DEVELOPING MAINTAINABILITY FOR
FUSION POWER SYSTEMS

Progress Report
for Period April 1, 1979 - June 30, 1979

H. S. Zahn

MASTER

McDonnell Douglas Astronautics Company - St. Louis
St. Louis, Missouri 63166

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or 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.

June 1979

Prepared For

DISCLAIMER

This book 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.

THE U.S. DEPARTMENT OF ENERGY
UNDER CONTRACT NO. EG-77-C-02-4184-A.003

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

leg

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.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

ABSTRACT

The principal objective of the study authorized by Modification A003 to the basic contract is to compare the maintainability of a Tandem Mirror Reactor (TMR) conceptual commercial design with the maintainability of a conceptual design of a tokamak commercial reactor. During the initial period from April 1 through June 30, 1979 the study has principally been directed toward the completion of Task 11, Reactor Concepts, and Task 12, Maintenance Scenarios. Work has been initiated on Task 13, Support Requirements.

The study progress has been reviewed with the Office of Fusion Energy, United States Department of Energy in a briefing on June 18. This progress report contains essentially the information submitted for review at that time.

The Tandem Mirror Reactor (TMR) reference system selected is that defined by the Lawrence Livermore Laboratory in 1977. Some elaboration of this design is necessary to enable the definition of maintenance scenarios and downtime estimates. This work is continuing as the scenarios for additional maintenance actions are defined. The tokamak system selected for comparison with the TMR is the tokamak Improved Maintenance System defined in earlier maintainability studies under this contract. These reactor concepts both produce 1000 MWe.

The reactor concepts have been examined and potentially critical maintenance actions have been selected for further analysis. In the TMR concept the maintenance actions that may be required in the end plug region appear to be of greater possible significance than the maintenance of the central cell first wall/blanket. The central cell access and first wall/blanket replacement is a relatively simple operation when compared with possible end plug maintenance actions and also when compared with the tokamak reference reactor. The replacement of a TMR central cell sector requires only approximately 52 percent of the time required to replace a tokamak first wall/blanket main sector module.

A concurrent commercial TMR study is being conducted at Lawrence Livermore Laboratory. The results of this study will be incorporated insofar as possible by spot comparisons with the basic reference TMR.

TABLE OF CONTENTS

<u>SECTION</u>	<u>PAGE</u>
ABSTRACT - - - - -	iii
TABLE OF CONTENTS - - - - -	iv
1.0 INTRODUCTION - - - - -	1
2.0 PROGRESS DURING THIS REPORTING PERIOD - - - - -	3
2.1 ADMINISTRATIVE ACTIVITY - - - - -	3
2.2 TECHNICAL ACTIVITY - - - - -	3
2.2.1 Summary - - - - -	5
2.2.2 Study Approach - - - - -	11
2.2.3 Reference Reactor Definitions - - - - -	14
2.2.3.1 Tandem Mirror Reactor Conceptual Design - -	14
2.2.3.2 Tokamak Reactor Conceptual Design - - - - -	22
2.2.4 Maintenance Plan Definition Progress - - - - -	25
2.2.4.1 Maintenance Plan Definition Approach - - - -	25
2.2.4.2 Tandem Mirror Reactor Maintenance Actions -	35
2.2.4.3 Tokamak Reactor Maintenance Actions - - - -	42
2.3 CONTACTS - - - - -	50
2.4 QUANTITATIVE ESTIMATE OF OVERALL PROGRESS - - - - -	51
3.0 WORK PLANNED FOR THE NEXT REPORTING PERIOD - - - - -	52
4.0 REFERENCES - - - - -	54

1.0 INTRODUCTION

Conceptual commercial designs for fusion power reactors have been devised for several of the fusion confinement concepts. These include the tokamak and the tandem mirror reactors. The tokamak reactors designs include those by the University of Wisconsin (UWMak-I, -II, -III and NUMAK), by General Atomic Company, by Oak Ridge National Laboratory and by Culham Laboratory, UKAEA Research Group in England. A Tandem Mirror Reactor (TMR) design was produced by Lawrence Livermore Laboratory. These designs all indicate the complex nature of fusion reactors and emphasize the need for incorporating maintenance requirements early in the conceptual development.

The economic benefits of a fusion power reactor are highly dependent on its availability. Availability, in turn, is dependent upon the capability to efficiently maintain the reactor. With such complex designs, efficient maintenance presents a challenge to the designer. He must design for ease of access and for efficient maintenance activities without introducing highly complex maintenance equipment with low reliability. Therefore, these studies have been initiated to determine the design features which govern efficient maintenance and to outline the design guidelines which should be followed to achieve a maintainable reactor.

Initially, the studies considered only the four tokamak reactor conceptual designs mentioned above. These designs have been evaluated principally on the basis of the scheduled downtime required to exchange the first wall and blanket system. This system has been chosen because it has a relatively short expected life and its replacement appears to be the major maintenance action. All other scheduled maintenance is assumed to be conducted during this first wall/blanket outage. Forced outage impacts are also related to the first wall/blanket.

The tokamak studies indicated that the intertwining of the poloidal field coils through the bore of the toroidal field coils may be essential for efficient reactor design but that this design presents serious availability losses in the event of a magnet failure. Therefore, the requirement to compare tokamak designs with another fusion reactor was deemed desirable and the TMR was chosen for this comparison.

The TMR is a reactor with a straight central cell axis that does not require intertwining magnets. However, the central cell mirror requires end plugs which

are, of themselves, very complex systems. Therefore, the outcome of a comparison of TMR maintainability with tokamak reactor maintainability is not a foregone conclusion.

The study will compare the maintainability of the two types of reactors. Since their design characteristics vary considerably it is necessary in this study phase to investigate all reactor related subsystems both for scheduled and forced outages in order to establish comparable downtime requirements. These downtimes are compared through the use of availability and cost of electricity goals in order to establish the design features and guidelines which are critical drivers in the maintainability of either reactor.

During this reporting period the reference design concepts have been selected and expanded where necessary to allow maintenance scenarios to be defined. Since the tokamak reactor designs have been defined earlier, this effort is primarily conducted on the TMR design. The subsystems of the TMR have been reviewed and maintenance actions selected for further detailed analysis to determine which may be the critical drivers. Several scenarios have been developed and downtime estimates made for these potentially critical maintenance actions. Since forced outage impacts are a critical part of maintainability, the estimation of relative failure frequencies for critical subsystems has been initiated to aid in the analysis of forced outages.

2.0 PROGRESS DURING THIS REPORTING PERIOD

The progress during this period has been reviewed with the Systems and Evaluation Branch of the Office of Fusion Energy, Department of Energy and this progress report will include all data given during this review. Each data chart will include a summary discussion.

2.1 ADMINISTRATIVE ACTIVITY

This initial progress report for contract modification A003 covers the period through June 30, 1979. The initiation of work under this contract modification was April 1, 1979.

The study plan by task is illustrated in Figure 1. This plan is defined by the statement of work tasks with the exception that basic time estimates for each maintenance action are included in task 2 and task 4 only derives the total time estimates. These totals are used in availability analyses. The first three tasks have been initiated and all personnel required to conduct these tasks are assigned.

A review of the progress made during this reporting period was conducted on June 18, 1979. The study was found to be responsive to the statement of work and areas of desired emphasis were indicated. These are defined in more detail in the following section.

2.2 TECHNICAL ACTIVITY

During this period the principal technical activities included:

- o Selection and definition of the Tandem Mirror Reactor (TMR) baseline configuration.
- o Selection and additional definition of the tokamak reactor concept to be used for comparison.
- o Selection of the maintenance actions considered significant in affecting availability and cost of electricity.
- o Estimation of the downtime requirements for some of the selected maintenance actions. This work is continuing.

