COO-4184-1

DEVELOPING MAINTAINABILITY IN CONTROLLED THERMONUCLEAR REACTORS

Progress Report
for Period February 1, 1977 - March 31, 1977

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DISCLAIMER

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ABSTRACT

During the period 1 February through 31 March, 1977 the study has concentrated on the selection of availability goals for tokamak fusion reactors and the development of time line flow diagrams for replacement of the first wall and blanket modules of the three baseline reactor designs. Overall plant availabilities have been selected at 72% for a nominal goal and 62% for a threshold. For fusion unique equipment these availabilities became 85% and 79%, respectively. The timeline for replacement of the UWMAK III first wall and blanket is complete with a total continuous time requirement of 29 days for one reactor segment. This translates to an availability of 87% (undiluted for personnel utilization and other similar factors) for fusion unique equipment when using one possible maintenance plan. In addition, a detailed study plan has been developed and accepted by DMFE, ERDA and a survey of maintenance practices and problems was conducted in eight fission reactor related facilities.

1.0 INTRODUCTION

The maintainability of a tokamak fusion reactor system is a significant factor in establishing this type of system as an economical source of commercial power. In particular, the feasibility of maintaining fusion systems and the cost of the maintenance, including facilities, equipment and alternate power source costs, require examination to aid in directing design efforts which result in economically maintainable systems. This study will conduct such an examination. The objectives defined include: (1) the establishment of overall maintainability requirements for selected designs, (2) identification of desirable maintenance design features, and (3) definition of a total maintenance approach.

Fusion reactor conceptual designs for producing commercially economical power have been developed. These designs vary widely in their maintainability characteristics, all of which affect the downtime required to conduct maintenance and, consequently, the availability of the fusion system and the cost of electricity produced by the system. Some of the principal factors affecting downtime are the capability to access the reactor components, the maintenance equipment and facilities provided, and the environment in which maintenance must be conducted.

The design characteristics most directly influencing the maintenance time required are those of the first wall and blanket. This subsystem has a limited life requiring periodic replacement throughout the life of the reactor. Under these circumstances, the characteristics affecting the maintainability of the first wall and blanket become critically important and must be closely analyzed. These characteristics include the type of coolant, i.e., whether lithium or helium; the location, number and type of construction of vacuum walls; the first wall module size; the arrangement of critical subsystems such as cryogenic vacuum pumps and neutral beam injectors or R.F. heaters; the geometric proportions of the reactor and the location of poloidal field coils.

The Fusion Power Reactor designs by the University of Wisconsin (i.e., UWMAK-I and UWMAK-III), and by General Atomic represent designs embodying a wide range of first wall and blanket module sizes, different poloidal coil and vacuum wall locations and different coolants. These will be the three basic designs used for reference designs in the study. Designs by Culham Laboratories, Oak Ridge National

Laboratory, and Brookhaven National Laboratory employ still other vacuum wall, shield, and poloidal coil arrangements as well as modular first wall and blanket designs. These additional features will be incorporated with the reference designs for use in defining their relative maintainability advantages. The external subsystem designs also vary extensively and some of these designs may materially influence the time required to conduct the overall maintenance of the system.

In addition, the study will evaluate those design approaches which could possibly enhance the maintainability of the TNS and Experimental Power Reactors. The potential exists in these earlier reactors to apply these approaches for more efficient maintenance, particularly in the event of planned growth of the experimental reactor's capability, or to prove the feasibility of advancing the state of the art for remote maintenance at relatively low cost. While many characteristics of experimental reactor design differ from commercial design, consideration of the commercial requirements may prove beneficial to an orderly development program.

Progress during the period from February 1 through March 31, 1977 includes:

- o Completion of detailed study plan and its review with the Division of Magnetic Fusion Energy, ERDA.
- o The survey of facilities in which maintenance is conducted by remote means in a radiation environment to determine maintenance practices.
- o The establishment of availability goals for fusion reactors for use in the study.
- o The development of timelines for the first wall and blanket replacement for two baseline reactor designs, UWMAK I and UWMAK III. The timeline for UWMAK I is only partially completed.

2.0 PROGRESS DURING THIS REPORTING PERIOD

2.1 Administrative Activity

This report initiates a series of bi-monthly reports required under this contract. The study was authorized to proceed beginning February 1, 1977 and reports will be submitted for bi-monthly periods from that data.

During this first period the study plan was detailed and modified to be consistent with comments received from the DMFE, ERDA. A review of the details of the plan was given at ERDA Headquarters on March 23.

2.2 Technical Activity

During this period the principal technical activities included:

- o A survey of maintenance practices currently employed for radioactive environments.
- o The establishment of goals for fusion plant availabilities to be used as an evaluation criterion in the study.
- o The partial completion of maintenance timeline studies for the UWMAK I and the UWMAK III designs. The first wall and blanket replacement timeline for UWMAK III is completed and for UWMAK I it is approximately 50% complete.

