DOE/SF/20282--T3

Task No. 8

ITER

Vacuum Vessel Fabrication Plan
and Cost Study (D 68)
for the International Thermonuclear
Experimental Reactor

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

A handwritten signature or set of initials, possibly "ph", written in black ink.

January 1995

MASTER

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

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

Vacuum Vessel Fabrication Plan and Cost Study (D68)Revision Summary

<u>Date</u>	<u>Rev</u>	<u>Page No.</u>	<u>Description</u>
3/24/95	1	ExecutiveSummary	replace all pages <ul style="list-style-type: none"> • <i>Table ES-1 - corrected WBS Account No. 15.F and Total Account No.15 costs</i> • <i>Modified text to reflect corrected Table ES-1 costs</i>
		Part C - Section C.4	replace all spreadsheets <ul style="list-style-type: none"> • <i>Corrected WBS Account No. 15.F and Total Account No. 15 costs</i> • <i>Added cost uncertainties</i>
		Part D- Section D.3.9	replace pages 4 & 5 add Table <ul style="list-style-type: none"> • <i>Added supplementary cost table</i> • <i>Modified text to incorporate supplementary cost table</i>

Executive Summary

The ITER vacuum vessel provides structural support for all internal components, maintains a boundary suitable for ultra-high vacuum environment, and establishes the first safety confinement barrier for the ITER fusion reactor. The vessel is designed to be capable of resisting plasma disruption electromagnetic forces, forces resulting from vertical displacement events, and other postulated abnormal event loadings without a loss of confinement. The present ITER design specifies that the vessel be fabricated in twenty four (24) segments of fully welded Alloy 625 (Inconel 625) material.

A Vacuum Vessel Fabrication Plan and Cost Study (D68), also designated as ITER Task 8, was initiated to investigate the manufacturing feasibility of the ITER vacuum vessel, develop manufacturing and assembly plans, and generate a cost estimate commensurate with the present design. The industrial team of Raytheon Engineers and Constructors and Chicago Bridge and Iron (Raytheon/CB&I) has performed the Task 8 study for the present baseline vessel design.

The guidance for the Task 8 activities was prepared by the ITER Garching Work Site. Additional information and clarifications were coordinated through the US Home Team (USHT) and its technical representative. Design detail sketches considered essential to the Task 8 assessments but, not available from the ITER Joint Central Team (JCT) were prepared by Raytheon/CB&I as required.

The results of the Raytheon/CB&I assessments are presented in five sections.

- Introduction
- Part A - Vacuum Vessel Fabrication Assessment
- Part B - Vacuum Vessel Assembly Plan
- Part C - Cost Estimate
- Part D - Assessment of Type 316LN Stainless Steel as Alternative Vacuum Vessel Material

The manufacture of an ITER vacuum vessel as presently specified is considered feasible and should generally not present any significant manufacturing concerns to experienced Alloy 625 fabricators. The use of an alternative Type 316LN stainless steel material for vessel manufacture appears feasible however, some issues associated with the increased vessel shell thicknesses have been identified. Recommendations for follow-up evaluations associated with the vacuum vessel manufacturing plan have been presented as appropriate.

Vessel assembly will require close integration with the assembly of the other large tokamak components yet, appears feasible. Shell segment handling stresses and deformations during assembly are relatively small and remain well within the allowable stress limits.

Vacuum vessel manufacturing and assembly costs are estimated to be approximately \$350 million (\$US - 1993). A tabulation of the these estimated costs by Work Breakdown Structure (WBS) account is shown in Table ES-1, Vacuum Vessel Summary Costs.

TABLE ES-1 : VACUUM VESSEL SUMMARY COSTS

WBS ACCOUNT NO.	ACCOUNT DESCRIPTION	MATERIAL COST (K\$)	MATERIAL COST UNCERTAINTY		LABOR COST (K\$)	LABOR COST UNCERTAINTY		TOTAL COST (K\$)	TOTAL COST UNCERTAINTY	
			(-%)	(+%)		(-%)	(+%)		(-%)	(+%)
15. A	VACUUM VESSEL MAIN ASSEMBLY: VENDOR SHOP FABRICATION	\$154,391	(5)	19	\$44,800	(5)	15	\$199,191	(5)	18
15. B	V.V. PORT ASSEMBLIES: VENDOR SHOP FABRICATION	\$49,979	(5)	30	\$20,727	(5)	15	\$70,706	(5)	25
15. C	V.V. SUPPORT ATTACHMENTS: VENDOR SHOP FABRICATION	\$17,709	(5)	30	\$5,440	(5)	15	\$23,149	(5)	26
15. D	V.V. Pb-B4C EXTERNAL SHIELDING: VENDOR SHOP FABRICATION	\$12,917	(5)	24	\$8,431	(5)	15	\$21,348	(5)	21
15. E	SPECIAL JIGS & FIXTURES, AND MAJOR EQUIPMENT	\$13,967	(5)	16	\$0	---	---	\$13,967	(5)	16
15. F	VACUUM VESSEL ASSEMBLY AND TESTING AT THE JOBSITE	\$0	---	---	\$21,150	(5)	17	\$21,150	(5)	17
15	VACUUM VESSEL: TOTAL COST	\$248,963	(5)	22	\$100,548	(5)	15	\$349,511	(5)	20

Vacuum Vessel Fabrication Plan and Cost Study (D68)

Table of Contents

1. Introduction	1
1.1 Overview	1
1.2 Vessel Description	1
2. Task Scope	2
3. Vacuum Vessel Basis	4

Part A	Vacuum Vessel Fabrication Assessment
Part B	Vacuum Vessel Assembly Plan
Part C	Cost Estimate
Part D	Assessment of Type 316LN Stainless Steel as Alternative Vacuum Vessel Material

Appendix 1	Raytheon/CB&I Supplementary Vessel Design Sketches
Appendix 2	ITER Garching Joint Work Site Memo (Draft #9)

1. Introduction

1.1 Overview

ITER Task No. 8, Vacuum Vessel Fabrication Plan and Cost Study (D68), was initiated to assess ITER vacuum vessel fabrication, assembly, and cost. The industrial team of Raytheon Engineers & Constructors and Chicago Bridge & Iron (Raytheon/CB&I) reviewed the current vessel basis and prepared a manufacturing plan, assembly plan, and cost estimate commensurate with the present design.

The guidance for the Raytheon/CB&I assessment activities was prepared by the ITER Garching Work Site. This guidance provided in the form of work descriptions, sketches, drawings, and costing guidelines for each of the presently identified vacuum vessel Work Breakdown Structure (WBS) elements was compiled in ITER Garching Joint Work Site Memo (Draft #9 - G 15 MD 01 94-17-05 W 1). A copy of this document is provided as Appendix 1 to this report.

Additional information and clarifications required for the Raytheon/CB&I assessments were coordinated through the US Home Team (USHT) and its technical representative. Design details considered essential to the Task 8 assessments but not available from the ITER Joint Central Team (JCT) were generated by Raytheon/CB&I and documented accordingly.

1.2 Vessel Description

The ITER vacuum vessel is the mechanical structure of the ITER machine that:

- provides a boundary suitable for maintaining an ultra-high vacuum,
- provides the structural support for all internal components, and
- establishes the first safety confinement barrier for the ITER fusion reactor.

The vessel is designed to resist all credible loads including dead weight, equipment loads, pressure loads, plasma disruption electromagnetic forces, forces resulting from vertical displacement events, and other postulated event loadings without a loss of confinement.

The vacuum vessel is a double walled toroidal shell structure joined by poloidal ribs. The volume between the shell walls is filled with stainless steel shield balls and provides the flowpath and containment for the vessel coolant. Horizontal ports are located at the vessel midplane and lower regions. Vertical ports are located in the top region. Gamma radiation and neutron shielding comprised of lead and boron carbide (Pb/B₄C) enclosed in stainless steel is installed on the vessel exterior.

The vessel fabrication basis for this report as identified by the ITER design team requires that the vessel be fabricated in twenty four (24) segments using fully welded Inconel 625 plates. Inconel 625 is the trade name for Alloy 625, the generic designation for the nickel-chromium-molybdenum-columbium (niobium) alloy (UNS N06625).

2. Task Scope

The scope of the ITER Task No. 8 Vacuum Vessel Fabrication Plan and Cost Study (D68) requires the:

- assessment of manufacturing feasibility of the vacuum vessel,
- development of manufacturing and assembly plans,
- generation of a cost estimate for the baseline vessel, and
- evaluation of Type 316LN austenitic stainless steel (316LN SS) as an alternative vessel material.

The results of the Raytheon/CB&I assessments are presented in five sections. This initial section summarizes the vacuum vessel design basis utilized in the subsequent assessments. Table 1 identifies the ITER design documents and design data received from the JCT and the USHT. Table 2 summarizes the supplementary design sketches prepared by Raytheon/CB&I to support the manufacturing plan, assembly plan, and the cost estimate. Table 3 presents a detailed compilation of the vessel fabrication basis by WBS element number.

Part A - Vacuum Vessel Fabrication Assessment

Part A presents an overall assessment of the vacuum vessel fabrication. Generic issues associated with Alloy 625 material availability, sizing and forming, machinability, weldability, heat treatment, and use in vacuum service are discussed.

A vessel shell segment manufacturing plan is presented. Topics addressed within the plan include:

- shop manufacturing sequence,
- ASME Code compliance,
- major equipment and fixturing,
- weld joint details and welding processes,
- shield ball procurement and installation,
- maintenance of subassembly tolerances,
- segment inspection and testing activities, and
- the manufacturing of the external lead and boron carbide (Pb/B4C) gamma shielding.

A manufacturing summary discussion is also provided.

Part B - Vacuum Vessel Assembly Plan

Part B presents a basic field assembly plan. A general assembly overview is provided as well as specific assembly steps to identify the various activities associated with pre-assembly preparations, segment and port fit-up, shield ball installation, and vessel assembly testing. Structural analyses performed to approximate vessel segment stress distributions and deformations during handling are also described.

Part C - Vacuum Vessel Cost Estimate

Part C presents the cost estimate for the fabrication and assembly of the vacuum vessel. Shop fabrication and field assembly activities are identified and costed for each vessel subsystem in accordance with the JCT Work Breakdown Structure (WBS) categories. Material quantities are summarized and likewise costed for each WBS element. Data is presented in a spreadsheet format. Estimating uncertainties associated with material quantities and/or costs are expressed as percentages.

Part D - Assessment of Type 316LN Stainless Steel as Alternative Vacuum Vessel Material

Part D presents a comparative assessment of Type 316LN stainless steel to the baseline Alloy 625 vessel material. Similarities and differences in manufacturing processes are presented. Potential effects on vessel costs are identified. An overall assessment summary and recommendations is provided.

3. Vacuum Vessel Basis

The ITER Task No. 8 assessment basis was initially provided in the ITER Garching Joint Work Site Memo (Draft #6 - G 15 MD 01 94-17-05 W 1) dated 5/17/94. This information was later supplemented with an ITER Garching Joint Work Site Memo (Draft #9 - G 15 MD 01 94-17-05 W 1) dated 9/20/94. The ITER documents were reviewed and supplementary design information, details, and clarifications were obtained (as available) from the JCT via the USHT technical representative. A listing of all JCT and USHT documents used in the ITER Task No. 8 Vacuum Vessel Fabrication Plan and Cost Study (D68) assessments is provided in Table 1.

Table 1: ITER Documents Supplied by JCT & USHT

Ref. No.	Document Title
1	ITER Garching Joint Work Site Memo Draft #9, Ref. N. G 15 MD 01 94-17-05 W1, G. Johnson and K. Ioki to D-68 Task Officers, Subject: Vacuum Vessel Fabrication Plan and Cost Study (Task D-68) - Detail Guidance, dated 20 September 1994
2	ITER Joint Work Site Telefax Message, K. Ioki and G. Johnson to B. Nelson, Subject: D68 Specification Changes, dated 28 November 1994
3	ITER Garching Joint Work Site Memo, G. Johnson to B. Nelson, Subject: D68 Questions from John Swanson, dated 2 December 1994 Associated References E-Mail Messages: <ul style="list-style-type: none"> • J Swanson to B. Nelson 21 November 1994 • B Nelson To G. Johnson 23 November 1994
4	San Diego Joint Work Site Telefax, F. Puhn to R. Aymar, R. Iotti, R. Parker, M. Huguet, Subject: Tokamak Assembly Draft Summary Document, dated 20 September 1994
5	ITER Task No. 16 Assembly Plan Development (D28) Task Report, RE&C/SW No. ITER-SW-4008C, Gravity Support and Mechanical Structure Preassembly and Assembly Plan Development, December 1994
6	(Draft) ITER Design Assessment -01, Introduction and General Requirements, Presented at Engineering Design Assessment Meeting San Diego - JWS 27 October 1994
7	(Draft) ITER Design Assessment -02, Design Outline JCT, Presented at Engineering Design Assessment Meeting San Diego - JWS 27 October 1994
8	Technical & Quality Classifications, S 74 CD03 2 94-06-27 W D1
9	ITER Joint Work Site Telefax Message, K. Ioki and G. Johnson to B. Nelson, Subject: SS Vessel Material Alternative, dated 26 October 1994
10	E-Mail Message, G. Johnson to B. Nelson, Subject: Answers to Questions on D-68, dated 5 October 1994

In addition to the information supplied by the JCT, numerous supplementary sketches were prepared to support the Raytheon/CB&I assessments. These sketches were generated to either depict specific details not included within the JCT supplied documents or to describe the fabrication concepts presented within this report. A summary of all Raytheon/CB&I initiated design sketches is provided in Table 2.

