing the Pile with an inner thermal shield consisting of a 10 inch layer of cast iron blocks of special shape and arranged to produce a continuous envelope, and an outside "biological" shield, more than 4 feet thick, to be made up of alternate layers of pressed wood (masonite) and steel, specially shaped and fastened to prevent the escape of gamma rays. Special flexible seals mounted on the outside surface along all end-block joints were found necessary to make the structure leakproof at a gas pressure of two pounds per square inch. The above completed assembly would constitute a mass of nearly 10,000 tons which would have to be supported on a concrete foundation especially designed for gas tightness and provided with special piping imbedded in the base of the unit. Many fundamental mechanical developments, therefore, were to characterize the evolution of the Pile design.

a. Graphite Development. - It was evident that the development of techniques and tools for the manipulation and precision machining of specially processed, hard, dense bars of graphite of which approximately 7000 tons (in finished form) would ultimately be cut, bored, turned or shaped to a dimensional tolerance of 0.0005 to 0.0040 of an inch would be a major problem. Initial manufacture of the graphite was expected to leave a contaminated surface on each bar which would have to be removed during a precise machining operation. Freedom from contamination was so vital to successful operation that it was necessary to devise or adopt special clothing, tools, supplies, and handling methods; and special training with constant alert supervision was necessary to insure satisfactory preparation of the material. The limitations on purity were so rigid that recovery from errors would be impossible. Having determined the neutron absorption capacity and availability of several moderators, graphite was chosen for the Pile structure because of its low neutron-capture cross section (See Vol. 2) and since industrial production of graphite already was very large. A small quantity of an impurity, such as boron, in the graphite might have such a high neutron absorption capacity as to render the Pile useless for a nuclear chain reaction.

Orders for the specially-processed, high-density graphite used in the Piles were placed with the National Carbon Company and the International Graphite and Electrode Company, after investigation of several vendors disclosed that these would be the only firms able to produce bars of the specified size. Since the total production, field machining and installation costs were found to vary approximately inversely with the size of the bars, much study and experimental work was necessary before the final dimensions could be specified. Extrusions were made of various cross sections up to eight inches square. However, it was learned by experiment that the density and uniformity of the graphite decreased with an increase in size; and a cross section which, with a minimum amount of machining, could be finished to a 4-3/16 inch square of high grade material was accepted. This size also was practicable for the optimum 8-3/8 inch spacing required as calculated from theoretical nuclear physics (See Vol. 2) for the aluminum tube pattern in the Piles. Since uniform production of the highest grade of graphite proved to be impracticable, it was decided that four different grades would be accepted in order to utilize as much as possible of the produced material. These grades were to be arranged carefully in the Piles, so that the highest grade should be near the center and the lower grades in the exterior portions, as research had indicated this layout to be most satisfactory for the process (See App. A 17).

b. <u>Aluminum Tubes</u>. - It was clear that the development of extra long, thin wall aluminum tubes, accurate and uniform in dimension, would be a vital factor in the design as well as the operating performance of the Pile. A smooth, unblemished outside surface, with an outside diameter controlled to within 0.0020 of an inch, was essential for installation in the Pile. Ribs were to be provided in the tubes to hold the uranium rods or "slugs" in such a position that cooling water could be evenly distributed around the slug and to provide a track on which to slide the slugs, thus saving wear on the tube walls. There was little doubt that the procurement of these tubes would present major problems both in development of fabrication methods and in actual production. Various vendors had to be contacted, and many different fabrication schemes had to be considered and tested before these unconventional tubes could be produced within the extremely close tolerances required. The cross-sectional center to center spacing of the uranium slugs, which had been accurately determined, dictated the amount of graphite, aluminum, and water allowable. The dimensions of the tubes and slugs were predicated upon the total amount of water which could be in the Pile at any instant, and this amount of water, in turn, would be limited by its neutron absorbing qualities; distribution of this maximum quantity of water among hundreds of cooling tubes would limit the amount of water present in any one tube at any instant and, in combination with the flow required to dissipate the heat generated, would determine the cross-section of the annular space. After dies had been developed with which the cross-sectional tolerances could be maintained, it seemed likely that difficulty would be encountered in drawing a tube which would not spiral. It was clear that the straightness and accuracy of such an unconventional cross section, therefore, would require several months of persistent development. Actually, the Aluminum Company of America~~x~~ required seven months to obtain satisfactory tubes on a production basis, to fulfill the requirements for over 6000 tubes for the three areas. A second, yet vital step in tube development was the necessity of developing new techniques and tools, specially designed to anneal, ream, and flange the tubes in position, with typically close tolerances and uniformity. Aluminum fabricators were of the opinion that three ribs were necessary. In fact, it at first seemed to be impossible that tubes with only two ribs, unsymmetrically placed, could be extruded. However, the Aluminum Company of America was finally able to extrude tubes 44 feet long with two longitudinal ribs in the bottom half of the tube. To accomplish this it was found necessary that the thickness of the wall of the top half of the tube would have to be greater than that of the bottom half by 0.0130 inch (See App. A 18). However, as long as the cross section of the annular space surrounding the slug was a constant, the variation in aluminum tube wall thickness could be permitted. In the design of the aluminum tubes and of a means of fixing the tubes in the Pile, every possibility of expansion and radiation had to be considered.

(1) Expansion. - To allow for longitudinal motion of the aluminum tube with respect to the biological shield, a sylphon bellows was designed to join the gun barrel (a tightly fitting sleeve over the tube running throughout the shielding and about one foot into the Pile) to the biological shield (See App. A 19). Since the gun barrel and its appurtenances would be made entirely of iron, it

would appear that a sizeable window would be provided for the escape of fast neutrons. It turned out, however, that the iron would scatter the neutrons into the masonite where they would be slowed down.

(2) Radiation. - To prevent escape of radiation through the small space between the gun-barrel and the biological shield, two series of six steel "doughnuts" were designed (See App. A 20); one series, closely fitted to the gun-barrel, and the other series, staggered with respect to the first series, closely fitted to a large steel tube which would pass through the laminations of the shield and enclose the tube and doughnuts. This staggered doughnut construction would permit the gun-barrel and its aluminum tube to move sideways without opening up a direct avenue of escape to the radiation.

(3) Motion. - The possibility of violent motion of the graphite block put forth the necessity of designing a means of allowing the aluminum tubes to rock with respect to the graphite to prevent shearing of the tubes. This was accomplished by designing a sleeve about eight inches long, enclosing the gun-barrel and tube, the inside surface sloping outwards from the center so that the tube would rest on a pivot (See App. A 20).

(4) Corrosion. - As pointed out in the discussion of the preliminary design suggestion for a liquid-cooled plant (See Par. 5-5), water would have left the Pile at a temperature 2° Fahrenheit above the boiling point. However, this idea of exit water at such a high temperature was later abandoned in favor of a lower temperature

(130° Fahrenheit) to minimize aluminum corrosion and to provide a factor of safety. It is obvious that, had the original idea been retained, the water pumping demands could have been lowered since heat would not have to be dissipated so rapidly.

c. <u>Pile Shielding (See App. A 21)</u>. - It was realized that the design, fabrication, and erection of the main shield or encasement about the Pile would involve a program requiring several months from inception to the beginning of erection. Ten months were required to complete this program, or thirteen months from its inception to the completion of the first unit. In this time, the scientific requirements were first reduced to available materials which could be fabricated and a program was outlined for subsequent design and procurement. The design of the shield was such that consultation with commercial fabricating shops would be necessary to keep specifications within attainable limits, expedite fabrication, and minimize erection difficulties in the field. A reinforced concrete wall was originally conceived as the best form of shielding. The thickness of concrete needed on all sides of the Pile would be several feet. In all, shielding would be massive, to say the least. For several reasons this type of shield would be unsatisfactory. The concrete shield would have to be much thicker than a shield made of some material which could absorb radiations better, and would therefore necessitate longer aluminum tubes. There was some doubt as to whether such tubes could be extruded satisfactorily. Secondly, longer tubes would necessitate railroad cars of larger dimensions for transporting them from the fabricator to the Hanford site. Thirdly, the exactness required in matching the aluminum tube openings in the Pile with those in the shield would be difficult to attain.

(1) Biological Shield. - It was necessary that the stopping of both neutrons and gamma rays be considered. Alpha and beta particles could be absorbed easily. The higher the density of material used against gamma rays, the more effective it would be in retarding them. On the other hand, the energy of neutrons would be reduced most effectively by the lighter elements. Therefore, a special high-density, pressed-wood sheet (a special type of masonite), rich in hydrogen content, was developed through negotiation with an outside vendor. According to design plans, over 20,000 tons of 1 to 3-3/4 inch steel plate and 7,500,000 square feet of pressed wood would be required. Steel would absorb primarily the gamma radiation and would add strength to the Pile face. The wood in masonite, containing hydrogen, would absorb both gamma radiation and neutrons that escaped the thermal shield (See App. A 22). It was found best that this material be distributed to 44 fabricating and machine shops where the plates and sheets could be bored, cut or machined, and the sleeves which would carry the aluminum tubes through the shield could be turned and cut to size. The components would then be shipped to assembly shops for the final assembly, welding, and machining of approximately 726 laminated blocks ("B" blocks) weighing approximately ten tons each, which would form the biological shield at the charging and discharging faces of the Pile (See App. A 20, 23). These results were finally obtained in spite of the complexity of construction and close tolerances required, coupled with the lack of time available

for complete development of fabricating technique.

(2) Thermal Shield. - From the beginning of design, it was clear that, regardless of the type of biological shield decided upon, a thermal shield would be required. This thermal shield would be located between the graphite of the Pile and the laminated-steel-and-masonite shield and would have a dual purpose; to absorb the heat produced and to absorb beta particles and neutrons (See App. A 22). Without such a shield, concrete would have disintegrated with neutron bombardment. This shield was to be composed of cast iron blocks since these could be machined or cast easily. The close fit required in the field assembly of these 10-inch blocks normally would have involved a machining operation. However, because of the lack of available machining equipment, it was decided to cast these blocks within very close dimensional tolerances. Orders for the more than 15,000 blocks required were placed with the Lynchburg Foundry Company and the U. S. Pipe and Foundry Company. Initially, it seemed as if neither vendor would be able to cast a single block within the specified tolerances. Eventually, by the use of refined foundry practices and very slight relaxation of tolerances, the two companies were able to produce acceptable castings and to complete the quantity required. One of the major problems in the design and construction of such a shield consisted of deciding on a means of hanging the shield on the Pile, so that the blocks could move with expansion of the tubes and the thermal shield. This could not be achieved by resting the blocks on the concrete foundation. Several possibilities were suggested. It was finally agreed that the blocks of the shield should be supported

by the steel gun-barrels in which the aluminum tubes were fitted (See App. A 20).

d. Slug Canning.

(1) Early Considerations. - Several methods of canning the slugs were proposed. These included one known as the "hot dip" method in which the slug would be dipped into molten lead. Another method suggested was the use of electrolysis. The best method, however, and the one adopted for further development, consisted essentially of forcing the slug into an aluminum sheath and sealing the can. It would be necessary that heat be conducted radially from the center of the slug to the coolant and not along the axis of the slug to the ends. If slugs were charged into the aluminum tubes with no space between adjacent slugs, heat carried down the axis of the slug could not escape. Furthermore, if a space between slugs were to be permitted, water in these spaces would not be under sufficient pressure to carry the heat away adequately, and the amount of uranium in the Pile would be reduced. It was at first decided, therefore, to place an aluminum wafer over each end of the slug, enclosing an air space, which would act as an insulator. Slugs of this design were produced and used experimentally by the Metallurgical Laboratory (See App. A 24, 25). However, these experiments showed that this was not a suitable solution. The welding of these caps to the aluminum sleeve, with an air pocket enclosed, was found to be difficult. This led to leaky cans. Furthermore, the expected heat transfer was not accomplished. Consequently, no slugs of this type were produced at Hanford. Calculations showed that a plug of aluminum about 3/8

inch thick at each end of the slug would be a good insulator and not affect the reproduction factor too seriously (See App. A 26). It must be remembered that throughout these experiments the amount of aluminum and other materials which might absorb neutrons faster than they were produced had to be kept at a minimum. Along this line, it might also be mentioned that for a period of approximately one month consideration was given to a double canning process, in which the slug would be canned as originally planned and the assembly sealed inside another aluminum can making the welded seal at the other end. This would require twice as much aluminum as would actually be necessary and, therefore, this idea was eliminated.

(2) Present Process. - In the production of slugs at the Hanford site, it may be pointed out that the original canning process involved introducing the slug into the can containing molten aluminum-silicon, and forcing the slug to the bottom of the can as rapidly as possible by means of hydraulic presses. This method was entirely unsatisfactory and caused innumerable interruptions to production for press maintenance. Effort was concentrated on improvement of press performance with the result that sufficiently continuous performance was gradually obtained. For example, it was learned that a reduction of 50° Fahrenheit from the prevailing molten bath temperatures resulted in an increase of from a few per cent to more than seventy-five per cent of the total slugs canned being considered to be acceptable. This improvement was made in August 1944 and resulted in the decision to reject all prior canning production. In September 1944, the hydraulic canning presses were abandoned

entirely and a modification to the process substituted. In this modification, the slug, can, and top cap are assembled manually below the surface of the final aluminum-silicon bath. With this modification the following advantages accrued:

1. Assembly of parts under closer control.
2. Improved seating of the top cap.
3. Simplification of operation.
4. Appreciably greater production rate.
5. Elimination of maintenance.
6. Reduction in canning operation costs.