2.2.1 Radioactive Maintenance Practices Survey

A survey of current maintenance practices and maintainability requirements for radioactive environments in existing facilities, or facilities under construction, was conducted during the week of February 14. The facilities visited are listed in Figure 1. The survey was conducted by a team consisting of Mr. G. M. Fuller, Program Manager, Mr. H. S. Zahn, Study Manager, and Mr. H. C. Mantz, Senior Design Engineer. The discussions and observations provided significant information and many helpful insights with regard to maintenance activities in a radioactive environment. We expect that the data will greatly enhance our estimates of maintenance time and selections of maintenance techniques during the study. Figure 2 summarizes some of the significant points learned as a result of this survey.

As a result of this survey some of the persons contacted expressed further interest in the results of the study and may provide further assistance in the review of the maintenance plans formulated during the course of the study.

FIGURE 1. SURVEY OF MAINTENANCE ACTIVITIES IN RADIOACTIVE ENVIRONMENT

FACILITIES VISITED:

DRESDEN POWER PLANTS, MORRIS ILLINOIS	
HOT FUELS EXAMINATION FACILITY	IDAHO NATIONAL ENGINEERING LABORATORY, IDAHO FALLS, IDAHO
EXPERIMENTAL BREEDER REACTOR-II	
ENGINEERING TEST REACTOR	
ADVANCED TEST REACTOR	
FAST FLUX TEST FACILITY	HANFORD ENGINEERING DEVELOPMENT LABORATORY RICHLAND, WASHINGTON
CHEMICAL AND MATERIALS ENGINEERING LABORATORY	
PUREX REPROCESSING FACILITY	
N-REACTOR	

FIGURE 2. PRINCIPAL LESSONS LEARNED - MAINTENANCE SURVEY

PLANT AVAILABILITY

- 70-80 PERCENT IS ACHIEVED WITH EXPERIMENTAL REACTORS
- MAINTAINABILITY IS CRITICAL FOR EXPERIMENTAL FACILITIES
- 79% AVAILABILITY ACHIEVED BY DRESDEN I, II, III IN 1976.

HANDLING AND EQUIPMENT

- REMOTE OR POWERED MOTIONS FOR HEAVY COMPONENTS ARE SIMPLE (LIFT, TRANSLATE, ROTATE)
- RADIOACTIVE COMPONENTS ARE USUALLY SHIELDED (SHIELD BLOCKS, CASKS, COOLANT)
- DESIGN FROM BEGINNING FOR MAINTENANCE (REMOTE) WILL SPEED OPERATIONS SIGNIFICANTLY

MAINTENANCE PERSONNEL

- FULL-SCALE MOCKUPS VALUABLE FOR MAINTAINING RADIOACTIVE COMPONENTS
- ALL MAINTENANCE PERSONNEL REQUIRE EXTENSIVE TRAINING
- CONTACT MAINTENANCE USED WHEREVER POSSIBLE
- ALL MAINTENANCE REQUIRES DETAILED PERSONNEL/TASK PLANNING

MAINTENANCE POLICIES

- INITIAL DESIGN REQUIRES EXTENSIVE MAINTENANCE PLANNING
- INITIAL DESIGN MUST PROVIDE MAINTENANCE SPACE AND ACCESS
- DECONTAMINATE FOR CONTACT MAINTENANCE WHEREVER POSSIBLE
- DISCARD FAILED IRRADIATED EQUIPMENT, IF COST EFFECTIVE

GENERAL

- FUSION REACTOR MAINTENANCE REQUIREMENTS ARE SIGNIFICANTLY DIFFERENT FROM FISSION REACTOR REQUIREMENTS
- THERE DOES NOT APPEAR TO BE ANY TECHNICAL LIMITATION TO REMOTE MAINTENANCE ACTIVITIES.

2.2.2 Availability Goals

Goals have been selected which define the availability criteria for fusion plants that will be used to evaluate maintenance plans formulated during the study. Three criteria are defined as follows:

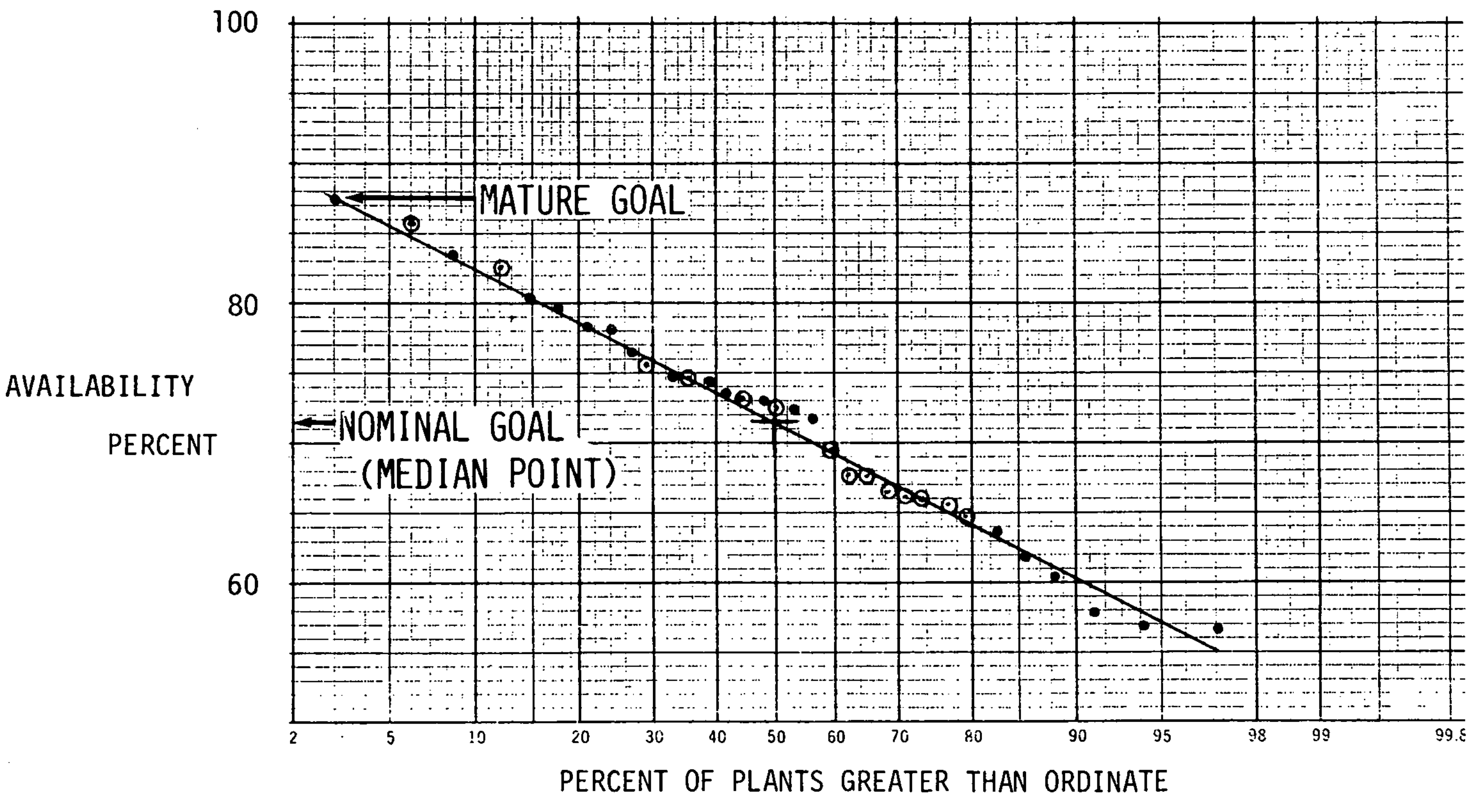
- o Nominal Availability. This is the minimum desired fusion plant availability. It is set at a level of 72% which is the median value achieved by a group of 33 fission reactor plants surveyed in the study reported in Reference (1). Figure 3 illustrates where the availability of 72% falls in the data presented in Reference (1). This availability is deemed to be "respectable performance" in Reference (1) and is in the range of availabilities being achieved by the fission power systems visited in the survey discussed in Paragraph 2.1.

- o Mature Availability. This is the maximum expected availability desired from a second generation fusion plant. It is set at 88% which is the maximum achieved over a long period by any of the fission plants surveyed in Reference 1. This goal indicates a range above the nominal goal which may be feasible if the design and maintenance learning capability demonstrated for fission reactors can be extrapolated as the learning potential for fusion power systems.

- o A Threshold Availability. This is a minimum acceptable fusion plant availability and one which provides an economic breakeven with a coal-fired plant about the year 2000. Figure 4 illustrates the economic breakeven dates achievable for a fusion plant threshold availability of 62% with three types of power plants, i.e., oil fired, coal fired, and fission.

The availabilities indicated in Figure 3 are based on a Nuclear Regulatory Commission (NRC) definition which uses the time that the generators were on line. Since the network and plant power production operations are not a subject of this study the availability used for the study is based on the time that the plant <u>can</u> be on line. Reference 1 states that this definition yields availabilities approximately 1 to 3 percentage points higher than the NRC definition. All availabilities which were used to set goals include outages for refueling since the goal is based upon an acceptable time percentage for power production. The causes for the outages will differ for fission and fusion reactors but this should not affect the acceptability of the availability achieved.

