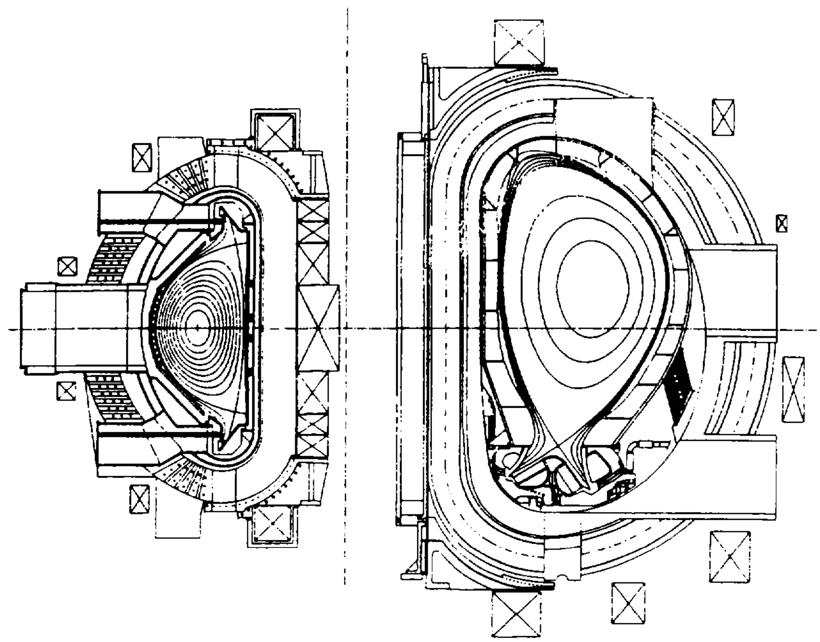
Technical and Cost Assessment of the PCAST Machine

Final Report



PCAST ITER

Volume II

Chapter 4.0 Cost

prepared by
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Chapter 4 - Cost Basis

1.0 INTRODUCTION

This chapter of the PCAST Study Report provides the estimated cost of the reference design point for the PCAST recommendation of an ignition-moderate-burn device and addresses some of the more important cost derivatives for variations around that reference design point. Since the PCAST recommendation was to explore an ignition-moderate-burn device smaller and less costly than ITER, the costing for this machine is presented using both the same Work Breakdown Structure (WBS) and format as for ITER. The basic ground-rules established for costing the reference design point in this study were to use cost scalings derived from ITER wherever appropriate and to use the data from other projects for deriving cost scalings in areas where ITER merely used fixed numbers or the data was considered more representative of the PCAST machine. The estimated costs for the reference design were developed using appropriate cost scalings derived from the cost data bases of three recently baselined fusion devices; ITER, BPX, and TPX.

Cost scaling, as opposed to a "bottoms up" estimating approach involves considerable judgment. The specific choices made are debatable, and result in a range of costs. There is also a range of costs associated with future design development. Reduced costs may result from future design optimization; on the other hand, increased costs may arise from a need for future design compromises. Both considerations are clearly a major factor in the PCAST Machine where there has been relatively little time for design development and optimization. Accordingly, a range of scaling uncertainty has been assigned for each WBS element to provide a basis for assessing this machine.

This is a U.S. initiated study and therefore the costs will also be established using the U.S. Total Project Cost (TPC) methodology. However, since neither the schedule for this device nor the potential funding profile for such a device is known at this time, the TPC will only be presented in constant FY-95 dollars.

The mission of this device is significantly different from ITER and even BPX, it is inevitable that comparisons will be made between the costs of this device and those two ignition machines. Rather than compare absolute costs of engineering/physics, R&D, and other items such as construction management, etc. that agreements between potential international partners may impact, it is more appropriate to only focus on the construction estimates which are not as sensitive to these potential agreements. Accordingly, any comparison data will be expressed as percentages of the current ITER construction cost and as percentages of construction cost of BPX.

A reference design point had to be selected early in the study process. In addition, the cost sensitivity of design variations around the reference design point was assessed. These variations around the design point were previously discussed in Chapters 1 through 3. Costing the impact of these variations was achieved using the SUPERCODE and the algorithms developed for this study.

This chapter is organized into four sections as follows:

- Section 1 - Introduction
- Section 2 - Cost Estimate Approach
- Section 3 - Cost Estimates
- Section 4 - Cost Scaling Sensitivity
- Section 5 - Listing of Annexes

2.0 Cost Estimate Approach

This section describes the approach taken to prepare the cost estimate for the Reference Design. It includes discussions of the estimate format, the cost data for the three reference projects (ITER, BPX, and TPX), and the derivation of the cost scalings used to cost the Reference Design Point.

2.1 Estimate Format

The cost estimate for this device follows the format established for ITER in the Interim Design Report. In the Interim Design Report all ITER manpower costs were reported in Professional Person Years (PPY's) and in ITER Unit of Accounts (IUA), where IUA = $1,000 U.S. (January '89 Value)[1]. ITER did not make any attempt to escalate costs from 1989 to present day for two reasons:

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[1] Also, 1 IUA = 127510 Yen (January 1989 buying power) = 875.8 ECU (January 1989 buying power). ITER Interim Design Report (June 12, 1995), page VIII-7.

- Present day costs would not provide a meaningful comparison between the estimates made for the CDA (1989) and the TAC 4 (1994); and
- Escalation factors to be applied would be different for the different Home Teams and the countries in which the hardware and construction would take place.

The ITER cost estimate was divided into four tables as follows[2]:

- Table 1 - Engineering Manpower and R&D Costs

  This table includes all engineering/physics and R&D costs needed to complete engineering/physics, exclusive of the manufacturing engineering (part of construction estimate) and engineering in support of construction (included in Table 3). This table encompasses the EDA and the period after the EDA and before physical construction begins.
- Table 2 - Construction Costs

  This table includes the estimated capital costs of construction, including Allowance for Indeterminables (AFI) - items which are part of the cost element, but for which no separate estimate is yet possible, and cost uncertainty (both positive and negative). This table includes manufacturing engineering.
- Table 3 - Construction Management, Engineering Support During Construction, and Commissioning

  This table includes the manpower support during the construction period.
- Table 4 - Operations and Decommissioning Costs

[2] ITER Interim Design Report (June 12, 1995), pages VIII-5 through VIII-15.

This table includes the cost of operating ITER on an annualized basis and the decommissioning costs based as a percentage of total capital costs for the ITER facility.

Conceptual design costs, the host country siting costs, and the host country regulatory costs were excluded from the ITER cost estimate. Conceptual design costs were excluded because they never considered part of the formal ITER Project. Host country costs siting and regulatory costs were also excluded by ITER because they believed them to be very dependent on the site that is chosen for ITER. However, the engineering/physics manpower that are foreseen as being needed by the JCT and Home Teams (or other similar organizations) is included in Table 1.[3]

2.2 Total Project Cost (TPC)

Since this is a U.S. initiated study, the cost of this device was also costed in absolute constant year (FY-95) dollars using the U.S. Total Project Cost (TPC) methodology. The TPC consists of the conceptual design costs, the engineering/physics manning (both before and during construction), construction costs, contingency, R&D, and other costs such as commissioning. The derived cost scalings (discussed later in this Section) were used to estimate the Engineering/Physics manning, construction project, other , and R&D costs. . Hence in terms of the ITER cost estimate format, the TPC would include Table 1 (Engineering Manpower and R&D), Table 2 (Construction Costs) with the U.S. concept of contingency added,

[3] ITER Interim Design Report (June 12, 1995), page VIII-14.

and Table 3 (Construction Management/Engineering Support During Construction/Commissioning). To these would be added the conceptual design costs and contingency costs based on the average percentage applied to the so-called "PACE" project costs. However, since the U.S. TPC methodology only addresses the costs leading to and including the construction project, the ITER Table 4 annualized operating and decommissioning costs, which are part of the life-cycle costs, are not included in the TPC.

2.3 Comparison Approach

One purpose of this PCAST study is to develop mission-related cost sensitivity information. While a comparison to U.S. TPC could be developed, it would be meaningless for the international arena in which this device would be built where U.S. TPC methodology is not applicable. Hence any comparisons had to be based in terms of an international project. Notwithstanding the significant differences in mission, it is almost inevitable that comparisons will be made to both ITER and BPX. In order to compare the devices on a consistent basis, any comparisons to ITER and BPX will be limited to percentage comparisons to the construction estimate, including Allowances for Indeterminables (AFI). Engineering and R&D estimates, annualized operating costs, and decommissioning costs would probably be highly dependent on agreements made between potential international partners, the site of this device, and the method of decommissioning selected, and therefore are excluded for comparison purpose. Additionally, the ITER cost estimate includes cost uncertainty, both positive and negative. This was derived by

ITER based on a comprehensive review of the range of individual estimates provided by the Home Teams. Since time does not permit a similar attempt to review cost uncertainties for this device, the comparison of construction estimates will be limited to only the capital cost estimate, without any attempt to assign contingency or cost uncertainty.

2.4 Reference Cost Data

For purposes of developing cost scalings to estimate the cost for this device, three reference project cost data bases were utilized. These were ITER, BPX, and TPX. In order to make the data bases consistent, site credits (excluding land and potable water) were added to the baselined costs for BPX and TPX. The reference cost data base for each of these devices was as follows:

- ITER - the recently issued Interim Design Report (June 1995);
- BPX - the last cost estimate presented to ESAAB (August 1991) -- with site credits added back in to put BPX on the same basis as ITER; and
- TPX - the last cost estimate presented in the 1996 Construction Project Data Sheet (June, 1995) -- with site credits added back in to put TPX on the same basis as ITER.

Table 4.2-1 below provides the three construction cost estimates for these reference projects:

Table 4.2-1
Reference Construction Estimates

ITER WBS	Title	ITER[4] (FY-89$)	BPX (FY-89$)	TPX (FY-89$)
1	**Tokamak Systems**			
1.0	Magnet Systems			
	1.1 TF Magnets	$1,160M	$ 126M	$ 43M
	1.2 PF Magnets	$ 447M	$ 30M	$ 11M
	1.3 Central Solenoid	$ 229M	$ 17M	$ 9M
	1.4 Structure	$ 73M	$ 12M	$ 1M
1.5	Vacuum Vessel	$ 175M	$ 17M	$ 6M
1.6	First Wall/Blanket System	$ 410M	$ 13M	$ 0M
1.7	Divertor	$ 178M	$ 5M	$ 18M
1.8	Fueling Systems	$ 34M	$ 7M	$ 0M
1.9	Internal Control Coils	$ 0M	$ 7M	$ 1M
	Subtotal Tokamak Systems	*$ 2,706M*	*$ 234M*	*$ 88M*
2	**Tokamak Aux Systems**			
2.1	Not Used			
2.2	Machine Assembly & Tooling	$ 177M	$ 77M	$ 11M
2.3	Remote Handling Equipment	$ 226M	$ 24M	$ 9M
2.4	Cryostat	$ 71M	$ 0M	$ 6M
2.5	Auxiliary Heat Transfer Sys			
	2.6 Primary Heat Transfer Sys.	$ 138M	$ 0M	$ 0M
	3.3 Secondary Heat Transport Systems	$ 65M	$ 0M	$ 0M
	3.5 Heat Rejection Systems	$ 16M	$ 6M	$ 7M
	3.6 Chemical Control Systems	$ 19M	$ 12M	$ 12M
2.7	Thermal Shields	$ 25M	$ 7M	$ 0M
	Subtotal Tok Aux Systems	*$ 737M*	*$ 126M*	*$ 45M*
3	**Tokamak Fluid Systems**			
3.1	Vacuum Pumping Systems	$ 61M	$ 10M	$ 6M
3.2	Tritium Plant	$ 72M	$ 12M	$ 0M
3.4	Cryogenic Systems	$ 243M	$ 44M	$ 6M
	Subtotal Tok Fluid Systems	*$ 376M*	*$ 66M*	*$ 12M*

[4] ITER Interim Design Report (June 12, 1995), Table 3.3-1.

Table 4.2-1
Reference Construction Estimates
(Continued)

ITER WBS	Title	ITER[5] (FY-89$)	BPX (FY-89$)	TPX (FY-89$)
4	**Power Supply/Control Sys**			
4.1	Coil Power Supply Systems	$ 339M	$ 123M	$ 45M
4.3	Steady State Power Supply	$ 39M	$ 18M	$ 11M
4.4	Not Used			
4.7	Poloidal Field Control	$ 1M	$ 0M	$ 0M
4.8	CODAC & Interlocks			
	4.5 Command Cntl/Data Acquist.	$ 76M	$ 20M	$ 11M
	4.6 Interlocks & General Alarms	$ 2M	$ 1M	$ 0M
	Subtotal Power Systems	*$ 457M*	*$ 162M*	*$ 67M*
5	**Additional Heating, Current Drive & Diagnostics**			
5.0	Auxiliary Heating Systems			
	4.2 Add'l Heating/CD Power Sys.	$ 85M	$ 8M	$ 0M
	5.1 - 5.3 ICRF, ECRF, NBI	$ 273M	$ 63M	$ 41M
	5.4 Other Heating/Current Drive	$ 0M	$ 0M	$ 8M
5.5	Diagnostics	$ 148M	$ 25M	$ 13M
	Subtotal Htg / CD / Diagnostics	*$ 506M*	*$ 88M*	*$ 62M*
6	**Site & Facilities Support**			
6.1	Site	$ 0M	$ 26M	$ 14M
6.2	Buildings	$ 891M	$ 88M	$ 44M
6.3	Waste Treatment/Storage	$ 69M	$ 0M	$ 0M
6.4	Radiation Monitoring	$ 4M	$ 0M	$ 0M
6.5	Liquid Distribution	$ 55M	$ 0M	$ 6M
6.6	Gas Distribution	$ 20M	$ 0M	$ 0M
6.7	General Testing Equipment	$ 25M	$ 0M	$ 0M
6.8	Sampling Systems	$ 4M	$ 0M	$ 0M
	Subtotal Site / Facilities Support	*$ 1,068M*	*$ 114M*	*$ 64M*
	Total	**$5,850M**	**$ 790M**	**$ 338M**

2.5 Derivation of Cost Scalings

The first choice in developing the costs for the PCAST machine was to use bottoms-up estimates to the maximum extent feasible. Failing

[5] ITER Interim Design Report (June 12, 1995), Table 3.3-1.

to have this choice, the alternate approach was to use cost scalings from a similar design.

There were two types of cost scalings developed for costing this device. The first ones were developed for estimating the construction costs. For the majority of hardware related systems, it was possible to develop scalings based on physical parameters (e.g., $/m^3, $/kg, $/w, number of pieces, etc.). The second type of costing parameters were used to estimate other non-construction project items such as engineering/physics manning and R&D costs. These were primarily derived from simple ratios of these elements to hardware. Appropriate scalings were derived after analyzing similar ratios of all three reference device cost data bases.

For purposes of developing construction cost scalings, we focused on identifying the key ITER costing parameters. To facilitate identifying the key ITER costing parameters, data sheets such as **Figure 4-1** were developed to link the ITER cost estimate for that element to physical parameters. These data sheets were then reviewed with members of the JCT and U.S. Home Team that participated in the development of the ITER Cost Element for the Interim Design Report. They assisted in identifying the most sensitive physical parameter for the ITER Project. Cost scalings based on these key parameters were then developed for ITER and compared to similar scalings developed for BPX and TPX. Since time did not permit development of bottoms-up estimates, costs were either derived from scaling components and systems from ITER costs, or from other projects like BPX and TPX when judged to be more applicable. A complete set of these ITER Data Sheets are provided as **Annex I** to this chapter.

Annex II to this chapter provides a more detailed WBS by WBS derivation of the cost scalings used for costing this device. It contains information from the ITER data sheets and the equivalent scalings based on BPX and TPX using the same physical parameters suggested for ITER. Some possible alternate cost scaling schemes are also addressed. It also contains a discussion of the estimates developed during the design concept development for the PCAST machine. Finally, it provides the PCAST estimate and discussion of the rationale for the cost scaling finally arrived at for costing this device.

Annex III to this chapter relates the Engineering, R&D, and Construction Support, and Conceptual Design costs for the three reference projects to their construction costs. Only a bottom-line comparison figure was developed since the ITER data had not yet allocated fully these categories to individual WBS elements. A composite ratio for Engineering, R&D, Construction Support, and

Sample ITER Data Sheet

CRYOSTAT (WBS 2.4)

Material	316 LN-IG Stainless Steel
Type of design	double wall, welded ribbed
Outside Diameter (m)	36.5
Inside Diameter (m)	36.0
Overall Height (m)	36.0
Cylindrical section, height (m)	20.9
Nominal inner and outer wall thickness (mm)	20
Mass (tonnes)	2,165
Internal surface area (m^2)	5,030
Volume (m^3)	31,400
Estimate (kIUA or 89M$)	71

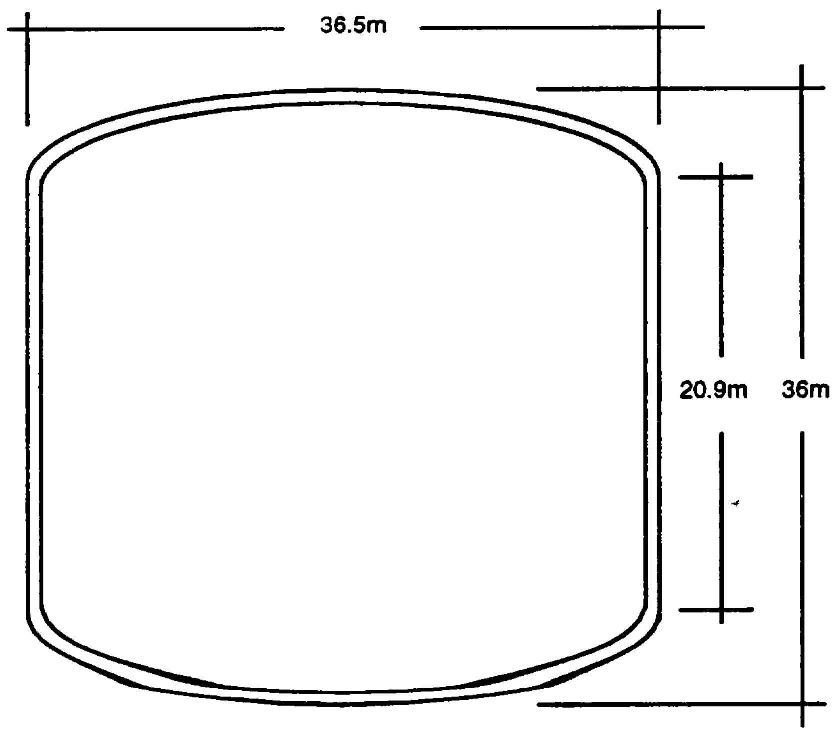


Figure 4-1

Conceptual Design is then used for purposes of estimating the Total Project Cost (TPC).

2.6 Allowance for Indeterminables

The ITER cost estimate included an Allowance for Indeterminables (AFI). The AFI included items which are part of the cost element, but for which no separate estimate is yet possible. When considering AFI for the PCAST estimate, the following approach was utilized:

- If the PCAST estimate was developed from unit cost scalings derived from the ITER cost estimate which included AFI, no additional AFI was applied to PCAST;
- If the ITER cost estimate did not include any AFI, no AFI was applied to the PCAST estimate;
- If the PCAST estimate was developed by scaling from the ITER estimate without AFI, the ITER AFI was added to the PCAST estimate after appropriate scaling; or
- If the ITER AFI were included for a complexity of the ITER design that was not applicable to PCAST, no AFI was applied to the PCAST estimate.

3.0 Cost Estimates

This section summarizes the details of the cost estimates for the Reference Design Point in terms of Total Project Cost (TPC) and as percentage comparisons to the ITER and BPX construction estimates.

3.1 Total Project Cost

Table 3.1-1 below summarizes the Total Project Cost of this device for the reference design point expressed in constant FY-95 dollars.

Table 3.1-1
PCAST Study Total Project Cost

TPC Category	Estimated Costs (FY-95$)
Conceptual Design[a]	$ 95M
Engineering/Physics Manning[b]	$ 650M
Construction Project[c]	$3,220M
R&D Costs[b]	$ 320M
Other Costs (construction support)[b]	$ 480M
Subtotal	*$ 4,765M*
Contingency[d]	$1,050M
Total	**$5,815M**

Notes: [a]Conceptual design costs based on data available from BPX and TPX Project cost data bases. Assumed ratio to construction costs of 3%.

[b]Engineering/Physics manning, R&D costs, and Other costs derived from cost scaling based on the data bases of the three reference projects (ITER, BPX, and TPX).

Ratio of engineering to construction costs was assumed to be approximately 20%. The ratio of R&D and other costs (construction management, title III engineering, commissioning, etc.) to construction costs was assumed to be approximately 10% and 15% respectively.

[c]Construction Project costs consist of hardware, installation craft labor, and manufacturing engineering. These costs were derived from cost scalings based primarily on physical parameters.

[d]Contingency costs based on data available from BPX and TPX Project cost data bases and consideration of the stage of this design - average of 22% used.

Costs are de-escalated from FY-95$ to FY-89$ using the factor of 1.2415 recommended in the ITER Interim Design Report of June 12, 1995. It should be noted that this de-escalation factor varies slightly from the recently published DOE "FY 1995 Inflation Rate Summary" -- this document recommends a de-escalation factor of 1.208 (a difference of approximately 10%). Notwithstanding this, the ITER de-escalation factor was used.

3.2 Comparison to ITER and BPX Construction Costs

Although this device has a significantly different mission than either ITER or BPX, it is inevitable that cost comparisons will be made. As stated in Section 2 of this chapter, agreements between potential international partners on this machine could significantly impact how engineering/physics manning, R&D, and other costs such as construction management, engineering support during construction, and commissioning costs will be treated. Because of this, any comparisons between these three machines should be limited to identifying construction costs of this device to those of ITER and BPX. Additionally, because there is insufficient time allotted this study to adequately address cost uncertainty or contingency as was done for ITER, only the construction costs will be addressed.

The construction costs of this device are **44%** of the ITER construction costs and **329%** of the BPX construction costs. The BPX construction costs are approximately **14%** of those of ITER. **Annex IV** to this chapter provides a more detailed WBS by WBS breakdown of this comparison and also identifies the scaling uncertainty range.

4.0 Cost Scaling Sensitivity

A reference design point had to be selected early in the study process. However, one purpose of this study was to provide mission-related cost sensitivity information. As a result, variations of parameters around the reference design point were considered and the cost impact of these variations determined using SUPERCODE. Chapter 1, "Trade Studies," addressed these variations and the cost sensitivity around the reference design point. This section deals with the sensitivity of scaling factors selected.

As indicated in the Introduction Section to this chapter, the costs were derived by scaling from ITER whenever appropriate and to use the data from other projects for deriving cost scalings in areas where ITER merely used fixed numbers or the data was considered more representative of the PCAST machine. However, it is recognized that cost scaling, as opposed to a "bottoms up" estimating approach involves considerable judgment. Additionally, there is also a range of costs associated with future design development. Both considerations are clearly a major factor in the PCAST Machine where there has been relatively little time for detailed evaluation of our judgment, design development, or optimization. Accordingly, a range of scaling uncertainty has been assigned for each WBS element to provide a basis for assessing this machine.

Based on our assessment of scaling uncertainty, the range of costs for PCAST might vary -4% to +14%.

5.0 List of Annexes

This chapter includes four annexes that provide additional detail and discussion of the bases of the PCAST cost estimates. These annexes which follow are:

- Annex I - ITER Date Sheets
- Annex II - Derivation of Cost Scalings and Estimate
- Annex III - Derivation of Total Project Cost (TPC) Ratios
- Annex IV - PCAST Cost Estimate Detail and Comparison

Annex I

ITER Data Sheets

ITER

DATA SHEETS

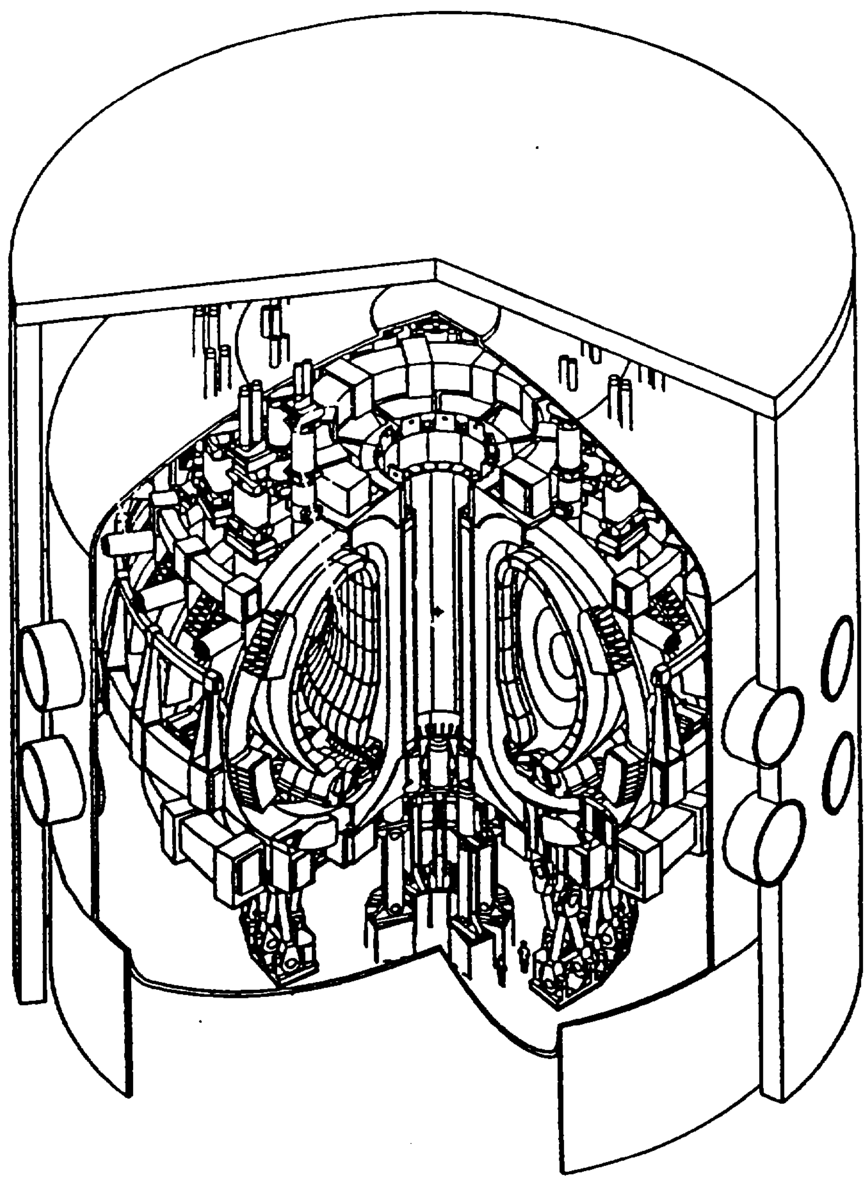
compiled by

Walt Lindquist

Reference: Interim Design Report, June 12, 1995

BASIC MACHINE PARAMETERS

Nominal Fusion Power	1.5 GW
Nominal Wall Loading	1 MW/m2
Plasma Major Radius	8.14 m
Plasma Minor Radius	2.8 m
Nominal Plasma Current	21 MA
Toroidal Field at Major Radius	5.68 T
Inductive Pulse Duration - burn conditions	1000 s
Nominal Repetition Rate	2200 s
Maximum Auxillary Heating power	100 MW
Total Number of Pulses	50,000
Total Number of Disruptions	4,000



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ITER SYSTEMS DATA/ESTIMATE SHEETS

	IDR Estimate incl. AFI kIUA 89USM$
1.1 TF coils	1160.0
1.2 PF coils	447.3
1.3 Central solenoid	229.0
1.4 Magnet Mechnaical Structure	73.0
1.5 Vacuum Vessel	175.0
1.6 Blanket System	410.0
1.7 Divertor	178.0
1.8 Fueling	34.0
2.2 Machine Assembly and Tooling	177.0
2.3 Remote Handling Equipment	226.0
2.4 Cryostat	71.0
2.6 Primary Heat transfer	138.0
2.7 Thermal Shields	25.0
3.1 Vacuum Pumping System	61.0
3.2 Tritium Plant	72.0
3.3 Secondary Heat Transfer System	65.0
3.4 Cryoplant and Distribution	243.0
3.5 Heat Rejection System	16.0
3.6 Chemical Volume Control System	19.0
4.1 Coil Power Supply and Distr.	339.0
4.2 Additional Heating PS System	85.0
4.3 SS Electrical Power System	39.0
4.5 CODAC	76.5
4.6 Interlocks and Alarms	2.0
4.7 Poloidal Control	0.5
* Heating (combo. systems)	293.0
5.4 Other Heating and Current Drives	na
5.5 Diagnostics	148.0
6.1 Site	na
6.2 Buildings	891.0
6.3 Waste Management	69.0
6.4 Radiological Protection	4.0
6.5 Liquid Distribution	56.0
6.6 Gas Distr. and Compressors	20.0
6.7 General Test Equipment	25.0
6.8 Sampling Systems	4.0
Total	5871.3

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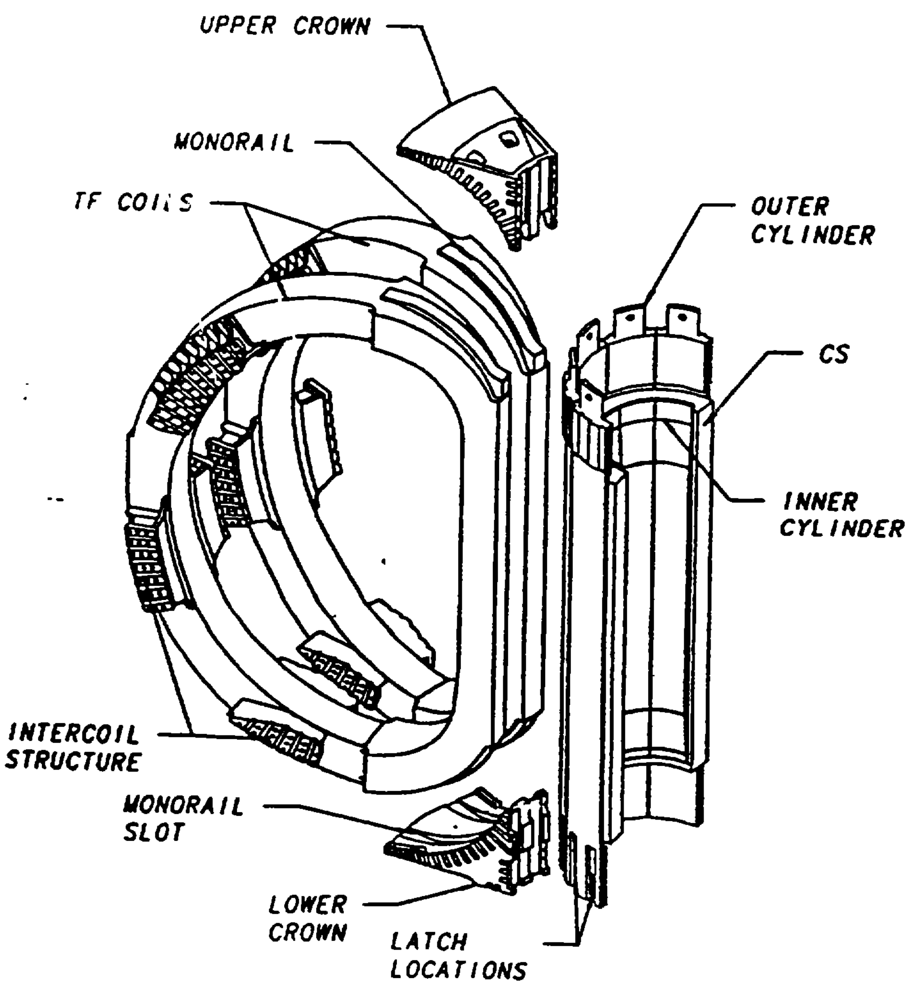
1.1 TOROIDAL FIELD COILS