With this and other gradual improvements to the process, almost ninety per cent of the total slugs canned were found acceptable for charging into the manufacturing Piles. The present process, known as the submerging process, utilizes an aluminum can with a thick bottom; after the uranium slug has been firmly soldered into the can, the top is sealed by welding into it the aluminum plug. The solder, or bonding material, is a composite of bronze, tin, and the "aluminum-silicon alloy."* It is applied to the slug by consecutive dipping into molten baths of these materials. While still hot, the slug is inserted into the can which is held beneath the surface of a final aluminum-silicon bath followed by insertion of the aluminum plug into the can on top of the uranium slug. The finished assembly is trimmed to length and the closure doubly sealed by sealing the cap to the wall of the can (See App. A 26). The canned slug is then subjected to a series of exacting tests and only those slugs which are considered to be perfect are accepted for charging into the Piles. For further discussion on the canning process, see Volume 6.

e. Types of Slugs (See App. A 27). - There was some question, when the Pile was not in operation and was shut down for considerable periods of time, whether the excess reproduction factor would not increase so rapidly that control and safety rods would be unable to hold it and whether there would not be some difficulty in the start-up of the Pile. For this purpose lead-cadmium slugs were designed to "poison" the Pile, since "cadmium"* is a neutron absorber. Other dummy slugs were designed to fill the spaces in the ends of the tubes where they pass through the shielding, in which the reaction would not be taking place.

f. Control Features. - The quantity of neutrons present in the Pile at any instant must be precisely controlled so that the birth rate of the neutrons just equals the death rate. As a safety precaution, therefore, three automatic safety devices were found necessary, making use of the properties of an element, such as boron, which has a high neutron absorption capacity. These features (See App. A 28) were the control and shim rods, the vertical safety rods, and the borax solution. Whenever any circumstance should appear that would present imminent danger to the Pile, one or more of these devices would be put into operation. The events that would trip these safety devices were as follows:

1. Drive the shim rods into the Pile.
    - a. High power output.
    - b. Low level of hydraulic fluid in any one of the three accumulators.

   c. Manual push button.

2. Drive in the shim rods and also drop the safety rods.
   a. Low pressure on chilled and unchilled water headers.
   b. High power output.
   c. Power failure.
   d. Manual push button.
3. Force borax solution into drop vertical safety rod wells.
   a. Extremely low pressure on inlet water.
   b. Failure of shim and safety rods to operate.
   c. Manual push button.

Experience in Pile operation indicated that several changes were necessary in the operation of these devices (See Vol. 6). In the event of a power failure, an arrangement would be necessary whereby the control rods would be driven automatically and instantaneously into the Pile to stop the reaction. Some form of energy stored in an accumulator would be ideal. Water and air pressure were both considered. Water pressure was abandoned as a possibility early in design because of the difficulty of eliminating the corrosive effects of the water. Air, being compressible, was apt to get out of hand, prohibiting exact control. Gravity weights and storage battery methods were also proposed. Finally, a weighted accumulator, storing and delivering oil at sufficient pressure, was provided (See App. A 29, 30). The design of this accumulator would be such that all seven shim rods would be driven into the Pile simultaneously at a speed of 30 inches per second. The hydraulic system designed to drive the shim and regulating rods during normal operation was to consist essentially of an electrically driven oil pump which would supply oil at a pressure of 1000 pounds per square inch to a hydraulic motor connected to the rod rack (See App. A 29, 31, 32). No driving device would be necessary to drive the vertical safety rods into the Pile since these would drop by gravity.

(1) <u>Control Rods (See App. A 33)</u>. - From the outset of design, it was clear that rods, capable of being inserted and withdrawn from the Pile, were the best means of control. Furthermore, original suggestions for the operation of rods called for hydraulic and electric controls. Along these two lines, therefore, design was directed. Since boron has a high neutron-capture cross section, it would be an effective control means. The Aluminum Company of America, however, was unable to supply an aluminum-boron alloy. Several experiments were performed, resulting in the spraying of boron on metallic aluminum tubes. Since many of these rods, and at times all of them, would be in the Pile, it was necessary that a cooling system be designed to remove approximately 50 kilowatts of heat in each rod. Three boron-sprayed aluminum tubes, one carrying the cooling water and the other two removing hot water, enclosed in an outer aluminum casing to give rigidity to the structure, were designed (See App. A 33). The horizontal control rods were to have sufficient capacity to absorb neutrons resulting from any condition except loss of water from the cooling tubes. Also to be considered in the design of these control rods were the factors of support for the rod, to

prevent bending, and lubrication, to prevent wear. The best means of supporting the rods externally to the Pile developed to be a rack supporting roller bearings perpendicular to the motion of the rod. As to lubrication, since the prime consideration was given to using only materials with low capture cross sections, graphite bearing blocks, similar to the ways of a lathe, were designed (See App. A 32-34). The number of rods to be used in the Pile would be determined by the excess reproduction factor to be controlled, disregarding the loss of factor by any other means. This data was supplied by the Metallurgical Laboratory. In determining the number of rods several other factors also had to be considered, among which were: (1) Shadowing effects of one rod upon the other and (2) Absorption effect of the boron, which depended on the location and amount of boron in the rod. Original design indicated that only five rods would be sufficient to hold the Pile. However, due to later calculations and as an extra precaution, it was decided that nine rods should be provided. This was a fortunate decision for it was found later that all nine were necessary in shutting down the Pile. Control rods would be divided into two categories; the first, shim rods, to be used in whatever quantity required, would be a rough control means in starting and shutting down the Pile and would be left in a more or less stationary position during operation. Seven of these rods would be known as shim rods. The other two rods would be known as the regulating rods, to be used in making fine power adjustments and keeping the Pile at a constant level.

(2) <u>Vertical Safety Rods (See App. A 35)</u>. - The safety

rods were designed primarily to shut down the Pile in case of an emergency such as water boiling in the tubes or loss of power. Through a series of steps, twenty-nine rods were finally decided on, although this figure was arrived at after design had progressed considerably. The idea of allowing these rods to drop by gravity into thimbles in the Pile existed from the beginning of design. Methods of lifting, holding, and controlling the rods by remote control had to be developed. As designed, these rods would be hollow steel tubes impregnated with boron (1.5 per cent) about 35 feet long. The top and bottom would be solid in order to form an effective means of cutting off radiation from the thimble openings when the rods were inserted and withdrawn (See App. A 36). The vertical safety rods were designed to hold the Pile with no water cooling since they would not be in the Pile during operation. Normally the rods would be suspended above the Pile with the lower end of the rods coinciding with the bottom face of the top thermal shield. Two cables, with left and right hand windings on the barrel of a winch about 40 feet above the top of each rod, would support it (See App. A 35). With this arrangement it would be possible to change the direction of the rod's motion. In order to absorb the shock of the falling rod when it was inserted into the Pile by tripping the safety circuit (See App. A 37), a braking motor was designed to slow down its motion and bumper mechanisms were provided at the thimble opening (See App. A 36).

(5) Borax Solution. - Should the control and shim rods and the vertical safety rods fail to operate, a third device would be necessary. What this device would be was uncertain for a considerable

period of time. Occasionally it seemed as if the idea would be abandoned. Finally, after considering the feasibility of dropping boron shot into the vertical safety rod "thimbles"* and in view of the delay with which this would be accomplished (2 or 3 minutes), it was decided that a borax solution, under a pressure of 75 pounds per square inch, should be allowed to fill the thimbles in emergency. By use of a solution, it would be possible to flood the thimbles when the rods were in, out, partially in or moving into the thimbles. However, some design changes were necessary for the thimble openings. These were accomplished satisfactorily.

g. <u>Charging and Discharging (See App. A 38, 39)</u>. - As mentioned previously, one reason for adopting a short slug in preference to a metallic rod was to simplify discharging operation, transportation, and handling. To prevent rupture of the aluminum sheath and the consequent induced radioactivity in the storage basin water, it was thought wise to allow a slug to fall a distance no greater than eight inches. In order to unload the Pile then, buckets would have to be brought to the level of the particular tube being discharged to catch the slugs. Experience proved this stipulation to be unnecessary. Final design as given to the Construction Division incorporated an~~d~~ aiming device (See App. A 40) from which the slugs would fall into a neoprene-lined funnel connected by a rubber hose to a mechanical sorting device and into the storage basin. The sorting device was so designed to permit a selective choice of slugs and to discharge them into different buckets depending on the particular type of slug. As operations progressed, however, this scheme was found impracticable and was discarded since the slugs would not slide on the rubber. The reason for this is unknown at present. No corrosion of the slugs could be noticed. It has been suggested that a thin film of scum was formed on the slugs. Present discharge operation allows the slugs to fall by gravity onto a sloping neoprene mattress (See App. A 41, 42) of sufficient thickness to absorb the shock of the fall and then to slide into a storage basin (described below), where they are sorted manually, by means of tongs and an underwater periscope, and loaded into buckets for storage. When the buckets are at the mouth of the discharge chutes, they are suspended from a section of the monorail that is connected to a scale which is sensitive enough to verify the count of dummies and slugs. Two other sorting devices considered might also be mentioned. One device involved selection according to weight, where slugs of a certain weight fall through a door upon passing over it, while lighter ones would pass over with no change. The other device consisted of two rubber belts moving in opposite directions. Slugs of one type would be carried in one direction and dumped into the appropriate bucket, while the other slugs would travel in the opposite direction.

h. Transfer Facilities. - The high degree of radioactivity of newly discharged slugs required shielding and also a means of handling remotely the individual, processed slugs. It was decided that a minimum of 16.5 feet of water would act as an excellent shield, which would serve a dual purpose: absorb the heat generated by the active metal, and shield personnel from the radiation.

(1) Discharge Storage Basin (See App. A 41, 43). - A

discharge storage basin was designed into which the slugs could fall through three chutes leading from the discharge face of the Pile. Buckets, suspended in the pool from overhead trolleys, were designed in which the slugs could remain during storage. A wooden floor, over the pool, with slots under the monorail tracks, was provided, as well as a means for loading slugs into the buckets.

(2) Transfer Area (See App. A 43). - After a bucket of slugs had been retained in the storage basin for a period long enough to allow its activity to decay considerably, it could then be taken by means of an overhead monorail system provided in the storage basin area to the transfer area. Here the bucket would be lowered by a crane into a massive lead cask, with openings in the lid and walls so that water could circulate around the metal (See App. A 44). Each cask would be designed to hold one bucket of metal (about a half a ton). These casks could be removed from a tank car by the crane and, on their way down into the transfer pit, the lids would be engaged by stops which would hold them while the casks could continue their way down until they were under the bucket. On the way up, through the same channel as it was lowered, the lid would be returned to the cask and locked. The covered cask and contents could then be removed from the pool into the tank of water on the flat car.

(3) Tank Car (See App. A 43). - The first suggestion for transporting the slugs to the Separation Area involved the construction of a concrete channel several miles long from the Pile Areas to the Separation Areas several feet under the ground level, through which slugs could move either on a moving belt or on small

cars run on tracks. To provide shielding and cooling, this channel would have to be water filled. A major reason for the discarding of this suggestion, however, lay in the necessity of insuring a dust-free or air-tight channel, since gases and vapors that found their way into the channel would become radioactive. An overhead monorail system was also considered for design, but was soon eliminated in favor of a specially-designed tank car, containing sufficient lead shielding and a means of water circulation through the lead walls for cooling. Each tank car would contain two casks, the capacity of each cask being one bucket of slugs.

i. Instrument Design. - The Metallurgical Laboratory developed and constructed many special electronic devices for the control of the Pile, while other instruments of special design were developed by the Prime Contractor in collaboration with outside vendors. Assistance was obtained from the Metallurgical Laboratory in the design of special optical equipment used for observing the Pile discharge face from shielded positions outside the discharge room and for examining the interior of the long aluminum tubes, since the high degree of radioactivity to be encountered would preclude direct contact. By means of electrical interlocks and devices, the system was designed to respond to every variation in water supply, Pile activity, and power supply, primarily for adequate control and safety of operation. A central control room equipped with panels for all types of meters and controls was to be provided (See App. A 45-52). There was some doubt as to the best means of measuring the Pile power and monitoring the Pile within safe operating limits. The most direct method of measuring the power would have been to determine the heat transferred to the cooling water. The requirements of satisfactory control, however, would be such as to make it necessary to control the Pile by means of variables which would respond more rapidly than the temperature of the cooling water. Instruments which would measure neutron intensity would be fast operating and, therefore, more suitable as primary control elements. In the design of the Pile, three experimental holes, entering the Pile horizontally and from the face opposite that by which the control rods would enter, were provided (See App. A 45). The primary neutron "ion chamber"* would be located in one of these holes. Current from this chamber could be indicated at the control desk. In the other holes, instruments to measure gamma radiation could be inserted. To provide a means of additional neutron density measurements, design provided for four concrete pipes located six feet below the bottom of the Pile (See App. A 45). Each pipe would be equipped with three risers, forming somewhat of a square array below the Pile. The outside risers were to be eight inches in diameter and the two inner risers, sixteen inches in diameter. By plugging each riser with lead it would be possible to reduce the gamma radiation, allowing the neutrons to impinge upon the ion chambers located in the tubes below the risers. The ion chamber currents provided by the instruments could then be amplified and used to operate relays to trip the safety circuits to shut down the Pile if the levels were to become too high. Also designed to measure power level was a gamma ray chamber which would function by measuring the gamma radiation emitted by the Pile discharge water. It was clear that, during the initial metal charging and for subsequent start-ups of the Pile, continuous monitoring of the neutron intensity at extremely low Pile levels would be necessary. Fortunately, a method was available whereby neutrons could be detected and counted. This method would involve the use of a "proportional counter"* inserted in one of the process tubes of the Pile or under the Pile with the neutron chambers. After the Pile level had risen to a certain value, these counters could be removed and the power could be measured by means of the neutron ion chambers mentioned above.

j. Miscellaneous Equipment. - A set of special micrometer instruments to monitor the movement and deflection of the Pile unit to check its mechanical stability, specially designed lead-lined cabs containing instruments for remotely controlling emergency operations on the discharge face of each of the Piles, and other special mechanical devices for use in testing and calibration of the Pile were designed and partially fabricated in the Prime Contractor's Wilmington shops and tested in these shops to detect any needed changes prior to final installation.

k. Pile Building Shielding (See App. A 11). - In addition to the Pile shield itself, plans were made for shielding critical equipment in concrete cells. Supplementing the extensive Pile shielding previously described, the Pile room walls were designed to be constructed of solid concrete three to four feet in thickness to form a secondary protection for operating personnel in the Pile building as well as in the area at large. A control room (See App. A 48), to house the elaborate instruments required to monitor and control every phase of the Pile operation, was to be located behind a three foot concrete wall, further shielded with lead for protection of instruments. These instruments were to include a telephone system to provide contact with all of the operating stations in the building and in the area and a centrally controlled public address (tele-talk type) and alarm system to warn all personnel in the area of impending danger and to permit issuing instructions for complete evacuation if necessary. It was clear that the thoroughness with which every source of radioactivity was shielded and protected would greatly simplify the design requirements of the other area buildings which could follow conventional design dictated only by the service imposed.

