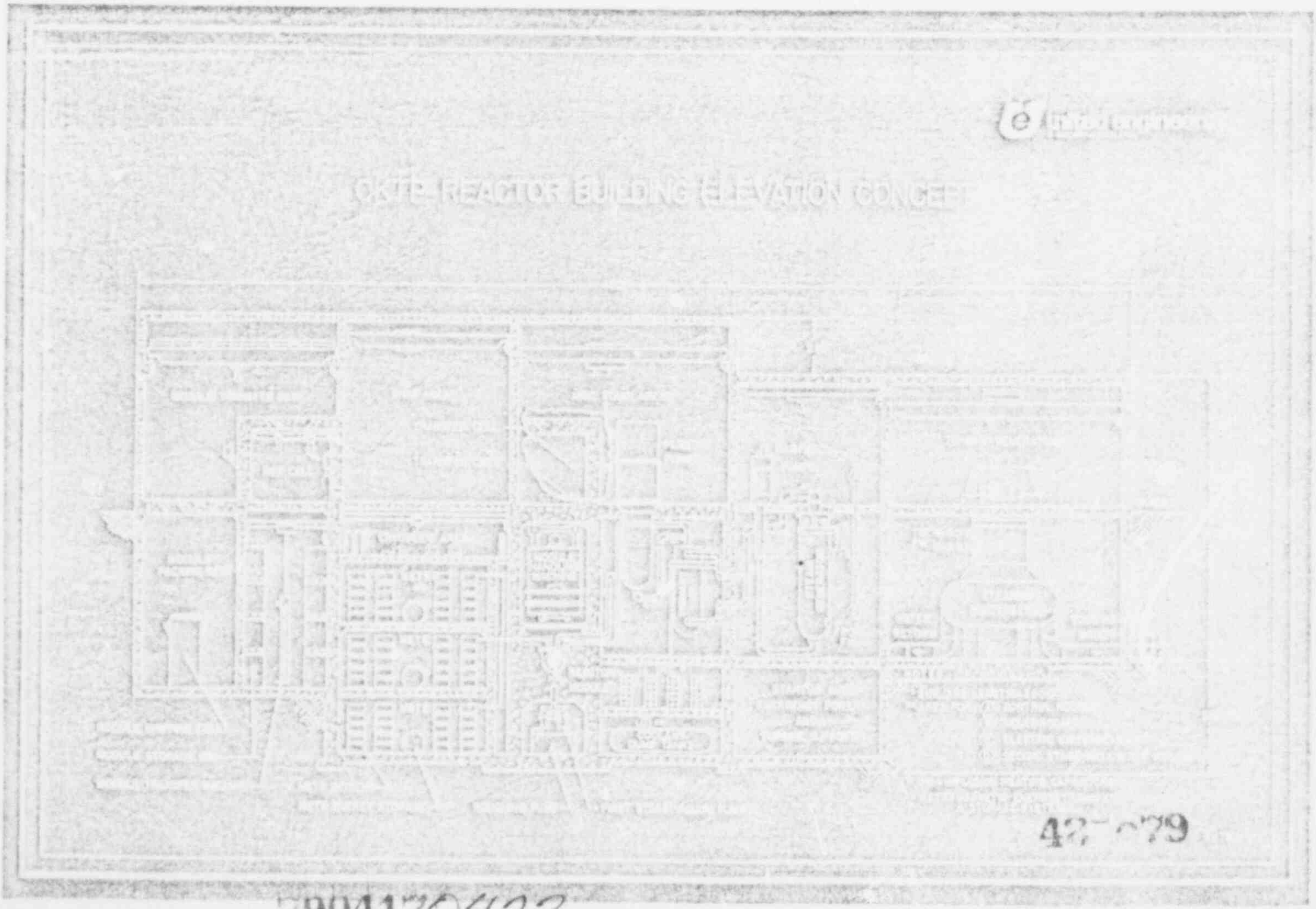
OKTP ONE KILOMETER THETA PINCH FUSION ENERGY CENTER

BRIEF DESCRIPTION OF PLANT



7904170423

OKTP ONE KILOMETER THETA PINCH FUSION ENERGY CENTER

BRIEF DESCRIPTION OF PLANT

united engineers
& constructors inc.

427 080

OKTP -- ONE KILOMETER THETA PINCH FUSION ENERGY CENTER

SUMMARY LIST OF SYSTEMS IN "BRIEF DESCRIPTION OF PLANT"

1 General

2 Site

3 OKTP REACTOR

4 REACTOR AUXILIARY SYSTEMS

4.1 Implosion Heating System
4.2 Adiabatic Compression System
4.3 Cryogenic System
4.4 Vacuum System

5 HEAT TRANSFER SYSTEMS

5.1 Primary Coolant System
5.2 Secondary Coolant System
5.3 Primary Coolant Doctor System
5.4 Secondary Coolant Doctor System

6 ENERGY CONVERSION SYSTEMS

6.1 Main Turbine Generators
6.2 Main Steam, Bypass & Feedwater
6.3 Turbine-Generator Auxiliary Sys.
6.4 Heat Rejection System
6.5 Alpha Endloss Energy Convertors

7 REMOTE HANDLING SYSTEMS

7.1 Module Handling Machine
7.2 Rotary Vacuum Lock
7.3 Module Storage
7.4 Hot Cells
7.5 Module Shipping

8 ELECTRICAL POWER SYSTEMS

8.1 Switchyards
8.2 Onsite a-c Power Systems
8.3 Onsite d-c Power System

9 INSTRUMENTATION & CONTROL SYSTEMS

9.1 Reactor I&C
9.2 Reactor Auxiliaries I&C
9.3 Heat Transfer I&C
9.4 Energy Conversion I&C
9.5 Remote Handling Systems Controls
9.6 Auxiliary Systems I&C
9.7 Control Rooms
9.8 Plant Computer Systems

10 AUXILIARY SYSTEMS

10.1 Tritium Processing System
10.2 Radioactive Waste Systems
10.3 Water Systems
10.4 Process Auxiliary Systems
10.5 Heating, Ventilating and
Air Conditioning (HVAC)
10.6 Other Auxiliary Systems

11 PLANT STRUCTURES

11.1 Reactor Building
11.2 Alpha Endloss Buildings
11.3 Administration Building
11.4 Warehouses, Visitor Bldgs,etc.

42 081

OKTP -- ONE KILOMETER THETA PINCH FUSION ENERGY CENTER

BRIEF DESCRIPTION OF PLANT

by Daniel M. Axelrod, 5/76

1.0 GENERAL

United Engineers & Constructors Inc. has performed a preliminary evaluation of an OKTP -- One Kilometer Theta Pinch fusion energy center as a potential large-scale, long-term replacement for depleting oil and gas supplies. The OKTP linear theta pinch reactor is an extrapolation from the Los Alamos/Argonne toroidal reference theta pinch reactor.* The OKTP is nominally rated at 34,000 megawatt thermal (MWt) and 10,000 MWe. The alternate version, which is not discussed below, would use ten hydrogen production plants to produce approximately 3.6 billion standard cubic foot (scf) H_2/day. The energy center output is equivalent in energy to a medium size oil refinery of 200,000 barrels per day.

The following brief description of the 10,000 MWe (10 GWe) OKTP is intended as a synopsis of the overall plant features based on the preliminary evaluation.** After a highlight regarding site requirements, the five main systems of the plant are described, namely: (1) OKTP reactor, (2) reactor auxiliary systems, (3) heat transfer systems, (4) energy conversion systems, and (5) remote handling systems. The remainder of this discussion then describes the electrical power systems, the instrumentation and control systems, the auxiliary systems, and the plant structures. An arrangement drawing is enclosed.

