ORNL-TM-4342

THE ORMAK-F/BX FACILITY — PRELIMINARY CONSIDERATIONS

M. Roberts

23,701

MASTER

OAK RIDGE NATIONAL LABORATORY
OPERATED BY UNION CARBIDE CORPORATION • FOR THE U.S. ATOMIC ENERGY COMMISSION

ORNL-TM-4342

Contract No. W-7405-eng-26

THERMONUCLEAR DIVISION

THE ORMAK-F/BX FACILITY — PRELIMINARY CONSIDERATIONS

M. Roberts

OCTOBER 1973

NOTICE This document contains information of a preliminary nature and was prepared primarily for internal use at the Oak Ridge National Laboratory. It is subject to revision or correction and therefore does not represent a final report.

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

Table of Contents

THE ORMAK-F/BX FACILITY — PRELIMINARY CONSIDERATIONS

M. Roberts

Abstract

In view of the anticipated needs of the U.S. CTR program in the late 1970's, consideration is being given to a large, flexible tokamak facility. This facility would be used first for experiments with H plasma to demonstrate the scientific feasibility of fusion in an injection-heated tokamak. Then parts of the device would be modified as necessary and planned shielding and containment features would be added to permit D-T burning experiments. A 10-manyear conceptual design study of such a facility is to be accomplished in FY-1974 by scientists and engineers at ORNL. The project is called ORMAK-F/BX for Oak Ridge Tokamak Feasibility and Burning Experiments. The initial estimates of system parameters, the questions to be addressed, and the organization for the study are described.

Keywords: fusion, tokamak, scientific feasibility, D-T burning, ORMAK, conceptual design.

Introduction — Rationale and Concept

Five conceptual steps have been identified in controlled thermonuclear research and development from demonstration of scientific feasibility to the achievement of commercial power production from a fusion reactor.[1] They are:

1) scientific feasibility demonstrations (SFX),
2) operation of plasma test reactors (PTR),
3) operation of experimental reactors at significant power for substantial periods (EPR),
4) operation of prototypic power reactors, and
5) operation of a demonstration power plant.

The facility described in this report would be concerned with the first two of these steps along the tokamak (toroidal diffuse pinch) approach to fusion power.

Considering the similarities and differences in the requirements of scientific feasibility and D-T burning experiments, a group in the Thermonuclear Division at ORNL in 1972 conceived the idea of a convertible facility.[2] This facility would be designed so that after it had served for a demonstration of the scientific feasibility of fusion in an injection-heated tokamak it could be adapted, at a fraction of the cost of a new facility, for D-T burning experiments. Evaluations of practicality, risks, benefits, and costs would require design studies, but elementary considerations indicated the possibility of substantial savings in both time and money.[*] Recognition of this possibility has led to a conceptual design

---

[1]Robert L. Hirsch, "Fusion Power: Past, Present and Future," *International Conference, World Energy Problems: Nuclear Solutions*, November 1972.

[2]*Thermonuclear Division Annual Progress Report*, period ending Dec. 31, 1972, p. 17, §2.5.2.2.

[*]Estimates by various investigators of the cost of a tokamak SFX fall in the range of \$50—100 million. By comparison, the costs of the special features that would have to be added to handle radioactivity in D-T burning experiments should be on the order of \$10 million.

BLANK PAGE

study, to be accomplished in FY-1974, of a facility that was originally called SCORE* but now is called ORMAK-F/BX for Oak Ridge Tokamak Feasibility and Burning Experiments. In view of the present state of thermonuclear research and reasonable projections for the next several years, we believe that such a dual-purpose facility deserves immediate, serious consideration. The premises from which we are led to this conclusion are as follows.

1. Operation of ORMAK with ohmic heating appears to have led to the observations[3] of a plasma with sufficiently low collisionality to permit physics studies of reactor interest, with detailed accounting of ion thermal energy losses which permitted probable agreement with neoclassical theory and, with electron particle losses accounted for by the semi-empirical pseudoclassical relation which has now been extended to low aspect ratio plasmas.

These observations form the basis for the first premise which is that the probable outcome of confinement scaling to plasmas of larger size and with higher temperature (the first major physics requirement) is favorable.

2. The viabilityof neutral beam injection as a way of heating to ignition temperatures is to be demonstrated in ORMAK in FY-1974; early indications are positive. This premise clears the way for achievement of the second major physics requirement — a technique usable for heating to ignition temperatures.

3. Experiments in high-field ORMAK and then in PLT could produce, in the late 1970's, combinations of plasma temperature, density, and confinement time close to that constituting a demonstration of scientific feasibility of fusion in tokamaks. This premise strongly underlies the need for a facility able to be used for D-T burning experiments while being available for feasibility attempts if needed — hence the convertability in the F/BX concept.

---

*SCORE stood for SuperConducting ORMAK Experiment. Superconducting magnets will eventually be required, but the first experiments may use cryogenic magnets.

[3]ORMAK Staff, "The Status of the ORMAK Experiment," *Proc., Third Int'l Symp. on Toroidal Plasma Confinement,* Garching, March 1973.

4. Because of the long lead time for large machines, the vigorous pursuit of fusion power requires that conceptual designs be developed now for a tokamak facility that can contribute to the program around the end of this decade. Ideally the design should be flexible, so that when completed the facility can meet current CTR program needs regardless of whether there be rapid, continuing progress or difficulties and delay in the intervening years. This premise is a statement of the fact of life which is that a five-year head start on a major facility is a bare minimum.