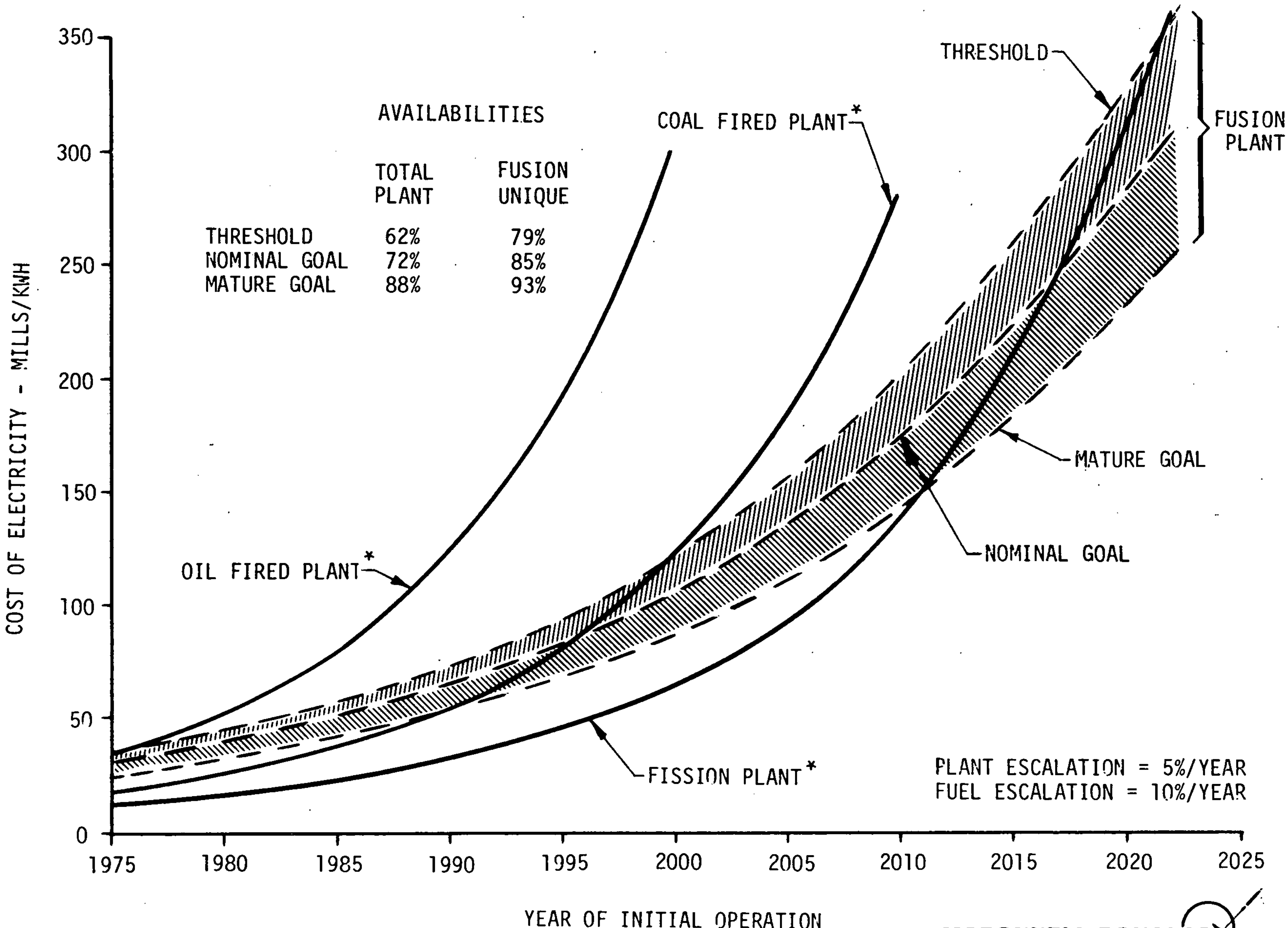
FIGURE 3. FISSION POWER PLANT AVAILABILITY DISTRIBUTION *



• PRESSURIZED WATER REACTOR
⊙ BOILING WATER REACTOR

* FROM REFERENCE 1

FIGURE 4. FUSION PLANT BREAKEVEN DATES WITH VARYING AVAILABILITY



MCDONNELL DOUGLAS CORPORATION

* REFERENCE - THE ECONOMICS OF NUCLEAR POWER, EDM-068 (3-76)

The availability goals critical to this study are those applicable to the fusion unique systems. It is assumed that the maintainability of the balance of plant equipment is similar to that for a fission power plant. The goals for the fusion unique systems are shown in Figure 5 together with a summary of the goals defined in Figures 3 and 4. The allocation of availability to fusion unique systems as shown in Figure 5 is based on the data shown in Figure 6 which has taken from Reference 1. Forced outages represented by this data represent 10% of the unavailability for the fission reactors included in the data of Figure 3. By prorating the outages for refueling and a portion of maintenance to the fusion unique equipment a nominal availability goal of 85% is derived for this equipment. The remaining unavailability of 13% includes forced outages, balance of plant scheduled maintenance not conducted during fusion scheduled outages and regulatory outages. The fusion unique threshold and mature goals were derived in a similar manner.

2.2.3 Maintenance Plans

An initial estimate of the time and functions required to replace the first wall and blanket of one segment of the UWMAK-III tokamak fusion reactor has been completed. Work on the timeline for the UWMAK-I has been initiated.

Some general ground rules have been established for the timelines which are being developed. These include:

- o Use existing reactor designs. The reactors as conceptually defined will not be modified except where additional design definition is required in order to make maintenance estimates and except to improve the equipment arrangement where this is necessary for maintenance and can be done without affecting performance.
- o Maintenance by remote operations. This is a baseline approach for maintenance in the containment hall. The impact of utilizing contact maintenance will be assessed later for those activities where contact maintenance is deemed to be feasible.
- o Maintenance conducted at near atmospheric pressure. The containment building will use an inert gas environment at near atmospheric pressure for maintenance of the baseline reactors. The effects of a vacuum environment will be investigated later.
- o Reduction of magnet currents to zero. It is assumed that all magnetic fields are reduced to zero for all maintenance when the reactor is shut down. However, residual fields are assumed to exist during maintenance.
- o Maintenance of subsystems other than first wall during first wall replacement. For initial analyses, all subsystems will be maintained during the same