2.0 SITE

The OKTP fusion energy center requires a level land site of approximately 5 to 6 square miles. The OKTP reactor building, which houses almost all of the basic plant systems, is 460 feet wide and 3600 feet long. Together with the two alpha end loss energy convertor buildings, the two switchyards and a few miscellaneous buildings (administration and warehouse), the plant proper requires less than 150 acres or 1/4 square mile. The bulk of the land area is for an artificial lake for transferring heat from the turbine-generators to the environment. Hopefully, such a system might be used productively for acquaculture or other purposes.

An alternative site offshore would probably consist of a manmade island sufficient for the reactor building and auxiliary structures, and would use the ocean as the heat sink.

---

* Los Alamos Scientific Laboratory--Argonne National Laboratory, "An Engineering Design of a Reference Theta-Pinch Reactor (RTPR)", LA-5336/ANL-8019, 3/74.

** Note that all data is preliminary and that the design requires iteration to achieve consistency in some areas.

3.0 REACTOR

The OKTP reactor is a linear theta pinch fusion reactor. The basic energy process is the fusion of deterium and tritium as follows:

$$D + T \xrightarrow[(5\ \text{Kev})]{50{,}000{,}000^{\circ}C} \underset{(3.5\ \text{Mev})}{He^{4}} + \underset{(14.1\ \text{Mev})}{n} + 17.6\ \text{Mev}$$

The reaction, which involves only a few grams of fuel in the plasma, takes place in a good vacuum in the presence of appreciable magnetic fields. Accordingly, the reactor consists of 528 OKTP reactor modules placed end to end to form a linear configuration. Since each module is nominally two meters long (approximately 6 ft), the total reactor length is 1,056 meters (approximately 3,600 ft). The reactor modules are basically a series of concentric rings surrounding an approximately 1 meter vacuum chamber. In the Los Alamos Scientific Laboratory design of the Reference Theta Pinch Reactor (RTPR), the blanket which consists of the lithium based coolant, graphite moderator, and niobium structure, extends from 100 centimeters in I.D. to 176 centimeters O.D. It is then surrounded by an insulator, a copper implosion heating coil (186 centimeters O.D.), further insulation, an adiabatic compression coil (276 centimeters O.D.), and titanium support bands. For the OKTP reactor, the copper compression and implosion heating coils may be placed inside the blanket to achieve higher magnetic fields in the vacuum spaces and to reduce stress and the magnet. The primary coolant chosen for the OKTP is FLIBE ($LiF.BeF_2$) molten salt, which still provides a lithium base for breeding tritium fuel by absorption of neutrons while avoiding the liquid metal-water reactions.

The 80 ton OKTP module is suspended from a thick, horizontal first vacuum isolation plate, which is supported at its edges on a concrete reactor cavity wall. The modules are placed in close proximity to each other, with only about a centimeter gap between them; but it is important to note that there is this gap, and there is no welded connection between modules which requires remote assembly and disassembly. Various lines penetrate the first vacuum isolation plate to provide a "superstructure" servicing each cylindrical module. These include the FLIBE inlet and outlet cooling lines, the D-T fuel line, the electrical leads to the implosion heating coil, the electrical leads to the adiabatic compression coils, and the water coolant lines for the adiabatic compression coils. Each of these leads has to be remotely disconnected and reconnected when the OKTP reactor module is removed and replaced. A view of the RTPR module is enclosed.

4.0 REACTOR AUXILIARY SYSTEMS

4.1 Capacitor Implosion Heating System (CIHS)

The purpose of the implosion heating system is to shock heat the plasma to its initial temperature prior to further adiabatic compression to final temperature. A capacitor implosion heating system (CIHS) is being evaluated, with an alternate being a laser implosion heating system (LIHS). The capacitor implosion heating system consists of capacitor banks, charge and discharge switches, electrical leads and a capacitor energy charging system. One capacitor bank (CB) will be used for each of the 527 OKTP reactor modules, with 10% spare CB's installed as redundant units. A preliminary concept for the capacitor bank suggests a 15'L x 15'H x 16'W unit, delivering six megajoules in 100 microseconds and composed of 360 8.5 kilojoule capacitors of 170 microfarad and 10 KV. The capacitor bank discharge switches (CBDS) associated with each of the 527 operating capacitor banks must close within + one microsecond and be capable of handling over 200,000 amps of average current during the 100 microsecond discharge. Since the OKTP operates on a one pulse per second cycle, there are over 25 million pulses per year at 80% load factor. Because of this, it is still to be determined whether a mechanical switch will be acceptable or whether solid state thyristor type switches will be required. By comparison, the capacitor bank charge switch (cbcs) need only close in approximately 1 millisecond and need handle only approximately 200 amperes during the 990 msec capacitor bank charge time.

It has not been determined yet whether leads from the CBDS to the implosion heating coil connection of the OKTP reactor module will be normally conducting copper or superconducting. The capacitor energy charge system (CECS) is used to transfer approximately 3,000 MWe from the capacitor auxiliary power (CAP) transformer in each switchyard to the cbcs. This system will include the necessary current dividing circuitry and rectifier equipment to convert from the switchyard a-c to the capacitor charging d-c. If direct convertors are used to transform alpha end-loss energy, they produce d-c and could be fed through CECS to cbcs without the need for a-c/d-c rectification.

4.2 Adiabatic Compression Magnetic Energy Transfer and Storage (METS) System

The purpose of the adiabatic compression METS system is to further heat and compress the theta pinch plasma from the initial temperatures achieved under implosion heating until the plasma sustains self heating by the deposition of energy from the helium products. When the burn is complete, about 3 milli-seconds after the start of the pulse, the adiabatic compression magnetic field is reduced allowing energy from the expanding plasma helium ions to be directly converted to electricity which is returned to the METS system. The primary energy storage services under consideration are 1 - 1.3 gigajoule homopolar motor generators. Because these rotating machines must discharge and recharge in one millisecond time intervals, which may not be practical for large moving components, superconducting magnetic energy storage (SMES) is also under consideration.

In the conceptual METS circuit under consideration, there are two homopolar motor generators in series acting as capacitors, with a combined voltage of approximately 22 kv and a combined current of 12 megamps. These discharge into 196 adiabatic compression coils (28 per module x 7 two meter long OKTP reactor modules) each carrying approximately 62 kiloamps of current. There are four solid state switches for each coil or approximately a total of 60,000 switches required for the entire OKTP. Conceptually, these switches each contain 525 silicon controlled rectifiers at 1,300 volts and 1,800 amp rating, but it is anticipated that advances in SCR technology over the next several years will improve the SCR rating and decrease the required number of SCR's per switch. A significant reduction in SCR cost will be required to meet METS and overall OKTP cost objectives.

4.3 Cryogenic System

The magnets of the OKTP reactor modules are not superconducting. However, cryogenic systems are required for the METS homopolar motor generators (or alternatively superconducting magnet energy storage), and possibly for the CHS to reactor module electrical leads. The cryogenic system will have to attain superconducting temperatures in the 5-15°K range.

4.4 Vacuum System

The OKTP plasma operates at densities of approximately 1×10^{17} ions/cubic centimeter which is equivalent to a density of approximately 1 torr (one mm Hg). This necessitates a flushing of the plasma chamber prior to the initiation of each pulse, down to perhaps 10^{-2} torr, which is a medium quality vacuum. In addition, initial outgassing at the start of operation or the resumption of operation following reactor outage may require 10^{-4} to 10^{-5} torr. These latter values are subject to further definition; however, it is clear that the vacuum systems must provide good vacuum and must do it on a pulse basis once a second following the fuel burn in each pulse. Conceptually, three types of vacuum pumps have been provided as follows:

1. Roughing pumps, 26 each (1 per 20 reactor modules)
2. First-stage vacuum pumps, 1056 each (2 per reactor module)
3. Second-stage vacuum pumps, 528 each (1 per reactor module)

Pathways are provided through the reactor cavity concrete shielding to the vacuum pumps which are located beneath the reactor. A welded steel wall lines the reactor cavity. The vacuum space enclosure is completed by the first vacuum isolation plate which forms the support for the reactor module and reactor superstructure. A second vacuum isolation plate is provided above the first as an additional buffer to the ambient atmosphere.