A machine and a facility must be designed that will, first of all, give the greatest assurance of demonstrating scientific feasibility. But, depending on the degree of success of earlier experiments, by the time the facility becomes available, the demonstration of scientific feasibility may require either a large or a small step up in plasma conditions. Because the latter is a distinct possibility, there is much to be gained if the facility is adaptable for experiments that push on into the area of a plasma test reactor. We believe that, given adequate forethought, such a facility can be designed.

The basic strengths that must be brought to bear in the design are:

1. fusion plasma physics, which defines objectives and guides the path;

2. the technology of large-bore magnets (either cryogenic or superconducting), which forms the fundamental constraint on the entire system;

3. neutral beam injection technology, which provides the mechanism for reaching ignition temperatures with, as a contingency, the supplemental technique of microwave field heating for possible surface heating or local profile variations;

4. the emerging field of fusion reactor technology and the more mature technologies of radioactivity containment and remote handling, which deal with problems beyond scientific feasibility; and

5. emgineering that is innovative but disciplined, melding the diverse requirements in a facility that can meet its objectives in a safe, economical, and timely manner.

Staff members of the Thermonuclear Division have given preliminary consideration to a facility for the late 1970's and, although the thinking to date must be regarded as only preliminary to a substantial conceptual design effort, certain features of F/BX and the program leading to it have emerged. The remainder of this document describes our tentative picture of the F/BX facility, its relation to the present ORMAK, the people who will be involved in its conceptual design, and the important questions that must be addressed.

Facility Objectives and Key Features

At the heart of the F/BX Facility is a tokamak coil structure accepting and confining a plasma that is heated by energetic neutral beam injection. Also included in the facility are the attendant power supplies, vacuum, refrigeration, diagnostics, control, and other ancillary systems. The objectives of the two phases of operation (described below) present different demands and we now visualize rebuilding the device itself (using the same toroidal field magnets), adding shielding and containment, and enlarging the torus between the feasibility experiments and the D-T burning experiments. The buildings and ancillary systems would serve for both phases of operation.

Feasibility Demonstration Phase

The demonstration of scientific feasibility is usually described as the production in a hydrogen plasma of conditions that would be equivalent to a breakeven between fusion power production and losses if D and T had been used. This significant goal encompasses two general objectives: a) advances in understanding and b) achievement of a clearly recognizable milestone. Pursuit of these objectives imposes two mutually compatible but not identical sets of specifications on the experiments.

The desired level of understanding in the ORMAK F/BX--"feasibility" phase would accompany production and study of a plasma whose basic physics characteristics, namely, transport properties, including both particles and radiation, were identical to those in a full scale fusion power reactor. Although it would be preferable to study plasmas in which all the reactor characteristics exist simultaneously, it might be necessary and sufficient to produce and study these properties singly or in partial sets.

The desired level of achievement in the ORMAK F/BX "feasibility" phase would be the attainment in hydrogen of values for the plasma parameters n, τ, and T equal to those satisfying the Lawson criterion. As the Lawson criterion strictly applies only to an ignitable fuel mixture, this achievement is somewhat artificial in view of the non-trivial physics differences (e.g. mass difference and alpha particle containment) between Lawson criterion values in hydrogen and in D-T, but this statement does serve as a convenient, recognizable, and clearly familiar point.

The understanding objective is the more fundamental and is, indeed, crucial, but a clearly defined achievement objective is essential for program planning, funding, and evaluation. It is in this spirit, then, that we can state the goal of the "feasibility" phase of ORMAK F/BX: a basic thrust toward simultaneous achievement in a hydrogen plasma of the basic characteristics (e.g., collisionality, radiation losses, and aspect ratio) of a fusion reactor plasma with the recognizable peg point of reaching Lawson criterion values for n, τ, and T. Use of quotation marks around the word "feasibility" is meant to imply that feasibility itself as defined by the Lawson criterion is not the sole, sharply defined goal of F/BX, but rather the convenient term for the range of possibilities described above, that is, simultaneous achievement of reactor properties including Lawson criterion values, or at least separate achievement of reactor properties.

We presently envision reaching the conditions required in the feasibility experiments in a toroidal plasma with a minor radius (r_p) of 0.75 meters, an aspect ratio (A_p) of 4, a central magnetic field (B_0) of 5 tesla, and a plasma current of 2.1 megamperes. The coil structure would have a major radius (R_c) of 4 meters and a minor radius (r_c) of 2 meters, affording sufficient room for significant changes in plasma dimensions or shape, fueling provisions, and divertors if these should be required to reach equivalent breakeven conditions in the plasma.* These dimensions are compared with those of other tokamak experiments in Fig. 1.

---

*If a much larger plasma diameter would prove necessary, toroidal field coils of the same size and maximum field at the conductor would permit a maximum r_p = 1.75 m and a central field of 5.4 T for A_p = 4. (R_c = R_p = 7m.) The facility would be designed to allow for this configuration.