2.2.1 Study Summary - The earlier phases of study effort have dealt solely with the maintainability of tokamak fusion reactors. As a result, desired maintenance features for tokamak reactors have been selected. In addition, several supporting efforts have been conducted in parallel with this study effort in which the lessons learned have been put to use.

Maintainability Study Spinoffs

Figure 2 lists the supporting maintainability efforts for tokamak studies that have been conducted over the past year.

The demountable superconducting magnet evaluation conducted by the DOE was supported by estimating the downtime required to replace a segmented toroidal field magnet as installed in the HFTR (Reference 1) defined by The Brookhaven National Laboratory. The downtime required to replace a toroidal field magnet of one piece design as used in the Doublet ITR (Reference 2) was also estimated. These estimates are reported in the Phase II report of this study (Reference 3).

The Superconducting Long Pulse Experiment (SLPX) study conducted by Princeton Plasma Physics Laboratory (PPPL) required removal of the getters in the plasma chamber. The maintenance procedures and equipment to accomplish this was conceptually defined and is incorporated in Reference 4.

Personnel from MDAC-St. Louis attended the Engineering Test Facility (ETF) workshop and participated in the Remote Maintenance and Engineering Operations session.

The Commercial Tokamak Reactor (CTR) maintenance approach for the bogey conceptual design utilizes some of the results of the maintainability study. This CTR study is continuing.

As a result of the INTOR meeting in February 1979, a reply to an action item was generated to estimate the maintenance plan requirements for obtaining 25 percent or 50 percent availability from this test reactor. The maintenance plan generated in this exercise assumed a completely remote system for comparison with the results of another action item which developed the advantages of using contact maintenance.

MAINTAINABILITY STUDY SPINOFFS

CONTRIBUTED TO DEMOUNTABLE SUPERCONDUCTING MAGNET EVALUATION

DEVELOPED SLPX MAINTENANCE APPROACH

CONTRIBUTED TO ETF REMOTE MAINTENANCE AND ENGINEERING OPERATIONS
WORKSHOP

COMMERCIAL TOKAMAK REACTOR MAINTENANCE APPROACH

PRELIMINARY ANALYSIS OF INTOR AVAILABILITY POTENTIAL

Figure 2

Study Objectives for FY 1979

The principal objective of this study phase as indicated in Figure 3 is to produce a maintainability comparison between a commercial size TMR and a tokamak reactor. To do this requires the determination of the relative required availabilities of the two machines to achieve the same cost of electricity. These required availabilities will differ principally because the recirculated power in the machines differs and because of differences in capital costs. The comparison of availabilities requires the estimation of both the total downtime for scheduled maintenance and for forced outages. The latter estimate will be based on the availability goal desired after the scheduled outage times are considered and will be used to estimate the required failure frequencies for the critical replaceable components.

Since the TMR and the tokamak design concepts are inherently different, a comparison of availabilities must be based on downtime requirements for all systems that differ. Therefore, not only must all reactor systems whose design or maintenance varies between the concepts be considered, but the maintainability drivers may also be expected to differ. One of the major objectives is to identify these drivers for the TMR.

STUDY OBJECTIVES (1979)

- o COMPARE TANDEM MIRROR REACTOR (TMR) MAINTAINABILITY WITH TOKAMAK
- o DETERMINE COMPETITIVE TANDEM MIRROR REACTOR (TMR) AVAILABILITY REQUIREMENTS
- o ESTIMATE THE TOTAL DOWNTIME FOR SCHEDULED MAINTENANCE OF A TMR
- o ESTABLISH FAILURE FREQUENCY ALLOCATIONS FOR A TMR TO MEET AVAILABILITY GOALS
- o IDENTIFY TMR MAINTAINABILITY DRIVERS

Figure 3

Competitive TMR Requirements

Figure 4 illustrates the approach used in deriving the competitive availability goals for the TMR and tokamak reactor comparison.

The availability goal of 72% is selected for the tokamak reactor based on currently acceptable performance for fission reactors. These, too, have relatively low recirculated power. A goal on the order of 72 percent has been used in earlier study phases. The cost of electricity corresponding to this goal is computed for the tokamak reactor. Using this cost of electricity as the basis for the TMR, a corresponding availability goal is defined for the TMR which will yield this cost of electricity. The downtimes allowed for this goal are then used to define outage requirements and allocations of downtime for the TMR.

COMPETITIVE TMR REQUIREMENTS

(1) GOAL BASED ON ACCEPTABLE PERFORMANCE OF EXISTING POWER PLANTS.

GOALS ARE ASSOCIATED WITH A SPECIFIC SCHEDULED MAINTENANCE SCENARIO
AND A SET OF REQUIRED FAILURE FREQUENCIES

Figure 4

Study Highlights to Date

Figure 5 lists the more important considerations defined up to this time. Since most of the effort has been to establish the study design and estimated down-time base, these findings only indicate potential drivers in determining the study results.

The TMR design selected for a baseline is that defined by the Lawrence Livermore Laboratory (LLL) in a 1977 study presented in Reference 5. A study of a commercial TMR is currently being conducted by LLL but this design can only be evaluated to a limited extent in this study.

Some major problems are encountered in the disassembly of the end plug region. This capability should be available, even for the solenoid magnets in the event of a failure. Each of these magnets, including cases, dewar and structure is estimated to weigh between 1500 and 2000 tonnes in the current configuration. Movement of this mass is assumed to be on gas bearings. However, the potentially more frequent task of replacement of the plug wall and shield is believed feasible without moving any magnets in the plug. Initial discussions with LLL indicate that the current study will result in a configuration with lighter and more accessible magnets and plug wall.

Because of the size and mass of the end plug magnets, direct convertor vane assemblies, and similar assemblies that must be designed for replacement, the location of the hot cell facilities for a TMR may be more economical when close to each operating region. This precludes the construction of the extensive transfer facilities required when using a single hot cell location. More study is required to determine whether duplicate end plug hot cell facilities are desirable.

A double vacuum wall in both the central cell and end plug regions appears feasible and desirable. This vacuum chamber arrangement should permit mechanical joints and provide access advantages as found for the tokamak reactors.

The orientation of the yin yang and transition coils at one end plug is indicated as possibly being rotated 90° about the reactor axis with respect to the coils at the opposite end plug. This requires that the direct convertor vanes be

as long as the major axis of the elliptical exit fan at one end. A brief examination indicates that, for long central cells with circular plasma, these coils may be oriented with the major axis of the exit fan horizontal at both end plugs. This latter orientation is assumed.

The estimate of downtime required to replace one central cell sector in the TMR is found to be 51.8% of the time required to replace one sector module in a tokamak reactor. This ratio of these estimates will vary with the number of sectors being replaced.

STUDY HIGHLIGHTS TO DATE

- o TMR DESIGN DEFINED INSOFAR AS POSSIBLE
 - o CURRENT TMR STUDY CONCLUSIONS NOT AVAILABLE IN TIME FOR THIS STUDY
- o SIGNIFICANT FINDINGS
 - o HEAVIEST UNIT IS SOLENOID COIL (ON ORDER OF 2000 TONNES)
 - o MOVE PLUG SOLENOID HORIZONTALLY ON GAS BEARINGS
 - o REPLACE PLUG WALL MODULES WITHOUT MOVING MAGNETS
 - o PLUG MAGNET ARRANGEMENT MAY CHANGE SIGNIFICANTLY IN REVISED DESIGN
 - o REPAIR FACILITIES LOCATED NEAR REPAIRABLE UNIT FOR MINIMUM COST
 - o DOUBLE VACUUM CHAMBER SELECTED FOR CENTER CELL AND END PLUG REGIONS
 - o ASSUME TRANSITION COIL AND YIN YANG ORIENTATION THE SAME AT BOTH PLUGS
 - o CENTRAL CELL SECTOR REPLACEMENT APPROXIMATELY 50 PERCENT OF TOKAMAK SECTOR TIME

Figure 5

2.2.2 Study approach - The analytical procedures used in this phase of the study are similar to those applied in earlier phases. One significant variation is the incorporation of a larger number of components and the allocation of forced outage time among these components in order to make a more complete estimate of both the scheduled and forced outages encountered in both reference reactors.

