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DEVELOPING MAINTAINABILITY
IN CONTROLLED THERMONUCLEAR REACTORS

Progress Report
for Period April 1, 1977 - May 31, 1977

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ABSTRACT

During the period 1 April through 31 May 1977 the study has developed three baseline time estimates for replacement of the first wall and blanket of the UWMAK-I, UWMAK-III and the General Atomic Demonstration Power Reactor (GA-DPR) conceptual design approaches. These estimates are for replacement of a complete reactor sector in UWMAK-I, the "A" module and one-half of the remaining modules in one sector of the UWMAK-III, and the first two modules in the wall of the GA-DPR. The total time for these minimum scope replacement estimates are 1133 hours, 687 hours and 848 hours, respectively, without productivity or other dilution factors. Maintenance equipment conceptual designs have been partially developed and equipment lists generated for each baseline concept maintenance approach. These time estimates and maintenance techniques will be reviewed by experts in the field during the next reporting period. In addition, development of the necessary cost code for the GA-DPR has been initiated for integration into the TOCOMO code and later use in the planned trade studies.

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 April 1, 1977 through May 31, 1977 includes:

- o The completion of the initial time line development for the first wall and blanket replacement for all three baseline reactor design approaches, UWMAK-I, UWMAK-III and the General Atomic DPR.
- o Initiate design approaches for the equipment required to conduct the maintenance represented by each of the baseline time lines.
- o Initiate adding the General Atomic DPR characteristics to the TOCOMO cost code for use in estimating system costs for tradeoff analyses.
- o Initiate preparation for a meeting of designated personnel to review the baseline time estimates and maintenance techniques.

2.0 PROGRESS DURING THIS REPORTING PERIOD

2.1 ADMINISTRATIVE ACTIVITY

During this second reporting period contact was made with a number of expert representatives of organizations engaged in the maintenance of radioactive equipment for the purpose of inviting their participation in a review of the baseline time estimates developed for the UWMAK-I, UWMAK-III and General Atomic DPR design approaches. This group was selected and coordinated with ERDA. A letter of invitation was extended on 27 May, together with a preliminary agenda. The date of the review was set for 20, 21 July, 1977. A preliminary informal document containing the time estimates and supporting data will be forwarded to each participant for his review. A meeting of participants at MDAC-E is planned on July 20-21, 1977 to provide an opportunity for cross-fertilization of all comments made in review of these time estimates.

The list of persons contacted is included in Section 2.3 of this report.

2.2 TECHNICAL ACTIVITY

During this period the principal technical activities included:

- o Completion of the time-to-perform estimates for the UWMAK-I and General Atomic DPR maintenance of the first wall/blanket and the development of time estimates for maintenance of the UWMAK-III reactor subsystems located in the reactor room.
- o The definition of design concepts for the special tools and equipment required for the maintenance of the first wall/blanket. The UWMAK-I is approximately 60% complete with the UWMAK-III and the General Atomic DPR approximately 40% complete.
- o The partial completion of the coding required to add the analytical cost capability for the General Atomic DPR to the TOCOMO (tokamak cost model) code. This is approximately 50% complete.

2.2.1 Development of Time Estimates - The estimates of time to perform first wall and blanket replacement have been completed for the UWMAK-I and the General Atomic Demonstration Power Reactor (GA-DPR) design approaches. These have been coordinated with the UWMAK-III estimate and revised to generally project equal time for the same functional requirements. Each estimate is conducted for a modular entity; i.e.,

one complete reactor sector for the UWMAK-I; one sector for the UWMAK-III with replacement of one "A" module, one "B" module, one central wall (diverter region) module and one-half of the ISSEC; and the first complete module in the General Atomic DPR in addition to those modules replaced in conjunction with the track laying operation during reassembly. The original estimates were to be made using approximately one year maintenance intervals, but the modular estimates are better suited for studies of different maintenance intervals. Some further adjustment of the third level estimates is required to pull out extraneous times in order to simplify the estimating process for use of the estimates in modular form.

The degree of detail used in describing the estimates follows a conventional hierarchy or tree breakdown of the maintenance functions. A segment of this hierarchy used for the UWMAK-III is illustrated in Figure 1 to establish the meaning of first, second and third levels as used in this study. All estimates have been made at least at the third level of detail with some functions of the UWMAK-I maintenance tasks being estimated at the fourth level. Since breakdowns of this type are highly subjective, some apparent inconsistencies may exist in designating levels.

An example of the functional time estimate breakdown used in the analyses is illustrated in Figure 2. This chart shows the estimate breakdown at level 3 for the removal of the modules of first wall and blanket for the GA-DPR design approach. The conventions show the use of parallel operations where appropriate and the indication of repetition of groups of functions. In this case, step .14 indicates the time required for the second set of equipment to remove a second module by following steps .01 through .13 concurrently. These conventions have been followed throughout the study.

UWMAK-I estimates are summarized for level 2 functions in Figures 3 through 5. The design approach data for defining the functions and time estimates is taken primarily from Reference 1. The total time estimated for replacement of a module is approximately 1133 hours. Since the maintenance concept used for this design approach can exchange several modules simultaneously, depending on the number of units available of each type of maintenance equipment, this estimate may be used as an input in conducting some of the trade studies. The number of modules to be removed will be a function of the maintenance interval and the first wall/blanket operating life.