Table 2: Raytheon/CB&I Supplementary Sketches

Sketch. No.	Date	Sketch Title
SK1001	01/10/95	15° Segment with Ports and Blanket Supports
SK1002	01/10/95	15° Segment Assembly Isometric
SK1003	01/10/95	Vertical Port Cover & Inner Port Extensions
SK1004	01/10/95	15° Vessel Segment Outer Shell Closure Plates
SK1005	01/10/95	Vessel Segment Assembly Isometric Outer Shell Removed
SK1006	01/10/95	15° Segment Rib Assembly
SK1007	01/10/95	Vessel Rib Details
SK1008	01/10/95	Inner Shell Development
SK1009	01/10/95	Elevation Vessel Shell with Ports
SK1010	01/10/95	Vessel Shell Plan & Elevation
SK1011	01/10/95	Vessel Shell Profiles
SK1012	01/10/95	Vessel Shell Typical Weld Details
SK1013	01/10/95	Assembly of (3) 15° Segment
SK1014	01/10/95	Field Closure Joint Detail
SK1015	01/10/95	Port Connection & Weld Details
SK1016	01/10/95	Port Structure Shield Door
SK1017	---	(Drawing Not Used)
SK1018	01/10/95	Blanket Support Details
SK1019	01/10/95	Typical Support Lugs Upper & Lower
SK1020	01/10/95	Section Thru Horizontal Port - 3 Segments

The combination of JCT/USHT documents and Raytheon/CB&I design sketches identified in Tables 1 and 2 respectively, has formed the basis for all Task No. 8 assessments and detailed cost estimates. Table 3 lists these bases by WBS component.

Table 3: Vessel Manufacturing, Assembly, and Cost Basis

WBS No.	WBS Name	Component/Item	Manufacturing/Cost Basis	*References
15	Vacuum Vessel			* - see note below
15.A	Vacuum Vessel Main Assembly	General	<ul style="list-style-type: none"> • (24) 15° vessel segments complete with top, middle, and lower ports • "Plain sector field joint" option used as base case (i.e. single field weld at outer shell & closure plate with (2) welds at inner shell) • Shell plate thickness tolerance -0.3 mm and +1.8 mm (mill std.) • GTAW root and cover passes at exposed vacuum surfaces. Fill passes with alternate process. • Alloy 625 material • ASME B&PV Code Section III Class 2 (N-Stamp not required) • Vessel segment leak rate 1×10^{-9} std. cc/sec 	SK1001 SK1014 & Section A.4.4 Table 1 - Reference 2 See Sections A.3.4 and A.4.4 Table 1 - Reference 3 & A.4.2
15.A.01	Inner & Outer Shell	General	<ul style="list-style-type: none"> • Sector height tolerance revised from ± 20 mm to ± 30 mm • Sector width tolerance ± 20 mm • Vessel segment testing conducted both before and after installation of shield balls 	See Section A.4.6 See Section A.4.7

* (Note: Primary Fabrication/Cost Basis Provided in ITER Garching Joint Work Site Memo Draft #9 (see Appendix 2) - Additional References Noted as Applicable

Table 3: Vessel Manufacturing, Assembly, and Cost Basis

WBS No.	WBS Name	Component/Item	Manufacturing/Cost Basis	*References
15.A.01 (Cont'd)	Inner & Outer Shell (Cont'd)	Inner Shell	<ul style="list-style-type: none"> • Wall thicknesses 3 cm and 4 cm • 2 to 3 facet design revised to double curvature forming to minimize shell welds • Full penetration double groove welded joints - NDE: Radiography or Ultrasonic 	See Section A.3.2 See Sections A.3.5, A.4.4 & A.4.8
		Ribs	<ul style="list-style-type: none"> • Plate thicknesses 3 cm • Full penetration single groove welded joints - NDE: Liquid Penetrant 	See Sections A.3.5, A.4.4.4 & A.4.8
		Outer Shell	<ul style="list-style-type: none"> • Wall thicknesses 3 cm and 4 cm • 2 to 3 facet design revised to individual rib compartment closure plates • Full penetration single double corner groove welded joints - NDE: Ultrasonic 	SK1004 See Section A.3.5, A.4.4, and A.4.8
15.A.02	Leak Detection System	Cover Plates, Piping, & Cryostat Feedthroughs	<ul style="list-style-type: none"> • Design not sufficiently developed to permit inclusion at this time 	
15.A.03	Shielding for Vacuum Vessel	Shield Balls	<ul style="list-style-type: none"> • Inner/outer shell volume filled with 20 mm diameter Type 304 stainless steel balls • Al₂O₃ coating (availability of coating uncertain) • Shield balls installed through holes in outer shell subsequent to initial testing - segment rotated in shop during shield ball installation 	See Section A.4.5

• (Note: Primary Fabrication/Cost Basis Provided in ITER Garching Joint Work Site Memo Draft #9 (see Appendix 2) - Additional References Noted as Applicable)

Table 3: Vessel Manufacturing, Assembly, and Cost Basis

WBS No.	WBS Name	Component/Item	Manufacturing/Cost Basis	*References
15.A.04	Cooling Piping	Cooling Loop Piping	<ul style="list-style-type: none"> Piping (Type 304 SS) extends 5m - 7m from vessel shell to cryostat (expansion bellows, expansion loops, & seismic supports not included in design basis) (12) Vessel segment cooling loops (1 per vessel segment pair) (12) Port extension cooling loops (1 per 6 port extensions) 300 mm inside diameter supply and return piping for (2) vessel segments connected in series 50 mm inside diameter supply and return piping for (6) inner port extensions connected in series (48) 8" & (48) 3" dia. outer shell nozzles 	Reference 10
15.A.05	Wall Conditioning System	All Components	<ul style="list-style-type: none"> Cooling system piping identified in WBS 15.A.04 suitable for wall conditioning - no additional cost components identified at this time 	

* (Note: Primary Fabrication/Cost Basis Provided in ITER Garching Joint Work Site Memo Draft #9 (see Appendix 2) - Additional References Noted as Applicable

Table 3: Vessel Manufacturing, Assembly, and Cost Basis

WBS No.	WBS Name	Component/Item	Manufacturing/Cost Basis	*References
15.B	Port Assemblies	General	<ul style="list-style-type: none"> Port & bellows height and width tolerance revised from ± 2 mm (Tolerances to be within $\pm 0.4\%$, but not less than ± 2 mm) Field joint leak detection system design not sufficiently developed to permit inclusion at this time Alloy 625 material - all components ASME B&PV Code Section III Class 2 (N-Stamp not required) Shell plate thickness tolerance -0.3 mm and $+1.8$ mm (mill std) Vessel segment leak rate 1×10^{-9} std. cc/sec. 	See Section A.4.6 See Section A.4.6
15.B.01	Port Structures	Port Structure at Vessel	<ul style="list-style-type: none"> Wall thickness 5 cm 	
		Top port	<ul style="list-style-type: none"> Cover plate of double wall design Wall thicknesses 3 cm Two chimneys Assessment interface defined at top of port chimney - (blanket cooling piping, bellows, supports, etc. not sufficiently developed to permit inclusion at this time) Full penetration double groove welded joints - NDE: Radiography or Ultrasonic 	SK1003 See Section A.4.4

* (Note: Primary Fabrication/Cost Basis Provided In ITER Garching Joint Work Site Memo Draft #9 (see Appendix 2) - Additional References Noted as Applicable

Table 3: Vessel Manufacturing, Assembly, and Cost Basis

WBS No.	WBS Name	Component/Item	Manufacturing/Cost Basis	*References
15.B.02	Port Extensions	Inner Port Extension at Middle & Lower Ports	<ul style="list-style-type: none"> Double wall design (1m to 2 m length from vessel interface) Inner wall thickness 5 cm Stiffening rib thickness 3 cm Outer wall design 1 cm Water cooled without shield balls Full penetration double groove welded joints at inner wall - NDE: Radiography or Ultrasonic Full penetration single groove welded joints at ribs to inner wall - NDE: Liquid Penetrant Single groove welded joints at ribs to outer shell - NDE: Ultrasonics 60 cm water cooled shield door with (24) 10 cm diameter holes pipe penetrations - Alloy 625 material 	SK1009 & Table 1-Ref. 3 SK1015 SK1016
		Outer Port Extension at Middle & Lower Ports	<ul style="list-style-type: none"> Single wall design 5 to 7 m length to cryostat penetration Wall thickness 5 cm Full penetration double groove welded joints - NDE: Radiography or Ultrasonic 	Table 1 - Reference 10
15.B.03	Port Bellows Assemblies	Middle & Lower Ports	<ul style="list-style-type: none"> Wall thickness 2-3 mm Bellows length 1.5 m Bellows provided at middle and lower ports only 	
15.B.04	Special Access Ports & Bellows Assemblies	Instrumentation Ports	<ul style="list-style-type: none"> (3) 2 cm diameter pipe penetrations per segment NBI ports design not sufficiently developed to permit inclusion at this time 	

* (Note: Primary Fabrication/Cost Basis Provided in ITER Garching Joint Work Site Memo Draft #9 (see Appendix 2) - Additional References Noted as Applicable)

Table 3: Vessel Manufacturing, Assembly, and Cost Basis

WBS No.	WBS Name	Component/Item	Manufacturing/Cost Basis	*References
15.C	Support Structures		All components Alloy 625 material	
15.C.01	Blanket to VV Support	Sliding Supports	<ul style="list-style-type: none"> • Sliding support concept • Water cooled • Integral with ribs at inside of inner shell • 3 cm stiffener thickness • 25 cm machined forging or weldment at interface with blanket support • (96) total support locations (48 inboard & 48 outboard) • Single combined (2) support structure at inner shell (24 total structures) • Individual supports at outboard location (48 total structures) 	SK1001, SK1018
15.C.02	VV to Mechanical Structure	Vessel Attachments	<ul style="list-style-type: none"> • Each support consists of a pair of 3 cm thick plates coincident with ribs and field welded to outside of outer shell • (96) total support locations (48 upper & 48 lower) • (2) individual supports per segment at upper location • (2) individual supports per segment at lower location 	SK1002, SK1009
15.C.03	Diverter to VV Support	Diverter Support Bars	<ul style="list-style-type: none"> • (2) 12 cm x 12 cm square bars welded to inner shell at bottom in field (bars extend to 2 segments) • Final machining to interface with diverter (by others) 	

* (Note: Primary Fabrication/Cost Basis Provided in ITER Garching Joint Work Site Memo Draft #9 (see Appendix 2) - Additional References Noted as Applicable

Table 3: Vessel Manufacturing, Assembly, and Cost Basis

WBS No.	WBS Name	Component/Item	Manufacturing/Cost Basis	*References
15.D	Additional Pb/B4C Shielding for TF Coils			
15.D.01	Pb/B4C Shielding	Shielding Panels	<ul style="list-style-type: none"> • 30 mm thickness around vessel exterior • 50 mm thickness around port exterior • B4C to Pb ratio is 2/3 by volume • Fabricated in stainless steel box panels (2 mm thk. Type 304 SS) • Overall size 500 mm x 2500 mm divided into 5 compartments • Panel pre-formed to conform to vessel outer shell surface 	See Section A.4.10
15.D.02	Shielding Support Structure		<ul style="list-style-type: none"> • Field welded studs to vessel exterior (10 studs per panel) 	
15.E	Assembly and Special Fixtures			
15.E.01	Assembly Fixtures		<ul style="list-style-type: none"> • Jigs and Fixtures for shop fabrication activities • Remote handling fixtures (by others) 	See Section A.4.3
15.E.02	Alignment Fixtures		<ul style="list-style-type: none"> • Jigs and fixtures for field assembly 	See Section A.4.3 & B.4

* (Note: Primary Fabrication/Cost Basis Provided in ITER Garching Joint Work Site Memo Draft #9 (see Appendix 2) - Additional References Noted as Applicable

Table 3: Vessel Manufacturing, Assembly, and Cost Basis

WBS No.	WBS Name	Component/Item	Manufacturing/Cost Basis	*References
15.F	Vacuum Vessel Assembly and Testing at the Site			See Part B - Vacuum Vessel Assembly Plan
15.F.01	Vacuum Vessel Main Assembly		<ul style="list-style-type: none"> • Assembly mockup prior to placement of segments in TF coils not assumed • Final vessel segment assembly • Rotating vessel (fixture by others) • Vessel segment welding • Vessel inner port extension welding • Installing shield balls in field joints • Field joint sector tests and inspections 	See Section B.4.1
15.F.02	Port Assemblies		<ul style="list-style-type: none"> • Final fit-up and assembly of middle and lower port bellows and outer port extensions • Welding port bellows and outer port extensions • Port extension tests and inspections • Port bellows tests and inspections 	
15.F.03	Support Structure Assembly		<ul style="list-style-type: none"> • Final fit-up and assembly of divertor support structures in vessel • Welding of divertor supports • Fit-up and welding of vessel to mechanical structure supports 	
15.F.04	Additional Pb/B4C Shielding Assembly		<ul style="list-style-type: none"> • Welding of support studs on vessel exterior • Final fit-up and assembly of shield panels on vessel exterior 	

* (Note: Primary Fabrication/Cost Basis Provided in ITER Garching Joint Work Site Memo Draft #9 (see Appendix 2) - Additional References Noted as Applicable)

Part A**Vacuum Vessel Fabrication Assessment****Table of Contents**

A.1. Introduction.....	1
A.2. Scope.....	1
A.3. Alloy 625 Material Assessment	2
A.3.1 Availability and Mill Surface Finish	2
A.3.2 Forming	2
A.3.3 Sizing and Machining	3
A.3.4 Weldability.....	4
A.3.5 Nondestructive Examination (NDE)	5
A.3.6 Heat Treatment	5
A.3.7 Vacuum Service Applicability.....	6
A.3.8 Summary & Recommendations	7
A.4. Manufacturing Plan.....	8
A.4.1 Manufacturing Sequence	8
A.4.2 ASME B&PV Code Compliance	13
A.4.3 Major Equipment and Fixturing.....	13
A.4.4 Weld Joint Details and Welding Processes.....	13
A.4.5 Shield Gas Procurement and Installation	16
A.4.6 Subassembly Tolerances	16
A.4.7 Segment Testing	17
A.4.8 Inspection Activities	18

Part A

Vacuum Vessel Fabrication Assessment

Table of Contents (Cont'd)

A.4.9 Pb/B4C Shielding	18
A.4.10 Manufacturing Summary and Recommendations.....	20

List of Figures:

Figure 1: Manufacturing Sequence Overview

A.1. Introduction

The Raytheon/CB&I fabrication assessment of the ITER vacuum vessel has focused on two principle aspects of the vessel manufacturing:

- evaluating Alloy 625 as a suitable material and
- developing a suitable manufacturing plan.

This **Part A - Vacuum Vessel Fabrication Assessment** provides an overall evaluation of the ITER JCT selected Alloy 625 material by investigating and discussing those processes considered applicable to the vessel manufacture. Using the vessel design basis established previously in this report (**Table 3: Vessel Manufacturing, Assembly, and Cost Basis**), a reasonable manufacturing plan commensurate with the current vessel design has been developed.

The various assumptions and sketches prepared by the Raytheon/CB&I Team for this assessment are not intended to depict a final manufacturing configuration nor are they intended to necessarily represent the most cost effective of all available alternatives. The purpose of these sketches is to provide a better defined basis for the broad scope of the Vacuum Vessel Fabrication Plan and Cost Study (D68) assessment. (The depicted weld joint details, for instance, represent the use of a conventional rather than a more advanced welding approach.) As the vessel design progresses, this manufacturing assessment must be revised accordingly to reflect additional manufacturing issues associated with the complexity of the ITER machine.

A.2. Scope

Part A - Vacuum Vessel Fabrication Assessment presents a manufacturing assessment of the ITER vacuum vessel as defined in the ITER Garching Joint Work Site Memo (Draft #9 - G 15 MD 01 94-17-05 W1) and supplemented by various Raytheon/CB&I assumptions. The vessel design basis is identified in the previous **Section 3. - Vacuum Vessel Basis**.

Important fabrication issues associated with Alloy 625 availability, forming, sizing and machining, weldability, nondestructive examination, heat treatment, and use in vacuum service are discussed. A vessel segment manufacturing plan is presented. Topics addressed within the plan include:

- a proposed shop manufacturing sequence,
- ASME B&PV Code compliance,
- major equipment and fixturing,
- welded joint details and welding processes,
- shield ball procurement and installation,
- the maintenance of subassembly tolerances,
- segment testing, and inspection activities, and
- the manufacturing of the external Pb/B4C gamma shielding.

A manufacturing summary and recommendations section is also presented.,

A.3. Alloy 625 Material Assessment

The generic issues associated with Alloy 625 material availability, sizing and forming, machinability, welding, heat treatment, nondestructive examination, and use in vacuum service as they may apply to the ITER vacuum vessel are presented in this Section. A manufacturing plan and discussions of specific manufacturing issues are presented in Section A.4.

A.3.1 Availability and Mill Surface Finish

The estimated quantity of Alloy 625 material required to fabricate the vacuum vessel is on the order of 6700 metric tons. This consists primarily of 10 mm to 50 mm plate with some quantities of 120 mm by 120 mm bar needed for the fabrication of the divertor to vessel supports. Other Alloy 625 material components include the 1.5 m port bellows assemblies, miscellaneous piping and feedthroughs, and possibly special forged components for the internal blanket supports (see SK1001 and SK1018 in Appendix 1).

Preliminary discussions with material suppliers indicate that Alloy 625 plate, bar, and components are available in the required thicknesses, quantities, and shapes. Fabricated specialty items such as the formed bellows for the ports are also expected to be available. Material delivery schedules will have to be established well in advance of manufacturing operations to ensure appropriate inventories at the manufacturing facility. Present mill delivery of plate material is estimated at 6 to 30 months.

Achievable mill surface finishes for the vessel sheet and plate material are on the order of a No. 4 finish (381-635 micro mm). This finish is typically specified and provided for vessels supplied for food processing applications. The ITER design basis (Table 1 Reference 2) has specified a surface roughness for those vessel component surfaces exposed to vacuum service both internal (plasma side) and external (cryostat) be no greater than a 6.3 micro-mm finish. This requirement is presently not obtainable using standard mill surface finishing operations and may only be obtainable via the use of post mill operations. Section A.3.7 presents additional comments related to the vessel material surface finish requirements.

A.3.2 Forming

The currently proposed vessel cross section geometry is not expected to be limiting to manufacturing although it must be recognized that the specification of the complex curvature (multiple non-coincident curvature radii) in the top, bottom, and outboard regions of the vessel will require numerous forming operations (See SK1011). The engineering, design and fabrication of press dies should be considered in the overall vessel manufacturing cost.

Alloy 625 material is generally adaptable to either cold or hot forming methods. Cold forming of the inner and outer shell segments with a minimum of machining is expected to be sufficient to achieve the overall ITER vessel cross section.

The relatively large bend radii of the ITER vacuum vessel are achievable for the specified vacuum vessel material thicknesses. These radii are approximately equal to those attainable for the austenitic stainless steels and should permit cold forming process to be used for the shell plates, port structures, and port extensions.

In the fabrication of the inner vessel shell the forming of the double curvature of the shell (i.e. poloidally and toroidally) is preferred to welding multiple poloidal shell facets. Press forming minimizes machining of weld preparations and associated welding and NDE costs as well as elimination of excessive weld shrinkage, and thereby improves control of shell cross section distortion.

Individual plates for the vessel shells and ribs will be oversized as necessary to maintain the specified overall vessel shape and dimensions after forming and welding. Plate used to formed segments will be thicker as required to maintain the minimum specified shell thicknesses after forming.

The relatively high yield and ultimate tensile strengths of Alloy 625, 55 ksi minimum and 110 ksi maximum at room temperature respectively, will generally require the use of alloy tool steels for forming dies. Rapid strain hardening which is characteristic of high nickel alloys such as Alloy 625, will tend to further increase the material yield stress and proportional limit. As a result it can be expected that 30 to 50% more power is required for Alloy 625 forming as compared to mild steel with the majority of the forming operations performed at relatively slow speeds. This requirement however, is well within the present capabilities of press forming equipment available in the facilities of experienced fabricators. Material springback is expected and must be considered in the attainment of the final formed shape.

Alloy 625 like other high nickel alloys tends to gall easily to materials of similar atomic diameter. Forming operations therefore, will require the use of lubricants to prevent cold welding and the rapid wear of the forming dies. All traces of selected lubricants must be removed during the final cleaning processes to preclude welding problems from contamination and ensure compatibility with high vacuum service.

A.3.3 Sizing and Machining

Machining operations required for the manufacture of the vacuum vessel are expected to include cutting, grinding, milling, and drilling. All such operations are conducted regularly by experienced Alloy 625 fabricators. As previously noted rapid strain hardening during working is expected, however, the use of sharp tools with positive rake angles and the establishment of appropriate feed rates and cut depths should permit all required operations to proceed efficiently. The starting hardness of Alloy 625 is typically 85 Rockwell B as compared to the typical 80 Rockwell B starting hardness of Type 316 SS.

Most cutting operations for the shell plates are expected to be performed using the plasma arc cutting process which will remove metal by localized melting and vaporization with high temperature, high velocity ionized gas. Numeric controls will be

utilized to direct the cut characteristics to achieve accuracy and to minimize the heat affected zone at the cut edges. Weld end preparations will be machined subsequent to cutting.

Abrasive water jet cutting is expected to be used for the cutting of rib material where applicable. The use of numerically controlled multiple cutting heads will increase the efficiency and accuracy of the cuts without concerns about heat effects. Weld edge preparations may be cut simultaneously or machined separately as appropriate.

Grinding processes similar to those used for steels are suitable for use with Alloy 625. Rough grinding with adequate time for the material to cool to room temperature followed by a fine grind can be employed. Aluminum oxide wheels or abrasive belts coated with aluminum oxide are expected to be used for surface grinding applications such as at weld joints.

Milling operations, where required to achieve a specified configuration, maintain tolerance and/or achieve specified surface finishes, will generally employ high helix type, high speed steel cutters. Nominal feed rates are expected to vary from 1.5 to 5 meters per minute. Milling operations are expected to be required for the manufacturing of the internal blanket supports, external mechanical structure supports, and in the vicinity of the port structures.

Drilling with conventional heavy duty high speed heavy web drills, crankshaft drills, and spade drills will be used for Alloy 625 material. Steady feed rates, rigid setup, and overall good drilling practices will enable required drilling to proceed without difficulty.

A.3.4 Weldability

All manual and automatic, conventional and most advanced welding processes utilizing either inert gas and flux shielding are suitable for use on Alloy 625. The weldability of Alloy 625 is fully characterized for 5 cm to 8 cm thick sections and does not introduce any welding concerns to experienced fabricators. Recently completed studies by one major supplier has demonstrated satisfactory weldability in plate 10 cm thick and additional welding development work was done by others also in the 8 cm to 10 cm inch thickness range. Alloy 625 has been used widely as a material of construction in thick welded commercial and military nuclear applications, as well as in fabrications of other nonmagnetic heavy components and vessels.

Welding filler metals are readily available and successfully used in Alloy 625 welding applications. Alloy 625 welding procedures are similar to those used for stainless steel. Preheating is not generally required for high nickel alloys such as Alloy 625 however, the base metal temperature prior to the start of welding should not be less than 10 °C (50°F) to avoid the formation of condensate that potentially cause porosity in the weld deposit.

Cleanliness is an important requirement for the successful welding of Alloy 625. At the high weld temperatures Alloy 625 like other nickel alloys is susceptible to embrittlement

by sulfur, phosphorus, lead, and other low-melting point substances. Weld beads should generally have a slightly convex contour.