PARAMETERS	
Field at Conductor	12.3 T
Average Current per Conductor	60 kA
Total Inductance	56.1 H
Stored Energy	101 GJ
Number of Turns	192
Average length per turn	45 m
Length of conductor per coil	8640 m
Coil size	18m H x 12.2 m
Coil mass	670 tonnes
Coil case and structure mass	415 tonnes
Coil radial plates mass	173 tonnes
Cooling tubes mass	4.2 tonnes
Coil insulation mass	6.6 tonnes
Coil cable	57 tonnes
Coil conduit	14 tonnes
Cases and structures	316 LN-IG-SS
Nb3Sn strand, Incoloy round conduit	

ESTIMATE ('89 M$ or kIUA)	
TF coils, 21 each	1,160
TF coil	55.2
TF structure/coil	32.7
Conductor/coil	22.5

UNIT COSTS ('89 US $'s)	
Conductor	2.6 k$/m
Structure	55 $/kg
Insulation	18 $/kg



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1.2 POLOIDAL FIELD COILS

PARAMETERS

coil	number of turns	conductor length km	conductor current kA	coil mass tonnes	outer diameter m
PF-2	640	23.5	42	571	14
3	254	19.8	41	419	27
4	384	38.9	44	869	32
5	448	37.1	42	1188	28
6	314	19.6	43	544	21
7	640	23.6	42	571	14
8	50	4.8	44	96	30

PF-2,7 - Nb3Sn strand and Incoly square conduit
PF 3,4,5,6,8 - Nb3Ti strand and SS square conduit

double pancake wound, typically 2 in-hand
cases and structures 316LN-IG-SS

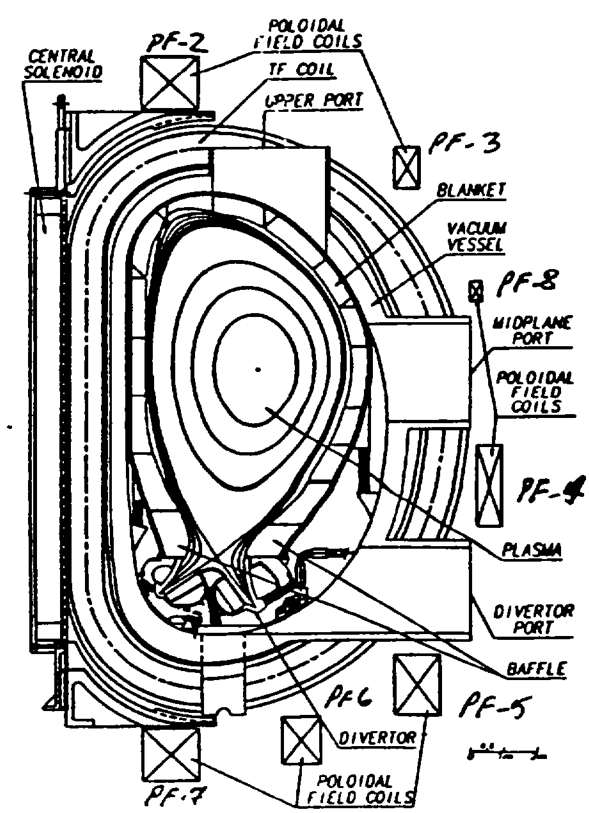
note: the winding pack is essentially self supporting and there is no additional structure

ESTIMATE ('89 M$ OR KIUA)

PF Coils total	447.3
Conductor	272.3
PF-2	15
PF-7	15
common equip	22
PF-3	15
PF-4	26
PF-5	27
PF-6	15
PF-8	6
common equip	34

UNIT COSTS ('89 US $'s)

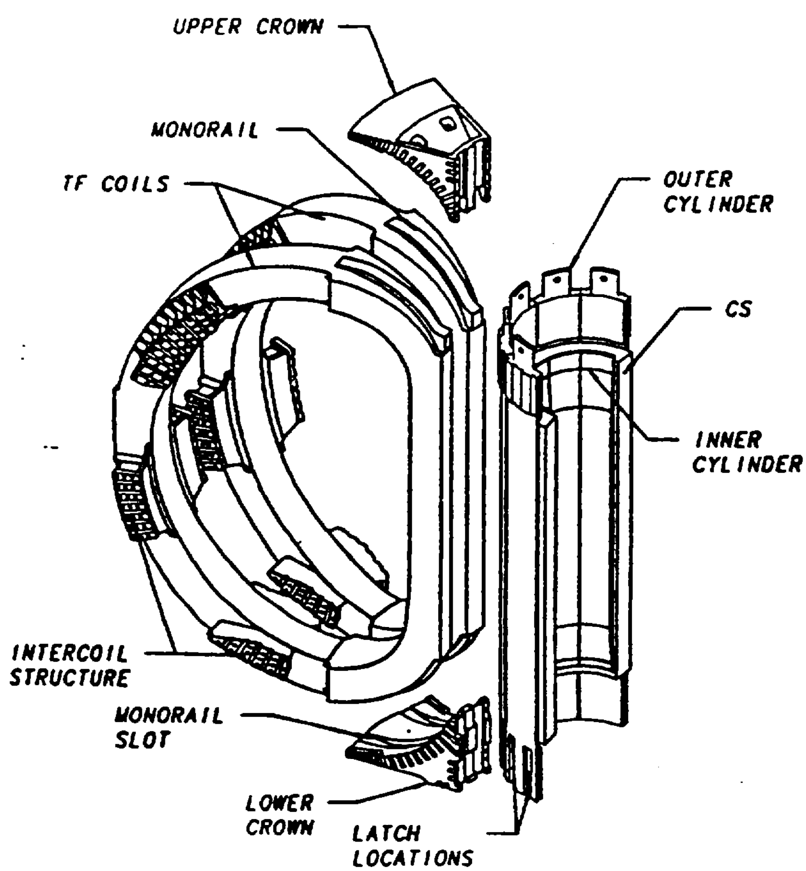
Conductor Sn	2.6 k$/m
Conductor Ti	1.25 k$/m



PARAMETERS	
Field at Conductor	13 T
Average Current per Conductor	39 kA
Total Inductance	16.2 H
Stored Energy	12.3 GJ
Number of Turns	3,356
Conductor length, total	49 km
Size	12m H x3.8m ID x 5.4 m OD
Mass	1850 tonnes
preload structure	500 tonnes
outer and inner cylinders	500 tonnes
buffer zone, etc.	60 tonnes
cooling tubes	26 tonnes
Insulation	45 tonnes
Cable	257 tonnes
Conduit	462 tonnes
Layer wound, 14 layers, 4 conductors in-hand	
Structures 316LN-IG-SS	
Nb3Sn strand and Incoloy square conduit	

ESTIMATE ('89 M$ OR KIUA)	
CS	229
Conductor	129.4
Structures	100

UNIT COSTS ('89 US $'s)	
Conductor	2.6 k$/m
Structures	94 $/kg
Insulation	18 $/kg

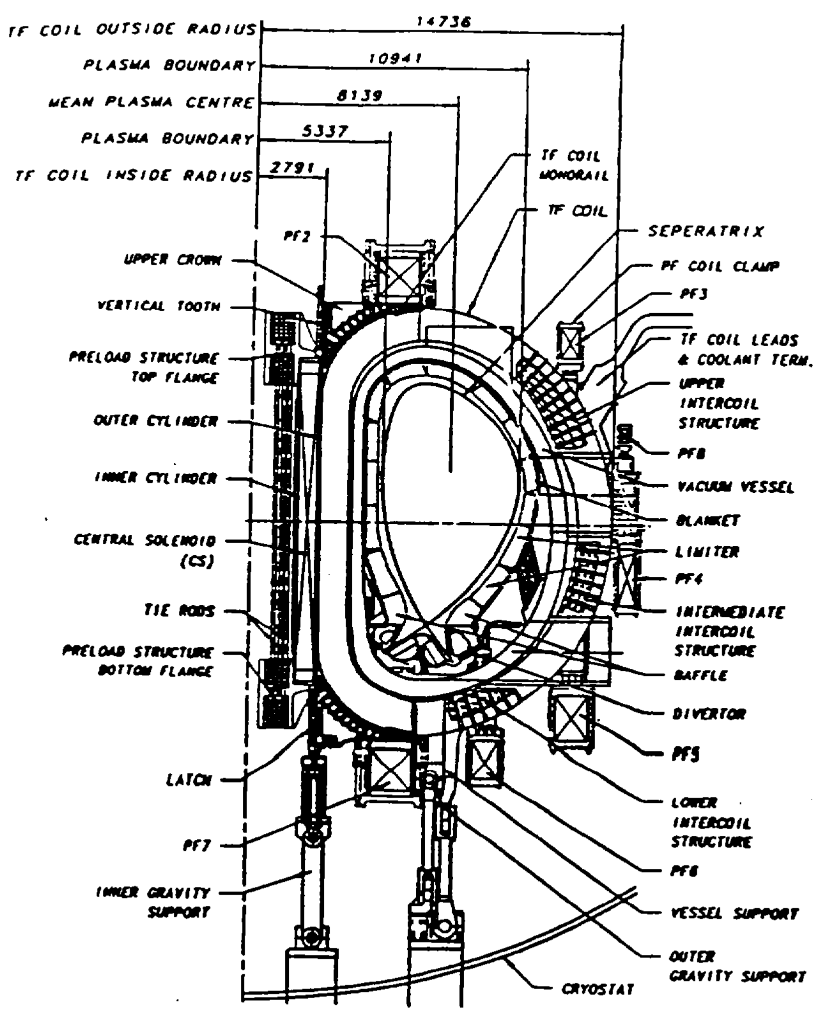


1.4 MAGNET STRUCTURES

PARAMETERS	quantity
Upper outer intercoil connector	20
Intermediate outer intercoil connector	20
Lower outer intercoil connector	20
Upper crown	10
Lower crown	10
Keys	420
Gravity supports	
structures - 316 LN-IG-SS	
total mass	2,378 tonnes

ESTIMATE ('89 M$ or kIUA))	
Magnet structure	73

UNIT COSTS ('89 US $'s)	
Structures	31 $/kg

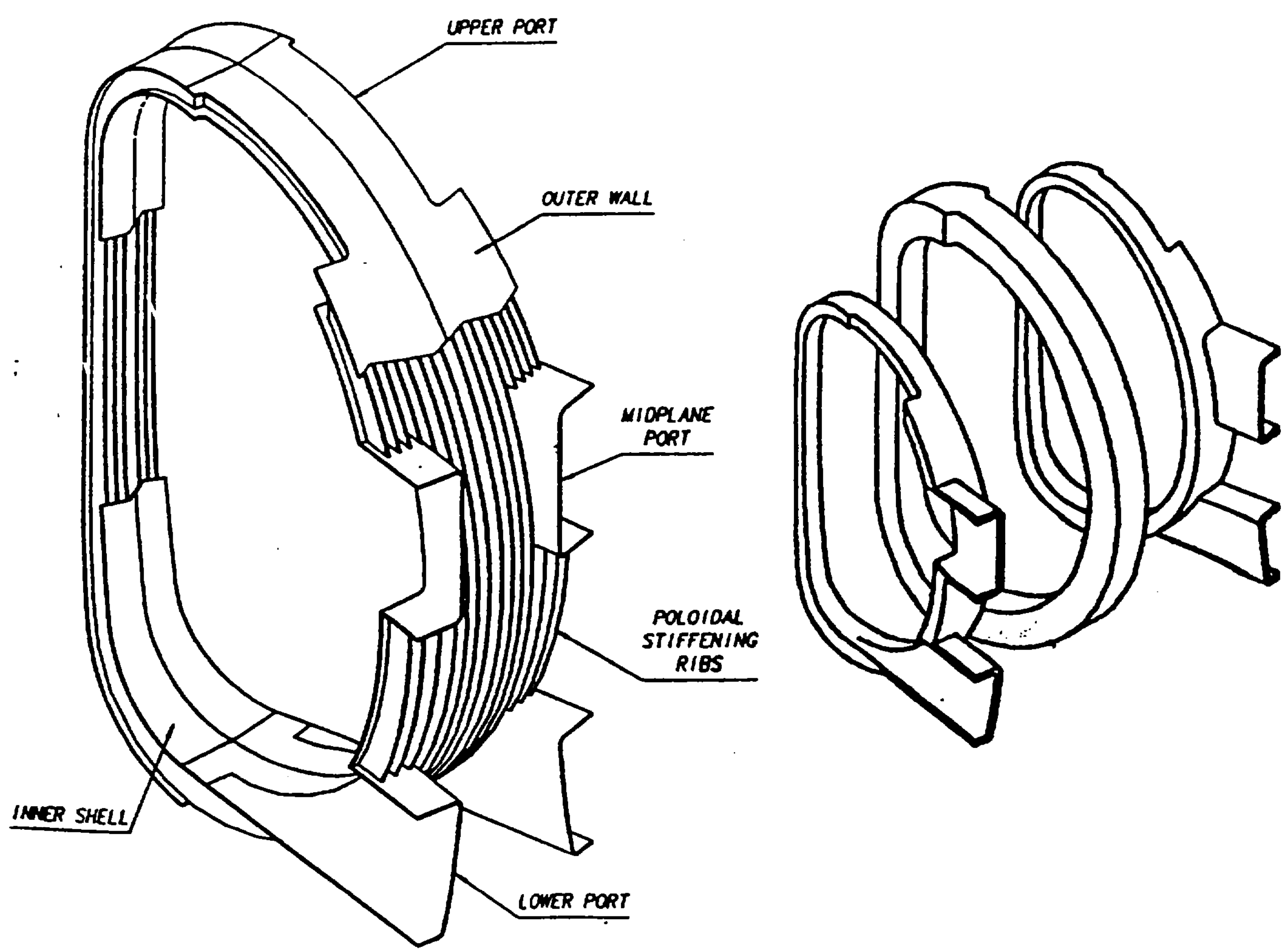


1.5 VACUUM VESSEL

PARAMETERS	
Sectored, 18 degrees/sector, number of sectors	20
Inside radius	4.1 m
Outside radius	13.1 m
Overall Height	14.5 m
Nominal inner and outer wall thickness	40 mm
Distance between inner and outer walls	0.45-0.83 m
Internal surface area	1426 m2
Volume	4250 m3
Mass, total	6022 tons
Vacuum vessel with shield, main chamber	4521 tons
Vertical ports, 20 each, total mass	166 tons
Midplane ports, 20 each, total mass	407 tons
Lower ports, 20 each, total mass	578 tons
Cover plates, 60 each, total mass	350 tons
Material - 316 LN-IG-SS	
Construction - double wall, welded ribbed	

ESTIMATE ('89 M$)	
Vacuum Vessel	175
VV main ass'y	111
Ports	40
Support structure	12
Special tooling	12

UNIT COSTS ('89 US $'s)	
Vessel, ports, struct.	29 $/kg



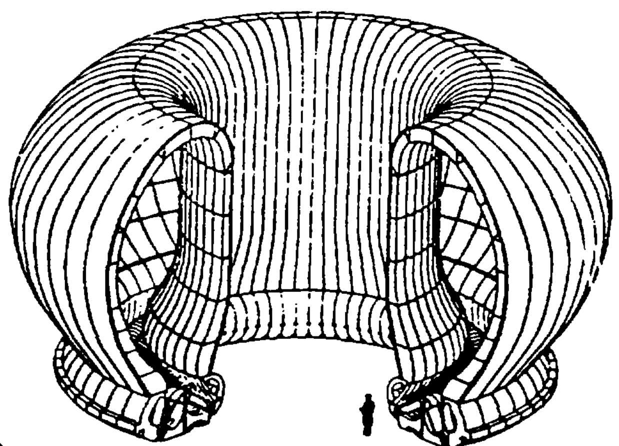
WBL

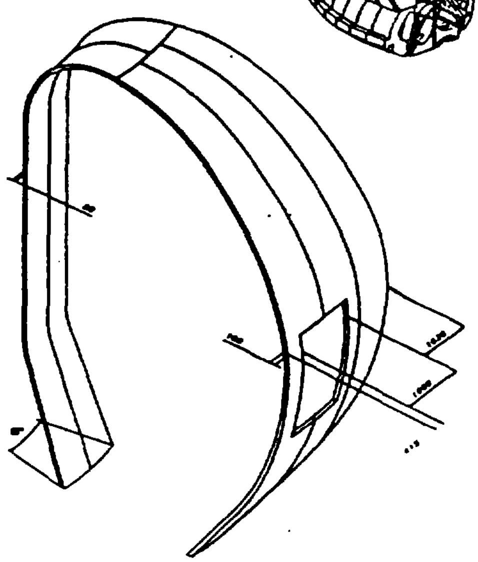
1.6 BLANKET/SHIELD

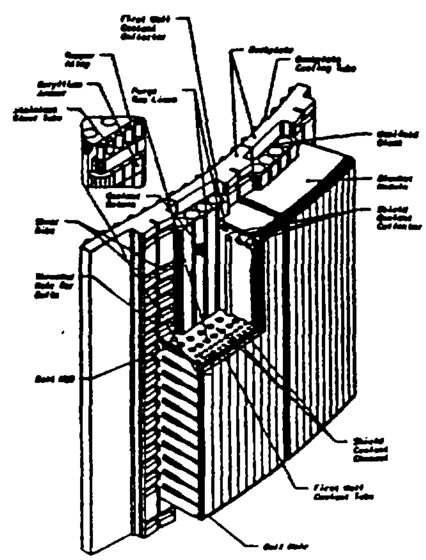
PARAMETERS	
Backplate	
Material	316 LN-IG-SS
18 degree sectors, number	20
2 inboard segments, thickness	80 mm
3 outboard segments, thickness	100 mm
Mass, total	900 tons
Mass, Inboard sector	12 tons
Mass, Outboard sector	32 tons
Modules	
Structural base	316 LN-IG-SS
Plasma Facing	Cu alloy, Be clad
Standard modules	500
Limiter modules	120
Baffle modules	100

ESTIMATE ('89 M$)	
Blanket/shield	410
Backplate	63
First wall/modules	347

UNIT COSTS ('89 $'s)	
backplate	70 $/kg
module	0.48M$







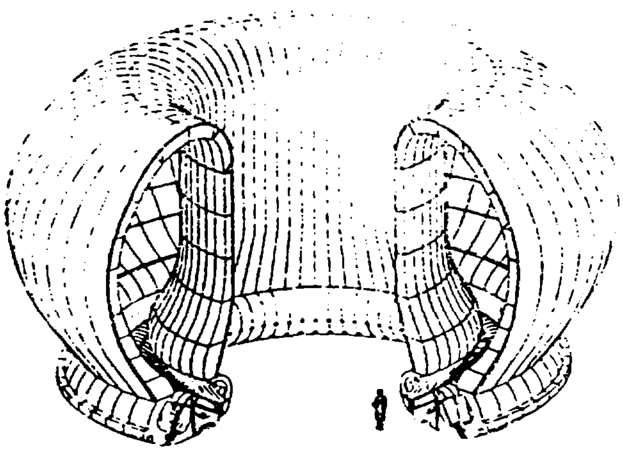
WBL

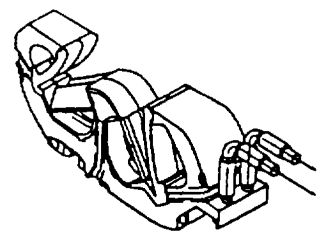
1.7 DIVERTOR

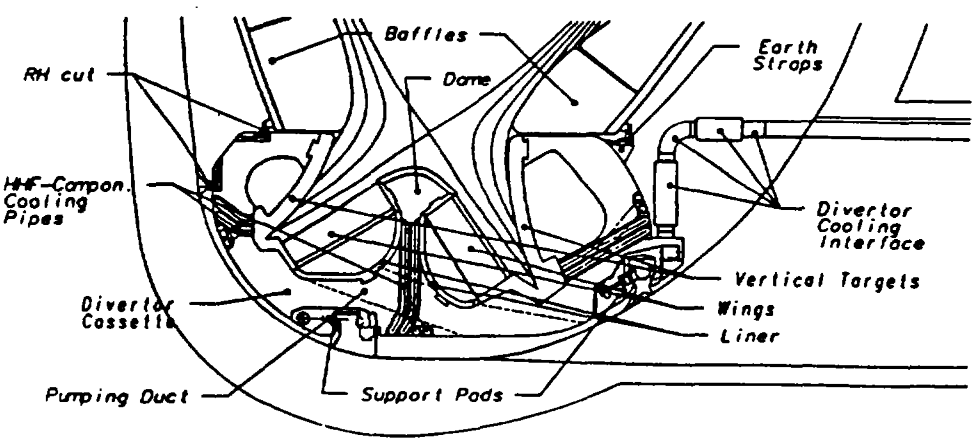
PARAMETERS	
Material	316 LN-IG-SS
Plasma facing material	Cu alloy, Be clad
Number of Cassettes	60
Size, each	5m L x 2m H x 0.5-1.0m W
Mass, each	20 tonnes
Heat load, local	5MW/m2
Heat load, all cassettes, max.	400MW

ESTIMATE ('89 M$)	
Divertor system	178

UNIT COSTS ('89 $'s)	
Cassette (each)	3M$





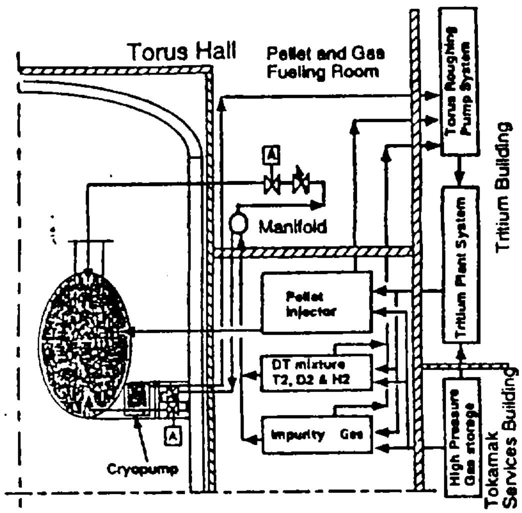


WBL

1.8 FUELING

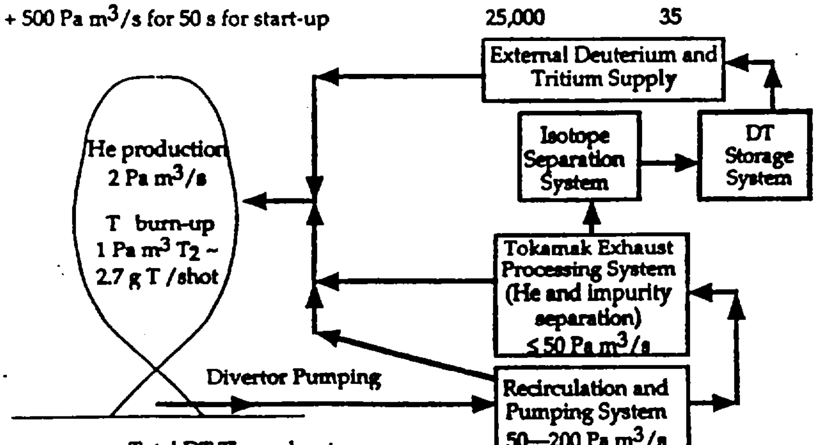
PARAMETERS
Reference: IDR

ESTIMATE ('89 M$)	
Pellet system	23 M$
Gas system	7M$
Wall conditioning	5M$
total	35M$



Particle Inventory Summary For DT Fuelling and Pumping

Fuelling Rate (50 % D 50 %T)	Gas injected (Pa m^3)	T injected (g)
— 200 Pa m^3/s for 1000 s	200,000	270
— 50 Pa m^3/s for 1000 s	50,000	70
+ 500 Pa m^3/s for 50 s for start-up	25,000	35



Fuel rate (Pa m^3/s)	Total DT Throughput divertor pressure (Pa)	T(g)	Tritium burn-up(%)
— 200	0.67	300	0.9
— 50	0.17	100	2.7

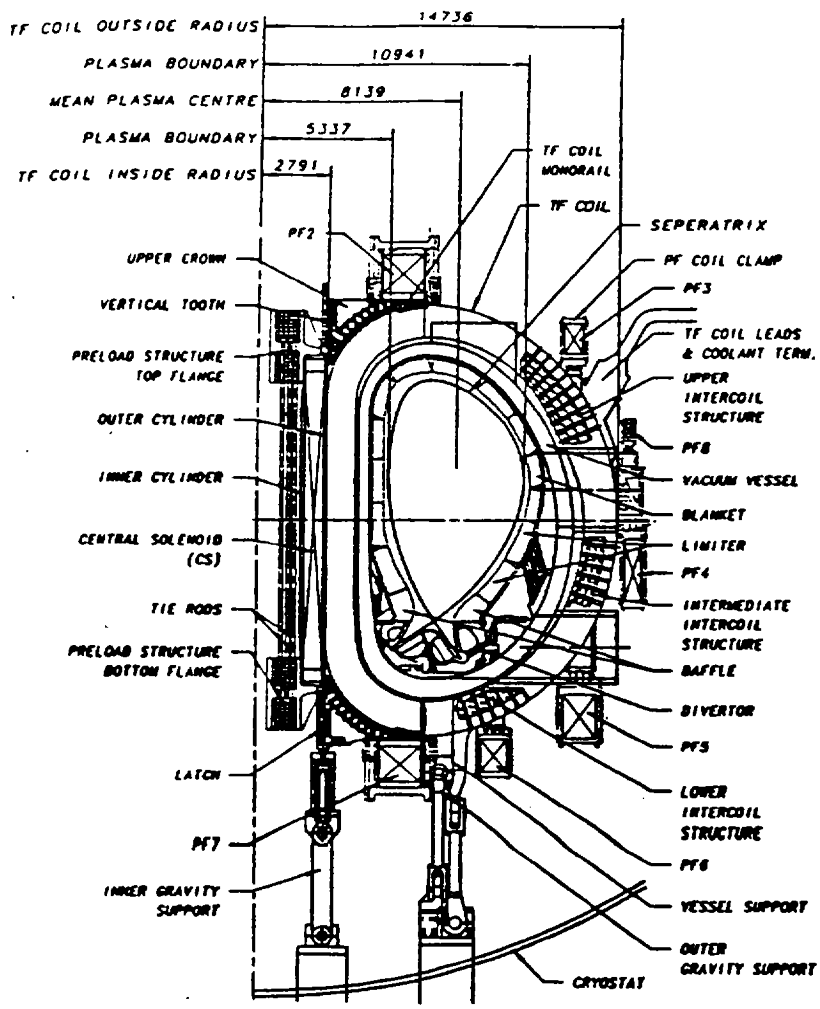
WBL

2.2 MACHINE ASSEMBLY and TOOLING

PARAMETERS	
Machine	20 sectors
reference: IDR	

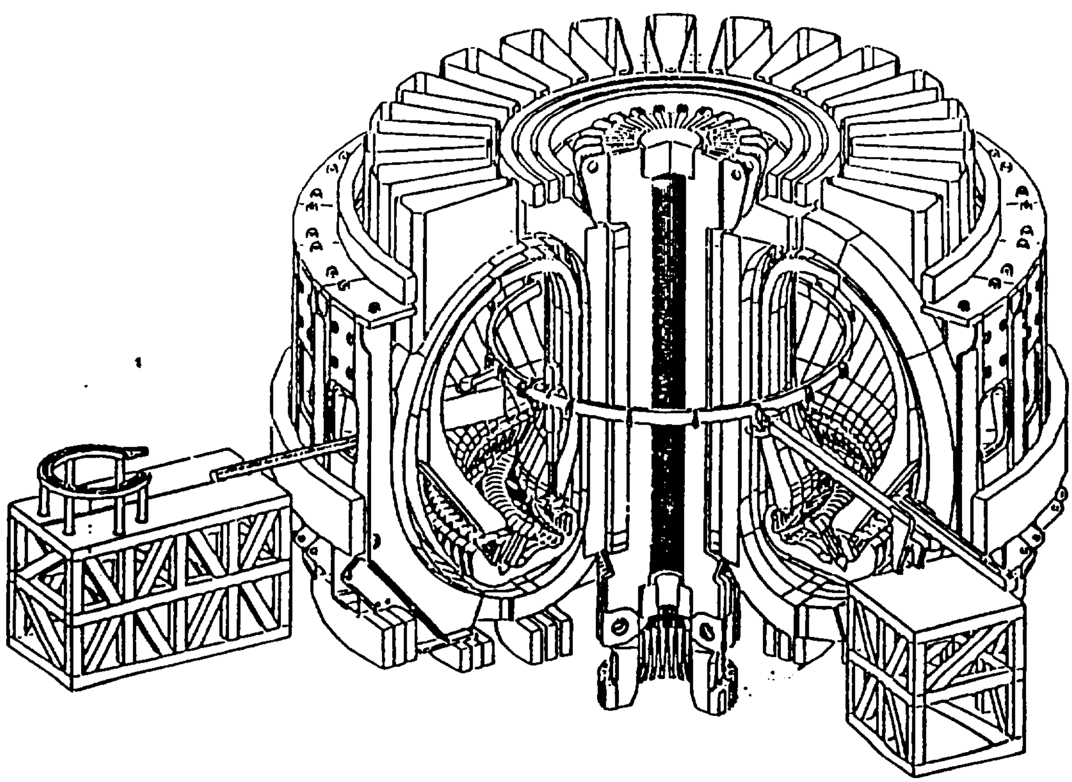
ESTIMATE ('89 M$)	
Ass'y and tooling	177M$

UNIT COSTS ('89 $'s)	
each sector	9M$



PARAMETERS	
Machine	20 sectors
Divertor, 60 cassettes, 5m L x 2m H x 0.5-1.0m W, 20 tonnes (each)	
First Wall, 720 modules, average mass -5 tonnes	

ESTIMATE ('89 M$)	
Remote handling	226



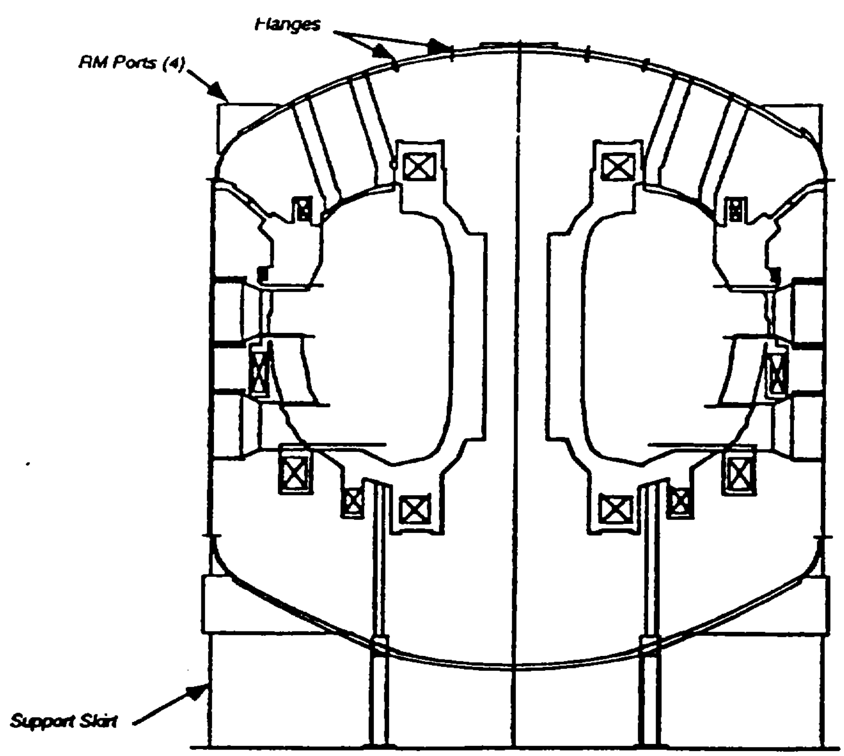
WBL

2.4 CRYOSTAT

PARAMETERS	
Outside Diameter	36.5 m
Inside Diameter	36 m
Overall Height	36 m
Cylindrical section, height	20.9 m
Nominal inner and outer wall thickness	20 mm
Internal surface area	5030 m2
Volume	31400 m3
Mass	2165 tons
Material - 316 LN-IG-SS	
Construction - double wall, welded ribbed	