FIGURE 1. FUNCTIONAL LEVELS

FIGURE 2. LEVEL 3 MAINTENANCE TASKS AND FUNCTIONAL TIME ESTIMATES (TYPICAL)

TASK: 2.08 REMOVE BLANKET MODULES		
SUBTASK NO.	ACTIVITY	TIME EST.
.01	USING ICMM NO. 1 - REMOVE FIRST WALL LINER FROM BLANKET MODULE AND TRANSFER TO RMM NO. 1.	:45
.02	WITHDRAW LINER FROM CHAMBER USING RMM NO. 1 AND PLACE ON STORAGE DOLLY.	:15*
.03	USING ICMM NO. 1 REMOVE GRAPHITE RING FROM MODULE AND TRANSFER TO RMM.	:45
.04	WITHDRAW RING FROM CHAMBER USING RMM NO. 1 AND PLACE ON STORAGE DOLLY.	:15*
.05	CONVERT ICMM NO. 1 TO LASER CUTTING MODE USING RMM NO. 1. CALIBRATE LASER CUTTING SYSTEM.	3:00
.06	CUT VACUUM SEAL ON BLANKET MODULE.	:30
.07	CONVERT ICMM NO. 1 TO POWER MANIPULATOR MODE USING RMM NO. 1.	2:00
.08	USE ICMM NO. 1 TO REMOVE VACUUM SEAL AND TRANSFER TO RMM NO. 1.	:20
.09	WITHDRAW SEAL FROM CHAMBER AND PLACE IN WASTE CONTAINER USING RMM NO. 1.	:20*
.10	USE ICMM NO. 1 TO GRASP MODULE CLAMPING RING. ROTATE AND WITHDRAW BLANKET MODULE. PLACE IN MODULE CONTAINER OF VACUUM PORT NO. 2.	:45
.11	REMOVE FILLED CONTAINER USING RMM NO. 1. PLACE ON TRANSFER DOLLY. PICK UP EMPTY CONTAINER AND PLACE IN ADAPTER.	:30*
.12	CONVERT ICMM NO. 1 TO SEAL DRESSING AND INSPECTION MODE USING RMM NO. 1.	2:00
.13	DRESS MODULE SEAL RING AND INSPECT CAVITY.	:40
.14	REPEAT STEPS .01 THROUGH .13 USING ICMM NO. 2 AND RMM NO. 2.	10:45*
TOTAL:		10:45 HRS

* CONDUCTED IN PARALLEL, NOT INCLUDED IN TOTAL TIME.

NOTE: INCREMENTAL MODULE TIME FOR ADDITIONAL 2 MODULES (1 BY ICMM NO. 1 AND 1 BY ICMM NO. 2) IS 3:45 HRS.

FIGURE 3. UWMAK-I CONCEPT SHUTDOWN TIME ESTIMATES

TASK CODE	LEVEL 1 TASK (SUBDIVISION)	LEVEL 2 TASK	TASK HRS.	CUMULATIVE TASK HRS.
1.0	Shutdown			
1.01		Shutdown Operations	0	
1.02		Cutoff Current to T.F. Magnets	24:00	
1.03		Circulate Coolant to Remove Afterheat	16:40*	
1.04		Cycle Tritium Extraction and Secure	12:00*	
1.05		Drain Coolant from Sectors to Be Exchanged	1:45*	
1.06		Bring Reactor Room (RR) to Pressure	2:05*	
1.07		Return Chamber to Atmospheric Pressure	2:05*	
1.08		Decontaminate RR Atmosphere	6:00*	
1.09		Isolate Shield He Coolant Systems in Sectors	5:30*	
1.10		Retract Lower Diverter Coils	25:00**	
1.11		Retract Vapor Diverter Coils	15:00**	
1.12		Rotate RR Hatch to Initial Position	1:50*	
1.13		Position Remote Maintenance Equipment in Hall	6:00*	
		SUBTOTAL:		24:00

* Operation Conducted in Parallel with Task 1.02.

** First 5 Hours of Operation Conducted in Parallel with Task 1.02.
Remainder of Operation Conducted in Parallel with Task 2.0.