FIGURE 5. FUSION POWER PLANT AVAILABILITY GOALS

	AVAILABILITY TOTAL PLANT (%)	AVAILABILITY REACTOR PLANT EQUIPMENT (%)	DATE OF ECONOMIC BREAKEVEN	COMPETITIVE ELECTRIC POWER SOURCE
THRESHOLD REQUIREMENT MINIMUM ACCEPTABLE	62	79	1976	OIL FIRED PLANTS
			2000	COAL FIRED PLANTS
			2022	FISSION PLANTS
INITIAL OPERATIONS, MINIMUM DESIRED	72	85	1996	COAL FIRED PLANTS
			2017	FISSION PLANTS
MATURE OPERATIONS, DESIRED	88	93	1989	COAL FIRED PLANTS
			2011	FISSION PLANTS

FIGURE 6. REPRESENTATIVE AVERAGE OUTAGE DURATION IN NUCLEAR UNITS THROUGH JUNE 1975 *

ITEM	DURATION (HOURS)	% TOTAL
Forced Outage (Equipment Malfunction)		
Turbine/Generator	140	4.7
Condenser	124	4.2
Steam Generator	189	6.3
Pumps	60	2.0
Valves	132	4.4
Vessel & Core	75	2.5
Plant Electrical Distribution	30	1.0
All Other	310	10.4
SUBTOTAL:	1060	35.5
Scheduled Outage		
Maintenance	280	9.4
'Refueling'	1500	50.2
Training & Administration	30	1.0
	1810	60.6
Regulatory	116	3.9
TOTAL	2986	100.0

Availability Factor (Based on One Year Operation Between Refueling)

$$1 - \frac{2986}{8760 + 1500} = 71\%$$

* From Reference 1.

outage period. Later estimates will be made of subsystem maintenance requirements. These estimates are expected to identify those components that will require modification of this ground rule.

o Availability of sufficient personnel for all maintenance operations. The impact of limiting the number of maintenance personnel for uniform manning will be considered in later estimates.

The total time for replacement of one UWMAK III first wall and blanket segment is estimated to be 29 days when working 24 hours per day, 7 days per week. Factors for dilution of the effort have not yet been applied. Figure 7 shows the distribution of this effort among the top level functions. To achieve a replacement in this time, most of the functions are conducted using state-of-art techniques.

The initial maintenance equipment concept for replacement of one first wall and blanket segment utilizes three different major machines plus dollies, fixtures, special tools, jacks and hoists. The utilization of the three major machines requires that one machine will conduct the functions to gain access and to reassemble; the second machine will remove and replace the first wall and blanket modules and the third machine will inspect the remaining first wall and blanket. Some imbalance in the utilization time for these machines exists and a better balance will be determined.

Since the life of the first wall for the UWMAK III is estimated at approximately 1-1/2 years and an estimated period of one year between maintenance seems reasonable for the other subsystems a nominal operating period between shutdown for first wall changeout of one half its life, or 9 months, is assumed. This provides approximately a one year cycle for scheduled maintenance outages and requires replacement of 9 first wall and blanket segments during one outage. When 9 segments are replaced during one outage the number of sets of maintenance equipment can be varied and the work on segments can be overlapped to reduce the total outage time. The availabilities achievable with a minimum, maximum and possible optimum number of sets of maintenance equipment have been estimated and are shown in Figure 8. The possible optimum availability of 87% is significant since this availability exceeds the nominal goal. If a derating factor of 75% is assumed for inefficiencies in personnel and equipment utilization, such as during shift changeover, the fusion unique availability becomes approximately 83.5%. For an initial estimate, this compares favorably with the nominal goal of 85%.

Figures 9 and 10 illustrate typical design clarifications that are required to define the timeline for UWMAK I. Figure 9 illustrates a neutral beam injector (NBI) arrangement using a design of the NBI defined in an Argonne National Laboratory report (Reference 2). To provide room for the NBI design the containment hall wall was modified by moving it outward. This will require an increase in the vacuum system size and will also affect the accessibility of the reactor. Figure 10 depicts a support system for the NBI and for the segment of the UWMAK I which uses air bearings for flotation. Translation will be accomplished with auxiliary devices. In addition, Figure 9 also defines a rerouting of the lithium and vacuum lines to provide for readily detachable and connectable sections.

FIGURE 7. UWMAK III PRELIMINARY TIMELINE SUMMARY
(1ST WALL/BLANKET REPLACEMENT - ONE SEGMENT)