ESTIMATE ('89 M$)	
Cryostat system	71.1
Cryostat	60.9
Press. suppression. sys.	9.1

UNIT COST ('89 US $'s)	
Cryostat	28 $/kg



WBL

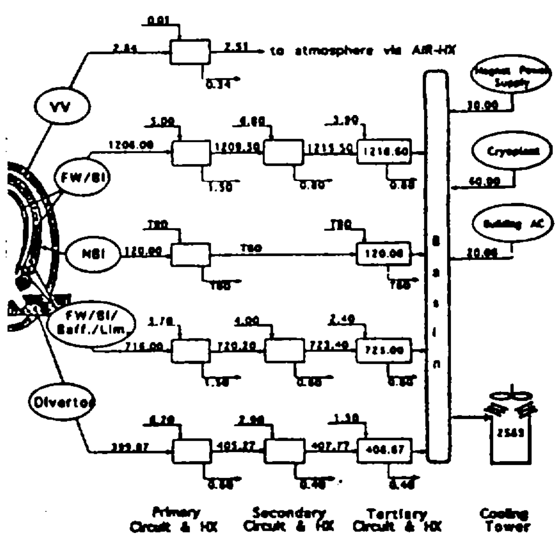
2.6 PRIMARY HEAT TRANSFER SYSTEM

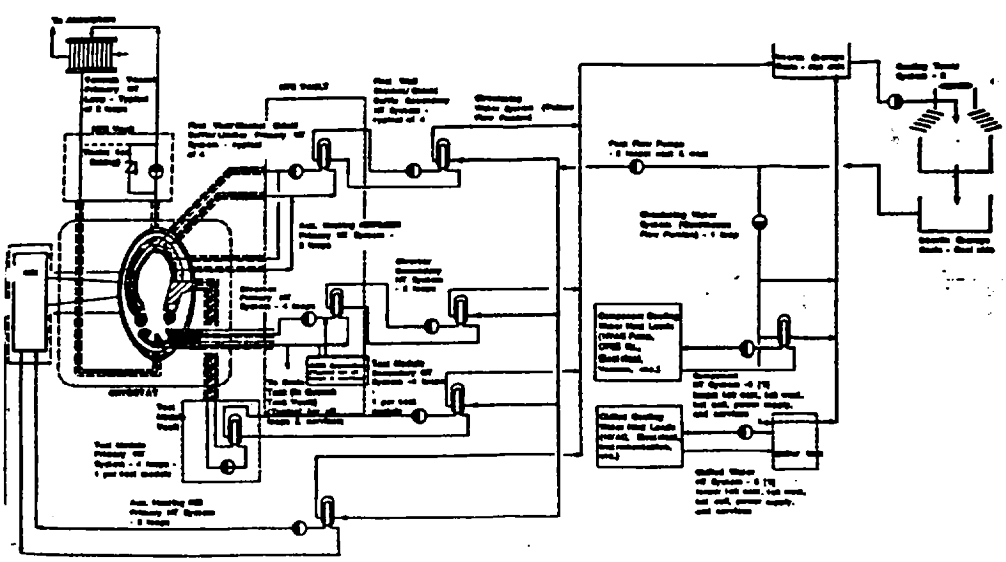
PARAMETERS	ESTIMATE ('89 M$)
Primary heat transfer system (4 loops)	138

UNIT COSTS ('89 $'S)
35M$/loop

HEAT TRANSPORT SYSTEM

(Heat loading displayed in MW)





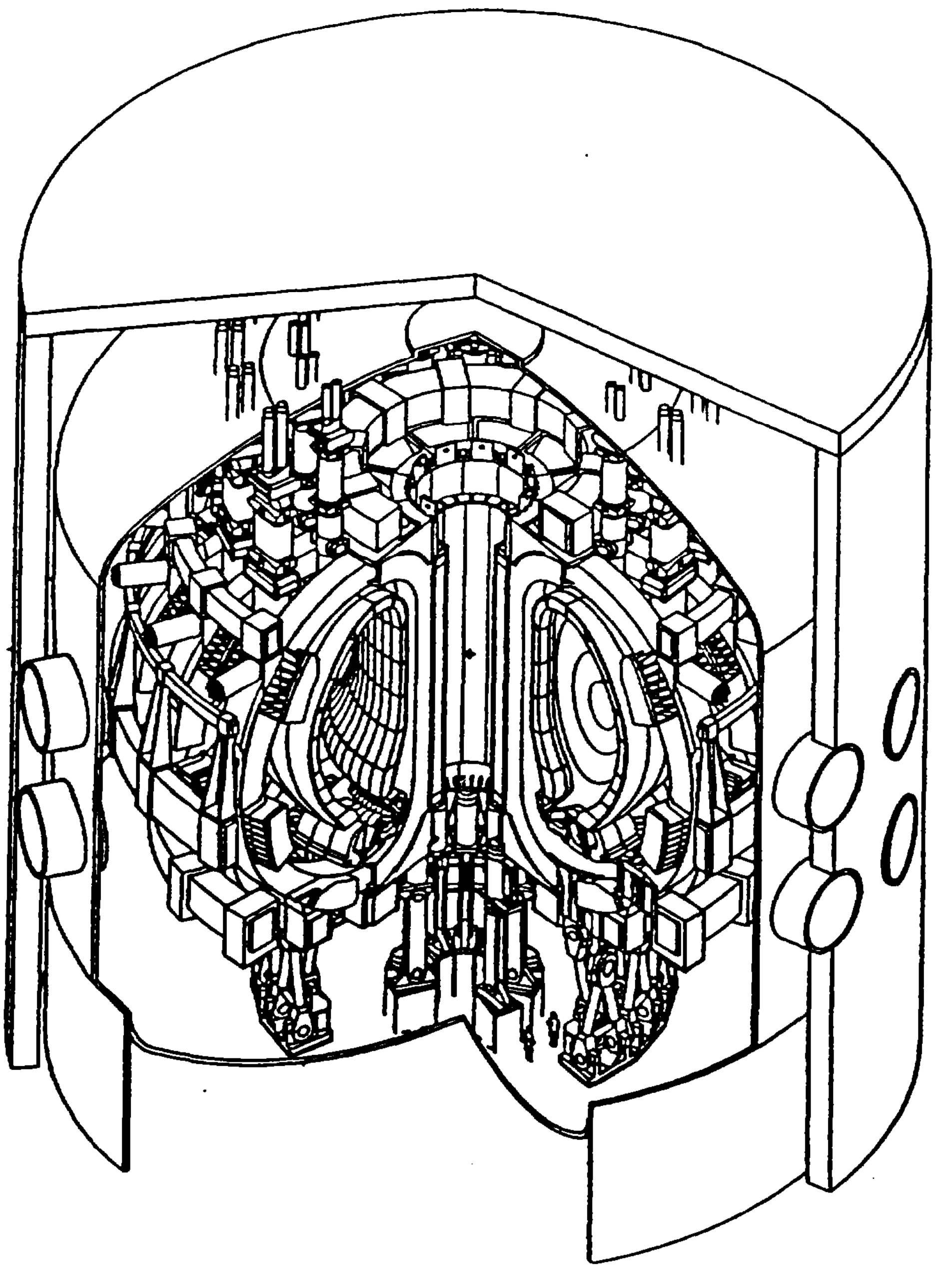
WBL

2.7 THERMAL SHIELD

PARAMETERS	
Thermal shield area	10,000m2

ESTIMATE ('89 M$)	
Thermal shield	25

UNIT COSTS ('89 $'s)	
Unit cost	2.5k$/m2



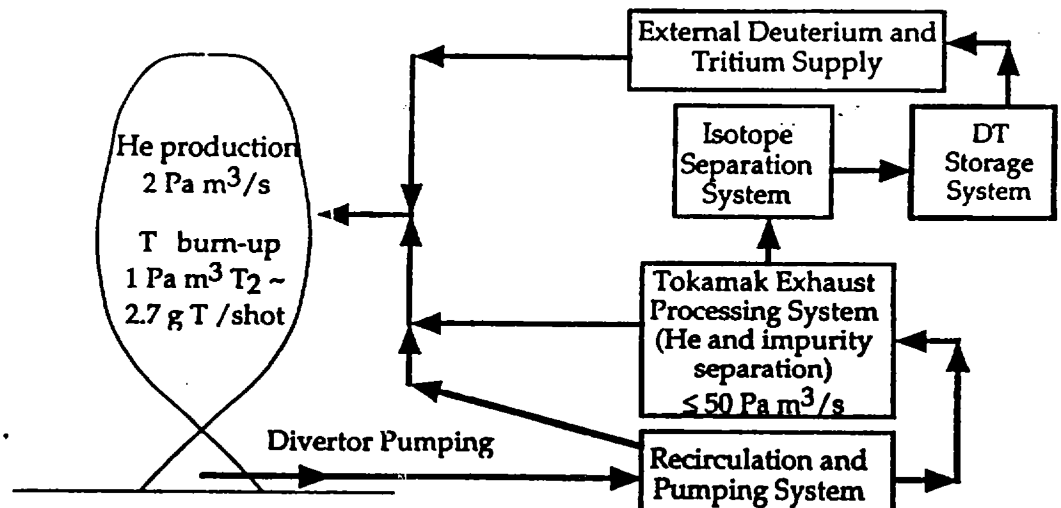
WBL

PARAMETERS	
Chamber volume	4,500 m3
VV cryo pumps	16
VV Leak rate	10-7 Pa m3/s
Roughing VV - atmosphere to 50 Pa in 60h	
Roughing cryostat - atmosphere to 5 Pa in 100h	

ESTIMATE ('89 M$)	
Torrus	20.9
Cryostat	5.0
Leak detection	13.4
Miscellaneous	21.7
total	61.0

Particle Inventory Summary For DT Fuelling and Pumping

Fuelling Rate (50 % D 50 %T)	Gas injected (Pa m^3)	T injected (g)
— 200 Pa m^3/s for 1000 s	200,000	270
— 50 Pa m^3/s for 1000 s	50,000	70
+ 500 Pa m^3/s for 50 s for start-up	25,000	35

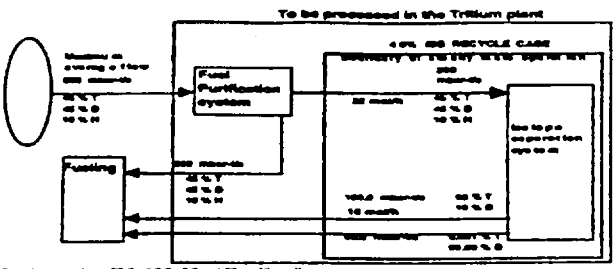


Fuel rate (Pa m^3/s)	Total DT Throughput divertor pressure (Pa)	T(g)	Tritium burn-up(%)
— 200	0.67	300	0.9
— 50	0.17	100	2.7

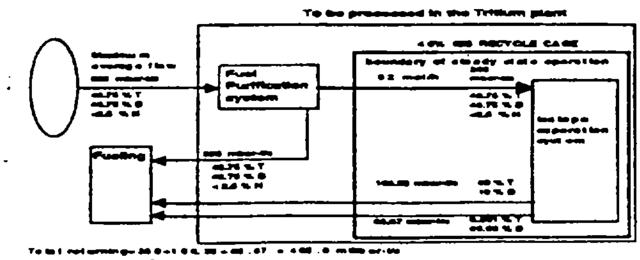
WBL

3.2 TRITIUM PLANT

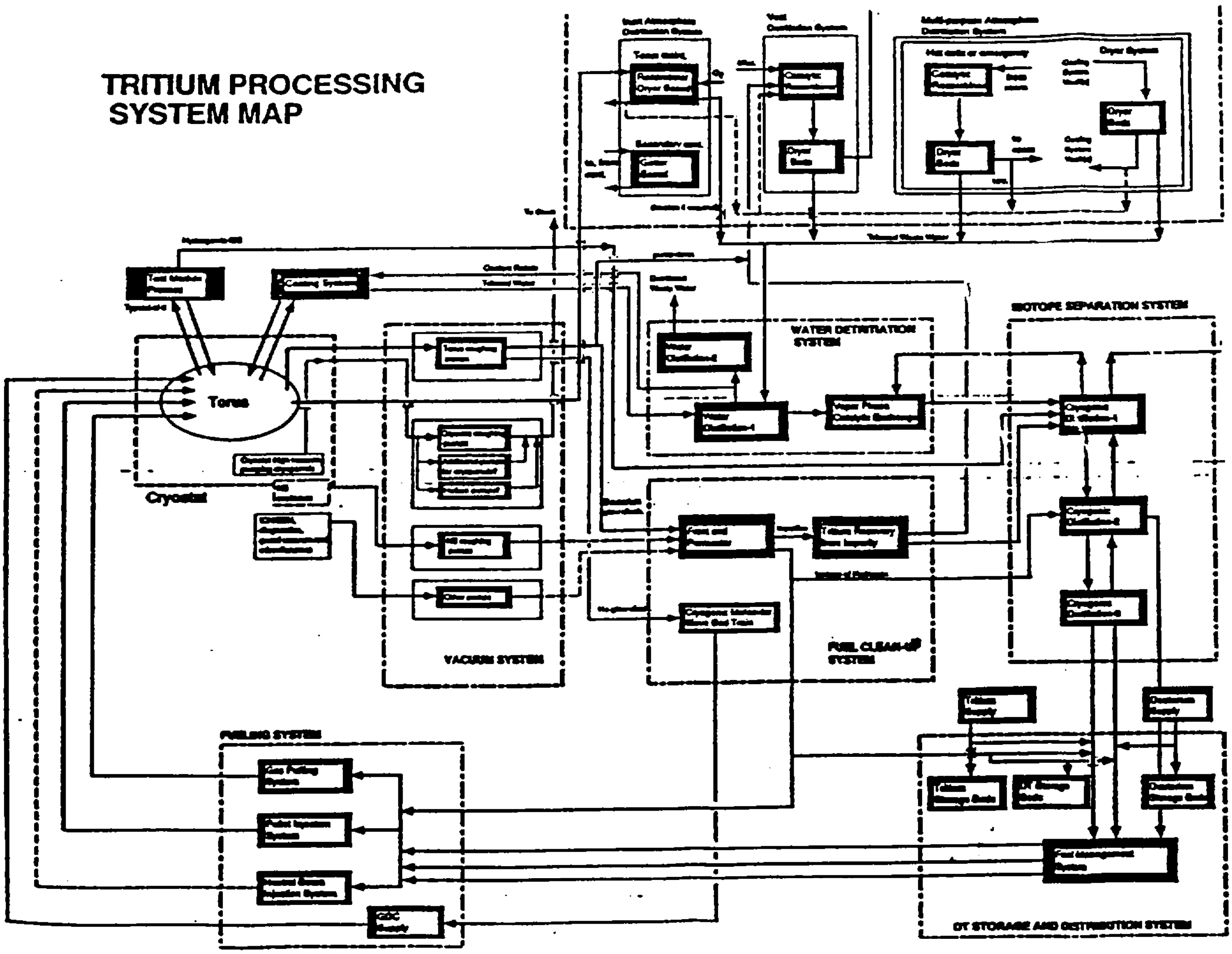
PARAMETERS	ESTIMATES ('89 M$'s)	
Reference: IDR	Plant	72



40% recycle to ISS, 10 % H_2 content



40% recycle to ISS, <2.5 % H_2 content



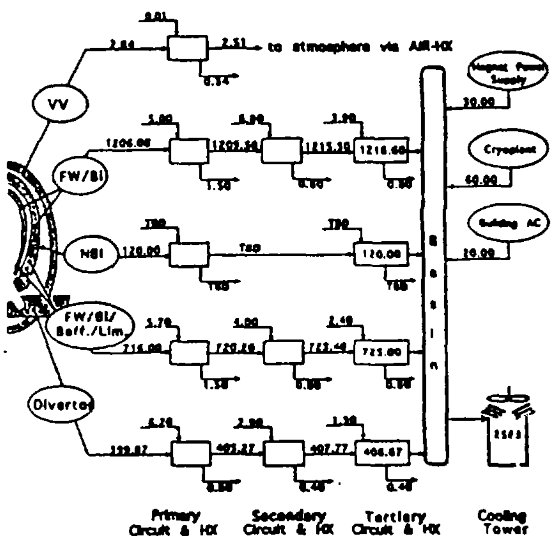
3.5 HEAT REJECTION SYSTEM

PARAMETERS
Heat rejection system - 2,583 MW

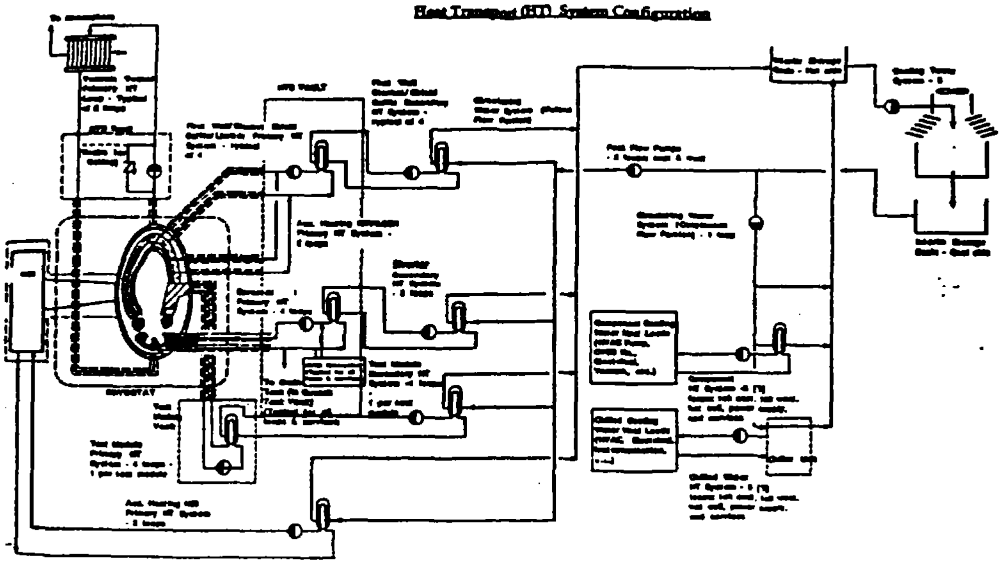
ESTIMATE ('89 M$)
16

UNIT COST ('89 US S's)
$6/kW

HEAT TRANSPORT SYSTEM
(Heat loading displayed in MW)

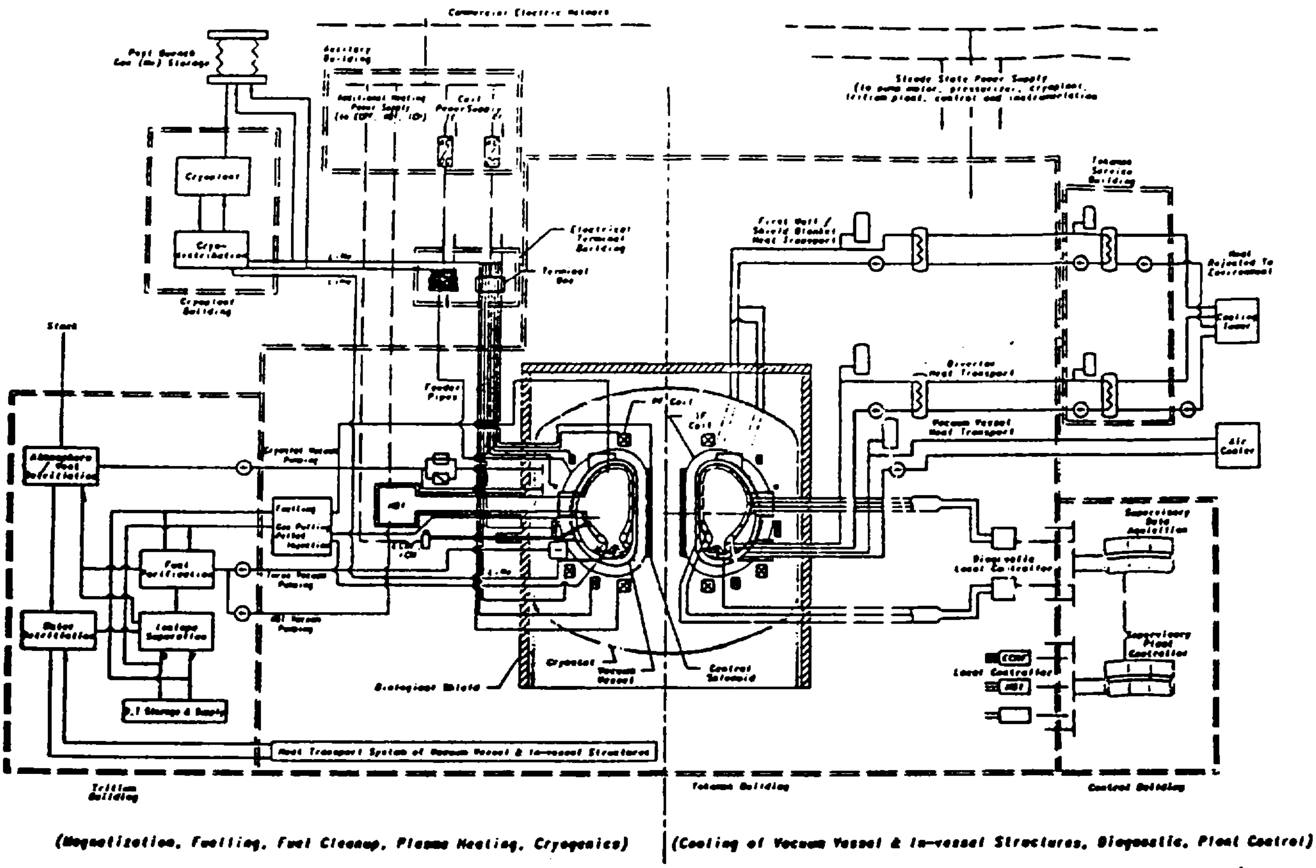


Heat Transport (HT) System Configuration



3.6 CHEMICAL VOLUME CONTROL SYSTEM

PARAMETERS	ESTIMATE ('89 M$)
Chemical volume control system	19



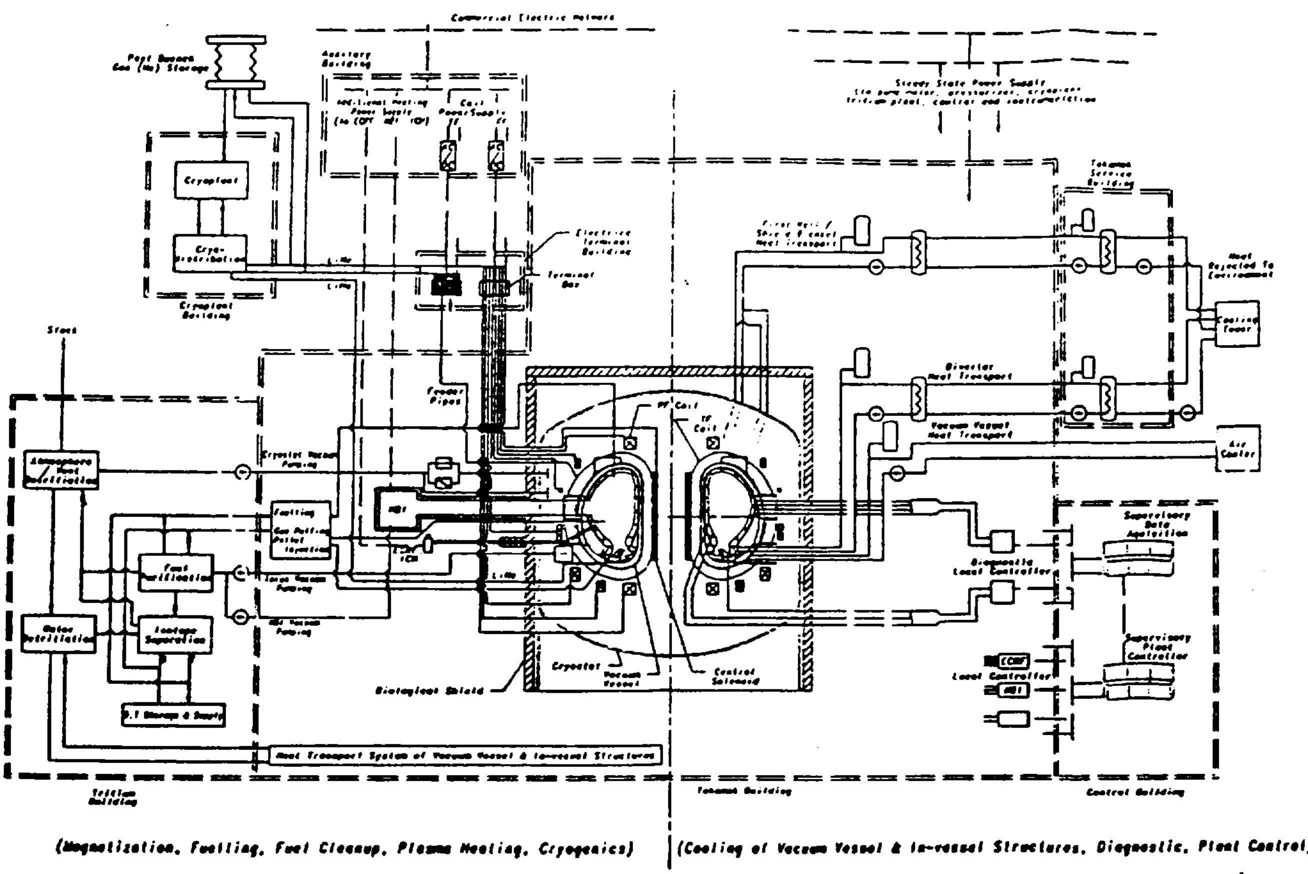
ITER BASIC PLANT SYSTEM CONFIGURATION

WBL

4.5 CODAC and 4.6 INTERLOCKS

PARAMETERS
Reference: IDR

ESTIMATE ('89 M$'s)	
CODAC	76.5
Interlocks	2
total	79.5



ITER BASIC PLANT SYSTEM CONFIGURATION

WBL

4.2, 5.1, 5.2, 5.3 HEATING SYSTEMS

PARAMETERS	
ECRH Startup- 90 & 140 GHz	8MW
ECRH Heating - 170 GHz	50MW
ICRF Heating - 40 - 90MHz	50MW
NBI Heating - 400 - 1000KeV	50MW

note 1: Heating requirement 100MW
note 2. For costing, the sum for ICRF and ECRH was averaged with the sum for ECRH and NBI

ESTIMATE ('89 M$'s)	
Heating Power Supplies	85
ICRH power supplies	17
ECRH power supplies	27
NBI power supplies	99
Heating Systems	272
ICRH system	110
ECH system	133
NBI system	168
Startup ECRH PS and System	21
Heating Systems and Startup	293

UNIT COSTS ('89 US $'s)	
ICRH	$2.50/W
ECRH	$3.20/W
NBI	$5.30/W

WBL

5.5 DIAGNOSTICS

PARAMETERS
see below

ESTIMATE ('89 M$)	
Diagnostics	148

Magnetic Diagnostics

- Ex-Blanket Magnetics*
- In-Blanket Magnetics*
- Divertor Magnetics*
- Continuous Rogowski Coils*
- Diamagnetic Loop*

Neutron Diagnostics

- Radial Neutron Camera*
- Vertical Neutron Camera*
- Microfission Chambers (In-Vessel)* N/C
- Neutron Flux Monitors (Ex-Vessel)*
- Radial Neutron Spectrometer
- Tangential Neutron Spectrometer
- Gamma-Ray Spectrometers
- Activation System
- Lost Alpha Detectors* N/C
- Knock-on Tail Neutron Spectrometer N/C

Optical/IR Systems

- Thomson Scattering (Core)*
- Thomson Scattering (Edge)
- Thomson Scattering (X-Point)
- Thomson Scattering (Divertor)
- Toroidal Interferometric/Polarimetric System*
- Polarimetric System (Poloidal Magnetic Field Measurement)
- Collective Scattering System N/C

Bolometric System

- Bolometric Array For Main Plasma*
- Bolometric Array For Divertor*

Spectroscopic and NPA Systems

- Active Spectroscopy (based on DNB)
- H Alpha Spectroscopy*
- Impurity Monitoring (Main Plasma)*
- Impurity Monitoring (Divertor)*
- X-Ray Crystal Spectrometers
- Visible Continuum Array*
- Soft X-Ray Array*
- Neutral Particle Analyzers
- Two Photon Ly-Alpha Fluorescence N/C
- Laser Induced Fluorescence N/C

Microwave Diagnostics

- ECE Diagnostics for Main Plasma*
- Reflectometers for Main Plasma*
- Reflectometers for Plasma Position
- Reflectometers for Divertor Plasma
- ECA for Divertor Plasma
- Microwave Scattering (Main Plasma)
- Fast Wave Reflectometry N/C
- Microwave Scattering (Divertor) N/C

Plasma-Facing Components and Operational Diagnostics

- IR Cameras (Divertor)*
- Thermocouples*
- Pressure Gauges*
- Residual Gas Analyzers*
- Hard X-Ray Monitor*
- Visible/IR TV (Main Plasma)*
- Langmuir Probes/Tile Shunts*

Diagnostic Neutral Beam

WBL

5.5 DIAGNOSTICS

PARAMETERS
see below

ESTIMATE ('89 M$)	
Diagnostics	148

Magnetic Diagnostics
Ex-Blanket Magnetics*
In-Blanket Magnetics*
Divertor Magnetics*
Continuous Rogowski Coils*
Diamagnetic Loop*

Neutron Diagnostics
Radial Neutron Camera*
Vertical Neutron Camera*
Microfission Chambers (In-Vessel)* N/C
Neutron Flux Monitors (Ex-Vessel)*
Radial Neutron Spectrometer
Tangential Neutron Spectrometer
Gamma-Ray Spectrometers
Activation System
Lost Alpha Detectors* N/C
Knock-on Tail Neutron Spectrometer N/C

Optical/IR Systems
Thomson Scattering (Core)*
Thomson Scattering (Edge)
Thomson Scattering (X-Point)
Thomson Scattering (Divertor)
Toroidal Interferometric/Polarimetric System*
Polarimetric System (Poloidal Magnetic Field Measurement)
Collective Scattering System N/C

Bolometric System
Bolometric Array For Main Plasma*
Bolometric Array For Divertor*