FIGURE 4. UWMK-I CONCEPT MAINTENANCE TIME ESTIMATE

TASK CODE	LEVEL 1 TASK (SUBDIVISION)	LEVEL 2 TASK	TASK HOURS	CUMULATIVE TASK HOURS
2.0	Maintenance			
2.01	(Access)	Open Reactor Room (RR) Hatch	:55	(453:30)
2.02		Prepare To Work in RR	6:00	
2.03		Remove Neutral Beam Injectors (NBI)	40:30	
2.03A		Remove Fuel Injector Units	40:30*	
2.04		Remove Magnet Cross Beam Supports	22:35	
2.05		Remove Shield Segments at Sector Joints	159:10	
2.06		Disassemble Blanket Joints	148:00	
2.07		Disconnect Shield He Coolant Lines	8:40	
2.08		Disconnect Reactor Sector Coolant & Vacuum Lines	26:20	
2.09		Disconnect T.F. Magnet Power Leads	3:50	
2.10		Disconnect Reactor Sector Instrumentation	6:00	
2.11		Disconnect T.F. Magnet Coolant and Vacuum Lines	6:40	
2.12		Remove T.F. Magnet Shear Pins	24:50	
2.13	(Exchange)		12:05	(12:05)
2.14	(Reassembly)	Install T.F. Magnet Shear Pins	23:25	(594:10)
2.15		Connect T.F. Magnet Coolant and Vacuum Lines	9:30	
2.16		Connect T.F. Magnet Power Leads	3:50	
2.17		Connect Reactor Sector Instrumentation	8:00	
2.18		Connect Reactor Sector Coolant and Vacuum Lines	41:40	
2.19		Connect Shield Helium Coolant Lines	23:25	
2.20		Assemble Blanket Joints	179:35	
2.21		Conduct Vacuum Chamber Integrity Check	24:00	
2.22		Install Shield Segments	159:50	
2.23		Install T.F. Magnet Cross Beam Supports	31:50	
2.24		Initiate Lithium Flow to Reactor Sector	13:50	
2.25		Initiate Helium Flow to Shield	3:35**	
2.26		Verify Integrity of T.F. Magnet	1:10	
2.27		Install NBI's	55:40	
2.28		Verify Integrity of NBI Installation	3:05	
2.29		Remove Remote Maintenance Equipment	9:30	
2.30		Close RR Hatch	:25	
2.31		Rotate RR Wall 120° (For Next Sector)	1:50	
Subtotal				1059:45

* Operation Conducted in Parallel with Task 2.03

**Operation Conducted in Parallel with Task 2.24

FIGURE 5. UWMAK-I CONCEPT STARTUP TIME ESTIMATE

TASK CODE	LEVEL 1 TASK (SUBDIVISION)	LEVEL 2 TASK	TASK HOURS	CUMULATIVE TASK HOURS
3.0	Validation & Startup			
3.01		Validate Integrity of Vacuum Chamber	2:50*	
3.02		Purge Vacuum Chamber of Impurities	39:45*	
3.03		Return RR to Operational Status	12:55*	
3.04		Raise Lower Diverter Coils	30:00	
3.05		Lower Upper Diverter Coils	18:00*	
3.06		Charge T.F. Magnets and Energy Storage System	24:00**	
3.07		Complete Reactor Preoperational Checks	12:00*	
3.08		Initiate Reactor Operation	6:00***	
3.09		Remove Remote Maintenance Equipment from Hall	35:10***	
		Subtotal		49:00
		Total		1132:45

Note: * Operations Conducted in Parallel with Tasks 2.04 and 3.06.

** First 5 hours Overlaps Last 5 Hours of Task 3.04

*** Operations Conducted after Completion of Readiness Procedures.
Time not Included in Timeline.

For the UWMAK-I design approach the shutdown and startup operations were detailed and presented separately. These phases of the operation are similar for the other two reactor concepts. The 24-hour time estimated for shutdown and preparation for maintenance, Figure 2, is controlled by the toroidal magnet energy removal rate. Since all operations are controlled from shielded enclosures, by remote means, the reduction in radiation intensity after 24 hours is considered sufficient to permit the start of maintenance operations. The startup time estimate is controlled by similar factors (Figure 5). The UWMAK-I maintenance time estimate, Figure 4, for removing the shield segments at the blanket joints and for disconnecting the blanket joints dominates the time requirements for replacement of the reactor sector. The estimate for replacement of the reactor sector does not include inspection of the first wall of adjacent sectors.

The UWMAK-III estimates are summarized for level 2 functions in Figures 6 and 7. The design approach data used as the basis for defining the maintenance functions and time estimates is taken primarily from Reference 2. The total time estimated to exchange the required modules in one reactor sector is approximately 687 hours. The required modules include the "A" module and only one-half of the "B" modules, central wall modules and ISSEC panels since their estimated life is twice that of the "A" module. Replacement times for upper "B" and central wall modules and ISSEC panels are assumed to be equal to the time required to replace the lower modules. Therefore, the estimate given in Figure 6 can be used as a unit of time for replacement of the modules in several of the reactor sectors. The number of reactor sectors which can be worked simultaneously is dependent upon the number of items of each type of maintenance equipment that is provided.

For the UWMAK-III, access to the "A" module and reassembly require 46% of the total downtime while the removal and replacement of the modules requires only 37%. These percentages vary slightly from the previous report and reflect adjustments made in the estimates.

The subsystem time estimates summarized in Figure 7 include removal and replacement of an upper cryo-vacuum pump and particle bombardment plate assembly for one reactor sector. The lower pump is assumed to require the same time. Some of the instrumentation replacement time estimates are also included. Since the number and type of instruments required needs additional definition, this estimate is considered very preliminary. Only the subsystems which are believed to require