5.0 HEAT TRANSFER SYSTEM

5.1 Primary Coolant

The functions of the primary coolant are to slowdown and absorb the neutrons emitted during the fusion reaction, to transfer the resulting heat energy toward the energy conversion system, and to breed new tritium fuel by capture of the neutron by a lithium atom.

The primary coolant selected is molten salt FLIBE ($LiF \cdot BeF_2$). A molten salt, rather than liquid lithium metal, was chosen for safety reasons to avoid potential liquid metal/water-air reactions, and also to minimize electrically conducting liquid metal interference with the OKTP reactor module magnetic fields. The beryllium component, which undergoes a (n, 2n) neutron multiplication, is added to the molten salt to partially offset the fluorine neutron capture. Tritium breeding ratios with Flibe should be on the order of 1.0 to 1.1, that is the OKTP will breed 1.0 to 1.1 atoms of new tritium for each atom of tritium fuel which is fused.

The primary coolant pumps will be large centrifugal type pumps. The primary heat exchangers will be molten salt (Flibe) to molten salt ($NaBF_4$) shell and tube heat exchangers with no change of phase planned in either working fluid under normal operating conditions. The heat exchangers will be four per 3000 MWth output and transfer heat toward one turbine generator. Initial design called for vertical primary coolant pumps and vertical primary heat exchangers, but space requirements for the implosion heating system capacitor banks and related equipment may require that horizontal pumps and heat exchangers be used.

The Flibe, flowing at nominally 8 ft per second, will traverse the approximately six foot long reactor module and 1 ft long entrance and exit, in approximately one second. During that one second the reactor is pulsed, and the fusion energy is released causing a temperature rise in the Flibe from about 800°F to 1000+°F. The flow from eleven reactor modules is headered to each primary heat exchanger, and amounts to approximately 19×10^6 lb/hr or 19,000 gal/min per heat exchanger, which then corresponds to the rating of each primary Flibe pump. A preliminary estimate of primary heat exchanger size suggests on the order of 10,000 1" O.D., 40' long tubes assembled into a ten foot O.D. shell.

5.2 Secondary Coolant

The secondary coolant selected is sodium fluoroborate, basically $NaBF_4$, at the suggestion of the ORNL molten salt program manager. It offers advantages in removing tritium which may diffuse or leak from the primary to the secondary coolant system. There will be four secondary coolant pumps and four molten salt-steam generators per 3000 MWth serving each turbine generator. The molten salt secondary coolant pumps will be vertical centrifugal pumps.

The molten salt-steam generator heats 3600 psi supercritical water from 700°F to somewhat less than 1000°F. The design avoids phase change in $NaBF_4$ (with a 722°F liquidus) and phase change in water by using supercritical pressures. The steam generator is envisioned as a J-tube design, with about 2000 3/4" O.D. tubes, each 140 ft long, in approximately a seven foot O.D. shell.

5.3 Primary Coolant Doctor System

The primary coolant system will have a "doctor" or purification system, which will operate on a partial flow bypass stream. The purpose of the doctor system will be to purify the primary coolant by removing foreign contaminants such as corrosion products, and also to permit separation of the tritium which is bred in the primary coolant. The tritium will then be sent to the tritium handling system (see Section 10.1)

5.4 Secondary Coolant Doctor System

The secondary coolant doctor system has functions similar to the primary coolant, except that tritium removal is less and limited to tritium which has diffused or leaked to the secondary coolant.

6.0 ENERGY CONVERSION

6.1 Main Turbine-Generators

There will be twelve main turbine-generators in the 1000 MWe class. There will be six right hand and six left hand turbine generators to accomodate plant layout requirements. The turbine generators are typically tandem compound, single shaft, six flow, 30" last stage bucket machines. They are typically 200 feet long, 28 feet wide, and 18 feet high. They are fossil type turbine generators rated at 3500 psig inlet, 1000/1000 F reheat, 5" Hg backpressure. The heaviest piece during erection, the generator stator weighs on the order of 400 tons; the heaviest piece after erection, the generator field rotor, weighs on the order of 100 tons.

The current preliminary main steam flow diagram calls for two 910 MWt steam generators and a 420 MWt reheater, for each 3000 MWt (nominal) turbine-generator, thereby modifying somewhat the secondary coolant steam generators described in Section 5.2.

6.2 Main Steam, Main Steam Bypass and Feedwater Systems

The main steam system transfers the steam from the two 910 MWt steam generators, with suitable headering, to the high pressure turbine; and also includes the reheat steam piping from the turbine generator to the reheater and back to the intermediate pressure turbine. There are 6.8×10^6 lb/hr of 1000°F and 3600 psia steam (3515 psia at turbine inlet) flowing to the turbine.

The main steam bypass system is used to divert steam past the turbine during startup until sufficient steam is ready to enter the turbine, and, most importantly, to divert steam flow from any turbine-generator that trips out without shutting down the balance of the plant. A steam vent is actuated for 15-30 seconds following turbine trip to blow off excess steam during the transient. The steam bypass includes pressure reducing valves and desuperheaters, using water spray from the condenser to cool the steam. A flash tank collects the main steam and passes it through the reheater, whence the reheated steam is again pressure reduced and desuperheated prior to being introduced to the main condensers. The bypass will be designed to handle 100% flow (less the small amount of venting), so that reactor power is not reduced on trip of a single turbine generator.

The feedwater heating systems includes two 14,000 HP turbines for the feedpumps, operating off extraction steam. There will be five to seven stages of feedwater heating.

42 087

6.3 Turbine and Generator Auxiliary Systems

The turbine auxiliary systems include the lubrication system, the condensate polishing system and the gland sealing system.

The generator auxiliary systems include the hydrogen cooling system and excitation auxiliaries.

The turbine-generator is normal controlled by an electrohydraulic control (EHC) system, typically considered part of the overall instrumentation and control system.

6.4 Heat Rejection System

The turbine-generators exhaust their steam flow to three water cooled condensers, one for each low pressure turbine of the twelve turbine-generator sets. The condensors operate at 3-5" Hg absolute on the steam side. Cooling water flows through the typical 1" O.D. condensor tubes. The steam condenses at about 115-125°F, while the cooling water inlet is typically at 90-95°F on a design basis summer day. On the order of 1,000,000 gpm at 10-15°F increase in temperature is required to condense the steam.

The cooling water leaving the condensor then flows through large (10-15 O.D.) concrete pipes, 1000' long into a manmade lake. The lake is approximately five square miles in area. Within the lake are sixteen, 400' diameter, natural draft dry cooling towers on 2500' center-to-center minimum spacing. Approximately half of the heat discharged to the atmosphere is through the natural draft dry cooling towers, and about half of the heat is lost from the lake by evaporation. The evaporation will require on the order of 100,000 gallons per minute of makeup water. The heat rejection density is about 6.7 MWt/acre or about 1900 MWt/km^2. The large area of the lake dominates the features of the plant proper which, as noted in section 2 above, requires less than 150 acres or less than ¼ square mile.

6.5 Alpha Endloss Energy Converters

Approximately 20% of the total fusion energy is in the form of 3.5 Mev alpha particles (helium ions), the other 80% being in the form of neutrons which are eventually converted to heat to drive the turbine generators. Of the 20%, half is anticipated to be directly converted to electric energy to be recovered in the adiabatic compression magnetic energy transfer and storage (METS) system. This still leaves about 5% of total fusion energy, or about 1500 MWt, to stream out of each end of the OKTP reactor as average 1.75 Mev alpha particles.