Study Tasks

Figure 6 summarizes the five tasks which define the flow of the study. The reactor concepts are first defined. Based upon these configurations the significant maintenance actions to be analyzed are selected and the procedures required to accomplish them are outlined. The mean time to repair or replace the affected component or subassembly is estimated based on the procedure. The maintenance equipment and personnel requirements are also defined for each maintenance action scenario.

Subsequent to the analysis of individual maintenance actions these activities are combined in task 4 for each reactor to formulate a total maintenance plan. Such a plan is devised for each variation assessed in task 5. The assessment of these maintenance plan variations, such as whether partial contact maintenance is used, uses the cost of electricity as the criterion for evaluation.

S T U D Y T A S K S

1. DEFINE REACTOR CONCEPTS
2. DEVELOP MAINTENANCE SCENARIOS FOR SELECTED MAINTENANCE ACTIONS
3. DEFINE SUPPORT EQUIPMENT AND PERSONNEL REQUIREMENTS
4. COMBINE MAINTENANCE ACTIONS AND SUPPORT REQUIREMENTS INTO MAINTENANCE PLANS
5. ASSESS MAINTAINABILITY AND MAINTENANCE IMPACT ON COE FOR TMR AND TOKAMAK

Figure 6

Assumptions and Guidelines

Figure 7 lists the principal assumptions and guidelines adopted for this study. The TMR concept used for the reference design is that defined by LLL in Reference 5. The tokamak concept developed in this maintainability study as an improved maintenance system (IMS) is selected as the tokamak reference reactor (Reference 3). These reactors are both approximately 1000 MWe reactors.

In the analysis of contact maintenance, both reactors are assumed to be sufficiently shielded to permit contact maintenance in the outer vacuum zone and in the reactor room when the shield around the plasma chamber is closed. When the plasma chamber shield is open all maintenance must be fully remote.

Only those components which cannot be made redundant and which are critical to reactor operation will be included in downtime analyses of forced outages. As many components as possible will be assumed redundant to reduce to a minimum those single point failures causing forced outages. For those single point failures that remain the total forced outage downtime is related to the time to repair each outage and relative failure rates. From such estimates the allowable total forced outage defined by availability goals will be allocated among the critical components which cause single point failures.

The total scheduled downtime will be optimized by selecting that fraction of the total components to be replaced during each outage, for those systems having several identical components, which results in minimum cost of electricity. This optimization includes consideration of the cost of spares and facilities required for maintenance. Maintenance equipment and personnel are not limited in determining downtime estimates.

ASSUMPTIONS AND GUIDELINES

- o USE TMR CONCEPT DEFINED BY LLL. (1)
 - o COMPARE TMR WITH IMPROVED MAINTENANCE SYSTEM (IMS) TOKAMAK CONCEPT. (2)
 - o 1000 MW_e REACTORS USED FOR COMPARISON.
 - o MAINTENANCE OF ALL REACTOR SYSTEMS INCLUDED IN DOWNTIME ESTIMATES.
 - o REMOTE AND CONTACT MAINTENANCE WILL BE COMPARED ONLY WHEN PLASMA CHAMBER IS CLOSED AND SHIELDED.
 - o REDUNDANT COMPONENTS USED TO REDUCE FORCED OUTAGES.
 - o DOWNTIME OPTIMIZED FOR REPLACEMENT FRACTIONS.
 - o TOTAL FORCED OUTAGE DOWNTIME RELATED TO DOWNTIME PER OCCURRENCE AND RELATIVE FAILURE FREQUENCY.
 - o MAINTENANCE EQUIPMENT AND PERSONNEL AVAILABLE WHEN REQUIRED.
 - o FACILITY SPACE AND SPARES ARE AVAILABLE WHEN REQUIRED.
- (1) REFERENCE - "PRELIMINARY DESIGN OF THE TANDEM MIRROR REACTOR," BY R. W. MOIR, ET AL, LAWRENCE LIVERMORE LABORATORY, JULY 15, 1977.
- (2) REFERENCE - "DEVELOPING MAINTAINABILITY FOR TOKAMAK FUSION POWER SYSTEMS," BY G. M. FULLER, ET AL, MCDONNELL DOUGLAS ASTRONAUTICS COMPANY, ST. LOUIS, NOVEMBER 1978.

Figure 7

2.2.3 Reference Reactor Definitions - The TMR and tokamak reference reactors used in this study are discussed in References 5 and 3 respectively. These conceptual designs have been expanded to some extent during this reporting period. These concepts are being continually revised in detail during the study as the maintainability features are developed. Continuing contacts with the concurrent conceptual design effort at LLL will be made to bring the revised design concept into the study results insofar as possible.

2.2.3.1 Tandem Mirror Reactor Conceptual Design - The TMR conceptual design selected is based on the design study conducted by Lawrence Livermore Laboratory in 1977 (Reference 5). This study was for a 1000 Mw_e reactor. The physics parameters from that study have been used for all sizing of the reactor.

Tandem Mirror Reactor (Side Elevation)

Figure 8 illustrates the principal features of the TMR derived from the data in Reference 5 and initial maintainability studies. Only one end plug is shown. A total of 36 central cell modules is assumed for the 100 meter long central cell region.

Two neutral beam injectors are installed in each end plug, one with the axis vertical and one with its axis horizontal. The major axis of the fan from the yin yang coils toward the direct convertor is horizontal.

The building arrangement provides an outer secondary confinement building for each end plug with the end plug zone separated from the central cell zone. Five overhead crane systems are provided. One for the central cell is not shown in Figure 8.

The interior wall of the direct convertor is lined with water cooled panels. The cryopumps for the direct convertor and plasma chamber are arranged in two rows around the elliptical inner wall of the direct convertor chamber. These pumps are protected by cooling panels and arranged in separate panels with shutters for shutting off those being regenerated.

The direct convertor grids and ion collectors are combined into 17 modules across the width of the convertor. These modules have water cooled backpanels. The modules are removed through doors in the roof of the direct convertor chamber.

TANDEM MIRROR REACTOR (SIDE ELEVATION)

Figure 8

Tandem Mirror Reactor (Plan View)

Figure 9 is a plan view of the reactor illustrated in Figure 8. This view shows the arrangement of the covers of the trench in which the central cell is installed. The small overhead crane above the trench is augmented by a 700 ton crane which spans the entire building. The large crane handles trench covers and central cell sectors.

In addition, this view indicates a location of the 120 KeV tritium injector to supplement the fuel injected by the 1.2 MeV end plug neutral beam.

Numerous revisions are being derived for this arrangement of the TMR. These include the movement of the central cell wall to beyond the end plug magnets which provides access to the end plugs by the central cell cranes. The secondary confinement building around the direct convertors will be made full height for the entire building and maintenance provided above the direct convertor and end plug. Also, the foundation in the end plug will be solid, because of the mass of the magnets, and the vertical axis neutral beam injector will have to be mounted above the end plug.

Figure 9

Tandem Mirror Reactor (Direct Converter Section)

Figure 10 shows the direct converter grid module arrangement in the elliptical vacuum chamber. All fluid and power connections are assumed to be above the modules and the modules differ in length. Each module supports about 45 sets of grids and ion collectors.