1. Headers (See App. A 11, 19). - Two particular problems in the design of the header system at the charging and discharging faces of the Pile might be mentioned. Because of the expansion of the aluminum tubes, a suitable means of bringing the water from the manifold to the tube had to be designed, so that there would be no buckling of tubes or undue stress placed on the manifolds. Swivel joints were originally considered but were found unsatisfactory. Flexible piping, known as "pigtails," acting as springs, were developed (See App. A 19 and 39). This solution also provided an answer to the problem of where the manifolds should be located, since operating requirements dictated that the headers be located so as not to interfere with charging and discharging procedures. These headers were, therefore, located next to the outside plate of the shield, inside the charging and discharging points. On the discharge face, risers were designed so that water would be present in the tubes

at all times. This would prevent draining of the unit and would act as a poisoning agent when the Pile was shut down.

5-11. Water System (Final Design). - Successful operation of the Pile would depend upon the ability to remove continuously the heat produced, and the rate at which plutonium could be produced would be dependent upon the rate of heat removal. This in turn required that every effort would have to be made not only to insure continuity of water flow under all conditions, but also that water treatment facilities which might minimize the corrosion of the aluminum tubes and aluminum-sheathed (canned) pieces of uranium during the extended periods of operation would be necessary. Furthermore, complete interruption of water flow could result in a steam explosion of catastrophic proportions. For these reasons elaborate water facilities were necessarily designed to avoid serious operating problems. As has been mentioned previously (See Par. 5-8), objections raised to once-through passage of raw water and discharging the hot water into the cold stream from which it was taken included the facts that the quantity of water required would be a considerable fraction of the river from which the water would have to be taken, that scale formation in the Pile would undoubtedly occur, and that a coating failure would result in contamination of the stream and thereby constitute a health hazard. Consequently, original design provided for a recirculation system, including gaseous waste removal, cooling, and additional radiation protection from the contaminated water. However, the Columbia River site provided an adequate supply of cool, pure water to permit cooling of the Piles without recirculation. This change involved considerable change in design, simplifying these problems considerably. It was estimated that approximately 30,000 gallons per minute of water, having a high degree of purity, would be required for process cooling in each of the three Pile Areas, in addition to the 5000 gallons per minute of filtered water to be pumped to each of the Separation Areas. Additional quantities would also be required for boiler make-up, condensing purposes, and for sanitary and miscellaneous service. Therefore, provision had to be made for 50,000 to 60,000 gallons per minute with emergency demands up to 90,000 gallons per minute for each Pile Area. The filtration of such large quantities of water would require a considerable expenditure for the construction and operation of the filter plants. In an attempt to by-pass the need for filtration, economics dictated that complete investigation of ground-water conditions be conducted in the hope that an adequate supply of suitable water could be obtained from wells. Tests showed, however, that the available ground-water was inadequate for the entire requirements of even one area, and, after thorough consideration was given to the reliability and character of the water, the Columbia River was chosen as the source of the entire supply. It was believed desirable, if not essential, to remove all dissolved or entrained gases as well as all solids before pumping the water through the Piles. In addition, because of uncertainty regarding the effect of impurities and dissolved chemicals on the process and equipment, facilities for demineralization were to be installed in one area, with provision for similar installations in all areas should demineralization be proved essential by operating experience. The main factor limiting the operating capacity of the Piles would be, as mentioned above, the rate at which the generated heat could be removed from the Pile without the exit cooling water reaching a temperature at which aluminum would be corroded. Since the Columbia River water during periods each summer reaches a temperature high enough so that maintenance of a limited exit cooling water temperature would reduce Pile capacity, a certain amount of refrigeration was considered necessary. Since such refrigeration installation would postpone completion of the first Pile, the equipment was to be provided for only the second and third Piles. In order to prevent possible corrosion, the installation of chemical addition and proportioning equipment was necessary to maintain uniform water quality. The particular needs for water supply would require the utmost reliability of this service. In case of failure of the river pumping plants, it was necessary that sufficient water for minimum operation requirements be available from storage. Therefore, facilities were to be provided in each of the three Pile Areas for storage of 25-, 10-, and 7-million gallons of raw, filtered, and process water respectively. In addition, two elevated storage tanks with a total capacity of 600,000 gallons were to be provided to supply minimum water requirements for about two hours by gravity flow should all power be interrupted. An interconnecting supply system varying in pipe size from 42 inches to 24 inches was also designed for installation between all the Pile and Separation Areas. This system would consist of approximately twenty miles of reinforced concrete pipe of a special design which was selected for its reliability in service and for the conservation of steel.

a. River Pump House. - Each Pile Area had to be provided with a river pump house designed to supply its own water requirements as well as some Separation Area water requirements, in addition to a stand-by capacity for delivering approximately 20,000 gallons per minute to other Pile Areas in case of emergency. As designed, normal operation would employ electrically driven pumps, but, for emergency use, three steam turbine-driven pumps were also to be provided. It should be noted that provision was made throughout the entire process water system for continuity of service by use of steam should an electric power failure occur. Protection to fish had to be given serious consideration in the design of the water intake screens. Consulting service was, therefore, requested and obtained from an ichthyologist retained by the Seattle District of the Corps of Engineers (See App. C 8), who periodically met with representatives of the Prime Contractor to discuss and approve design prior to procurement and installation of these facilities. Although of standard design, the screens were provided with special mesh to prevent fingerlings from entering the cooling water system. To avoid injuring or killing the fish, special facilities were to be installed to return the fingerlings to the river promptly.

b. Raw Water Storage Reservoir. - A 25-million gallon reservoir, so constructed that 15-million gallons could be reserved for emergency use, was designed, into which the normal flow of raw water in each Pile Area could be discharged from the river pump house. Chlorine and other chemicals could be added as needed to the water entering the reservoir, for prevention of algae growth. Design provided that additional raw water could be pumped directly to the refrigeration equipment in the D and F Pile Areas when this equipment was in operation.

c. Filter Plant. - Designs were made for distributing the raw water in each Pile Area from the reservoir pump house through mains to the Separation Areas, to the condensers, to the power house, and, in emergency, directly to the Pile. The bulk of the raw water, however, would be pumped to the area's gravity sand filter plant, designed to filter 36,000 to 38,000 gallons per minute, for subsequent purification and for use as process cooling water. This plant could be of standard design and would produce water suitable for process, sanitation, and steam generation. A clear well of 10-million gallon capacity was included as a part of this plant.

d. Demineralization Plant (One Pile Area Only). - In Pile Area D design was such that water from the filter plant pump house could be pumped to or by-passed around the demineralization equipment. Although the demineralization process to be used had been well established in small-scale practice, certain recently developed refinements to reduce the impurities to approximately 5 parts per million were to be incorporated in this installation. The Hanford requirements of 30,000 gallons per minute capacity, therefore, necessitated that the Prime Contractor delegate to the manufacturer the extensive work necessary to design equipment of a size sufficient to handle this volume. Because water so treated would have a corrosive effect upon iron or steel, design included storage in wooden tanks with a total capacity of approximately two million gallons. These were to be housed within a dusttight concrete storage vault to prevent contamination of the water by dust. The corrosive characteristics also necessitated stainless steel or rubber-lined piping and pumping facilities for handling the water after demineralization to prevent subsequent contamination prior to reaching the production unit. This equipment was not installed in Pile Area B since the greatest amount of speed in its construction was required, and in Pile Area F it was proved unnecessary by tests performed at the Hanford site (See Vol. 6).

e. Deaerators. - As it was necessary that "deaeration"* would have to be accomplished without raising the water temperature, this equipment necessitated special investigation and extensive studies with interested vendors before specifications could be established, inasmuch as no known installations provided such complete deaeration nor approached the capacity desired. Orders were finally placed with the Cochrane Corporation for the design and fabrication of these special, large-capacity, rubber-lined, cold water deaerators. Filter plant pumps in each Pile Area were designed to deliver filtered water to ten of these deaerators of 3000 gallons per minute capacity each, to be mounted on the roof of the process pump house. In Pile Area D the filter plant pumps were designed to deliver to either the deaerators or the demineralization plant. Demineralization plant pumps were designed to deliver processed water to the deaerators. However, development work carried on at Hanford during the construction period proved that deaeration of the cooling water would be unnecessary (See Vol. 6).

f. Refrigeration. - In the second and third Pile Areas, lines were designed to carry a part of the water through refrigeration units. Total refrigerating capacities of approximately 15,000 and 10,000 tons per day, respectively, were necessary. This installation was designed to insure chilled water for the cental parts of the Pile during the summer period when Pile capacity would be lowered because of the higher temperature of the river water, since the maximum outlet temperature would be fixed by tolerable corrosion and other process considerations. Insufficient time was available to install refrigeration equipment in Pile Area B, the first unit to be completed and placed in operation; however, the process water piping is identical to that of the other two Pile Areas, providing for future installation of this equipment in this area if the need developed.

g. <u>Process Water Storage.</u> - Design permitted water from the deaerators in all areas, or from the refrigeration units in Pile Areas D and F when in use, to be piped to a battery of four steel tanks, each tank having a capacity of 1,750,000 gallons. Each tank was to contain many special design features. To minimize pick-up of air by the deaerated water, pontoon-type roofs were to be provided which would seal against air infiltration by means of synthetic-rubber-coated-fabric curtains connecting the pontoons to the side walls of the tank. These storage facilities were designed for reliability of service and continuity of operation and, because of the greater probability of corrosion from demineralized water, the four tanks in Pile Area D had to be rubber-lined. This work was performed by the U. S. Rubber Company under a subcontract awarded by the Chicago Bridge and Iron Works, the subcontractor for the tanks. All process water piping beyond the demineralization plant in Pile Area D was necessarily to be of stainless steel or lined with rubber.

h. Process Water Pumps. - From the process water storage tanks, the next step in design called for 12 sets of process pumping units (See App. C 9) to which the water would flow by gravity from the process water storage tanks. Each set of pumps would consist of a turbine-driven pump in series with an electrically driven pump, in keeping with continuity requirements. The design provided for ten units to supply the cooling water requirements, leaving two units as spares. The process pumps were designed to insure continuity of service and to prevent any sudden changes in the water flow. Steam pumps were designed to operate continuously at partial load to deliver water to the electrically driven pumps at about 1/3 of the ultimate pump discharge pressure. In case of failure of electric power, the steam pumps, already operating, were designed to respond instantaneously and deliver water at their full capacity, a capacity considered sufficient to protect the Pile from a possible disastrous and rapid increase in temperature. Similarly, the motor-driven pumps were designed to permit operation alone and deliver the minimum water requirements for safety. The electrically driven pumps operating alone would be able to supply approximately 33 per cent of the regular flow while the steam turbine-driven pumps would supply approximately 80 per cent of the regular flow. Two concrete tunnels were designed to carry the delivery lines from the pumps to the Pile Building. The cooling water system was designed to maintain a pressure of approximately 370 pounds per square inch by an automatic pressure control system operating on the turbine-driven pumps. Normally, about 120 pounds per square inch would be supplied by the steam pumps and about 250 pounds per square inch by the electrically driven pumps. The motor-driven pumps were to be equipped with heavy flywheels which, in event of electric power failure, would delay the drop in water flow for the critical seconds until the steam turbines could increase their speed and while the control and safety rods were being inserted into the Pile to stop the reaction. The pumping equipment was so designed that in case of electrical failure the flow would not drop below 56 per cent of the normal requirements. The turbine-driven pumps were designed for condensing operation using barometric condensers. Unusual precautions had to be taken throughout the design of the entire system to prevent dust, scale, or other foreign material from contaminating the process water.

i. <u>Water Discharge from Pile</u>. - In order to prevent possible injury to fish life in the Columbia River (See App. C 8), and in view of the great volume of water discharged from the Pile, the radioactive effluent cooling water would necessitate the complete enclosure of all piping in cells shielded with five foot concrete walls. Design provided for conducting this water underground in a concrete sewer line to a six million gallon retention basin for decay of radioactivity. This basin would be equipped with specially designed instruments to monitor the water as it was returned to the river.

5-12. <u>Helium System (Final Design)</u>. - It was clear that the gaseous impurities which would collect in the voids within the Pile structure should be replaced by some gas which would neither affect the process adversely nor present a serious health hazard in the event of leakage from the Pile. Air, the commonest of gases, could not be used because its "nitrogen"* absorbs neutrons effectively and its argon becomes intensely radioactive presenting a potentially serious health hazard. Helium does meet these requirements perfectly, since it could be obtained in a pure state and has a negligible neutron-capture cross section, and, in addition, possesses the desirable quality of being able to conduct heat to the cooling tubes at a satisfactory rate. Only those impurities which may be present in the helium would present a serious problem. Thus, helium circulation and purification systems were designed so that impurities could be removed, and the helium recirculated through the Pile. Moisture could be removed by circulation through "silica gel"*; other impurities could be removed by compressing the helium to extremely high pressures and refrigerating to extremely low temperatures followed by circulation through "activated carbon."* All of these operations had to be carried on behind massive concrete walls, and by remote control of the equipment because of the intense radioactivity of the impurities. High-pressure helium storage tanks were provided in the design of the system to permit ready replacement of that helium which is normally lost from the system.

5-13. Steam Generation (Final Design). - Steam would be required for heating and other general purposes and for the turbine-driven process water pumps normally in operation. In addition, it was decided to provide turbine-driven pumps and generators as stand-by equipment in the event of electrical failure. To supply the steam for power and for heating, each Pile Area was to be equipped with four boilers, each capable of producing 100,000 pounds of steam per hour, fired by spreader stokers using lignite. The boilers were designed to respond to emergency demands (approximately two-thirds of the maximum output) in about 25 seconds. A steam pressure of 200 pounds per square inch was selected to give an economical installation in combination with the barometric condensers on the pumping units. The boiler plant, of simple design for maximum reliability, would contain feed-water-softening equipment and necessary auxiliary equipment. In addition, a 750 kilowatt emergency turbo-generator, with controls, was included in the design, so that it would start automatically in case of a power failure, to handle the necessary power plant auxiliaries, emergency lighting throughout the area, and certain special process demands.

5-14. Ventilation (Final Design). - Considerable provision had to be made to remove from the work rooms whatever irradiated gas may have leaked out of the helium system. For this purpose, three 50,000 cubic feet per minute intake fans and two 75,000 cubic feet per minute exhaust fans were provided. These fans would be capable of circulating air through the rooms and around the Pile and the helium carrying lines. They would exhaust the ventilating air to an underground trench leading to a 200-foot exhaust stack. A minimum dilution factor of 50,000 was planned for the anticipated leakage of toxic gases from the Pile shields.

