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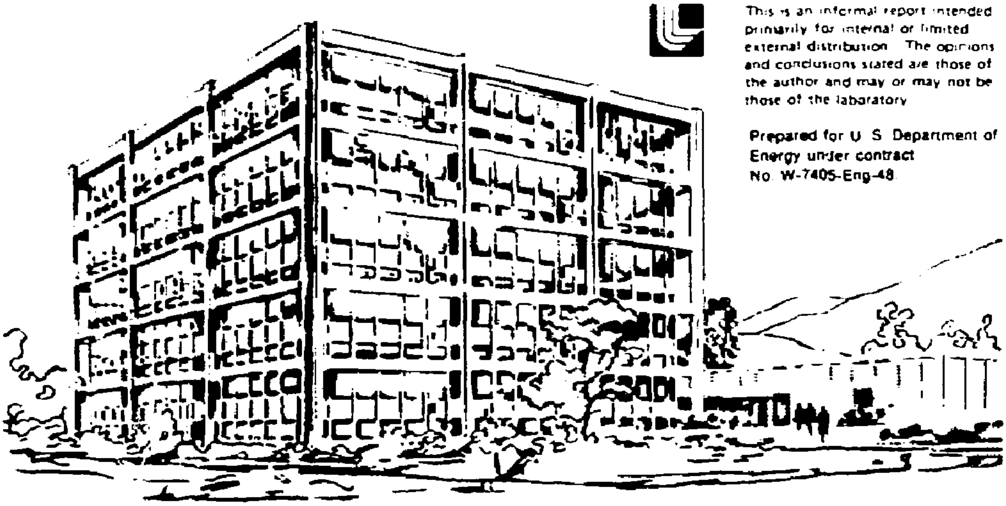

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ABSTRACT

We have begun a study to define the features of the experimental mirror fusion device--the "Mirror Next Step," or MNS--that will bridge the gap between present mirror confinement experiments and a power-producing reactor . We outline the project goals and organization of the study, describe some initial device parameters, and relate the technological requirements to ongoing development programs.

I. INTRODUCTION

The TMX and MFTF sequence of experiments at Lawrence Livermore Laboratory (LLL) are expected to provide the plasma physics base needed for the design of a tandem-mirror fusion-power reactor. These experiments--particularly MFTF--will also demonstrate much of the reactor-relevant technology. Optimizing the path between MFTF and the construction of a demonstration commercial power plant of the mirror type will require a device to bring the physics parameters a final step to the reactor regime and to test and demonstrate all of the technology and engineering appropriate to reactor operation. The purpose of the present study is to develop the features of this "next-step" device in the mirror program, carrying the study through a conceptual design phase. After the conceptual design, we will be in a position to proceed with design and construction of the device at the same time the basic premises of the conceptual design are demonstrated by the ongoing mirror physics program and the relevant technology development program. In recognition of its current shadowy form, we call this device the "Mirror Next Step" (or MNS), anticipating a more descriptive designation as the device takes shape.

Specific goals of the MNS will depend on whether a tokamak Engineering Test Facility (ETF) has been approved for construction at the time MNS approval is requested. If a tokamak ETF is scheduled for operation before an MNS could be operational, MNS goals will be directed to engineering tests on features of magnetic-mirror systems distinct from those of tokamak--assuming that tests on generic features of fusion reactors will be assigned to the ETF. However, if construction of the tokamak ETF is delayed for some unforeseen reason, the goals of MNS could include engineering tests of features common to any magnetic-fusion reactor.

The MNS will be a small-scale fusion reactor capable of functioning as an engineering test facility, demonstrating a level of plasma performance and device technology comparable with that of a full-scale demonstration reactor. We picture MNS as a steady-state D-T burning tandem mirror with reactor-grade end plugs and shortened solenoid section, that will aim at a fusion-power output of about 200 MW. Iteration of design features, cost estimates, and funding projections will enable us to converge on a conceptual design.

These conceptual design studies are expected to extend over the next several years, meshing with the mirror confinement physics program, as Fig. 1 illustrates. On this schedule, we will be ready for initial capital funding in Fiscal Year 1984 (hereafter, "FY1984"). Although this appears to be an optimistic timetable for the MNS study, the likelihood of meeting it depends largely on how well and how quickly we can reduce the uncertainties for both physics and engineering features of the design.

This report presents a "straw-man" set of physics and engineering parameters for MNS as a starting point for the preconceptual design study. Initial layouts for the magnet and for the overall facility are based on these parameters. We also briefly relate the technological requirements to in-place DOE development programs. Our project organization and plan for proceeding with the study are outlined below in Section II.

II. STUDY ORGANIZATION

The MNS study underway at LLL is directed by the Deputy Associate Director for MFE Experiments, F. H. Coensgen. The the organization of the study for FY1980 is shown in Fig. 2. The study will be coordinated by C. C. Damm, with J. N. Doggett responsible for engineering design. Subsystem designations will be Nuclear, Nuclear Auxiliaries, and Plant Facility, which roughly correspond to elements within the radiation environment, special facilities outside of the radiation field supporting the nuclear systems, and conventional plant. (Further itemization appears in Section IV, below.) In general, the most complex requirements occur for the nuclear systems, and work in this area has begun under R. Bulmer.