Revisions to be made in this arrangement include squaring off of the floor of the building for more general access from inside; reduction of the number of doors accessing the converter modules to three; increasing the clearance above the modules inside of the doors to about three meters; and placing the disconnects inside of the doors. In addition, all modules may be made the same size, if this is a viable design.

Figure 10

Tandem Mirror Reactor (Central Cell Section)

Figure 11 illustrates a cross section of Figures 9 and 10 in the central cell region. The use of a trench and a double vacuum zone is the selected arrangement. The outer vacuum zone is contained by the trench cover doors and the inner zone is contained within the plasma chamber by high impedance joints between the central cell sectors.

The service lines for the central cell sectors (including magnet cryogen services, power and dewar vacuum, and first wall/blanket coolant lines) all exit the sector at the side and pass through the trench wall. Manipulators above and to the side of the central cell are used for replacement of sectors during first wall/blanket exchange.

This concept is used in the general sense but, as for the other arrangement sketches, revisions are constantly being made as will be indicated in later figures.

TANDEM MIRROR REACTOR (CENTRAL CELL SECTION)

Figure 11

Alternate Arrangement of TMR Central Cell Section

In Figure 12 a cross section of an alternate arrangement to the selected central cell region defined by Figure 11 is shown. In this arrangement the entire reactor room is evacuated as the outer vacuum zone. The central cell sectors are removed to one side and the equipment for disconnecting service lines and structural supports is floor mounted.

Several potential benefits appear feasible when using the trench concept shown in Figure 11. The outer vacuum zone is smaller and heavy maintenance equipment can be maintained during reactor operation. Lateral movement requires fairly complex transfer systems to exit the main reactor hall to a hot cell while a crane is a reasonably proven device which provides relatively simple transfer operations. Also, a bridge mounted manipulator close to the work may be used with the trench concept. This is a current state-of-art technique.

ALTERNATE ARRANGEMENT OF TMR CENTRAL CELL SECTION

Figure 12

Conceptual Arrangement of TMR Facilities

Figure 13 shows a general arrangement of suggested TMR maintenance facilities. No facility sizing is shown and this arrangement is not to scale. The figure shows that the central cell sectors are moved to the center of the central cell room, through one of two transfer locks into a transfer passage. From here they may be moved to a decontamination room or directly into a hot cell. Other components which are not activated may be removed into the maintenance equipment storage area after decontamination.

A variation of this arrangement incorporates the transfer locks with the transfer passage and this may be used instead of the transfer passage.

A mockup and maintenance control room are also indicated on the sketch. The mockup emphasizes the need for practice and prior planning of all maintenance actions. It is anticipated that direct vision of maintenance actions may not be necessary in the year 2000 time period and, therefore, the control room will be removed from the reactor for all fully remote operations. However, small special purpose viewing rooms or manned capsules may also be used where the advantage is apparent. Contact maintenance when conditions permit is the preferred maintenance mode for all other maintenance actions studied.

CONCEPTUAL ARRANGEMENT OF TMR FACILITIES

Figure 13

2.2.3.2 Tokamak Reactor Conceptual Design - The tokamak reactor concept defined in the earlier phase of this study (Reference 3) as an improved maintenance system is selected as the base for comparison with the TMR.

Improved Maintenance System Selected for Tokamak Concept

A comparison of the downtime requirements for the improved maintenance system (IMS) for tokamak reactors with the requirements for two other tokamak concepts is given in Figure 14. The scheduled downtime for this system is less than the nominal balance of plant outage of 28 days. The allowable forced outage (unscheduled) downtime, with time allowed for maintenance equipment failures already deducted, is also much greater than for the comparable reactors. This comparison is made with all reactors producing electricity at the same cost. The significant increase in allowable forced outage downtime is caused by the lower capital cost required for a smaller reactor room and significantly less maintenance equipment.

IMPROVED MAINTENANCE SYSTEM INCREASES ALLOWABLE UNSCHEDULED DOWNTIME

GOAL COE - 52 MILLS/kWhr

CONCEPT	SCHEDULED DOWNTIME (DAYS PER OPERATING YEAR)	TOTAL ALLOWABLE UNSCHEDULED DOWNTIME WITH EQUIP. FAILURES ¹ (DAYS PER OPERATING YEAR)	REMAINING ALLOWABLE UNSCHEDULED DOWNTIME	
			ONE WALL/ BLANKET FAILURE YEAR ²	FOUR WALL/ BLANKET FAILURES/ YEAR ²
IMPROVED MAINTENANCE SYSTEM	23	107	94	55
CULHAM	30	61	44	< 0
GA-DOUBLET	85	45	38	17

1 AVERAGE VALUE

2 DOWNTIME FOR AN UNSCHEDULED WALL/BLANKET FAILURE

IMPROVED MAINTENANCE SYSTEM	13 DAYS
CULHAM	17 DAYS
GA-DOUBLET	7 DAYS

Figure 14

Improved Tokamak Maintenance System (Side View)

This reactor concept employs the first wall/blanket sector arrangement and dual vacuum chamber concept initially specified by a Culham Laboratory conceptual design. The principal features indicated in the side view of Figure 15 which differ from the Culham arrangement are the access to the sector modules and the vacuum pump arrangement.

For access to the sectors the outer shield door, the support panel between the toroidal field magnets, and the neutral beam injector are all one assembly. The outer shield door is also the outer vacuum wall. This assembly is lowered to form a bridge over which the reactor sector is moved.

The cryovacuum pumps are cylindrical pumps which can be isolated from a plenum individually for regeneration or replacement. Access from above allows use of the crane.

Figure 15

Improved Tokamak Maintenance System (Plan View)

The plan view of the selected tokamak reference reactor as shown in Figure 16 illustrates the method for withdrawing each sector. The toroidal field magnets are sized to permit removal of the first wall/blanket sector between the magnets. The rails in the floor will engage wheels either on the sector module or on a separate truck placed under the module. These rails are permanently installed on the inner surface of the outer shield and in the floor. A floor mounted withdrawal device moves the module out far enough to be engaged by the overhead crane and moved to the transfer lock for exit from the reactor room.

In the IMS reactor design the inner vacuum wall is located at the first wall/blanket. The wall joints between the first wall/blanket sectors are designed to provide a high impedance to gas flow without requiring structural attachments between sectors.

The cryovacuum pump arrangement above the reactor plenum and divertor region is also illustrated. This arrangement can provide sufficient pump area to handle the gas throughput and the conductance is believed to be almost as high as any of the other arrangements examined.

IMPROVED TOKAMAK MAINTENANCE SYSTEM (PLAN VIEW)

Figure 16

Improved Maintenance System Reactor Facility (Plan View)

The facilities defined for maintenance of the selected tokamak as shown in Figure 17 are taken from earlier study work (Reference 3). The transfer lock arrangement for movement to the hot cells and the maintenance equipment areas appear to provide sufficient paths for the heavy traffic during a scheduled outage. Redundancy is provided to prevent interruption of maintenance activities in the event of failure of a transfer lock or a door in the decontamination area. Sufficient space for a mockup is deemed essential for efficient maintenance.

The arrangement utilizes an 85 meter diameter primary reactor building with auxiliary systems, including the primary and secondary coolant loop systems, in the secondary confinement building. The size of these buildings is a preliminary estimate which includes consideration for adequate space for maintenance of the systems.