SECTION 6 - SEPARATION AREA

6-1. General. - The research program for the separation of plutonium from the Pile metal was inaugurated at the Metallurgical Laboratory of the University of Chicago in April 1942 (See Vol. 2). By the end of that year, the successful microchemical preparation of some plutonium salts and a study of their properties had established the fact that it would be possible to separate plutonium chemically from the other materials in the Pile metal. Having proved the feasibility of a chemical separation, the aid of chemical engineers was enlisted to supplement the work of the chemists in order to obtain a workable design for a Separation Plant. The history of the actual design progress is difficult to follow from its inception to the issuance of drawings to the field, because the urgency of the entire program made it impossible to spend time in preparing a complete historical record of the problems and changes encountered.

6-2. Possible Separation Processes. - During the research program, a number of possible separation processes were investigated. These fell into four general classifications: precipitation processes; solvent extraction processes; adsorption processes; and a fractional volatilization process. A number of variations of most of these types were considered, the more important of which are described in the Metallurgical Laboratory reports CN 1017, CN 1603, and CN 2519—each entitled "Survey of Separation Processes" (See App. C 10-12).

a. Precipitation Processes. - A precipitation process permits the separation of one or more substances from a solution by the conversion of those substances, through chemical or physical change, to the solid state. Precipitation processes for the separation of plutonium would consist of a series of precipitations in which compounds of plutonium and radioactive fission products would be separately co-precipitated with inactive compounds, such as bismuth phosphate and lanthanum fluoride, which act as carriers. This technique would be necessary because the plutonium and fission products would not usually be present in sufficient concentrations to be precipitated directly. Carriers would have to be selected so that the plutonium would be carried in only one of its oxidation states. Precipitating conditions would be regulated so that a minimum quantity of fission products would be carried simultaneously with the plutonium and a substantial fraction would be carried when the plutonium remains in solution. A typical precipitation process would consist of extraction, decontamination, concentration, and isolation steps. It would be required that the process separate the plutonium from the uranium solution (extraction), reduce the radioactivity to about one ten-millionth of that present at the start of processing (decontamination), reduce the bulk of the plutonium solution (concentration), and further concentrate and purify the solution (isolation).

b. Solvent Extraction Processes. - Solvent extraction may be defined as a process which separates two or more substances or groups of substances, each from the others, through the use of immiscible solvents; each substance or group of substances must be almost entirely soluble in one of the solvents but not in the others. To be used in the separation of plutonium, a solvent would have to satisfy the following requirements:

1. It should be safe with ordinary precautions in handling.
2. It should be stable under the conditions encountered in the process, i.e., to chemicals and to radioactivity.
3. It should be readily available and low in cost.
4. It should have a high selectivity and a reasonable solubility.
5. It should have a high settling rate, and
6. It should have a low water solubility to facilitate its recovery.

Since no one solvent would satisfy all these requirements, only those which most nearly approached the ideal would be considered for use in the separation process. In the solvent extraction processes, the plutonium and a small percentage of fission products would be extracted from an aqueous solution of uranyl nitrate by a solvent-uranyl nitrate solution which would be immiscible with the aqueous solution. The plutonium would then be extracted from the solvent by a small volume of aqueous reducing solution containing an equilibrium amount of uranyl nitrate. Additional decontamination, concentration, and isolation would be accomplished by repeated extraction cycles.

c. Adsorption Processes. - An adsorption process separates two or more substances or groups of substances, each from the other, through the selective collection of some of the substances on the microscopic surfaces of a suitable adsorbent material. In the adsorption processes for the separation of plutonium, a reduced metal solution would be diluted to ten per cent uranyl nitrate hexahydrate and would then be passed through a column containing a synthetic ion-exshange resin which would remove all of the plutonium and small amounts of uranium and fission products. These elements would then be elutriated from the column selectively by a series of washes. Subsequent adsorption cycles would be performed on the plutonium wash for additional decontamination, concentration, and isolation.

d. Fractional Volatilization Process. - Fractional volatilization permits separation of two or more substances, each from the other, by the slow distillation of a mixture of the substances and the separate collection of the distillates at each boiling point, or after definite temperature intervals. As applied to the separation of plutonium, fluorine would be passed over the uranium slugs forming the volatile fluorides of uranium, plutonium, and a few fission products. Most of the fission products would be left as residues. The fluorides would then be condensed and separated in a distillation column. The distillation system would be operated under pressure to total reflux, until the concentration of low boiling fission product fluorides, such as those of molybdenum and tellurium, in the top of the column, reached a constant value, at which time the condensate would be drained to by-product storage. This step would be repeated until the charge in the column was sufficiently free of the low boiling fission products. The column would then be operated at a low reflux ratio and the uranium hexafluoride would be drawn off continuously and drained to storage. The residues would then contain the fluorides of plutonium and the high boiling fission products, such as "columbium"* and zirconium, dissolved in about one gallon of uranium hexafluoride. Further decontamination would be accomplished by volatilization or precipitation methods.

6-3. <u>Early History</u>. - In order to facilitate the design of a Separation Plant, a group of engineers was assigned to each of the processes, whose duty it was to proceed with design of a large scale plant for their particular process and list the questions and difficulties encountered. These questions were then answered by actual experimentation and the design was resumed. In addition, a design group was assigned the task of preparing plans for the buildings and shielding required, in such a way that the plans would be adaptable to the process finally selected. Tentative building plans evolved quickly, based on concrete thicknesses and "labyrinth"* arrangement information supplied by the Metallurgical Laboratory. Many of the process features were recognized very early in the design period. The Metallurgical Laboratory's "Feasibility Report" of 26 November 1942 (See App. C 4) cites: the need for remote control operation behind considerable shielding; the use of cubicles or cells which would be covered by large concrete blocks for process equipment; the provision of spare cells for unforeseen changes; and the use of a crane, with lead-shielded cab, for heavy lifting in the process area. The requirements were, of course, of a general nature and could be adapted for use in any of the processes under consideration at that time. During the period from October 1942 to January 1943, the problem of filtration versus centrifugation for the precipitation processes was decided in favor of centrifugation. This decision was made after consultation with established vendors of both types of equipment. The basic factor favoring centrifugation was the particle size of the fluoride precipitate, which caused it to penetrate all available filtering media. The basic process for the solution of the slugs in nitric acid was decided upon; and the oxidation and reduction reactions to be used in the various processes were established, although considerable refinement was necessary before they could be workable on a large scale. During this period too, corrosion data for 25-12 Cb stainless steel (25 per cent chromium, 12 per cent nickel, columbium stabilized) were made available in the design groups.

a. <u>Process Decisions</u>. - During the early months of 1943, all design work was concentrated on a plant for two of the precipitation processes, the first using bismuth phosphate as a carrier and the second using lanthanum fluoride. These processes were selected because, at that time, they were more fully developed than their alternatives and they seemed to offer the greatest certainty of successful operation in time for the scheduled startup of production operations. Although the other types of processes were no longer factors in plant design, the processes were kept under study and reviewed periodically to be ready as alternative methods if the need should arise.

(1) <u>Solvent Extraction Processes.</u> - The solvent extraction processes, although continuous and, therefore, more subject to reproducible operation and remote control than batch processes, offered a difficult problem in control to assure the simultaneous functioning of all parts of the system; they presented phase problems as the result of emulsions caused by oil or impurities; and they presented a potential fire and explosion hazard in the handling of the large quantities of volatile solvents required.

(2) <u>Adsorption Processes.</u> - The adsorption processes, although requiring equipment that was simple and readily available, resulted in large volumes of waste solutions and were handicapped by the fact that radiation on the ion-exchange resin for long periods of time and at the expected levels would be detrimental to the resin.

(3) <u>Fractional Volatilization Process.</u> - The fractional volatilization process required equipment that was relatively simple, used only one major chemical, and resulted in small volumes of waste solutions; but it presented a problem of critical temperature and pressure control, presented severe corrosion problems, permitted a build-up of plutonium in the process equipment, and required prohibitive experimentation time before successful operation could be assured.

b. <u>Equipment Grouping</u>. - Having decided upon a precipitation process, the design of equipment and buildings was greatly simplified. Where, previously, the building designs had to be adaptable to any one of a number of processes, some requiring entirely different types of equipment than all the others, now the design had to be adaptable to only two generally similar processes which required much the same type of equipment. The building design, as it was used at Hanford, was, as a result of the process decision, evolved in the early part of 1943. To insure completion of design in time for construction, the equipment for the separation process was planned to fit either of the two processes under consideration. Thus, where filtration methods could have been used for the Bismuth Phosphate Process, centrifugation was provided in case the Lanthanum Fluoride Process was the one selected; where a less corrosion-resistant material might have served for a Bismuth Phosphate Process, 25-12 Cb stainless steel was used because of the corrosion problems encountered in the Lanthanum Fluoride Process. Tank sizes, set by choosing a processing capacity of one ton of Pile metal per day, and concrete block sizes, which governed the size of the individual cells, determined the cell groupings as they now exist. Connectors for the remote maintenance of pipe lines to process cells had been developed and, with the development of a remotely controlled "impact wrench,"* the practicability of remote maintenance of process equipment was assured. Thus, although the processes were still under study, much of the detailed equipment and building design was established.

6-4. Selection of Separation Process. - In June 1943, emphasis was placed on the Bismuth Phosphate Process, although there was relatively little choice between it and the Lanthanum Fluoride Process. The decision was essentially the choice of the poorer carrier, Bismuth Phosphate, in order to avoid the corrosion problems involved in the use of a fluoride. The Bismuth Phosphate Process (See App. C 13) involves the use of bismuth phosphate as a carrier in the extraction and decontamination steps, a cross-over to lanthanum fluoride in the concentration step for bulk reduction, and a metathesis, or conversion, of the fluoride precipitate to the hydroxide in preparation for the final purification. With the selection of a separation process, it was necessary to adapt the process to the plant as designed, a reasonably easy matter in view of the flexibility of the design.

6-5. Final Separation Area Design. - Original plans provided for a total of eight Separation Plants, and supplementary facilities which included power houses, water reservoirs, filter plants, offices, laundries, shops, and storehouses. As process information developed, the required number of Separation Plants was reduced from eight to four, and on the basis of process data developed at Clinton Laboratories (See Vol. 2) during the summer of 1944, it was found possible to cancel construction of another plant, reducing the total to three. Each Separation Area, as designed, provided for two Separation Plants, one mile apart with a service plant midway between (See App. A 9). An Isolation Building was also designed in the Separation (200-W) Area, where concentrates from all the Separation

Plants would be treated further and where the plutonium would be prepared for shipment. Because of the design changes mentioned above, only one Separation Plant was completed in the Separation (200-E) Area. Each Separation Plant was designed to include a Separation Building, a Concentration Building, a Ventilation Building, and a Waste Storage Area. Three buildings were designed for the storage of active uranium under water during the decay period following discharge from the Piles; these were to be spaced one-half mile apart in the Lag Storage (200-N) Area, located midway between the Pile and Separation Areas. Since the first steps of the separation process would involve the extraction of plutonium from uranium and fission products under highly radioactive conditions, it was necessary to provide for unusual thicknesses of shielding around process materials and equipment in the Separation Buildings. It was evident that such unprecedented circumstances would dictate remote control operation and remote maintenance of chemical and mechanical equipment. It was mandatory to assume that conditions might arise which would prevent any direct personal contact with equipment requiring inspection and repair. Even proximity to process materials, vapors, or wastes had to be guarded against because of the high degree of radioactivity involved. To minimize shutdowns, design was directed toward (1) a minimum number of moving parts, (2) simplicity, (3) mechanical perfection, (4) segregation into separately shielded units, (5) flexibility in piping arrangement, and (6) interchangeability. Designs expected to provide these results involved extremely close tolerances in concrete in-concrete placement, pipe bending, location of tank nozzles, and equipment fabrication. Well-bottom flat cars, special buckets, and shielded casks had to be designed (See App. A 43, 44) for the transportation of irradiated uranium to the Lag Storage Buildings and thence to the Separation Plants.

a. Lag Storage (212) Building. - To allow for additional decay of radioactivity and provide an adequate shield during the period, Lag Storage Buildings were planned for the storage of the Pile metal (See App. A 53). The design of these buildings was to be similar to that of the storage basins of the Pile Buildings (See Par. 5-10). Processed uranium would be brought into the buildings in a water tank on the specially designed railroad car. During storage the buckets containing the metal would remain hanging in the pool, suspended from the overhead trolleys. In order to check the activity of the water in the storage pool, monitoring equipment was to be provided in the Lag Storage Buildings.

b. Separation (221) Building. - The "dissolving"* of the cans from the uranium, the extraction, and the decontamination steps were to be carried out in the Separation Building (See App. A 54). Pumps and valves could not be used on the process lines carrying radioactive materials because of the personnel contact required to maintain stuffing boxes and valve seats. Therefore, design had to provide for transporting process liquids and slurries by some other means. This was accomplished by providing "steam jet syphons"* (See App. A 55) specially designed and tested to effect positive action with a minimum temperature rise. Centrifuges, adopted because of the characteristics of the precipitate formed in the Lanthanum Fluoride Process, were found advantageous, in the process selected, as a means of avoiding back-flow or reverse direction discharge of active solutions which might contaminate the areas occupied by personnel. A minimum of vessel sizes and designs was utilized, thus simplifying design and fabrication, and accomplishing maximum interchangeability. Where agitation was necessary, it was decided that vessels should be fitted with paddle agitators (See App. A 56), developed from extensive laboratory and full scale tests. Agitator shafts were given particular attention in design to avoid failure in operation, since the overhang would, necessarily, be great in order to keep the drive free from process fluids. Agitator drives were studied with great care to minimize failure due to faulty grease packing in the motors and faulty oil lubrication on the drive proper. In order to approach perfection in operation, stringent specifications were issued to the vendor and a test of each unit prior to installation was ordered. Solid-bowl, vertical-shaft centrifuges (See App. A 57) were developed for installation in the Separation Plants and the most minute attention was given to avoiding possible failures. Special stress tests under the maximum operating conditions were necessary before the centrifuges could be accepted for use in the process. New design features had to be developed because of the remote control and maintenance requirements; windage had to be reduced to avoid entrainment which might contaminate the cells; and hydraulic devices had to be incorporated to effect remote control of the skimmer and plow.