FIGURE 6. UWMK-III CONCEPT MAINTENANCE TIME ESTIMATE

TASK CODE	LEVEL 1 TASK (SUBDIVISION)	LEVEL 2 TASK	TASK HOURS	CUMULATIVE TASK HOURS
1.0	Shutdown	Reactor Preparation	24:00	24:00
2.0	Maintenance			638:45
2.01	(Access)	Remove Lateral Support Access Panel	21:15	(135:00)
2.02		Raise/Lower Poloidal Magnets	35:00*	
2.03		Remove RF Heater Wave Guide	12:15	
2.04		Disconnect Lithium Manifolds (Outer Wall)	65:00	
2.05		Disconnect Lithium Manifolds (Central Wall)	17:30*	
2.06		Raise/Lower Shield Segments	36:30	
2.07	(Removal)	Remove "A" Module	38:00	(104:00)
2.08		Remove Graphite ISSEC	19:30	
2.09		Remove "B" Module and Central Wall Module	46:30	
2.10	(Inspection)	Inspect Remaining Modules	72:00	(72:00)
2.11	(Replacement)	Replace Central Wall Module and "B" Module	63:00	(148:30)
2.12		Replace Graphite ISSEC	16:30	
2.13		Replace "A" Module	69:00	
2.14	(Reassembly and Test)	Replace Shield	28:00	(179:15)
2.15		Reconnect Lithium Manifolds (Central Wall)	20:30*	
2.16		Replace Lithium Manifolds (Outer Wall)	63:00	
2.17		Vacuum Check Plasma Chamber	88:15	
2.18		Replace RF Heater Wave Guide	19:00*	
2.19		Reposition Poloidal Magnets	43:00*	
2.20		Replace Lateral Support Access Panel	34:00*	
3.0	Startup	Validation and Startup	24:00	24:00
		TOTAL		686:45

*Operations conducted in parallel with adjacent task(s) in list. 28 Days
14:45 Hrs

FIGURE 7. UWMK-III SUBSYSTEM MAINTENANCE TIME ESTIMATE

TASK CODE	LEVEL 1 TASK (SUBDIVISION)	LEVEL 2 TASK	TASK HOURS	CUMULATIVE TASK HOURS
2.0	Maintenance			
2.31	(Cryo Pumps)	Remove Cryo-Vacuum Pump	21:00	74:00*
2.32		Remove Particle Bombardment Plate	8:00	
2.33		Replace Particle Bombardment Plate	11:00	
		Replace Cryo-Vacuum Pump	34:00	
2.41	(Instruments)	Replace Inner Wall Instruments (Time per Instrument)	:45	19:30**
2.42		Replace External Manifolding Instruments (Time per Instrument)	2:15	258:45***
2.43		Neutron Monitor	6:30	6:30*

*One complete assembly only

**25 Instruments assumed

***115 Instruments assumed

scheduled maintenance have been estimated. Other subsystems including the magnets, instrumentation outside of the reactor room or integral with the removed modules or the RF heaters are either maintained on failure or during reactor operation. Inspection of the remaining first wall in adjacent sectors to that being worked is included in the time estimate but inspection time required for coolant and other service lines, which is scheduled maintenance, has not been estimated. The scheduled work on subsystems other than maintenance of instrumentation and vacuum pumps appears only to involve inspection.

For the General Atomic DPR the time estimates for replacement of the modules are shown in Figure 8. The design concept data upon which the maintenance functions and time estimates are based is taken primarily from Reference 3 and supported by data from the GA-Experimental Power Reactor described in Reference 4. The total time estimate to exchange just two modules plus the modules included for replacement below the track is included. This time is approximately 848 hours. The replacement time required to remove and replace the first two modules totals 22 hours but this includes tooling conversions for the several required operations. Since these changes are planned only once for all modules to be replaced, each additional two modules will require only 8 additional hours. Two modules are used as the increment since two sets of maintenance equipment are installed as the basis for these time estimates.

In addition, the time required for removal of the in-chamber track includes replacement of the 22 modules which are removed to install the track and 11 modules which were replaced under the ceiling track in the original estimate. These are included in this preliminary estimate since the original objective was to replace approximately one-third of the total modules. The estimate will be revised to the modular approach in the next reporting.

The GA-DPR maintenance plan requires a relatively long initial setup time but no additional time for additional modules. Therefore, the outage time distribution between access and replacement functions varies widely for this approach to maintenance since it is dependent on the percentage of the modules being replaced during any particular shutdown.

FIGURE 8. GA-DPR CONCEPT MAINTENANCE TIME ESTIMATE

TASK	LEVEL 1 TASK (SUBDIVISION)	LEVEL 2 TASK	TASK HOURS	CUMULATIVE TASK HOURS
1.0	SHUTDOWN	PREPARATION FOR MAINTENANCE	24:00	24:00
2.0	MAINTENANCE			797:55
2.01	(ACCESS)	REMOVE VACUUM DUCTS	92:55	270:35
2.02		INSTALL REMOTE MAINTENANCE MACHINES	11:00	
2.03		INSTALL MODULE CONTAINER ADAPTERS	2:50	
2.04		INSTALL IN CHAMBER LIGHTING AND TV BOOMS	17:20	
2.05		PREPARE FOR ICMM INSTALLATION	20:50	
2.06		INSTALL ICMM'S	26:30	
2.07		COMPLETE IN CHAMBER TRACK	99:10	
2.08	(REMOVAL)	REMOVE BLANKET MODULES (TWO MODULES)(2)	10:45	(10:45)
2.09	(REPLACEMENT)	REPLACE BLANKET MODULES (TWO MODULES)(3)	11:15	(11:15)
2.10	(REASSEMBLY)	PARTIAL IN CHAMBER TRACK REMOVAL (INCLUDES UNDER TRACK MODULE REPLACEMENT)	169:10	(416:50)
2.11		REMOVE ICMM'S	21:00	
2.12		REMOVE REMAINING TRACK SEGMENTS	40:45	
2.13		REMOVE IN CHAMBER LIGHTING AND TV BOOMS	17:20	
2.14		REMOVE MODULE CONTAINER ADAPTERS	3:50	
2.15		REMOVE REMOTE MAINTENANCE MACHINES	11:00	
2.16		REPLACE VACUUM DUCTS	153:45	
2.17	(CHECKOUT)	PLASMA CHAMBER VACUUM CHECK	88:30	(88:30)
3.0	STARTUP	VALIDATION AND STARTUP	26:30	26:30
		TOTAL:		848:35