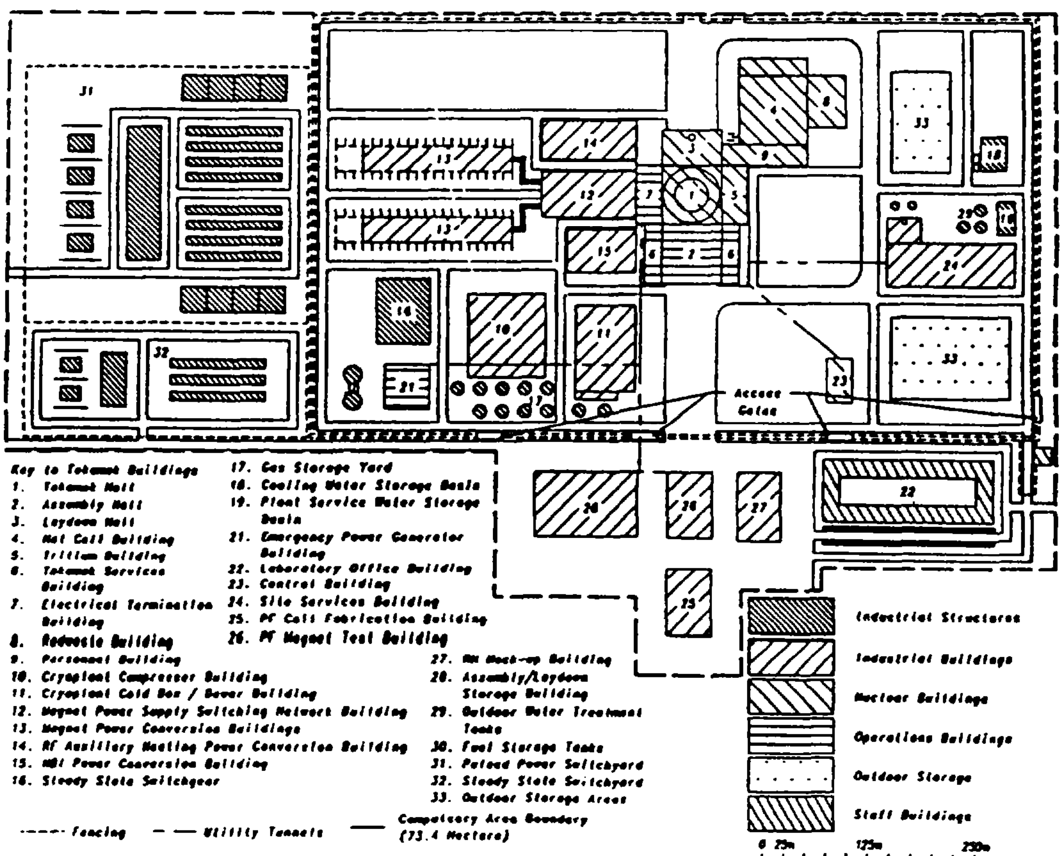
Spectroscopic and NPA Systems
Active Spectroscopy (based on DNB)
H Alpha Spectroscopy*
Impurity Monitoring (Main Plasma)*
Impurity Monitoring (Divertor)*
X-Ray Crystal Spectrometers
Visible Continuum Array*
Soft X-Ray Array*
Neutral Particle Analyzers
Two Photon Ly-Alpha Fluorescence N/C
Laser Induced Fluorescence N/C

Microwave Diagnostics
ECE Diagnostics for Main Plasma*
Reflectometers for Main Plasma*
Reflectometers for Plasma Position
Reflectometers for Divertor Plasma
ECA for Divertor Plasma
Microwave Scattering (Main Plasma)
Fast Wave Reflectometry N/C
Microwave Scattering (Divertor) N/C

Plasma-Facing Components and Operational Diagnostics
IR Cameras (Divertor)*
Thermocouples*
Pressure Gauges*
Residual Gas Analyzers*
Hard X-Ray Monitor*
Visible/IR TV (Main Plasma)*
Langmuir Probes/Tile Shunts*

Diagnostic Neutral Beam

PARAMETERS						ESTIMATE '89 M$'s)	UNIT COSTS	
Bldg. #	Footprint m2	Gross Volume m3	Structural Concrete m3	Structural Steel tonnes	Floor Area m2	M$	$/m2	$/m3
1,2,3	13,060	1,060,000	160,370	18,980	35,790	363	27,894	343
4	8,000	164,800	50,500	0	20,800	92	11,492	558
5	2,130	89,460	21,810	2,500	12,780	44	20,824	496
6	2,804	117,600	6,400	2,500	11,200	35	12,655	302
12,13,14,15	25,250	396,200	24,510	5,630	37,700	71	2,810	179
Stack	100	na	na	na	na	2	na	na
8,9	5,260	50,000	10,750	0	6,480	16	3,066	323
22	8,460	70,270	10,480	1,800	17,570	23	2,669	321
10,11	15,600	381,800	12,830	2,000	15,550	62	3,981	163
23	2,600	34,800	9,890	0	5,760	12	4,652	348
21	2,500	17,500	3,370	0	2,500	6	2,258	323
24	8,100	103,000	8,100	2,070	8,100	19	2,290	180
28	9,000	108,000	9,000	1,500	9,000	15	1,613	135
25	4,030	69,000	4,030	850	4,030	10	2,602	152
26	4,030	84,900	4,030	1,020	4,030	13	3,202	152
tunnels	na	na	na	na	na	31	na	na
31,32	na	na	na	na	na	7	na	na
7	2,130	89,460	21,010	2,300	10,650	35	16,659	397
27	4,000	228,160	10,910	2,300	5,950	35	8,871	156
Bldgs. total	117,054	3,064,950	367,990	43,450	207,890	891		



Annex II
Derivation of Unit Cost Scalings

- **WBS 1.0 - Magnets Systems**

  This PCAST WBS element is a composite of the following four ITER WBS elements:

  - WBS 1.1 TF Magnets
  - WBS 1.2 PF Magnets
  - WBS 1.3 Central Solenoid
  - WBS 1.4 Magnet Systems Mechanical Structure

  Each ITER WBS element is discussed below:

  - **<u>WBS 1.1 - TF Magnets</u>**

    Basis:

    The suggested ITER JCT unit scaling factor for the TF Magnets is $/kg. Since the ITER conductor is superconducting whereas the PCAST device utilizes OFHC copper conductor, the ITER figure was adjusted to remove the mass and the cost of the ITER conductor delivered cabled on the loading dock. The remaining costs then represent the TF cases and the effort to manufacture the TF magnets (e.g., procurement and manufacture of the structural material , the effort to wind the coil, etc.) - approximately $56/kg.

    The effort to produce the OFHC copper conductor for PCAST was derived from the SSAT cost algorithms - approximately $12/kg.

    The sum of the ITER coil manufacturing cost/kg and the SSAT winding pack cost/kg yields a composite scaling factor -

approximately \$68/kg. The ITER unit cost with superconducting conductor would be \$82/kg.

Discussion:

The equivalent BPX scaling factor to manufacture the TF coils (excluding the cost of the conductor delivered on the loading dock) is approximately \$65/kg and the equivalent TPX scaling factor is \$139/kg.

Historic unit costs of other large TF coils including conductor, converted to FY-89\$, are: TFTR coils @ \$103/kg; TFTR cases @ \$77/kg; DIII TF coils @ \$98/kg.

The ITER unit cost scaling was selected assuming that the unit cost for manufacture of coils of this scale are equivalent independent of the type of conductor.

ITER is of a much larger scale than BPX, TPX, TFTR, or DIII, for which the unit costs are all larger than those chosen for the PCAST machine. One would expect larger machines to have a lower unit cost of vendor engineering, for example. We attribute the factor of scale as the major contributor to the discrepancy, and have chosen to use the ITER-scale unit costs.

It was further that the BPX and TPX equivalent scalings were not representative due to: (1) the complexity of dealing with Be-Cu conductor for BPX and (2) the probability that both the BPX and TPX estimates include a large portion of the "magnet structure" costs specifically identified in the ITER WBS Element 1.4, Mechanical Coil and Support Structure.

The ITER cost estimate included approximately $33M in AFI for leads and cooling lines. Since the ITER scaling factor was developed from the total ITER costs, including AFI, there is no need to apply a separate AFI to this estimate.

Results and Scaling Uncertainty:

The PCAST machine has 16 coils at approximately 209.5 tonnes each for a total mass of conductor of 3,352 tonnes. The 16 cases have an estimated mass of 82.5 tonnes each for a total mass of cases of 1,320 tonnes. The total TF magnet mass for the PCAST machine is then 4,672 tonnes; at $68/kg, the total estimated cost for the PCAST TF magnets is approximately $318M.

If one were to use a 50% larger unit cost on the historical basis of the smaller machines, the PCAST TF coil cost estimate would increase from $318M to $477M, an increase of $159M.

Separately from scaling, a rough bottoms-up approximation was done using our experience in manufacturing other copper coils and cases. This bottoms-up approach is discussed in greater detail at the end of the section on WBS 1.4. However, this approximation yields at total for the Magnet Systems (which include WBS 1.1 TF Magnets, WBS 1.2 PF Magnets, WBS 1.3 Central Solenoid, and WBS 1.4 Structure) of about

Results and Scaling Uncertainty:

The PCAST machine has 6 PF coils (PF 5 U&L, PF 6 U&L, and PF 7 U&L) for a total mass of coils of 1,160 tonnes. As with the ITER PF magnets, the structure is inconsequential relative to the conductor and therefore the simplifying assumption is that the total mass is all due to the conductor. The total PF magnet mass for the PCAST machine is therefore assumed to be 1,162 tonnes; at $68/kg, the total estimated cost for the PCAST PF magnets is approximately $79M.

If one were to use a 50% larger unit cost on the historical basis of the smaller machines, the PCAST TF coil cost estimate would increase from $79M to $119M, an increase of $40M.

Separately from scaling, a rough bottoms-up approximation was done developed our experience in manufacturing other copper coils and cases. This bottoms-up approach is discussed in greater detail at the end of the section on WBS 1.4.

- <u>WBS 1.3 - Central Solenoid</u>

Basis:

The suggested ITER JCT unit scaling factor for the Central Solenoid is $/kg. As with the TF Magnets, the PCAST device utilizes OFHC copper conductor, whereas the ITER Central Solenoid conductor is superconducting; the ITER figure was therefore adjusted to remove the mass and the cost of the ITER conductor delivered cabled on the loading dock. The remaining mass and costs then represent the effort to manufacture the Central Solenoid (e.g., the effort to obtain the structure material and its manufacture, the effort to wind the coil, etc.) - approximately $54/kg. Since this is very close to the derived ITER unit cost scaling for the TF magnets, we have elected to use the ITER unit cost scaling for the TF magnets of $56/kg as representative.

The effort to produce the OFHC copper conductor for PCAST was then derived from the SSAT cost algorithms - approximately $12/kg. The sum of the ITER TF coil manufacturing cost/kg and the SSAT winding pack cost/kg yields a composite scaling factor - approximately $68/kg. The ITER unit cost with superconducting conductor would be 124 $/kg.

Discussion:

The equivalent BPX scaling factor to manufacture the CS coils (excluding the cost of the conductor delivered on the loading dock) is approximately $65/kg and the equivalent TPX scaling factor is $332/kg.

The ITER unit scaling was selected assuming that the effort to manufacture an OFHC coil was equivalent to that required to manufacture a superconducting magnet.

Historic unit costs of other large PF coils including conductor, converted to FY-89$, are: TFTR PF coils, @ $180/kg, and DIII PF coils @ $84/kg.

As with the other PCAST coils, It was also felt that the BPX and TPX equivalent scalings were not representative due to: (1) the complexity of dealing with Be-Cu conductor for BPX and (2) the probability that both the BPX and TPX estimates include a large portion of the "magnet structure" costs specifically identified in the ITER WBS Element 1.4, Mechanical Coil and Support Structure.

The ITER cost estimate included approximately $7M in AFI for leads and cooling lines. Since the ITER scaling factor was developed from the total ITER costs, including AFI, there is no need to apply a separate AFI to this estimate.

Results and Scaling Uncertainty:

The PCAST Central Solenoid is estimated to have a total mass of 500 tonnes, including structure; at $68/kg, the total estimated cost for the PCAST PF magnets is approximately $34M.

If one were to use a 50% larger unit cost on the historical basis of the smaller machines, the PCAST TF coil cost estimate would increase from $34M to $51M, an increase of $17M.

Separately from scaling, a rough bottoms-up approximation was done developed our experience in manufacturing other copper coils and cases. This bottoms-up approach is discussed in greater detail at the end of the section on WBS 1.4.

- WBS 1.4 Magnet Structure

Basis:

The suggested ITER JCT scaling factor for the Magnet Structure is $/kg. As a simplifying assumption, the ITER cost scaling was derived by dividing the total mass of the magnet structure by the total costs - approximately $31/kg.

The ITER cost scaling was selected as representative.

Discussion:

The equivalent BPX scaling was only $12/kg, but is probably not representative since much of the "magnet structure" was included in the magnet costs. The equivalent TPX scaling factor is $58/kg.

A representative historically based unit cost in FY-89$ would be the heavy case structures for MFTF-B at $35/kg.

The PCAST estimate was derived by estimating the mass of the current PCAST design and then applying the representative scaling factor.

The ITER cost estimate included approximately $6M in AFI for cooling lines. Since the ITER scaling factor was developed from the total ITER costs, including AFI, there is no need to apply a separate AFI to this estimate.

Results and Scaling Uncertainty:

The PCAST Mechanical Support Structure made up of the Gravity Supports to the bottom of the Cryostat (cost of the Cryostat supports are included in that WBS), Intercoil Structure, and Collar/Crown is approximately 24.8 tonnes per coil or approximately 396 tonnes; at $31/kg, the total estimated cost for the PCAST PF magnets is approximately $12.3M.

Historical data from other machines indicated only a scaling factor of approximately $35/kg, essentially the same as our derived scaling from ITER. Accordingly, no scaling uncertainnty is indicated.

WBS 1.1 - 1.4 Supplemental Cost Information

Separately from scaling, a rough bottoms-up approximation was done based on our experience in manufacturing other coils and cases. The vendor labor was first estimated for each major fabrication/assembly process as follows:

- TF Coils
- TF Cases
- Installing Cable in Conduit
- PF Coils
- Intercoil Structure
- Substructure
- Central Solenoid
- Testing of Coils Prior to Shipment

The table below details the development of these cost using the rough bottoms-up approximation:

Magnet Systems Cost Estimate

Description	Units	Cost (FY-89M$)
Labor	Manweeks	
TF Coils	5,200	
TF Cases	6.656	
Installing Cable in Conduit	3,328	
PF Coils	3,155	
Intercoil Structure	1,560	
Sub-Structure	1.331	
Central Solenoid	2,100	
Testing	4,666	
Total Labor (manweeks)	27,996	
Total Labor (PPY's)[1]	560	$112.0
Other		
Tooling Engrg/Fabrication (@ 20% of Labor $)		$22.4
Manufacturing Engineering (@ 50% of Labor $)		$56.0
Material	Tonnes	
TF Coils	3,352	
CS Coils	500	
PF 5, 6, & 7	1,162	
TF Cases	1,320	
Structure	396	
Total Material	6,730	
Material Costs (@$12/kg)		$80.8
Material G&A Costs (@ 10% of Material)		$8.1
Total Magnet Systems Base Cost		$279.2
General Admin/Mgmt Expenses (@ 30% of Base Cost)		$83.8
Profit (@ 20% of Base Cost)		$55.8
Total Magnet Systems Costs		**$418.8**

Note: [1] Assumed that 1 PPY = 50 manweeks and that 1 Vendor PPY = $200K.

The vendor labor estimate for the coils included the time to prepare the material and to wind and insulate the coil (including VPI). For the cases, the vendor labor estimate included receiving inspections, preparation of material, bending and forming, welding, and machining. The vendor labor estimate also included support functions such as QA, etc. that would occur during the manufacturing process. The vendor labor man-hours were then converted to Professional People Years (PPY's) and then dollarized using the approximate cost of $200K/PPY for vendor labor.

Tooling engineering and fabrication was estimated at 20% of the total vendor labor dollars. Manufacturing engineering was estimated at 50% of total vendor labor dollars.

Material costs were developed by multiplying the calculated mass of the PCAST magnet systems components by $12/kg. General and Administrative expenses of 10% on material costs were then added to account for the handling and processing of the material.

To the above subtotal an allowance of 30% was applied for general administrative and management costs and an allowance of 20% for profit was added.

Using this methodology, the estimated costs for the magnet systems is approximately $419M vs. the approximately $443M derived by using scaling factors.

- **WBS 1.5 Vacuum Vessel**

Basis:

The suggested ITER JCT scaling factor for the Vacuum Vessel is $/kg. The ITER Vacuum Vessel is a double walled stainless steel vessel filled with steel balls. Using a simple scaling of the total mass of the vacuum vessel (without the steel balls) vs. the total cost, the scaling is approximately $29/kg.

The PCAST vessel will be made of Inconel 625. As part of the ITER cost development for the vessel, both a stainless steel and Inconel vessel were considered. A factor of approximately 1.5 was determined as representative of the increase in material and machining costs of a stainless vessel relative to an Inconel 625 vessel. Accordingly, a scaling factor of approximately 1.5 times the ITER scaling (1.5 x $29/kg) yields a PCAST scaling factor of approximately $44/kg for the Inconel 625 vessel and $29/kg for the stainless steel shield .

The thermal shield for the PCAST vessel is a multi-layer insulation (MLI) system comprised of aluminized Kapton separated by Lydall-Manning Cryotherm 233. The material cost for this system is \$2.28/ft^2-layer for Kapton and \$.0038/ft^2-layer for the Cryotherm separator.

Discussion:

The BPX equivalent scaling for its thick walled Inconel 600/625 vessel was approximately $94/kg, however the cost of forming such a thick vessel dominated the costs and hence are not considered representative for PCAST. The TPX design used a double walled titanium vessel. Adjusting the total cost ($5.45M in FY-89$) by the relative costs of Inconel vs. titanium, ($21/kg)/($37.4/kg) and adjusting the total mass of the vessel (37 tonnes) by the relative densities of the Inconel and titanium, (.305/.16) results in an equivalent scaling factor of $43/kg, which is in agreement with the ITER figure.

The thermal shield costs are based on the estimated cost of the MLI materials for the TPX vacuum vessel adjusted to FY-89$. The ITER estimate included $2.0M in AFI for the small shield details. However, since the PCAST estimate specifically estimated the thermal shields, there is no need to apply a separate AFI to this estimate.

Results and Scaling Uncertainty:

The PCAST Vacuum Vessel is estimated to have total mass of slightly in excess of 560 tonnes; at $44/kg for Inconel 625, the estimated cost for the PCAST vacuum vessel is approximately $24.7M. The estimated mass for the stainless steel shield is approximately 745 tonnes; at $29/kg for stainless steel, the cost for the shield is $21.6M. The estimated cost of the vessel thermal insulation is $3.8M. Thus the total estimated cost for the PCAST Vacuum Vessel System is $50.0M.

Since we are using the ITER unit scaling factors directly, there is no cost uncertainty indicated in the estimated cost of the vessel and shielding. The installation cost for the MLI is estimated as being equal to the material cost. While there is a level of uncertainty associated with this cost the estimate is considered conservative.

- **WBS 1.6 - First Wall and Blanket/Shield**

  Basis:

  This WBS element consists of three sub-elements:

  - WBS 1.6.1 - First Wall
  - WBS 1.6.2 - Blanket (N/A for PCAST)
  - WBS 1.6.3 - Miscellaneous Shielding (e.g., shield plates, plugs, and intercoil shields). This category was included in ITER's estimate for WBS 1.6.2.

  <u>First Wall</u>

  It has been the ITER experience (based on the assessment of several design options) that for the First Wall and Blanket/Shield the dominant cost factor was the number of connections that had to be made. They felt that the number of modules were representative of the number of connections and hence the ITER JCT recommended a scaling factor of k$/module. However, PCAST has no nuclear testing mission or need for an integrated cooled blanket/shield and therefore a "module" on ITER is of a much different design than a "module" on PCAST.

  We believe that the TPX first wall modules are more representative of the design to be used in this machine and therefore the PCAST first wall modules were scaled from the TPX design using surface area of plasma facing components. However, we agree that coolant connections, which must be compatible with remote handling and which must be designed for disruption events, are significant factors in the design and hence unit costs. Although the TPX design concept was used as a starting point for scaling, the much larger PCAST PFC (both first wall and divertor) design required the number of modules to increase significantly over TPX in order to keep the unit weight within the limits of remote handling. Our costs were therefore based on scaling the TPX modules by relative surface area and number of connections, with several scaling factors applied (for coolant connections and increased electromagnetic loads).

Blanket/Shield

PCAST will not have a Blanket/Shield.

Miscellaneous Shielding

The PCAST estimate is based on a shielding configuration to meet the functional requirements of the machine. The cost was determined based on component configurations and cost scaling factors.

Discussion:

First Wall

The total surface area of first wall modules is approximately 260m^2. The first wall consists of the following components:

- An inboard toroidal limiter to protect the vessel wall and magnetic diagnostics located on the inboard VV wall from energetic particles during normal operation, from plasma radiation heat loads , and from damage during disruptions. A modular design consisting of water-cooled panels armored with carbon-carbon tiles will be used. The inboard limiter is divided into 16 toroidal sectors upper and 16 toroidal sectors lower for a total of 32 modules.

- Two outboard toroidal limiters, used for startup and to protect the outboard vessel wall from energetic particle fluxes during normal operation and during startup. A modular design consisting of water-cooled panels armored with carbon-carbon tiles will be used. There are 32 modules top and 32 modules bottom, resulting in 64 modules total.
- Three poloidal limiters which protect equipment in the port region from energetic particle fluxes during normal operation and during disruptions. The limiters will consist of water-cooled heat sinks protected by carbon-carbon tiles.

Based on scaling up from TPX and accounting for the number of connections, the approximate unit cost scaling becomes \$303K/module in FY-89\$. The ITER equivalent unit cost scaling factor, with the cost of the Blanket/Shield backplate subtracted, is approximately \$482K/module. However, the mission and design of the module for ITER is much different from that of PCAST. See the supplemental discussion following WBS 1.7.

The equivalent BPX scaling is only \$16K/module, but these modules were inertially cooled and hence scalings related to number of connections would not be applicable. The equivalent TPX scaling is approximately $125K/module.

Blanket/Shield

PCAST will not have a Blanket/Shield.

The ITER cost estimate for the First Wall/Blanket did not include any AFI and therefore none is applied to this estimate.

Miscellaneous Shielding

The Miscellaneous Shielding consist of the following subsystems:

- Torus shielding around the vacuum vessel (this is included in the WBS 1.5 Vacuum Vessel estimate);
- Shielding around the vacuum pumping ducts and biological port plug;
- Penetration shielding in and around the radial ports;
- Shielding in the inter-coil structure; and
- Vacuum duct shielding to limit activation in cryostat assembly (if needed for ex-vessel shielding to reduce neutron activation to about 10 mrem/hr after one week of cooling) -- however this was not considered for the baseline case.

The Miscellaneous Shielding is assumed to be installed as part of WBS 2.2.

Results and Scaling Uncertainty:

First Wall

The estimated costs for the PCAST first wall components, including vendor engineering and instrumentation is approximately $30M in FY-89$. The methodology for developing these costs are discussed in greater detail in the supplemental cost information presented following WBS 1.7. This is an approximate cost per module of $303K/module in FY-89$.

If the ITER per module unit cost is used rather than the scaling from TPX, the PCAST $30M first wall cost increases to $47.7M, an increase of about $18M. Alternately, the ITER number can be scaled down by the relative areas of the device (roughly 0.38) to arrive at an approximate figure of $130M. However, this ignores the significantly simpler design utilized by PCAST. Accordingly, in recognition of the significantly different mission and design of the two first wall concepts, we feel that the scaling uncertainty should range from $30M to about $50M, and not the $130M which assumes a similar design to ITER but on a smaller scale. Overall, the PCAST first wall costs are significantly less than the ITER first wall costs. The reasons for this difference is addressed in the supplemental cost discussion on the Plasma Facing Components following WBS 1.7.

Blanket/Shield

PCAST will not have a Blanket/Shield.

Miscellaneous Shielding

The approximate cost of the Miscellaneous Shielding is $13M. Should additional shielding of the vacuum ducts be required to reduce the neutron activation of ex-vessel components to about 10 mrem/hr after one week of cooling, the cost would increase by approximately $32M to about $45M. Although, the present design of PCAST does not require this additional shielding, the cost uncertainty range has included this possibility as the upper bound; hence the cost uncertainty ranges from $13M to $45M.

WBS 1.6 and 1.7 Plasma Facing Components Supplemental Cost Information

See supplemental cost information presented at end of WBS 1.7 which covers both WBS 1.6 (First Wall) and WBS 1.7 (Divertor).

WBS 1.63 Miscellaneous Shielding Supplemental Cost Information

The table below provides the detailed breakdown of the Miscellaneous Shielding Systems costs:

Miscellaneous Shielding Systems Costs

	PCAST FY-95M$	PCAST FY-89M$[1]	Comment
Hardware			
Torus Shielding Around the Vacuum Vessel	$ 0.0	$ 0.0	Included in WBS 1.5 (Vacuum Vessel) Estimate
Biological Shield Plug	$ 1.6	$ 1.3	
Vacuum Duct Shield to Protect Coil	$ 4.5	$ 3.6	
Vacuum Duct Shield to Limit Activation in Cryostat Assembly[2]	$ 0.0	$ 0.0	
Penetration Shielding in the Radial Ports	$ 3.5	$ 2.8	
Shielding Around the Intercoil Structure	$ 6.6	$ 5.3	
Total Hardware	$16.2	$13.0	
Vendor Engineering & Installation	$ 0.0	$ 0.0	Included in WBS 2.2
Total Costs	**$16.2**	**$13.0**	

Note: [1] FY-95$ de-escalated to FY-89$ using ITER Interim Design Report factor of 1.2425

[2] To limit the activation of components in the cryostat assembly, additional shielding around the vacuum ducts will cost approximately $39.3M in FY-95$ ($31.6M in FY-89$)

- **WBS 1.7 - Divertor**

Basis:

As for the ITER First Wall and Blanket/Shield, it has been the ITER experience (based on the assessment of several design options) the dominant cost factor for the Divertor is also the number of connections that had to be made. They felt that the number of modules were representative of the number of connections and hence the ITER JCT recommended a scaling factor of k$/divertor cassette.

We believe that the TPX divertor modules are more representative of the design to be used in this machine and therefore the PCAST divertor modules were scaled from the TPX based on surface areas. However, we agree that coolant connections, which must be compatible with remote handling and which must be designed for disruption events, are significant factors in the design and hence unit costs. Although the TPX design concept was used as a starting point for scaling, the much larger PCAST PFC (both first wall and divertor) design required the number of modules to increase significantly over TPX in order to keep the unit weight within the limits of remote handling. Our costs were therefore based on scaling the TPX modules by relative surface area and number of connections, with several scaling factors applied (for coolant connections and increased electromagnetic loads).

Discussion:

The total surface area of divertor is approximately 193m^2. The PCAST divertor is a double-null divertor system, composed of a total of (64) outer divertor modules and (32) inner divertor modules for a total of 96 modules. Carbon-carbon fiber composites will be used for all plasma facing surfaces; the modules will be cooled by deionized water. Based on scaling up from TPX and accounting for the number of connections, the approximate unit cost scaling becomes $795K/module in FY-89$.

Using the number of ITER divertor cassettes, the approximate ITER scaling factor is approximately $3000K/module for the 60 modules used. However, the design and material of the PCAST divertor is much different than that of ITER. See the supplemental cost discussion below.

The equivalent BPX scaling is only $11K/module, but these modules were inertially cooled and hence scalings related to number of connections may not be applicable. The equivalent TPX scaling is $174K/module and is of a similar design to ITER. We believe that the TPX module design concept of CFC macrobolocks and support structure is much more representative to the PCAST concept than the ITER design of a heavy frame and Be plasma facing materials.

The ITER cost estimate for the Divertor did not include any AFI and therefore none is applied to this estimate.

Results and Scaling Uncertainty:

The estimated costs for the PCAST divertor components, including vendor engineering, is approximately $76M in FY-89$. The methodology for developing these costs are discussed in greater detail in the supplemental cost information presented below. This is an approximate cost per module of $795K/module in FY-89$.

Using the unit cost scaling factor of $3M/module from ITER, the resultant PCAST costs would be significantly more than that of ITER. See the supplemental cost discussion below for reasons why this simple scaling is not considered appropriate.

It is recognized that some cost uncertainty of the divertor plasma facing components is warranted. However, the estimate based on the ITER design with its heavy frame and Be components is not seen as representative of this design. Therefore a cost uncertainty ranging from $76M to $100M is considered reasonable.

WBS 1.6 and 1.7 Plasma Facing Components Supplemental Cost Information

The PCAST PFC designs, and hence the costs, are based largely those developed for TPX. Additional costs or factors were applied to account for specific differences, as discussed below:

Hardware costs:

In developing the TPX modular design for the PFC components we note that coolant connections, which must be compatible with remote handling and which must be designed for disruption events are significant factors in the design and hence unit costs. The much larger PCAST PFC design had to increase the number of modules significantly over TPX in order to keep the unit weight within the limits of remote handling.

The hardware cost estimate consists of two major elements: a cost for the basic unit, based on TPX $\$/m^2$ for similar components, and an estimated cost for each pair of coolant connections. For the coolant connections, and estimate of $100K/coolant pair (inlet and outlet pipes) has been assumed for the divertor and $50K/coolant pair for the first wall components.

An additional cost multiplier of 1.15 was applied to reflect the higher electromagnetic loads which the PCAST machine PFCs must resist during disruptions due to PCAST's much higher plasma current.

Hardware cost =1.15 (structural cost multiplier) * [(PCAST area * TPX $/unit area) +(estimated cost of coolant connection pair * no. pairs of coolant connections)]

Vendor Engineering Costs:

Based on discussions with ITER JCT personnel involved in developing the ITER estimate, we have assumed that the design of the plasma facing components would be accomplished by the vendor and have therefore included these as part of the construction estimate. The vendor engineering cost of PFCs is , to a large extent, insensitive to the size of the components within practical limits. Nevertheless, PCAST will have increased engineering due to the increased fluence of PCAST compared to TPX; this will require greater consideration of materials and more R&D related to those special materials. Therefore a multiplier of 1.5 was applied to cover these. In addition, the structural cost multiplier discussed above of 1.15 was also applied to account for the increased level of engineering required for additional structural analyses and strengthening of components.

Engineering costs =1.5 (Engrg. cost multiplier) * 1.15 (Structural cost multiplier)* TPX cost for engineering of similar components.

TPX/PCAST PFC Cost Summaries and Comparisons

As indicated above, the PCAST costs are largely derived by scaling from TPX. Table I below provides a comparison cost summary of the two projects and their relative parameters for the divertors. The major area of difference is in the method used to calculate the cost of the coolant connections.

Table I
TPX/PCAST Divertor Cost Summary & Comparison

ITEM	TPX	PCAST
	(FY-95$)	(FY-95$)
Divertor		
Divertor H/W Costs	$13.4 M	$76.4 M
Divertor Area (m^2)	45.3 m^2	192.9 m^2
No. Modules	32	96
Divertor Engrg. Cost	$10.7M	$18.4M
Total Divertor Cost (FY-95$)	**$24.1M**	**$94.8M**
Total Divertor Cost (FY-89$)[1]	**$19.4M**	**$76.4M**

Notes: [1] FY-95 costs de-escalated to FY-89 using ITER de-escalation factor of 1.2425 from ITER Interim Design Report .

Similarly, Table II below compares the first wall components of the two machines:

Table II
TPX/PCAST First Wall Cost Summary & Comparison

ITEM	TPX	PCAST
	(FY-95$)	(FY-95$)
First Wall Components		
Inboard Limiter		
Divertor H/W Costs	$1.6 M	$8.1 M
Limiter area (m^2)	14	81
No. modules	16	32
Inbd. Limiter Engrg. Cost	$2.9 M	$5.0 M
Total Inboard Limiter Cost	**$4.5M**	**$13.1M**
Outboard Limiter H/W Cost		
Outboard Limiter H/W Cost	$2.3 M	$13.0 M
Outbd. limiter area (m^2)	37	176
No. modules		64
Out. limiter Engrg. Cost	$3.2 M	$5.5 M
Total Outboard Limiter Cost	**$5.5**	**$18.5M**
Poloidal Limiter		
Poloidal Limiter H/W Cost	$3.3M[2]	$1.0M
No. Limiters	3	3
Pol. Limiter Engrg. Cost	$1.7 M	$2.9 M
Total Poloidal Limiter Cost	**$5.0M**	**$3.9M**
Instrumentation[3]	**In Above**	**$1.4M**
Total First Wall Costs (FY-95$)	**$15.0 M**	**$36.9M**
Total First Wall Cost (FY-89$)[1]	**$12.1M**	**$29.7M**

Notes: [1] FY-95 costs de-escalated to FY-89 using ITER de-escalation factor of 1.2425 from ITER Interim Design Report .
[2] TPX Cost was not revised to reflect changes since CDR and therefore should not be considered for comparison.
[3] Instrumentation costs for PCAST adopted directly from ITER estimate.