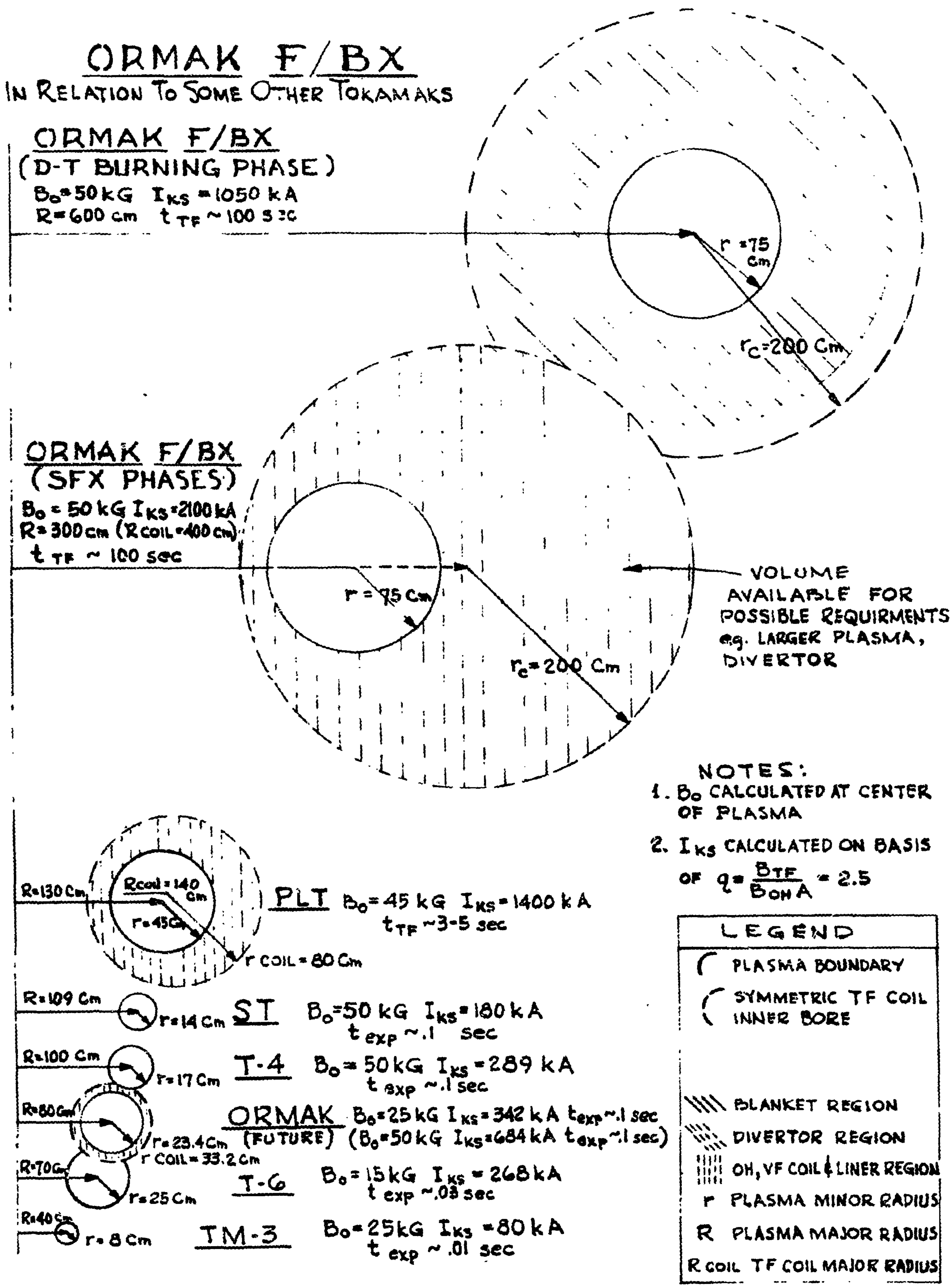


Fig. 1. ORMAK F/BX in Relation to Some Other Tokamaks

The F/BX design will rely only on well-established technology or reasonably conservative projections of technological developments in the next few years, the intention being to assure the highest probability of a successful feasibility demonstration. For this reason, the choice between cyrogenic* magnet coils and superconducting coils will depend largely upon the amount of development in this area that can be expected to be funded and accomplished in FY-74, FY-75, and FY-76. Among the possibilities that may be considered is the use of a cryogenic coil system in F/BX as a full-scale toroidal test facility in which one or more superconducting coils could be introduced for testing in the actual toroidal geometry with pulsed fields.

D-T Burning Phase

Following a successful scientific feasibility demonstration, the emphasis in F/BX would shift toward studying technological feasibility questions. It is toward this second, more difficult and, perhaps more appropriate objective that the basic design of F/BX is aimed, while taking care to assure that achievement of the "feasibility" objective (if in fact it still is necessary by the late 1970's) is as little prejudiced as possible. As with the "feasibility" objective, the D-T burning phase has a range of understandings and achievements that would be considered as successes. This range varies from a partial burning of a mixture of deuterium and tritium for a time long enough to characterize the process expected in a full-scale fusion reactor, through a demonstration of a self-sustained burning or ignition, to a host of useful technological studies, including tritium handling, fueling and refueling, heat shielding, and possibly even tritium breeding. (Neutron fluences would not be sufficiently large to result in or allow studies of radiation damage.)

The objective, then, of the D-T burning phase is the fundamental one of burning some fraction of a plasma and studying the properties of a H,D,T plasma that is similar to a full-scale fusion reactor plasma in all respects except size. Extension of the burning to ignition would be a highly desirable goal. Additionally, experience with any one or more of the technology questions that must be faced before a full-scale plant can be envisioned would be welcomed as long as provisions made for these secondary

---

*Cryogenic as used in this context means liquid nitrogen coolant technology.

achievements do not in any significant way prejudice the fundamental D-T burning objectives.

Dimensions visualized for the D-T experiments are shown at the top of Fig. 1. The device would be larger overall and there would be shielding between the plasma and the toroidal field coils (in the region labelled "blanket" in Fig. 1). Biological shielding and tritium containment barriers would become necessary at this time. Preliminary consideration has been given to the possible advantages of housing F/BX in the complex that was built at Oak Ridge for the Experimental Gas-Cooled Reactor and is presently unused. Figure 2 illustrates possible locations for the SFX and D-T burning experiments in the EGCR buildings. The large bay area could be used as is for the SFX and with the addition of tritium handling equipment it might be used for the D-T burning experiments. Location of the ignition experiment inside the domed containment building, as suggested by this sketch, would be hampered by the massive shielding and structures now there, but will be considered as an alternative, as will a new building adjacent to the present structures.