IMPROVED MAINTENANCE SYSTEM REACTOR FACILITY (PLAN VIEW)

Figure 17

2.2.4 Maintenance Plan Definition Progress - The maintenance plan effort to date is principally concerned with the development of scenarios for specific maintenance actions including time to repair (downtime) estimates and maintenance equipment requirements. These scenarios are being developed for both scheduled and unscheduled maintenance and for fully remote and contact (or partial contact) maintenance operations. The progress in this effort is discussed in this section.

2.2.4.1 Maintenance Plan Definition Approach - The general approach being used for defining the maintenance plans for scheduled and forced outage maintenance is described in this section.

Scheduled Maintenance Approach

Figure 18 lists the general approach for estimating and evaluating scheduled maintenance characteristics. Initially, these maintenance actions are selected from among many possible actions and are those actions which are deemed to be the most critical or which are representative of the lesser tasks anticipated. The specific downtime, equipment, personnel and facility requirements for these tasks are estimated. This work is currently being accomplished.

The results of these specific analyses are used to estimate the requirements of other similar scheduled maintenance actions throughout the reactor. These requirements for all maintenance actions are then combined to estimate the total scheduled downtime. The combined scenario is varied to optimize the maintenance plan for minimum cost of electricity. Variations include combinations of remote or contact maintenance, level of redundancy and maintenance equipment failures. In this analysis, redundant equipment failures are maintained during scheduled outages.

SCHEDULED MAINTENANCE APPROACH

- o ESTIMATE REQUIREMENTS FOR SELECTED MAINTENANCE ACTIONS.
 - EQUIPMENT, DOWNTIME, PERSONNEL, FACILITIES
- o DEVELOP REQUIREMENTS FOR REMAINING MAINTENANCE ACTIONS.
 - ESTIMATES BASED ON SIMILARITY TO SELECTED MAINTENANCE ACTIONS.
- o COMBINE MAINTENANCE ACTIONS TO ESTIMATE TOTAL SCHEDULED DOWNTIME.
 - VARY REPLACEMENT FRACTION FOR MODULAR SUBSYSTEMS.
 - OPTIMIZE FOR COE.
 - OMIT MAINTENANCE ACTIONS PERFORMED DURING REACTOR OPERATION.
 - INCLUDE REDUNDANT COMPONENT AND MAINTENANCE EQUIPMENT FAILURE IMPACTS.
- o DEFINE TOTAL SCHEDULED DOWNTIME SUPPORT REQUIREMENTS.
- o VARY SCHEDULED REQUIREMENTS TO CONDUCT TRADE STUDIES.
 - e.g. REMOTE OR CONTACT, REDUNDANCY LEVEL, MAINTENANCE EQUIPMENT FAILURE FREQUENCIES.

Figure 18

Forced Outage Approach

The procedure used to generate estimates and analyze forced outages is similar to that used for scheduled outages in several respects. The requirements for forced outage maintenance actions are determined in the same manner as those for scheduled maintenance actions. Figure 19 defines the approach to forced outage analysis.

Since the reactor equipment is only sketchily defined, the failure rates are based on the allowable forced outage time to achieve a selected cost of electricity (COE) goal and a compatible availability goal. The allocation of forced outages to components of the reactors is determined by estimating the downtime for each maintenance action resulting in a forced outage as defined above and relating this to an estimated relative failure rate. This procedure results in a set of failure frequencies for the system components which become approximate required goals if the overall COE goal is to be achieved.

FORCED OUTAGE APPROACH

- o ESTIMATE REQUIREMENTS FOR SELECTED MAINTENANCE ACTIONS.
 - EQUIPMENT, DOWNTIME, PERSONNEL, FACILITIES
- o DEVELOP REQUIREMENTS FOR REMAINING MAINTENANCE ACTIONS.
 - ESTIMATES BASED ON SIMILARITY TO SELECTED MAINTENANCE ACTIONS.
- o DETERMINE TOTAL ALLOWABLE DOWNTIME TO SATISFY COE AND AVAILABILITY GOALS.
- o ALLOCATE ALLOWABLE DOWNTIMES FOR SUBASSEMBLIES.
 - IDENTIFY SUBASSEMBLIES WITH POTENTIAL REDUNDANCY.
 - OMIT MAINTENANCE ACTIONS PERFORMED DURING REACTION OPERATION
- o IDENTIFY ALLOWABLE RELATIVE FAILURE FREQUENCIES.
- o IDENTIFY SIGNIFICANT FORCED OUTAGE REQUIREMENTS.

Figure 19

Selected Maintenance Actions (Tandem Mirror Reactor)

The scheduled and forced outage maintenance actions selected from TMR components for detailed analysis are listed in Figure 20. In all cases, maintenance actions are defined to a replaceable or repairable component level. Some components are expected to last the life of the reactor and, therefore, no scheduled maintenance is considered for them.

The maintenance actions which are expected to be most significant drivers include:

- o Central cell first wall blanket
- o Fuel injection ion sources
- o End plug wall and shielding
- o End plug neutral beam ion sources
- o Cryopump valves
- o Direct Convertor vanes

Yin Yang magnet replacement will also require significant downtime if replacement is necessary. However, The frequency of occurrence is expected to be very low.

Most of the other selected maintenance actions are considered typical of scheduled or forced outage maintenance actions with less significant repair times but which must be added into the total maintenance plan to derive comparable downtimes for the reference reactors.

**SELECTED MAINTENANCE ACTIONS
TANDEM MIRROR REACTOR**

<u>CENTRAL CELL</u>			<u>END PLUG</u>		
	<u>SCHEDULED</u>	<u>FORCED</u>		<u>SCHEDULED</u>	<u>FORCED</u>
FIRST WALL/BLANKET	✓	✓	PLUG WALL	✓	✓
FUEL INJECTION CRYOPUMPS	✓	✓	YIN YANG MAGNET	-	✓
REACTOR TRENCH COVER SEAL	✓	✓	NEUTRAL BEAM ION SOURCES	✓	✓
POWER CABLE	-	✓	ION BEAM DUMP PLATES	✓	✓
PRIMARY COOLANT ISOLATION VALVE	-	✓	NEUTRAL BEAM CRYOPUMPS	✓	✓
FUEL INJECTION ION SOURCE	✓	✓	DIRECT CONVERTOR CRYOPUMPS	✓	✓
TRITIUM RECOVERY CONTROL	-	✓	POWER CABLE	-	✓
MAINTENANCE EQUIPMENT	-	✓	DIRECT CONVERTOR VANES	✓	✓
VIEWING SYSTEM	✓	✓	DIRECT CONVERTOR THERMAL PANELS	-	✓
CONTROL INSTRUMENTATION	-	✓	FUEL PURIFICATION	✓	✓
			CONTROL INSTRUMENTATION	-	✓

Figure 20

Maintenance Action Data Compiled on Summary Charts

The charts illustrated in Figure 21 are samples of summary charts defined for the TMR Central Cell scheduled and unscheduled maintenance data. These charts are representative of similar charts defined for the TMR End Plug and the tokamak reference reactor. The charts list the reactor plant equipment by the cost code found in the Standard Accounts for Cost Estimates (Reference 6). More detailed breakouts to component or subassembly level are made where the cost code breakout does not define elements at a desired level for maintenance analysis. Using the cost code assures that all major systems are considered in the analysis even though some, such as structure, are omitted from the maintenance analysis.

The summary chart for scheduled maintenance defines the expected maintenance actions. In many cases these maintenance actions require only inspection or a long term overhaul. Only maintenance actions requiring reactor shutdown are selected for detailed analysis. The summary chart will also include estimates for maintenance operations which are similar to the selected actions. The personnel requirements on which the total maintenance outage requirements will be based, are also included for each maintenance action.