Welding fabrication experience presently exists for Alloy 625 in fusion specific welded vacuum vessels. These include the DIII, DIII-D, and the JT60 (65 mm wall thickness) vessels. Alloy 600, a lower strength nickel base material, of similar weldability, was used in the double walled JET design involving shells thicknesses of 12 mm to 20 mm. Common to all of the noted fusion vessels was the use of inert gas shielded welding processes except for JT60 which was electron beam (EB) welded in a hard vacuum environment.

A.3.5 Nondestructive Examination (NDE)

Nondestructive examination (NDE) techniques such as radiography (RT), ultrasonics (UT), dye or liquid penetrant (PT), and visual have been applied widely on Alloy 625 weld joints. Conventional RT and UT techniques used for ferritic material welds are not directly applicable to welds of austenitic and high nickel alloys such as Alloy 625 therefore, it will be necessary to utilize special procedures/techniques. UT application on Alloy 625 welds is sufficiently developed and is not considered limiting for internal weld examination. UT and RT were both used on the 65 mm thick Alloy 625 welds in JT60. Additionally, UT is often used exclusively on certain critical austenitic and nickel base alloy weldments in nuclear and military applications.

The ITER specification identified that the inner and outer shell welds be RT inspected and that rib to inner and outer shell welds be PT inspected only. Outer shell joint details presented in the Raytheon/CB&I sketches are not suitable for RT, since after shell closure the back side of the joint is inaccessible for film placement. At these weld locations UT examination will be required to accomplish internal volumetric weld examination. Acceptance criteria for the UT examination will be as required by the ASME Code and is considered equivalent to that specified for radiographic examination.

A.3.6 Heat Treatment

A post weld heat treatment (PWHT) to relieve stresses is not considered necessary for most welded Alloy 625 thick section applications. A major supplier of commercial weldments has indicated that weldments as thick as 3 inch are not given a PWHT. Additionally, as discussed in more detail in Section A.3.7 conventional post weld heat treatments, typically 899 °C (1650 °F) can cause material property changes in the as-supplied Alloy 625.

A.3.7 Vacuum Service Applicability

The suitability of high nickel alloys such as Alloy 625 and Alloy 600 (UNS NO6600) in vacuum service, as discussed previously, has been demonstrated in the DIII, DIII-D, and JT-60 (all Alloy 625) and JET (modified Alloy 600) machines. Metallurgical considerations that influence their performance for vacuum service are related to outgassing, and outgassing operations such as baking, and leakage rate requirements.

Alloy 625 has limitations with respect to an acceptable baking temperature cycle. This is due to metallurgical changes experienced by Alloy 625 when heated in the 538 °C (1000 °F) to 1093 °C (2000 °F) range. When held in this range for periods exceeding 10 hours, the alloy precipitates phases which causes age hardening (strength increases and ductility decreases). Moreover, even short times in this range cause carbides to precipitate in the grain boundaries which ultimately form a continuous grain boundary film. This elevated temperature exposure essentially alters the properties of the material.

The temperature limitation on Alloy 625 of 538 °C (1000 °F) maximum to avoid metallurgical changes and degradation, therefore limits baking operations accordingly. Other in-vessel outgassing options such as glow discharge cleaning will not affect the material metallurgically.

Dissolved gas contents of the materials supplied from the mill also need to be addressed. For wrought product forms, the double vacuum melting method (vacuum induction melting followed by vacuum arc remelting (VIM/VAR)) yields the lowest dissolved gas contents of available melting methods. It is assumed that weld wire heats will be at the same level of dissolved gases as plate.

In high vacuum applications, such as with the ITER vacuum vessel, the weld processes and shielding gas techniques that minimize gas pickup are recommended. In addition, welding joint designs that minimize weld volume, and optimize outgassing are preferred.

As previously discussed, mill supplied plate is limited to a ground and polished surface equivalent to a No. 4 finish which is significantly less than the specified 6.3 micro mm finish. One supplier reports that the same melting practices which reduce gas content facilitates polishing and an improved surface finish may be obtainable by special processing such as electropolishing as was done on JET.

A.3.8 Summary & Recommendations

In summary, the Alloy 625 material specified for the ITER vacuum vessel is considered readily available and should generally not present any significant manufacturing concerns to experienced Alloy 625 fabricators. The weldability of Alloy 625 material is fully characterized for plate sections in the 5 cm to 8 cm range and the overall manufacturability does not appear limiting with regard to the presently described vacuum vessel geometry.

Initial manufacturing considerations as the vessel design progresses include recommendations to:

- investigate double forming the vessel inner shell to eliminate the poloidal segment facet welds and thereby reduce distortions induced by weld shrinkage.
- consider UT, an accepted Code substitute for RT, for extended use particularly on built up segment assemblies. UT allows greater flexibility than RT with regard to in-situ application and requires less restrictive safety regulations.
- review the requirements associated with the specified vacuum surface finish of 6.3 micro mm. Such a finish, if achievable, will require post mill finishing operations that will increase manufacturing costs.

Additional discussions regarding these recommendations and others applicable to the specific vessel manufacturing plan are presented in Section A.4.10.

A.4. Manufacturing Plan

The manufacturing plan for the shop fabrication, assembly, and testing of the vessel segments is presented in this Section. This plan is consistent with the vessel fabrication basis documented in Section 3. - Vacuum Vessel Basis of this report.

A.4.1 Manufacturing Sequence

A shop manufacturing sequence overview for the vacuum vessel is provided in Figure A-1. As noted by the figure, the primary manufacturing operations include the following:

1. Prefabrication Planning and Procurement Activities
2. Shell Manufacture
 - Shell Segment Test
 - Shield Ball Installation
 - Shell Segment Re-test
3. Port Manufacture
 - Port Segment Test
 - Port To Vessel Fitup
4. Preparation for Shipment

Prefabrication Planning and Procurement

- Prepare contract specific quality assurance (QA) plan (as required)
- Prepare shop fabrication detail drawings.
- Identify and prepare/revise (as required) contract specific shop procedures for material handling, welding, NDE, forming, inspection, machining, etc.
- Conduct contract specific training of personnel.
- Engineer, design detail, and fabricate required forming dies, machining and welding fixtures, test stands, lifting fixtures, etc.
- Procure special equipment.
- Procure vessel materials.
- Procure middle and lower port bellows.

Figure 1: Manufacturing Sequence Overview

Shell Manufacture

(Note: Appropriate dimensional verifications, NDE, machining, grinding, etc. will be performed as necessary for each of the following activities)

1. Fabricate and form inner shell subassemblies exclusive of holes for top, middle and lower ports.
2. Fit and weld inner shell subassemblies to create 15° segment.
3. Fabricate, fit and weld rib subassemblies.
4. Fit and tack weld end ribs to inner shell.
5. Fit and tack weld as many as possible of the other remaining ribs to the inner shell (actual number of installed ribs to accommodate weld accessibility and sequence).
6. Establish vessel manufacturing and assembly control points using appropriate system for determining spatial coordinates.

7. Install shell framing fixture into inner shell (See Part B Figure B-2 of this report)
 - Framing fixture engineered and designed to provide:
 - rigidity during segment shop fabrication and handling,
 - restraint during shop welding operations,
 - attachment locations for temporary shop scaffolding, rigging, fixturing, etc.,
 - access to weld areas to permit required welding and NDE,
 - vacuum compatibility for use during helium mass spec testing,
 - rigidity during shipment and field assembly, and
 - reasonable removal through the vertical port at the completion of vessel assembly in the field.
8. Temporarily box stiffen inner shell and cut openings for (1) vertical and (2) horizontal ports.
9. Fabricate, form, fit, and tack weld port structures.
10. Fabricate, fit, and tack weld remaining ribs to inner shell.
11. Fabricate outer shell closure plates (holes provided in plates to permit shield ball installation within the inner/outer shell compartments).
12. Temporarily stiffen ribs (to control distortion and warping during welding operations).
13. Weld ribs to inner shell.
14. Perform preliminary fit-up of port structures and inner port extensions/vertical port cover.
15. Weld port structures to inner shell.
16. Fit, tack, and weld outer shell closure plates to ribs.
17. Machine and weld inner blanket support components.
18. Perform dimensional inspection.
19. Machine segment closure joint weld preps.
20. Cut and machine vessel (to mechanical structural) support lugs and blanket supports.

Shell Segment Test

1. Temporarily plug outer shell holes in preparation for shop testing
2. Perform the following tests:
 - water channel pressure test
 - water channel leak test (room temperature), and
 - water channel leak test (300°C).

Shield Ball Installation

1. Remove temporary plugs in outer shell closure plates and fill inner/outer shell compartment volumes with shield balls (rotate/tilt vessel during filling operations to provide maximum fill).
2. Weld permanent plugs into shield ball fill openings in outer shell closure plates.

Shell Segment Re-Test (after shield ball installation)

1. Perform the following tests (with shield balls installed):
 - water channel pressure test,
 - water channel leak test (room temperature),
 - water channel leak test (300°C), and
 - pressure drop and flow tests through cooling circuits.
2. Clean vessel segment in preparation for helium leak test.
3. Temporarily seal segment openings.
4. Perform helium leak test of inner wall.

Port Manufacture

(Note: appropriate dimensional verifications, NDE, machining, grinding, etc. will be performed as necessary for each of the following activities)

Inner Port Extension (middle and lower ports):

1. Fabricate and form inner shell subassemblies.
2. Fit, form, and tack weld inner shell subassemblies.
3. Perform preliminary fit-up of inner shell subassemblies to vessel port structures and bellows.
4. Weld inner shell subassemblies.
5. Fabricate, fit and weld rib subassemblies.
6. Fit and tack weld ribs to inner shell subassemblies.
7. Establish shop spatial coordinate control points.
8. Fabricate outer shell closure plates.
9. Temporarily stiffen ribs (to control distortion and warping during welding operations).
10. Weld ribs to inner shell subassemblies.
11. Fit and tack weld outer shell closure plates to ribs.
12. Confirm fit-up of inner port extension subassemblies with vessel port structure and bellows.
13. Weld outer shell closure plates to ribs.
14. Fabricate port shield door components.
15. Fit, tack, and weld port shield doors.
16. Fit-up port shield doors to inner port extension (machine as required).
17. Weld port shield door to inner port subassemblies.
18. Machine port closure field joint weld preps.

Outer Port Extension (middle and lower ports):

1. Fabricate and form shell.
2. Fit and tack shell subassemblies.
3. Perform preliminary fit-up of shell subassemblies to bellows.
4. Weld shell subassemblies.
5. Confirm fit-up of outer port extension with bellows.
6. Machine field joint weld preps.

Top Port Cover Plate:

1. Fabricate and form outer shell cover plate.
2. Perform preliminary fit-up of cover plate to vessel port structure.
3. Fabricate, fit and weld rib subassemblies.
4. Fit and tack weld ribs to port cover.
5. Fabricate inner shell closure plates.
6. Temporarily stiffen ribs (to control distortion and warping during welding operations).
7. Weld ribs to cover plate.
8. Fit and tack weld inner shell closure plates to ribs.
9. Weld inner shell closure plates to ribs.
10. Form and fabricate vertical chimneys.
11. Fit and tack chimneys to cover plate assembly.
12. Weld chimneys to cover plate assembly.
13. Confirm fit-up of cover plate assembly to vessel port structure.
14. Machine cover plate closure field joint weld preps.

Port Segment Tests**Inner Port Extensions for Middle and Lower Ports and Top Cover Plate**

1. Temporarily plug outer shell penetrations in preparation for shop testing
2. Perform the following tests:
 - water channel pressure test,
 - water channel leak test (room temperature), and
 - water channel leak test (300°C),
3. Clean port assembly in preparation for vacuum leak test.
4. Temporarily seal port openings.
5. Perform vacuum leak test of inner wall.

Outer Port Extensions for Middle and Lower Ports

1. Temporarily seal port openings.
2. Clean port assembly in preparation for vacuum leak test.
3. Perform vacuum leak test.

Preparation for Shipment

1. Clean vessel segment and ports as necessary.
2. Package and prepare segment for shipment.
3. Package and prepare ports for shipment.

A.4.2 ASME B&PV Code Compliance

The ITER design basis for the vacuum vessel specified compliance with the ASME Boiler & Pressure Vessel Code, Section III, Division 1, Subsection NC (i.e Class 2). Subsequent ITER Garching Work Site direction identified that N-stamping of the vessel is not required (Table 1 Reference 3).

Vacuum vessels are not specifically addressed in ASME Section III however, this does not preclude the use of the Section III requirements as a design and fabrication basis. Actual code adherence though, must consider the unique nature of the component design (double shell connected by ribs) and the service environment.