ITER / PCAST PFC Cost Summaries and Comparisons

Table III compares the ITER estimates to the PCAST estimates for the first wall. On a direct comparison basis, the PCAST estimates at first appears to be low - for example, line 1.6A (First Wall Cost) \$200.1M for ITER (adjusted to \$240.7M to agree with final ITER Interim Design Report figure) vs. \$24.0M for PCAST . However, one must take into account the large size differences of the two devices - the first wall surface areas of ITER is 1200 m^2. whereas the surface area of the PCAST device is only 257 m^2. The first wall cost per unit area of ITER is \$213.4 K/ m^2 vs. \$115.6 K/ m^2 for PCAST - a ratio of 1.8. Considering the significant differences of the two designs, the cost ratio is felt to be reasonable.

Another measure of the reasonableness of the PCAST estimate can be obtained by measuring the ratio of the first wall coolant connection/manifolds cost (WBS 1.6C below) to the first wall cost (WBS 1.6A below). The ratio for ITER is approximately 27% whereas the PCAST ratio is approximately 19%. The slight difference in the two ratios can be explained by the fact that the ITER cooling/manifold costs include the connections to the blanket/shield whereas the PCAST estimate does not include these since PCAST has no blanket/shield.

Table III
First Wall Cost Comparisons
(Excluding Blanket/Shield)

ITER WBS Element	ITER Estimated Cost (FY-89$)	PCAST Estimated Cost (FY-89$)	Ratio of ITER to PCAST
1.6A First Wall Cost[1]	$240.7M	$24.0M	2.1[2]
1.6B Shield/Blanket Sectors	Not Included[2]	Not Applicable	
1.6C Cost of First Wall Cooling Manifolds, etc.[4]	$54.6M	$4.6M	2.5[2]
1.6D FW/S/B Supports	Incl. in 1.6C Above	Incl. in 1.6A Above	
1.6E FW/S Instrumentation	$1.4M	$1.4M	0.2[2]
1.6F FW/S/B Assy./Maint. Fixtures[5]	$50.3M	Incl. in WBS 2.2	
Total Cost (Exclusive of Blanket)	$347.0M	$29.7M	
Adjusted Total First Wall Costs (Exclusive of Blanket & Maint. Fixtures)	$296.7M	$29.7M	2.1[2]
First Wall Area, m^2	1200m^2	257m^2	4.7
Cost per Unit ($K/m^2)	$213.4K/m^2	$115.6K/m^2	1.8

Notes:

[1] ITER First Wall costs of $200.1M from May 19th Interim Cost Estimate adjusted upward by $40.6M to agree with ITER Interim Design Report First Wall total of $347M.

[2] Normalized Ratio - i.e., ITER estimated cost/PCAST estimated cost/area ratio

[3] Not included in comparison because PCAST has no shield/blanket. (ITER's estimate was $46.3.M)

[4] Manifold/Cooling Connection costs for PCAST based on 50K/connection pair - for 99 modules this comes to approximately $4.95M in FY-95$ times the factor of 1.15 to yield a cost of about $5.7M in FY-95$ or about $4.6M in FY-89$.

[5] Not included in comparison, since PCAST includes these charges in WBS 2.2. (ITER's estimate was $50.3 M).

In a similar manner, Table IV compares the divertor elements of the two machines:

Table IV
Divertor Cost Comparisons

ITER WBS Element	ITER Estimated Cost (FY-89$)	PCAST Estimated Cost (FY-89$)	Ratio ITER/PCAST
1.7A Divertor Cassette[2] (Including Cooling Connections[3]	$149.0M	$76.4M	1.25[1]
1.7B Baffles	Incl. in 1.6B above	Incl. in 1.7A Above	n/a
1.7C Divertor Suppt. Cooling & Maintenance[4]	$7.1M	Cooling Not Required - Maintenance in WBS 2.3	n/a
1.7D Assembly[4]	$9.4M	Incl. in WBS 2.2	n/a
1.7E Divertor Maintenance[4]	$12.5M	Not included (See WBS 2.3)	n/a
Total Cost	$178.0M	$76.4M	
Adjusted Total Cost (Exclusive of 1.7C-E)	$149.0M	$76.4M	1.25[1]
Divertor Surface Area	300m^2	192m^2	1.56
Cost per Unit Area ($K/m^2)	$496.7/m^2	$398K/m^2	1.25

Notes: [1] Normalized Ratio - i.e., ITER estimated cost/PCAST estimated cost/area ratio

[2] ITER Divertor costs of $114.2M from May 19th Interim Cost Estimate adjusted upward by $34.8M to agree with ITER Interim Design Report First Wall total of $178M.

[2] Manifold/Cooling Connection costs for PCAST based on 100K/connection pair - for 96 modules this comes to approximately $9.6M in FY-95$ times the factor of 1.15 to yield a cost of about $11.0M in FY-95$ or about $8.9M in FY-89$.

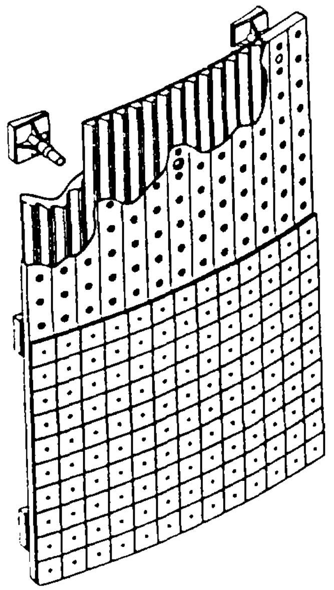
[3] Not included in this comparison since PCAST either excludes these costs (i.e., cooling for divertor supports) or includes them in a different WBS.

ITER estimates the cost of all divertor cassettes to be $114.2 M (adjusted to $149M to agree with final ITER Interim Design Report figure); the PCAST estimate for their divertor modules (counterpart to the ITER cassettes) is \$76.4M of which approximately \$8.9M is for the cooling connections. In spite of the fact that ITER uses a single null divertor and PCAST has a double null divertor, ITER's divertor surface area is 56% larger. On a unit area basis, the ITER cost is 125% of the PCAST cost (\$496.7 K/m^2 vs. \$398K/m^2).

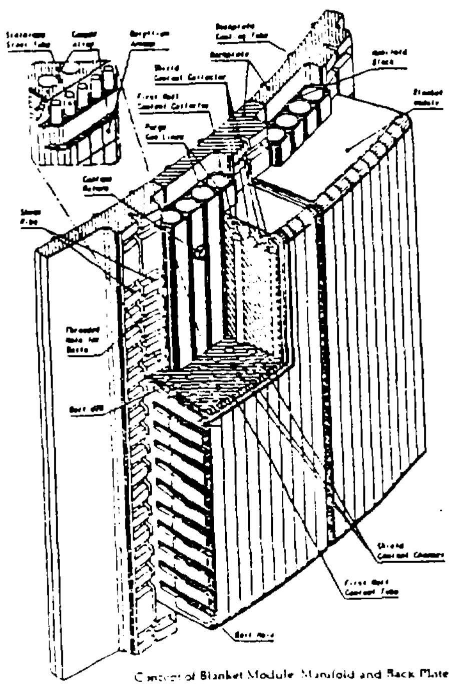
There is a significant difference between the design of both the first wall and divertor for PCAST relative to ITER. These differences account the significant differences in relative costs. The PCAST designs are much simpler. A comparison of the PCAST and ITER First Wall is shown in Figures A-1 and A-2 below. Likewise, Figures A-3 and A-4 compare the PCAST and ITER divertor designs. The relative cost differences are felt to be reasonable, given the significant differences between the designs of the plasma facing components for these two machines.

<u>Comparision of a PCAST First Wall Panel to an ITER Blanket Module/First Wall</u>

The inboard first wall armor consists of a ring of 16 curved plates, made from Inconel sandwich panels, symmetrical to the midplane. The CFC tiles are attached to the panel by a single central fastener.

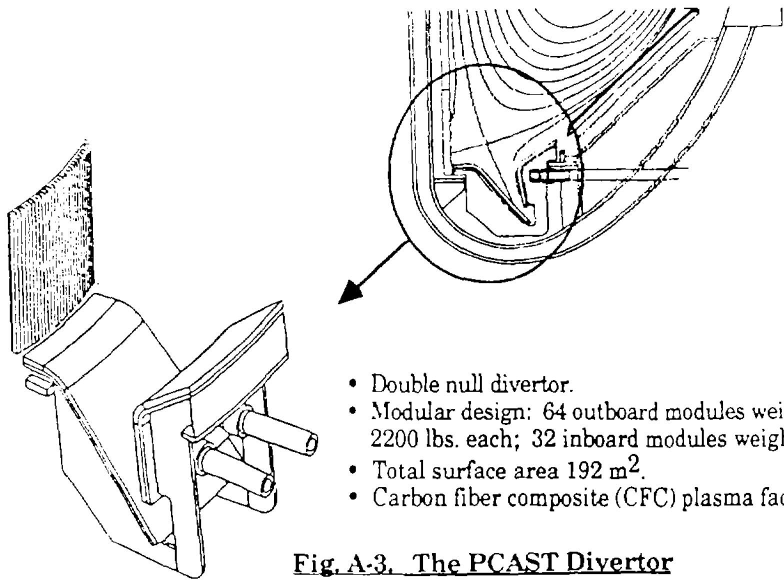


<u>Fig. A-1. A PCAST First Wall Moldule</u>



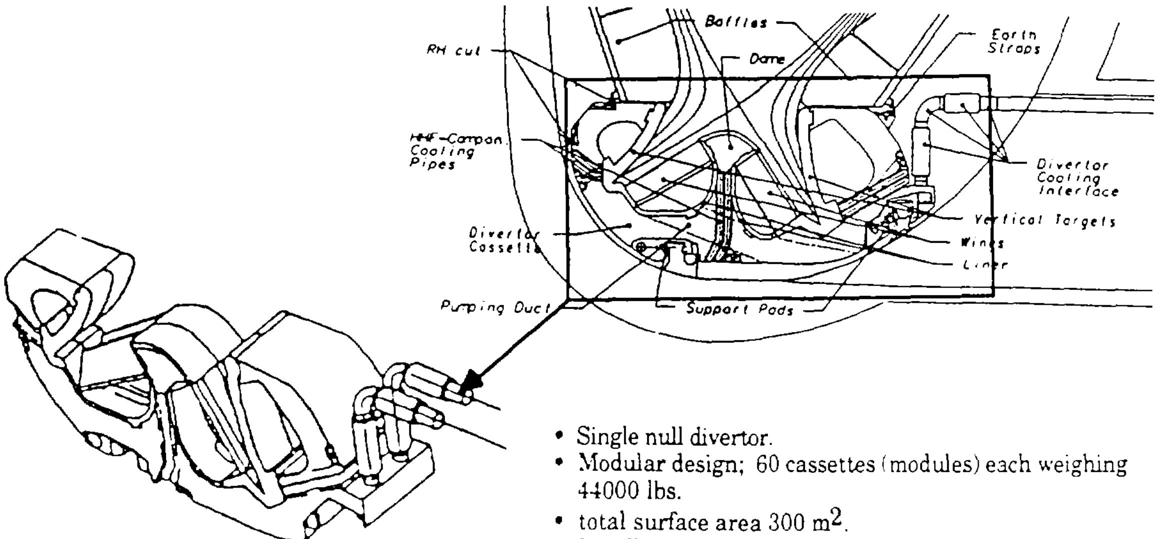
<u>Fig. A-2. An ITER Blanket Module/First Wall</u>

Comparison of the PCAST to the ITER Divertor



- Double null divertor.
- Modular design: 64 outboard modules weighing 2200 lbs. each; 32 inboard modules weighing 1300 lbs. each.
- Total surface area 192 m^2.
- Carbon fiber composite (CFC) plasma facing material.

Fig. A-3. The PCAST Divertor



- Single null divertor.
- Modular design; 60 cassettes (modules) each weighing 44000 lbs.
- total surface area 300 m^2.
- Beryllium plasma facing material.

Fig. A-4 The ITER Divertor

- **WBS 1.8 - Fueling Systems**

Basis:

A scaling from the ITER estimate was developed, taking into account the reduced fueling requirements.

Discussion:

The PCAST estimate for the Pellet Injection System includes only 3 pellet injectors (2 Centrifugal and 1 Pneumatic) since PCAST does not have the nuclear testing mission. The estimate for both the Fueling Enclosure and the Gas Fueling System was assumed to be 50% of ITER's based on relative machine requirements. The ITER estimate for the Wall Conditioning Systems was assumed to be the same as that for ITER.

The equivalent BPX fixed cost is about $15 M in FY-89$.

The ITER cost estimate for the Fueling Systems included $6.0M for wall conditioning systems. This estimate scaled from this to arrive at an estimate of $5.0M for wall conditioning. Hence a separate AFI need not be applied to this estimate.

Results and Scaling Uncertainty:

Based on scaling from the ITER estimate with the above adjustments, the estimated cost for the Pellet Fueling System is approximately $4.5M, the estimated cost for the Fueling Enclosure is approximately $5.7M, the estimated cost for the Gas Fueling Systems is approximately $2.2M, and the estimated cost for the Wall Conditioning Systems is approximately $5.0M. This totals to approximately $17.3M.

If the ITER fixed input were chosen, the cost would increase to $35M, an increase of approximately $18M. However, in recognition of the reduced fueling requirements, a scaling uncertainty of 50% increase on the derived value seems reasonable. Hence the scaling uncertainty ranges from $17M to $25M.

WBS 1.8 Fueling Systems Supplemental Cost Information:

The table below provides the detailed breakdown of the Fueling Systems costs:

Fueling Systems Costs

	PCAST FY-95M$	PCAST FY-89M$[1]	Comment
Hardware			
Pellet Fueling System	$ 5.6	$ 4.5	2 Centrifugal and 1 Pneumatic Injectors
Fueling Enclosure	$ 7.0	$ 5.7	50% of ITER
Gas Fueling	$ 2.7	$ 2.2	50% of ITER
Wall Conditioning Systems	$ 6.2	$ 5.0	Same as ITER
Total Hardware	$21.5	$17.3	
Vendor Engineering & Installation	$ 0.0	$ 0.0	Included in Above
Total Costs	**$21.5**	**$17.3**	

Note: [1] FY-95$ de-escalated to FY-89$ using ITER Interim Design Report factor of 1.2425

[2] To limit the activation of components in the cryostat assembly, additional shielding around the vacuum ducts will cost approximately $39.3M in FY-95$ ($31.6M in FY-89$)

- **WBS 1.9 - Internal Control Coils**

Basis:

ITER does not require Internal Control Coils. The BPX and TPX internal control coils are similar in design to the PCAST machine coils and therefore are the model for developing estimates.

There are two pairs of Internal Control Coils for the PCAST machine. One pair provides fast vertical control of the plasma and the other pair provides fast radial control. Rather than develop simple scalings based on $/kg, a rough bottoms-up estimate was developed for costing these coils.

Discussion:

There are two Vertical Position Control Coils which each have two turns per coil. Starting with an estimated cost of conductor at $23/kg (for the Inconel jacketed, MgO insulated hollow copper conductor) the estimate is developed by adding estimated costs for vacuum feed-throughs, supports and other miscellaneous items and development of a conductor forming machine. This is then multiplied by various burdens, corporate G&A, and profit to arrive at an estimated cost of $1.6M in FY-95$ ($1.3M in FY-89$). The total estimated mass is 2411kg. Since ITER did not require IC coils, the cost to wind these coils in place is also included here. This equates to an overall scaling unit cost of $539/kg in FY-89$ for the Vertical Position Control Coils. Note that the coils will be formed within the vacuum vessel during machine assembly. Cost of R&D for specialized conductor development is also assumed to be covered elsewhere. The resulting unit cost is $0.65M per coil in FY-95$.

There are also two Radial Position Control Coils which each have four turns per coil. The coil design and estimating methodology is similar to the Vertical Position Control Coils. Starting with an estimated cost of conductor at $23/kg (for the Inconel jacketed, MgO insulated hollow copper conductor) the estimate is developed by adding estimated costs for vacuum feed-throughs, supports and other miscellaneous items, and development of a conductor forming machine. This is then multiplied by various burdens, corporate G&A, and profit to arrive at an estimated cost of $5.6M in FY-95$ ($4.5M in FY-89$). The total estimated mass is 8947kg. Since ITER did not require IC coils, the cost to wind these coils in place is also included here. This equates to an overall scaling unit cost of $503/kg in FY-89$ for the Radial Position Control Coils. Cost of R&D for specialized conductor development is also assumed to be covered elsewhere. The resulting unit cost is $1.2M per coil in FY-95$.

For rough comparisons of costs based on $/kg, a composite cost for the PCAST IC Coils on this basis is $511/kg in FY-89$.

The unit cost scaling for the BPX Internal Control Coils is approximately $150/kg (including conductor, structure, and insulation). The BPX IC coils were located outboard of the plasma major radius between the vacuum vessel and the TF inner ring structure; they were clamped directly to the structure in the TF bore. The location of these coils relative to the location of the PCAST IC coils which are inside the vacuum vessel is important; the BPX coils were much more massive (approximately 49,500kg vs. the approximately 11360kg for the PCAST coils). Hence the costs of the PCAST IC coils are less than those for BPX

The TPX equivalent unit cost scaling is approximately $275/kg based on very preliminary CDR data. However, this did not represent the latest design that was being updated at the time TPX and hence is not considered representative. The initial PCAST design concepts for these coils are basically an extension of the latest TPX design.

Since there were no position control coils included in the ITER estimate (with the possible exception of the small AFI of $2.0M in the PF Magnet estimate), there is no AFI in this estimate.

Results and Scaling Uncertainty:

The estimated cost for the Internal Control Coils, including the in-place winding is approximately $5.8M. There is no cost uncertainty indicated.

- **WBS 2.2 - Machine Assembly and Tooling**

Basis:

The PCAST estimate was derived by developing direct comparisons between PCAST and ITER and from experience on other machines and machine estimates.

Discussion:

Neither the time available nor the details of the design permitted a bottoms-up analysis and cost estimate of the assembly of the PCAST machine. Instead, the approach adopted was to review the ITER assembly procedures and estimates, and to make comparisons to the PCAST proposal in those areas where differences were expected to be significant. The areas of particular interest included welding, in-vessel components, alignment, tooling, crane usage, complexity, and cryogenic connections. Scaling factors were developed from direct comparisons between PCAST and ITER and from experience on other machines and machine estimates.

The ITER JCT estimate is based on input from industry and JCT experience for the rest of the work. It is their belief that the cost driver is complexity rather than size or mass. ITER JCT suggested scaling factor is by number of sectors to be assembled - for ITER there are 20 sectors. This yields an approximate scaling factor of $8.85M/sector. The equivalent BPX factor is $9.61M/sector and for TPX the equivalent scaling factor is approximately $3M/sector. This simplified approach was not utilized in developing the estimate for PCAST.

As discussed below, the considerable AFI applied to this estimate has been considered when developing the PCAST estimate.

Results and Scaling Uncertainty:

Scaling from ITER, the estimated cost is approximately $118.8M. No scaling uncertainty is indicated.

Since ITER did not require any IC Coils, the cost to wind these coils in place is included in the costs of the IC Coils (WBS 1.9).

WBS 2.2 Supplemental Cost Information

ITER Cost Estimate

The cost estimate for the ITER machine assembly is $177 M, which is based on an initial industry assembly estimate of $81M plus an allowance for indeterminables (AFI) of $80M and an additional estimate of $16M for the assembly of the first wall and blanket systems. The industry estimate was broken down into the following components:

Area	Costs FY-89$
Labor (craft labor and craft supervision)	$ 24.7M
Materials (consumable materials, rentals, etc.)	$ 4.2M
Tooling (specialized tools, lift fixtures, transporters, etc.)	$ 19.2M
Support (field engrg. & supv., ass'y.) planning, constructibility[1]	$ 32.4M
Total	$ 80.5M

Note: [1] Support was derived from an industry factor applied to the Labor.

Neither the "indeterminables" (AFI) nor the first wall/blanket system estimates were broken down into component parts. The following adjustments were made: $2M was added to the Material estimate and $10M to the Tooling estimate. The remaining funds were divided between Labor and Support in the same proportion as the initial estimate. These assumptions result in the following estimates, which will be used in making comparisons between ITER and PCAST, and applying the scaling factors:

Area	Costs FY-89$
Labor (craft labor and craft supervision)	$ 61.0M
Materials (consumable materials, rentals, etc.)	$ 6.7M
Tooling (specialized tools, lift fixtures, transporters, etc.)	$ 29.2M
Support (field engrg. & supv., ass'y.) planning, constructibility[1]	$ 80.1M
Total	**$ 177.0M**

Note: [1] Support was derived from an industry factor applied to the Labor.

PCAST Cost Estimate

- Welding

  It was assumed that the welding of ports would scale in proportion to the surface areas of the vacuum vessel or ITER/PCAST equals 2.7:1. TPX manpower estimates indicate that field welding operations on the vacuum vessel were 9.6% of the total assembly labor costs. These same ratios were used in deriving the PCAST costs. Applying 9.6% to the total ITER assembly estimate (craft labor plus support) and the scaling factor for PCAST of 1:2.7 or 0.63 results in a total welding cost for PCAST of $8.5M. The resulting savings for PCAST would be $13.5M - $8.5M = $5.0M.

- Assembly of In-vessel Components

  The ITER cost estimates for the first-wall/blanket assembly of $16.0M can be reduced by 75% due to the elimination of the blanket in PCAST. The scaling factor of 1:2.7 or 0.37, based on the difference in surface area, can be applied to the remaining first-wall estimate of $4.0M resulting in a PCAST estimate of $1.5M or a savings of $2.5M. The total savings in the first-wall blanket assembly from PCAST is therefore $12.0M + $2.5M = $14.5M.

The ITER cost estimate for the divertor assembly is $9.4M. Applying the scaling factor of 0.53 to this estimate results in a PCAST assembly estimate of $5.0M. The savings resulting from PCAST is $9.4M - $5.0M = $4.4M.

The total cost savings for PCAST in the assembly of in-vessel components is therefore $14.5M + $4.4M = $18.9M.

- Alignment of Major Components

  Applying 7.5% to the total ITER assembly estimate (craft labor plus support) and the scaling factor of 8/20 or 0.4 results in an alignment cost for PCAST of $4.2M. The resulting savings for PCAST would be $10.6M - $$4.2M = $6.4M.

- Assembly Tooling

  The derived assembly tooling estimate for ITER is $29.2M. A scaling factor of 0.53 based on weight applied to 70% of the ITER results in a cost of $10.8M. The remaining 30% or $8.8M of the ITER estimate would remain unchanged for PCAST. Therefore the tooling cost estimate for PCAST is $8.8M + $10.8M = $19.6M. The resulting savings for PCAST would be $29.2M - $19.6M = $9.6M.

- Crane Usage

  Applying a crane usage factor of 0.3, plus a factor of 0.59 representing the heavy assembly portion of the total labor costs, plus a factor of 0.33 for the percentage of the work crew involved in heavy lifts, to the total ITER labor cost results in a crane usage estimate for ITER of $22.2M. Assuming a 10% reduction for PCAST, or a scaling factor of 0.9 applied to the ITER estimate results in a crane usage cost estimate for PCAST of $20.0M. The resulting savings for PCAST would be $22.2M - $20.0M = $2.2M.

- Design Complexity

  A global simplicity factor of 0.10 applied to the ITER assembly labor estimate results in a savings for PCAST of $14.1M.

- Materials

  Materials primarily represent the consumables required during assembly operations. Applying the scaling factor of 0.70 to the materials estimate derived for ITER of \$6.7M results in a PCAST materials estimate of \$4.7M. The resulting savings for PCAST would be \$6.7M - \$4.7M = \$2.0M.

Summary

The following table summarizes the cost savings in the assembly operation resulting from the PCAST design. It should be noted that only those areas addressed in the above discussion have been considered in estimating the reduction in the ITER estimate resulting from the PCAST design. In all other areas, the ITER assembly estimates remain essentially the same for PCAST.

Assembly Cost Comparison
PCAST versus ITER

Area	ITER	PCAST	Savings
	(FY-89M$)	(FY-89M$)	(FY-89M$)
Welding	$ 13.5	$ 8.5	$ 5.0
In-Vessel Components	$ 25.4	$ 6.5	$18.9
Alignment	$ 10.6	$ 4.2	$ 6.4
Tooling	$ 29.2	$ 19.6	$ 9.6
Crane Usage	$ 22.2	$ 20.0	$ 2.2
Materials	$ 6.7	$ 4.7	$ 2.0
Balance of Assembly (Including Complexity)	$ 69.6	$ 55.3	$14.1
TOTALS	**$177.0**	**$118.8**	**$58.2**
Category	**ITER**	**PCAST**	**Savings**
	(FY-89M$)	(FY-89M$)	(FY-89M$)
Labor	$ 61.0	$ 40.6	$ 20.4
Materials	$ 6.7	$ 4.7	$ 2.0
Tooling	$ 29.2	$ 19.6	$ 9.6
Support	$ 80.1	$ 53.9	$ 26.2
TOTALS	**$177.0**	**$118.8**	**$58.2**

PCAST represents a reduction of $58.2M or a scaling factor of 0.67 applied to the derived ITER assembly cost estimate.

- **WBS 2.3 - Remote Maintenance Handling Systems**

Basis:

The cost is scaled from ITER R/M costs on a sub-element basis. The overall ratio to ITER costs is 0.88.

Discussion:

See attached Supplemental Discussion for detailed cost scaling.

Since the estimate was developed by scaling from the ITER estimate which included the $16.0M of AFI, there is no need to apply a separate AFI to this estimate.

Results and Scaling Uncertainty:

The PCAST estimate is approximately $199M. No scaling uncertainty is indicated.

WBS 2.3 Maintenance Systems Supplemental Cost Information

The PCAST maintenance systems evaluation is based on the approach and concept adapted for ITER. As a result the ITER Design Description Document 2.3 was used as the foundation of the analysis and write-up. The same basic WBS breakdown was also adapted to facilitate a side-by-side comparison of costs.

Because the PCAST and ITER systems will experience many of the same radiation damage and operational complexities the cost of deploying the two systems will be virtually the same in many areas.

However, PCAST has a cost advantage with reduced size and the use of PFC modules inside the vessel.

The philosophy of cost distribution for the PCAST machine would be slightly different than that used in ITER. Namely, maintenance requirements for specific components such as the ICRH and PFC modules would be given to the component designers along with cost responsibility. However, for this study, these elements are costed in Maintenance Systems to keep the continuity between the two systems with one exception tabulated below:

The cost comparison covers WBS 2.3 of the ITER IDR. Other areas of interest not included are:

- The ITER In-vessel First Wall/Blanket Manufacturing and Assembly Jigs/Fixtures are estimated at approximately $50.3M in WBS 1.6. This estimate does not include any additional remote maintenance tooling that might be required; these costs are included in this WBS.
- The ITER In-vessel Divertor Maintenance Tooling is estimated in WBS 1.7 at $12.5M. This is assumed to be $0M for PCAST due to differences in the way divertors will be handled.
- The Remote Handling and Mockup building (WBS 6.2V) at $28M for 4000m^2 could be reduced approximately 33% to 2800m^2 with a total cost of $18.8M due to the reduced size of PCAST relative to ITER.
- The maintenance equipment portion of the Hot Cell Building (WBS 6.2B) could be reduced due to the size difference of the two machines. This is addressed in WBS 6.3, Waste Management Systems.
- EDA engineering and development costs for PCAST will scale in proportion to hardware costs for a reduction of roughly 12%.

ITER/PCAST Cost Comparison

ITER		PCAST	
Subsystem	FY-89M$	Subsystem	FY-89M$
In-Vessel R/H Equipment	$ 72.5M	In-Vessel R/M Equipment	
Common In-Vessel Transporter		Common In-Vessel Booms	$ 41.0M
Divertor Module Handling Equipment		Module Handling Fixtures	$ 5.4M
Shield Blanket Handling Equipment		N/A PCAST	
Blanket Test Handling Equipment		N/A PCAST	
Vacuum Pumping Handling Equipment		(See In-Cryostat Handling Equipment Below)	
In-Vessel Diagnostics Handling Equipment		(See In-Cryostat Handling Equipment Below)	
Ex-Vessel R/H Equipment	$ 33.8M	Ex-Vessel R/H Equipment	$ 26.8M
Common Ex-Vessel Handling Equipment		Common Ex-Vessel Handling Equipment	
ECH Handling Eqmt		ECH Handling Eqmt	
ICRH Handling Eqmt		ICRH Handling Eqmt	
NBI Handling Eqmt		NBI Handling Eqmt	
Ex-Vessel Diagnostics Handling Equipment		(See In-Cryostat Handling Equipment Below)	
Coil Handling Equipment		(See In-Cryostat Handling Equipment Below)	
Vacuum Vessel Handling Equipment		(See In-Cryostat Handling Equipment Below)	
Pellet Injection Handling Equipment		Pellet Injection Handling Equipment	
		LHH Handling Equipment	
		In-Cryostat Handlg Equip.	$ 7.0M
Viewing Equipment	$ 33.8M	Viewing Equipment	$ 33.8M
Remote Handling Tools	$ 18.5M	Remote Handling Tools	$ 18.5M
Radiation Hard Compnts	$ 20.1M	Radiation Hard Compnts	$ 20.1M
Control System	$ 18.5M	Control System	$ 18.5M
Test Stand	$ 12.1M	Mockup and Test Stand	$ 12.1M
AFI	$ 16.0M	AFI	$ 16.0M
TOTAL R/M HANDLING	$225.3M	TOTAL R/M HANDLING	$199.2M

- **WBS 2.4 - Cryostat**

Basis:

The ITER JCT suggested unit scaling factor for the cryostat is $/kg. The recommended unit scaling factor is $28/kg in FY-89$, not including either the cryostat thermal shields or the pressure suppression system.

Discussion:

Using a simple ratio of cryostat costs to mass, the approximate scaling factor for ITER is $28/kg. We were unable to obtain the BPX cryostat mass accurately and therefore the relative scaling factor. The equivalent TPX scaling factor is $25/kg - in close agreement to ITER scaling. The equivalent scaling cost factor for the MFTF-B vacuum vessel is about $30/kg, and for the vacuum vessel for the Large Coil Project it was about $28/kg, all in FY-89$. We therefore selected the ITER scaling factor of $28/kg.

For cryostat thermal shields, the PCAST machine is using aluminized mylar multi-layer insulation (MLI) as the passive thermal radiation shields. No actively cooled shields are used, as is intended for ITER. The entire cryostat internal area is presumed to be covered by 2 batts, each batt having 20 layers of aluminized mylar and fabric separating sheets. The cost used is based on MLI batts that were supplied in 1995 for large sizes. The cost of these 20 layer batts works out to be \$33/m^2 in FY-95\$ for batts of the 20 m^2 size.

For consistency with ITER the pressure suppression system is included. The pressure suppression system cost for ITER is approximately $9.1M. Since limited information was found on the ITER pressure suppression system, we have elected to scale the ITER cost by the cryostat vessel volumes.

Results and Scaling Uncertainty:

The estimated cost for the PCAST Cryostat is approximately $37.1M, including the cryostat thermal shields and suppression system. No scaling uncertainty is indicated.

The ITER cost estimate for the Cryostat did not include any AFI and therefore none is applied to this estimate.