(1) Building Design. - Because of the shielding requirements of the process, the Separation Buildings were designed as massive reinforced concrete structures, over 800 feet long, 65 feet wide, and 80 feet high, with wall and roof thicknesses designed to afford adequate shielding. Access doors and stairways to danger zones had to be shielded and equipped with remotely controlled locks and a telephone system to afford constant surveillanse. An intricate communication system was included in the design to enable a central dispatcher to direct all process operations and the movements of personnel into and out of danger zones (See App. A 58). It was decided to locate the operating galleries along one side of the building on three levels, the lowest level for electrical controls, the intermediate level for piping and remote lubrication equipment, and the upper level for the operating control panel boards (See App. A 54). The galleries were to be separated from the process equipment by a minimum of seven feet of concrete, and the processes controlled remotely through such walls. Liquid level and density meters were to be utilized in tracing the progress of each operation. Cam-operated, multiple-valve assemblies were designed and given extensive tests for use in controlling steam supply to the syphons and preventing backflow of radioactive process fluids from the cell equipment in the operating gallery when the steam would be shut off.

(2) Cells (See App. A 59). - Design called for the location of all process equipment in cells below the operating level, each cell being separated from any other area by a minimum of six

feet of concrete and covered by large concrete blocks. The cell openings were designed in step fashion to provide adequate shielding. It was evident that each concrete cover would entail the pouring of approximately 35 tons of concrete to dimensions at first thought by experts to be impossible. Machined cast iron forms were developed for the openings and covers. Most of the Separation Building operations were to be carried out in the standard equipment group, consisting of a precipitator, a catch tank, a centrifuge, and a solution tank, and occupying two cells (one section) (See App. A 60). So that a completely new unit of equipment could be installed when needed, it was necessary that each cell be designed to facilitate the removal and installation of process equipment. The equipment was such that it could be assembled and adjusted in a separate building, carefully disassembled and then reassembled in any cell by remote control. This was made possible by standardizing on (1) the buried piping (See App. A 61, 62), (2) the lateral and vertical location of the pipe flanges at the cell walls relative to the accurate cell floor which would be sloped for drainage, and (3) the exact location of equipment guides (See App. A 54) fastened to the walls at the floor, which would receive trunnions attached to the vessels. A piece of equipment would be lowered into a cell to rest on the sloped floor with its trunnions fitting into the guides, thus spotting the equipment so that each piece of pipe, previously fitted in the assembly building to connect the wall flange to the equipment flange, would fit accurately. Pipe connections in the cell could be made by a specially designed and tested connector

(See App. A 63) consisting of three jaws and a single stud which could be tightened or loosened by means of a remotely controlled impact wrench, also of special design. The equipment in a cell (generally two pieces, sometimes one) with its connecting piping would constitute a complete unit which could be installed in any cell, thus effecting interchangeability and allowing for major process changes. This was imperative because the processes were not clearly defined until design was almost complete, and because equipment failure under radioactive conditions not tolerable by personnel would require abandonment of a complete cell and its equipment, if it could not be removed by remote control. Special gaskets would be required to withstand the corrosive conditions of the process and the mechanical stresses involved in making a connection with the impact wrench. Vessels were to be fitted with noise pickups and vibration detecting devices to assist the operators, who would, of course, not be able to see the equipment. Design of cell and trench floors, walls, and cover blocks would call for unusually careful work to fill in all pin holes in which active material might lodge and make them unapproachable. All of these surfaces had to be specified for painting with a special paint that would offer resistance to the acid conditions, be smooth enough to permit easy washing by water sprays in the cell walls, and be adequately adherent to the concrete. Cleanliness and freedom from corrosion that would plug the steam-jet syphons were subjects of constant concern in design and construction. Special sampling devices were designed to permit safe sample taking from the cell vessels (See App. A 64). All pipe passing through concrete was to be bent in special curves to avoid direct paths for radioactivity.

(3) Stainless Steel. - Pipe and Equipment. - The corrosion severity of the chemicals involved, and the necessity of avoiding vessel and pipe failure, dictated an extensive metallurgical study. The only material that would approach the needs was 25-12 Cb stainless steel. Because it was necessary to give this material a special heat treatment after fabrication, at about 2050 degrees Fahrenheit, a special heat-treating furnace was designed for the Separation (200-E) Area, in order to avoid the delays and uncertainties attending shipment of items long distances. Since 25-12 Cb stainless steel had not been made previously in large commercial quantities, the large tonnage required and the stringent specifications imposed made its manufacture very unattractive to alloy-steel mills. Welding rod specifications had to be obtained because fabricators were unfamiliar with the technique of 25-12 Cb stainless steel welding and heat-treating. The high welding temperatures required would cause considerable distortion of nozzles, brackets, and tank bottoms unless suitable precautions were taken. It was clear that pipe fabricators would be reluctant to accept the task of producing 25-12 Cb stainless steel welded pipe (25-12 Cb stainless steel seamless pipe could not be obtained). It was only by persuasion, constant attention, and a very early start that this type stainless steel could be obtained and the fabricating techniques developed.

(4) Crane. - A special 75-ton bridge crane (See App. A 54) was designed for handling cell and trench cover blocks.

vessels, pipe, and incoming buckets and active metal and for replacing and servicing remotely the process equipment. Since the radioactivity would be considerable when the cell covers were removed, the crane design called for an operating cab entirely enclosed with sufficient lead and steel shielding to protect the personnel within. It would also have to be equipped with a means of permitting normal operation for lifting equipment and for manipulating the impact wrenches. Two large specially designed periscopes and two television units were decided upon for this purpose. The Whiting Corporation agreed to revise its standard crane design to provide very low speeds, which would afford the crane operators maximum control, in accurate placement of items, with only monocular vision through a periscope and without manual contact with the equipment being serviced. Contrasting colors were specified for cell groups to assist the crane operators in handling blocks and equipment.

(5) Instruments. - Despite the simplicity of the separation process chemistry, the requirements of remote operation and health protection necessitated the use of many specially designed instruments, in addition to an extraordinarily large number of the usual industrial types. Special design was required for instruments measuring radiation throughout the process (See App. A 65) and for visible and audible aids to remote operation. It was decided to use standard industrial recording and indicating instruments, adapted to suit the process requirements, to follow temperature, pressure, and density changes (See App. A 66). All visual and recording instruments in the Separation Buildings were to be located on panel boards

in the upper, or operating, gallery (See App. A 67-69).

c. Concentration (224) Building. - After processing in the Separation Building, further decontamination and bulk reduction of the crude product would be necessary. It was clear that the activity level of the plutonium solution from the Separation Building (See App. A 70-71) would be sufficiently low that the design of subsequent processing equipment and shielding could be modified, on the assumption that vessels could be worked on directly for maintenance, after relatively little decontamination. Therefore, the Concentration Buildings were designed to use the same types of equipment as were to be used in the Separation Buildings, modified somewhat when savings could be effected. Shielding and remote control would still be required, but equipment for remote maintenance, such as the special pipe connectors, would no longer be necessary. Even though the radioactivity would decrease as the product was purified and concentrated, it would still be sufficiently high that direct contact or ingestion would have to be avoided. This required shielding of personnel from process equipment, remote control of operations, and careful ventilation. Also the extreme value of the product made it necessary that any spills or leaks would have to be recovered, no matter how minute. This, and the need for thoroughly cleaning any process equipment before it could be approached, necessitated that all surfaces be smooth and free of pockets and pits.

d. Isolation (231) Building. - The final process step involving equipment somewhat similar to that used in the previous steps, but on a smaller scale, would be performed in the Isolation Building. Although little radioactivity would be encountered in this phase of the process, it was decided that specially designed hoods should enclose the equipment because of the danger of inhalation or ingestion of the highly toxic product. The value of the product required that all metal parts should be ground free of pits and other blemishes in order to avoid excessive holdup of product in the system. Closely controlled ventilation and air conditioning would be required, as well as extremely efficient filters on the exhausts from the hoods, to prevent contaminating the discharge air.

e. Process Waste Storage (241) Area. - For reasons of health and security, it was deemed essential that the active process wastes be stored underground until such time as proper disposal of the wastes could be made. Therefore, design of the Separation Areas called for a Waste Storage Area in each of the Separation Plants. Active process wastes were to be brought into this area in buried lines terminating in transfer boxes. By altering connections in these boxes, the flow of waste could be changed from one tank to another as desired. The boxes contained pipe connections equipped with the same remote maintenance facilities provided in the Separation Buildings. From the transfer boxes, buried lines ran to the tanks which were of steel set in concrete. It was necessary that the tanks be buried in order to eliminate radiation hazards. A cascade arrangement, in groups of three, was designed to allow the suspended solids, containing the bulk of the radioactivity, to collect in the first tank in each series (See App. A 72). The subsequent tanks could then be emptied when the activity had decayed to a safe level, thus increasing the waste disposal capacity. Since most of the active wastes (uranium solution and first fission product precipitate) would eventually heat up to boiling, tanks for these wastes were to be equipped with air-cooled reflux condensers so that they would not boil dry. The other tanks were to be provided with outlets on which condensers could be installed if required. Each Waste Storage Area was designed to contain 12 tanks, 75 feet in diameter by 33 feet deep, and four tanks, 20 feet in diameter by 28 feet deep. The low activity wastes from the process buildings and the decayed wastes from the tank farm could be stored in a retention pond and diluted with cooling water from the process buildings.

f. <u>Ventilation (291) Building</u>. - As with the Pile Areas, it was evident that a ventilation system, including a stack, for the disposal of various plant gases would be necessary. Waste gas from the dissolver (See App. A 73) could be diluted with the ventilating air from the Separation Building at the base of a 200-foot stack and discharged to the atmosphere. It was planned that approximately 60,000 cubic feet per minute of ventilating air would be discharged to the stack by two electrically driven fans, or in the event of power failure, by a stand-by steam-driven fan. The vent lines from the top of the dissolver condensers would be run underground from the Separation Building to the stack. The waste gases would then be transferred to the stack by means of steam-jet ejectors located just before the stack (See App. A 74). These jets would also serve to keep the dissolver under a slight vacuum and thus prevent leakage of the radioactive gases into the equipment cells. Ventilation air would enter the Separation and Concentration Buildings through inlets placed in the front stair towers and would then be drawn into the cells through small cracks left between the cell covers and the floor. From the cells, the air would be collected in a large duct buried in the concrete and exhausted through a buried duct by the ventilating fans located in the Ventilation Building. Since any drainage collecting in the base of the stack might be radioactive, buried lines were designed to take the drainage to the Separation Building sewer system.

g. Water System. - Interconnecting lines from the Pile Areas were designed to supply the Separation Areas with water for process cooling, sanitation, and steam generation. Each Separation Area was to contain a three million gallon, concrete, storage reservoir which would be capable of supplying the minimum requirements for a period of three days in the event of a major emergency. An 800 gallon per minute filter plant was also designed for each Area to supply filtered water for the power plant, for sanitary services, and for certain process equipment.

h. Steam System. - It was necessary that each Separation Area be equipped with a boiler plant having three boilers, each capable of producing 80,000 pounds of steam per hour at a pressure of 200 pounds per square inch and fired by spreader stokers. Steam would have to be distributed throughout the area for process and heating requirements. Each area was also to be equipped with a 750-kilowatt emergency turbo-generator similar to those planned for the Pile Areas.

i. Meteorological Station. - It was necessary to include in the design of the Separation Areas a meteorological station for securing the weather information necessary for the scheduling of operations in the Separation Buildings. The station was planned to consist of a 408-foot tower, oriented so that the instrument booms would be pointed in the direction of the prevailing wind, and buildings for housing equipment for the measurement and recording of wind direction, wind velocity, relative humidities, and air temperatures.

j. Separation Semi-Works. - Separation Area design included a semi-works for all the processes carried out in the Separation Buildings. This semi-works would be located in the head-end of the Separation (221-T) Building and would contain equipment similar to the actual process pieces but on a smaller scale, providing the equivalent of three standard sections and a dissolver. Since the semi-works was to operate with active process materials, it required the provision of the shielding that was to be provided for the production units.

SECTION 7 - SERVICE UTILITIES

7-1. General. - Of early consideration in the design of the Hanford Engineer Works was the supplying of adequate electrical power, communication, rail, and highway facilities to all construction, operating and housing areas (See App. A 5). Because of the magnitude of the Project and the consequent demand upon these facilities, it was necessary, not only to expand the existing facilities, but to design additional new and reliable power and communication lines, roads, and railroads.

7-2. Power Transmission and Distribution. - At the inception of the Project and the beginning of the studies for the design of the power system, it was indicated that approximately 140,000 kilovolt-amperes at 95 per cent power factor would be required. The point at which this power was to be taken was the Midway Station (See App. A 2), a substation in the twin 230 kilovolt lines between Bonneville and Grand Coulee Dams. It was realized that the use of this much power would affect the entire Bonneville Power Administration system and that the nature of the Project dictated not only the quantity but also the quality of power. The greatest stability possible was required since an interruption of service might result in disaster (See Sec. 5). As design and research were carried on simultaneously, the estimated power demand varied during the design period from the original 140,000 kilovolt-amperes to a final figure of 86,000 kilovolt-amperes.

a. Off-Area Modifications. - An electrical engineer was assigned to the engineering office of the Bonneville Power Administration in order to make calculating-board studies and recommendations for alterations in their system which would place it in a more stable condition. As a result of these investigations the Hanford Engineer Works aided the Bonneville Power Administration in obtaining priorities for a second Coulee-Covington 230 kilovolt line and a Columbia-Midway 230 kilovolt line. An additional 50,000 kilovolt-ampere, 230 kilovolt to 115 kilovolt bank was installed at Midway Substation. An extensive carrier current relay system to improve system stability by speeding up oil circuit-breaker operations, re-arrangement of Coulee-Midway busses, and sectionalising the Bonneville transmission system were recommended. Automatic, rapid breakers and carrier current transfer tripping arrangements to isolate automatically the Hanford Engineer Works load and the two generators at Bonneville in the event of a loss of both Midway-Coulee lines were also recommended.

b. <u>Area Transmission.</u> - For transmission within the plant area it was considered economical to use a 230 kilovolt loop (See App. A 5) involving approximately 52 miles of 230 kilovolt aluminum conductor transmission line passing near each of the five operating areas. This loop could be fed from either end, causing a power flow in either direction, sectionalized, and equipped with carrier current relay protection for the automatic isolation of faults. All of the 230 kilovolt transmission lines constructed (See Vol. 5) were to be of the two pole, three wire, suspension bell-insulator type using aluminum stranded wire, and 70 to 85-foot wooden poles with a 50-foot cross arm, allowing a 24-foot minimum clearance between cables. The loop was designed with an overhead ground wire and underground counterpoise for additional protection.

c. Area Distribution. - One substation for the two Separation (200) Areas and separate substations for each Pile (100) Area, where the voltage would be reduced from 230 kilovolts to 13.8 kilovolts, were incorporated in the design for distribution within the areas. Secondary substations for further voltage reduction were incorporated within the plant areas. All main plant transformers were of identical design so that they could be interchanged. Power for the Richland Area is conducted by means of an existing 66 kilovolt line extending between Pasco and Hanford. The source of power for this line is a Bonneville Power Administration line, the reduction being accomplished at the substation at Pasco. This 66 kilovolt line was acquired in fee within the Project boundaries from the Pacific Power and Light Company and serves no outlets other than Richland and the Metal Fabrication and Testing (300) Area. In case of outage below the Metal Fabrication and Testing (300) Area or Richland, power may flow south from the Hanford substation.