A.4.3 Major Equipment and Fixturing

Numerous major equipment items and fixtures will be required for the shop manufacturing and field assembly of the vacuum vessel components. A listing the required components is provided in the Part C - Cost Estimate.

A.4.4 Weld Joint Details and Welding Processes

The weld joint details used as the fabrication and cost bases presume that the presence of significant electromagnetic forces will require the development of full base metal stresses within the vessel shell. Complete penetration welds have been assumed as the vessel segment design basis. Accordingly, weld joint details have been prepared and are shown on SK1012, SK1014, and SK1015.

The development of full base metal stress in accordance with the requirements of the ASME B&PV Code and American Welding Society (AWS) Structural Welding Code requires assurance of complete penetration at the weld root opening. Various options for ensuring such penetration exist including the use of backing material, back gouging of the material and rewelding, or open root.

To achieve complete penetration at the root, considering the specific configuration and assembly requirements for the vacuum vessel, similar but slightly different weld details were identified for the various areas of the shells, shell closure sections, and ports. Where access to the root side of the joint is not possible, a joint design that allows root side inspectability to achieve the full design allowances as specified by the welding codes is required.

Distortion and shrinkage of the vessel welds (and its resultant effect on the maintenance of the specified assembly tolerances) particularly in the inner shell are expected to be major concerns during manufacturing and assembly. Minimizing inner shell welds by utilizing a combination of double curvature forming processes and maximum plate sizes will reduce weld induced distortions.

Actual manufacturing welding process selection is influenced by various factors including material type, thickness, component design and intended service specific requirements. A vessel of the size and complexity of the ITER vessel can be expected to utilize a combination of weld processes depending upon the type of weld joint, accessibility, and volumetric examination required. Both automated and manual welding are expected to be used during the actual vessel manufacturing.

As previously noted all conventional manual, automatic, and most advanced welding processes are suitable for use on Alloy 625. ITER specifications identified Gas Tungsten Arc Welding (GTAW) as the process to be used exclusively for the vessel and port welds. Considering the total weld length, vessel material thicknesses, welding positions, and conventional GTAW weld metal deposition rates, it is considered impractical to assume (even for the maintenance of cost comparison consistency) that only the conventional GTAW process will be used in an actual vessel manufacturing scenario.

Furthermore, an exclusive cost bases for GTAW could not be realistically extrapolated from the standard estimating criteria available from CB&I therefore, for costing purposes, manual GTAW is assumed for root passes and cover passes exposed to vacuum service and the shielded metal arc welding (SMAW) process has been assumed for fill passes. Although an actual vessel fabrication would consider more productive semiautomatic and automatic inert gas welding processes and narrow gap weld joint details the utilization of manual welding processes and conventional weld joint designs for preliminary cost estimating purposes assures a relatively conservative baseline.

It is recognized that GTAW process variations including semi automatic, conventional cold wire automatic, and hot wire automatic variations are available and as the vessel design develops these weld process alternatives should be reviewed for applicability. (All of the above noted processes are capable of increased productivity without sacrificing weld quality and/or properties. As an example, hot wire GTAW procedures have been developed specifically for thick section Alloy 625. These procedures allow the use of narrow gap weld joint designs that reduce weld volume and shrinkage and attain weld metal deposition rates equivalent to conventional gas metal arc (GMAW) welding.)

Vessel Inner Shell

The proposed vessel inner shell weld is a double side groove joint as shown in Detail D on SK1012. Since there is access to both sides of the vessel shell, the weld joints will be prepared using standard, available shop processes welding from both sides to minimize distortion due to weld shrinkage.

Poloidal Ribs

The welding of the poloidal ribs to the inner shell will typically utilize both the single and double groove weld joints as appropriate. In locations where access permits, the double groove type will be utilized to minimize distortion and residual stress concentrations resulting from weld shrinkage. Use of single groove joints will be limited

to vessel areas where access is limited to one side only. Typical weld details both open root type and with a backing bar are shown in Detail A on SK1012.

Vessel Outer Shell

The rib to outer shell fabrication basis presented in SK1002, SK1003, SK1004, SK1012, and SK1014 shows that the outboard edge of the poloidal ribs extend flush with the face of the outer shell in all areas except at the field closure joints. The extension of these ribs assist installation and alignment of the outer shell and also permit the use of single groove complete penetration welds, typically in a double groove corner configuration as depicted in SK1012. The alignment of plate segments will be accomplished by initially tack welding the plate segments in place and sequencing the weld operations to uniformly apply the root welds and subsequent passes.

Field Poloidal Weld Joints at the Vessel Segment Assembly Connections

Field welding of vessel segments is assumed to be accomplished from inside the vessel only. Initially the outer shells will be joined using a full penetration single groove weld. The poloidal weld joint for a typical vessel segment assembly is shown on SK1014. The poloidal ribs adjacent to the field welds do not penetrate the vessel outer shell. At these locations they will butt flush to the inner surface of the outer shell. In the shop during the manufacturing of the vessel segment, temporary gusset plates will be welded between the outmost rib and the outer shell to assist field alignment of the adjacent segments and control the free-edge distortion of the outer shell. These gussets will remain in place until after the completion of the segment assembly welds in the field.

After completion of welding and NDE of the outer shell weld joint, the inner shells will be joined using inner shell closure plates and a weld configuration similar to that employed in the shop for the outer shell closure plates to rib connections. The inner shell closure plates will be final fit in the field and welded in place using a single groove weld joints as shown in SK1014. (Backing bars may be optionally installed during shop manufacture per alternate detail on SK1014) Weld joint alignment and additional details are discussed in **Part B - Vacuum Vessel Assembly Plan**.

Port Welds

The double walled middle and lower inner port extensions are comprised of a 50 mm inner wall and a 10 mm outer shell. A typical port elevation is shown on SK1009. Weld joint details for the port structure at the interface with the vessel, as well as, the double walled port to port structure weld joint detail are provided on SK1015. As shown the port structure assembly welds and the field connection welds are predominately single groove joints.

Welding will be performed from inside the vessel as it is assumed that accessibility from the vessel exterior is not available. The welding of the 10 mm outer shell to the poloidal ribs utilizes a single groove weld that uses the rib edge to provide backing at the root opening. Should greater structural strength be required, a weld detail similar to used to weld the vessel outer shell to the poloidal ribs may be substituted in those regions.

The welding of the single walled bellows and the single walled outer port extension is assumed to be done from the outside, requiring single sided groove welds.

A.4.5 Shield Ball Procurement and Installation

Procurement

Discussions with various industrial contacts and suppliers has not identified any commercially available (i.e. off-the-shelf) source of aluminum oxide (Al_2O_3) coated stainless steel balls. It is therefore assumed that the procurement of the shield balls will require two activities, initial procurement of uncoated 20 mm stainless steel balls followed by an application of the aluminum oxide coating.

Preliminary discussions with vendors regarding the feasibility of coating the stainless steel balls with Al_2O_3 indicate that problems associated with the selection of a suitable coating process and the durability of the coating may be encountered. Stainless ball coating will therefore require additional investigation.

Installation

Installation of the shield balls subsequent to the performance of water channel testing requires multiple access holes in the outer shell closure plates. The outer shell closure plate details shown on SK 1004 indicates that a minimum of 1 access hole per outer shell closure plate is required to ensure access to all segment water channels not including the field closure joint. These access holes will be cut during the fabrication and forming operations prior to final closure plate to rib welding.

An access hole diameter of 7-8 cm is expected to permit satisfactory ball installation. Corrugated fill hoses connected to ball hoppers will be inserted through the access holes and each water channel will be filled with balls from the bottom up (similar to the process used when pumping concrete for foundations). The hose corrugations will permit maximum flexibility to reach the bottom of the channel and create resistance to reduce the vertical ball velocity during filling.

The vessel will be tilted and/or rotated as necessary to ensure uniform filling of the channels. The actual installed weight of balls within each compartment will be closely monitored during loading and compared with projected installed weights to attain reasonable assurance that an adequate fill has been achieved.

Closure plugs of the same thickness as the outer shell will be full penetration groove welded after the shield balls have been installed.

A.4.6 Subassembly Tolerances

The ITER specifications for dimensional tolerances have been evaluated for applicability to a vessel the size and magnitude of the proposed vacuum vessel. Review of the vessel configuration in combination with standard manufacturing

capabilities indicate that the specified tolerances for the vessel and port assemblies in particular instances are very limiting. A comparison of the specified tolerances with those presently considered achievable is provided below.

Component	ITER Specification	Achievable Basis
Vessel Sector Height	± 20 mm	± 30 mm
Vessel Sector Width	± 20 mm	± 20 mm
Port Component Height	± 2 mm	± 6 mm
Port Component Width	± 2 mm	± 6 mm
Shell & Port Plate Thickness	-0.3 mm and +1.8 mm	-0.3 mm and +1.8 mm
Port Bellows Thickness	± 0.1 mm	± 0.3 mm

A.4.7 Segment Testing

Vessel segment testing at the manufacturing facility as presently indicated in the manufacturing plan will be performed in two phases, initial testing of the segment prior to the installation of the shield balls and final testing of the segment after the installation of the shield balls. As noted in Section 4.5, the manufacture of the outer shell closure plates will incorporate access holes to provide the capability to install the shield balls subsequent to the initial tests. Temporary plugs will be installed to permit the pressure and leak testing of the water channels during these initial tests.

The specified initial and final vessel segment tests include a water channel pressure test, water channel leak test at room temperature, and a water channel leak test at 300°C. An additional pressure drop and flow test through the cooling circuits is specified during the final testing after shield ball installation.

Performance of the specified tests at the manufacturing facility is not expected to present any particular difficulties. The required test quantities to perform each segment test is estimated to be on the order of 40 m³ gas and water. Pumps, valves, and piping in addition to the required test medium must be considered in the test setup. Thermal insulation blankets in combination with electric and/or forced air heaters) will be used to raise and maintain the vessel segment temperature to the desired 300°C temperature for the duration of the elevated temperature tests. Potentially an temporary, portable oven may be used in lieu of the blankets and heaters.

Although not specified in the ITER Detail Guidance it is recommended that a gross vacuum leak test of the vessel segment inner shell and port structures be performed at the manufacturing facility. This leak test would be performed by temporarily sealing the vessel segment or port ends, evacuating the inner shell volume, and using helium in the inner-outer shell volume. Conventional helium leak detection techniques would be used to detect helium in-leakage.

A.4.8 Inspection Activities

In process inspection activities will be required throughout the manufacturing operations. These activities will typically be identical to the inspection activities required for nuclear or similar projects that require fabrication of large scale precision components with a high degree of quality. As identified within the manufacturing sequence, a contract specific Quality Assurance Plan will be prepared prior to the commencement of actual manufacturing activities. This plan will establish the minimum process quality standards and identify appropriate manufacturing inspection activities.

Receipt and inspection activities will focus on ensuring that proper certifications and documentation exist for all materials to be used in the manufacturing processes. Fabrication and forming processes shall be controlled to ensure that materials are not subject to deterioration during processing. Welding shall be performed in accordance with detailed written procedures qualified in accordance with ASME B&PV Code Section IX, to demonstrate that the specified mechanical properties are achieved. Radiography, ultrasonics, visual, and dye (liquid) penetrant examinations will be conducted where specified to detect weld imperfections.

Manufacturing process witness and hold points will be implemented to verify adequate manufacturing quality control. Optical and other dimensional inspection techniques will be employed as needed to verify that the overall vessel profile tolerances have been maintained.

A.4.9 Pb/B4C Shielding

Pb/B4C shield panel fabrication to maintain close proximity with the profile of the outer shell and yet accommodate discontinuities and protrusions such as the port interfaces, penetrations, support lugs, etc., is expected to require custom design and fit-up. Actual panel sizes will therefore deviate in many areas from the 500 mm by 2500 mm overall dimensions specified in the ITER Garching Work Site Detail Guidance.

Panel weights for a 500 mm by 2500 mm by 30 mm thick panel, given the specified 2/3 boron carbide (B4C) to lead (Pb) ratio by volume are estimated at 300 kg. Support stud attachment to the vessel exterior as well as panel installation is recommended to be performed at the ITER site subsequent to shipment from the manufacturing facility.

As shield panel fabrication details and specifications have not been provided, the following alternatives are considered feasible from a manufacturing viewpoint:

1. Use of layers of the commercially available aluminum clad B4C sheet product, Boral, with lead sheets to form a composite shield of the desired Pb/B4C ratio and thickness. [Boral as commercially available utilizes a hot press process to form a B4C/aluminum core. This core is clad with aluminum sheet for use in various commercial shielding applications such as in spent fuel pool storage racks.]