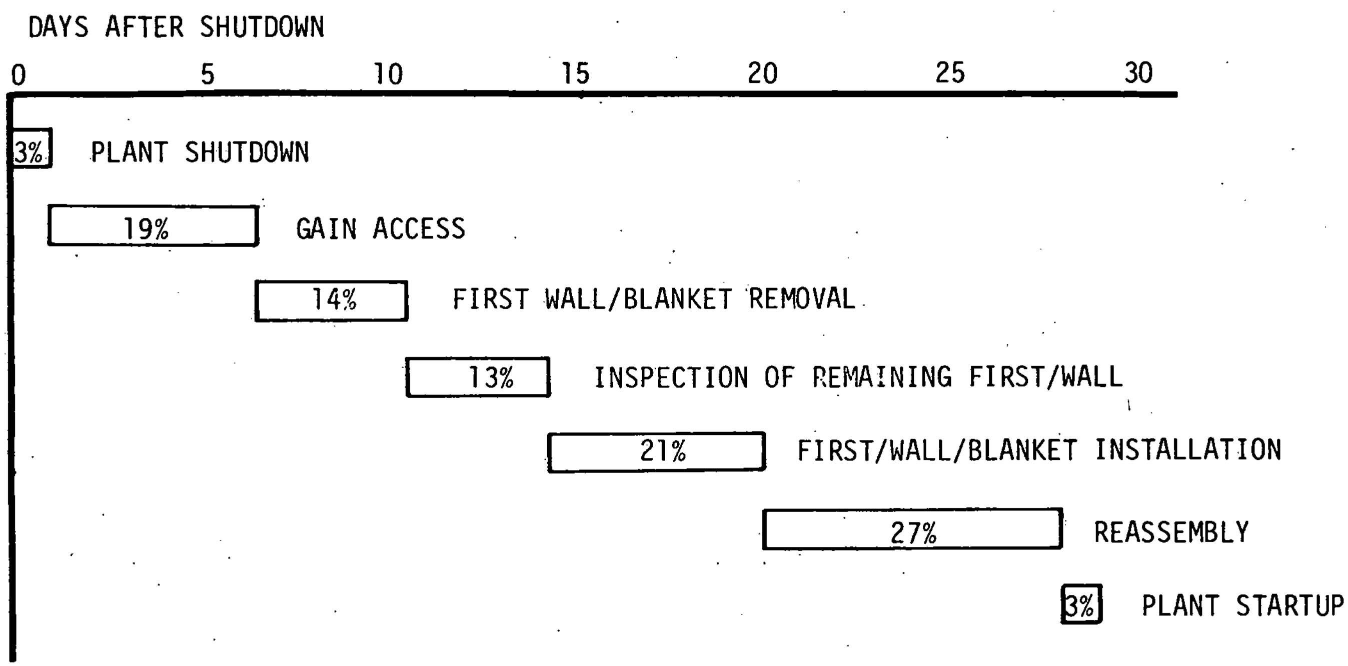


FIGURE 8. PRELIMINARY AVAILABILITIES
UWMAK-III FUSION EQUIPMENT

MAINTENANCE MODE	AVAILABILITIES FUSION * EQUIPMENT	TOTAL ** PLANT	SELECTION CRITERIA FOR MODE
REMOVAL AND REPLACEMENT (R/R) OF 9 SEGMENTS			
SIMULTANEOUS R/R FUNCTIONS (SAME AS SINGLE SEGMENT)	92	78	MAXIMUM AVAILABILITY, MAXIMUM CAPITAL COST
SERIES R/R FUNCTIONS (SINGLE SET OF MAINTENANCE EQUIPMENT)	57	48	MINIMUM AVAILABILITY, MINIMUM CAPITAL COST
SERIES/PARALLEL R/R FUNCTIONS (THREE SETS OF MAINTENANCE EQUIPMENT)	87	74	POSSIBLE OPTIMUM BALANCE OF AVAILABILITY AND CAPITAL COST

* ASSUME ALL SCHEDULED MAINTENANCE IS COMPLETED DURING EXCHANGE OF 1ST WALL/BLANKET

** ASSUME ALL OTHER OUTAGES BASED ON NOMINAL GOAL RATE OF 47 DAYS PER YEAR.

FIGURE 9. TYPICAL DESIGN ASSUMPTIONS

NEUTRAL BEAM INJECTOR ARRANGEMENT FOR UWMAK-I

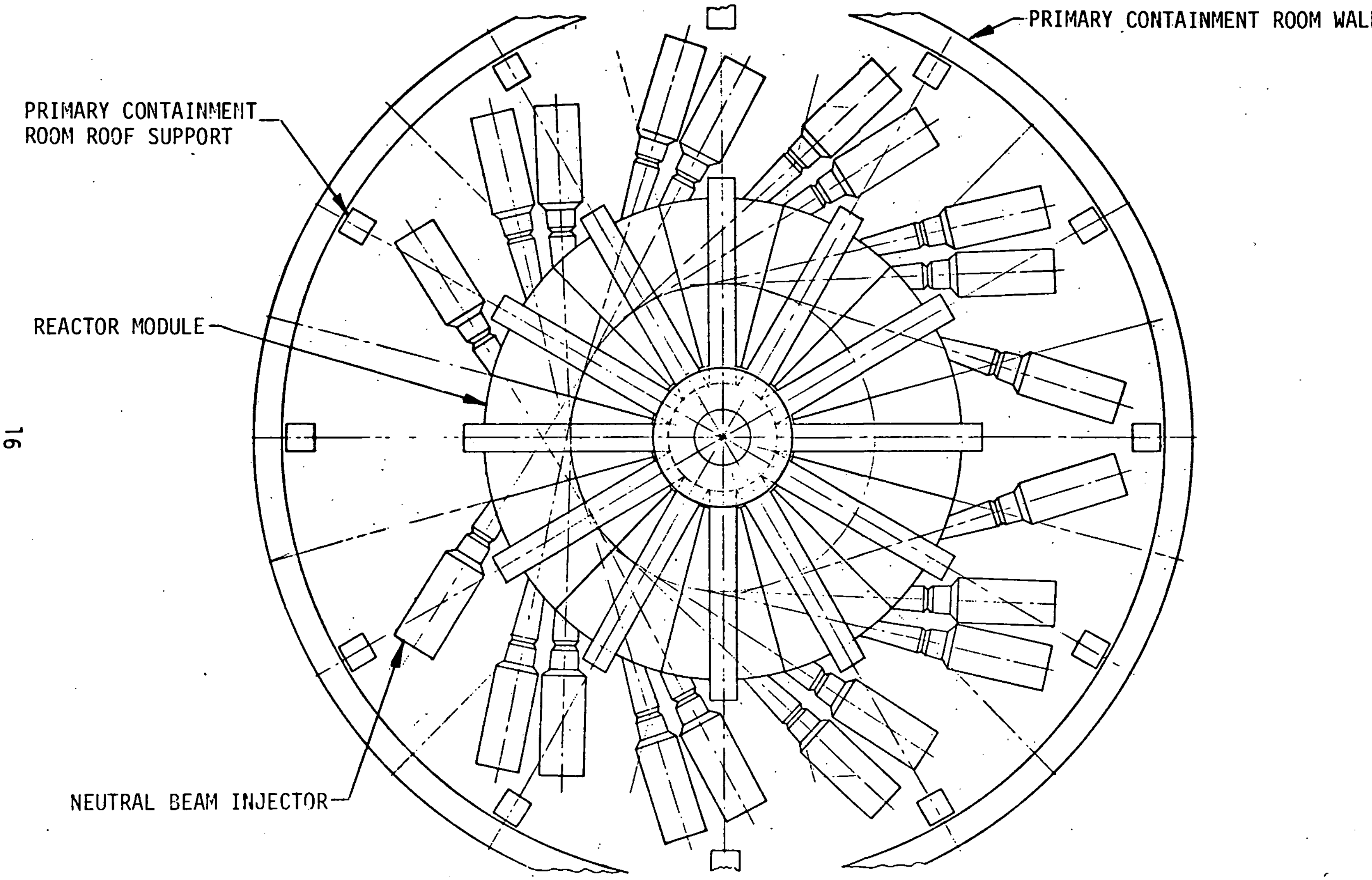
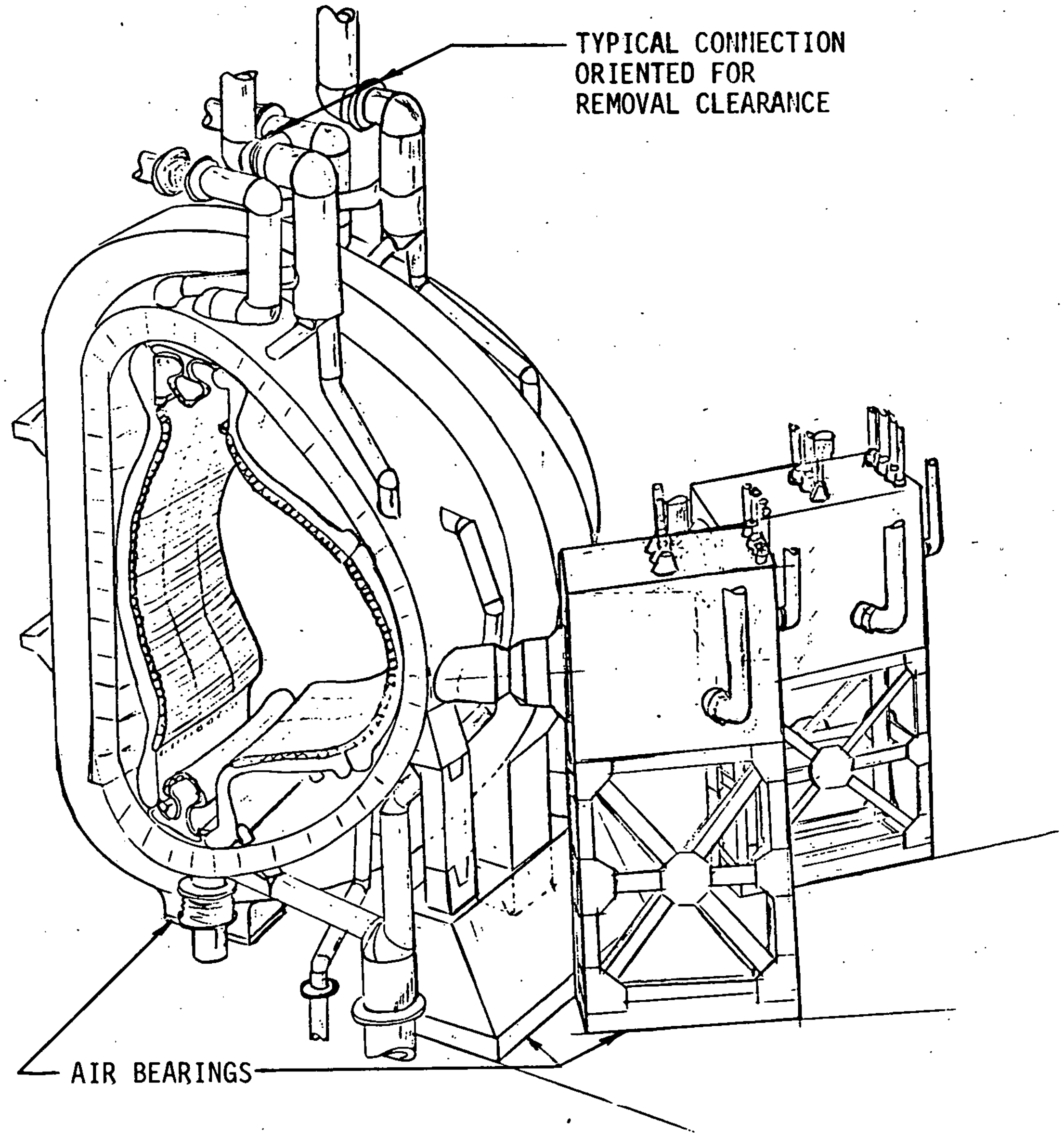


FIGURE 10. TYPICAL DESIGN ASSUMPTIONS
UWMAK I TRIMETRIC



2.3 Visits

The following personnel were visited during this reporting period:

DATE	CONTACT	LOCATION
2/14/77	Mr. Eugene E. Meintel Maintenance Staff Assistant	Dresden Nuclear Power Station Commonwealth Edison, Morris, Illinois
2/15/77	Mr. Dale A. Tobias Operations System Engineer	Hot Fuel Examination Facility Argonne, West, INEL Idaho Falls, Idaho
2/15/77	Mr. Jim Leman Manager, Maintenance	Experimental Breeder Reactor II Argonne, West, INEL Idaho Falls, Idaho
2/16/77	Mr. Dave Schoonen Manager, Maintenance Branch	Advanced Test Reactor EG&G, Idaho, INEL Idaho Falls, Idaho
2/17/77	Mr. Jerry Marshall Manager, Maintenance	Fast Flux Test Reactor Westinghouse, Hanford, HEDL Richland ,Washington
2/17/77	Mr. L. A. Pember Manager, Postradiation Testing	Chemical and Materials Engineering Lab. Westinghouse, Hanford, HEDL Richland, Washington
2/18/77	Mr. Homer Pittman Manager	Purex Plant Atlantic-Richfield, Hanford Co., Richland, Washington
2/18/77	Mr. Jim McKay Manager, N. Plant Maintenance	N-Reactor United Nuclear Industries Richland, Washington
3/23/77	Mr. Bruce Twining	Systems and Applications Studies Branch DMFE, USERDA Washington, D.C.

2.4 Quantitative Estimate of Overall Progress

Figure 11 provides the estimated completion percentage accomplished through this first reporting period for each study task.

FIGURE 11. COMPLETION PERCENTAGE BY TASK

Task		Completion Percentage		
Number	Title	Prior Periods	This Period	Total
1.	Maintenance Plans	0	44%	44%
2.	Time-to-Perform Estimates	0	30%	30%
3.	Maintenance Equipment Requirements	0	13%	13%
4.	Evaluation	0	0	0%
5.	Desirable Maintenance Design Features	0	0	0%
	TOTAL:			19%

The level of effort planned for the study will increase by 67 percent during the next time period to apply specific skills to the effort required by Tasks 2, 3 and 4. This increase will provide an estimated completion percentage during the next two reporting periods that will assure study completion within the required time.

3.0 WORK PLANNED FOR THE NEXT REPORTING PERIOD

3.1 First Wall/Blanket Timeline Development

The maintenance timelines for the first wall and blanket will be completed for the UWMAK I and the General Atomic Demonstration designs. These timelines will include definition of the maintenance functions and estimates of the time required to perform them. Additional emphasis will be placed on the definition of conceptual designs of the maintenance equipment required to replace the first wall and blanket of all three baseline designs.

Initial estimates of the availabilities of each design will be made and compared with allocated times. Probable areas of improvement in the timelines will be defined in preparation for evaluation of the design features.

3.2 Integrated System Timeline Development

The development of maintenance timelines for subsystems installed in the primary or secondary containment areas of the three baseline fusion reactor designs will be initiated. Upon completion these will be integrated with the first wall and blanket timelines to establish the critical path during first wall and blanket replacement. These subsystems include the vacuum system, neutral beam injectors, RF heaters, and the primary coolant system - both lithium and helium. Scheduled maintenance of subsystems other than the first wall and blanket which is required during the interval between shutdowns for replacement of the first wall and blanket will also be examined.

3.3 TOCOMO Coding Supplement

The TOCOMO code will be enhanced by the addition of the General Atomic demonstration reactor characteristics to provide for costing of this design and revision of the maintenance system cost routines. This work will be initiated during the next reporting period.

3.4 Preparation for Timeline Reviews

A review of the timelines for the three baseline reactors is planned. The purpose of this review is to increase the accuracy of the time estimates and the credibility of the techniques selected for maintenance. Preparation for this review will be initiated by establishing a review team and beginning the documentation of the timelines in a form suitable for their review by the team. The most suitable method of review will be selected.

4.0 REFERENCES

1. Lapides, M. E., and Zebroski, E., "Use of Nuclear Plant Operating Experience to Guide Productivity Improvement Programs," EPRI Report No. EPRI SR-26, November 1975.

2. Tokamak Experimental Power Reactor Conceptual Design, by W. M. Stacey, Jr., et al, Argonne National Laboratory Report No. ANL/CTR-76-3, August 1976, Volume 1.