WBS 2.4 Cryostat Supplemental Cost Information

Cryostat Information

Cryostat Section	Mass
Shell with ribs	800 tonnes
Ports and flanges	120 tonnes
Structural attachments	160 tonnes
Support structure	160 tonnes
Total Weight	**1,240 tonnes**

The estimated cost per kg from the ITER Interim Report is $28/kg. Using this unit cost scaling factor, the total cost becomes:

Total Cost = Weight X Cost per kg = 1240 tonnes X $28/kg X 1000kg/tonne

Total Cost = $34.7 M (FY-89$)

Cryostat Thermal Shield Costs

Cryostat surface area	1,965 m^2
Total for 40 layer coverage	3,930 m^2
Allowance for seams, 27%	1070 m^2
Total area of 20 layer batts	5,000 m^2
MLI Material cost, FY-95$	$165,000
Misc. Materials	$50,000
Installation cost	$200,000
Total Shields Cost, FY-95$	$415,000
Total Shields Cost,, FY-89$	$0.33 M

Cryostat Pressure Suppression System

ITER Cryostat Volume	31,400 m^3
PCAST Cryostat Volume	7,200 m^3
Ratio of volumes, PCAST/ITER	23%
ITER Pres. Sup. cost, FY-89$	$9.1 M
Ratioed PCAST Cost, FY-89$	$2.1 M

- **WBS 2.5 - Heating and Cooling Systems**

  Basis:

  For purposes of simplification, this WBS element is a composite of several ITER WBS elements:

  - WBS 2.6 - Primary Heat Transfer System
  - WBS 3.3 - Secondary Heat Transfer System
  - WBS 3.7 - Heat Sink and Chemical/Volume Control Systems
    - WBS 3.5 - Heat Rejection Systems
    - WBS 3.6 - Chemical and Volume Control (CVCS) Systems

  For purposes of estimating costs for PCAST, we have scaled the TPX Heating and Cooling System subsystem hardware and cost estimates to arrive at the PCAST estimate. However, since the PPPL site credits were included in the TPX estimates, these site credits were added back in to the PCAST estimate.

Discussion:

The PCAST Heating and Cooling System includes the following loads:

- TF and PF Magnet Refrigerator Cooling;
- Plasma Facing Components Heating and Cooling;
- Hardware Bakeout;
- Vacuum Vessel Heating and Cooling;
- Auxiliary Systems Cooling including:
    - NINB (Including Power Supplies);
    - ICH (Including Power Supplies);
    - Diagnostics; and
    - Vacuum Pumping
- Motor Generator Sets;
- Power Conversion Equipment;
- Balance of Plant; and
- Internal Control Coils

The PCAST Heating and Cooling System is planned as to include the following subsystems:

- WBS 2.6 Primary Heat Transfer Systems
    - 50°C - 1 M-Ohm Subsystem
    - 350°C Bakeout Subsystem
- WBS 3.3 Secondary Heat Transfer Systems
    - 27°C - 1 M-Ohm Subsystem
- WBS 3.7 Heat Sink and Chemical/Volume Control Systems
    - WBS 3.5 Heat Rejection Systems
        - 35°C Tower Water Subsystem
    - WBS 3.6 Chemical and Volume Control Systems (CVCS)
        - H&C System Subsystem Utilities

Hardware is grouped by common heating and/or cooling requirements. It is assumed that the vacuum vessel and all in-vessel hardware will be at 50°C at plasma initiation.

The ITER cost estimate included approximately $6M in AFI for a filtered vent system. We have estimated the cost of a filtered vent system as part of the Utilities.

Results and Scaling Uncertainty:

The estimated costs for the PCAST Heating and Cooling Systems is approximately $33M, including the ITER AFI for the filtered vent system. After discussion with the ITER JCT personnel, it is suggested that one other feasible scaling is with fusion power. Based on the approach, the ITER scaling factor becomes approximately $159/kW of fusion power. Using this ITER scaling, the equivalent PCAST figure for 400MW of fusion power would be approximately $64M. Accordingly, the range of uncertainty is between $33M and $64M.

WBS 2.5 Heating and Cooling Systems Supplemental Cost

Information:

- WBS 2.6 Primary Heat Transfer Systems

  This WBS element consists of two Heating and Cooling subsystems; the 50°C - 1 M-Ohm Subsystem and the 350°C Bakeout Subsystem. Each is discussed below.

  50°C 1 M-Ohm Subsystem: This subsystem will provide heating and/or cooling for the Vacuum Vessel, PFC's and the Internal Control Coils. The 50°C water will be sufficient in quantity to bring the VV, PFC's and IC Coils to 50°C for experiment initiation. The VV cooling water will see an outlet temperature of 100°C (50°C rise). The Vacuum Vessel requires the storage of 75,000 gallons of 50°C water to perform a pulse. The total water through the IC Coils during the pulse is 435 gallons and will be provided as a once-through coolant as will all water in this subsystem. The PFC's require a flow of 37,500 GPM for 3 minutes or $115x10^3$ gallons.

  350°C Bakeout Subsystem: The 350°C Argon Bakeout Subsystem is projected to physically be an upscale of the TPX Bakeout Subsystem. The basic PCAST Bakeout subsystem will consist of electric heaters, blowers, Argon gas supply tanks, tank for holding compressed Argon gas and a compressor. The ratio of PCAST mass to be baked out to the TPX mass to be baked out is 1606 Tons/79 Tons or a factor of 20.

- WBS 3.3 Secondary Heat Transfer Systems

  27°C Chilled Water 1 M-Ohm & 17 M-Ohm Subsystem: The 27°C Chilled Water Subsystem will provide 1 M-Ohm and 17 M-Ohm cooling water to the NINB, ICH, Diagnostics, Vacuum Pumping and Power Conversion Equipment. The larger loads in this subsystem are the NINB, ICH and Power Conversion Equipment, which are 94% of the load, while the Diagnostics and Vacuum Pumping are only 6%. The provision of 27°C cooling water will require 120 Tons of chiller capacity and the storage of 30×10^3 gallons of cooled water to be used during the pulse.

- WBS 3.7 Heat Sink and Chemical/Volume Control Systems

This WBS element is a composite of two ITER WBS elements; WBS 3.5 Heat Rejection Systems and WBS 3.6 Chemical and Volume Control (CVCS) Systems. Included in this element are two PCAST Heating and Cooling subsystems. Each is discussed below:

35°C Tower Water Subsystem: This system provides cooling for the Magnets LN2 and Helium Refrigeration Plant, the 4 Motor Generators and the Balance of Plant (plant utilities). A set of cooling towers provide 35°C potable cooling water. The refrigeration plant cooling will be provided by 2 cooling towers while a 3rd tower will provide cooling for the 4 motor generators and the balance of plant loads. The refrigerator plant and balance of plant are steady state loads and the 4 MG's are also assumed as steady state loads for this estimate.

Heating and Cooling System Utilities Subsystem: The Heating and Cooling System subsystems require utilities to setup, maintain and operate the subsystems as specified. This utility subsystem estimates the major utilities that provide this capability. The parts of this subsystem are makeup water (including deionizing equipment), Argon gas blanket and drainage including quench and drain tanks. These utilities on TPX, with the exception of the quench and drain tanks, are estimated at 15.3% of the other subsystems estimated cost. To this estimate were added the costs for the quench and drain tanks plus associated pumps and piping to arrive at the total PCAST subsystem costs.

Not in TPX and in addition to the above utilities is a filter vent system, estimated in ITER WBS 2.6 (PHTS) at $6.0M. This $6.0M estimate is related to the ITER building sizes and the ratio of the PCAST buildings estimated cost to the ITER buildings estimated cost of 596/891= 0.67. The ITER estimate multiplied by this factor results in a estimate of $4.0M for PCAST.

The ITER estimated cost for WBS 2.6, 3.3, 3.5, and 3.6, which are judged to be the equivalent of the PCAST Heating and Cooling System, total $231.3M ($237.3M when the AFI is included). The PCAST estimated cost totals $29M, which is very close to a factor of 8 times smaller than the ITER estimate. The table below shows parameters that indicate the credibility of the factor of 8 difference, particularly the input energy /pulse.

PCAST/ITER Parameter Comparisons

DESCRIPTION	ITER	PCAST	ITER/PCAST Ratio
Fusion Power	1500 MW	400MW	3.75
Pulse Length	≥1000s	120s	8.33
Repetition Rate	2000s	17280s	0.12
Input Energy/Pulse	9600 GJ	1260 GJ	7.62
Cycle Time	2000s	420s	4.76
Pulses/Day	12	5	2.4
Operating Time	24000s	2100s	11.42
Aux Syst Oper Pwr	210MW	160MW	1.32
Aux System Energy	7584GJ	8597GJ	0.88
Fusion Energy	18000GJ	240GJ	75

PCAST Heating and Cooling System Cost Estimate

Subsystem	Load Descrip.	Load MW	Load BTU[1]	Pulse (Sec)	Flow Rate (GPM)	Kgal H20 Stored	PCAST (M$)	TPX (M$)	ITER (M$)
WBS 2.6 Primary Heat Transfer Systems									
• 50°C - 1 MΩ Subsystem									
	Vac Ves	320	40	180	24,400	75	$ 5.3		
	IC Coils	4	1	180	193	1	$ 0.2		
	PFC's	100	17	180	37,500	115	$ 8.2		
Subsystem Cost							*$13.7*	*$ 4.1*	*$132*
• 350°C - Bakeout Subsystem									
	Vac Ves Intrnl Compn.	1,606 Tons			Similar to TPX				
Subsystem Cost							*$ 4.4*	*$ 0.2*	*In Above*
Total WBS 2.6							$ 18.1	$ 4.3	$132
WBS 3.3 Secondary Heat Transfer Systems									
• 27°C Chilled Water Subsystem									
	NINB			135					
	ICH			135					
	Diag	51	7	135	13,300	30			
	Vac Pump'g			SS[2]					
	Pwr Conv.			180					
Total WBS 3.3							$ 1.6	$ 2.3	$ 64.7

PCAST Heating and Cooling System Cost Estimate

Subsystem	Load Descrip.	Load M.W	Load BTU[1]	Pulse (Sec)	Flow Rate (GPM)	Kgal H20 Stored	PCAST (M$)	TPX (M$)	ITER (M$)
WBS 3.7 Heat Sink and CVCS Systems									
• 35°C Cooling Tower Potable H20 Subsystem									
	Magnet Refrig	80		SS[2]	27,527		$ 3.1		
	Bal of Plt	20		SS[2]	6,900		$ 0.8		
	MG Sets	14		SS[2]	4,800		$ 0.5		
Subsystem Cost							*$ 4.4*	*$ 0.6*	*$ 15.7*
• Heating & Cooling Utility Subsystem									
	Similar to TPX[3]						$ 3.7		
	Add'l Quench & Drain						$ 1.2		
	Filtered Vent Sys.[4]						$4.0		$6.0
Subsystem Cost							*$ 8.9*	*$ 1.1*	*$ 24.9*
Total WBS 3.7							$ 13.3	$ 1.7	$ 40.6
Total PCAST Heating & Cooling System Costs[5]							$33	$ 8.6	$237.3

Notes:
[1] BTU x 10^6
[2] SS means Steady State
[3] Includes makeup water, gas blanket, and drainage systems estimated at 15.4% of other subsystems
[4] ITER includes cost of Filtered Vent System as AFI - we have included these costs in WBS 3.7 as part of Utilities.
[4] All costs exclude contingency, engineering, testing, etc. (Title I, II, and III)

- **WBS 2.7 - Thermal Shields**

Basis:

Thermal Shields are required for both the Vacuum Vessel and Cryostat. Because these shields are essentially only super-insulation, the costs have been included as part of the Vacuum Vessel (WBS 1.5) and Cryostat (WBS 2.4) costs.

Discussion:

The thermal shields in ITER were appropriate to a LHe cooled machine. Only moderate thermal shielding of super-insulation material is required with the PCAST machine.

Some consideration would need to be given to shields if the PCAST machine were to use sub-cooling in the toroidal field coils. This is not a large cost item, and if needed would scale by surface area from ITER to PCAST. Scaling by surface area would be used to cost these actively cooled shields.

The ITER cost estimate for Thermal Shields included $6M for AFI, presumably for some cooling line details not estimated. Since the thermal shield for PCAST is merely MLI super-insulation, there is no need to apply a separate AFI to this estimate.

Results and Scaling Uncertainty:

The costs for the super-insulation thermal shields for the Vacuum Vessel and Cryostat are included in their cost estimates.

Should more extensive shields be required in the event that the PCAST machine were to use sub-cooling in the toroidal field coils, the costs could be estimated by scaling by relative surface areas. Based on surface area ratios (approximately 0.38) an approximate savings of $16M (from ITER at $25M to PCAST at approximately $6M) would result. Therefore, if actively cooled thermal shields were to be required, the approximate costs would be $6M.

- **WBS 3.1 - Vacuum Pumping**

  Basis:

  The PCAST estimate was derived from the ITER estimate as adjusted for pumping requirements.

  Discussion:

  The Vacuum Pumping Systems consist of the following subsystems:

  - Torus and Divertor Pumping - these costs were scaled by the relative pumping requirements.
  - Torus Roughing and Backing - these costs were assumed to be 50% of ITER.
  - Cryostat Pumping - these costs were assumed to be 50% of ITER.
  - Leak Detection - these costs estimated based on engineering experience.
  - Miscellaneous Vacuum Services - these included NBI, RF, PI, and Diagnostics and were estimated based on engineering experience.

The ITER JCT suggested scaling factor is $/pumping capacity. A review of the ITER design data does not clearly yield a definitive total pumping capacity. Per discussions with the ITER JCT, a measure of the total pumping capacity is the total plasma volume required to be pumped. Accordingly, using this relationship, the approximate ITER unit scaling factor is $13.6k/m^3 of plasma volume.

The equivalent BPX scaling is $91.7k/m^3 of plasma volume and for TPX the equivalent scaling is $68.3k/m^3 of plasma volume.

The ITER cost estimate for Vacuum Pumping System did not include any AFI and therefore none is applied to this estimate.

Results and Scaling Uncertainty:

The estimated cost for the Vacuum Pumping Systems is approximately $31.8M. This is approximately 31% of the ITER estimate.

Had we elected to scale on a plasma volume basis using the ITER unit cost scaling of $13.6k/m^3 for a plasma volume of 1058m^3, the PCAST costs would have been reduced by approximately $18M to $14M. The cost uncertainty of the Vacuum Pumping Systems ranges from a low of $14M to $32M.

WBS 3.1 Supplemental Cost Information

The table below provides the detailed breakdown of the Vacuum Pumping Systems costs:

Vacuum Pumping Systems Costs

	PCAST FY-95M$	PCAST FY-89M$[1]	Comment
Hardware			
Torus and Divertor Pumping	$ 8.2	$6.6	Ducts, Turbopumps, Valves
Torus Roughing and Backing	$ 4.0	$3.2	50% of ITER
Cryostat Pumping	$ 1.5	$1.2	50% ITER
Leak Detection	$ 5.0	$4.0	Based on Engrg Exp.
Misc. Vacuum Services (roughing/backing)	$ 8.5	$6.8	NBI, RF, PI, Diagnostics
Total Hardware	$27.2	$21.9	
Vendor Engineering & Installation	$ 12.2	$9.9	
Total Costs	$39.4	$31.8	

Note: [1] FY-95$ de-escalated to FY-89$ using ITER Interim Design Report factor of 1.2425

- **WBS 3.2 - Tritium Plant**

Basis:

We have scaled from the ITER cost according to relative hydrogenic throughputs for ITER and PCAST. These ratios were then adjusted to reflect assessments of PCAST requirements.

Discussion:

The ratios of hydrogenic throughputs for ITER and PCAST is a factor of approximately 560 for total hydrogenic and tritium throughputs, with ITER total hydrogenic and tritium throughputs being approximately 40M Torr-l/day and 7050g/day respectively and the PCAST throughputs being only about 72,700 Torr-l/day and 12.6g/day respectively. The respective instantaneous divertor throughput yields a ratio of about 10 when comparing ITER to PCAST. It was this ratio that was used when deriving the scaling factors for the PCAST cost estimate.

These economies of scale will certainly impact the gas processing systems which include the Tokamak Exhaust Processing, HDT Isotope Separation, and Storage and Delivery subsystems. Although the PCAST instantaneous hydrogenic throughput is a factor of approximately 10 less than that of ITER, the economy of scale for gas processing hardware for the Tokamak Exhaust Processing and HDT Isotope Separation has been roughly estimated as only a factor of 2 lower. For the Storage and Delivery subsystems, the factor of 4 was derived.

For the Water and Atmospheric Detritiation subsystems, consideration was taken of potential accidents. Although both the rate of water and atmospheric tritiation in PCAST under normal conditions is expected to be very low, there is a potential for an accident that could contaminate a substantial amount of water and atmosphere. The Water Detritiation subsystems were assumed to have a capacity of 10% of ITER and resulted in a scaling factor of 50%. The Atmospheric Detritiation subsystems were assumed to have a capacity of 25% of ITER and resulted in a scaling factor of 44%. The Analytical Facilities and the Tritium Plant Control Systems were assumed to be the same as for ITER.. Although the processing systems of PCAST are expected to be much smaller and simpler, the costs are not expected to scale linearly because there is probably still the need for instrumentation and control at a large number of points.

The ITER estimate assumed a factor of approximately 45% on hardware costs for vendor engineering, QA support, etc. We have adopted the same ratio for the PCAST estimate.

The ITER JCT acknowledged that the cost of a tritium plant is dependent on the amount of tritium required. The tritium requirements for the for the PCAST machine/pulse would be related to the fusion power and burn time, which would be about 3 % of ITER. The relative fusion powers are 1500 MW and 400 MW. LANL has recommended that the cost of the tritium plant should be a weak function of fusion power, and recommended an 0.3 power.

The ITER cost estimate included approximately $9M in AFI for water and atmospheric detritiation systems. Since the PCAST estimate was scaled from ITER without the AFI included, the AFI was included, but at 50% of the AFI for these systems.

Results and Scaling Uncertainty:

Based on the above scaling from ITER, the estimated costs for the PCAST Tritium Plant is approximately $35M.

If the tritium plant were scaled as the 0.3 power of fusion power, the cost of the PCAST machine would be $48 M, a cost increase of approximately $13M$.

Because of the assumptions above, a scaling uncertainty of 20% increase is assumed. If this scaling uncertainty is assumed, the costs would increase from $35M to $52M. The upper bound of this uncertainty is consistent with scaling by fusion power.

WBS 3.2 Supplemental Cost Information:

- Hydrogenic Daily Throughput Calculations
  - PCAST

    PCAST Throughput = (100 Torr-l/s)(145s/shot)(5 shots/day)
    = 72,500 Torr-l/day

    If 50% is Tritium = (0.5)(72,500 Torr-l/day)
    (1 mole/760 Torr*22.4l)
    = (2.1 mole/day)(6 g/mole)
    = 12.6g tritium/day
  - ITER

    ITER Throughput = (1000 Torr-l/s)(1000s/shot)
    (40[max] shots/day)
    = 40 x 10^6 Torr-l/day

    If 50% is Tritium = (0.5)(40 x 10^6 Torr-l/day)
    (1 mole/760 Torr*22.4l)
    = (1175 mole/day)(6 g/mole)
    = 7050g tritium/day
  - Ratios
    - Daily Hydrogenic Throughput = $\frac{\text{40 x 10^6 Torr-l/day}}{\text{72,500 Torr-l/day}} \approx 560$
    - Instantaneous Divertor Throughput = $\frac{\text{1000 Torr-l/s}}{\text{100 Torr-l/s}} = 10$

The table below compares the ITER estimate to that of PCAST in FY-89$:

	ITER[1]	PCAST			
		H/W	Engr & Support[2]	AFI	Total
Tokamak Exhaust Process	$10.6	$ 3.6	$ 1.6		$ 5.2
HDT Isotope Separation	$11.4	$ 3.6	$ 1.6		$ 5.2
Storage and Delivery	$ 7.7	$ 1.3	$ 0.6		$ 1.9
Water Detritiation[3]	$15.7	$ 2.7	$ 1.2	$3.0	$ 6.9
Atmospheric Detritiation[3]	$21.5	$ 6.6	$ 3.0	$1.5	$11.1
Analytical Facilities	$ 3.1	$ 2.1	$ 1.0		$ 3.1
Tritium Plant Control Sys.	$ 2.1	$1.4	$ 0.6		$2.0
TOTALS	$72.0	$21.3	$ 9.6	$4.5	$35.4

Notes:
[1] ITER estimate includes the cost of hardware, vendor engineering and support (@ 45% of hardware) and AFI.
[2] Engineering and Support assumed to be 45% of hardware costs.
[3] ITER AFI includes $6.0M for Water Detritiation Systems and $3.0M for Atmospheric Detritiation Systems. PCAST AFI assumed to be 50% of that of ITER.

- **WBS 3.4 - Cryoplant**

Basis:

The PCAST estimate was developed based on historical data as applied to the requirements for this machine.

Discussion:

Both a baseline system which utilizes a Nitrogen System to cool from 300K to 80K and a Helium System from 80K and a Subcooled Option were considered. The baseline option was selected.

The ITER estimate included approximately $13M for parts of the distribution system not estimated. The PCAST estimate has included the costs of the distribution system and hence no additional AFI is warranted.

Results and Scaling Uncertainty:

The cost of the baseline option was scaled from historical data to yield a cost of $121M in FY-95$ ($99.6M in FY-89$), including the distribution system. No scaling uncertainty is indicated.

Although not selected, the cost of a subcooled option was $194M in FY-95$ ($156M in FY-89$).

WBS 3.4 Cryoplant Supplemental Cost Information:

In estimating the cost of the PCAST cryogenic system, a number of sources of information were used. The actual cost experience from MFTF-B for both the helium refrigerators and also for the liquid nitrogen reliquifier was used extensively. Information from the PHPK company on recent 20 K helium plants that have been built was also very useful. The cost data base for 4.5 K helium refrigerators, "Estimating the Cost of Superconducting Magnets and the Refrigerators Needed to Keep them Cold" by M. A. Green, R. A. Byrns and S. J. St Lorant in the "Advances in Cryogenic Engineering, Vol. 37, Part A 1992. was also a primary source. Cost estimates by Praxair for the nitrogen plants were very useful, as they were based on actual existing very large plants that have been built.

Based on the requirements for the PCAST machine, the following table was developed:

PCAST Cryogenic System Scoping

Description	BASELINE SYSTEM		TF 30K OPTION SYSTEM	
	NITROGEN SYSTEM, Refrigeration from 300K to 80K	HELIUM SYSTEM, Refrigeration from 85 K to 30 K	NITROGEN SYSTEM, Refrigeration from 300K to 80K	HELIUM SYSTEM, Refrigeration from 85 K to 30 K
	80K PF2-7, 30K TF & PF1 (Adiabatic Heat Absorption)		80K PF2-7, 30K TF & PF1 (Adiabatic Heat Absorption)	
	Heat Load (GJ)	Heat Load (GJ)	Heat Load (GJ)	Heat Load (GJ)
TF (Note 1)	85		10	18
PF 1 U/L (Note 2)	7	1.1	7	1
PF 2-7 U/L (Note 2)	17		16	0
Total per Pulse	109	1.1	33	19
Total 5 Pulses/Day	545	5.5	166	96
Total Load per 24 Hour Day With 30% Pumping Losses	709	7.2	215	125
[Mega-Watts Refrigeration] Required to Cool Based Upon 24 hour per Day Operation.	8.2	0.083	2.49	1.44
Refrigeration Temperature, K	80	30	80	30
Number of Plants	8.2	1.38	2.5	24.1
Size	LN Plants of 1 Mw Size (500 Ton/Day)	MFTF-B Plants of 60 kW Size (Note 5)	LN Plants of 1 Mw Size (500 Ton/Day)	MFTF-B Plants of 60 kW Size (Note 5)
Electrical Power of a Single Plant[MW]	10.00	4.10	10.00	4.10
Capital Cost [FY-95$M] (Note 3 or 6)	$112	$9	$34	$160
Capital Cost Totals (FY-95M$)	$121		$194	
Electrical Power [MW] (Note 4)	82	5.7	24.9	98.7
Total Electrical Power (MW)	87.7		123.6	

The ITER cost estimate for Steady State Power included AFI for approximately $9.0M. This AFI was added to the PCAST estimate.

The suggested ITER JCT scaling factor for the Steady State Electrical Power is also $K/MW. Using a simple ratio of steady state electrical power costs to total steady state power loads, the approximate ITER scaling factor is $120K/MW.

For BPX the equivalent scaling factor is approximately $236K/MW. The TPX the equivalent scaling factor is approximately $425K/MW. Both the BPX and TPX scalings are viewed as anomalously high.

Results and Scaling Uncertainty:

The total costs for the PCAST Steady State Power Supplies is approximately $29.9M, including AFI. No scaling uncertainty is indicated.

WBS 4.1, WBS 4.3, and WBS 4.4 Supplemental Cost Information

See discussion at end of presentation on WBS 4.4, Internal Control Coils.

- **WBS 4.4 - Internal Control Coil Power Systems**

Basis:

The PCAST machine will require Internal Control Coils to handle the elongation of the plasma whereas ITER does not. Therefore this is an unique WBS element for the PCAST machine. The cost estimate was derived using a bottoms up methodology based on the power requirements for the IC coils. The cost of the Internal Control Coils themselves are included in WBS 1.9.

Discussion:

See attached supplemental discussion. Since ITER did not require position control coils, there is no need to apply any AFI to this estimate.

Results and Scaling Uncertainty:

The cost estimate for the Internal control Coils Power Supply Systems is approximately $16.9M. No scaling uncertainty is indicated.

WBS 4.1, WBS 4.3, and WBS 4.4 Supplemental Cost Information

The ITER costs and specific costs (e.g. $/MVA) were derived from the design[1] and detailed costs assessments[2] associated with the ITER Interim Design Report. Costs herein are presented in 1995 US dollars. The original costs were obtained by the ITER JCT from EU Home Team industrial estimates in 1995 ECU. Using the ITER convention the conversion from 1995 ECU to USD was assumed equal to 1.3 USD/ECU. Per the ITER documentation the costs include explicit allowances for manufacturing (detailed design, fabrication, factory testing), local control & protection, installation, site commissioning, documentation & QA, recommended spares, and transportation costs.

Because of the large difference in the duty cycle of the equipment an adjustment to the ITER cost basis was made where appropriate. The effect is present in all conductors which carry the pulsed load of the power system, whose design is driven by two factors, namely

[1]Design Description Document (DD), Coil Power Supply & Distribution (WBS 4.1), Issue 3,: June 2, 1995

[2]Cost Assessment Document, Coil Power Supply & Distribution (WBS 4.1), Issue 1: 19 April 1995.

ampacity and ability to withstand forces under fault conditions. The duty cycle effect the former but not the latter. The primary consequence of the reduced duty cycle is a reduction in the required cross section and/or active cooling of conductors.

For the purposes of this study the following assumptions were made:

- Cables, Bus Bar, Switches, DC inductors - a 50% reduction from the ITER requirement is assumed. The conductor cross sections would be reduced beyond this amount but the costs associated with bracing for fault conditions remains the same as for ITER.
- Transformers - no reduction was taken since the impedance must not be increased (e.g. the MVA rating cannot be decreased) and since the bracing for fault conditions remains the same as for ITER. In practice it is expected that the converter transformers would be less costly, however, since their high current secondary windings would be simplified.
- Thyristors - no reduction was taken since the water cooled thyristors reach thermal equilibrium within the time interval of the pulse.
- Switchgear - no reduction was taken since the fault interrupting rating, which is the primary cost driver, remains the same as for ITER.

The above reductions were taken on the hardware portion of the costs where appropriate; the other cost categories (e.g. design, commissioning, etc. were not adjusted).

Annex II
Derivation of Unit Cost Scalings

A comparison of the PCAST and ITER power supply costs, without Allowance for Indeterminables (AFI), is given in the Table below :

Comparison of ITER and PCAST Costs

WBS 4.1

	CATEGORY	ITER Rating (MVA)	PCAST Rating (MVA)	ITER Scaling ($95/ MVA)	ITER Cost (M$95)	PCAST Cost (M$95)	Ratio
	WBS 4.1 Coil Power Supplies						
1	Utility Grid Interface	1200.0	1200.0	$4.6	$5.6	$5.6	1.00
2	Substation	1200.0	1200.0	$15.1	$18.2	$18.2	1.00
3	Energy Storage System	0.0	1900.0		0.0	$80.1	na
4	Reactive Power Compensation Sys	600.0	300.0	$29.2	$17.5	$8.8	0.50
5	AC Distribution	4816.0	4835.3	$3.0	$15.7	$14.4	0.92
6	Toroidal Field AC/DC Converters	40.8	810.0	$49.8	$3.8	$40.3	10.59
7	Toroidal Field Switching Networks						
	-Fast Discharge Circuits				$51.8	$0.0	0.00
	-Slow Discharge Circuits				$11.8	$0.0	0.00
8	Poloidal Field AC/DC Converters	2765.4	3089.2	$56.2		$173.6	1.04
	-Main AC/DC Cnvtrs (Type A)	1720.0		$55.6	$95.7		
	-Main AC/DC Cnvtrs (Type B)	903.0		$58.6	$52.9		
	-Booster Converters	108.0		$132.4	$14.3		
	-CS Current Balancing Convert.	34.4		$134.1	$4.6		
9	Poloidal Field Switching Networks						
	-Fast Discharge Circuits				$74.4	$0.0	0.00
	-Switching Network Units				$28.3	$28.9	1.02
10	Instrumentation				$2.4	$2.4	1.00
11	DC Components & Dummy Loads				$70.6	$15.1	0.21
	Total WBS 4.1				$467.6	$387.5	0.83

Adjustments to Match IDR Cost

ITER		$M89	$376.6	
	IDR Cost	$M89	$322.4	
	Factor		0.856	0.856
	AFI	$M89	$ 17.0	
Total		**$M89**	**$339.4**	

PCAST	Adjusted	$M95	$331.7
		$M89	$267.2
	AFI	$M89	$ 0.0
Total		$M89	**$267.2**

Comparison of ITER and PCAST Costs
WBS 4.3

	CATEGORY	ITER Rating (MVA)	PCAST Rating (MVA)	ITER Scaling ($95/ MVA)	ITER Cost (M$95)	PCAST Cost (M$95)	Ratio
	WBS 4.3 Steady State Power Supplies						
12	Steady State Power Supplies	312.5	215.4	120.8	$37.7	$26.0	0.69
	Descalation to FY-89$			$M89	$30.4	$20.9	
	AFI			$M89	$ 9.0	$ 9.0	
	Total WBS 4.3			$M89	**$39.4**	**$29.9**	

Comparison of ITER and PCAST Costs
WBS 4.4

	CATEGORY	ITER Rating (MVA)	PCAST Rating (MVA)	ITER Scaling ($95/ MVA)	ITER Cost (M$95)	PCAST Cost (M$95)	Ratio
	WBS 4.4 IC Coils Power Supplies						
13	Fast Position Control PS	0.0	486.1	49.8	$0.0	$24.2	N/A
	Descalation to FY-89$			$M89	$0.0	$19.5	
	Adjustment Factor (See 4.1)					0.856	
	Adjusted Cost					$16.9	
	AFI			$M89	$0.0	$ 0.0	
	Total WBS 4.4			$M89	$0.0	**$16.9**	

Costs are de-escalated from FY-95$ to FY-89$ using the factor of 1.2415 recommended in the ITER Interim Design Report of June 12, 1995.

The following is a discussion of the methodology used in the table:

- Items 1 and 2 - Since the power taken from the grid in both the ITER and PCAST scenarios is identical, the same costs are assumed for both cases.