7-3. Communications. - The design requirements for the Hanford Engineer Works telephone system required switchboard positions at Hanford and Richland and stations located in the six manufacturing areas. Because of the classified nature of the Project, it was considered advantageous for expediency and from a security standpoint for the fundamental design of the communications system to be undertaken by the Prime Contractor with the consultant services of the American Telephone and Telegraph Company and the collaboration of the Chief Signal Officer. Final designs were submitted to the Area Engineer for approval and then to the office of the Chief Signal Officer, Plant Engineering Agency, Philadelphia. Upon approval by the latter the designs were sent to the Signal Officer, 9th Service Command, for execution (See Vol. 5).

7-4. Roads and Railroads. - The isolation of the Hanford Engineer Works site and the distances separating the various manufacturing areas made the establishment of a complete transportation net-work a necessity. An extensive system of roads and railroads was designed and constructed (See App. A 2) to expedite transfer of the enormous quantities of construction equipment and materials to the various areas as well as to provide adequate transportation facilities in case of an emergency in one or more of the areas during plant operations. The design and specifications for area roads and railroads were prepared on the site by the Prime Contractor's Engineering Section. These were then submitted to the Prime Contractor's Design Division for final approval and layout.

a. Roads. - Design of the plant road system was based upon the great peak construction requirements and upon traffic needs during the operating period in the event that mass evacuation of the operating personnel might be necessary. As the result of an investigation made to determine the availability of materials on the plant site and the feasibility of building gravel roads for permanent usage, it was found that it would be necessary to use an asphalt-bound road owing to the lack of sufficient binding material in the local gravel deposits. It was also disclosed that the Washington State Highway Department had found an oil surface road most economical over a period of years. A two-inch thick, bituminous mat surfacing over a five-inch gravel base was adopted as standard design for the majority of the plant roads. It was decided that seal coats with non-skid surfaces should be applied to all main inter-area plant roads. All road building materials, except asphaltic road oils, could be produced from local sand and gravel aggregate pits. The final road system serving the Hanford Engineer Works is comprised of approximately 350 miles of roads without regard to width, surface, or classification (See App. B 2). The main roads consist of two 20-foot lanes with a 10-foot separation strip between opposite traffic lanes. Primarily inter-connecting roads and area approach roads are 30 feet wide. Intra-area roads vary in width from 12 to 20 feet (See Vol. 5).

b. <u>Railroads</u>. - At the time that the site for the Hanford Engineer Works was chosen, the local communities embraced at the site were served by the Priest Rapids Branch of the Chicago, Milwaukee, St. Paul and Pacific Railroad, which extended southward on the west bank of the Columbia River from Beverly Junction to Hanford, a distance of 46 miles. The southern portion (approximately 25 miles) of this line lay within the Project and was taken over by the Government in April 1943. Since rail transportation direct to the working areas would minimize the rehandling of construction materials and equipment, immediate steps were taken to put these existing tracks in condition for the heavy service anticipated, and design for the permanent area railroads was started so that these tracks could be used during the construction period. Design of area railroads was divided into two classifications:

1. Process Tracks - Those tracks characterized by heavier rail and wider road bed, over which irradiated uranium would be transported between the Pile, Storage, and Separation Buildings.
2. Service Tracks - All other track, such as that used for transporting dry and liquid chemicals, fuel, equipment, and materials.

It was decided that process tracks should be laid with both new and used rail weighing not less than 80 pounds per yard, using No. 10 turnouts. For safety reasons it was considered necessary to widen the standard road bed section from eighteen to twenty-eight feet for the approximately 40 miles of process track. Service tracks were to be laid with used 65 to 85 pound rail, using No. 8 turnouts. Both new and used rail, as well as track materials, except for ballast and grade material which were produced on the site, were procured through the Corps of Engineers. The Hanford Engineer Works is served by approximately 125 miles of standard gauge, single track railroads, including a seven track classification yard at Riverland, which has a capacity of 225 cars and is the point of interchange between the Chicago, Milwaukee, St. Paul and Pacific Railroad and the plant system which is operated by the Prime Contractor. Rail service is provided to the Pile and Separation Areas, the Metal Fabrication and Testing Area, Richland Village, and the Administration Area. Included in the above total are approximately 25 miles of the old Milwaukee Branch Line from Vernita to Hanford which was reconditioned for plant usage (See Vol. 5).

SECTION 8 - RICHLAND VILLAGE

8-1. General. - The planning of the Hanford Engineer Works envisaged the fact that the surrounding communities would be able to supply living facilities for only a very small portion of the operating personnel. Consequently, arrangements were made and plans developed to construct a village for the production workers and their families. The location selected is in the southernmost portion of the Project at the site of the town of Richland. Although the village was designed for the use of the operating personnel and their families, its construction was expedited for the purpose of making a portion of the village temporarily available for construction personnel. Richland was unlike most war housing projects in that an entirely new village had to be constructed where, for all practical purposes, none previously existed. It was not simply a case of extending existing water, sanitary, and electrical facilities, but of constructing entirely new systems. Existing commercial and recreational facilities were not adequate and additional facilities had to be provided. Speed of construction was paramount so that in most cases only a minimum of study could be given to the various problems and questions arising before arriving at decisions or determining policy.

8-2. Site.

a. Selection. - In the selection of a site for the Hanford Engineer Works Village the various conditions which had to be met made the choice of Richland more or less automatic. Obviously, it was desirable to locate the site as close to the major process areas as practicable. In addition, the use of an existing village or town site was highly desirable because of the fact that the necessary grading could be kept to a minimum, and use could be made of existing buildings and facilities. The nature of the plant and the product to be manufactured required that no living or housing facilities could be located closer than 10 miles from any Pile or Separation Area. Although this condition was later modified, the sites in that portion of the Project known as land area "A" (See App. A 3) were still not suitable. It was not desirable from a security viewpoint to locate living facilities close to an operating area. Thus, since there was no town within a reasonable distance to the northeast or west of the Project, the location naturally narrowed down to the two closest towns to the south, Richland and Benton City (See App. A 2). Inasmuch as the Government had already acquired Richland (See Vol. 4), its selection was a natural one.

b. Description. - The entire village of Richland consists of approximately 2500 acres gently rolling and sloping from northwest to southeast. It extends about two and three-quarters miles in a north-south direction and approximately one and one-half miles in an east-west direction. Situated as it is in the bottom land between the Columbia and Yakima Rivers, it is only a few hundred feet above sea level. The elevations vary from 330 feet above sea level at the mean level of the Columbia River to 410 feet above sea level at some of the higher points in the western portion of the village.

c. Original Village of Richland. - The original village of Richland, located in the triangle formed by the confluence of the Columbia and Yakima Rivers, had a population of approximately 250 persons within its limits. This comprised about one-third the territory of the present village. The population of the entire Richland site numbered approximately 600 persons. The civic and commercial center of the existing village was grouped around the main highway between Pasco and Hanford, now known as George Washington Way (See App. A 6). Most of the buildings in this vicinity were of common red brick or cement block and were substantially built. A number of residences were grouped in this vicinity also, but the major portion of the site was a rural region consisting of various small farms and orchards with scattered residences, barns, and other farm buildings. The central portion of the village had an underground water system, fed from a driven well, but no central sewage system was provided. There was a small, modern park and community area, including a concrete swimming pool. The local grade school was a modern type comparable with those in many large cities. Most of the residences of the area had electric service and many had telephone service. The village had no organized fire protection system; rural fire fighting methods, and equipment available from Kennewick and Pasco, were relied upon. The roads of the area were mainly of the gravel or packed earth type and some were asphalt-stabilized.

8-3. New Richland Village. - Estimates made in March 1943 indicated a minimum requirement of 4000 operating employees for the manufacturing plant. Initial village design provided for the housing of 6500 persons, with possible expansion to 7500 persons, this figure being based on the assumption that 40 to 50 per cent of the employees could find accommodations in surrounding communities.

In June 1943, however, it became evident that revisions were necessary. The difficulties in obtaining housing in the surrounding communities had by this time become evident and it was agreed that only a very small percentage of the operating forces could obtain adequate housing outside of Richland. Consequently, the proposed size of the village was increased to 7750 persons, with a possible expansion to 12,000. Almost immediately after this second estimate, rapid changes in conditions indicating the need for increased plant operating forces raised these figures, until, by September 1943, it was agreed that housing would have to be provided for a total population of 16,000 persons in Richland. After 1 December 1943 all designing and planning for the village was based on this revised estimate. Up to this time, all plans for the village had been based solely on the requirements of the operating department. Although a portion of the village was to be made available for construction personnel, it was felt that the increase in the operating forces and the decrease in the construction forces would dovetail sufficiently so that no additional housing would be necessary for construction employees. During 1944, however, it became apparent that there would be an overlap between construction and operation forces sufficient to make further studies on the problem desirable. Consequently, housing for 500 construction families was provided during the overlap period. This placed the estimated peak population of the village at 17,000 to 17,500. Because the Prime Contractor was not able to spare the necessary personnel from work on the plant and its other war projects, the general village layout and the design of the living quarters and commercial buildings was sub-contracted to G. A. Pehrson, a resident architect-engineer from the Northwest (See App. C 14).

a. Administration Area. - Administrative facilities for the Hanford Engineer Works are located in the central portion of Richland Village. The Administration Area (See App. A 6) was designed by the Prime Contractor and included the heating plant, repair shops, central supply houses, laundry for plant work, administration buildings, telephone exchange, control laboratory, and freight terminal. This area was erected on a plot 1200 feet by 1450 feet and contains approximately 40 structures of various types. Its heating plant was designed to furnish central heat to all municipal and commercial buildings within a reasonable distance.

b. Housing Facilities. - The greatest single problem encountered in the design and planning of the Hanford Engineer Works Village at Richland was the determination of the number and types of housing units to be built. This difficulty was heightened by (1) the fact that it was difficult to determine in the beginning what the actual operating forces would be, and (2) the estimates on the housing available in the nearby towns fluctuated considerably from time to time. As finally designed, the housing units in Richland Village included new and existing houses, dormitories, and a hotel.

(1) Houses. - At the start of the village construction, there were approximately 200 existing residences in the general vicinity. It was at first estimated that approximately 75 to 100 of these would be made a permanent part of the new village. However, further study reduced this number considerably because of the amount

of work required to renovate them, since, in some cases, the cost of renovating was estimated to be higher than the cost of building an entirely new house. As of 15 February 1945 approximately 25 existing houses (called Tract Houses) were in use in Richland. It was determined after considerable study that three classes of houses, costing approximately $4000, $6000, and $7500, respectively, should be constructed. Wood construction was adopted in the interests of economy and speed, but its use dictated a greater than normal spacing between buildings, to eliminate the conflagration hazard inherent in closely grouped frame buildings in an arid country.

(a) Types. - When the first population estimate was arrived at, the following conventional type houses were approved and authorized for immediate design and construction:

80 - $7500 Class
400 - $6000 Class
500 - $4000 Duplex Units

As the population estimate rose to 7500, a second group of 1020 houses (similar to the types listed above but including also 100 one-bedroom apartments) was authorized. On 25 September 1943, a third group of 1000 was authorized, bringing total authorization to date to 3000, with population estimate set at 12,000. On 3 November 1943, the possibility of using prefabricated houses in the village was investigated, this study indicating that this type of house would be suited for use in Richland, particularly in view of the speed with which they could be constructed. As a result, approval was recommended for the purchase of 300 one-bedroom and 100 two-bedroom prefabricated houses, 24 feet by 16 feet and 24 feet by 24 feet, respectively; at the same time it was recommended that 100 one-bedroom apartments, previously authorized in the conventional type lists, be cancelled and 100 additional one-bedroom prefabricated houses be substituted. These recommendations were accepted with the result that, of 3000 houses now authorized, 2500 were to be of conventional type and 500 of prefabricated type. However, since the construction contractor for the conventional type houses was on the Project site and had facilities immediately available and since some delays were encountered in arranging procurement of prefabricated houses, it was recommended that 700 of the conventional type houses already authorized (consisting of 656 duplex units and 44 four-bedroom houses) be designed and constructed immediately. When the 16,000 population estimate had been agreed upon, authorization was received for an additional 800 prefabricated houses of all sizes, bringing the total houses authorized to 3800. On 6 May 1944, 500 prefabricated houses for construction personnel were added to this figure. These, together with four prefabricated houses procured for study by the Area Engineer, brought the total number of all types of new houses authorized for the village to 4304. These were broken down as follows:

Class	1BR	2BR	3BR	4BR	Total
Prefabricated	400	800	600	-	1800
$4000	-	1040	816	-	1856
$6000	-	-	500	-	500
$7500	-	-	84	60*	144
Authorized	400	1840	2000	60*	4300

Class	1BR	2BR	3BR	4BR	Total
Prefabricated houses procured for study	2	2			4
Total Available	402	1842	2000	60*	4304

(*One house in use as Public Health Center, see App. B 56, page 58, Code 1153.)

(b) Layout. - In the layout of the houses in the village every attempt was made to take advantage of existing terrain in order to minimize grading and landscaping. No particular effort was made to segregate the houses by types, but by the time the prefabricated houses were decided upon, the only portion of the village left in which to locate them was along the western edge. Consequently, the majority of the prefabricated houses are located in the western portion of the village.