The ORMAK Program

ORMAK-F/BX is viewed as a logical continuation of the present ORMAK program which has as one of its aims the study of the efficacy of neutral beam and possibly microwave heating techniques in a low-aspect-ratio tokamak; more generally, the ORMAK program is devoted to determining the possibility of the tokamak route to controlled fusion. Figure 3 illustrates the configurational steps contemplated between the basic ORMAK experiments and ORMAK-F/BX and lists various machine and plasma parameters as well as brief explanatory comments concerning the choice of parameters.

The first ORMAK experiments have been directed toward establishing an ohmically heated, low collisionality plasma in which questions relating to reactor-like plasma physics problems can be asked and answered. A modest extrapolation of the empirically based pseudoclassical model for particle transport and the theoretically based neoclassical model for ion thermal transport has been initially checked with these experiments.

ORNL-DWG. 72-8075

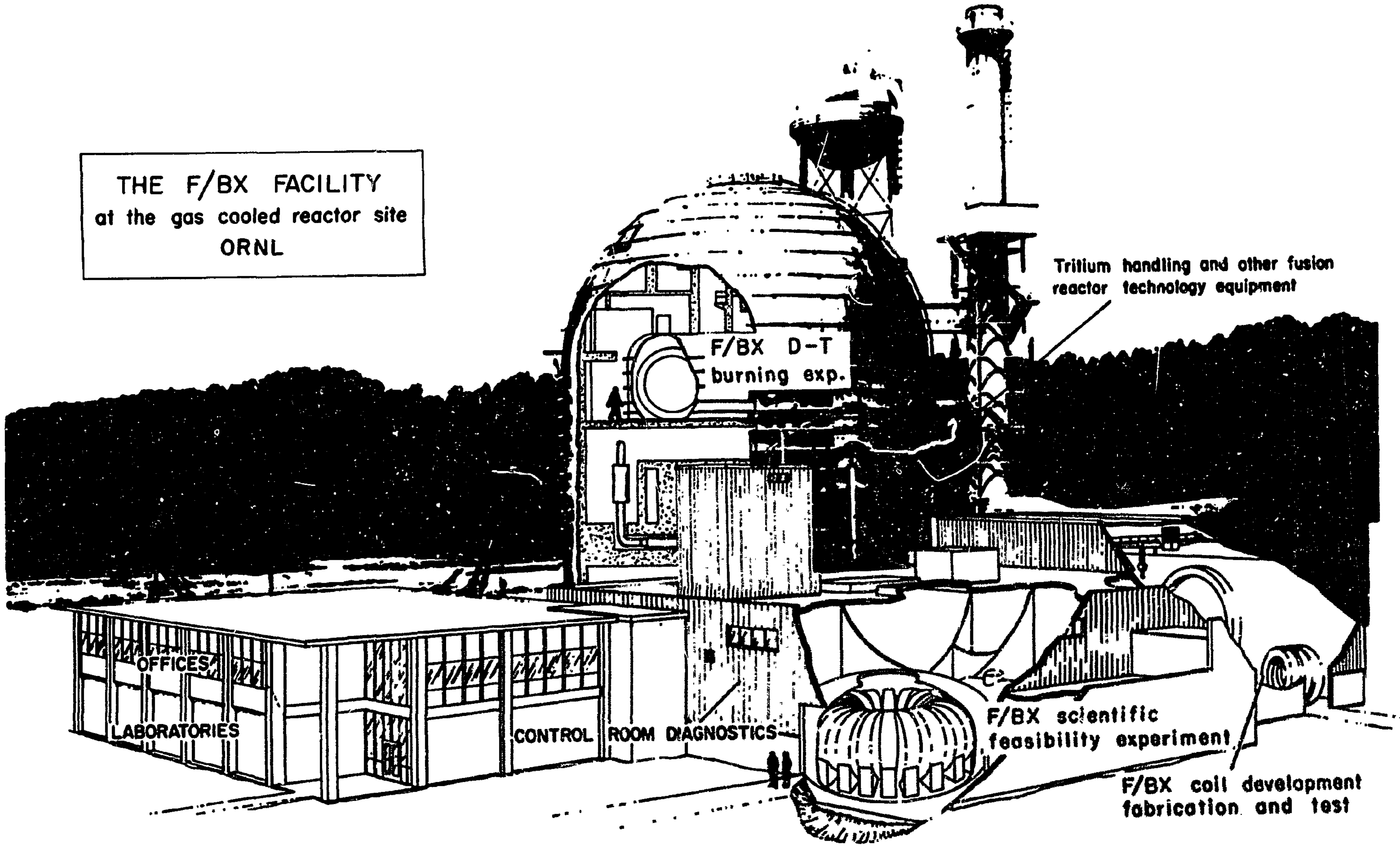


Fig. 2. The F/BX Facility at the Gas-Cooled Reactor Site ORNL

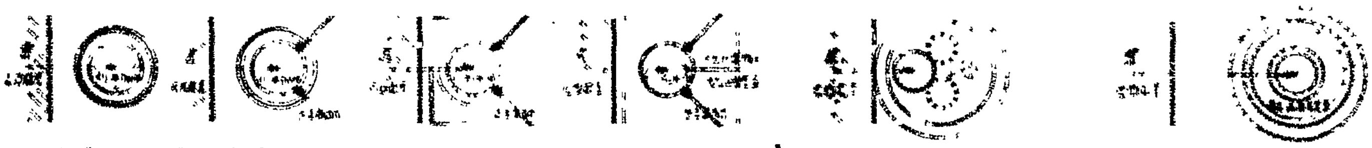
THE ORNL TOKAMAK PROGRAM

Prepared by M. Roberts 5/2/73

Year — 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 1985

Facility — Objective —	ORMAK Ohmic Heating	ORMAK Injection Heating	High Field ORMAK Feasibility Physics	ORMAK μW Heating; F/BX Testing	ORMAK F/BX Scientific Feasibility	ORMAK F/BX D-T Burning

Main Line Experiment — Schematic



Symmetric Cryogenic TF Coils (70-80K) — Scale: 1 meter

Asymmetric Cryogenic TF Coils (70-80K) (Prototypes for F/BX)

Asymmetric Cryogenic TF Coils (70-80K) or possibly Symmetric Superconducting TF Coils (4K) — Scale: 1 m

Nominal Machine Parameters						
B_{TF} (at plasma center)	22 kG. Permits deep penetration into collisionless regime.	25 kG	50 kG. Permits higher current (I_T) which reduces diffusion and also introduces bremsstrahlung and synchrotron losses, and permits even deeper penetration into collisionless regime	50 kG	50 kG. Cryogenic coils employed to maximize certainty of operation and to avoid high power supply costs of water cooling.	50 kG (SUPERCONDUCTING COIL DEVELOP.) Superconducting coils used for needed experience with technology for next stage.
r_p (plasma minor radius)	23 cm	23 cm	23 cm. Objective is to modify coils only, while retaining rest of structure.	23 cm	75 ~ (150) cm. Radius variable if required to reach feasibility.	75 cm. 75 cm is smallest, non-marginal size to permit α-heating.
R_p (plasma major radius)	79.5 cm	79.5 cm	79.5 cm	79.5 cm	200 cm. Off center to permit 50 kG on plasma axis.	600 cm
A_p (plasma aspect ratio)	3.4. Designed to enter reactor-like, collisionless regime at lowest practical ion temperature generated by ohmic heating.	3.4	3.4	3.4	4 ~ (2)	8. Successful injection heating obviates the physics requirement for low A_p.
r_c (coil minor radius)	33 cm. Same coils used in both phases except perturbations for injectors.	33 cm	33 cm. Same coils used in both phases	33 cm	200 cm. Allows for possible large bore plasma, divertors or other required innovative solutions.	200 cm. Allows for α-heating sized plasma, 3/4 m blanket and 1/2 m spacing for coils, clearances, etc.
R_c (magnet major radius)	79.5 cm	79.5 cm. Constancy of R_c maintained to minimize incremental cost of converting to higher field in ORMAK, thereby using same internal pieces.	79.5 cm	79.5 cm	400 cm. Minimum size for 50 kG at plasma. (Same 4 m bore coils used in both phases, just increase in number.)	600 cm. Necessary to achieve 50 kG with 3/4 m blanket.
A_c (magnet aspect ratio)	2.38	2.38	2.38	2.38	2.0	3.0
ΔΦ (core flux change)	.55 V-S	.55 V-S	1.0-1.2 V-S. Range results from material/cost alternatives.	1.0-1.2 V-S	20 V-S	20 V-S
I_T (plasma current, assuming q=2.5)	313 kA. Power supply capability-actual value determined by plasma behavior	250 kA	700 kA	700 kA	2100 kA (OH CURRENT TECH. DEVELOP.)	1050 kA. Lower current magnitude reflects decrease in importance of ohmic heating w/o consideration of α particle confinement
t_{exp} (flat B_{TF})	200 ms	200 ms. e-i and i_{inj}-e-i equilibration times are ≤ 100 ms	300 ms	300 ms	(SURFACE-VACUUM PHYSICS DEVELOP.) 100 sec. Long time permits complete study of fusing plasma from initiation, through ignition, to burnup.	100 sec
Duty Cycle	1/300	1/300	1/300?	1/300?	1/10	1/10
P_{inj}	0	250-500 kW. Provides plasma temperature control independent of ohmic current as well as demonstrating heating technique.	1000 kW	1000 kW. Power level depends on design optimization as well as development.	(HIGHER INTENSITY POSITIVE ION SOURCE DEVELOP.) 5,000 kW	(NEGATIVE ION SOURCE DEVELOP.) 10,000 kW
$P_{microwave}$	0	10's of kW ?	10's of kW	100 kW	> 100 kW	> 100 kW
Filling Gas	H	H,D	H,D	H,D	H,D (TRITIUM HANDLING DEVELOPMENT). Tritium usage unveils full range of actual technological problems (except radiation damage) to be encountered in reactors.	H,D,T

Predicted ORMAK Parameters	Based upon present ORMAK results with ohmic heating, expected usefulness of neutral beam heating and computer simulation using the pseudo/neoclassical model.					
T_i (peak ion temperature)	.35 keV	.5 - 1 keV	1 - 3 keV	1 - 3 keV	> 5 keV	> 5 keV
T_e (peak electron temperature)	1.1 keV	2 keV	3 keV	3 keV	5 keV	5 keV
$n\tau_{Ei}$ (peak density × energy replacement time for ions)	$4 \cdot 10^{11}$ (sec/cm^3)	$6 \cdot 10^{11}$ (sec/cm^3)	$2 \cdot 10^{12} - 1 \cdot 10^{13}$ (sec/cm^3)	$2 \cdot 10^{12} - 1 \cdot 10^{13}$ (sec/cm^3)	$2 \cdot 10^{14}$ (sec/cm^3)	$> 2 \cdot 10^{14}$ (sec/cm^3)
ν_i^* (normalized collisionality with Z = 2)	.6	.2	.03 - .01	.03 - .01	< .016	< .016

Information developed by: J. F. Clarke, W. F. Gauster, J. T. Hogan, G. G. Kelley, H. M. Long, M. S. Lubell, O. B. Morgan, M. Roberts, D. Steiner, L. D. Stewart

Fig. 3. The ORNL Tokamak Program

The next set of experiments to be initiated in the immediate future centers on a test of neutral beam injection, both as a viable heating scheme and as an effective means of varying β_p (= plasma pressure/magnetic pressure generated by the plasma current along) for further confirmation of the presently conceived model of the physics. The results of this test will indicate the best approaches to be taken from amongst the various possible combinations of plasma size and position, and injection parameters in F/BX.

Based upon successful injection heating, the next step in the ORMAK program would be an extension of the testing of the combined pseudo/neoclassical model to near SFX plasmas using the 5-tesla version of ORMAK. Predictions of the plasma state in high-field ORMAK based upon first calculations using this model indicate that qualitatively new physics having a crucial bearing on reactor physics will be encountered. This new physics can either be bremsstrahlung and synchrotron radiation loss domination (if the present scaling is still applicable at high temperatures) or collisionless losses more severe than presently expected (if the scaling is not applicable). The former situation would give practical experience with the plasmas to be encountered in F/BX and the latter situation could dictate, as could the neutral injection test, a change in the choice of F/BX alternatives.

As the optimism generated by the predictions of the pseudo/neoclassical scaling is clearly based upon the presumption of continued extrapolation to higher parameter regimes, it behooves us to use the various ORMAK experiments to attempt to understand the underlying physics of the tokamak discharge thoroughly. ORMAK experiments are now permitting a detailed investigation of the nature of the physics in plasmas with low collisionality and in the near future will enable an assessment of neutral beam injection heating to be made. Assuming that at least a moderate degree of success with the tokamak approach will be the result of these experiments, we are preparing for the high-field version of ORMAK and have sketched the lines of the F/BX facility.

Implementation and Schedule

Implementation of these broad brush strokes will require a considered study of the alternatives possible at each major decision point. As a first step, a conceptual design study is being launched in July, 1973 with the objectives of producing a consistent set of physics goals and experiments, an engineering evaluation of the development areas and design problems, an estimate of the costs and time, and an estimate of the numbers and types of personnel required.

A simplified schedule of activities culminating in the ignition experiments is the following:

Year	Major Activity
FY-1973	Establish requirements, develop concept.
FY-1974	Conceptual design, submission of formal proposal.
FY-1975	Preliminary engineering design; begin development specifically for F/BX.
FY-1976	Initiate final, detailed design; start fabricating toroidal field coils and other long-lead items.
FY-1977	Continue final detailed design and component fabrication; start site preparation.
FY-1978	Begin assembly; complete final design and fabrication.
FY-1979	Complete assembly; testing.
FY-1980	Begin operation in first phase (scientific feasibility or D-T burning, as the need may be).
FY-1981	Experimental operation.
FY-1982	Conversion to second phase (if still applicable). Testing and startup of D-T burning experiments.

F/BX Conceptual Design Study

General Introduction

Funding for the F/BX conceptual design study permits a 10-man-year effort in FY-1974. This must cover contributions of many people with different skills and experiences related to the science and engineering of a large, experimental fusion device. The primary areas of competence required include plasma physics (both experimental and theoretical), neutral beam injection heating technology, magnetics, fusion reactor technology, engineering of mechanical, electrical, and vacuum systems, manufacturing and estimating knowledge, and support services; each of these areas is described in more detail below.

As indicated in Table 1, the staff will consist of a Group Leader (part-time), a Program Manager (full-time), four or more engineers (at least two of whom are full-time), five or more principal scientists from the present research groups (all part-time on a continuing basis), many technical personnel from the Thermonuclear Division as well as consultants (all probably on an occasional, part-time basis), and three or four support personnel (part-time). In addition to the daily interactions of one, two, or three persons, involvement and communication will be effected through weekly meetings of the principal participants, and "information meeting" type gatherings of interested technical personnel. Communication and coordination between the ORNL design team and the AEC's Division of Controlled Thermonuclear Research (DCTR) will be maintained. Written reports will serve to document the progress.

The scope of the study will include consideration of not only the requirements for a feasibility demonstration, but also those requirements needed at various stages for D-T burning and ignition experiments. In particular, provision for a divertor (of unknown detailed design) will be considered for the burning experiment although the feasibility demonstration probably does not depend upon it.

At the outset of the design study, design bases will be adopted, crucial decisions to be made will be identified, tasks will be assigned, and a schedule including appropriate milestones will be laid out. By the end

Table 1. Personnel Requirements* of ORMAK-F/BX Conceptual Design Study (within the ORMAK program — under the direction of G. G. Kelley, ORMAK Section Leader)

Group Leader -- M. Roberts	(1/2)	
Program Manager -- P. N. Haubenreich	(1)	
		TOTAL (1-1/2)
Scientific Staff		
Plasma Physics -- J. F. Clarke	(1/2)	
Diagnostics -- J. L. Dunlap	(1/6)	
Magnet Design --M. S. Lubell	(1/2)	
Neutral Beam Injection -- O. B. Morgan	(1/3)	
Fusion Reactor Technology -- D. Steiner	(1/2)	
Divertors -- G. G. Kelley	(1/12)	
Miscellaneous Staff	(1/6)	
		TOTAL (2-1/4)
Engineering Staff		
Electrical Engineer -- R. S. Lord	(1)	
Mechanical Engineer -- D. D. Cannon	(1)	
Fabrication-Estimator -- R. M. Hill	(1)	
Special Analysts	(1)	
		TOTAL (4)
Support		
Drafting	(1-1/2)	
Computational	(1/4)	
Secretarial	(1/2)	
		TOTAL (2-1/4)
		∿ 10 MY

*Names are those of principal people in the study. Numbers are total man years in the area although not necessarily those of the principal person alone. A more complete listing of personnel appears in the Section II Specific Topic Areas and Personnel.

of the first quarter of FY-1974 we expect to have made the crucial decisions and have adopted a reference design with nominal values close to the final parameters. The sensitivity analyses to determine and support the choices of size, field strength, field homogeneity, injection specifications, etc., in the reference design will also permit preliminary cost estimation of the various components. A description of the reference design and a preliminary cost estimate for the facility and supporting development program will be ready by mid-FY-1974 to allow DCTR to proceed with its formal review process concurrently with further work. Comprehensive conceptual layouts, projected solutions to the developmental problems, and further calculations supporting optimization of the design would fill the third quarter. The study will culminate in a conceptual design report, including a detailed cost estimate, which is expected to serve as the basis for a proposal in the fourth quarter of FY-1974 to proceed with ORMAK-F/BX.

The preparations which were made in the fourth quarter of FY-1973 include the following:

1) an evaluation of present knowledge and likely development in all facets of the plasma physics and application of this information toward the choices of preliminary design parameters,

2) identification of the kinds of problems and decisions that must be dealt with in the course of the design study, and

3) identification of the skills and abilities required for solution of these problems along with a manyear time estimate for each area.

Specific Topic Areas and Personnel

A tentative outline of the areas and personnel is shown in Table 1, with details given in the following paragraphs.

A. Plasma Physics

J. F. Clarke,† J. T. Hogan, D. G. McAlees, and many others.
(~ 1/2 MY*)

Inputs to Reference design-first quarter FY-74

1. Immediate Problems

a. What is the optimum size of the device which can maximize both values of plasma parameters achieved and new physical knowledge gained at minimum cost?

b. What is the best toroidal field in terms of magnitude, pulse time, and uniformity? The criteria on uniformity will depend on the heating scheme adopted and the desirability of containing fusion alpha particles.

c. What is the best heating scheme? Presuming neutral beam injection, what is the proper mix of energies for the optimum radial power distribution and what is the injection time required?

d. Startup: How will the large plasma be created and confined during its early stages? What roles will neutral beam or relativistic electron beam created equilibria play? Can ohmic heating suffice in this stage? How do transient fields interact with superconducting coils?

Work to be done in second and third quarters.

2. Intermediate Problems

a. How do we replace plasma particles that diffuse to the surface? If by neutral injection, what is the best energy; if by pellet injection, what size?

b. Cleanup: What is the best wall design? Do we require a full or local diverter or a magnetic limiter or something else?

c. What is the process which produces impurities? This depends upon the well interaction during startup, in particular upon the choice of divertor or magnetic limiter and the diffusion/charge exchange processes during startup.

---

†Person underlined is responsible for the particular area being discussed.

*MY figure is approximate number of funded scientific years devoted to this particular area.

d. What is the effect of impurity flow in large devices? How does this affect the radial power balance and how can we adjust the heating either to accommodate or to utilize this effect?

Third and fourth quarters.

3. Long Range Problems

a. What can we learn about synchrotron radiation transport in large, but finite, plasmas? This process will dominate the energy flow in reactors and it must be understood.

b. What does superbanana loss of injected or alpha particles in non-uniform toroidal fields do to the plasma as it creates large radial potentials?

B. Diagnostics

J. L. Dunlap and others (1/6 MY)

Reference design & diagnostic requirements need to be iterated in the 1st qtr. at least once.

1. We need to develop CO_2 or HCN laser interferometers for density information.

2. Thomson scattering in large systems needs development.

3. The use of neutral beam probes to measure electron and impurity density and ion temperature is vital and must be developed.

4. Infra-red measurement techniques for synchrotron radiation analysis must be applied.

C. Magnetics:

M. S. Lubell, H. M. Long, and others (~ 1/2 MY)

Specification for reference design in First Qtr. as input to Magnetics Group.

1. Immediate Questions

a. Major R

b. Minor r for coil (i.e., plasma wall radius plus thickness of shielding, blanket, and other coils)

c. Central axial field B_o and uniformity required.

d. Space needed in central axis for the iron core.

e. Pulse time and field magnitude of the ohmic heating coils.

f. One vacuum chamber or multiple vacuum chambers.

First Qtr. Work

2. Immediate Problems

Work program for July to end of October

a. Economic comparison between cryogenic, superconducting and water-cooled coils including magnet material and winding costs, refrigerator, power supply, structure, and dewars.

b. In addition to the basic reference design, an economic comparison must be made for variations in R and r of up to ±25%.

c. Estimate the development time and cost for cryogenic and superconducting systems.

d. Outline in detail the development program for superconducting magnets including time and cost.

Work to be done in second and third quarters

3. Intermediate Problems

a. Provide space needs in central zone for magnets, dewars, and structure (check for compatibility of iron core requirements).

b. Provide space required at center and top of the toroidal system (check to see if it is compatible with injection demands).

c. Provide ripple and uniformityof the field (see if it is compatible with physics needs).

By fourth quarter

4. Final Work

a. Execute detailed design using final size and field parameters with complete cost and time scale worked out.