The summary chart for unscheduled maintenance indicates an expected dominant failure mode for which a time to repair estimate is given. Those failures which require forced shutdown and those redundant systems which are repaired during a scheduled outage or during reactor operation are indicated in the failure impact column. Allowable failure rate allocations based on availability goals and associated maintenance requirements will also be defined in this chart.

MAINTENANCE ACTION DATA COMPILED ON SUMMARY CHARTS

SCHEDULED MAINTENANCE ACTIONS (TWR CENTRAL CELL)

COST ACCOUNT NUMBER	MAINTENANCE COMPONENT (SUBASSEMBLY)	SCHEDULED MAINTENANCE ACTION	NUMBER OF UNITS	COMPONENT LIFE, OP. YRS.	ESTIMATED DOWNTIME PER MAINT. ACT., DAYS	MAINTENANCE ACTION INTERVAL, OPERATING DAYS	NUMBER OF UNITS MAINTAINED, PER MAINT. ACT.	UNIT		TYPE OF MAINTENANCE; REMOTE, CONTACT, PARTIAL
								SIZE	LOCATION	
22 22.01 22.01.01 ✓	REACTOR PLANT EQUIPMENT REACTOR EQUIPMENT BLANKET AND FIRST WALL FIRST WALL AND STRUCTURE ATTENUATORS WALL MODIFIERS (COATINGS) PRIMARY SHIELD	REPLACE FW/B CENTRAL CELL (NOT APPLICABLE) RECOAT FIRST WALL (WITH FW/B CENTRAL CELL)								

UNSCHEDULED MAINTENANCE ACTIONS (TWR CENTRAL CELL)

COST ACCOUNT NUMBER	MAINTAINABLE COMPONENT (SUBASSEMBLY)	PROBABLE DOMINANT FAILURE MODE	UNSCHEDULED FAILURE IMPACT	NUMBER OF UNITS	REDUNDANCY PERCENT	ESTIMATED FAILURE RATE, FAILURE/OP. YR.	ESTIMATED DOWNTIME, PER MAINTENANCE ACTION	NET FORCED OUTAGE RATE, FOR ALL UNITS, OUTAGES/OP. YR.	FORCED OUTAGE MTBF DAYS
22 22.01 22.01.01 ✓	REACTOR PLANT EQUIPMENT REACTOR EQUIPMENT BLANKET AND FIRST WALL FIRST WALL AND STRUCTURE ATTENUATORS WALL MODIFIERS (COATINGS) PRIMARY SHIELD	FIRST WALL MODULE LEAK (NOT APPLICABLE) BURNOFF ANY CONNECTION LEAK							

- (1) SYSTEM ACCOUNT BREAKDOWN PER "FUSION REACTOR DESIGN STUDIES -
STANDARD ACCOUNTS FOR COST ESTIMATES, BATTELLE PNL, MAY 1978.
✓ INDICATES MAINTENANCE ACTIONS SELECTED FOR ANALYSIS.

Figure 21

TMR Component Reliability Survey

A brief survey of reliability data available for the types of components required for a fusion reactor is summarized in Figure 22. As anticipated, very little data is available for failures of the components unique to fusion reactors such as first wall/blanket segments, superconducting magnets and direct convertor vanes. While life estimates are being made for these components the random failure mode estimates will eventually be based on data for similar components.

TMR COMPONENT RELIABILITY SURVEY		
<u>COMPONENT (ASSEMBLY)</u>	<u>REDUNDANCY APPROACH</u>	<u>FAILURE DATA AVAILABLE</u>
MAGNETS, SUPERCONDUCTING	NO REDUNDANCY	NONE
FIRST WALL/BLANKET SEGMENT	NO REDUNDANCY	NONE
VACUUM CRYOPUMPS	EXCESS SURFACE AREA WITH ISOLATION VALVING, SHUTDOWN FOR REPLACEMENT	BY COMPONENT CLASS ONLY
VACUUM PUMP, MECHANICAL	REDUNDANT UNITS WITH ISOLATION VALVING, OPERATING REPLACEMENT	YES
POWER SUPPLIES	REDUNDANT UNITS, OPERATING REPLACEMENT	FOR SIMILAR COMPONENTS
DIRECT CONVERTOR VANES	NO REDUNDANCY	NONE

Figure 22

2.2.4.2 Tandem Mirror Reactor Maintenance Action - Maintenance scenarios have been defined and downtimes estimated for several of the maintenance actions selected for the TMR. This work is reported in this section and is continuing.

TMR Replacement Time Estimates

The TMR scheduled downtime estimates for some of the critical maintenance actions are shown in Figure 23. The replacement of a central cell sector is the most significant downtime found in maintenance of the central cell. The replacement time for the central cell in any specific outage will depend on the number of sectors being replaced, the number being worked simultaneously and the amount of overlap feasible during replacement of the sectors. The time given does not include time for reactor shutdown and startup.

The replacement of the end plug first wall and of its supporting shield and structure appears to be the most critical maintenance assembly in the end plug. It is assumed that this will require replacement because of limited wall life. The wall and shielding will be replaced together because the limited space available within the yin yang coils indicates that this will probably be a series of integral modules with a single coolant system.

TMR REPLACEMENT TIME ESTIMATES

SUBSYSTEM	ELAPSED TIME FOR SCHEDULED MAINTENANCE* (HOURS: MINUTES)
CENTRAL CELL SECTOR (ONE SECTOR)	89:00
PLUG NEUTRAL BEAM CRYOVACUUM PUMP PANEL (ONE PANEL)	40:45
PLUG NEUTRAL BEAM CRYOVACUUM PUMP (23 PANELS)	376:15
END PLUG FIRST WALL/SHIELD (ONE END PLUG)	251:45
DIRECT CONVERTOR MODULE (ONE MODULE)	34:30
DIRECT CONVERTOR GRID (17 MODULES)	271:30

*DOES NOT INCLUDE TIME FOR REACTOR SHUTDOWN AND STARTUP

Figure 23

While cryovacuum pumps and direct convertor grids require relatively little time to replace one module, the replacement of all modules in each of these systems requires significant downtime.

TMR Central Cell Joint Concept

One possible arrangement of the joint between the central cell sectors to prevent neutron streaming and still provide clearance between the sectors for removal is illustrated in Figure 24. A shield segment is installed between the sectors. Stepped shoulders are used to inhibit both neutron streaming and gas flow. This acts as a high impedance joint between the plasma chamber and central cell trench vacuum zones. The shield segments are attached to the outer face of the shielding in each sector by either a bolted or latched arrangement.

The shield segments are divided in 3 sectors around the periphery of the central cell sectors. Removal of the shield segments requires detachment of the number 1 (top) sector and then hoisting this sector out of the slot by the reactor room crane. Small remotely operated machines are placed in the trench on both sides of the central cell. Each of these machines supports a sector of the shielding segment while it also detaches the shielding sector from the main reactor shielding. The shield segment sector is then moved outward. The crane is attached to a hoist loop on the outer surface of the shield sector and it is hoisted out of the trench for intermediate storage during maintenance. It is assumed that cooling is required for the shield segment and that cooling lines are detached in this process. Replacement of the shield segment sectors essentially requires a reversal of the procedure.

TMR CENTRAL CELL JOINT CONCEPT

INTER MODULE SHIELD SEGMENT REMOVAL

REMOVAL OF SECTOR 1

REMOVAL OF SECTORS 2 AND 3

MAGNET

INTER MODULE SHIELD SEGMENT

Figure 24

TMR Central Cell Sector Removal

Removal of one of the 36 central cell sectors is illustrated in Figure 25. A 700 tonne crane with dual trolleys is used to hoist both the trench cover segments and the central cell sectors. Hoist lugs are built in to these components of the reactor. Two 700 tonne cranes will probably be required to handle the traffic and for redundancy. Therefore, the trench covers are assumed to cover 9 central cell sectors instead of 3 as shown in Figure 9 since a cover of this size can be handled by the two cranes. The covers are stowed to provide access to the vacuum seal area on each cover.