(c) Furnishings. - Because of the isolated location of the Hanford Engineer Works, and the fact that most of the construction employees would live in Richland for a relatively short period of time, it was recognized that furniture would have to be provided for those individuals not owning furniture, as well as for those who were unable to have their furniture shipped to the Project. In purchasing, every attempt was made to procure durable furniture consistent with good taste and economy. Practically all of the houses in Richland (conventional, prefabricated, and existing houses) were provided with certain basic items of furnishings. These included an electric refrigerator, electric stove, electric water heater, 50-foot hose including a spray and nozzle, and garbage can.

1. Conventional Type Houses. - A total

of 1175 sets of maple furniture was purchased for use by construction personnel, but at no time were more than 900 of these houses furnished. The remainder of the furniture was used for furnishing tract houses or for supplying furniture for operations employees who were transferees from the construction roll.

2. Prefabricated Houses. - All prefabricated houses were purchased furnished. Most of the furniture was of plywood construction similar to the house itself. Since space was the major requirement in a prefabricated house, many of the chairs were of the folding type and furniture was selected which would take up as little space as possible. The beds, for example, had no head or foot, but were supported instead on six small legs. In the combined living-dining room, the table, when not in use, folded to a very small size.

(d) Heating. - Lignite-burning hot-air furnaces were selected as the least expensive and best method of heating the conventional type houses because of the availability of lignite in this section of the country and of the low installation cost. Electrical unit heaters were selected for the prefabricated houses as the result of an extensive study made on available electric capacity, diversification of loads, and advantages of lower requirements for coal.

(2) Dormitories. - The earliest estimates and plans called for the construction of men's and women's dormitories. However, the actual number of each to be constructed remained indefinite for some time. In November 1943, eight men's dormitories, each

housing 38 persons, and eleven women's dormitories, each housing 37 persons, were authorized. One room was provided in each women's dormitory to serve as a washroom or laundry room. By December 1943 it was realized that additional women's dormitories would be necessary because of the large number of women to be employed by the operating department. Consequently, six additional women's dormitories were authorized. The first nineteen dormitories contained both double and single rooms, but the last six contained double rooms only, and the capacity of each of these six was thus increased to 50 persons. These twenty-five dormitories provided living quarters for approximately 1000 persons and were served by the central heating plant in the Administration Area.

(3) Hotel. - A transient quarters or hotel was included in the plans for the village, and it too went through a series of changes. Originally this building was to house 50 guests, but through subsequent additions, its capacity was tripled to accommodate at least 150 guests in its 114 rooms. Furnishings in the dormitories and transient quarters were similar to those in the conventional type furnished houses.

e. Commercial Facilities. - The determination of the number and type of commercial establishments necessary to serve Richland efficiently was complicated by the everchanging population estimates.

(1) Description. - On 12 March 1943, the architect-engineer was furnished with a proposed list (See App. C 14) of the buildings for a shopping center, based on an estimated population of

6500 persons. Only two food stores were regarded as necessary, covering a floor space of approximately 10,000 square feet each. There was one store each for drugs, shoes, and hardware and one building each for the following service establishments: milk depot, coal yard, garage and service station, combined bank and post office, and cafeteria. This initial list of commercial establishments was tentative, and in May 1943, was revised to include a shoe repair shop, a barber shop, a beauty shop, a shoe store, and two clothing stores which were incorporated into a general merchandise establishment, and a laundry. The architect-engineer then undertook to determine statistically the number, type, and size of commercial establishments needed for the village, based on an estimated population of 6500. All the data gathered from surveys were compiled and correlated in a complete report dated 8 June 1943 (See App. C 14). This report called for a much more extensive list of establishments than had heretofore been proposed. The list of commercial establishments, authorized after submission of this report, remained in effect even after the population estimate had risen to 7500. On 20 April 1944, this list was revised because of the increased population estimate of 16,000. All further revisions in the number of commercial establishments were made to fit the actual needs of the village, inasmuch as a sufficient number of houses had been completed to determine the future requirements. Most of the village's commercial establishments (See App. B 3) were completed and in operation by 15 February 1945.

(2) Locations. - The layout and location of the commercial facilities in Richland was not much of a problem. At least one of every type of commercial establishment was to be located in the downtown section and neighborhood establishments were to consist primarily of grocery stores, drug stores, and gasoline stations. Consequently, one food store was located in the downtown section, the second in the northern portion, the third in the southern portion, and the fourth and fifth in the western portion of the village. Originally, it was planned to locate a drug store adjacent to each food store; however, it was found that three drug stores were all that would be necessary. The first was located in the downtown section, the second in the northern portion, and the third in the western portion. Inasmuch as the automotive garage and repair shop, which also contained a service station, was to be located in the downtown section, the three service stations were located in the residential areas.

(3) Use of Existing Facilities. - In the original village of Richland there was one medium-sized food store and post office in the same building, a barber shop, pool hall, a small drug store, a frozen-food storage locker building, a small food store and general variety store in the same building, and a combined milk depot and meat market. Although it was intended that as many as possible of the existing commercial facilities would be utilized, it was found that in every case the facilities were too small, too poorly located, or unsuitable for incorporation in the new village. The building containing the food store and

post office was expanded and converted into a hardware store. The original drug store was expanded and converted into a Western Union Office. The combined food and variety store building was expanded and converted into a men's apparel shop and shoe store. The combined milk depot and meat market continued as such for approximately eight months and was then converted and used as a temporary bus station for approximately five months. In March 1945, the Villagers' Library was opened in this structure. The original barber shop was converted to a temporary laundry station and used for approximately one year; then converted into an optical shop. An existing residence was converted into an electrical shop. All commercial facilities existing at the time of federal acquisition of Richland were permitted to operate for several months with very little restriction, because of the fact that these facilities were needed. As these buildings were required for incorporation into the fixed building program, or as the new commercial facilities were made available for operation, the existing establishments were replaced.

(4) New Facilities. - New buildings constructed included the five food stores, three drug stores, general merchandise store, variety store, women's apparel store, barber and beauty shop, bank, post office, automotive garage, three service stations, shoe repair shop, laundry, and milk depot.

d. Service Facilities.

(1) Schools. - A school system had to be provided with a minimum of delay and study. Existing in Richland were a high

school and an elementary school accommodating 100 students and 320 students, respectively. In order to expedite the school program, a 15-room elementary school (later enlarged to 16 rooms) was authorized on 16 March 1943. Conditions were most uncertain, however, so that on 8 April 1943, a survey was authorized to determine the actual school needs for a village with a population of 6500 persons. This survey showed that, for Richland, an average of 0.6 children of school age per family was a reasonable figure and that, of all the students, 28 per cent would be of high school age. These figures were used throughout the early phases of the planning and construction of the village; however, as more of the residences were occupied and the village began to develop, it was possible to determine more accurately what the actual future needs of the village would be. On the basis of the above study an addition of 13 rooms to the existing high school was designed. When the population estimate had risen to 7750, a more thorough and careful inspection was made of this building and it was determined then that the necessary additions required would not be feasible because of the poor condition of the building. Although this existing high school was used during the school year 1943-~~1844~~1944, it was later abandoned and condemned for school purposes, and a new 15-room high school, to serve some 340 students, was authorized about 1 July 1943. In January 1944, an addition to the high school was authorized, in line with the population estimate at that time, in order to serve some 660 students. As the population estimate rose to 7750, an additional elementary school of eight rooms was designed, making a total of three elementary schools, including the existing one. Later, as the population estimate advanced to 12,000 and then to 15,000, a second 16-room elementary school and an addition to the existing elementary school were authorized. These four elementary schools and the high school provided adequate facilities for approximately 1900 students. Every effort was made to locate the elementary schools so that the students would be required to cross as few of the well-traveled streets as possible in going to and from school. The high school, of course, was located centrally so as to be equally accessible from all parts of the village. The existing grade school was located to serve adequately those residents in the southern portion of the village. The first 16-room elementary school authorized was located so as to serve the northern section of the village and a portion of the residents in the western section of the village. This is practically the only case where it is necessary for the children to cross important thoroughfares in going to and from school. Inasmuch as the northeast section of the village was isolated from all other sections, the eight room elementary school was placed there, while the second 16-room elementary school authorized was located in the western section. Ample grounds were included in the design of the elementary schools, for recreational purposes. In addition, the area in front of the high school was made into the high school athletic field. Each elementary school contained a combination gymnasium and auditorium, whereas the high school had a separate gymnasium, an auditorium seating approximately 500 persons, and a cafeteria for serving lunches to the students. With the exception of the existing elementary school, which is a red brick structure, all of the Richland schools are of wood frame construction.

(2) Medical Facilities.

(a) Community Needs. - Prior to establishment of a medical program for the village of Richland, survey of neighboring facilities showed the necessity, as in the case of construction needs at Hanford, of providing complete facilities for medical care of all Richland residents dependent upon the Hanford Engineer Works either directly or indirectly, for both occupational and non-occupational illnesses and injuries. The determining factor in this decision was the isolation of the project, removed from population centers with established medical facilities of sufficient capacity to render the required service. As an additional factor, it was decided that the medical facilities provided at Hanford for construction personnel should not be used after the start of operations since possible plant hazards dictated the evacuation of the construction village.

To provide the required medical facilities for a village with estimated 15,000 population, the construction of a 75-bed hospital was authorized at Richland, 30 miles from the operating area boundary. Since a population of only 15,000, plus the factor of isolation as well as a high percentage of dormitory-housed workers, prevented application of normal hospital patient-population ratios, a ratio of 5 beds per thousand population was set, even though the national average was not as high. After a short period of operation, it was found that, while this ratio proved adequate for general needs, obstetrical cases and out-patient load called for additional facilities, resulting in the construction of a wing to the obstetrical section and of a separate building for dental and out-patient treatment; in addition, two housing units were provided for use as isolation wards in contagious cases.

(b) Policy. - To establish the most adequate and desirable type of medical service for the operation of Hanford Engineer Works, the medical organization was designed with two major divisions, village health and industrial medical care. The village health program was planned to offer specialities, such as obstetrics, pediatrics, surgery, internal medicine, otolaryngology, procuring specialists to head each field and thus offering better service than a type of general practice would make possible. The Washington State License Bureau offered cooperation in making exceptions to the medical practice act during the emergency, by enabling doctors and nurses with proper credentials to secure temporary licenses.

All employees of this section, including physicians, were reimbursed by salary, maintaining for the village residents free choice of physician as far as the latter's time permitted. Fees and charges, while generally based upon Washington State compensation fees, were scheduled after due consideration of those in the surrounding communities and were somewhat lower than normal for specialized services as an inducement in procuring personnel and reducing labor turn-over.

(c) Type of Service Rendered. - It had been planned to take over medical care of village residents at the

Richland facility on 1 August 1944, but by 20 May 1944, after operating from March 1944 under a method whereby physicians from the Construction Medical Department furnished medical care and charged non-industrial patients a regular fee, it was decided to take over complete medical care at once. However, this created an excessive load and all care was placed on an emergency basis, resulting in an arrangement whereby plant injuries, or very minor personal illnesses or injuries, would be treated without charge by the first-aid station, all other patients being referred to the clinic for care at regular fees. From this arrangement, procedures gradually developed until patients came to the clinic only with prior appointment, except in cases of emergency.

By 1 August 1944, hospital facilities were being utilized 100% and a wing addition to the obstetrical section was necessary, while by November, overcrowded out-patient facilities forced construction of a separate medical and dental out-patient building. By this time, full specialty services such as surgery, pediatrics, obstetrics, internal medicine, otolaryngology and ophthalmology were a regular part of the medical program available to both hospital and out-patient cases, supplemented in all ways with adequate laboratory and X-ray facilities.

(d) <u>Dental Program.</u> - As indicated in the preceding paragraph, the dental program was closely established with the medical program, service starting in June 1944 on an emergency basis. With the arrival of additional personnel in August 1944, regular service was offered on a fee basis, leaving patients free to choose dentists within limits of the doctor's availability. Dental procedures were not standardized, each dentist conducting his practice according to his ability, training and judgment, receiving reimbursement as regular salary, with no bonus or percentage although records were kept of each dentist's "earnings."

(e) <u>Public Health Program.</u> - On 15 January 1945, the Public Health Section of the Construction Medical Department was completely transferred to Operations after having been gradually shifted on a loan basis. The function assumed likeness to a Public Health Department of a normal city, with clinics for tuberculosis, venereal disease, and maternity cases maintained for the protection of project personnel. An inspection service for milk, water and food was established, along with sanitary inspection service for all cafeterias, canteens, cafes, dormitories, barracks and food stores, as well as sewage disposal, malaria and pest control and water analysis. All such services were without charge as a protection to the project as a whole, and included public health nursing service for infant and pre-school, school, adult, and industrial hygiene, and morbidity and crippled children's services.

(f) <u>Emergency Disaster Program.</u> - To minimize possible results from a major disaster, a medical preparedness program was established under over-all direction of Mr. N. Stapleton. Definite emergency assignments were given all medical personnel, and emergency field units were organized, together with plans to evacuate the plant areas and Richland Village if such drastic action were called for in the emergency.

(3) Churches. - In view of the fact that it was impossible to determine in advance the church requirements for Richland, the question of the number and sizes of the new churches to be provided was left open until the early summer of 1944. Prior to this time, ample temporary facilities were available for church use. Four churches existed in Richland at the start of construction. Three were small and in such poor condition that they were not considered for further use as churches in the new village. The fourth, which originally was a United Protestant Church, was renovated and improved and used as one of the continuing protestant churches. The question of determining what church facilities should be provided in Richland was handled almost entirely by the Government, which had made it known that facilities would be provided for all church groups desirous of meeting. The problem of churches in Richland was greatly simplified, however, through the existence in this portion of the State of Washington of what is known as the United Protestant Church (See App. B 4). The Episcopal and Lutheran groups later withdrew from the United Protestant group, so that, in determining the church facilities to be provided in Richland, the Catholic, United Protestant, Episcopal, Lutheran, and Mormon groups were to be represented. The original United Protestant Church was used by most of the Protestant groups during the construction of the village. When the high school auditorium was completed, however, the United Protestant group moved to this location and the former United Protestant Church was used by the Lutheran, Episcopal, and Mormon groups. Since there was no Catholic Church in the original village, the

Grange Hall was converted for use as a temporary Catholic Church. A number of small groups made use of the various school facilities in the village. In view of the fact that the Corps of Engineers had a design immediately available for a standard Army chapel seating approximately 250 persons, the Government proposed that two of these chapels be used in Richland. A study of the matter, however, determined that these chapels would be inadequate. Consequently, the Government undertook to expand the original design to provide for a seating capacity of 650 persons in each church. The continuing church facilities in Richland, therefore, consist of one existing church to serve the Episcopal, Lutheran, Mormon, and miscellaneous groups, one new Catholic Church, and one new United Protestant Church.