D. Neutral Beam Heating:

O. B. Morgan, L. D. Stewart, T. C. Jernigan, W. L. Stirling

(∿ 1/3 MY)

Specifications in first Qtr. as input to EPI group

1. Immediate Questions

Beam Requirements — From Physics and ORMAK Injection Studies

a. Energy

b. Power

c. Distribution in angle and space

d. Impurity content

e. Gas load

f. Ion species

g. Time of Injection

First Qtr. input to engineering

2. <u>Immediate Problems</u>
Machine design requirements to make these beam requirements technologically possible.

   a. Access into liner

   b. Vacuum system, i.e., two stage or not

   c. Coil construction

Work to be done in second and third quarters

3. <u>Intermediate Problems</u>
What Energetic Particle Injection developments will be required to accomplish and satisfy the above.

   a. Ion current per module

   b. Energy → one stage acceleration, two stage acceleration, or negative ions

   c. Impurities → all metal bakeable source

   d. Vacuum requirements - cryogenic pumping

   e. Time of injection

By fourth quarter

4. <u>Final Work</u>
Development and construction costs of the above.

E. Fusion Reactor Technology:

<u>D. Steiner</u>, and many others (∿ 1/2 MY)

Continuous interchange through study

1. <u>Materials</u>

   a. Contacts — C. J. McHargue, J. H.DeVan, F. W. Wiffen and F. W. Young

   b. Approach — Keep in close contact with F/BX design group and help identify materials development requirements for F/BX. Also will provide materials consultation.

2. Tritium Handling

a. Contact — J. S. Watson

b. Approach — Will work closely with F/BX design effort and help guide design with regard to "best" design alternatives for easing tritium handling and containment in D-T burning phase of operation.

c. Some Immediate Problems to Consider:

Inputs to first reference design

i) Proper ventilation for continuous release.

ii) Best method for introduction into F/BX, that is, as feed or through neutral beam injection system.

iii) Optimum design for good access in case of maintenance.

d. Some Intermediate Problems.

Work resulting from reference design decisions

i) Magnitude of tritium inventory in F/BX

ii) Monitoring of tritium levels.

iii) Feasibility and costs of various alternatives.

iv) Interfacing with other design boundary conditions.

3. Neutronics

a. Contact — D. Steiner

b. Approach — Will work closely with F/BX design effort and help guide design with regard to neutronics considerations.

c. Some Immediate Problems to Consider:

Input to reference design

i) Biological shielding

ii) Will remote maintenance be required?

iii) Problems with disassembly and "end-of-life" of materials.

d. Some Intermediate Problems to Consider:

Work in 2nd, 3rd quarters

i) Nuclear heating in magnets.

ii) Structural activation.

iii) Radiation monitoring.

iv) Costs and Interfacing as with tritium.

F. Mechanical Engineering (1 MY) — D. D. Cannon and others

1. Internal components and assembly

This includes the wall nearest the plasma, any internal structure (plasma limiter and, possibly, divertor), the enclosing toroidal conducting shell, and attached coils. It also includes penetrations for injectors and diagnostic devices, cooling and coil power connections. The design must consider constraints on heat transfer, electrical insulation, assembly procedures, cleanliness, and maintainability.

2. Magnets

The supporting structure for the large toroidal field coils must be designed to withstand large forces (on the order of 10^4 tons toward the torus axis, for example). Supports, thermal insulation, vacuum shell, and relation to toroidal components must be designed to accommodate dimensional changes over the temperature range from 500K (or 800K) to 65K (possibly to 4K).

3. Vacuum systems

The plasma region must reach at least 10^{-8} torr and the region housing the magnets and insulation will probably be required to operate below 10^{-6} torr. Design will involve consideration of available pumping systems (pumps, valves), seals, and coatings and surfaces for electrical and thermal-radiation insulation.

4. Cryogenic system

Integrate chosen cryogenic system (see Section C.2 above) with balance of plant.

G. Electrical Engineering (1 MY) R. S. Lord and others

1. Power

There will be three coil systems (toroidal, ohmic heating, and vertical) with their respective energizing supplies, interconnections, and controls. Design must consider problems of coil symmetry, location, insulation, cooling, and power supply and must be coordinated with other areas of design.

2. Control

This includes the interconnection of several large, high-energy power supplies feeding into inductive loads, all of which are energized simultaneously with extremely sensitive electronic measuring equipment and all of which are tied to a central computing facility to be used for operational control and diagnostic analysis. In addition to these driving and measuring systems there are the utility systems providing routine power, vacuum, cryogenics, and reliable safety and monitoring systems.

H. Engineering (Building) (1/4 MY)

New structures or modifications of existing structures must be designed to accommodate the system. Special attention must be given to shielding, tritium containment, and maintenance.

I. General Engineering (1 MY)

This deals with specifications, quality assurance, fabrication techniques, manufacturing capabilities, and estimates of costs and schedules.

J. Special Analysts and Consultants (3/4 MY)

This activity will involve many people possessing specialized skills required for particular questions (namely, consultants within or without the Laboratory, engineers presently involved on ORMAK, scientific and technical personnel within the Division).

K. Support personnel (∿ 2-1/2 MY)

1. One or one-and-a-half draftsmen capable of making thorough layouts of all the various systems on F/BX.

2. A secretary able to assist the information flow and documentation.

Program Direction

A. Program Manager — P. N. Haubenreich

B. Group Leader — M. Roberts

C. Review Committee — ORMAK Section steering committee, led by G. G. Kelley.

D. Interaction with ORNL Management — Management of Thermonuclear Division, General Engineering Division and Laboratory.

E. Interaction with AEC-DCTR — Office of Development and Technology and Office of Confinement Systems.