Because the MNS, in effect, will be a small reactor, close liaison with the Reactor Studies Group (G. Carlson) will be maintained. (Differences between MNS and power-producing reactors, of course, arise from the different criteria for parameter selection and optimization.) Code development for parameter studies is being supported jointly by MNS and Reactor Studies, with members of the latter group assigned directly to MNS-oriented problems. By extending this close coordination throughout the design study, we can expect the MNS to remain directly on the path to a commercial plant.

The MNS study will also remain tightly coupled to the realities of the ongoing physics program, factoring in results from the TMX operation, advances in theoretical understanding, and--later--MFTF results. G. Logan will be the main contact for synthesizing the mirror physics related to the MNS design.

Liaison with the D & T program under the direction of R. Borchers at LLL will have a twofold aspect: During the next several years, we will base our design on D & T projections for technology development; at the same time, we expect emerging MNS requirements to influence the course of D & T work by defining the technology developments and milestones necessary to achieve the goals of the program. This interaction will certainly extend beyond the programs at LLL/Lawrence Berkeley Laboratory (LBL). We will generate a more formal R & D needs assessment as the first design iteration emerges.

Physics information will also originate from outside LLL; in particular,, we can expect significant input from the tandem experiments at the University of Wisconsin, from the Gamma experiments in Japan, and from AMBAL at Novosibirsk.

Regular participation by the MNS Study Leader in the staff meetings at the ETF Design Center Oak Ridge National Laboratory (ONRL) ensures a close coordination between the two similar activities.

Industrial involvement in MNS at present is minor (we are helping to support a structural analysis of high-field magnets for tandem reactors by Grumman Aerospace Corp.). It is clear that major industrial involvement will be needed at an early date, if we are ever to build an MNS device. While some studies of the above type could profitably be started now (given adequate funding--as in Case B of Table 1, below), a more pronounced need will appear toward the end of FY80, when a reference design is in hand.

Funding for the MNS study is shown in Table 1. Entries correspond to the LLL Work Package Proposal and Authorization System (WPAS) submission of April, 1979. The "A" case corresponds to a minimum level for progress in the study, while the "B" case--which calls for significant escalation of the effort beyond FY1980--is a more realistic requirement, if we are to meet the schedule of Fig. 1. At the "B" case level, serious industrial participation could begin in FY81. The present DOE guideline budget for FY80 is $400 thousand, which implies a level of effort at LLL of approximately five FTE .

Table 1. MNS Study Funding
(Dollars in Thousands)

	FY79	FY80	FY81
Case "A" Request	$255	$500	$1300
Case "B" Request	--	800	2000
Current DOE Guideline	--	400	--

During FY80, we expect the MNS study to develop a reference design in sufficient detail to allow a preliminary cost estimate, although the guideline budget is probably marginal to achieve this goal. This reference design will also provide the basis for a mission statement, for an R & D needs assessment, and for estimating the detailed conceptual design that will be required to the point of project initiation. During FY80, we will also begin planning the organization necessary to carry out the complete design, construction, and supporting R & D for the device.

III. PHYSICS PARAMETERS

Our guiding principle in approaching an MNS design is that the device should closely resemble a tandem-mirror reactor (Ref. 1)--except for a shortened solenoid section--with an overall Q well above unity. This means we are aiming for a steady-state, D-T-burning tandem device that employs thermal barriers for improved confinement (Ref. 2), leading to an ignited central cell. To meet the goal of $Q > 1$, we have selected a design value for fusion power output that centers on 200 MW, with a nominal first-wall loading of 2 MW/m^2 to provide for significant wall and blanket tests. These design values lead to a central solenoid length of 10-15 m.

We are also specifying a neutral-beam energy of 200 keV and a maximum magnetic-field intensity (at the superconductor) of 12 T because we expect these values to match the state of technology development when the decision to proceed with MNS (Title I) is planned. Although the reactor studies (Ref. 1) call for higher beam energies, these would be achieved by the same technology (negative ions) used for MNS.

With these input conditions, we have employed the model described in Ref. 2 to calculate the set of preliminary parameters for MNS listed in Table 2. This set of parameters allows us to proceed with an engineering layout of the facility because the gross features of the device are defined. However, several important physics considerations (described below) are not yet included in these calculations; accordingly, Table 2 presents only a starting point and not yet a reference case. Below we discuss some of the features and implications of this set of parameters and note some of the missing physics.

The plug design benefits from the lower plug density possible with thermal barriers. A central vacuum-field intensity of 3.4 T is adequate to confine the plug plasma at modest $\beta_p = 0.4$. With a mirror ratio of $R_p = 1.75$, the conductor field can be held to 8 T, which permits the use of Nb-Ti superconductor for the minimun-B plug magnets. Moreover, with a plasma potential of 204 kV, an R_p of 1.75 is adequate for trapping the 200-keV beam. The plasma radius of 0.55 m provides a radial dimension of 20 ion gyro-radii for protons at an average energy of 400 keV. Together with the selected value of β_p, this radial size matches an approximate criterion for gradient-stabilization of the drift-cyclotron, loss-cone (DCLC) microinstability.[2] Primarily for this reason, we have specified hydrogen for the plug neutral beams. A secondary benefit of using hydrogen is that plug fusion power is greatly reduced, easing the shielding problem in critical magnet areas.