The Boral/Pb layered composite would be placed within fabricated stainless steel panel compartments and a top cover seal welded in place.

2. Combine B4C powder with molten lead and use a hot press formed process similar to that used in the manufacture of Boral. Some research and development would be required to substantiate the process although preliminary discussions with AAR Advanced Structures, the commercial supplier of Boral, has identified that experimentation with such a process was undertaken some years ago. Commercial application of the process however, was abandoned.

The Pb/B4C composite material would be placed within stainless steel panel compartments and a top cover seal welded in place.

3. Fabricate the stainless steel compartmented panels complete with the desired thickness of lead sheet. The panel would be completely fabricated with holes provided to access each compartment. B4C powder, multigraded to achieve higher compaction ratios, would be inserted through the access holes and vibrated to ensure compaction. Access holes would be seal welded at the completion of the powder installation.

All assembly welding and/or eventual removal operations associated with either sealing of panels or closure of access holes will incorporate precautions required to prevent possible lead fumes with regard to safety and contamination of structural material to be welded.

A.4.10 Manufacturing Summary and Recommendations

In summary, the manufacture of an Alloy 625 ITER vacuum vessel as presently conceived is considered very feasible and should generally not present any significant manufacturing concerns to experienced Alloy 625 fabricators. Given the conceptual basis of the present design details, it must be recognized that this assessment must be revisited as the design progresses.

To reiterate the recommendations identified in Section A.3.8, follow-up evaluations to the (D68) assessment should be initiated to:

- investigate double forming the vessel inner shell to eliminate the poloidal segment facet welds and thereby reduce distortions induced by weld shrinkage,
- evaluate UT, an accepted Code substitute for RT, for extended use particularly on built up segment assemblies. UT allows greater flexibility than RT with regard to in-situ application and requires less restrictive safety regulations, and
- review the requirements associated with the specified vacuum surface finish of 6.3 micro mm. Such a finish, if achievable, will require post mill finishing operations that will increase manufacturing costs.

Additional recommendations for follow-up evaluations associated with the vacuum vessel manufacturing plan should focus on the:

- investigation and selection of appropriate weld processes and associated acceptable weld joint designs for use in the fabrication of the vessel segment,
- evaluation of the vessel segment water channel flow characteristics and the resultant effect of these requirements on the fabrication of the ribs and the inner shell volume (The present design basis does not appear to address water channel flow characteristics in the detail of the ribs and port structures),
- the suitability of the dimensional tolerances described as reasonably achievable,
- shielding design (both Al_2O_3 coating of internal shield balls and the fabrication of the Pb/B4C exterior panels), and
- the preparation of an overall manufacturing schedule for the vacuum vessel considering material lead times, tooling requirements, and equipment related issues.

In conclusion, given the complexity of the ITER vessel and the preliminary nature of the detailed design, the material assessment and proposed manufacturing plan presented in this this Section provides an overview of manufacturing related issues.

Part B**Vacuum Vessel Assembly Plan****Table of Contents**

B.1. Introduction.....	1
B.2. Scope.....	2
B.3. Assembly Approach	3
B.3.1 Assessment of ITER Tokamak Assembly Scenario.....	4
B.3.2 General Assembly Overview	4
B.4. Assembly Sequence	6
B.4.1 Pre-assembly Preparations	6
B.4.2 Vessel Segment/TF Coil Placement onto Mechanical Structure.....	6
B.4.3 Vessel Closure	7
B.4.4 Port Fit-up and Assembly	7
B.4.5 Vessel and Port Assembly Testing.....	8
B.4.6 Pb/B4C Shield Panel Installation.....	8
B.4.7 Top Port Cover Installation	8
B.4.8 Vessel Assembly Final Testing.....	8
B.5. Vessel Shell Deformations and Stresses During Handling.....	9
B.5.1 Analysis Approach.....	9
B.5.2 Vessel Segment Handling Scenarios	10
B.5.3 Analysis Results	10

List of Tables

Table B- 1: Vessel Segment Static Analysis Summary

List of Figures

Figure B-1: Mechanical Structure Assembly within Cryostat

Figure B-2: Vessel Shell Segment Framing Fixture

Figure B-3: Vessel Assembly Overview

Figure B-4: Vessel/TF Coil Installation onto Mechanical Structure

Figure B-5: Vessel Segment Finite Element Model

Table B- 1: Vessel Segment Static Analysis Summary

Figure B-6: Stress Distribution (Horizontal Orientation with (4) Fixturing Locations)

Figure B-7: Deformed Shape (Horizontal Orientation with (4) Fixturing Locations)

Figure B-8: Stress Distribution (Vertical Orientation with (2) Top Fixturing Locations)

Figure B-9: Deformed Shape (Vertical Orientation with (2) Top Fixturing Locations)

**Figure B-10: Stress Distribution (Vertical Orientation with (2) Top Fixturing Locations
(Sensitivity Case)**

**Figure B-11: Deformed Shape (Vertical Orientation with (2) Top Fixturing Locations
(Sensitivity Case)**

**Figure B-12: Stress Distribution (Vertical Orientation with (2) Bottom Fixturing
Locations)**

Figure B-13: Deformed Shape (Vertical Orientation with (2) Bottom Fixturing Locations)

B.1. Introduction

Although various scenarios and/or variations of scenarios for the assembly of the ITER vacuum vessel may be feasible, the Task 8 (D68) assessment has focused on an approach deemed most compatible with the overall ITER Tokamak Assembly philosophy. The basis of the assembly plan presented in the Task 8 (D68) has remained consistent with the assembly scenarios and approaches identified in the ITER Tokamak Assembly Draft Summary and the Task No. 16 Assembly Plan Development (D68) Report (References 4 and 5 - Table 1).

The referenced ITER assembly documents appropriately recognize that the installation of the vacuum vessel components within the cryostat will require close integration with the assembly of the other large tokamak components. The proposed assembly scenario requires, for instance, that the installation of the mechanical structure assembly as well as the temporary installation of the lower PF Coils be completed prior to installation of the vacuum vessel. Additionally, the vacuum vessel segments will be pre-assembled with the TF Coils and installed within the cryostat as modules. Figure B-1 obtained from the Task No. 16 Assembly Plan Development Report shows the extent of mechanical structure assembly that is presently required prior to the installation of vacuum vessel segment/TF Coil assemblies.

Figure B-1: Mechanical Structure Assembly within Cryostat

(Reference: Task No. 16 Assembly Plan Development (D28) Task Report - December 1994)

B.2. Scope

Part B - Vacuum Vessel Assembly Plan presents a basic field assembly plan for the vacuum vessel that is compatible with the manufacturing plan described in the Part A - Vacuum Vessel Fabrication Assessment. The described plan also retains the general ITER Tokamak assembly philosophy described in the ITER Tokamak Assembly Draft Summary and the Task No. 16 Assembly Plan Development (D68) Report. The activities identified in this Part B - Vacuum Vessel Assembly Plan include:

- pre-assembly preparations,
- vessel segment placement within the cryostat,
- alignment fixturing,
- welding,
- installation of the shield material between the vessel shells at the field joints,
- port fit-up/installation, and
- vessel testing.

Finite element models were prepared and various cases analyzed to determine order of magnitude stresses and deformations for different vessel segment handling orientations. The results of these analyses including stress distribution and deformed shape and plots are presented in Section B.5.

B.3. Assembly Approach

The manufacturing plan presented in Part A - Vacuum Vessel Fabrication Assessment, identifies that pre-assembled and pre-tested vacuum vessel subassemblies will be shipped to the site. These subassemblies will include:

- vessel shell segments complete with shield balls and internally installed shell segment framing fixture,
- inner port extension assemblies,
- port bellows assemblies,
- outer port extensions,
- top port cover plates, and
- pre-formed Pb/B4C shield panel assemblies.

Views of these components are shown on Sketches SK 1002, SK 1003, and SK 1009 (Appendix 1).

The shell segment framing fixture similar to the one shown in Figure B-2 will be installed during shell segment manufacturing to provide additional structural stability and reinforcement. This fixture will remain in place (i.e. throughout transport and assembly) until the completion of the vessel segment welding at the ITER site.

The field joint inner shell closure plates depicted on SK 1014 (Appendix 1) and the horizontal port inner shell closure plates (SK1015) will be pre-formed and shipped to the site for final fit-up. Containerized shield balls for installation at the field joint locations, miscellaneous alignment and assembly fixtures, and test equipment will also be shipped separately to the ITER site.

Figure B-2: Vessel Shell Segment Framing Fixture

(Reference ITER D68 Detail Guidance Figure 15.E.-1)

B.3.1 Assessment of ITER Tokamak Assembly Scenario

The assembly of the vacuum vessel as described in the Tokamak Assembly Draft Summary requires pre-assembly of the individual vacuum vessel segments within the TF Coils. The Vessel/TF Coil assemblies are then lifted into the cryostat and installed onto the mechanical structure. After all 24 Vessel/TF Coil assemblies have been placed onto the mechanical structure, the vessel segments are required to be rotated 7.5° to provide the proper orientation within the TF Coils to permit the installation of the ports. The individual segments are then aligned to each other and welded.

The horizontal ports are installed after the vessel rotation and final vessel segment field joint welding activities are completed. Temporary covers are welded to the top ports and the vacuum vessel leak checked. The temporary top cover plates are removed subsequent to the initial leak check, and the internal blanket assemblies are installed into the vessel interior through the top port openings. Top port cover plate assemblies are aligned and welded in place.

Conceptually the proposed vacuum vessel assembly plan noted above appears feasible. The combined weight of the Vessel Segment/TF Coil assembly is approximately 700 tons and, although significant, still remains less than the weight of various other components (the most notable of which is the bucking cylinder/central solenoid which is estimated at 2500 tons). The Task No. 16 Assembly Plan Development (D68) Report has noted that mobile cranes and transporters with capacities on the order of 1000 tons are presently available. Construction fit-up techniques currently utilized in commercial large precision component installation activities are expected to be applicable for the vacuum vessel assembly.

The most uncertain aspect of the proposed assembly scenario remains the availability of a suitable fixture to rotate the vessel. It will be imperative that such a fixture which as noted in the ITER Detail Guidance is not included in the scope of this effort, be designed to minimize the friction coefficient at the sliding surfaces to prevent vessel damage.

B.3.2 General Assembly Overview

A general overview of the vessel assembly activities is provided in Figure B-3. As noted by the figure, the principle assembly operations will include the following activities:

1. Pre-Assembly Preparations
 - Component Receipt and Inspection
 - Segment Placement within TF Coil
2. Vessel Segment/TF Coil Placement onto the Mechanical Structure
 - Vessel Segment Fit-up and Alignment
 - Vessel Assembly Rotation
3. Vessel Closure
 - Field Joint Closure Welding
 - Shield Ball Installation at Closure Joints

4. Port Fit-up and Assembly
Inner Port Extension Installation at Middle and Lower Ports
Bellows and Outer Port Extension Assembly Installation
5. Vessel Assembly Testing
Final Closure Joint Testing
Water Channel Testing
Port Assembly Testing
6. Lead/Boron Carbide (Pb/B4C) Shield Panel Installation
7. Top Port Cover Installation
8. Final Vessel Assembly Testing
Vacuum Leakage Test

Figure B-3: Vessel Assembly Overview

B.4. Assembly Sequence

B.4.1 Pre-assembly Preparations

1. Prepare on-site pre-assembly areas. Required areas include those suitable for receipt and inspection of the 24 vessel segments, ports, and other components as well as areas suitable for the placement of the vessel segments within the TF Coils.
2. Remove vessel segments and other components from the shipping containers. Inspect field joint weld preps. [As identified in the manufacturing plan, the vessel segment field joints will be fixtured and matched machined in the manufacturing facility with the segment oriented in the vertical position. Inner port extensions and the inner shell closure plates per the manufacturing plan have also been fit-up and match machined. These activities are expected to eliminate the need for an on site pre-installation vessel segment fit-up prior to the placement of the individual segments within the TF Coils.]
3. Install temporary support fixtures as required to interface with the vessel segment rotation system (by others).
4. Rig and place individual vessel segments within TF Coils.
5. Transport TF Coil/Vessel subassemblies to cryostat area.
6. Install lifting fixture onto TF Coil/Vessel subassembly in preparation for lift into place onto the mechanical structure.
7. Establish vessel assembly control points within the cryostat using computerized topometric system appropriate for determining spatial coordinates

B.4.2 Vessel Segment/TF Coil Placement onto Mechanical Structure

1. Lift all 24 subassemblies symmetrically into place onto the mechanical structure. Figure B-4 shows a typical installation of a Vessel Segment/TF Coil subassembly onto the mechanical structure.
2. Install vessel closure and alignment fixtures at field joint locations. [Special alignment fixtures attached to the shop installed gusset plates at the field joint locations in combination with standard industry heavy plate fit-up equipment will be used for outer shell alignment (See SK 1014 - Appendix 1 for gusset location).]
3. Align segments using previously established vessel assembly control points. Maintain alignment by welding temporary gusset plates at all 24 field joint locations.
4. Rotate assembled vessel 7.5° to proper orientation within the TF Coils.