After removal of the cover and the intersector shield segment, guide rails are installed and all services disconnected. The spacers between sectors are removed and the sectors are hoisted out of the trench. Removal from the reactor room hall requires movement to the side of the trench and then to the center of the reactor hall where the sector is placed on a transporter dolly. This dolly moves the sector through the airlock into the hot cell.

TMR CENTRAL CELL SECTOR REMOVAL

Figure 25

TMR Neutral Beam Cryopanel Access

The time estimate shown in Figure 23 assumes access to the TMR Neutral Beam Injector (NBI) through a shielded door as shown in Figure 26. The door is bolted in place since it also forms a vacuum seal. Movement of such a door in the shielded wall requires a crane whether the door is horizontal or vertical. A mobile machine is required to access the NBI for disconnecting the internal components and withdrawing them in the horizontal direction if the door is on the side of the NBI. If the door is on top, an overhead manipulator and a crane for withdrawing components in the vertical direction is required.

TMR NEUTRAL BEAM CRYOPANEL ACCESS

Figure 26

Yin Yang Shielding Concept

Removal of the plug inner wall and shielding requires that these elements of the yin yang magnet be demountable as simply as possible. It is desired to remove just the wall and shield since concurrent removal of the magnet is believed an unnecessary and time consuming operation when the requirement is to replace only the plug wall. Wall and shield are removed together, however, because the coolant and physical connections of the first wall to the shield appeared too complex to break and remake in the limited space available.

Two removable shield segments are shown in Figure 27. These would be bolted to the magnet case and would also provide restraining connections to prevent magnet distortion during operation. The ears on one of the pieces aid in registering the ducts on the other piece in proper alignment. Since the shielding around the plasma ducts is sufficient to protect the magnets at the point of closest approach of the duct to the magnet, the complete void between the magnets need not be filled.

YIN-YANG SHIELDING CONCEPT

Figure 27

TMR Direct Converter Module Configuration

Figure 28 illustrates the conceptual configuration of the longest and shortest of the direct converter modules. Nine different length modules are required in the elliptical building. Each module supports approximately 40 sets of grid wires and ion collector vanes. The modules include tensioning devices, electrical connectors, a cooled back plate, and coolant lines. All connectors are at the top of each module and are inside of the large vacuum doors. Wall penetrations are beside the doors to allow door removal without interference with these services.

Removal and installation should be in the vertical direction and it is deemed inadvisable, if not infeasible, to lay the module on its back or side since the weight of the ion collector vanes may be too great for their supports when in this attitude.

TMR DIRECT CONVERTOR MODULE CONFIGURATION

Figure 28

2.2.4.3 Tokamak Reactor Maintenance Actions - The maintenance actions selected for the tokamak IMS reactor are similar to those selected for the TMR. These scenarios are based on maintenance actions defined in the earlier study phase and new actions are defined only when necessary to be compatible with the TMR maintenance actions.

Tokamak (IMS) Replacement Time Estimates

The downtime estimates for both scheduled or unscheduled maintenance of some of the tokamak reference reactor selected maintenance actions are listed in Figure 29. The times have been reviewed to accommodate revised estimates for specific subsystem procedures necessitated by the IMS. This effort will provide only sufficient data to permit comparison with the TMR, thereby placing emphasis on the maintainability of the TMR systems.

A comparison was made of the scheduled downtime for replacement of one sector of the tokamak with the scheduled downtime for replacement of one sector of the TMR. This comparison utilizes the time specified in the first item of Figure 29. This 247 hour estimate includes 76 hours for inspection of adjacent tokamak sectors. The inspection function is not included in the TMR estimate of 89 hours. When it is removed from the tokamak estimate the 247 hours becomes 171 hours and the TMR downtime is 52 percent of this total.

The downtime estimated for replacement of the vacuum wall seal at the outer shield door on a scheduled basis is only 11.25 hours. This time starts only after access to the seal is attained during a first wall/blanket sector scheduled replacement operation. The time does not include any reattachment of the outer shield door to the sector. The total time required in the event of a seal leak causing a forced outage during reactor operation, however, is 94 hours. This includes access and reassembly time in addition to the replacement time of 11.25 hours.

TOKAMAK (IMS) REPLACEMENT TIME ESTIMATES

SUBSYSTEM	ELAPSED TIME (HRS:MIN)	
	SCHEDULED ⁽¹⁾	UNSCHEDULED ⁽²⁾
FIRST WALL/BLANKET (ONE SECTOR)	247:40	N/A
FIRST WALL/BLANKET (EIGHT SECTORS)	303:30	N/A
FIRST WALL/BLANKET (DIVERTOR MODULE)	N/A	268:10
NEUTRAL BEAM ION SOURCE (ONE SOURCE)	22:05	67:05 ⁽³⁾
NEUTRAL BEAM ION SOURCE (THREE SOURCES)	52:15	97:15 ⁽³⁾
NEUTRAL BEAM ISOLATION VALVE (ONE)	25:30	70:30 ⁽³⁾
CRYOVACUUM PUMP (ONE)	30:00	75:00 ⁽³⁾
DIVERTOR BOMBARDMENT PLATE (ONE)	15:05 ⁽⁴⁾	71:05 ⁽³⁾
VACUUM WALL SEAL (ONE)	11:15 INCLUDED IN FIRST WALL/ BLANKET SCHEDULED REPLACEMENT	94:00 ⁽³⁾

(1) DOES NOT INCLUDE TIME FOR REACTOR SHUTDOWN AND STARTUP (45:00 HRS)

(2) INCLUDES TIME FOR REACTOR SHUTDOWN AND STARTUP (45:00 HRS)

(3) ASSUMES NO REACTOR DOWNTIME REQUIRED FOR FAULT ISOLATION

(4) DOES NOT INCLUDE ACCESS TIME, ALREADY INCLUDED FOR FIRST WALL/BLANKET

Figure 29

Tokamak NBI Isolation Valve Location

The isolation valve time itemized in Figure 29 is for the replacement of the isolation valve next to the reactor vacuum wall shown in Figure 30. Removal of this valve first requires bringing the entire reactor up to ambient pressure. Then the shield blocks are removed from around the isolation valve and neutral beam duct. The ring clamps are detached on either side of the valve. During this operation, the valve and the integral section of neutral beam duct are supported by a crane when the neutral beam is in the operating position. If the NBI is lowered to allow access to the first wall/blanket sector, the valve must be removed horizontally by special equipment. A small bellows on the NBI cabinet side of the valve is retracted to provide for clearance during removal of the valve and to allow realignment during installation.

Figure 30

Tokamak Ion Source Conceptual Disconnects

The ion source installation illustrated in Figure 31 and also in Figure 30 for the tokamak reference reactor assumes several improvements over the ion source being developed for TFTR (Reference 7). As explained during the earlier study phase, connections to the source are manifolded within the shielded housing to provide a minimum of connections outside of the housing for each service function.

The ion source can be removed without breaking the system vacuum by closing the isolation valve located between the ion source and the remainder of the NBI assembly. After all services except structural attachments are removed the ring clamp is disconnected and the structural attachment is removed. In the horizontal attitude a crane can be used to lift it out of position. When the NBI is lowered for first wall/blanket replacement, special equipment is required because the ion source is inaccessible to the crane. The isolation valve need not be operated in this orientation since the plasma chamber and NBI are at ambient pressure. Because of the anticipated short life of the ion source, most replacements will be with the NBI in the horizontal attitude.