These alpha particles might be absorbed and converted to heat energy and thence to steam to drive two 600 MWe turbine generators (one at each end of the reactor) with overall efficiency of about 40% of energy recovery. The alpha heat absorbing surface might be a 1" thick plate, 100' high by 100' of 60° arc for a total surface area of 10,000 ft^2. The alpha particles would have to be suitably diverted by magnetic fields from their 20 cm diameter stream to uniformly strike the impingement surface. Nevertheless, there would still be a 500,000 BTU/hr-ft^2 heat rate, which is approximately ten times good conventional heat transfer, creating a feasibility problem.

Alternately the alpha particles might be directly converted to electricity at over 80% conversion efficiency, using either a Post LLL multigrid collector evacuated converter or a magnetohydrodynamic (MHD) converter designed for multi-mev alphas. Over 1200 MWe of 400 KV dc would be produced by the direct convertors at each end of the OKTP reactor.

7.0 REMOTE HANDLING SYSTEMS

7.1 Module Handling Machine (MHM)

The OKTP reactor is exposed directly to the 14 Mev neutrons emitted by the fusion plasma in the evacuated reactor space. Further, there are roughly four times as many neutrons emitted per unit of energy release in fusion than in fission. Further, because the 14 Mev neutrons are considerably more energetic than the fission spectrum, it has not yet been possible to measure their effect on metals. However, it is known that the intense, high energy neutron bombardment will cause every atom in the walls of the fusion reactor to be displaced every year, and that some of the high energy neutrons will be absorbed by the wall creating new metalic elements of creating helium bubbles by (n,α) reactions. It is therefore necessary to design the OKTP plant to permit periodic replacement of OKTP reactor modules, although at this time we cannot predict the replacement frequency.

Two module handling machines are used to replace the OKTP reactor module. The module handling machines ride on overhead steel beam tracks and are positioned above the OKTP reactor modules. One module handling machine is used to disconnect and remove the reactor module which is to be replaced; the second module handling machine is used to install the replacement module. Because of the induced radiation in the OKTP reactor modules, the module handling machines are all remotely operated. They have the following functions: viewing, positioning, lifting reactor module, disconnecting/reconnecting Flibe cooling lines and adiabatic compression water cooling lines, disconnecting/reconnecting implosion heating and adiabatic compression electrical leads, disconnecting/reconnecting module D-T fuel line, disconnecting/reconnecting valve electrical operator leads and reactor module instrumentation and controls, cooling the removed module, and also of performing necessary quality assurance to assure proper installation of the replacement module. The LA-5336 LASL/ANL report on the RTPR suggested that "it is conceivable that a module can be replaced in less than an hour." However, further careful analysis of the actual mechanical design of the module connections and the module handling machine will be required to substantiate this replacement time estimate.

7.2 Rotary Vacuum Lock

Six rotary vacuum locks are provided, one for each of the 600' long reactor building sections. They separate the module handling machine space above the evacuated OKTP reactor chamber from the atmosphere of the module storage bins. They serve to minimize inleakage of air during module replacement and routine operation.

7.3 Module Storage

A transfer cart slips under the module handling machine and the OKTP reactor module that it carries, and transfers the reactor module from the rotary vacuum lock area to the module storage bins. A transfer cart is also available on the hot cell floor level should it be desired to transfer a module by use of the overhead crane through hatches in the module handling machine area ceiling.

Numerous module storage bins are provided, estimated at 1728 storage spaces, or roughly three time the number of modules in the reactor during operation. This is significantly greater than fuel element storage capability for fission reactors, but allows for on-site hot cell maintenance operations. The linear geometry has more module storage capability than the KTPR toroidal geometry. Twelve module transfer machines are provided for moving the modules and other replacement parts within the module storage bin area.

7.4 Hot Cells

Significant hot cell space is provided in the linear geometry as the hot cells run the entire length of the 3600' reactor building. The hot cells permit off-line repair and maintenance of irradiated reactor modules. Four foot thick shielded windows are provided on either side of the 30' wide hot cells. Servo-controlled powered remote manipulators are provided at each shielded window station, with one spaced every ten to twenty feet of hot cell length. At 15' average length, there are 240 hot cells.

7.5 Module Shipping

The exterior bay of the reactor building is provided for module shipping activities. These will consist primarily of wash downs after the spent modules or other plant components which may have radioactivity are packed in shipping casks for offsite disposal. There is grade level access for trucks, and the possibility exists for grade level or below ground railroad access running the length of the reactor building. However, a decision may be made to reduce hot cell/storage bin capacity, which may be excessive, and incorporate the module shipping function periodically within the currently assigned hot cell/storage bin area. This would reduce the width of the reactor building by up to 50 feet, with considerable savings, and also reduce the requirements on the cranes used for reactor building construction.

8.0 ELECTRICAL POWER SYSTEMS

8.1 Switchyards

There are two SF_6 gas insulated 765 KV switchyards. Each switchyard contains fifteen circuit breakers in breaker and one-half configuration. This allows six main turbine-generators and one alpha turbine-generator inputs to the switchyard, two 765 KV offsite transmission lines, and one on-site auxiliary power line per switchyard. Each switchyard is only 200' x 260'.

Each generator transformer is connected to the nearest switchyard with three single phase gas insulated bus runs carried in an open trench. Approximately 100,000 feet of single phase 765 kv gas insulated bus is required to connect the generator transformers to the switchyard.

8.2 Onsite a-c Power Systems

The on-site auxiliary power line in each switchyard feeds a 765KV/69KV, 1600 MWe capacitor auxiliary power (CAP) transformer. The CAP transformers are provided to feed energy, through the capacitor energy charging system (CECS), to the capacitor implosion heating system (CIHS). Auxiliary power can be tapped off the CAP transformer, or if CAP transformer rating in final design exceeds available transformer capability, four instead of two CAP transformers will be used and the switchyard rearranged accordingly.

The on-site a-c power distribution system includes necessary buses, transformers, breakers, and motor control centers to deliver power to the major pump requirements (e.g. primary coolant, secondary coolant, feedwater, circulating water, and cooling tower pumps) typically at 6.9 or 4.16 KV and to other energy users, including fans, motors, lighting, etc. (typically in 480 [illegible] motor control centers).

Twelve emergency diesel generators, rated at 3000 KW$_e$ each based on fission plant experience, are provided in the reactor building. They are located at the base of the control room/relay room/switchgear room/diesel generator room hierarchy, and are placed between the secondary coolant pump and heat exchanger systems. This is the reason there are six left-hand and six right-hand turbine-generators; it gives maximum spacing of secondary coolant systems to allow room for the control room-electrical complex.

8.3 Onsite d-c Power System

A battery operated, 125 V dc onsite power system is provided for instrumentation functions.

9.0 INSTRUMENTATION AND CONTROL SYSTEMS

The instrumentation and control systems are the "nerves" which sense and control the operations of the entire plant. The first two types of I&C listed below will have many unique requirements to fusion power; the other four should be more similar to conventional power plants and remote handling systems.

9.1 Reactor I&C
9.2 Reactor Auxiliaries I&C
9.3 Heat Transfer I&C
9.4 Energy Conversion I&C
9.5 Remote Handling Systems Controls
9.6 Auxiliary Systems I&C

9.7 Control Rooms

Six control room areas are provided, one in each 600' reactor building section. They are nominally 70' wide by 140' long, with the length divided into 80' control rooms and 60' office/computer/service areas. Each control room handles the operation of two main turbine generators, the hot cells & storage areas of its building section, and the OKTP module remote handling of its building section. In addition each control room is assigned additional responsibility, as follows:

Control Room 1&6:Alpha turbine-generator 1& 2, respectively
Control Room 2: Emergency control center, site access, environment,
health physics
Control Room 3: Main control center
Control Room 4: Reactor control
Control Room 5: Auxiliary power, switchyards, load dispatch

9.8 Plant Computer Systems

The control rooms will be based on extensive use of CRT (cathode ray tube) display systems. This in turn will require extensive use of computer systems for receiving, storing, analyzing, displaying and controlling functions.