Detailed estimates of DCLC stability based on plasma profiles have not yet been made. We have also not addressed other possible microinstability modes--such as the convective loss-cone--in this design. These stability questions are central to the entire mirror program and are discussed more fully in other documents (Ref. 3).

Although trapped-neutral-beam requirements are modest, the low plug density results in low trapping efficiency, so that total beam power is appreciable--over 17 MW, total, for two plugs. The ECRH power for heating electrons may be applied at a frequency between 60 and 110 GHz, with a requirement for about 5 MW in each plug-barrier region.

The effectiveness of the thermal barrier is sensitive to the peak field value, so that we will advocate a 12-T design for the conductor. With realistic diameter and length, a solenoidal barrier magnet should then achieve at least 10 T on-axis. Specifications of the barrier design--including transitions to plug and central cell--are not yet certain for several reasons.

Table 2. Preliminary MNS Parameters

Fusion power, P_{fus}, MW	200
Wall-loading parameter, $r_W\Gamma$, MW-M^{-1}	2.5
Plug	
Field at conductor, B_{COND}, T	8
Field at mirror, B_{MP}, T	6
Mirror ratio, R_p	1.75
Beam energy, keV	200
Plasma β_p	0.4
Plasma radius, r_p, m	0.55
Density, n_p, m^{-3}	2.5×10^{19}
Potential, $\phi_c + \phi_e$, kV	204
Neutral-beam power, trapped, P_{NB} MW	3.2
Incident, P_{NB}(INC), MW	17.4
ECRH power, P_{ECRH}, MW	9.7
Barrier	
Field at conductor, B_B(COND), T	12
Field at peak, B_{MB}, T	10
Mirror ratio, R_B	17.8
Plasma density, n_B, m^{-3}	9×10^{18}
Barrier confining potential, ϕ_B, kV	67
Central cell	
Field, B_c, T	3.5
Length, L_c, m	13
Plasma β_c	0.4
Density, n_c, m^{-3}	2.6×10^{20}
Radius, r_c, m	0.54
Plasma confinement parameter, $(n\tau)_c$, m^{-3}- s	1.7×10^{21}
potential, ϕ_e, kV	115
temperature, $T_{ec} \approx T_{ic}$, keV	20

First, the overall MHD flute stability depends on the magnetic-field design, with the min-B plug anchoring the unfavorable curvature regions in the barrier and barrier-solenoid transition. The specified barrier mirror ratio of 17.8 and possibly the central field intensity may be too high to permit meeting this requirement; dropping either value will affect all of the plasma parameters.

Secondly, the barrier length and the barrier-solenoid transition design affect MHD-ballooning stability in the latter region, resulting in a central-cell β limit. Following a successful MHD-flute-stable magnet design, the β-limit for ballooning must be checked against the selected value of $\beta_c = 0.4$ and the magnet design (or plasma requirement) iterated. These represent the next steps to be taken for a parameter evolution beyond Table 2.

Also missing is an estimate of the pump power required to maintain the barrier density at a low level (see Ref. 2). In keeping with the reactor approach described in Ref. 1, our primary scheme for barrier pumping is to use a set of charge-exchange pump beams. As input, the power estimate requires both the plasma parameters from Table 2 and a magnet design. Our first estimate is under way, and, because we expect the results to be in the range of tens of megawatts, the value obtained will affect and perhaps dominate the overall Q of the device. (However, based on the relatively low plug-power requirements, we can expect a $Q > 1$, even with the high pump power.)

The central solenoid plasma confinement is specified to achieve ignition at a temperature of 20 keV. Initial calculations set $T_{ec} = T_{ic}$, but this may change in optimized designs. The tandem barrier code, which is now coming on-line, will be used to vary MNS parameters. With machine parameters fixed, we will also be testing for the minimum power level for ignition to furnish input for a startup scenario. Missing so far from the central confinement estimate, however, are all aspects of radial-loss processes.

We have not yet addressed the question of a machine startup scenario. We expect the plug startup to behave in a manner similar to the MFTF startup, with pulsed-plasma target and startup beams to initiate the hot plasma. Startup of the center cell to ignition is less well-defined. We will probably require neutral-beam heating and will attempt ignition at the lowest possible power level. The power level would then be increased slowly--perhaps over a period of many minutes to avoid thermal shock--by control of plasma heating and fueling. Control and stability of the burn (and alpha-particle physics in general) will be the main physics questions addressed during MNS experiments.

IV. ENGINEERING DESCRIPTION

As indicated in the project organizational diagram, we have broken the system into three major components:

- Nuclear system.
- Nuclear auxiliaries.
- Plant facilities.

The nuclear system in general consists of all equipment inside the containment/shield (magnets, vacuum vessel, cryopumps, sources, etc.). The nuclear auxiliaries are components that directly support the nuclear system (power supplies, controls, tritium system, etc.). The plant facilities are conventional items (site utilities, cryoplant, cooling plant, main buildings, etc.).

Our discussion is divided into topics within these three broad categories. The nuclear system is the starting point for the design and will receive the major emphasis early in the study, with due consideration for the other systems (particularly to establish costs).

Using the physics parameters shown in Table 2, we describe the major requirements of the systems, comment on the availability of the required technology in the proposed timescale of MNS, and, in some cases, suggest development programs.

NUCLEAR SYSTEM

We have established a preliminary set of machine parameters in order to generate a "first-cut" description of the MNS. The various subsystems are outlined to highlight the more critical and fruitful areas for study during the next year.

MAGNETS

The magnet system for MNS will include all elements necessary to provide a tandem-mirror field configuration with a thermal-barrier cell. Figure 3 represents the initial design-point magnet configuration for MNS. It is comprised of the following elements:

Region	Coil type
Plug	Yin-yang pair
Transition	C-coil
Barrier	Hybrid solenoid
Central cell	Solenoid

Neutron shielding, which is required for adequate lifetimes and acceptable nuclear heating levels in the coils, will strongly influence the size of the magnets. Particular attention will be given to integrating the coil and shield designs for an effective and realistic overall design.

Although the field levels are quite high, Nb-Ti conductor technology will satisfy most of the coil requirements, except for the barrier coil. In their overall appearance, the plug and transition coils will resemble current TMR concepts.

The central-cell solenoids will be designed around a modular unit, probably about 2 m long. This not only facilitates installation and maintenance, but makes available a central-cell module for testing materials and blankets.

One issue to be pursued is the field coupling between the plug region and the barrier coil. Minimizing the length of the transition and barrier-well regions is expected to improve confinement and reduce ion-pumping requirements in the thermal barrier. Additional coils--with bucking currents--may be needed to achieve significant improvements.

In general, the superconductor designs and concepts now in use or under development for such programs as the Large Coil Project (LCP), MFTF, and conductor development at LLL provide the necessary technology base. The high-field environment of MNS, coupled with nuclear heating in the coils, may require force-flow cooling of the windings. It will probably be cost-effective to use relative thin shielding--which implies small coil dimensions--and to invest more in the cryogenic cooling system for the magnets.

Materials characterization and evaluation will be necessary for coil structural materials and conductor insulations. Manufacturing feasibility studies for these magnet systems will also be required.

ECRH

The ECRH system will be used to heat the electrons in the plug in order to enhance end-stoppering; 9.7 MW of ECRH will be required (4.8 MW per plug) at 60 or 110 GHz.

ECRH of plasmas is planned for several MFE experiments--both toroidal and linear--in the near future. TMX and MFTF-B will both employ ECRH

(TMX at 28 GHz, MFTF-B at 60 GHz). A development program is in progress to develop a 110-GHz tube for EBT. Experience with applying ECRH to TMX and MFTF-B, coupled with the development of a 110-GHz tube for EBT, should make this technology available in time for use in the MNS.

VACUUM CHAMBER

The vacuum chamber is 70 m long, with a maximum diameter of 14 m and a volume of 7,000 m^3. Its main function is to provide the vacuum envelope for the machine. It also provides mechanical support for the magnets, neutral-beam system (NBS), blanket, shield, vacuum pumps, and diagnostics.

From the vacuum standpoint, the MNS features a straightforward pressure-vessel design that stresses vacuum-tight walls, proper seals, and cleanliness. As a structure, it must support a complex set of loads imposed by gravity, magnetic forces, thermal motions, maintenance operations, and possible seismic activity.

It is implicit in the concept that the vessel is shielded from the plasma to the extent that neutron damage to the structural material is not a serious design problem.

BEAMS

Beams are required to start up and sustain the plasma. Startup beams provide the target plasma in the plugs, while those in the central cell heat the reaction plasma for ignition. The sustaining beams provide energetic particles to maintain the end plugs at operating density and temperature. Table 3 lists beam requirements.

Table 3. Beam Requirements

		Species	Energy	Total current	Module current
Sustaining		H^0	200 keV	80 A	10 A
Startup:	Plug	---	---	---	---
	Center cell	---	---	---	---

A goal of the 200-keV negative-ion program proposed for MFTF-B is the development of a 10-A module that will be a prototype for the MNS module. Further development of a 20-A module would simplify the design and reduce radiation problems in the vault.

PLASMA DIRECT CONVERTER

The plasma direct converter collects electrical energy from the charged particles streaming out the ends of the plug plasma and returns that energy to the electrical system of MNS. The total charged-particle power is equal to the absorbed injected power plus 25 percent of the fusion power:

$$P = 7.9 \text{ MW } (200 \text{ keV}) + 9.7 \text{ MW } (\text{ETB}) + 0.25 \times 200 \text{ MW } (\text{fusion})$$

$$= 67.6 \text{ MW}, \quad P_{END} = 31.5 \text{ MW}.$$

The direct converter is limited to approximately 1 MW/m², by grid-wire thermionic emission, which translates to a direct-converter area of approximately 32 m^2.

The direct-converter program proposed for TMX will provide a demonstration of the single-stage direct converter on a small scale for short pulses. A similar program for MFTF-B long pulses would provide the design information required for MNS application.

FUELING

MNS is intended to provide thermonuclear ignition conditions in the central cell; external heating is needed only for startup. Operating in this mode, then, will require a system for efficiently adding fuel to the central cell.

The system to be used in MNS is still undefined, but work on fueling methods for tokamak systems should be applicable to MNS. Pellet injection appears to be a method that would have minimal negative impact on the central-cell geometry. Other schemes will be investigated (e. g., particle streaming from the barrier cells).