Figure B-4: Vessel/TF Coil Installation onto Mechanical Structure

(Reference Tokamak Assembly Draft Summary 9/20/94)

B.4.3 Vessel Closure

1. Confirm segment outer shell alignments after rotation.
2. Weld outer shell closure joints.
3. Remove outer shell alignment fixtures and temporary gussets.
4. Fit-up, align, and weld pre-formed inner shell closure pieces. (SK1014) [Install closure joint shield balls in parallel with closure piece installation to ensure adequate fill of the volume.]
5. Fit-up, align, and weld vessel segment/mechanical structure support lugs to vessel exterior. (SK1019)
6. Fit-up, align, and weld divertor support bars to vessel interior (final machining by others).

B.4.4 Port Fit-up and Assembly

1. Establish port assembly control points using computerized topometric system appropriate for determining spatial coordinates.

2. Fit-up, align, and weld inner port extensions to vessel segment at middle and lower port locations. [Port weld sequence will require the field weld of the port extension outer shell to the vessel outer shell. Install pre-formed port inner shell closure plates.] (SK1003, SK1009, SK1015)
3. Fit-up, align, and weld port structure shield doors to inner shell of port extensions. (SK1016)
4. Fit-up, align, and weld outer port extensions to cryostat penetrations at middle and lower port locations. (SK1009)
5. Fit-up and weld bellows assemblies to inner and outer port extensions. (SK1009)
6. Remove vessel segment internal framing fixture (i.e. Figure B-2 fixture that was previously installed at segment manufacture).

B.4.5 Vessel and Port Assembly Testing

1. Perform the following tests:
 - pressure tests of vessel and port field joint water channels,
 - leak tests of vessel and port field joint water channels (room temperature),
 - leak tests of vessel and port field joint water channels (300°C), and
 - pressure drop and flow tests of field joint water channels.
2. Clean vessel and port interior shell surfaces.
3. Install temporary top port cover plates.
4. Install temporary seals at miscellaneous vessel pipe penetrations.
5. Perform preliminary vacuum leakage test.

B.4.6 Pb/B4C Shield Panel Installation

1. Locate and weld shield panel attachment studs to vessel exterior.
2. Clean vessel exterior shell surfaces.
3. Clean pre-formed shield panels.
4. Install pre-formed shield panels to vessel exterior.

B.4.7 Top Port Cover Installation

(The following activities may only be performed at the completion of the interior blanket installation)

1. Fit-up, align, and weld top port cover plates. (SK1003)

B.4.8 Vessel Assembly Final Testing

1. Clean vessel interior shell surfaces in preparation for final vacuum leak check.
2. Install temporary seals at vessel penetrations.
3. Perform final vacuum leakage test.

B.5. Vessel Shell Deformations and Stresses During Handling

B.5.1 Analysis Approach

A 3-D finite element model of the double walled 15° vacuum vessel segment exclusive of the horizontal and vertical ports) was prepared to evaluate the shell stresses and deformations during handling. The vessel model shown in Figure B-5 is comprised of 822 nodes and 1072 elements. The poloidal ribs were modeled consistent with the arrangement shown in SK 1006 (Appendix 1).

Applied static loadings included dead weight and pressure loading induced by the presence of the shield balls installed within volume between the inner and outer shells. The pressure induced by the shield balls was modeled as the hydrostatic pressure of an artificial fluid with a density (ρ) of 6.24 g/cm³ (0.8 volume packing factor x stainless steel shield ball material density). The applied hydrostatic loadings at element locations were computed as $\rho(h)$, where h is a distance determined independently for each element based upon the segment orientation and applicable "equivalent fluid surface".

Figure B-5: Vessel Segment Finite Element Model

(Reference ITER D68 Detail Guidance Figure 15.E.-1)

B.5.2 Vessel Segment Handling Scenarios

Four handling scenarios were evaluated in order to obtain a gross approximation of vessel stresses and deformations for different vessel segment orientations. The four handling scenarios included:

1. vessel segment in a horizontal orientation- crane pick (i.e. supports) defined at four locations,
2. vessel segment picked vertically from top (i.e. two support locations at top),
3. a sensitivity case similar to the previously described top support scenario was also performed with the support locations closer together, and
4. vertical vessel segment supported at bottom.

Support locations were modeled across the outer shell of the segment for all cases.

None of the scenarios reflected the existence of additional segment bracing and/or temporary shipping supports. The absence of such bracing provides very conservative order of magnitude maximum stresses and deformations for comparison purposes.

B.5.3 Analysis Results

The results of the static analyses performed for each of these scenarios is summarized in Table B-1. The results for both the horizontal orientation and the top support vertical orientation indicate that the computed maximum displacements associated with the vessel cross-section (model x and z axes) are in the range of 0.3 cm to 1.0 cm. Localized maximum stresses on the order of 385 kg/cm² to 457 kg/cm² (5.6 ksi to 6.5 ksi) are noted in the regions of the support attachments. Considering an Alloy 625 material allowable of 46.7 ksi, these stresses are considered small and may in fact be significantly reduced by the addition of local temporary reinforcement during segment handling. (The sensitivity case performed with the top supports moved more closely together demonstrate as expected that both the stresses and deformations increase significantly as the top attachment locations are varied.)

The analyzed case with two bottom support locations only (i.e. without the benefit of a poloidal load distribution saddle) results in maximum deformations on the order of 0.9 cm to 2.35 cm. The computed maximum stresses for this support case are on the order of 840 kg/cm² (11.9 ksi) and are very localized in the region of the support locations. The computed average stress for this case however, is significantly less at approximately 50% of this maximum value. Fringe plots of the vessel segment stress distributions and deformed shapes for each of the four cases are provided in Figures B-6 through B-13.

Table B- 1: Vessel Segment Static Analysis Summary

Case	Support Configuration	Max Response
Horizontal Orientation		$\sigma_{\max} = 457 \text{ kg/cm}^2$ $= 6.5 \text{ ksi}$ $\Delta X = 0.29 \text{ cm} = 0.11''$ $\Delta Y = 0.19 \text{ cm} = 0.07''$ $\Delta Z = 1.00 \text{ cm} = 0.39''$
Vertical Orientation w/ Top Fixturing Locations		$\sigma_{\max} = 385 \text{ kg/cm}^2$ $= 5.6 \text{ ksi}$ $\Delta X = 0.48 \text{ cm} = 0.19''$ $\Delta Y = 0.06 \text{ cm} = 0.02''$ $\Delta Z = -0.30 \text{ cm} = -0.12''$
Vertical Orientation w/ Top Fixturing Locations (Sensitivity Case)		$\sigma_{\max} = 1332 \text{ kg/cm}^2$ $= 18.9 \text{ ksi}$ $\Delta X = -4.22 \text{ cm} = -1.66''$ $\Delta Y = 0.55 \text{ cm} = 0.22''$ $\Delta Z = -1.66 \text{ cm} = -0.65''$
Vertical Orientation w/ Bottom Fixturing Locations		$\sigma_{\max} = 840 \text{ kg/cm}^2$ $= 11.9 \text{ ksi}$ $\Delta X = 2.35 \text{ cm} = 0.92''$ $\Delta Y = -0.31 \text{ cm} = -0.12''$ $\Delta Z = -0.88 \text{ cm} = -0.35''$

Fringe: LC=4.1-RES=2.1-P3/PATRAN R.1-(Tresca)-P3/FEA-18-Jan-95 13:25:26

Deformed_plot: LC=4.1-RES=1.1-P3/PATRAN R.1.2-DISPLACEMENT-P3/FEA-25-Jan-95 08:

+

Figure B - 7

Deformed Shape (Horizontal Orientation With (4) Fixturing Locations)

Fringe: LC=6.1-RES=2.1-P3/PATRAN R.1-(Tresca)-P3/FEA-25-Jan-95 08:18:35

+

Figure B - 8
Stress Distribution (Vertical Orientation With (2)Top Fixturing Locations)
(Kg/Sq.Cm)

Deformed_plot: LC=6.1-RES=1.1-P3/PATRAN R.1.2-DISPLACEMENT-P3/FEA-24-Jan-95 15:

Figure B - 9

Deformed Shape (Vertical Orientation With (2) Top Fixturing Locations)

Fringe: LC=6.1-RES=2.1-P3/PATRAN R.1-(Tresca)-P3/FEA-17-Jan-95 14:17:33

Deformed_plot: LC=6.1-RES=1.1-P3/PATRAN R.1.2-DISPLACEMENT-P3/FEA-25-Jan-95 09:

Figure B - 11

Deformed Shape (Vertical Orientation With (2) Top Fixturing Locations[Sensitivity Case])

Fringe: LC=5.1-RES=2.1-P3/PATRAN R.1-(Tresca)-P3/FEA-19-Jan-95 12:53:15

+

Figure B - 12
Stress Distribution (Vertical Orientation With (2) Bottom Fixturing Locations)
(Kg/Sq.Cm)

840.5

785.0

729.6

674.2

618.8

563.4

508.0

Deformed_plot: LC=5.1-RES=1.1-P3/PATRAN R.1.2-DISPLACEMENT-P3/FEA-25-Jan-95 10:

Figure B - 13

Deformed Shape (Vertical Orientation With (2) Bottom Fixturing Locations)

Part C**Cost Estimate****Table of Contents**

C.1. Introduction.....	1
C.2. Scope.....	1
C.3. Cost Basis	1
C.3.1 Vessel Basis.....	1
C.3.2 Material and Labor Rates	1
C.3.3 Cost Estimate Assumptions.....	1
C.4. Cost Estimate Spreadsheets	3

List of Tables

Table C-1: Vacuum Vessel Work Breakdown Structure (WBS)

C.1. Introduction

The Part A Vacuum Vessel Fabrication Assessment and Part B Vacuum Vessel Assembly Plan described manufacturing and assembly plans for the ITER vacuum vessel. A cost estimate consistent with these established plans has been prepared for the Task 8 (D68) assessment.

C.2. Scope

Part C Cost Estimate presents an estimate of manufacturing, assembly, and testing costs consistent with the manufacturing and assembly plans established in Part A and Part B, respectively. The vessel design basis described in **Section 3. Vessel Design Basis** of this report, provides the detailed listing of cost basis references and assumptions associated with each of the Vacuum Vessel Work Breakdown Structure (WBS) cost elements.

C.3. Cost Basis

C.3.1 Vessel Basis

The vessel basis presented in the Table 3, Vessel Manufacturing, Assembly, and Cost Basis, of this report has been used in combination with the costing guidelines and spreadsheet samples provided in the ITER Garching Joint Work Site Memo (Draft #9). The vacuum vessel WBS 15 as prepared by the JCT was used in the development of the cost estimate. The WBS 15 elements are identified in Table C-1.

C.3.2 Material Costs and Labor Rates

The cost of materials identified in the cost estimate were obtained using both auditable CB&I internal estimating rates and costs obtained from external material suppliers and vendors.

Shop labor rates were obtained from CB&I standard rates similar to those historically used for estimating commercial nuclear manufacturing. These rates have been identified with a Commodity Code prefix of "CVE".

The site labor rates associated with site construction activities were obtained from the site labor rates identified in the Garching Work Site Memo #9. These rates maintain the Garching Work Site Commodity Code "XL" prefix.

C.3.3 Cost Estimate Assumptions

Cost estimate assumptions in addition to those identified in the ITER Garching Joint Work Site Memo (Draft #9) and the Table 3, Vessel Manufacturing, Assembly, and Cost Basis provided in this report include the following:

- The estimated costs for specific shop and field assembly fixtures and equipment have been identified on separate spreadsheets provided in Section C.4
- No costs have been assumed for site related interface items such as electric power, compressed air, crane use, etc.
- Contingency has not been included within the estimate.
- All costs are presented in 1993 \$US.
- Customs, duties, agent fees, and freight to the site have not been included.