- Item 3 - The Energy Storage System is assumed to consist of four TFTR MG sets. The cost (including installation) was translated from 1977 to 1995 US$ using a factor of 2.315 based on the recently published DOE "FY 1995 Inflation Rate Summary" data.
- Items 4 and 5 - The Reactive Power Compensation and AC Distribution costs were scaled directly from the ITER data on the basis of installed MVA, with a reduction taken on account of the lower duty factor. The scaling of the AC Distribution considered the installed power rating of the overall AC/DC converter systems as well as the Heating and Reactive Power Compensation systems.
- Item 6 - The ITER TF AC/DC Converter cost is the ITER estimate. The PCAST cost is based on the $/MVA cost of the ITER Type B (1.5kV, 21.5kA) PF AC/DC converters which are similar to those required for the PCAST TF. Since the PCAST TF converters are 2-quadrant whereas the ITER Type B converters are 4-quadrant, a 25% reduction in the cost of the thyristor bridge part of the ITER estimate was taken. An additional reduction was taken based on duty factor.
- Item 7 - The PCAST coils are not superconducting and therefore the quench protection discharge networks are not required in the TF system.
- Item 8 - The ITER PF AC/DC Converter cost is the ITER estimate. The PCAST cost is based on the $/MVA cost of the ITER Type B (1.5kV, 21.5kA) PF AC/DC converters which are similar to those required for the PCAST PF. A reduction in the ITER scaling was taken based on duty factor.
- Item 9 - The PCAST coils are not superconducting and therefore the quench protection fast discharge networks are not required in the PF system. However, the Switching Networks are required for plasma initiation. The Switching Network cost was derived from the itemized ITER costs for discharge resistors and DC circuit breakers, with due consideration of the relative discharge energy and interruption current of PCAST compared to ITER

- Item 10 - The ITER and PCAST instrumentation costs are assumed identical.
- Item 11 - The ITER DC component costs were adjusted for PCAST based on the reduced length of DC bus bar and number of bus links required by PCAST, as well as the reduction in duty factor, since the PCAST coils are not subdivided into interleaves as are the ITER coils.
- Item 12 - The cost of the Auxiliary Power System is obtained by scaling the ITER cost (as reported in the ITER Project Cost Estimate) on the basis of the power rating.
- Item 13 - The PCAST cost is based on the $/MVA cost of the ITER Type B (1.5kV, 21.5kA) PF AC/DC converters which are similar to those required for the PCAST FPPC. Since the PCAST FPPC converters are anti-parallel 2-quadrant whereas the ITER Type B converters are 4-quadrant, a 25% reduction in the cost of the thyristor bridge part of the ITER estimate was taken. An additional reduction was taken based on duty factor.

It is noted that a final adjustment is required on the total Experimental Power System and IC Coil Power Supply costs. The total cost of the ITER power systems from the table is in agreement with the reference Cost Assessment document but, after conversion to FY-89$, is higher than the final summary value given in the ITER Project Cost Estimate. Therefore an adjustment factor is derived and applied equally to the total PCAST Experimental Power System and the IC Coil Power Supply costs. Perhaps this factor relates to the removal of the AFI.

- **WBS 4.7 - Poloidal Control Systems**

Basis:

ITER breaks the cost of the Poloidal Control Systems out separately whereas the BPX and TPX costs for these systems are included in the Coil Power Supplies cost. Accordingly, we have elected to adopt the ITER costs directly for the control itself.

Discussion:

Since the estimate for the control subsystem is so small (i.e., approximately $500K), the ITER JCT suggested that we adopt the ITER estimate. There was no comparable scaling from either BPX or TPX since the cost of this subsystem is included in WBS 4.1, Coil Power Supplies.

The PF control power supplies are scaled from ITER on the basis of power rating. A discussion can be found under WBS 4.1 Coil Power supplies, supplemental attachment.

The ITER cost estimate for Poloidal Control Systems did not include any AFI and therefore none is applied to this estimate.

Results and Scaling Uncertainty:

The ITER estimate of $0.5M is adopted. No scaling uncertainty is indicated.

- **WBS 4.8 - CODAC and Interlocks**

Basis:

This WBS element is made up of the following ITER WBS elements:

- WBS 4.5 - Command Control and Data Acquisition (CODAC) System; and
- WBS 4.6 - Interlocks Systems

We have costed the PCAST CODAC systems (WBS 4.5) by scaling from ITER costing, taking into account the reduced pulse length and duty cycle. The resultant PCAST CODAC estimate is approximately 0.90 the ITER estimate for these reasons.

We have adopted the ITER estimate for Interlocks (WBS 4.6).

Discussion:

The CODAC cost estimate depends most heavily on assumptions about:

- The total data load and the characterizations of the various types of data to be acquired;
- The networking capacity that will be required; and
- Projections of cost/capacity trends within the rapidly changing computer industry.

This PCAST estimate is based on the previous cost estimate developed for ITER and takes into account primarily the reduced pulse length and duty cycle.

The ITER Interlocks estimate developed by Yonekawa was adopted directly.

The ITER cost estimate included approximately $21M in AFI for uncosted instrumentation. This same AFI is being applied to the PCAST estimate.

Results and Scaling Uncertainty:

The estimated costs for the CODAC Systems is approximately $69M, including the AFI. The cost for the Interlocks Systems is $2M. Therefore, the total cost is approximately $71M. No scaling uncertainty is indicated.

WBS 4.5 CODAC Supplemental Cost Information

There are six major subsystems that make up the Command Control and Data Acquisition (CODAC) System. These are the:

- Supervisory Control System - Includes the Physics Computer, the Engineering Computer, the Massively Parallel Computer, Operator Stations, Printers, Software Toolkits (Configuration and Display), Software and Hardware Maintenance, Training and Travel;
- Machine Control System - Includes 5000 subsystem control points, Computer, Operator Stations, Printers, Test Equipment, and Software Toolkits;
- Diagnostic Control System - Includes 5000 diagnostic control points, Computer, Operator Stations, Printers, Test Equipment, and Software Toolkits;
- Data Management System: Includes the Computer, 62 TB magnetic disk, 372 TB optical disk, 3,720 TB tape silo system, and Database software;
- Synchronization System - Includes 200 synchronizer modules, 10 synchronizer displays, Synchronizer central unit, and Test Equipment; and

- Networks and Communication Systems - Includes 11 high-speed networks; 4 wide-area networks; 100 cameras, 100 monitors, 4 video switchers, Public Address System, 10 large-screen displays, 4 video-conferencing systems.

The costs of the CODAC System are summarized below:

CODAC Subsystem	Hardware Costs (FY-89$)	Engrg M/H[1]	Engrg Costs[2] (FY-89$)
Supervisory Control System	$11.2M	86,400	$ 6.7M
Machine Control System	$ 1.7M	40,800	$ 3.2M
Diagnostic Control System	$ 1.7M	40,800	$ 3.2M
Data Management System	$ 2.1M	26,550	$ 2.1M
Synchronization System	$ 0.4M	20,400	$ 1.6M
Networks and Communications System	$ 6.0M	101,540	$ 7.9M
Subtotals	$23.1M	316,490	$24.7M
Total Hardware and Eng			$47.8M

[1] Engineering and technician man-hours required to support ongoing design, engineering, installation, and testing support as well as operational support during the construction phase.

[2] Engineering man-hours costed at $78/hr.

In the ITER cost estimate, approximately $21M was added as AFI for known but uncosted instrumentation. This same amount of AFI is assumed for PCAST. Therefore, the total estimated cost for PCAST is the $47.8M for the hardware and engineering plus the AFI of $21M for a total of $68.8M. This is approximately 90% of the ITER total construction estimate for this WBS element.

- **WBS 5.0 - Auxiliary Heating Systems**

Basis:

This WBS element is a composite of the following ITER WBS elements:

- WBS 4.2 - Auxiliary Heating Systems Power Supplies
- WBS 5.1 - ICRH

- WBS 5.2 - ECH
- WBS 5.3 - Negative Ion Neutral Beams
- WBS 5.4 - Other Auxiliary Heating Systems (LHH, etc.)

We adopt the following unit costs from ITER (or JT-60U for NBI):

- ICRH - $2.96/watt
- ECH - $3.20/watt
- Negative Ion NBI - $3.76/watt (Based on 3 NBIs like the JT-60U 500keV Negative Ion Neutral Beam)

Discussion:

The ITER JCT suggested scaling factors for each of the auxiliary heating systems is $/w delivered to the plasma, including the costs of their respective power supplies. Accordingly, the suggested ITER scaling factors were adopted. For more detail, see the WBS 5.0 supplemental information from ORNL below.

For future upgrade considerations, the cost of LHH heating was also estimated. Since TPX is the only one of the reference designs to use LHH, the scaling factor for LHH is determined to be approximately $2.73/watt.

The ITER cost estimate for Auxiliary Heating Systems and Auxiliary Heating Systems Power Supplies did not include any AFI and therefore none is applied to this estimate.

Results and Scaling Uncertainty:

The PCAST machine will utilize 30MW of ICRH and 30MW of negative ion Neutral Beams using the JT-60 500keV beams. The approximate cost of ICRF is $88.8M in FY-95$ or approximately $72M in FY-89$. The estimated cost for the NBI is $140M in FY-95$ or approximately $113M in FY-89$.

WBS 5.0 Supplemental Cost Information

WBS 5.1 ICRF

A detailed cost estimate for the ITER 50 MW IC system was done in March 1995 by the ITER US Home Team as part of ITER Design Task D89. This estimate used the ITER costing rules, and is summarized below:

ITER IC System Cost Estimate Summary

WBS	Description	Cost FY-89M$
5.1 A	Antenna Arrays	$ 40.5
5.1 B	Vacuum Transmission Lines	$ 7.9
5.1 C	Matching and Decoupling System	$ 8.6
5.1 D	Main Transmission Line	$ 9.3
5.1 E	RF Power Sources	$ 52.4
5.1 F	DC Power Sources	$ 21.3
5.1 G	RF Controls and Monitors	$ 8.1
5.1 H	Auxiliaries (Cooling System)	$ 11.1
	Total	**$159.2**

It includes the fabrication and testing of all the components in the system, with manufacturing engineering during fabrication (about 7% of the total). Fully burdened US labor rates for fabrication labor were used, and costs are expressed in 1995 US dollars. No R&D is included in the estimate.

As is usual, the interface between the RF system and other systems must be defined carefully before the cost estimate is completed, to make sure that all components and procedures are included but not double-counted. After the submission of this estimate, Sections 5.1 F and 5.1 H were removed by the ITER Joint Central Team from the IC system cost estimate, and included in different WBS elements (5.1 F was included in power supplies, and 5.1 H in the cooling system for the machine).

The table below gives costs under several assumptions for the ITER system in dollars per watt. These numbers were used to estimate the cost for a 30 MW PCAST IC system, shown in the right-hand column.

System Description	ITER System Cost per watt (FY-95$/watt)	PCAST System Cost for 15 MW FY-95$	PCAST System Cost for 30 MW FY-95$
Entire System as Described Above	$3.18	$47.7M	$95.4M
Without Cooling System (Baseline)	**$2.96**	$44.4M	**$88.8M**
Without Cooling System or DC Power Supply	$2.54	$38.0M	$76.0M

WBS 5.3 Negative Ion Beams

This cost estimate is based on the preliminary cost estimate of the ITER NBI system using the cost data of the JT-60U 500keV N-NBI system. In addition, we assume the order of this NBI system is placed to a manufacture company in 1995 and this company prices the system at a cost similar to the Japanese manufactures involved in the construction of the 500 keV NBI system. We also assume the exchange rate is 1 US dollar equal 100 Yen.

The NBI system should inject 30 MW deuterium/tritium beams using 3 beamlines. This system has a cryogenic system that costs about \$5 M. Each beamline has 8 cryopump modules, a power supply system, and a NBI beamline system that cost about \$3 M, \$27 M, and \$18 M, respectively in FY-95\$. The first beamline could have additional cost of \$20 M in FY-95\$ for engineering beam system; preparing the site with civil services and supporting utilities that include cooling water system, plant air system, and nitrogen system, and tritium recovery and process system; and performing integration tests for beamline qualification and tokamak interface. Thus the first beamline system costs about \$73 M in FY-95\$. Each of the other two beamlines costs about \$33.5 M in FY-95\$ that is slightly above 2/3 of \$48 M (= \$3 M + \$27 M + \$18 M). The total cost of this NBI system is about \$140 M in FY-95\$. If the PCAST tokamak needs the fourth beamline, the total cost could be about \$173 M in FY-95\$.

The table below provides the detailed breakdown of the Negative Ion Neutral Beam Systems costs:

Negative Ion Neutral Beam Systems Costs

	PCAST FY-95M$	PCAST FY-89M$[1]	Comment
Hardware			
NBI Beamline Systems	$ 45.0	$ 36.2	Based on JT-60U 500Kev NBI - 3 @ $15M each
Power Supply Systems	$ 63.0	$ 50.7	3 @ $21M each
Cryopump Systems	$ 7.0	$ 5.6	3 @ $2.33M each
Cryogenic System	$ 5.0	$ 4.0	Sufficient for all 3 Beamlines
Total Hardware	$120.0	$ 96.7	
Vendor Engineering & Installation	$ 20.0	$16.1	
Total Costs	**$140.0**	**$112.8**	

Note: [1] FY-95$ de-escalated to FY-89$ using ITER Interim Design Report factor of 1.2425

- **WBS 5.5 - Diagnostics**

Basis:

We believe that the diagnostic set for the PCAST machine will be substantially the same as for ITER. The ITER cost has therefore been adopted.

Discussion:

Together with the ITER JCT, we believe that the costs are dependent on the type and number of diagnostics selected for the PCAST machine. However, we believed that ITER is the correct device to compare PCAST with since ITER developed their estimate from data from TFTR, JET, JT-60U and some new estimates of yet undeveloped diagnostics. As a first cut, we suggest that the initial scaling be based on the same number of systems as are being used for ITER.

Initial studies indicate that the in-vessel PCAST diagnostics will receive higher flux, but about the same fluence as they do in ITER with no blanket.

The ITER cost estimate for Diagnostics did not include any AFI and therefore none is applied to this estimate.

Results and Scaling Uncertainty:

The ITER estimate for the start-up diagnostics set of $148M was adopted. No scaling uncertainty is indicated.

WBS 5.5 Diagnostics Supplemental Cost Information:

No independent cost estimates have been made for diagnostics for the PCAST device and the estimates prepared for ITER are the basis for this section. The ITER cost estimates were arrived at in July 1995 by making use of historical diagnostic costs for the three large tokamaks, TFTR, JET and JT-60U, with some recently derived numbers for TPX. A set of algorithms was applied to scale up to the specific requirements for ITER. Elements in these multipliers were size-scaling, differences in quantity of detector and electronic channels, need for redundancy and remote maintainability, etc.. The final proposed budget for construction was 381 kIUA (approximately $381M in FY-89$.

This estimate is probably high in that it includes a larger complement of diagnostics, with redundant measurements, than can probably be accommodated on the tokamak. The proportion of diagnostic cost to the total device cost for ITER is in the same range as that for the three large tokamaks.

By assuming a start-up phase for ITER (Table II.C.7.2 for the ITER Interim Design Report), and providing only the diagnostics to fulfill the physics mission for that period, together with the tokamak interface design needs for the full set, the ITER management determined a budget of 148 kIUA (approximately $148M in FY-89$). A further 117 kIUA ($117M in FY-89$) has been allocated for bringing the complete system into operation later (ITER Document # TAC-95-19). For the PCAST machine, these numbers are appropriate.

There are some small differences between the diagnostic requirements for the choice of double-null versus single-null plasmas and for the shorter pulse. The presence of the top divertor certainly leads to a need to add more protection diagnostics, but the cost will be low because of the near-total duplication involved in the systems. There will probably not be much increase in the number of physics diagnostics in the divertors, since some will now be placed in the top instead of in the bottom divertor region. The shorter pulse does not significantly reduce the reliability and maintenance requirements and makes a very modest saving in the electronics/data storage area, which is anticipated to be a very low cost element in any diagnostic.

- **WBS 6.2 - Buildings**

Basis:

The PCAST buildings are keyed to the ITER building layout. Each building was evaluated relative to the impact of the PCAST design on the ITER facility. Parameters include the building footprint, gross volume, structural steel and concrete, and the floor area. It should be noted that these costs include the A/E Title I and Title II costs. Engineering and design of the buildings would be subcontracted to industry.

Discussion:

See discussion of each building below.

The ITER cost estimate for Buildings did not include any AFI and therefore none is applied to this estimate.

Results and Scaling Uncertainty:

The estimated costs for the PCAST buildings is approximately $596M. The table below summarizes the comparison costs of each PCAST Building to the companion ITER Building. Additionally, the discussion on each building provides our assessment of the scaling uncertainty for that building.

The building costs for ITER and thereby the PCAST machine are the largest cost element in the overall cost estimate. For the PCAST machine very conservative assumptions have been made concerning the building sizes resulting in a building estimate that is a significantly larger fraction of the project cost than ITER. For example if we were to simply scale the test cell size as the tokamak major radius the estimate would be reduced by about 50 M$. This suggests that a value engineering effort applied to the buildings would result in significant costs savings. For this reason we should consider the building costs as a significant element of negative cost uncertainty.

PCAST Building Cost Comparison

Building Name and Number (Based on ITER)	ITER Floor Area[1] (m^2)	PCAST Scaling Factor	PCAST Floor Area (m^2)	Unit Costs[2] (m^2)	ITER Estimate (FY-89M$)	PCAST Estimate (FY-89M$)
Tokamak Hall (1,2,3)	35,790	0.71	25,411	10,142	$363	$258
Hot Cell Building (4)	20,800	0.50	10,400	4,423	$ 92	$ 46
Tritium Building (5)	12,780	0.40	5,112	3,443	$ 44	$ 18
Tokamak Service Building (6)	11,200	0.70	7,840	3,125	$ 35	$ 25
Power Supply Network Switching Building (12)	8,800	0.00	0	--		$ 0
Power Conversion Buildings (13)	10,200	1.48	15,096	2,158	$ 71[3]	$ 33
Auxiliary Heating Power Supply Buildings (14, 15)	13,900	0.40	5,560	2,158		$ 12
Stack	na	na	na	na	$ 2	$ 2

PCAST Building Cost Comparison

Building Name and Number (Based on ITER)	ITER Floor Area[1] (m^2)	PCAST Scaling Factor	PCAST Floor Area (m^2)	Unit Costs[2] (m^2)	ITER Estimate (FY-89M$)	PCAST Estimate (FY-89M$)
Radwaste and Personnel Buildings (8, 9)	6,480	0.33	2,158	2,469	$ 16	$ 5
Laboratory Office Building (22)	17,570	0.75	13,178	1,309	$ 23	$ 17
Cryoplant Buildings (10, 11)	15,600	0.09	1,400	3,981	$ 62	$ 6
LN2 (New)	--	--	5,700	3,981	--	$ 23
Control Building (23)	5,760	1.00	5,760	2,083	$ 12	$ 12
Emergency Power Building (21)	2,500	1.00	2,500	2,258	$ 6	$ 6
Site Services Building (24)	8,100	1.00	8,100	2,290	$ 19	$ 19
Assembly Laydown Storage Building (28)	9,000	0.40	3,600	1,613	$ 15	$ 6
PF Coil Fabrication Building (25)	4,030	0.60	2,418	2,606	$ 10	$ 6
Magnet Coil Test Building (26)	4,030	0.00	0	--	$ 13	$ 0
Tunnels	na	1.00	na	na	$ 31	$ 31
Switchyard and Misc. Structures (31, 32)	na	0.85	na	na	$ 7	$ 6

Annex II
Derivation of Unit Cost Scalings

PCAST Building Cost Comparison

Building Name and Number (Based on ITER)	ITER Floor Area[1] (m^2)	PCAST Scaling Factor	PCAST Floor Area (m^2)	Unit Costs[2] (m^2)	ITER Estimate (FY-89M$)	PCAST Estimate (FY-89M$)
Electrical Terminations Building (7)	10,650	0.63	6,710	3,286	$ 35	$ 22
Remote Handling Mockup Building (27)	5,950	0.66	3,927	5,882	$ 35	$ 23
MG (New)	--	--	7,432	2,630	--	$ 20
Total	203,090		131,302		$891	$596

Notes: [1] From Table 6.2.2-1
[2] Derived from Table 6.2.2-1
[3] Combination of Buildings 12, 13, 14, &15

A new floor area was developed for the combination of buildings 12, 13, 14, and 15 based on a review of the drawings. Unit costs for the floor areas were derived where necessary to agree with the ITER estimates. The PCAST facility estimate totals $596M compared to the ITER total estimate of $891M, a reduction of 33% or an overall scaling factor of 0.67 applied to the ITER estimates. Details on a building by building basis are discussed below.

- **Tokamak Building**

Basis:

The recommended basis is $10.142K/m^2 of floor area using the ITER unit cost. A reduction in area factor for the PCAST machine is 0.71.

Discussion:

This building is equivalent to ITER Buildings 1 (Tokamak Hall), 2 (Assembly Hall), and 3 (Laydown Hall).

The Tokamak Building has undergone a major change as a result of the PCAST configuration and consequently has been redrawn as shown in Plan View (Fig. 6.2.3-1), East-West Section (Fig. 6.2.3-2) and North-South Section (Fig. 6.2.3-3). The Tokamak Hall in the center of the structure includes the tokamak pit in which the cryostat containing the tokamak is located. The pit has been reduced in size reflecting the smaller dimensions of the PCAST cryostat. The annular space surrounding the cryostat biological shield contains several levels and is used for neutral beams, RF launchers, remote maintenance and auxiliary equipment. It was assumed that this equipment would basically occupy the same radial dimension and therefore the radial dimension of the annular space was not reduced for PCAST. The upper portion of the Tokamak Hall was reduced in area and height to reflect the new pit dimensions and reduction in cryostat height.

The adjacent Assembly Hall located south of the Tokamak Hall was reduced to reflect the reduction in size of the machine components. The area in the basement of the Assembly Hall contains a neutral beam test cell and some neutral beam power supply equipment. This area is also available for diagnostic operations. The Laydown Hall to the north of the Tokamak Hall is intended for storage of machine components. Since the individual components are not expected to differ appreciably in size, the area underwent a relatively smaller reduction than the Assembly Hall. The space in the Laydown Hall basement is dedicated to remote handling operations, and is connected to the annular space around the cryostat biological shield by means of a vertical shaft and tunnel providing a passageway for the transfer of components requiring remote maintenance. Remote maintenance control and actuation systems are also located in the Laydown Hall basement.

The new dimensions of the PCAST Tokamak Building result in a scaling factor of 0.71 in the floor area when applied to the ITER design.

The ITER JCT suggested scaling factor for the Tokamak Building is $/volume (m^3). Using a ratio of the Tokamak Building cost to its gross volume is approximately $343/m^3. Using a ratio of the pit volume, the scaling factor is $2,783/m^3. The equivalent BPX scaling factor based on gross volume is approximately $544/m^3. TPX reused the TFTR building, so any scalings derived from TPX would not be applicable.

Results and Scaling Uncertainty:

Based on scaling by floor area, the estimated cost for the Tokamak Building is approximately $258M. Alternate scalings based on pit volume or building surface area all yield approximately the same figure of $258M. However, should the gross volume scaling derived from ITER be used, with an approximate PCAST gross volume of 618,405m^3, the cost of the building would be reduced by $50M to $208M. Accordingly, the scaling uncertainty ranges from $208M to $258M.

- **Hot Cell Building**

Basis:

The recommended basis is $4,424/m^2 of floor area using the ITER unit cost. A reduction in area factor for the PCAST machine is 0.50..

Discussion:

This building is equivalent to ITER Building 4 (Hot Cell Building).

The Hot Cell Building provides space for decontamination and waste processing. In particular the building is designed for the reprocessing of divertor cassettes. Based on an evaluation described in section WBS 6.3 of the report, a scaling factor or 0.50 is applied to the floor area.

The ITER JCT suggested that the Hot Cell Building should be scaled directly from ITER, since the components being handled are probably broken into similar sizes. This building is assumed to be approximately one-half the size as the ITER building due to reduced size of components and the reduced contamination levels. There is not an equivalent for BPX or TPX as they both made extensive use of existing TFTR facilities.

Results and Scaling Uncertainty:

Based on scaling by floor area, the estimated cost for the Hot Cell Building is approximately $46M. No scaling uncertainty is indicated.

- **Tritium Building**

Basis:

The recommended basis is $3.443K/m^2 of floor area using the ITER unit cost. A reduction in area factor for the PCAST machine is 0.40.

Discussion:

This building is equivalent to ITER Building 5 (Tritium Building).

The Tritium Building houses the tritium storage and processing facilities including the Exhaust Gas Processing System, the Fuel Cleanup System, the Isotope Separation System, the Fuel Storage System, the Water Detritiation System, and the Atmosphere Detritiation System. It is estimated that the PCAST machine will require 1.4E23 tritons or 6700 curies per pulse. At 5 pulses per day this equates to 33,500 curies. ITER has ~ 5 times the volume and ~ 8 times the pulse length of PCAST, so its requirements would be a factor of 40 higher. The Tritium Building provides space for the vacuum pumping system, a tritium laboratory, changing areas for personnel, maintenance areas, and areas to accommodate a control system and a DT storage and distribution system. A scaling factor of 0.40 is applied to the floor area

There is not an equivalent for BPX or TPX as they both made extensive use of existing TFTR facilities.

Results and Scaling Uncertainty:

Based on scaling by floor area, the estimated cost for the Tritium Building is approximately $18M. No scaling uncertainty is indicated.

- **Tokamak Service Building**

Basis:

The recommended basis is $3.125K/m^2 of floor area using the ITER unit cost.. The area reduction factor for PCAST is 0.7.

Discussion:

This building is equivalent to ITER Building 6 (Tokamak Services Building).

The Tokamak Services Building actually consists of two buildings similar in size and located east and west of the Assembly Hall. The building houses the secondary heat transfer system for the first wall and divertor, for plasma heating, for diagnostics, and for the test module. In addition, the building provides space for the chilled water distribution system. Work areas for maintenance functions must able accommodated. It is assumed that the Tokamak Services Buildings would scale with the linear dimension of the Assembly hall but maintain the same width. This would result in a scaling factor of 0.70 applied to the floor area.

The ITER JCT suggested scaling factor for the Tokamak Service Building is $/area (m^2).

There is not an equivalent for BPX or TPX as they both made extensive use of existing TFTR facilities.

Results and Scaling Uncertainty:

Based on scaling by floor area, the estimated cost for the Tokamak Service Building is approximately $18M. No scaling uncertainty is indicated.

- **Auxiliary Buildings**

Basis:

The recommended basis is $2.158K/m^2 of floor area using the ITER unit cost. The adjustment for area is 1.48 for the Magnet Power Conversion Building and 0.40 for the Auxiliary Heating Power Conversion Buildings.

Discussion:

The Auxiliary Buildings consist of five independent structures. A magnet power supply switching network building (12), two power conversion buildings (13), an ICRF/ECRF power supply building (14), and a power supply building for neutral beam (15).

The Magnet Power Supply Switching Network Building (12) basically provides quench protection for superconducting coils. This building would not be necessary for PCAST. The scaling factor is therefore 0.00.

The TF/PF Power Conversion Buildings (13) would be larger than ITER because the PCAST TF/PF coils are not superconducting. The scaling factor applied to the floor area will be 1.48 for PCAST.

The ICRF/ECRF Power Conversion Building (14) and the Neutral Beam Power Conversion Building (15) can be scaled based upon the power generated. ITER power to the plasma is 100 MW. ITER assumes an efficiency of 33-1/3%, therefore power generated is 300 MW. PCAST power to the plasma is 60 MW. PCAST assumes an efficiency of 50%, therefore power generated is 120 MW. The resulting scaling factor is 120/300 or 0.40 applied to the floor area.

The ITER JCT suggested scaling factor for the Auxiliary Buildings is also $/area (m^2).

There is not an equivalent for BPX or TPX as they both made extensive use of existing TFTR facilities.

Results and Scaling Uncertainty:

Based on scaling by floor area, the estimated cost for the Auxiliary Buildings is approximately $45M. No scaling uncertainty is indicated.

- **Effluent Stack**

Basis:

Fixed input costs from ITER.

Discussion:

The primary function of the Plant Gaseous Effluent Stack is to provide an elevated release point for all gaseous effluents which may contain radioactive or hazardous materials. It is assumed that there would be little change in the requirements for PCAST. The resulting scaling factor is 1.0..

The ITER JCT suggested scaling factor for the Effluent Stack is to use the ITER estimate directly.

There is not an equivalent for BPX or TPX as they both made extensive use of existing TFTR facilities.

Results and Scaling Uncertainty:

The ITER estimate of $2M for the Effluent Stack is adopted. No scaling uncertainty is indicated.

- **Radwaste and Personnel Building**

Basis:

The recommended basis is $2.469K/m^2 of floor area using the ITER unit cost, with an area reduction to 0.33 that of ITER.

Discussion:

These building are equivalent to ITER Buildings 8 (Radwaste Building) and 9 (Personnel Building).

The building provides space for the liquid waste processing system, the dry waste processing system, shipping and receiving activated and processed material, an analytical chemistry laboratory and change areas and other amenities of personnel. It is assumed that the reduction in neutron fluence and the smaller size of the PCAST machine would affect the amount of radwaste material produced in the lifetime of the machine. The neutron load in ITER is 1.0 MWa/m^2 compared to 0.01 MWa/m^2 for PCAST, a factor of 100 less. The major radius of PCAST is approximately 60% that of ITER. The PCAST Radwaste & Personnel Building floor area has been taken as 33% of the ITER building area.

The ITER JCT suggested scaling factor for the Radwaste and Personnel Building is to use the ITER estimate directly.

There is not an equivalent for BPX or TPX as they both made extensive use of existing TFTR facilities.

Results and Scaling Uncertainty:

Based on scaling by floor area, the estimated cost for the Radwaste and Personnel Building is approximately $5M. No cost uncertainty is indicated.

- **Laboratory Office Building**

Basis:

Fixed input costs from ITER

Discussion:

This building is equivalent to ITER Building 22 (Laboratory Office Building).

The primary function of the Laboratory Office Building is to provide office space for the scientists, engineers, administrators and support personnel assigned to the ITER site. The building is designed for offices, computer network equipment, meeting rooms, a library, and amenities for an occupancy of 750 personnel. The size of the Laboratory Office Building will be reduced to reflect an anticipated 25% reduction in staff for PCAST. The reduction in staff will result in a scaling factor of 0.75 applied to the floor area.

The ITER JCT suggested scaling factor for the Laboratory Office Building is to use the ITER estimate directly. However, it was felt that the PCAST staff will be less than that required for ITER since there is no equivalent engineering mission.

There is not an equivalent for BPX or TPX as they both made extensive use of existing TFTR facilities.

Results and Scaling Uncertainty:

The PCAST estimate for the Laboratory Office Building is approximately \$17M, 25% less than that of ITER. The cost uncertainty ranges from \$17M to \$23M.

- **Cryoplant Building**

Basis:

The recommended basis is \$3.981K/m^2 of floor area using the ITER unit cost, with scaling made for the amount of He refrigeration required (approximately 9%). The recommended basis is also \$3.981K/m^2 of floor area for the new LN_2 building.

Discussion:

This building is equivalent to ITER Buildings 10 (Cryoplant Compressor Building) and 11 (Cryoplant Cold Box/Dewar Building. A new LN_2 building will be required.