We plan to follow closely developments in fueling for tokamak--such as ETF--with the object of incorporating similar systems in MNS.

BARRIER PUMP

The barrier pump is needed to remove ions trapped in the barrier well that, if not kept to an acceptable density, destroy the ability of the barrier to isolate the central-cell electrons from the plug electrons.

Several schemes to remove these ions have been proposed (charge-exchange involving neutral-beam injection into the barrier loss cone is the most favored method at this writing). The principal engineering issues associated with this method are the geometrical arrangement of the sources and dumps and the associated gas-pumping loads. The sources themselves will fall within the state-of-the-art equipment developed for MFTF-B long-pulse operation.

INTERNAL SHIELDING

The internal shielding protects the nuclear system components (particularly the magnets) from damage that would degrade their performance below design level for the specified life of the reactor. In addition, the shielding reduces the neutron-induced heat load on the magnets that acts to increase the heat load on the cryogenic system. Shielding designs will be evaluated as a cost tradeoff between increased magnet cost (which equates with size) and added cryoplant size.

The most critical shielding problems are are presented by the barrier magnet and the fan region of the yin-yang magnet. This is because it is highly desirable to maximize magnet efficiency by locating the conductors as close to the plasma as is practical.

Many shielding schemes have been proposed in fusion reactor studies; and we will use that work as input in our early designs, following up with detailed calculations that will permit development of the best options for our final design.

THERMAL DUMPS

Thermal dumps will be required to absorb untrapped neutrals in the plugs, some fraction of the energetic particles in the beamlines, and charged particles that are not stopped by the direct converter in the leakage fan.

The specific thermal load in the leakage fan will be modest because of the geometry of the direct converter. The major problem in this dump will be to reduce the reflux of low-energy neutrals to an acceptable level.

Developing the beamline dumps will be an integral part of the development of the source systems, which may include beamline direct converters to allow a more compact dump in the limited space available close to the mirror magnets. The MFTF-B long-pulse option will provide much of the technology required for these systems.

The dumps that absorb the untrapped portion of the plug beams will be highly loaded because of the large fraction of the beam that is not trapped,, even at full-density operation. Various steady-state beam-dump concepts including dynamically cooled plates and flowing liquid metals. will be investigated.

VACUUM SYSTEM

The pumping loads for MNS will arise from the neutral-beam sources, central-cell unburned fuel, helium from particle production, and outgassing from internal surfaces. Pumping deuterium and tritium are well-understood processes from the standpoint of vacuum engineering, but the combination of steady-state operation, the use of hydrogen in the plug injectors, and significant production of helium will pose some new problems in MNS operation.

At 200 MW thermal, MNS would require on the order of 7×10^{19} fusions per second. This fusion rate would produce 7×10^{19} alpnas per second, or 2 torr-litre/second of helium gas. To pump 2 torr-litre/second of helium at 10^{-5} torr would require 200,000 litre/second of pumping speed that is not compromised by the presence of deuterium and tritium. Such pumping techniques are in very early stages of development.

Steady-state-reactor operation will require development of cryopump-degassing techniques that will minimize the tritium inventory and maintain the total inventory of hydrogen isotopes below 12 torr (related to total system volume at 300^{o}k). The tritium throughput of MNS will be at least 10 gm/h; hence, at $10,000/gm, it is desirable to minimize the steady-state accumulation on the cryopumps.

Most of the MNS system that depends on the relative exposure to the neutron flux will require an all-metal hard-vacuum system with suitable remote maintenance.

CENTRAL-CELL BLANKET, SHIELD, AND FIRST WALL

The presence of high neutron flux in the central cell requires special consideration beyond that required in the plug regions, where the neutron flux is much lower. A shield that is capable of dissipating this energy--as well as protecting the magnet--is required for the full length of the cell. A cylindrical blanket will be provided--for some portion of the central cell--to permit verification of parameters relating to neutron multiplication, energy recovery, and tritium breeding.

Modular construction for the central cell is favored for the following reasons:

- Weight limitations.
- Servicing, repair, or replacement ease.
- Special-purpose zones, such as beam penetrations, dumps, diagnostics, etc.

The Tandem Mirror Reactor Study Group at LLL has defined, and subsequently refined, a modular blanket concept. Similarly, we have examined the questions of integration of the vacuum vessel, solenoid, and shielding, as well as the vacuum seals.

The module concept permits one or more blanket designs in some modules and none in others. The problem of removing large quantities of heat must be addressed in either case.

Removal of modules, components of modules, and in situ replacement or repair of components have also been analyzed by the Reactor Study Group. However, plumbing, provisions for pumping, and vessel penetrations (shield and blanket interruptions) in an operating reactor will require a more detailed study.

NUCLEAR AUXILIARIES

The nuclear auxiliary systems consist of the following: controls, diagnostics, cryo-plants, power supplies, tritium processors, secondary heat exchangers, and remote maintenance. Most of these systems requirements are design-specific and will, therefore, be studied in detail late in the project.

CONTROLS

The control system will depend on the operating scenario selected and on the particular combination of components employed; it, therefore, cannot be detailed until later in the study. However, apparently MNS will not require control technology beyond what will be available from other experiments, such as MFTF-B and TFTR.

DIAGNOSTICS

Two classes of diagnostics must be considered: those required for machine operation and control and those associated with the experimental portion of the program.

The operational diagnostics will evolve from those of MFTF-B, with the added diagnostics from fission-reactor technology.

The experimental diagnostics will be specified as we define the experimental portion of the program.

CRYOGENICS PLANT

MNS requires large quantities of both LN_2 and LHe. The heat loads are larger than those of MFTF-B because of steady-state operation, fusion-power loading, and the somewhat larger size of MNS.

Even with this increase in load, the cryogenics plant will be of the same order of magnitude as the plant required for MFTF-B and should not press the state of the art. We will be undertaken a careful study of system tradeoffs and optimal unit sizes.

POWER SUPPLIES

Special power supplies are required to drive the magnets, neutral-beam sources, ECRH, and other electronic components.

The magnet power supplies of MFTF-B will be fully prototypical of those for MNS.

The characteristics of the CW, ECRH, and neutral-beam sources used in MNS will lie beyond the parameters of MFTF-B both in potential and pulse length (CW vs approximately 30 seconds). Because they will give some experience at MNS potential, the 200-keV supplies for the HVTS are viewed as developmental.

TRITIUM SYSTEM

Because it will depend on the specific pumping and processing scheme employed the tritium inventory for MNS has yet to be determined. We will depend on the tritium system test assembly (TSTA) and ETF work in this area to provide the core of a workable system design for MNS.

MAINTENANCE

Maintenance for MNS will vary from "hands-on" to completely remote, depending on the system involved and the level of exposure to radiation and tritium contamination.

The maintenance philosophy is to design for high reliability, long life, and minimal radiation dosage, and then to categorize planned maintenance into contact and remote modes. We will provide generalized remote-handling equipment for unscheduled maintenance, along with the more specialized tooling for scheduled work

Because remote maintenance equipment and tooling are always highly design-specific, they will be a high priority design review topic throughout the final design phase.

PLANT FACILITIES

The plant facilities include the site and its development, major buildings, utilities, and cooling system.

CONFINEMENT BUILDING

The confinement building contains the reactor and its auxiliaries. It must provide a workable space for both operating and maintaining the machine. Special problems include radiation shielding--both for gammas and neutrons, a tritium barrier to ensure containment in the event of a spill, and spaces for maintenance that ranges from contact to fully remote.

The detail design of the building requires a complete nuclear system design as input. Until the nuclear system is fully specified, we will work on the general philosophy of the building, considering such things as sealing methods, tradeoffs between close and far biological shielding, and the general arrangement of major subsystem areas.

OUTPUT-POWER HANDLING

MNS must discharge a significant heat load from both fusion power generation and thermal losses from system components.

The design alternatives available range from dumping all the power, on the one hand, to generating electricity to the maximum practicable extent, on the other. We will study the alternatives from the standpoints of program objectives and cost-effectiveness. Some intermediate scheme will be the likely choice.

SITE

Site location considerations include the following:

- Environmental impact, including seismic stability.
- Moderate water and relatively large power demands.
- Accessibility to scientific and operating personnel.

The following buildings and areas are required:

- Vault containing the reactor, with remote-handling equipment, radioactive part, disposal, staging area for new and replacement components, and possibly repair facilities.
- Building to house a control room and scientific and operating personnel.
- Technician shop and component storage building.
- Building to house the vault; power supplies for the magnets, beams, ECRH, etc.; cryogenic dewars; pumps; and all near-proximity equipment required.
- Cryogenic compressor area.
- Cryogenic high- and low-pressure storage areas.
- LCW cooling system area.
- Power substation.
- Equipment staging and on-site construction area.

GENERAL SYSTEMS DESCRIPTION

In this first report, we present a set of initial drawings of our "first cut" at the MNS system design. The magnetic-field configuration is the heart of the design of a tandem reactor, and the specified magnetic requirements from a representative set of MNS parameters were used to generate the design of this magnet set. Next to the field configuration, the most significant design constraint is the need for magnetic shielding. These two requirements, along with the total fusion power, govern the overall size of the machine.

The central cell solenoid section is sized to accept a cylindrical full-thickness blanket section and shielding to protect the solenoids. In the portion of the solenoid section that does not have a blanket, cooled shielding is provided.

External to the magnet set, the beam systems and direct converter are the most prominent elements. Beams are provided on four sides of the plugs, each providing 10 A of H^0 at 200 keV.

A direct converter is provided at the end of the horizontal-fan end of the reactor, and a smaller thermal dump is located at the vertical-fan end.

The nuclear system is housed in a vault (see Fig. 4)that provides both biological shielding and a tritium seal. The tritium processors--primary heat exchangers--and remote-maintenance system are housed in auxiliary vaults that are tritium-sealed and capable of being isolated from the nuclear system vault.

Outside the vaults are the control and diagnostic areas, cold-maintenance facilities, and system-preparation spaces. Other facilities, such as secondary cooling, power-handling, power supplies, and administrative offices, are also housed in this outer area. (See Fig. 5.)

We must emphasize that this is only a first concept and that it has been developed as a starting point for iteration of all the design parameters.

REFERENCES

1. G. Carlson, et al., Tandem Mirror Reactor with Thermal Barriers, Lawrence Livermore Laboratory, Livermore, CA, UCRL-52836 (in preparation).
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3. See, for example, R. F. Post, Anomalous Transport in Mirror Systems, Lawrence Livermore Laboratory, Livermore, CA, UCRL-82882 (1979).

FIGURE CAPTIONS

Fig. 1. MNS project schedule in relation to mirror confinement experiments.

Fig. 2. MNS study project organization for FY1980.

Fig. 3. Magnet configuration for MNS.

Fig. 4. MNS vault layout.

Fig. 5. MNS facility schematic.

Relation of MNS Project to Confinement Program

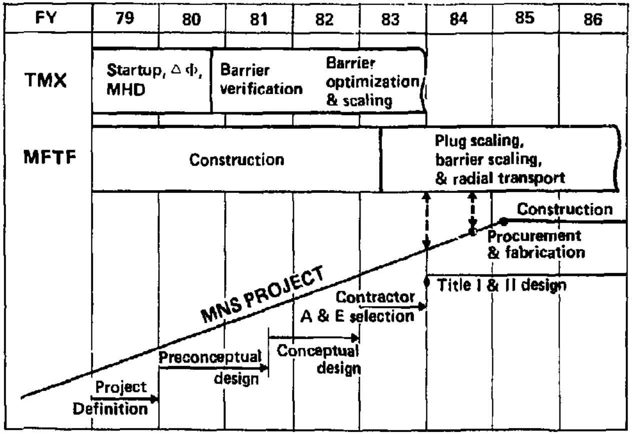


Fig. 1

MNS Study Organization

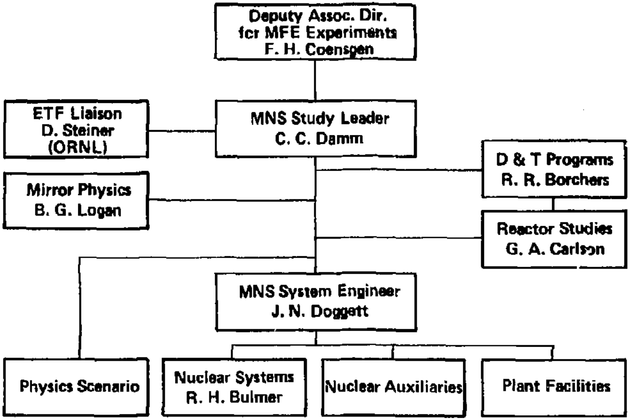
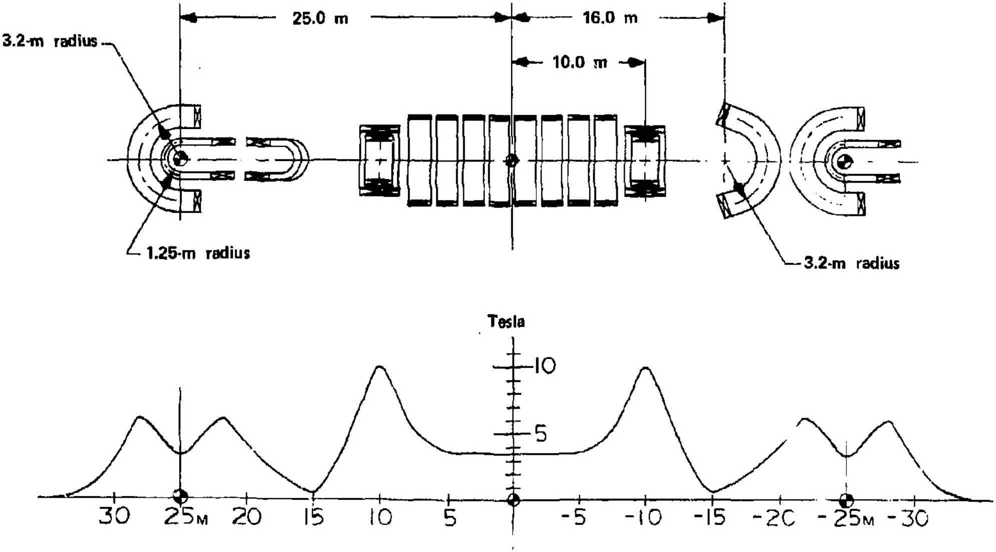


Fig. 2



25.0 m
16.0 m
10.0 m
3.2-m radius
1.25-m radius
3.2-m radius
Tesla
10
5
30
25M
20
15
10
5
-5
-10
-15
-20
-25M
-30

Fig. 3

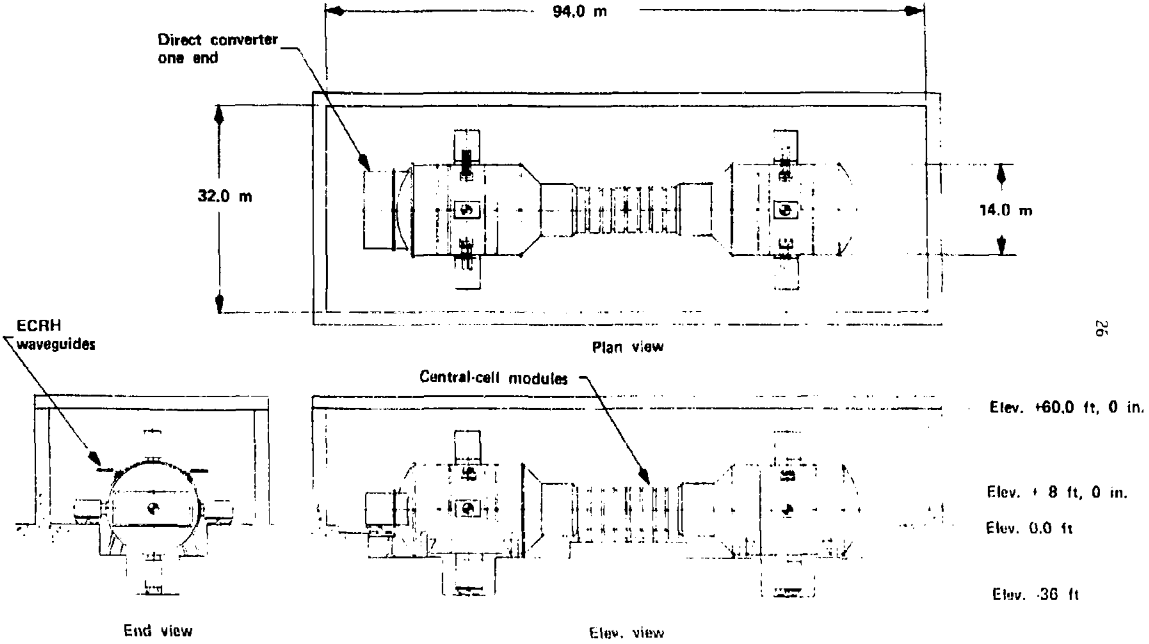

94.0 m
Direct converter one end
32.0 m
14.0 m
Plan view
ECRH waveguides
Central-cell modules
Elev. +60.0 ft, 0 in.
Elev. + 8 ft, 0 in.
Elev. 0.0 ft
Elev. -36 ft
End view
Elev. view

Fig. 4

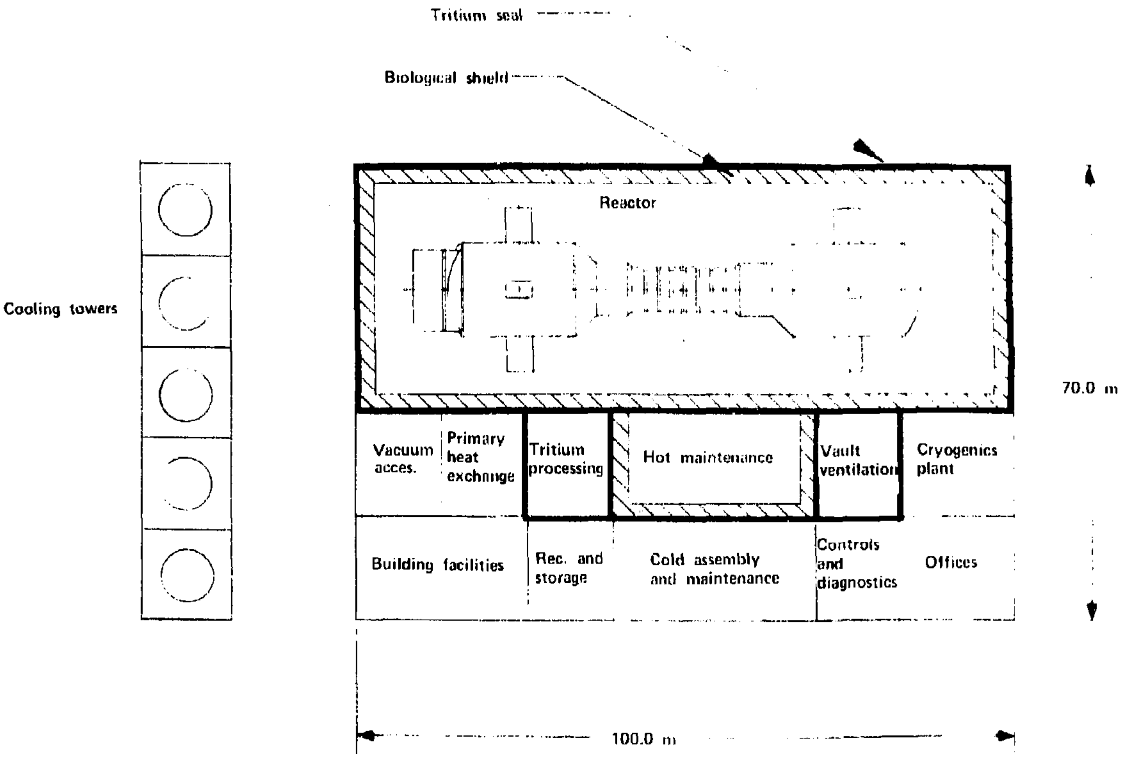

Tritium seal
Biological shield
Cooling towers
Reactor
70.0 m
Vacuum acces.
Primary heat exchange
Tritium processing
Hot maintenance
Vault ventilation
Cryogenics plant
Building facilities
Rec. and storage
Cold assembly and maintenance
Controls and diagnostics
Offices
100.0 m

Fig. 5