10.0 AUXILIARY SYSTEMS

10.1 Tritium Processing Systems

There are two tritium processing systems: one which separates the fuel-ash mixture, and one which separates bred tritium from the primary coolant.

LASL/ANL (LA-5336) base their fuel-ash mixture on a maximum inlet of 3 Kg/hr of 49% D, 49% T, 1% H, 1% He. The 1% He would represent approximately 1% fuel burnup per pulse of OKTP reactor operation; the 1% H is due to residual H in the D-T fuel mixture and also due to D-D fusion reactions. The object is to remove the H and He and recycle the D and T. To do this the inlet stream is chilled to 50°K, compressed and enters a 6" dia x 15' high distillation column with a Joule Thomson valve bypass. The overhead product or distillate, at 22.5°K and 800 torr, is fed to a catalyzer which converts 2HD to H_2 and D_2. A second column, of 3" diameter and 15' height, distills off the He and H_2 and recycles as bottom product a D_2/HD mixture. The bottom product of distillation column 1, a mixture of D_2, DT, T_2 and 1% HT is returned to the fuel injector.

A tritium handling and storage system holds the fuel mixture in storage and feeds it to the OKTP reactor modules as required for each pulse. It is to be determined whether the fuel will be fed, possibly uniformly, along the entire length of the 3600' OKTP reactor, or whether fuel feed will be limited to a small (perhaps 10 module) section at the center of the OKTP reactor. Fuel lines to the reactor modules are expected to be about 1mm diameter.

The tritium processing system which separates the bred tritium from the blanket is part of the primary coolant doctor system and secondary coolant doctor system. Based on their specified liquid metal lithium blanket, LASL/ANL (LA-5336) recommend a liquid-liquid extraction system for removal of the bred tritium, but they caution that the data used in the conceptual design summarized below is based on extensive extrapolation which needs to be experimentally confirmed. In their concept LiH is extracted from LiH-Li by use of a LiH-LiCl molten salt. In practice the lithium and the lithium halide salt (e.g. LiCl-KCl) are fed simultaneously into a centrifugal contactor where they are intimately mixed to effect an equilibrium separation of the LiT, and then further separated by centrifugal action. LA-5336 estimates a molal distribution coefficient for LiH between LiCl and Li of about 6 at 870°K; and the report notes that salt/liquid metal specific gravity ratio is greater than 3. Tritium partial pressure over the lithium flow is limited to 10^{-10} torr. Fifty conventional contactor units (50 cm dia. x 43 cm high), running at rotor speeds of 1700 rpm, and operating continuously on 1 MWe are required. After the salt phase is separated, the tritium is either removed electrochemically or by sparging the salt using DCl ($DCl + LiT \rightarrow LiCl + DT$).

Doctor systems also have to remove oxygen, nitrogen and carbon which can be expected to find their way into the primary and secondary coolant, as well as solid corrosion products. In the case of the primary coolant, which is exposed to the neutron flux, the solid corrosion products may be radioactive.

10.2 Radioactive Waste Systems

In addition to the tritium handling systems, it is expected that radwaste systems will be required for such items as the primary coolant corrosion products, for hot cell air filters, for decontamination facilities, for the module shipping decontamination waste water, and for other items which are still to be identified. These may be both high level, small volume and low level, high volume radioactive wastes in liquid and solid form. In addition there will be low level solid wastes from routine operations such as protective gear which are used once and disposed of. Accident systems may also be required.

10.3 Water Systems

Water systems supply auxiliary cooling and process makeup water. In the latter category is makeup water to the steam turbine generators, and up to 20,000 gpm process feedwater if the ten H_2 process energy center (rather than 10GWe) is built. Water supply is also used for fire protection and sanitary and potable water purposes.

The auxiliary cooling streams will typically transfer heat to secondary heat exchangers, with secondary water loops connected to the ultimate heat sink.

Important examples of auxiliary cooling water streams are:

- Adiabatic compression coils cooling water for the OKTP reactor module
- Adiabatic compression MFTS system solid state switches cooling
- CIHS system capacitor bank cooling water
- Module handling machine cooling water (if required)

10.4 Process Auxiliary Systems

Process auxiliary systems required for the normal functioning of a power plant, including OKTP fusion energy center, include: instrument air, service air, hydraulic power system (for large hydraulically activated valves), sampling system (some of which may be radioactive), and equipment and floor drains.

10.5 Heating, Ventilating and Air Conditioning (HVAC) Systems

HVAC systems are required throughout the OKTP reactor building, and in the auxiliary building. (If the alpha end loss energy converter is a direct energy converter, the alpha end loss building may be a huge vacuum chamber, rather than use a HVAC system). In the OKTP reactor building, because of its size and different functions there are a number of different HVAC requirements. These range from nonradioactive HV for the turbine-generator areas of the building, to class I type HVAC for the control rooms which must maintain habitability in the event of accidents, to potentially radioactive primary coolant system areas, to MFTS and CIHS reactor power supply areas which may use extensive air as well as water cooling, to radioactively contaminated hot cell areas.

10.6 Other Auxiliary Systems

Other auxiliary systems are those required for the normal functioning of a power plant, including the OKTP fusion energy center, and include: fire protection, communication, lighting, cathodic protection, and storm drain systems, and equipment & personnel decontamination facilities.

11.0 PLANT STRUCTURES

11.1 Reactor Building

The OKTP reactor building is the dominant structure of the OKTP fusion energy center, housing almost all of the functions of the plant. Its overall dimensions are 3600' long x 460' wide x 210' high. It contains at least 1.5 million cuyds of concrete floors and walls, and may contain up to 2.2 million cuyds if all floors, walls and roofs are made of concrete. (By comparison the largest hydroelectric plants have up to 7.5 million cuyds of concrete for 6000 MWe of capacity.) Consideration is being given to emplacing the concrete as precast concrete modules, using a goliath (shipyard-type) crane which spans the entire width of the building.

The following list of reactor building functional floor areas is indicative of the large size of the building. (By comparison a 50 story office building with floors 100' x 200' has a total floor area of 1.0 million ft^2.)

. Reactor	0.2 Million ft^2 floor area
. Reactor Auxiliaries	1.3 Million ft^2 floor area
. Heat Transfer	0.4 Million ft^2 floor area
. Turbine-Generator	0.8 Million ft^2 floor area
. Remote Handling	0.6 Million ft^2 floor area
. Electrical, controls, maintenance, shops	1.2 Million ft^2 floor area

The OKTP reactor building is not designed as a containment building. Indeed, because of tritium's characteristic as a lighter-than-air molecule, consideration is being given to providing rapid escape paths for tritium in the event of an accident or normal leakage. This way the tritium, which is absorbed only 0.1% in the body, can escape to the upper atmosphere before forming tritiated water, which is 100% absorbed by the body.

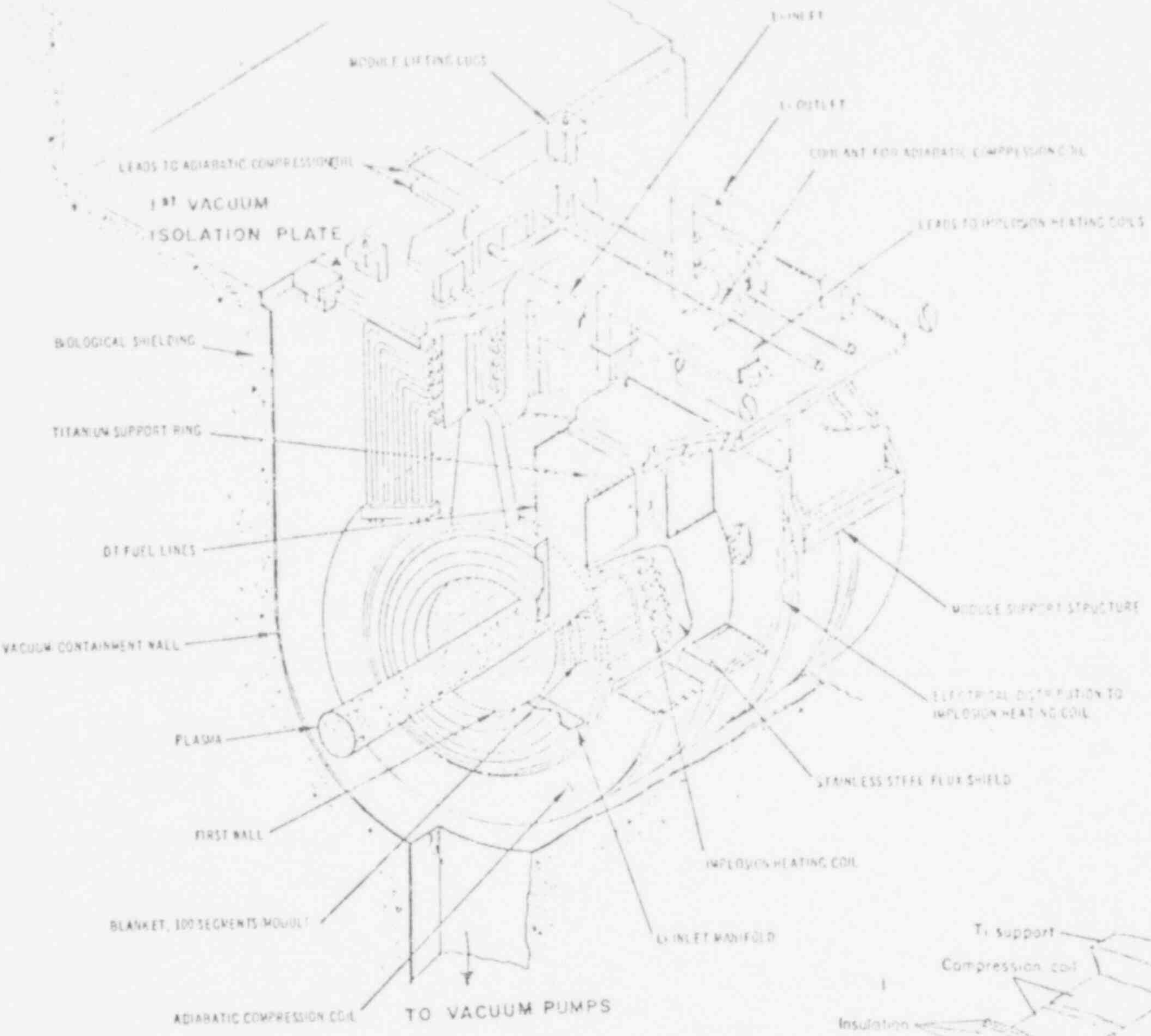
11.2 Alpha Endloss Buildings

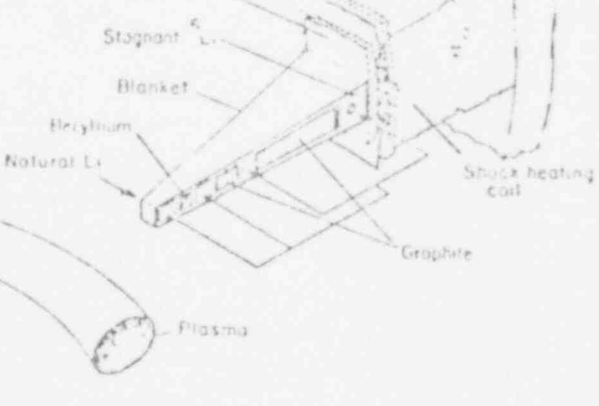
Two alpha endloss buildings house the alpha endloss energy converters at either end of the OKTP reactor building. They will either be conventional turbine-generator buildings with steel framing at atmospheric pressure, or there will be two large evacuated housings if a multigrid direct converter is used. The evacuated housing case might be a fan shape over a 270° arc, with a major radius of up to 400 foot length.

11.3 An administration building will be provided. This may also house the control room simulator rooms.

11.4 Other Structures will include several warehouses, a visitor building, guard houses, possibly additional maintenance buildings, and small miscellaneous buildings such as fire pump houses.

MODULE FOR
REFERENCE THETA-PINCH REACTOR (RTPR)





A poloidal section of one radial blanket sector illustrating specific blanket regions and lithium flow paths

RTPR MODULES

Toroidal Reactor
176 modules
2 m long
3 m diameter
80 tons
$1.2 million per module (1975 $)

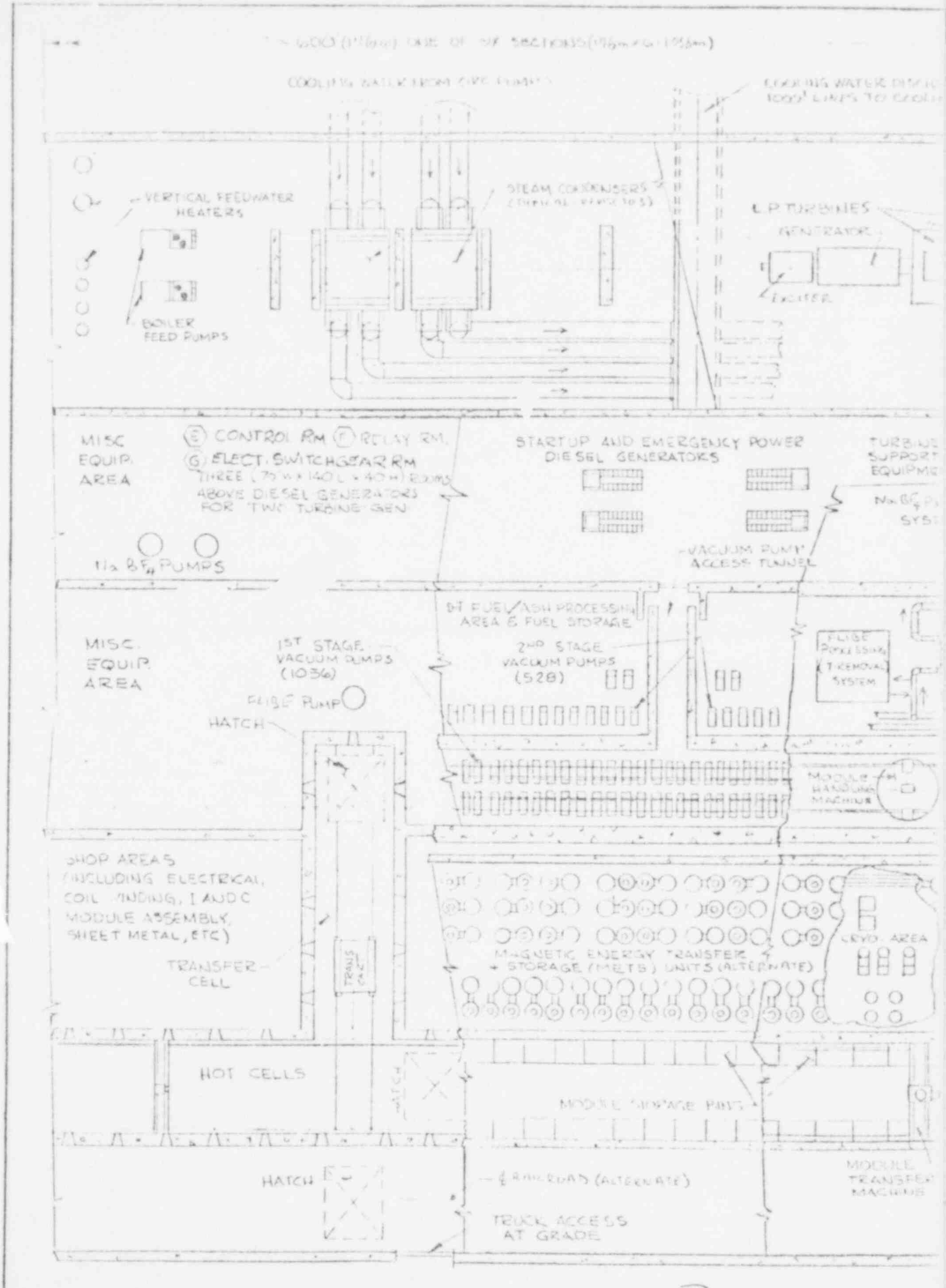
CONNECTIONS

1. Li Inlet
2. Li Outlet
3. Adiabatic Comp.Coil (ACC)Coolant Inlet (6")
4. ACC Coolant Outlet(6")
5. ACC Electric Leads
6. Implosion Heating Coil Electric Leads
7. D-T Fuel Line (1 mm)
8. 1st Vacuum Isol.Plate

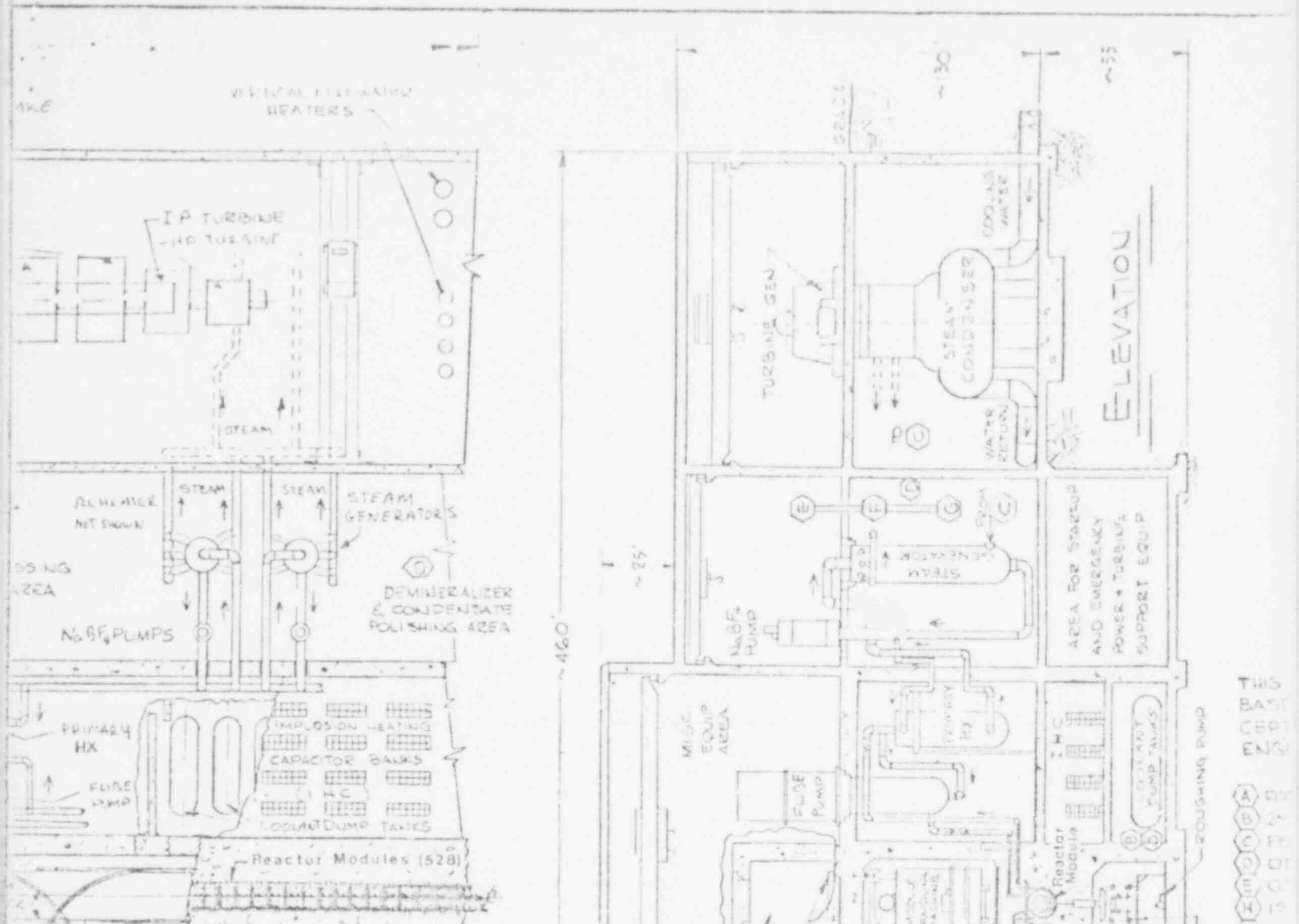
Reference: Los Alamos Sci.Lab & Argonne Natl Lab, "An Engineering Design of a Reference Theta Pinch Reactor (RTPR)," LA-5336/ANL-8019, 3/74

42-086

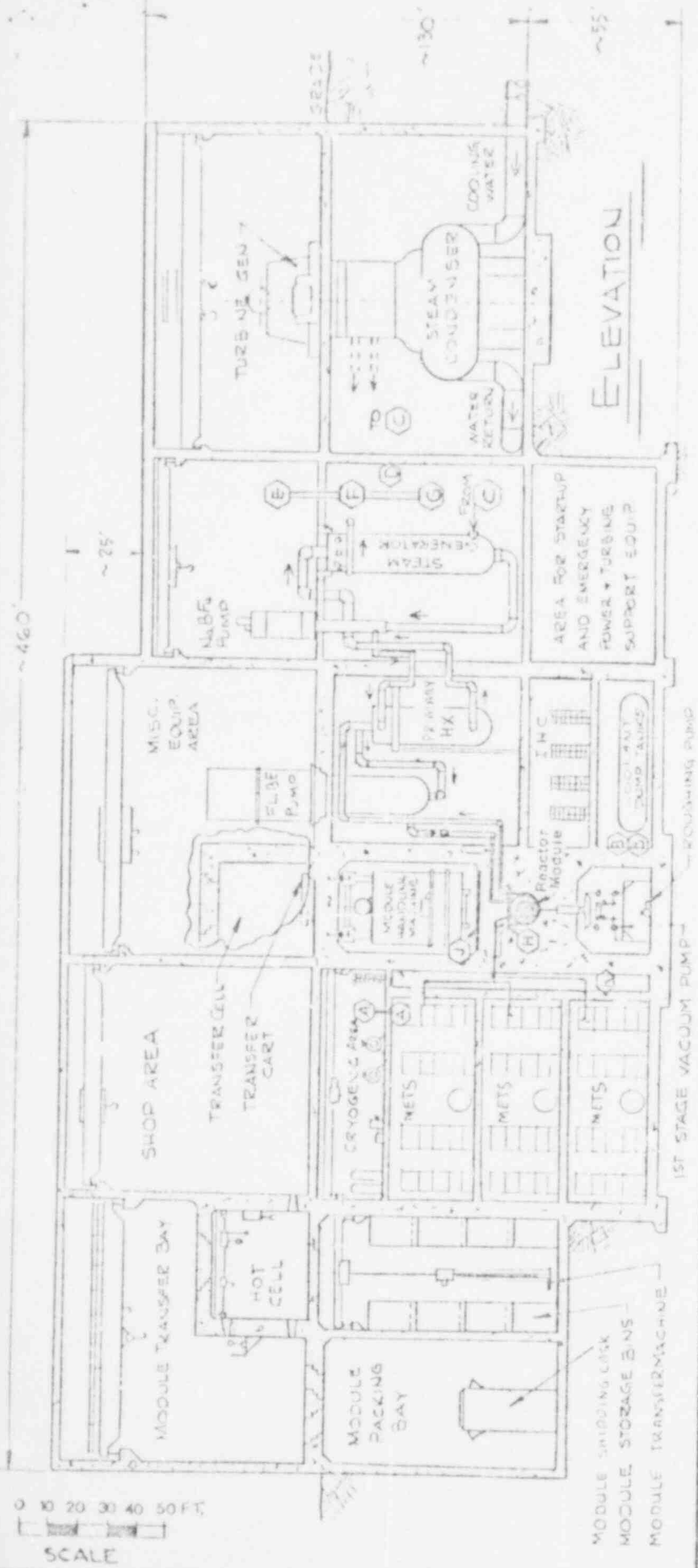
1393-L-ECI-0002A
Rev 1, 6/1/76


~ 600' (176m) ONE OF SIX SECTIONS (176m × 6 = 1056m)
COOLING WATER FROM CIRC PUMPS
COOLING WATER DISCH
1000' LINES TO COOLI
VERTICAL FEEDWATER HEATERS
BOILER FEED PUMPS
STEAM CONDENSERS (TYPICAL REMOTES)
L.P. TURBINES
GENERATOR
EXCITER
MISC EQUIP. AREA
Ⓔ CONTROL RM Ⓕ RELAY RM.
Ⓖ ELECT. SWITCHGEAR RM
THREE (70 W × 140 L × 40 H) ROOMS ABOVE DIESEL GENERATORS FOR TWO TURBINE GEN
1/2 BF$_H$ PUMPS
STARTUP AND EMERGENCY POWER DIESEL GENERATORS
TURBINE SUPPORT EQUIPME
Na BG & P SYST
VACUUM PUMP ACCESS TUNNEL
MISC. EQUIP. AREA
1ST STAGE VACUUM PUMPS (1036)
FLIBE PUMP
HATCH
DT FUEL/ASH PROCESSING AREA & FUEL STORAGE
2ND STAGE VACUUM PUMPS (528)
FLIBE PROCESSING T REMOVAL SYSTEM
MODULE HANDLING MACHINE
SHOP AREAS (INCLUDING ELECTRICAL, COIL WINDING, I AND C MODULE ASSEMBLY, SHEET METAL, ETC)
TRANSFER CELL
TRANS CELL
MAGNETIC ENERGY TRANSFER + STORAGE (METS) UNITS (ALTERNATE)
CRYO. AREA
HOT CELLS
HATCH
MODULE STORAGE PITS
MODULE TRANSFER MACHINE
HATCH
℄ RAILROAD (ALTERNATE)
TRUCK ACCESS AT GRADE

PLAN


VERTICAL FEEDWATER HEATERS
I P TURBINE
HP TURBINE
STEAM
REHEATER NOT SHOWN
STEAM
STEAM
STEAM GENERATORS
SSING AREA
DEMINERALIZER & CONDENSATE POLISHING AREA
NaBF4 PUMPS
PRIMARY HX
FLIBE PUMP
IMPLOSION HEATING CAPACITOR BANKS
IHC COOLANT DUMP TANKS
Reactor Modules (528)
K (TYP)
METS HOMOPOLAR MOTOR-GEN
METS SWITCHES
A
MODULE STORAGE BINS
TUNG CART
GRADE
~30
~33
TURBINE GEN
STEAM CONDENSER
COOLING WATER
WATER RETURN
ELEVATION
~25'
~460'
NaBF4 PUMP
STEAM GENERATOR
FROM
AREA FOR STARTUP AND EMERGENCY POWER + TURBINE SUPPORT EQUIP
MISC EQUIP AREA
FLIBE PUMP
PRIMARY HX
IHC
COOLANT DUMP TANKS
ROUGHING PUMP
Reactor Module
MODULE HANDLING MACHINE
TRANSFER CELL
TRANSFER CART
SHOP AREA
CRYOGENIC AREA
METS
METS
METS
1ST STAGE VACUUM PUMP
MODULE TRANSFER BAY
HOT CELL
MODULE PACKING BAY
MODULE SHIPPING DOCK
MODULE STORAGE BINS
MODULE TRANSFER MACHINE
0 10 20 30 40 50 FT
SCALE
THIS
BAS
CEP
ENG
A ROT
B 2N
C FE
D DE
E CO
H 1S
K 1
REV NO.
ENGINE
STATE
OKT
C
12
2
1
5-2
1-2

42-098



◄ OKTP KEY EQUIPMENT LIST ►

• REACTOR MODULES (2 m long)	528
REACTOR AUXILIARIES	
• IMPLOSION HIG CAPACITOR BANKS	528·52
• METS ENERGY STORAGE MOTOR GEN	150
• METS SOLID STATE SWITCHES	58 800
• ROUGHING PUMPS	26
• 1st STAGE VACUUM PUMPS	1056
• 2nd STAGE VACUUM PUMPS	528
• CRYOGENICS AREA	Misc.
HEAT TRANSFER	
• FLIBE PUMPS	48
• FLIBE-NaBF$_4$ HEAT EXCHANGERS	48
• NaBF$_4$ PUMPS	48
• NaBF$_4$ STEAM GENERATORS	48
• FLIBE & NaBF$_4$ DUMP TANKS	24 & 24
• FLIBE & NaBF$_4$ DOCTOR SYSTEMS	12 & 12
POWER CONVERSION	
• 1000 MWe HP-IP-3LP TURBINE-GEN	12
• STEAM CONDENSORS	36
• TURBINE DRIVEN FEEDWATER PUMPS	24
• FEEDWATER HEATERS	72
• ALPHA END-LOSS ENERGY CONVERTERS (EXTERIOR TO ENDS OF RCTR BLDG)	2
REMOTE HANDLING	
• MODULE HANDLING MACHINE	12
• ROTARY VACUUM LOCKS	6
• TRANSFER CARTS	12
• MODULE TRANSFER MACHINES	12
• HOT CELLS (15' long)	240
• REACTOR MODULE STORAGE BINS	1728

◄ SPECIAL NOTE ►

THIS 1-KILINEAR θ-PINCH CONCEPTUAL DESIGN IS BASED ON A 352m TOROIDAL θ-PINCH CONCEPTUAL DESIGN (REF: LA-5336/ANL-8019, ENGG DESIGN STUDY OF RTPR, 3/74)

◄ NOTES ►

Ⓐ ROTARY VACUUM LOCK FOR MODULE HANDLING MACH.
Ⓑ 2ND STAGE VACUUM PUMPS + ACCESS WAY
Ⓒ FEEDWATER HEATERS + BOILER FEED PUMPS
Ⓓ DEMINERALIZER + CONDENSATE POLISHING AREA
Ⓔ CONTROL Ⓕ RELAY Ⓖ ELEC SWITCHGEAR ROOMS
Ⓗ 1ST VAC ISOLATION PLATE Ⓙ 2ND VAC ISOLA PLATE
Ⓚ CONDUCTORS TO REACTOR COMPRESSION COIL

REV NO.	DATE	DESCRIPTION	ENGR.	SUP. ENG.
2	5-28-76	REVISE EQUIP LIST, METS, SPECIAL, TURBINE, TITLE, MISC CHANGES		DMA
1	1-28-75	REDRAWN, ADDED EQUIP LIST	WEO	DMA
	1-13-75	FIRST ISSUE		DMA

ENGINEER

STATE REG. NO.

OKTP – ONE KILOMETER THETA PINCH
10GWe FUSION ENERGY CENTER
REACTOR BUILDING
CONCEPTUAL ARRANGEMENT

united engineers & constructors Inc.

1393 - C' - EC1 - 0001