- NOTE: (1) INSPECTION OF UNCHANGED MODULES NOT INCLUDED
 (2) ADDITIONAL MODULE REMOVAL = 3.45HRS/1 OR 2 MODULES
 WITH 1 OR 2 RMM
 (3) ADDITIONAL MODULE REPLACEMENT = 4.15 HRS/1 OR 2
 MODULES WITH 1 OR 2 RMM

35 DAYS
 8:35 HRS

2.2.2 Maintenance Equipment Design Approaches - The maintenance equipment concepts are developed in a preliminary manner along with the time estimates. Any estimate of time is associated with an equipment concept that would be required to support the function being performed in that estimated time. However, additional work is required to establish the feasibility of these concepts. Therefore, while lists of equipment have been developed for each of the three baseline design approaches, the feasibility investigations are continuing. The lists of equipment for the baseline design approaches are briefly defined in Figures 9 through 11 for the UWMAK-I, UWMAK-III and GA-DPR reactor design approaches respectively. In addition to identifying the major equipment items and the major functions each performs, the approximate maximum lifting capability required, the principal source of power for the unit and the source or sources from which it is controlled are also identified for each equipment item.

For the UWMAK-I some design feasibility investigations have been conducted. Figures 12 and 13 illustrate the equipment required to move the reactor modules replaced in this first wall/blanket maintenance concept. The transporter shown in Figure 12 is installed beneath each reactor sector (module) and provides structural support at all times. This transporter is designed with minimum moving parts and uses gas bearing supports for translation of the module during replacement. The tractor shown in Figure 13 provides the gas pressure (up to 315 psi for the forward gas bearing near the reactor core) and the tractive forces and translational moments to move the module. A manned concept is indicated for the tractor operation although more analysis of this approach must be conducted before recommendations can be made.

For UWMAK-I, several specialized tool designs have also been outlined to support unique or frequently performed functions. One of these is illustrated in Figure 14. This tool is required to remotely disconnect and reconnect quick attachment connectors considered for small lines. Its use will speed up these functions considerably. The limitations of quick attachment fittings must be further considered for feasibility of their leak-proof integrity to meet requirements in these applications. Another specialized tool is shown in Figure 15. This is an adaptation of the well known impact wrench for use at the end of manipulator arms. Such a concept reduces the time required for the placement of such tools. One further illustration of a specialized tool concept derived for UWMAK-I is shown in Figure 16. This mechanism is installed on large lines, such as vacuum

FIGURE 9. MAJOR MAINTENANCE EQUIPMENT TO SUPPORT
THE UWMAK-I MAINTENANCE CONCEPT

DESIGNATION	MAJOR FUNCTIONS (FIRST WALL/BLANKET)	OPERATING LOCATION	OTHER EQUIPMENT INTERFACE	LIFTING CAPABILITY	POWER SOURCE	CONTROL AUTHORITY
HEAVY MAINTENANCE UNIT (HMU)	LIFT AND TRANSFER MAGNET CROSS BEAMS	REACTOR ROOM & HALL	NONE	30 TONNES	FACILITY	REMOTE CONTROL ROOM (RCR), CAB ON UNIT
OPERATIONAL MAINTENANCE UNIT (OMU)	DISASSEMBLE JOINTS, REMOVE SHIELDS, SEG- MENTS, OPERATE JACKS, DOLLIES	REACTOR ROOM (RR)	DOLLIES, TOOLS, FIXTURES	≈ 1 TONNE	FACILITY	RCR, CAB ON UNIT
REACTOR MODULE TRANSPORTER (RMT)	SUPPORT REACTOR MODULE (SECTOR), BASE FOR MODULE MOVEMENT	BENEATH REAC- TOR MODULE, RR	TRACTOR UNIT	≈ 3500 TONNES	TRACTOR UNIT	TRACTOR UNIT
TRACTOR UNIT (TU)	TOWS HEAVY REACTOR COMPONENTS, PRO- VIDES COMPRESSED GAS FOR BEARINGS	RR, HALL, HOT CELL, STORAGE	REACTOR MODULE & NEUTRAL BEAM UNIT TRANS- PORTERS	N/A	FACILITY	RCR, CAB ON UNIT
HIGH ACCESS MAINTENANCE UNIT (HAMU)	PROVIDES ACCESS TO POLOIDAL BORE	RR	YOKE REMOVAL TOOL, SHEAR PIN EXTRACTOR	≈ 50 TONNES	FACILITY	RCR, CAB ON UNIT
SHIELD SEGMENT DOLLIES	SUPPORTS SEGMENTS DURING MAINTENANCE	RR, REACTOR HALL, HOT CELLS	OPERATIONAL MIANTENANCE UNIT (OMU)	30 TONNES	OMU	OMU
YOKE INSTALLATION TOOL	REMOVE & INSTALL YOKE	RR	OMU, HAMU	N/A	OMU, HAMU	OMU, HAMU
MAGNET SHEAR PIN EXTRACTOR	EXTRACT AND INJECT TF MAGNET PINS	RR	HAMU	N/A	HAMU	HAMU
SPECIAL TOOLS (4 TYPES)	WRENCH, PIPE CONNECTION TOOLS	RR	OMU	N/A	OMU	OMU
CREW TRANSFER UNIT	TRANSFER CREW TO UNIT CABS	RR, REACTOR, HALL, HOT CELLS	HMU, OMU, TU, HAMU	N/A	FACILITY, SELF	RCR, CAB ON UNIT

FIGURE 10. MAJOR MAINTENANCE EQUIPMENT TO SUPPORT
THE UWMK-III MAINTENANCE CONCEPT

DESIGNATION	MAJOR FUNCTIONS (FIRST WALL BLANKET)	OPERATING LOCATION	OTHER EQUIPMENT INTERFACE	LIFTING CAPABILITY	POWER SOURCE	CONTROL AUTHORITY
OVERHEAD CRANE (OC)	LIFT AND MOVE LARGE COMPONENTS	ABOVE REACTOR	SUPPORT FIXTURES, UPPER VACUUM PUMP MACHINE, DOLLIES	150 TONNES	FACILITY	REMOTE CONTROL ROOM (RCR)
OVERHEAD MANIPULATOR (OM)	OPERATE TOOLS AND DISCONNECT LINES	ABOVE REACTOR	VACUUM PUMP MACHINE, OC	≈ 2 TONNES	FACILITY	RCR
PRIMARY MAINTENANCE MACHINE (PMM)	REMOVE AND REPLACE (R/R) COMPONENTS OUTSIDE OF FIRST WALL	REACTOR ROOM (RR)	SHEAR PANEL FIXTURE, DOLLIES, TOOLS	150 TONNES	FACILITY	RCR, CAB ON UNIT
MODULE HANDLING MACHINE (MHM)	R/R "A" AND "B" MODULES, ISSEC	REACTOR ROOM	MODULE FIXTURES, DOLLIES, TOOLS	75 TONNES	FACILITY	RCR, CAB ON
VACUUM PUMP MACHINE - UPPER (VPM-U)	R/R UPPER VACUUM PUMP COMPONENTS	ABOVE REACTOR	OC, OM, TOOLS	10 TONNES	FACILITY	RCR
VACUUM PUMP MACHINE - LOWER (VPM-L)	R/R LOWER VACUUM PUMP COMPONENTS	BELOW RR FLOOR	OC, TOOLS	10 TONNES	FACILITY	RCR
TRACTOR UNIT (TU)	MOVE DOLLIES, TRANSFER CREWS	RR, HOT CELL, STORAGE	OC, PMM, MHM, DOLLIES	N/A	SELF CONTAINED	RCR, CAB ON UNIT
FIXTURES (4 TYPES)	SUPPORT ACCESS PANELS, MODULES	ON PMM, MHM	OC, PMM, MHM, DOLLIES	100 TONNES, MAX.	PMM, MHM	PPM, MHM
SPECIAL TOOLS	JACK SHIELDS, WELD/ CUT, BOLT, ATTACH, CLEANING, ALIGNMENT	ON PMM, MHM, VPM-U, CPM-L	OC, PMM, MHM, VPM-U, VPM-L	N/A	PMM, MHM, VPM-U, VPM-L	PMM, MHM, VPM-U, VPM-L
DOLLIES (9 TYPES)	TRANSPORT COMPONENTS TO HOT CELL, STORAGE	RR, HOT CELL, STORAGE	OC, PMM, MHM	N/A	TU	RCR, CAB ON TUG
LINE FREEZE UNITS	SOLIDIFY LITHIUM PLUGS IN LINES	LITHIUM MAN- IFOLDS	PPM	N/A	N/A	RCR, PMM

FIGURE 11. MAJOR MAINTENANCE EQUIPMENT TO SUPPORT
THE GA-DPR MAINTENANCE CONCEPT

DESIGNATION	MAJOR FUNCTIONS (FIRST WALL/BLANKET)	OPERATING LOCATION	OTHER EQUIPMENT INTERFACE	LIFTING CAPABILITY	POWER SOURCE	CONTROL AUTHORITY
OVERHEAD POLAR CRANE (OC)	TRANSFER MAINTENANCE EQUIPMENT	ABOVE REACTOR	OVERHEAD MANIPULA- TOR ICMM, RMM	270 TONNES	FACILITY	REMOTE CONTROL ROOM (RCR), OC CAB
OVERHEAD REMOTE MANIPULATOR (OM)	INSTALL & SERVICE MAINTENANCE EQUIPMENT	ABOVE REACTOR, BELOW OC	OC, RMM, ICMM CONTAINER	≈5 TONNES	FACILITY	RCR, OC CAB
REMOTE MAINTENANCE MACHINE (RMM)	SUPPORT ICMM FUNCTIONS, MODULE REPLACEMENT, LAY TRACK	AUXILIARY VACUUM PORT	OC, OM, ICMM ADAPTERS, TOOLS, DOLLIES, CON- TAINERS, TRACKS	10 TONNES	FACILITY	RCR, OC CAB
IN-CHAMBER MAINTENANCE MACHINE (ICMM)	MODULE REPLACEMENT, LAY TRACK	PLASMA CHAMBER INTERIOR	RMM, TRACKS, TOOLS, CONTAINERS	1 TONNE	ADAPTER	RCR
LIGHTING AND TV ADAPTER	INTERIOR CHAMBER LIGHTING AND TV, LASER BEAM DIRECTION	AUXILIARY VACUUM PORT	OC, OM, ICMM, RMM	0	FACILITY	RCR, COMPUTER
ICMM CONTAINER	ICMM INSERTION, STORAGE	ON RMM ADAPTER	OC, OM, ICMM, RMM, RMM ADAPTER	10 TONNES	RMM ADAPTER	RCR, OC CAB
MODULE CONTAINER ADAPTER	HOLD MODULES, PARTS AND TRACK ADAPTERS	AUXILIARY VACUUM PORT	OM, ICMM, RMM	1 TONNE	N/A	AUTOMATIC, MECHANICAL
SHIELDED VEHICLES (2 TYPES)	TRANSFER CREWS, CONNECT POWER, TOW DOLLIES	REACTOR ROOM, HOT CELL, STORAGE	OC, OM, RMM	0.5 TONNE	SELF CONTAINED	SELF CONTAINED, RCR
SPECIAL TOOLS (6 TYPES)	ATTACH, MANIPULATE, WELD/CUT, TEST, CLEAN	ON RMM & ICMM	ICMM, RMM, ADAPTERS	≈1 TONNE MAX.	ICMM, RMM	ICMM, RMM
DOLLIES (10 TYPES)	TRANSPORT EQUIPMENT & MODULES	REACTOR ROOM, HOT CELL STORAGE	ALL MAINTENANCE EQUIPMENT	≈20 TONNES MAX.	VEHICLES	VEHICLES