The ITER cryoplant consists of two buildings. The Cryoplant Compressor Building houses the compressor portion of the liquid helium refrigeration and supply system, and the Cryoplant Cold Box/Dewar Building houses the expander portion of the liquid helium refrigeration system including liquid helium circulation pumps and tanks for volume control of the liquid and gas phases of cryogenic helium. The refrigeration capacity for the PCAST machine will require 83KW of gaseous helium at 30°K plus 8200KW of liquid nitrogen at 80°K. Scaling from the MFTF-B 11KW refrigerator, the size required for the PCAST helium system would be approximately 1200 m^2, or a factor of 0.08 relative to ITER. Based on MFTF-B experience, the helium refrigeration capacity of the cryoplant at 30°K is approximately 6 times higher than the capacity at 4.5°K. The 150KW ITER cryoplant is therefore capable of producing 900KW of helium at 30°K. Since only 83 KW is required, a scaling factor of 83/900 or 0.09 can be applied to the ITER facility for helium. As this is a slightly more conservative value, it will be used for scaling, and it results in an estimated area layout of 1,400 m^2 for the helium building. An 8200 KW liquid nitrogen plant will require a floor area of 5700 m^2. This is based on the scaling of the MFTF-B 500KW reliquifier, as well as using current manufacturer's estimates for the amount of space required for each 1 MW 80°K refrigerator. The building cost per square meter of the liquid nitrogen plant would be comparable to the ITER costs.

Results and Scaling Uncertainty:

Based on scaling by floor area, the estimated cost for the Cryoplant Building is approximately $29M. No scaling uncertainty is indicated.

- **Control Building**

Basis:

Fixed input costs from ITER.

Discussion:

This building is equivalent to ITER Building 23 (Control Building).

The Control Building provides space for the CODAC (Control and Data Acquisition) system, the plasma control supervisor system, interlock system, vacuum pumping control system, diagnostic data acquisition system, radiation monitoring system, etc. In addition, the area will house the on-line computer control system. It is assumed that the PCAST control building will provide space for similar systems and personnel, therefore a scaling factor of 1.0 will be applied.

The ITER JCT suggested scaling factor for the Control Building is to use the ITER estimate directly.

There is not an equivalent for BPX or TPX as they both made extensive use of existing TFTR facilities.

Results and Scaling Uncertainty:

The ITER estimate of $12M for the Control Building is adopted. No scaling uncertainty is indicated.

- **Emergency Power Building**

Basis:

Fixed input costs from ITER.

Discussion:

This building is equivalent to ITER Building 21 (Emergency Power Generator Building).

The Emergency Power Supply Building is designed to accommodate the emergency generator units which provide emergency power to the loads on the emergency power buses within the ITER plant. In addition, the building provides space for the electrical power control room, maintenance shops, and fire fighting equipment. The functions and the space required would be similar for PCAST therefore a scaling factor of 1.0 will be applied.

The ITER JCT suggested scaling factor for the Emergency Power Building is to use the ITER estimate directly.

There is not an equivalent for BPX or TPX as they both made extensive use of existing TFTR facilities.

Results and Scaling Uncertainty:

The ITER estimate of $6M for the Emergency Power Building is adopted. No scaling uncertainty is indicated.

- **Site Services Building**

Basis:

Fixed input costs from ITER.

Discussion:

This building is equivalent to ITER Building 24 (Site Services Building).

The Site Services Building houses a variety of site services including potable water, deionized water plant, chilled water, low pressure steam generation, compressed air, non-toxic storage, maintenance, etc. Similar services will be required for PCAST therefore a scaling factor of 1.0 will be applied.

The ITER JCT suggested scaling factor for the Site Service Building is to use the ITER estimate directly.

There is not an equivalent for BPX or TPX as they both made extensive use of existing TFTR facilities.

Results and Scaling Uncertainty:

The ITER estimate of $19M for the Site Services Building is adopted. No scaling uncertainty is indicated.

- **Assembly Laydown Storage Building**

Basis:

The recommended basis is $1.613K/m^2 of floor area using the ITER unit cost, with an area reduction to 0.40 that of ITER.

Discussion:

This building is equivalent to ITER Building 28 (Assembly/Laydown Storage Building).

The Assembly Laydown and Storage Building is designed to house and provide storage of large tokamak components which require a protected environment prior to installation. Since the PCAST components are smaller, the length and width of the building were reduced by 5/8 but with the same height. The resulting scaling factor is 0.40 applied to the floor area.

The ITER JCT suggested scaling factor for the Assembly Laydown Storage Building is $/area (m^2).

There is not an equivalent for BPX or TPX as they both made extensive use of existing TFTR facilities.

Results and Scaling Uncertainty:

Based on scaling by floor area, the estimated cost for the Assembly Laydown Storage Building is approximately $6M. No scaling uncertainty is indicated.

- **PF Coil Fabrication Building**

Basis:

The recommended basis is $2.606k/m^2 of floor area using the ITER unit cost, with an area reduction to 0.60 that of ITER.

Discussion:

This building is equivalent to ITER Building 25 (Poloidal Field Coil Fabrication Building).

The Poloidal Field Coil Fabrication Building has to accommodate the equipment and systems used to fabricate the ITER PF coils. The largest PCAST PF coils (~ 20.4 m in diameter) are smaller than the largest ITER coils (~ 32 m in diameter), but still too large to be shipped to the site. The working area of the ITER Poloidal Field Coil Fabrication Building has been reduced proportionally. Offices and machine shop areas were not reduced. The resulting scaling factor is 0.60 applied to the floor area.

Results and Scaling Uncertainty:

Based on scaling by floor area, the estimated cost for the PF Coil Fabrication Building is approximately $6M. No scaling uncertainty is indicated.

- **Magnet Coil Test Building**

Basis:

Not required for the PCAST machine.

Discussion:

This building is equivalent to ITER Building 26 (Poloidal Field Coil Testing Building).

The PCAST design specifies copper coils which should not require a pre-test, therefore the Magnet Coil Test Building would not be required. The scaling factor is 0.00.

The ITER JCT noted that a Magnet Coil Test Building will not be required for the PCAST machine as the copper coils will not require a pre-test.

Results and Scaling Uncertainty:

The estimated cost for the Magnet Coil Test Building is $0M since it is not required for the PCAST machine. No scaling uncertainty is indicated.

- **Utility Tunnels and Site Improvements**

Basis:

Fixed input costs from ITER.

Discussion:

These are equivalent to the ITER Building tunnels.

It is assumed that the cost of utility tunnels and site improvements will be the same for ITER and PCAST. The resulting scaling factor is 1.0.

The ITER JCT suggested scaling factor for the Utility Tunnels and Site Improvements is to use the ITER estimate directly. Although there may be some small adjustments due to the smaller PCAST machine, the relative differences should not be great.

Results and Scaling Uncertainty:

The ITER estimate of $31M for Utility tunnels and Site Improvements is adopted. The scaling uncertainty is not considered significant.

- **Switchyards and Miscellaneous Structures**

Basis:

The recommended basis is to adjust the ITER estimate by a factor of 0.85.

Discussion:

These are equivalent to the ITER structures 31 (Pulsed Power Switchyard), 32 (Steady State Switchyard), and other miscellaneous structures.

There are two switchyards in the ITER facility layout. One is the Pulsed Power Switchyard and Miscellaneous Structures (31), and the other is the Steady State Switchyard and Miscellaneous Structures (32), Miscellaneous structures are also provided for the Cryoplant, Emergency Power Supply, Site Services area and the Cooling Towers. Basemats are provided for power supply equipment such as towers, transformers, etc. The Pulsed Power Switchyard (31) would remain the same for both ITER and PCAST as the power from the grid is equal. The Steady State Switchyard (32) for PCAST would be 70% of the size and cost required for ITER. Since both switchyards are essentially equal in cost, the combined scaling factor is 0.85.

Results and Scaling Uncertainty:

The ITER estimate of $7M for the Switchyards and Miscellaneous Structures is reduced slightly to $6M. The scaling uncertainty is not considered significant.

- **Electrical Terminations Building**

Basis:

The recommended basis is $3.286K/m^2 of floor area using the ITER unit cost, with an area reduction to 0.63 that of ITER.

Discussion:

This building is equivalent to ITER Building 7 (Electrical Terminations Building).

The Electrical Termination Building is a five story building designed to accommodate the electrical feed equipment including the cabling and switchgear up to the point at which the current leads become superconducting. The building is also designed to accommodate the auxiliary cold boxes and cold terminal boxes. In addition, space for diagnostics is provided as well as for the vacuum vessel air-cooled heat exchanger. The requirements for PCAST are different with LN2 and gaseous helium replacing LHe, however, the scope of the equipment is somewhat comparable. For PCAST the length of the Electrical Termination Building has been scaled to agree with the length of the Tokamak Hall. The width and height of the building have not been changed. The resulting scaling factor is 0.63 applied to the floor area.

The ITER JCT suggested scaling factor for the Electrical Terminations Building is $/area (m^2).

There is not an equivalent for BPX or TPX as they both made extensive use of existing TFTR facilities.

Results and Scaling Uncertainty:

Based on scaling by floor area, the estimated cost for the Electrical Terminations Building is approximately $22M. No scaling uncertainty is indicated.

- **Remote Handling Mockup Building**

Basis:

The recommended basis is $5.882k/m^2 of floor area using the ITER unit cost, with an area reduction to 0.66 that of ITER.

Discussion:

This building is equivalent tc ITER Building 27 (Remote Handling Mockup Building).

The Remote Handling Mockup Building is a facility to perform verification tests of remote handling equipment, including preparation of the equipment for initial assembly operations and to develop equipment for ITER decommissioning. A test stand (mockup) will contain 3 segments of the vacuum vessel. In addition, the building will provide space for a control room and associated offices. For PCAST the length and width of the mockup itself can be reduced in proportion, however, the work area surrounding the mockup would remain about the same as ITER, and the area of the control room, office, and machine shop would also remain the same. The result is a scaling factor of 0.66 applied to the floor area.

The ITER JCT suggested scaling factor for the Remote Handling Mockup Building is $/area (m^2).

There is not an equivalent for BPX or TPX as they both made extensive use of existing TFTR facilities.

Results and Scaling Uncertainty:

Based on scaling by floor area, the estimated cost for the Remote Handling Mockup Building is approximately $23M. No scaling uncertainty is indicated.

- **MG Building**

Basis:

The recommended basis is $2.630/m^2 of floor area.

Discussion:

An MG Building will be required for PCAST. This will be a new building and will house 4 MG sets similar in size to TFTR. TFTR has 2 MG sets (950 MVA), therefore a building twice the size of the TFTR MG complex would be required for PCAST. The present TFTR MG building floor area is 42,000 ft^2 or 3716 m^2. Four MG sets of the TFTR size would require a floor area of 7432 m^2. Based on actual building costs corrected to FY-89$, the cost of a new MG building would be approximately $20M.

Results and Scaling Uncertainty:

The estimated cost for the New MG Building is approximately $20M. No scaling uncertainty is indicated.

- **WBS 6.3 - Waste Management Systems**

Basis:

The costs are based on scaling the ITER Waste Management Systems to reflect the reduced Hot Cell Equipment required. A scaling factor of 41% was derived.

Discussion:

A review of each subsystem in this WBS element was conducted. For the Subsystem 6.3C (Hot Cell Maintenance Equipment) the ITER estimate includes two types of remote maintenance equipment; a series of machines to refurbish divertors and a multipurpose maintenance cell. The divertor refurbishment system would not be required for PCAST because the divertors are assumed to be replaced rather than repaired. The multipurpose maintenance cell(s) would be retained for the reasons stated in the ITER WBS 6.3 including cutting, welding, disassembly and reassembly of large components. Accordingly, the ITER estimate of $25.4M is can be scaled by a factor of 0.25.

All other subsystems in WBS 6.3 are required to perform waste management functions such as decontamination, storage, packaging and waste concentration and reduction. The quantity and scale of equipment required for these operations is estimated to be approximately 50% of that required for ITER. This estimation is based on a reduced LL waste volume due to fewer cleaning requirements, reduced component waste volume due to the smaller machine size and reduced storage because contaminated divertors modules are not recycled. The ITER estimate of $43.9M is thus scaled by a factor of 50%.

The ITER JCT suggested scaling factor for the Waste Management Systems is to use ITER directly. However, this did not take into account that the divertor refurbishment equipment is not required. The JCT believed, that although there may be some small adjustments due to the lower volume of waste product in the smaller PCAST machine, the relative differences should not be great.

The ITER cost estimate for Waste Management Systems did not include any AFI and therefore none is applied to this estimate.

Results and Scaling Uncertainty:

The estimated costs for the Waste Management Systems is approximately $6.4M for the Hot Cell Maintenance Equipment and $22M for the other subsystems for a total of about 28.4M. Should the ITER estimate for all but the Hot Cell Maintenance Equipment be adopted, the total estimated costs would rise to about $50M. Thus the range of scaling uncertainty is from about $28M to $50M.

- **WBS 6.4 - Radiological Protection Systems**

Basis:

Fixed input costs from ITER.

Discussion:

The ITER JCT suggested scaling factor for Radiological Protection Systems is to use ITER directly. For ITER, this WBS element includes portable shielding, all health physics tasks (monitoring, surveys, personnel dosimetry and contamination control). All of these functions will also have to be performed for the PCAST Machine. The cost of these functions is relatively insensitive to the differences in the scale of the two devices so the ITER cost estimate was also used for PCAST.

The ITER cost estimate for Radiological Protection Systems did not include any AFI and therefore none is applied to this estimate.

Results and Scaling Uncertainty:

The ITER estimate of $4M was adopted directly. The scaling uncertainty is not expected to be significant.

- **WBS 6.5 - Liquid Distribution Systems**

Basis:

Recommended scaling from the ITER cost of $56M with the overall plant area. The PCAST footprint is approximately 0.65 of that of ITER.

Discussion:

The ITER JCT suggested scaling factor Liquid Distribution Systems is $/m^2 of the overall plant area.

It is obvious that the same or similar systems will be required for PCAST. In the absence of any available detail in this area, and the time required to generate a bottoms-up estimate without the specific requirements, an attempt will be made to apply a scaling factor to the ITER estimate in order to arrive at a reasonable estimate for PCAST.

There are two areas that would affect the Liquid Distribution System in a global sense:

- The reduction in personnel staff required for PCAST; and
- The reduction in area over which the distribution would take place.

There are no figures available for the staffing level required to operate the ITER complex, with the exception of the Laboratory Office Building where a reduction in administrative and professional personnel of 25% has been assumed (See WBS 6.2 above). There are other areas where buildings have been eliminated, or their operations greatly curtailed. For example, the reduction in the amount of decontamination and radwaste should result in a reduction of staff handling that function. Although a reduction in personnel would result in a reduction of some of the services provided by the Liquid Distribution System, no attempt is being made to develop a scaling factor reflecting this reduction.

The elimination of certain buildings and the reduction in size of many of the remaining buildings has resulted in an overall reduction in floor area (See WBS 6.2 above). The site layout would be more compact with reductions in the distances over which the distribution system must operate. The ITER floor area is 203,090 m^2 and the PCAST floor area is 131,302 m^2 resulting in a reduction ratio of 1.55:1 or a scaling factor of 0.65. This scaling approach is admittedly simplistic but reasonable enough for the purpose.

The ITER cost estimate for Liquid Distribution Systems did not include any AFI and therefore none is applied to this estimate.

Results and Scaling Uncertainty:

Applying the 0.65 scaling factor to the ITER Liquid Distribution System estimate of $56M results in a PCAST estimate of $36M. No scaling uncertainty is indicated.

- **WBS 6.6 - Gas Distribution Systems**

Basis:

Recommended scaling from the ITER cost of $20M with the overall plant area. The PCAST footprint is approximately 0.65 of that of ITER.

Discussion:

The ITER JCT suggested scaling factor Gas Distribution Systems is also $/m^2 of the overall plant area.

The same or similar systems will obviously be required for PCAST. Available detail is absent in this area, and time does not permit generating a bottoms-up estimate. In the absence of specific requirements, an attempt will be made to apply a scaling factor to the ITER estimate in order to arrive at a reasonable estimate for PCAST.

There are two areas that would affect the Gas Distribution System in a global sense:

- The reduction in personnel staff required for PCAST; and
- The reduction in area over which the distribution would take place.

In this sense it can be compared with the approach used in estimating the costs for WBS 6.5.

There are no figures available for the staffing level required to operate the ITER complex, with the exception of the Laboratory Office Building where a reduction in administrative and professional personnel of 25% has been assumed (See WBS 6.2 above). There are other areas where buildings have been eliminated, or their operations greatly curtailed. For example, the reduction in the amount of decontamination and radwaste should result in a reduction of staff handling that function. Although a reduction in personnel would result in a reduction of some of the services provided by the Gas Distribution System, no attempt is being made to develop and apply a scaling factor reflecting this reduction.

However, the elimination of certain buildings and the reduction in size of many of the remaining buildings has resulted in an overall reduction in floor area (See WBS 6.2 above). Consequently the site layout for PCAST would be more compact with reductions in the distances over which the distribution system must operate. The ITER floor area is 203,090 m^2 and the PCAST floor area is 131,302 m^2 resulting in a reduction ratio of 1.55:1 or a scaling factor of 0.65. This scaling approach is admittedly simplistic but reasonable enough for the purpose.

The ITER cost estimate for Gas Distribution Systems did not include any AFI and therefore none is applied to this estimate.

Results and Scaling Uncertainty:

Applying the 0.65 scaling factor to the ITER Gas Distribution System estimate of $20M results in a PCAST estimate of $13M. No scaling uncertainty is indicated.

- **WBS 6.7 - General Test Equipment**

Basis:

The PCAST estimate was derived by assessing the vacuum pumping and leak checking equipment and coil testing required on site.

Discussion:

The ITER JCT noted that the majority of General Test Equipment was needed for the magnet coil testing. The PCAST Machine would not require the same equipment as ITER but would require vacuum pumping and leak checking equipment to verify the field welds of the cryostat and vacuum vessel. This would include temporary blank-off flanges and special fixtures to isolate section of the vessel and cryostat for testing as the welding proceeds.

The PCAST Machine coils would undergo acceptance testing at the vendor's plant before shipping. This would include ground plane insulation integrity tests (meggar and hi-pot), partial discharge tests and turn-to-turn testing. At the assembly site, a sub-set of these tests would be repeated to verify the quality of the insulation after assembly.

The ITER cost estimate for General Test Equipment did not include any AFI and therefore none is applied to this estimate.

Results and Scaling Uncertainty:

The estimated cost is $6.5M in FY-95$ ($5.2M in FY-89$). The leak checking fixtures and temporary blank-off flanges are estimated at 10% of the cost of the component being tested and the coil test equipment is estimated to cost 0.5$M in FY-95$. No scaling uncertainty is indicated.

WBS 6.7 General Test Equipment Supplemental Cost Information:

Component	Component Cost (FY-95M$)	WBS 6.7 Costs[1] (FY-95M$)
Vacuum Vessel[2]	$24.7	$2.5
Cryostat	$34.7	$3.5
Subtotal Components	$59.4	$6.0
Coil Test Equipment		$0.5
TOTAL (FY-95M$)		$6.5
TOTAL (FY-89M$)[3]		$5.2

Notes: [1] Blank-off flanges and leak checking fixtures estimated at 10% of component costs.
[2] Vacuum vessel component costs exclusive of thermal shield and steel inside vessel.
[3] FY-95 costs de-escalated to FY-89 using factor of 1.2415 from ITER Interim Design Report.

- **WBS 6.8 - Sampling Systems**

Basis:

Fixed input costs from ITER.

Discussion:

The ITER JCT suggested scaling factor for the Sampling Systems is to use ITER directly.

The ITER cost estimate for Sampling Systems did not include any AFI and therefore none is applied to this estimate.

Results and Scaling Uncertainty:

The ITER estimate of $4M was adopted directly. The scaling uncertainty is not expected to be significant.

Annex III

Derivation of Total Project Cost Ratios

Annex III
Derivation of Total Project Cost (TPC) Ratios

Background

The Total Project Cost (TPC) consists of the following cost elements:

- **Conceptual Design Costs** - those costs for activities supporting the development of a Conceptual Design that is culminated with a Conceptual Design Review (CDR)
- **Engineering** - those activities supporting the development of preliminary and final designs (typically called Title I and Title II Engineering in U.S. terminology). These activities are culminated by both Preliminary Design Reviews (PDRs) and Final Design Reviews (FDRs) that naturally lead into construction.
- **R&D** - those research and development and prototyping activities supporting the development of both the preliminary and final designs of components and systems. Some R&D activities such a proof-of-principal prototyping may carryover into the beginning of construction, however, all R&D costs are captured in this category.
- **Construction** - those activities supporting the fabrication and installation of components and systems. The manufacturing engineering involved in finalizing the detailed production drawings to be used during the fabrication process is included in this category.

- **Construction Support** - those activities occurring during the construction phase that supports construction. Included in this category are the Construction Management effort, the engineering supporting construction (typically called Title III Engineering in U.S. terminology), and the costs to test and commission components and systems.
- **Contingency** - historically until 1993, the contingency was only applied to the so-called "PACE" portion of the project which included the above categories of Engineering, Construction, and portions (Title III Engineering and Construction Management) of the Construction Support. However, in 1993, DOE revised their position on contingency to permit it to be applied to all project costs.

Derivation of TPC Ratios

- Overall Approach - to simplify the development of the TPC in the categories described above, it was decided to develop ratios of the respective cost category for each of the three reference projects to their construction costs. Only a bottom-line comparison figure was developed since the ITER has not fully allocated these categories to individual WBS elements.

Annex III
Derivation of Total Project Cost (TPC) Ratios

- Conceptual Design - The ratio of the BPX Conceptual Design Costs to the BPX Construction Costs was approximately 2% and for TPX the ratio was approximately 3%. Published data for the ITER CDA costs were not readily available, so we relied on BPX and TPX data. We elected to use the TPX costs as representative.

- Engineering

  - The BPX ratio of Engineering to Construction costs was approximately 20%.
  - The TPX ratio of Engineering to Construction costs was approximately 46%. This was considered anomalously high due to the fact that the site credits added back in to put TPX on the same basis as ITER probably did not accurately reflect the engineering associated with those site credits and hence the relative construction costs may have been too low.
  - The ITER data was obtained from Table I in Chapter VIII of the ITER Interim Design Report.[1] In Table I the total JCT manning in Professional Person Years (PPY's) is 798 PPY for the EDA and 387 PPY for "After EDA and Before Physical Construction." The total Home Team is 756 PPY for the EDA and 370 PPY for "After EDA and Before Physical Construction." Thus the total Engineering Manpower is 2,311 PPY. If we assume a PPY is

[1] ITER Interim Design Report (June 12, 1995), page VIII-1.

approximately $300K in FY-89$, then the approximate Engineering cost is $694M in FY-89$ or about 12%.

- We elected to use the BPX ratio as representative.

- R&D

  - Both the BPX and TPX ratios of R&D to Construction costs were approximately 10%.
  - The ITER data was also obtained from Table I in Chapter VIII of the ITER Interim Design Report.[2] In Table I the R&D costs during the EDA are $653M and the R&D costs "After EDA and Before Physical Construction" are $94M for a total R&D costs of $747M in FY-89$ or approximately 13%.
  - Although this is a copper machine which should minimize some R&D associated with more high-tech conductors, the recent TPX experience (notwithstanding the ratio of R&D costs to construction costs) is that a higher amount of R&D is always needed. Hence, we elected to use a factor of 10% for the R&D.

- Construction Support

  - The BPX ratio of Construction Support activities to construction was about 8%, but was considered anomalously low since Construction Management activities were not fully estimated at the time that BPX was canceled.

[2] ITER Interim Design Report (June 12, 1995), page VIII-1.

- The TPX ratio was about 12%.
- The ITER data was also obtained from Table III in Chapter VIII of the ITER Interim Design Report.[3] The ITER estimate of Construction Support activities ranged from $800M-$900M in FY-89$. If we select the mid-range figure of $850M in FY-89$, the approximate ratio to construction costs is 15%.
- We elected to use the ITER ratio of 15% as representative.

- Contingency

  - The BPX ratio of contingency (on only the PACE project) was $21%.
  - The TPX ratio of contingency (on only the PACE project) was $23%.
  - The ITER estimate did not include contingency, but rather a cost uncertainty figure, both positive and negative, that was assigned based on a review of each estimate from the individual home teams.[4] Because there is insufficient time allotted this study to adequately address cost uncertainty as was done for ITER, the PCAST TPC excluded this category from the ITER construction estimate; the ITER construction estimate includes only the construction estimate and the allowances for indeterminables.

[3] ITER Interim Design Report (June 12, 1995), page VIII-3.
[4] ITER Interim Design Report (June 12, 1995), page VIII-22.

- We have elected to use the average of the BPX and TPX contingency -- or approximately 22%. In accordance with the new DOE policy, this will be applied to all project costs.

Escalation Differences

The ITER costs are expressed in ITER Units of Account (kIUAs) which are approximately the same as FY-89$. For comparison purposes of comparing PCAST construction costs to the ITER construction costs, the PCAST estimates will be de-escalated from FY-95$ in which they are estimated, to FY-89$ using the ITER de-escalation factor of 1.2415 provided in Annex I to the ITER Interim Design Report Cost Estimate Chapter VIII. Additionally, for purposes of developing unit cost scalings for BPX and TPX to compare to ITER, the suggested ITER de-escalation factors were used. It should be noted, however, that published DOE FY 1995 Inflation Rate Summary based on updated OMB guidance reflects a de-escalation factor of 1.208.

Annex III
Derivation of Total Project Cost (TPC) Ratios

Summary

The ratios for developing a TPC for the PCAST machine based on the construction costs in FY-95$ are as follows:

Cost Category	Ratio to Construction Costs
Conceptual Design	3%
Engineering	20%
R&D	10%
Construction Support	15%
Construction	100%
	Ratio to All Project Costs
Contingency	22%

This results in an overall multiplier on PCAST construction cost of 1.82.

Annex IV

PCAST Cost Comparisons

Annex IV

PCAST COST COMPARISIONS

WBS Element	ITER FY-89M$	PCAST FY-89M$	PCAST Scaling Uncertainty Range: Lower Bound FY-89M$	PCAST Scaling Uncertainty Range: Upper Bound FY-89M$	BPX FY-89M$	PCAST/ITER Percentage	PCAST/BPX Percentage
1.0 Magnet Systems	$1,909	$443	$419	$659	$185	23%	239%
1.1 TF Magnets	$1,160	$318			$126	27%	252%
1.2 PF Magnets	$447	$79			$30	18%	263%
1.3 Central Solenoid	$229	$34			$17	15%	200%
1.4 Magnet Structure	$73	$12			$12	16%	100%
1.5 Vacuum Vessel	$175	$50	$50	$50	$17	29%	294%
1.6 First Wall/Blanket Shield	$410	$43	$43	$93	$13	10%	331%
1.6.1 First Wall Components	$347	$30			$13	9%	231%
1.6.2 Blanket/Shield (ITER WBS 1.6.1B)	$63						
1.6.3 Miscellaneous Shielding		$13					
1.7 Divertor	$178	$76	$76	$100	$5	43%	1528%
1.8 Fueling Systems	$35	$17	$17	$25	$7	49%	266%
1.9 Internal Control Coils		$6	$6	$6	$7		78%
2.2 Machine Assembly & Tooling	$177	$119	$119	$119	$77	67%	154%
2.3 Remote Maintenance Handling	$225	$199	$199	$199	$24	89%	830%
2.4.1 Cryostat Systems	$71	$37	$37	$37	$7	52%	524%
2.4.1 Cryostat Structure	$61	$35			$7	57%	496%
2.4.2 Pressure Suppression System	$10	$2				20%	
2.5 Heat Transfer Systems	$238	$33	$33	$64	$18	14%	180%
2.6 Primary Heat Transfer Systems	$138	$18				13%	
3.3 Secondary Heat Transfer Systems	$65	$2					
3.7 Heating and Cooling Systems							
3.5 Heat Rejection Systems	$16	$4				28%	
3.6 Chemical Systems (CVCS)	$19	$9				47%	
2.7 Thermal Shields (Incl in WBS 1.5 & 2.4)	$25						
3.1 Vacuum Pumping	$61	$32	$14	$32	$10	52%	309%
3.2 Tritium Plant	$72	$35	$35	$52	$12	49%	307%
3.4 Cryoplant	$243	$100	$100	$100	$44	41%	229%
4.1 Coil Power Supplies	$339	$267	$267	$267	$123	79%	218%
4.3 Steady State Electrical Power	$39	$30	$30	$30	$18	77%	167%
4.4 IC Coil Power Supplies		$17	$17	$17			
4.7 Poloidal Coil Control	$1	$1	$1	$1	$0	100%	
4.8 CODAC & Interlocks	$77	$71	$71	$71	$21	92%	342%
4.5 CODAC	$75	$69			$21	92%	332%
4.6 Interlocks	$2	$2				100%	

Annex IV

PCAST COST COMPARISIONS							
WBS Element	ITER	PCAST	PCAST Scaling Uncertainty Range		BPX	PCAST/ITER Percentage	PCAST/BPX Percentage
			Lower Bound	Upper Bound			
	FY-89M$	FY-89M$	FY-89M$	FY-89M$	FY-89M$		
5.0 Auxiliary Heating Systems	$358	$184	$184	$184	$63	51%	293%
4.2 Auxiliary Heating Power Supplies (Included in WBS 5.1 - 5.4 Below)							
5.1 ICRH Systems		$72			$63		114%
5.2 ECH Systems							
5.3 NBI Systems		$113					
5.4 Other Aux Heating Systems							
5.5 Diagnostics	$148	$148	$148	$148	$25	100%	592%
6.2 Buildings	$891	$596			$114	67%	521%
Tokamak Building	$363	$258	$208	$258		71%	
Hot Cell Building	$92	$46	$46	$46		50%	
Tritium Building	$44	$18	$18	$18		41%	
Tokamak Service Building	$35	$25	$25	$25		71%	
Auxiliary Buildings	$71	$45	$45	$45		63%	
Plant Effluent Stack	$2	$2	$2	$2		100%	
Radwaste & Personnel Building	$16	$5	$5	$5		31%	
Lab Office Building	$23	$17	$17	$23		74%	
Cryoplant Buildings	$62	$29	$29	$29		47%	
Control Building	$12	$12	$12	$12		100%	
Emergency Power Building	$6	$6	$6	$6		100%	
Site Service Building	$19	$19	$19	$19		100%	
Assembly & Laydown Storage Building	$15	$6	$6	$6		40%	
PF Coil Fabrication Building	$10	$6	$6	$6		60%	
Magnet Coil Test Building	$13	$0	$0	$0		0%	
Tunnels & Site Improvements	$31	$31	$31	$31		100%	
Switchyards & Miscellaneous Structures	$7	$6	$6	$6		86%	
Electrical Terminations Building	$35	$22	$22	$22		63%	
Remote Handling Mockup Building	$35	$23	$23	$23		66%	
New MG Building	$0	$20	$20	$20			
6.3 Waste Management	$69	$28	$28	$50	$0	41%	
6.4 Radiological Protection	$4	$4	$4	$4	$0	100%	
6.5 Liquid Distribution Systems	$56	$36	$36	$36	$0	64%	
6.6 Gas Distribution Systems	$20	$13	$13	$13	$0	65%	
6.7 General Test Equipment	$25	$5	$5	$5	$0	20%	
6.8 Sampling Systems	$4	$4	$4	$4	$0	100%	
TOTAL	$5,850	$2,595	$2,502	$2,968	$790	44%	329%

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PCAST COST COMPARISIONS								
WBS Element	ITER	PCAST	PCAST Scaling Uncertainty Range		BPX	PCAST/ITER Percentage	PCAST/BPX Percentage
			Lower Bound	Upper Bound			
	FY-89M$	FY-89M$	FY-89M$	FY-89M$	FY-89M$		
Magnet Systems (WBS 1.1 - 1.4)	$1,909	$443	$419	$659	$185	23%	239%
Other ITER Systems with Costs >$100M	$2,691	$1,450	$1,427	$1,582	$446	54%	325%
Remaining ITER Systems with Costs < $100M	$1,250	$702	$656	$727	$159	56%	442%
TOTAL	$5,850	$2,595	$2,502	$2,968	$790	44%	329%

Notes:

1 See Annex II discussion of reasons for large differences between ITER and PCAST.