(4) Fire Protection. - In the design of the village, the problem of fire protection was given careful consideration because practically all of the buildings were to be of frame construction. In the design layout of the conventional type houses, a minimum spacing between houses was established. Since the prefabricated houses are heated electrically and the fire risk is greatly lessened, a smaller minimum spacing between the prefabricated houses was established. A total of 441 frost-proofed fire plugs and 99 fire alarm boxes have been provided for Richland. At the start of construction in Richland, a small church was converted for use as a fire station. It was planned that this would be used temporarily and that a new fire station would be constructed in the Municipal Building. As the population estimates of the village rose, a second new fire station was authorized. When these two new structures had been completed,

however, it was decided that adequate fire protection for the village would necessitate retaining the original temporary fire station as a continuing structure. A total of 10 stalls, housing equipment capable of pumping a total of 3500 gallons of water per minute, were provided. In cases of emergencies, additional equipment could be drawn from the various other portions of the plant or from Kennewick and Pasco.

(5) Recreational Facilities. - The isolation of Richland required that recreational facilities be provided. Those existing in Richland at the start of construction consisted of a 1½-acre park containing a swimming pool, bath houses, a wading pool, and various picnic facilities. This park, located along the river, was incorporated almost intact in the new village. The major changes were the addition of four bituminous-surfaced tennis courts and a small chlorination station for the two pools. The pools were connected to the village water supply system, whereas the water previously had been pumped directly from the Columbia River. Open plots of land in the village were graded and planted for use of small neighborhood parks, and baseball and softball diamonds were established in convenient locations. One baseball diamond in the northeastern section contained bleachers for seating some 500 persons. An athletic field containing baseball and softball diamonds, tennis courts, a ¼-mile track, and a regulation football field with bleachers to seat 2500 persons was designed to be constructed southeast of the high school. Although primarily for school purposes, this athletic field, as well as the gymnasiums in each of the five schools, is available for village use when not employed for school activities. One movie

theatre seating approximately 525 persons was originally designed for Richland. However, this small structure proved inadequate, and a second identical theatre was authorized. To supplement the theatres and outdoor recreational facilities, a recreation building was designed containing bowling alleys, billard and pool room, two card or lounge rooms, and a ballroom. Later a taproom and a dining room were added. There is also a small lunch counter in the building capable of seating 35 persons. Along the southeast portion of the building is a concrete-paved open-air terrace providing space for tables and chairs.

e. Utilities.

(1) Electrical Distribution. - A 66 kilovolt Pacific Power and Light Company line extended through Richland between Hanford and Pasco with a 300 kilovolt-ampere substation at Richland. All electrical design for the village was based on the use of this line. As the line could be supplied individually from either the Pasco or the Hanford end, an adequate safety factor was provided. The existing substation was not incorporated into the new village but was used until the first new substation was completed. The first substation constructed in Richland had a capacity of 5000 kilovolt-amperes and a rating of 66 kilovolts to 7.2 kilovolts. At the time this substation was designed, it was capable of handling the electrical load for the village and the Administration Area combined. As the population estimates of the village increased, additional primary transformer capacities became necessary and a second 5000 kilovolt-ampere primary substation was designed. In order to handle the additional

load required to heat the prefabricated houses electrically, another primary substation having a capacity of 10,000 kilovolt-amperes was authorized. All electrical lines in Richland were located in the centers of the blocks, behind the houses, and the secondary or distribution transformers were placed on poles at necessary locations. These secondary transformers reduced the voltage from 7.2 kilovolts to 440, 220, and 110 volts. Standard street lights were erected in the central portion of the village and along all main or interconnecting thoroughfares. In outlying sections, however, the street lights were generally restricted to intersections.

(2) Sanitary Facilities. - A modern sewage disposal system was designed for the new village as it was not advisable, and it would have been contrary to the laws of the State of Washington, to permit dumping raw sewage into the river. The disposal system was designed to separate the solids, chlorinate the liquor, and reduce the bacteria count sufficiently to allow it to be discharged to the river. The solids were to be digested, dried, and placed on a refuse dump or distributed as a low grade fertilizer. Prior to the completion of the permanent sewage disposal plant, the construction of the village had progressed sufficiently so that temporary sewage disposal facilities were necessary. For this purpose, two "Imhoff tanks"* were used until 13 April 1944, when the new sewage disposal plant went into operation. The temporary plants were then broken up and buried. The design of the sanitary system in Richland was a combination of gravity and forced flow. The sewage from the northern portion of the village drained by gravity to a lift

station and was pumped approximately one and one-half miles to the sewage disposal station located southeast of the Village. The southern and central portion of the system drained by gravity to the sewage disposal plant. The sewage lift station contained an underground reservoir and had a total pumping capacity of 2800 gallons per minute. The pumps were automatically float controlled. The original sewage disposal plant was designed to handle 900,000 gallons of sewage per day. Studies made during the latter part of 1944, based on the increased size of the village, indicated that the original design would be inadequate. Consequently, the capacity of the sewage disposal plant was increased to enable it to handle 1,800,000 gallons per day. As soon as the first houses in the northern portion of the village were occupied, a garbage disposal system was inaugurated.

(3) Water Supply. - Two methods for securing an adequate water supply for Richland, driven wells and a pump house on the Columbia River, were available. However, the river pump house was never given serious consideration since wells could be construted more easily and quickly and would provide water which did not require filtering. Preliminary investigation of the subterranean water fields in Richland disclosed that the most suitable locations, at least for the initial wells, would be in the hollow south of Swift Boulevard between the railroad line and the main irrigation canal. The first group of wells was drilled in this vicinity (See App. A 6). The design of the continuing water system for Richland called for all of the wells to feed into one raw water collection header, which would in turn feed into a ground water storage reservoir (See App.

A 6). From there, the water would be pumped into the system. Prior to the completion of the permanent water reservoir and pumping facilities, a water supply was necessary for those completed residences in the northern portion of the village. Consequently, a temporary water supply system was established. The use of the existing underground water lines in the central portion of the village, in conjunction with the new system, continued until the early part of 1944, when the laying of all water lines in this section of the village was completed. For the continuing water supply system in Richland one 1,000,000-gallon ground storage reservoir was constructed. Because of increased population, a second reservoir was constructed adjacent to the north end of the first reservoir. All wells in the village fed into these reservoirs through a small chlorination station located between them. The first pump house constructed in Richland had a total capacity of 6000 gallons per minute and the second had a total capacity of 4000 gallons per minute. Although a well developed irrigation system fed by water from the Yakima River existed in the village, it was not capable of supplying irrigation water to other than isolated portions of the village or to those portions where no construction had, as yet, been undertaken. Consequently, during the fall of 1943 and during 1944, water for irrigation was supplied principally from the water supply system. Close observation of the water table during 1944, however, disclosed that it was dropping at an alarming rate and fears were expressed at that time that the table might drop so low that the wells would be incapable of supplying the Richland water needs. Consequently, three separate steps were taken to insure that Richland would at no time be without an adequate supply of water. A design for a river pump house and filter plant was prepared by the architect-engineer and placed on file, available for immediate use whenever necessary. The second step consisted of additional well drillings and investigations to determine whether other subterranean water sources underlying Richland were available. The third step, consisting of an investigation of the method by which the water table was being fed, disclosed that the major portion of tho underground water was obtained by seepage from the irrigation system. During the summer and fall of 1944, therefore, as an emergency measure, several low portions of land in Richland were flooded with water from the irrigation system in order to maintain the water table. In addition, designs were prepared and construction was started on an underground irrigation system for distributing the major portion of the irrigation water from the irrigation canal. This system went into operation in the spring of 1945, reducing the demand on the wells, and increasing the supply of ground water.

(4) <u>Streets and Walks</u>. - A total of approximately 55 miles of asphalt-bound macadam streets was provided in Richland. The width, exclusive of sidewalk, varies from 20 feet for the majority of the residential streets to 56 feet for the main thoroughfares. By using asphalt-bound macadam, it was possible to use all native material except for the asphalt, thereby eliminating the necessity of shipping stone, sand, and other ingredients. Because of the narrowness of the streets in the residential areas, it was necessary to

establish parking compounds within the interior of the blocks. Sidewalks in the village center are of concrete and are provided on both sides of the street while in the residential areas macadam sidewalks are provided on one side of the street only.

(5) <u>Communications.</u> - The design and construction of Richland Village included a complete telephone system. Except for a few scattered cases, all telephone lines in the village are carried on the electric poles. The original telephone exchange for Richland was used for a short time only. A new telephone exchange for both the village and Administration Area was located in the Administration Area.

f. <u>Inter-City Transportation Facilities.</u> - Existing bus lines providing transportation for Richland and surrounding communities continued to operate after federal acquisition of the village and these lines used any suitable location on George Washington Way for terminal purposes. A commercial bus depot (See App. A 6), including a waiting room, ticket booths, parking facilities, and a lunch room, was authorized. Design for the structure was prepared, free of charge, by the Washington Motor Coach Company. However, this service did not give the coach company any special rights or privileges, nor did it eliminate the necessity for approvals of design by the Corps of Engineers and the Prime Contractor. The depot was to be used by all inter-city lines. Prior to the completion of the fixed depot, an existing structure was used as a temporary depot for approximately five months. Although a railroad spur line is provided into Richland, it is intended for freight use only.

SECTION 9 - COSTS

9-1. <u>Cost of Design.</u> - The cost of the design of the Hanford Engineer Works, according to the latest available data (See App. B 5), was $2,681,866.00. The major expense of design was for salaries and wages in the design section of the Prime Contractor's Engineering Division in Wilmington.

9-2. <u>Cost Tabulation.</u> - The break-down of design costs is made, according to the Prime Contractor's accounting designations, by Areas. The 100, 200, and 300 Areas are the primary manufacturing areas. The 500, 600, 800, and 900 Areas are service facilities. The 700 Area is the Administration Area, including maintenance facilities, and the 1700, 2700, and 3700 Areas are the administration and maintenance buildings in 100, 200, and 300 Areas respectively. The 1100 Area is Richland Village. TC is for Temporary Construction, throughout the reservation. CC includes all Commercial Contracts for temporary facilities and is further broken down into: HC - Hanford Commercial contracts and temporary facilities; GC - General Commercial contracts and temporary facilities which includes rehabilitation of residences and facilities in nearby communities; and XC - Commercial contracts and temporary facilities for the 3000 Area (See App. B 5).

SECTION 10 - ORGANIZATION AND PERSONNEL

10-1. General. - Preliminary design of all primary plutonium manufacturing facilities was furnished by the Metallurgical Laboratory at the University of Chicago under the general supervision of the Area Engineer, Chicago (See Vol. 2), and in close liaison with technical representatives of the Prime Contractor. The preliminary designs were translated into formal working drawings and specifications by the Prime Contractor at Wilmington, Delaware. Process designs, ready for construction, were approved by the Area Engineers at Wilmington and at Chicago. Auxiliary process design, such as the elaborate water and power systems, were accomplished by du Pont without Metallurgical Laboratory assistance and approved only by the Area Engineer at Wilmington, Delaware. Concurrently, the design of Richland Village and the Hanford Construction Camp was accomplished at Hanford (See Vol. 5 - Construction).

10-2. Wilmington Area Office. - The Manhattan District was represented at the Wilmington Area Office by Major W. L. Sapper, Area Engineer. The Engineering Section (See App. B 6) was headed by B. Bowelle. In addition, engineering consultants representing the Hanford Area Engineer reviewed all design for primary and auxiliary manufacturing facilities for the Hanford Engineer Works. These consultants were as follows: R. C. Hageman, primary and auxiliary process engineering during the entire design period; O. S. Clark, high voltage electrical transmission; and C. O. Henning, structural and civil engineering, during the first few months, after which he was transferred to Hanford.

10-3. Chicago Area Office. - The Manhattan District was represented at the Metallurgical Laboratory by Captain, now Lieutenant Colonel, A. V. Peterson, Area Engineer, during the period when the bulk of Hanford research and design was accomplished. During the final part of the work Captain, now Major, J. McKinley served as Area Engineer.

10-4. Contractor's Organization. -

a. TNX Division. - The TNX Division of the Explosives Department of the E. I. du Pont de Nemours and Company was organized at Wilmington, Delaware to coordinate and direct all activities of the Prime Contractor relating to design, construction, and operation of the Hanford Engineer Works. This division was headed by R. Williams. The TNX Division consisted of two primary divisions: the Technical Division headed by C. H. Greenewalt and G. Graves; the Manufacturing Division headed by R. M. Evans and J. Tilley. The Technical Division was responsible for obtaining, compiling, checking, and correlating information from the Metallurgical Laboratory and making such information available for translation into working drawings and specifications. The Manufacturing Division was closely associated with the Technical Division, assisting in design, carrying out the vast preparatory program required for plant operations, and furnishing consulting service to the Construction Division.

b. Engineering Department. - The Prime Contractor's Engineering Department under E. G. Ackart and G. M. Read was responsible for converting the process research and development furnished by the Metallurgical Laboratory through the TNX Technical Division into working drawings and specifications suitable for construction of the plant (See App. B 7). In addition, this department provided the industrial and technical knowledge and the design for those elements of the plant conforming more nearly to standard practice. This work of the Engineering Department was headed by T. C. Gary, assisted by J. P. Martel. The Supervising Engineer was F. W. Pardee, Jr., assisted by H. T. Daniels. Pile design was headed by J. A. Burns, Separation Plant design by R. P. Generaux, and Metal Fabrication and Testing Area and Administration Area design by L. H. Haupt. The design of the steam power and water systems was headed by W. T. Homewood and G. S. Coffin and that of the electrical power transmission and distribution system by R. W. Reynolds and R. S. Coughlan. Engineering design work at the site was under the direction of S. Sawin. Richland Village was designed by G. A. Pehrson, an architect-engineer, under a subcontract.

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