FIGURE 12. RME-3 REACTOR MODULE TRANSPORTER

FIGURE 13. RME-4 TRACTOR UNIT

FIGURE 14. RME-10 LINE CONNECTOR INSTALLATION/REMOVAL TOOL

FIGURE 15. RME-11 IMPACT WRENCH

FIGURE 16. RME-12 BELLOWS RETRACT MECHANISM

ducts, where a bellows connection must be retracted during the disconnect operation. Such an installation was conceived for the vacuum lines where an inner and outer bellows is used and the outer bellows must be retracted and held in place to provide access to the inner bellows during its disconnect operation. Additional tools will be devised in conceptual form as the study progresses.

For the UWMAK-III design approach an extension of the Bechtel concept shown in the UWMAK-III report is used for the principal maintenance equipment. Figure 17 illustrates the concept of the Primary Maintenance Machine indicated in Figure 10. This machine illustrates a "working face" principal in which the tools on the vertical face are varied as required to conduct the functions of gaining access to the blanket modules. The figure shows the fixture which supports the access panel that is removed from between the toroidal field coils installed on the "working face". Since this approach differs from that used for UWMAK-I, it is being analyzed separately for feasibility.

The equipment approach used for the GA-DPR concept is illustrated by the in-chamber maintenance machine illustrated in Figure 18. This machine was conceived by General Atomic for their Experimental Power Reactor (Reference 4) and requires support by the equipment listed in Figure 11. The feasibility of the equipment conceived to support this concept, particularly the Remote Maintenance Machine, must be investigated further. The concept requires precise control of all items passing through the vacuum ports and, therefore, special machines are conceived instead of using crane and overhead manipulator devices.

2.2.3 Development of TOCOMO Code for Doublet Configuration - During the study reporting period, activities were focused on adapting the TOCOMO code to a doublet configuration and characterizing the DPR configuration for inclusion of this code. The representation of the doublet plasma shape was defined for a true doublet configuration rather than the double ellipse approximation. Derived relationships were obtained for plasma cross-sectional area, shape factor, plasma volume and wall area (assuming a 10 percent scrape-off). The locations of all the poloidal field coils (F-coils, E-coils and two distinct plasma currents) were specified for the DPR size reactor as well as relationships to scale the locations and currents to other size reactors. The locations and shape of the B-coils were also characterized as a function of the wall loading (variations in thickness of blanket and shield), maximum field strength of the F-coils, major and minor plasma radii and assumed

FIGURE 17. PRIMARY MAINTENANCE MACHINE (WITH ACCESS PANEL FIXTURE)
(BECHTEL CONCEPT)

FIGURE 18. IN-CHAMBER MAINTENANCE MACHINE FOR THE GA-DPR
(GA-EPR CONCEPT)

plasma scrape-off. Thermal power output for a doublet shape plasma was analyzed using a zero dimensional plasma physics code for a TIM confinement law. Power levels were varied from 1000 MW to 10,000 MW for poloidal betas equal to one-half the aspect ratio.

2.3 Contacts - The following persons were contacted during this reporting period and invited to participate in the review of time estimates and maintenance technique feasibility to be held at MDAC-EAST, St. Louis, MO on 20 and 21 July 1977. A letter of invitation was forwarded together with a preliminary agenda on 27 May 1977.

<u>Date</u>	<u>Contact</u>	<u>Location</u>
5/13/77	Mr. Bruce G. Twining Systems and Applications Branch Division of Magnetic Fusion Energy	Energy Research and Development Administration Washington, DC
5/13/77	Mr. Eugene E. Meintel Maintenance Staff Engineer	Commonwealth Edison Co. Joliet, IL
5/18/77	Mr. Dale A. Tobias Operations System Engineer	Hot Fuel Examination Facility Argonne, West, INEL Idaho Falls, ID
5/18/77	Dr. Mike Roberts	Oak Ridge National Laboratories Oak Ridge, TN
5/18/77	Mr. Jerry L. Marshall Manager, Maintenance Engineering	Fast Flux Test Facility Westinghouse, Hanford, HEDL Richland, WA
5/18/77	Mr. Jim McKay Manager, N Reactor Maintenance	United Nuclear Industries Richland, WA
5/18/77	Mr. Richard L. Bean Director, Commercial Division	United Nuclear Industries Richland, WA
5/18/77	Mr. Herbert C. Stevens	Argonne National Laboratory Argonne, IL
5/18/77	Mr. Ronald E. Mullen Supervisor, Remote Operation Systems	Aerojet Manufacturing Co. Fullerton, CA
5/24/77	Mr. John Purcell Program Manager	General Atomic Company San Diego, CA
5/24/77	Dr. Thomas E. Shannon Union Carbide	Oak Ridge National Laboratory Oak Ridge, TN

<u>Date</u>	<u>Contact</u>	<u>Location</u>
5/24/77	Mr. Igor Sviatoslavsky Nuclear Engineering Department	University of Wisconsin Madison, WI
5/26/77	Mr. Philip T. Spampinato Grumman Aerospace Corporation	Oak Ridge National Laboratory Oak Ridge, TN
5/26/77	Mr. James W. French Fusion Power Systems Department	Westinghouse Advanced Energy System Division Pittsburgh, PA

2.4 QUANTITATIVE ESTIMATE OF OVERALL PROGRESS

Figure 19 provides the estimated completion percentage accomplished through this second reporting period for each study task.

FIGURE 19. COMPLETION PERCENTAGE

<u>Number</u>	<u>Task Title</u>	<u>Completion Percentage</u>		
		<u>Prior Periods</u>	<u>This Period</u>	<u>Total</u>
1.	Maintenance Plans	44%	26%	70%
2.	Time-to-Perform Estimates	30%	20%	50%
3.	Maintenance Equipment Requirements	31%	27%	40%
4.	Evaluation	0	31%	31%
5.	Desirable Maintenance Design Features	0	0	0%
TOTAL:		19%	24%	43%

The level of effort planned for the study will remain constant during the next time period to complete the TOCOMO programming and to initiate effort on Task 5. This level will provide an estimated completion percentage during the next reporting period that will assure study completion within the required time.

3.0 WORK PLANNED FOR THE NEXT REPORTING PERIOD

3.1 MAINTENANCE SYSTEM CONCEPTS

Conceptual design studies of the maintenance equipment items required to conduct the functions included in the baseline time estimates will continue. This work will be conducted only to ascertain spacial and movement feasibility as a basis for defining cost of the maintenance system and the validity of the time estimates. Initial emphasis will be placed on the UWMAK-I maintenance equipment followed by the GA-DPR and UWMAK-III equipment. Smaller items such as dollies and tools will be detailed only when necessary to indicate critical dimensions.

3.2 PREPARATION OF DOCUMENTATION FOR TIME ESTIMATE REVIEW

An informal summary of the time estimates for each baseline configuration will be prepared to provide a basic data source for the review of the time estimates. This document will be forwarded to each member of the review team far enough in advance of the review meeting to allow him to prepare for the meeting on 20 and 21 July. A briefing to summarize the data and coordinate the review activities will be prepared in addition to the document.

3.3 TIME LINE AND MAINTENANCE TECHNIQUE REVISIONS

Subsequent to the time line analysis and maintenance technique review the comments will be examined and revisions made in the maintenance techniques and time estimates as deemed necessary to attain credible baseline estimates. Upon completion of these revisions it is planned to develop the time estimates for the alternatives required as data for the trade studies.

3.4 TOCOMO CODING SUPPLEMENT

The coding of the General Atomic Demonstration Power Reactor characteristics for sizing and casting this design will continue during the next reporting period. This work should near completion by the termination of this period.

Activities to be performed include characterization of the maintenance approach/equipment and the wall/blanket/shield. To assure the power plant may be scaled from a DPR size to a commercial power plant size, an intermediate heat transfer loop (Na) will be added with thermal storage capability. All other ancillary systems will be adapted to the doublet configuration. Trial runs of TOCOMO will be conducted to assure consistent output data.

4.0 REFERENCES

1. "UWMAK-I, A Wisconsin Toroidal Fusion Reactor Design," by The University of Wisconsin Fusion Feasibility Study Group, Nuclear Engineering Department, University of Wisconsin, Sponsored by the Wisconsin Electric Utilities Research Foundation and the U.S. Energy Research and Development Administration, Report No. UWFD-68, Vol. I and Vol. II, May 1975.
2. "UWMAK-III, A Noncircular Tokamak Power Reactor Design," by Conn, Robert W. and Kulcinski, Gerald L., et al, University of Wisconsin, Madison, Wisconsin, Report UWFD-150, July 1976.
3. "Conceptual Design Study of a Noncircular Tokamak Demonstration Fusion Power Reactor," by the Fusion Engineering Staff, General Atomic Company, prepared for U.S. Energy Research and Development Administration, General Atomic Report BA-A13992, November 1976, ERDA Contract (E(04-3)-167).
4. "Experimental Fusion Power Reactor Conceptual Design Study," by Baker, C. C., et al; General Atomic Company, EPRI Report ER289, December 1976, EPRI Contract 323-1.