TOKAMAK IMS ION SOURCE CONCEPTUAL DISCONNECTS

Figure 31

Tokamak IMS Cryopump Connections

Access to the tokamak cryopump connections is simple and relatively rapid. This is illustrated in Figure 32. Since these cryopumps are located above the reactor as shown in Figure 15 the overhead crane is used for replacement. The pumps can be replaced without breaking the vacuum in the plasma chamber by closing the isolation valve and the regeneration valve. The regeneration valve is placed above the ring clamp disconnect in the regeneration duct to achieve this isolation.

The replacement procedure resulting in the downtime listed in Figure 29 requires isolation of the pump, disconnecting all services, removal of the upper ring clamp and movement of the regeneration duct to a retracted position to the side of the pump, removal of the lower ring clamp, attachment of the crane to the pump housing, detaching the structural attachments and lifting the pump out of the supporting saddle. In-line bellows provide for movement of the regeneration duct and alignment of the main vacuum duct with the pump at the ring clamp. Adjustments in the saddle may also be used to make this alignment since this operation may utilize contact maintenance up to the removal of the pump if shielded pumps and ducts are installed.

TOKAMAK IMS CRYOPUMP CONNECTIONS

Figure 32

Divertor Particle Bombardment Plate Removal

Replacement of the particle bombardment plates in the divertor region is expected to be a critical operation because of the potentially short life of these surfaces. An access port is provided in the outer shield at each sector of the reactor. This port is unfastened using remote or contact operations and then opened remotely. The extraction assembly is emplaced through the open port. The bombardment plate is then supported by the retraction device while the disconnect device disconnects the coolant lines and the structural attachments. Movement of the old and new plates and the extraction equipment utilizes the crane and the Operational Maintenance Unit. The latter unit is required for attaching and detaching the support equipment outside of the reactor.

DIVERTOR PARTICLE BOMBARDMENT PLATE REMOVAL

Figure 33

2.3 CONTACTS

The following contacts have been made during this period for the purposes stated:

Contact	Date	Purpose
W. Neef Mechanical Engineering Dept. Lawrence Livermore Laboratory Livermore, California	3/19-20/79, and telephone contacts	TMR Commerical Reactor Study Status
J. Myall Lawrence Livermore Laboratory Livermore, California	3/19-20/79	Plug Magnet Design
T. Chargin TMX Program Manager Lawrence Livermore Laboratory Livermore, California	3/19-20/79	TMX Design, Operation and Maintenance Plans
V. Karpenko MFTF Program Manager Lawrence Livermore Laboratory Livermore, California	3/19-20/79	MFTF Design, Operation and Maintenance Plans
J. Day MFTF Engineering Lawrence Livermore Laboratory Livermore, California	3/19-20/79	MFTF Reliability Analysis
J. Doggett Deputy Chief Mechanical Engineering Lawrence Livermore Laboratory Livermore, California	3/19-20/79	MFTF-B Study
R. Field General Atomic Company San Diego, California	3/21/79	Helium Cooled Reactor Maintenance

Contact	Date	Purpose
R. Brandt General Atomic Company San Diego, California	3/21/79	HTGR Maintenance
C. Head Office of Fusion Energy Department of Energy Washington, DC	6/18/79	Study Progress

2.4 QUANTITATIVE ESTIMATE OF OVERALL PROGRESS

Figure 34 defines the estimated completion percentage accomplished through this reporting period for each study task covered by the Modification No. A003 to the basic study contract. Tasks 1 through 10 have been completed in earlier phases of the study.

COMPLETION PERCENTAGE BY TASK

Number	Task Title	Completion percentage		
		Prior Periods	This Period	Total
11	Reactor Concepts	0	58	58
12	Maintenance Scenarios	0	52	52
13	Support Requirements	0	26	26
14	Maintenance Plans	0	29	29
15	Assessment	<u>0</u>	<u>0</u>	<u>0</u>
Total:		0	36	36

Figure 34

3.0 WORK PLANNED FOR THE NEXT REPORTING PERIOD

The next reporting period will be through the duration of the study. The highlights of the work required to complete this study are summarized in Figure 35.

The next task to be completed is the definition of the maintenance scenarios. This is Task 12 in the study and, as shown in Figure 34, it is currently only partially completed. These scenarios include the selected maintenance items only.

The maintenance plans have also been initiated with the estimation of downtime requirements for the individual maintenance action scenarios. The combining of maintenance actions to a total maintenance plan must be accomplished.

The assessment of TMR maintainability includes the comparison with the tokamak IMS reference reactor. The four elements derived from this assessment that are listed are the outputs of the principal subtasks to be conducted. Other outputs are listed in Figure 36. Task 11 and 13 listed in Figure 34 will be completed. The TMR reactor arrangement is being redefined as the scenarios are established and the views shown in Figures 8, 9, 10, and 11 will be revised as required. The support equipment and personnel requirements are being developed as the scenarios are completed.

WORK TO BE COMPLETED

- o COMPLETE SCENARIO DEFINITIONS
- o DEFINE TMR AND TOKAMAK MAINTENANCE PLANS
- o ASSESS TMR MAINTAINABILITY
 - MAINTENANCE DRIVERS
 - AVAILABILITY REQUIREMENTS
 - FAILURE FREQUENCY ALLOCATIONS
 - MAINTAINABILITY DESIGN GUIDELINES

Figure 35

STUDY OUTPUTS

- o COMPARISON OF TANDEM MIRROR AND REFERENCE TOKAMAK REACTORS
 - o SCHEDULED DOWNTIME REQUIREMENTS
 - o FORCED OUTAGE DOWNTIME REQUIREMENTS
 - o POTENTIAL FOR CONTACT OPERATIONS
 - o MAINTENANCE EQUIPMENT CONCEPTS
 - o AVAILABILITY REQUIREMENTS TO SATISFY GOALS
 - o ALLOWABLE FORCED OUTAGE FREQUENCY
 - o RELATIVE COST OF MAINTENANCE
 - o RELATIVE MAINTENANCE EQUIPMENT DEVELOPMENT RISK
- o TMR MAINTAINABILITY DESIGN GUIDELINES
- o TMR MAINTAINABILITY DESIGN FEATURES
 - o MAINTAINABILITY TECHNOLOGY REQUIREMENTS

Figure 36

4.0 REFERENCES

1. "A Niobium - Tin DEALS Toroidal Magnet System for a High Field Ignition Test Reactor," by Powell, J., et. al., Brookhaven National Laboratory and Grumman Aerospace Corporation for the U.S. Department of Energy, Draft Report, December 1977.
2. "GAC-ANL TNS Scoping Studies, "General Atomic Company, Report GA-A14614, October 1977.
3. "Developing Maintainability for Tokamak Fusion Power Systems, Phase II Report," by Fuller, G. M., et al., McDonnell Douglas Astronautics Company, St. Louis, Report No. C00-4184-6, November 1978.
4. "SLPX, Superconducting Long Pulse Experiment, Final Report on Scoping Study, Volume II, SLPXI, by File, J., et al., Princeton Plasma Physics Laboratory, Report No., PPPL-1500, November 1978.
5. "Preliminary Design Study of The Tandem Mirror Reactor (TMR)," by Moir, R. W., et al., Lawrence Livermore Laboratory, University of California, Report UCRL-52302, July 15, 1977.
6. "Fusion Reactor Design Studies-Standard Accounts for Cost Estimates," by Schulte, S. C., et al., Pacific Northwest Laboratory, Battelle Memorial Institute, Report No. PNL-2648, May 1978.
7. "Tokamak Fusion Test Reactor, Final Design Report," Princeton Plasma Physics Laboratory, Report No. PPPL 1475, PH-R 007, August 1978

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK