LEGIBILITY NOTICE

A major purpose of the Technical Information Center is to provide the broadest dissemination possible of information contained in DOE's Research and Development Reports to business, industry, the academic community, and federal, state and local governments.

Although a small portion of this report is not reproducible, it is being made available to expedite the availability of information on the research discussed herein.

NOV 01 1989

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36

LA-UR--89-3299

DE90 002443

TITLE CONFINEMENT PHYSICS RESEARCH FACILITY/ZTH:
A PROGRESS REPORT

AUTHOR(S) HAMMER, C.F., CTR-4
THULIEN, P., ET/MFE

SUBMITTED TO presented to the 13th IEEE Symposium on Fusion Engineering,
Knoxville, TN, October 2-6, 1989

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, irrevocable, and exclusive license to publish or reproduce the published form of this contribution or to allow others to do so for U.S. Government purposes.

The Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy.

MASTER

Los Alamos Los Alamos National Laboratory
Los Alamos, New Mexico 87545

LA-UR-89-3299

**CONFINEMENT PHYSICS RESEARCH FACILITY/ZTH:
A PROGRESS REPORT**

C. F. HAMMER and P. THULLEN

Los Alamos National Laboratory, Los Alamos, NM 87545

Presented To

IEEE 13th Symposium on Fusion Engineering
Knoxville, Tennessee

October 2-6, 1989

CONFINEMENT PHYSICS RESEARCH FACILITY/ZTH: A PROGRESS REPORT[†]

C. F. Hammer and P. Thullen

Los Alamos National Laboratory, Los Alamos, NM 87545

ABSTRACT

In October 1985 the Los Alamos National Laboratory's Controlled Thermonuclear Research (CTR) Division began the design and construction of the Confinement Physics Research Facility (CPRF) and the ZTH toroidal, reversed field-pinch (RFP), plasma physics experiment. The CPRF is a facility which will provide the buildings, utilities, pulsed power system, control system and diagnostics needed to operate a magnetically confined fusion experiment, and ZTH will be the first experiment operated in the facility. The construction of CPRF/ZTH is scheduled for completion in the first quarter of 1993.

1. INTRODUCTION

The CPRF/ZTH consists of a facility and an experiment so its description covers both the bricks and mortar and scientific aspects of construction (Fig. 1).

ZTH constitutes the scientific research portion of the construction program. It is the next generation in a series of RFP experiments which have been built and operated at Los Alamos. Its immediate predecessors are ZT-40, a 40 cm minor bore 400 kA plasma current device and, ZTF, a fifth geometric scale prototype of ZTH. ZTH will have a nominal 80 cm bore and the capability of operation at 4 MA although operation will be limited to 1.7 MA by initially installed power supplies and magnet support structure.

The objectives of the ZTH research program are to extend and enhance the physics base of the RFP toroidal confinement configuration by demonstrating the principle of toroidal flux self-sustainment and high beta operation in a compact configuration. The ZTH research program will study:

- The dependence of plasma parameters and ohmic heating on toroidal current in a high beta plasma,
- Transport in the collisionless regime and the effect of field errors on confinement,
- RFP formation, plasma current ramping, $E \times B$ control, plasma heating and equilibrium control,
- Density and termination control techniques,
- Edge plasma physics, impurity control, and wall protection techniques,
- Steady state current drive using oscillating field current drive or other helicity injection techniques,
- Technological issues, and confinement physics at high current, ignition-like temperatures, fusion-relevant thermal wall loads, and significant d and neutron flux.

ZTH is designed to allow, after system modification, the installation of pellet injectors, diverters, and helicity injection systems,

[†] Work performed under the auspices of the U.S. Dept.

Fig. 1.

including oscillating field current drive. These components and related system modifications are not included in the scope or cost of the CPRF construction Program.

At 1.7 MA plasma current the ion and electron temperatures are expected to be 1.7 keV, the plasma density 10^{11} cm⁻³, the average plasma poloidal beta 10 to 20%, and the energy containment time 12 ms.

The CPRF is the bricks and mortar portion of the program. It is located at an existing Los Alamos site the Torus Hall having 6 ft thick walls, at its center. Power will be supplied to the facility by a pulsed generator and solid state converter system. Generator and Power Supply buildings are being constructed in close proximity to the Torus Hall. The facility will occupy about 35 000 square feet of building space by the beginning of FY93.

The engineering design of the CPRF and ZTH has as its objectives:

- A 1.7 MA toroidal current capability with a 0.4 second experimental pulse (current rise and flat-top),
- A vacuum liner minor radius of 0.4 m with an aspect ratio of about 50,
- Ohmic heating coils which maximize electromagnetic energy transfer to the plasma consistent with minimum field errors and good diagnostic and maintenance access to the torus,
- Equilibrium field coils must minimize the required control power and asymmetric field errors in the discharge chamber and allow good diagnostic and maintenance access to the torus,
- Facility operating criteria:
 - 20 000 2 MA discharges,
 - 50 000 1 MA discharges,
 - One 2 MA discharge per ten minute period at plasma discharge point conditions.

The program began in FY86 and is over 50% complete. Most designs are complete and present activities are focused on procurement and construction.

2. STATUS OF MAJOR SUBSYSTEMS

The CPRF/ZTH construction program is divided into a small number of tasks, each under the control of a Task Leader. These tasks combine related aspects of the construction program and constitute the second level of a work breakdown structure. This description of the progress of the CPRF Construction Program is based on this task structure. The brief descriptions given here may raise questions in the reader's mind about various aspects of the subsystems. Many of the Task Leaders have written papers for this meeting, and they should be consulted for detailed information about subsystems.

A. Facilities at TA-35

The CPRF/ZTH experiment is located at Technical Area 35 (TA-35) about 2 miles from the CTR Division and ZT-40 site. The facility (Figs. 1 and 2) consists of the Torus Hall (TSL 124), a power supply building which has not been built, and CPRF generator building which is under construction. There is space in the existing building complex for a main control center and a room which will house the electro optic interface hardware for the vacuum and diagnostic systems.

Fig. 2.

Torus Hall (TSL-124) The Torus Hall contains the ZTH experiment which consists of the vacuum liner and graphite tiles (plasma 1st wall), the conducting shell, the toroidal field (TF) ohmic heating (OH), equilibrium field (EF) coils, and various structural elements. Also in Torus Hall are the electrical diagnostic hardware, the plasma physics diagnostic equipment, and the vacuum and gas fill systems.

The Torus Hall is constructed of concrete, with six foot thick walls and a five foot thick ceiling providing neutron shielding for TF's at 4 MA plasma current. The building inside dimensions are 56 ft by 200 ft which provides adequate additional space for assembly of the torus and coil systems.

Modifications of the building have been minimal. It was necessary to cut a 26 ft x 12 ft opening for a door in the west wall to allow the 24 ft diameter ohmic heating coils to be brought into the building. An existing fifteen ton crane is being replaced with one that can handle forty tons. The concrete floor immediately

under the diagnostic platform is being replaced to accommodate increased load requirements. These modifications have been or will be completed by the end of 1989.

Power Supply Building The Power Supply building will house the transformers and SCR power supplies, the capacitive energy storage hardware, switching systems, and a portion of the bus system that is required to connect the OH, EF, and TF electrical circuits to the coils. A portion of the power supply building will house the multi point Thomson scattering diagnostic screen room.

The Power Supply building floor will be about 240 ft by 65 ft and the roof about 40 ft tall. Design of the building is complete and construction should start in the spring of 1990. The design of the building is such that a major portion of it consists of a roof that spans the space between the Torus Hall to the north and an existing building to the south, using the existing buildings' outside walls as the walls for the Power Supply building. The remaining parts are conventional construction: steel frame and metal walls. Initially the building will not have a second floor, however, to implement the 4 MA plasma current option, a second floor can be easily added.

Generator Building The Generator building will house the 1430 MVA electrical generator and its associated auxiliary hardware, which provides the energy for the ZTH experiment. The building floor is 200 ft by 60 ft, it is 30 ft high, and it will be serviced by a 25 ton crane. Construction of the building is conventional steel frame with sheet metal siding. The building is scheduled to be complete by mid November, 1989. Construction of the building is quite unique because the generator and most of its hardware has already been installed on the foundation, therefore the building construction must go on around the generator hardware. The schedule calls for the building to be weather tight and habitable by the end of September, 1989, so that the generator hardware can be kept at a moderate temperature while the building construction is completed. Adjacent to and east of the generator building is a switch yard that contains the AC power transformers and switch gear required to provide electrical power to CPRF.

Control Room An existing shielded room in TSL 124, that had been used as a control room for an earlier experiment, will also be used as the control room for CPRF. The control room will contain the main control computer, a control console, and an area reserved for users of the experiment. The room is currently not large enough, therefore modifications to increase the size of the shield room are being planned. Design of the modifications should be complete by the end of 1989 and construction should begin in 1990.

B. Torus

The vacuum liner and conducting shell assembly (shown in Fig. 3) are similar in concept to those used in ZT-40M and ZT-4P. The shell, besides being larger and stronger, includes a unique feature. It is constructed of a material consisting of 1/4 cm thick stainless steel with 3 mm of copper explosively bonded to the inner surface. The stainless steel provides the necessary mechanical strength and the copper provides the proper electrical conductivity.

The shell is made in 12' diam shell sections which are bolted together with flanges to form a torus. It supports the toroidal field coils, termination forces, and loads from the vacuum liner. The shell will be provided with water cooling. It also has an oblique insulated break in both the toroidal (long way around) and the poloidal (short way around) directions. The poloidal field gap is designed to minimize the field errors resulting from the insulating gap.

Fig. 3. PERSPECTIVE VIEW OF TORUS

The interspace, the space between the liner and shell, contains support rings, thermal and electrical insulation, thermocouples and electrical diagnostic pickup loops.

The vacuum liner is made of many wedged shaped cylindrical sections that are welded together to form a close approximation to a torus. The individual sections consist of Inconel 625 bellows that are welded to Inconel armor support rings.

The design of the torus has been completed. Selection of the hardware fabrication vendor is about complete. The contract for fabrication of the hardware should be in place in late FY89. Fabrication, construction, assembly, and installation of the torus is the CPRF critical path activity.

The CPRF/ZTH plasma first wall consists of a number of discrete graphite tiles (5632). These tiles attach to the Inconel liner and cover about 96% of the torus surface. The tile system (Fig. 4) consists of ATJ and HDG graphite tiles and a tile mounting system that fastens the tile to the liner and assures that it will not rotate during operation. Preliminary design of the system is complete. A prototype assembly has been tested to verify the design concept. Further testing by the hardware will begin in October. Procurement of the hardware for CPRF/ZTH is scheduled to begin by the end of FY90.

C. Energy System

The OH coils are driven by an inductive energy storage system during start-up and SCB power supplies during flat-top. The TF coils are initially driven with a capacitor bank, after the toroidal field reverses, at the vacuum liner an SCB controlled power supply is used to maintain the reversed toroidal field. Plasma equilibrium control is accomplished also by using SCB power supplies to provide the TF coil current required to produce equilibrium. The TF and TF flattop power supplies require conceptually similar feedback control systems.

The conceptual design of the energy system has proceeded to a point where all of the components have been identified and sized. Most of the hardware remains to be purchased. There are some exceptions. The transfer reactor for the OH system is on order, capacitors for the TF system will be taken from ZF-40, and the cable

Fig. 4.

for the OH, EF and TF bus has been purchased.

The electrical energy for the entire experiment is provided by a 1430 MVA electrical power generator. The generator, part of a cancelled nuclear power plant, was obtained from Tennessee Valley Authority (TVA). The generator system is in the process of being installed. Generator system commissioning (no load testing) is scheduled for mid 1990.

The generator will be operated in pulsed mode. The generator is run as a motor from standstill to 1800 rpm. It is then configured electrically as a generator and the load (the ZTH experiment) is connected to the output. As the electrical energy is extracted from the spinning generator the rotor slows, when 1/2 the energy is removed from the generator rotor, the rotor speed will be reduced to 1350 rpm.

D. Magnet Coils

Forty-eight TF coils are mounted on the torus, located at 7.5 intervals. Each coil consists of six turns of a water cooled copper with epoxy glass insulation.

The OH coil system consists of 10 discrete coil assemblies, each total turns and the equilibrium field control system is made up of 6 coils (240 turns). There are also 8 smaller trim coils. These poloidal field coils are all of similar design. All have provisions for water cooling except the trim coils. The largest OH coil is 24 ft in diameter.

All coils are designed and the TF coils have been fabricated. The final shipment will arrive at Los Alamos by mid October 1989. Fabrication of the OH TF and trim coils is well under way. They

will begin to arrive in January 1990 and the last coil shipment is scheduled to arrive in Los Alamos by spring of 1990.

The torus with the TF coils, OH coils, EF coils and trim coils are held in place by a mechanical structure which is made of non-metallic, non conducting material (G 10 fiberglass). The structure is designed to support the coils and absorb the puled forces which are generated when the machine is operated. The configuration of bulkhead assemblies resemble the spokes of a wheel when viewed from the top. Sixteen bulkheads are required for 4 MA operation; for 1.7 MA, we will install 8 bulkhead assemblies. The detailed design of the machine structure is proceeding. Fig. 5 shows the bulkhead structure and coil locations.

Fig. 5.

E. Control System

The control system will provide overall control of the entire system during experiment operation. Also it will provide the capability to operate the systems independently during the check out phase of the construction. The control system configuration consists of a central control console and four controller subsystems, that are linked together using a fiber optic communication network. The four subsystems are:

- Vacuum and Gas Handling Subsystem,
- Generator Subsystem,
- Energy Subsystem, and
- Front end Subsystem.

Conceptual design of the control system is complete. Commercial programmable logic controllers (PLC) have been selected for use as subsystem controllers. The vacuum and gas handling subsystem hardware has been purchased and arrived in Los Alamos, the summer (1989). Bids for the main machine software are currently being evaluated. The rest of the control hardware will be purchased as subsystem requirements are identified.

F. Vacuum and Gas Handling System

An important factor in the successful operation of the ZTH experiment is that have a high quality vacuum and gas handling system. The vacuum system design consists of two high vacuum pumping stations (HVPS), a gas handling system, a roughing system

and control system. The HVPS contains a turbomolecular pump that is connected to the torus by means of bellows that mechanically isolate the pump from the torus. The gas handling system will supply high purity gas (hydrogen and/or deuterium and/or helium) to the torus. Gas can be supplied continuously during operation and discharge cleaning or pulse injected as required. The design of this system is complete, some of the components have been purchased. The first pump stand has been fabricated and tested.

3. CONCLUSION

The CPRF construction program has been underway since the beginning of FY86, and has passed the 50% completion point. Construction and fabrication have begun on elements of all major subsystems. The 1430 MVA generator system will be commissioned in the summer of 1990. All coils will be delivered and work will be underway on the front end within the next year. At the present pace, and with presently anticipated budget profiles, integrated system check out should begin as scheduled in the spring of 1993.

4. ACKNOWLEDGEMENTS

It is through the efforts of a staff, which includes Los Alamos and contractor personnel, dedicated to progress of research in magnetically confined fusion, that the CPRF construction program has come to its present state of completion. We thank these people for their continued hard work and unfailing optimism.