Table C-1: Vacuum Vessel Work Breakdown Structure (WBS)

WBS Element No.	Description
15	Vacuum Vessel
15.A	Vacuum Vessel Main Assembly
15.A.01	Inner and Outer Shell
15.A.02	Leak Detection System
15.A.03	Shielding for VV
15.A.04	Cooling Piping
15.A.05	Wall Conditioning System
15.B	Port Assemblies
15.B.01	Port Structures
15.B.02	Port Extensions
15.B.03	Port Bellows Ass'ys
15.B.04	Special Ports
15.C	Support Structures
15.C.01	Blanket Supports
15.C.02	Structure Supports
15.C.03	Divertor Supports
15.D	External Pb/B4C Shielding for TF Coil
15.D.01	Pb/B4C Shielding
15.D.02	Pb/B4C Supports
15.E	Assembly and Special Fixtures
15.E.01	Shop Assembly Fixtures
15.E.02	Field Assembly/Alignment Fixtures
15.F	Vacuum Vessel Assembly and Test at Site
15.F.01	Vacuum Vessel Assembly
15.F.02	Port Assembly
15.F.03	Support Structure
15.F.04	External Pb/B4C Shielding Assembly

C.4. Cost Estimate Spreadsheets

VACUUM VESSEL SHOP FABR. & SITE ASSEMBLY
GENERAL COMMODITY TABLE
ITER TASK No. 8

1/29/95

VACUUM VESSEL SHOP FABR. & SITE ASSEMBLY
GENERAL COMMODITY TABLE
ITER TASK No. 8

1/29/95

ITER EDA PHASE
PROJECT COST ESTIMATE (Rev. 1)
U.S. TEAM RE & C AND CB & I

VACUUM VESSEL MAIN ASSEMBLY
SHOP FABRICATION
ITER TASK No. 8

Account No.	Account Description	Comd. Code	Commodity Description	Qty.	Unit	Material Cost (K\$)	Material Cost Uncert.		Labor Cost (K\$)	Labor Cost Uncert.		Total Cost (K\$)	Total Cost Uncert.	
							(-%)	(+%)		(-%)	(+%)		(-%)	(+%)
15.A	Vacuum Vessel Main Assembly (Total for 24 Segments)			7,900	ton									
				653,870	mhr	\$154,391	(5)	19	\$44,800	(5)	15	\$199,191	(5)	18
15.A.01	Stiffened Double Wall Main Vessel Segments :													
15.A.01.1	Manufacturing Engineering													
	Manuf. Fabrication Drawings	CVE101	Engineering Drawings Labor	9,000	mhr				\$585	(5)	20	\$585	(5)	20
	QA, MS, Weld, NDE, etc Proc's	CVE102	Engineering Design Labor	4,000	mhr				\$360	(5)	20	\$360	(5)	20
	Project Management	CVM202	Shop Project Management	39,200	mhr				\$1,960	(5)	20	\$1,960	(5)	20
15.A.01.2	Material Procurement													
	Inconel 625 Plate Material (30, 40, 50 mm thick)	N/A	Contract Material	2,600	ton	\$62,336	(5)	30				\$62,336	(5)	30
	Mill Polish Inside Surface of Inner Wall Shell Plates	N/A	Finish to 32 rms		sqm	\$124	(5)	10				\$124	(5)	10
	Welding Consumables	N/A	Contract Material	140	ton	\$3,366	(5)	25				\$3,366	(5)	25
15.A.01.3	Shop Manufacturing Fabrication													
	Cut, Bevel, and Form Plates	CVM201	Shop Manufacturing Labor	100,500	mhr				\$6,432	(5)	15	\$6,432	(5)	15
	Assemble Inner Shell	CVM201	Shop Manufacturing Labor	30,950	mhr				\$1,981	(5)	15	\$1,981	(5)	15
	Attach Ribbs and Port Openings	CVM201	Shop Manufacturing Labor	189,120	mhr				\$12,104	(5)	15	\$12,104	(5)	15
	Install Outer Shell Cover Plates	CVM201	Shop Manufacturing Labor	101,640	mhr				\$6,505	(5)	15	\$6,505	(5)	15
	Clean and PWHT	CVM201	Shop Manufacturing Labor	24,000	mhr				\$1,536	(5)	15	\$1,536	(5)	15
	Cut and Bevel Field Weld Joints	CVM201	Shop Manufacturing Labor	100,000	mhr				\$6,400	(5)	15	\$6,400	(5)	15
15.A.01.4	Shop Testing and Inspection													
	Pressure and Leak Tests	CVM201	Shop Manufacturing Labor	12,980	mhr				\$831	(5)	15	\$831	(5)	15
	Clean and Vacuum Leak Test	CVM201	Shop Manufacturing Labor	4,000	mhr				\$256	(5)	15	\$256	(5)	15
	Dimensional Inspections	CVM201	Shop Manufacturing Labor	8,700	mhr				\$557	(5)	15	\$557	(5)	15
	Trial Fit Segments Together	CVM201	Shop Manufacturing Labor	34,100	mhr				\$2,182	(5)	15	\$2,182	(5)	15
	Pack and Load Out Segments	CVM201	Shop Manufacturing Labor	760	mhr				\$49	(5)	15	\$49	(5)	15
	SUB-TOTALS					\$65,826	(5)	30	\$41,737	(5)	15	\$107,563	(5)	24

ITER EDA PHASE
PROJECT COST ESTIMATE (Rev. 1)
U.S. TEAM RE & C AND CB & I

VACUUM VESSEL MAIN ASSEMBLY
SHOP FABRICATION
ITER TASK No. 8

Account No.	Account Description	Comd. Code	Commodity Description	Qty.	Unit	Material Cost (K\$)	Material Cost Uncert.		Labor Cost (K\$)	Labor Cost Uncert.		Total Cost (K\$)	Total Cost Uncert.	
							(-%)	(+%)		(-%)	(+%)		(-%)	(+%)
15.A.02	Leak Detection System :	"Will Price Later When Design Sufficiently Developed"												
15.A.02.1	Manufacturing Engineering													
	Manuf. Fabrication Drawings	CVE101	Engineering Drawings Labor	0	mhr				\$0	(5)	15	\$0	(5)	15
15.A.02.2	Material Procurement													
	Inconel Pipe for Covers	N/A	Contract Material	0	m	\$0	(5)	15				\$0	(5)	15
	Feedthroughs and Tubing	N/A	Contract Material	0	m	\$0	(5)	15				\$0	(5)	15
15.A.02.3	Shop Manufacturing Fabrication													
	Fabricate Cover Plates	CVM201	Shop Manufacturing Labor	0	mhr				\$0	(5)	10	\$0	(5)	10
	Feedthroughs and Tubing	CVM201	Shop Manufacturing Labor	0	mhr				\$0	(5)	10	\$0	(5)	10
15.A.02.4	Shop Testing and Inspection													
	Inspect and Pack for Shipment	CVM201	Shop Manufacturing Labor	0	mhr				\$0	(5)	10	\$0	(5)	10
	SUB-TOTALS					\$0	---	---	\$0	---	---	\$0	---	---
15.A.03	Shielding Inside Vessel Walls :													
15.A.03.1	Manufacturing Engineering													
	Manuf. Drawings & Procedures	CVE101	Engineering Drawings Labor	300	mhr				\$20	(5)	10	\$20	(5)	10
15.A.03.2	Material Procurement													
	Balls (20 mm dia): 304 S.S.	N/A	Contract Material	5,080	ton	\$86,661	(5)	10				\$86,661	(5)	10
	Ball Coating (AL2O3)	N/A	Apply at .025 cm Thick	0	ton	\$0	(5)	20				\$0	(5)	20
	"Will Price Later When Compatable Type Coating is Identified"													
15.A.03.3	Shop Manufacturing Fabrication													
	Install Balls Inside Walls of Each													
	Vacuum Vessel Segment	CVM201	Shop Manufacturing Labor	17,200	mhr				\$1,101	(5)	15	\$1,101	(5)	15
15.A.03.4	Shop Testing and Inspection													
	Pressure, Leak, Flow Tests	CVM201	Shop Manufacturing Labor	1,000	mhr				\$64	(5)	15	\$64	(5)	15
	Load Out Balls for Field Installation	CVM201	Shop Manufacturing Labor	120	mhr				\$8	(5)	5	\$8	(5)	5
	SUB-TOTALS					\$86,661	(5)	10	\$1,192	(5)	15	\$87,853	(5)	10

ITER EDA PHASE
PROJECT COST ESTIMATE (Rev. 1)
U.S. TEAM RE & C AND CB & I

VACUUM VESSEL MAIN ASSEMBLY
SHOP FABRICATION
ITER TASK No. 8

Account No.	Account Description	Comd. Code	Commodity Description	Qty.	Unit	Material Cost (K\$)	Material Cost Uncert.		Labor Cost (K\$)	Labor Cost Uncert.		Total Cost (K\$)	Total Cost Uncert.	
							(-%)	(+%)		(-%)	(+%)		(-%)	(+%)
15.A.04	External Cooling Piping :													
15.A.04.1	Manufacturing Engineering													
	Manuf. Drawings & Procedures	CVE101	Engineering Drawings Labor	420	mhr				\$27	(5)	15	\$27	(5)	15
15.A.04.2	Material Procurement													
	Nozzles Thru Outer Wall of V.V.	N/A	Contract Material: Inconel	10	ton	\$781	(5)	30				\$781	(5)	30
	S.S. Piping and Fittings	N/A	Contract Material	70	ton	\$1,123	(5)	15				\$1,123	(5)	15
15.A.04.3	Shop Manufacturing Fabrication													
	Install Nozzles in V.V.	CVM201	Shop Manufacturing Labor	25,900	mhr				\$1,658	(5)	10	\$1,658	(5)	10
15.A.04.4	Shop Testing and Inspection													
	Inspect and Pack for Shipment	CVM201	Shop Manufacturing Labor	2,900	mhr				\$186	(5)	10	\$186	(5)	10
	SUB-TOTALS					\$1,904	(5)	21	\$1,871	(5)	10	\$3,775	(5)	16
15.A.05	Wall Conditioning System :		"No Costs Required in this Element at this Time"			\$0	---	---	\$0	---	---	\$0	---	---
	SUB-TOTALS					\$0	---	---	\$0	---	---	\$0	---	---

ITER EDA PHASE
PROJECT COST ESTIMATE (Rev. 1)
U.S. TEAM RE & C AND CB & I

PORT ASSEMBLIES FOR VACUUM VESSEL
SHOP FABRICATION
ITER TASK No. 8

Account No.	Account Description	Comd. Code	Commodity Description	Qty.	Unit	Material Cost (K\$)	Material Cost Uncert.		Labor Cost (K\$)	Labor Cost Uncert.		Total Cost (K\$)	Total Cost Uncert.	
							(-%)	(+%)		(-%)	(+%)		(-%)	(+%)
15.B	Port Assemblies for Vessel (Total for 24 Segments)			2,090	ton									
				320,900	mhr	\$49,979	(5)	30	\$20,727	(5)	15	\$70,706	(5)	25
15.B.01	Port Structures : Intergral Part of Main Vacuum Vessel :		"No Costs Required in this Element, as All Costs are Included with Account No. 15.A.01 (Main Double Wall Vessel Segments)"									\$0	---	---
	SUB-TOTALS					\$0	---	---	\$0	---	---	\$0	---	---
15.B.01	Top Port Cover Structures :													
15.B.01.1	Manufacturing Engineering Manuf. Drawings & Procedures	CVE101	Engineering Drawings Labor	600	mhr				\$39	(5)	20	\$39	(5)	20
15.B.01.2	Material Procurement													
	Inconel 625 Plate Material	N/A	Contr. Material (30 & 50 mm)	330	ton	\$7,738	(5)	30				\$7,738	(5)	30
	Polish Inside Surface of Plates	N/A	Finish to 32 rms		sqm	\$7	(5)	10				\$7	(5)	10
	Welding Consumables	N/A	Contract Material	10	ton	\$374	(5)	25				\$374	(5)	25
15.B.01.3	Shop Manufacturing Fabrication													
	Cut, Bevel, and Form Plates	CVM201	Shop Manufacturing Labor	60,100	mhr				\$3,846	(5)	15	\$3,846	(5)	15
	Assemble Port Cover Assm's	CVM201	Shop Manufacturing Labor	80,000	mhr				\$5,120	(5)	15	\$5,120	(5)	15
15.B.01.4	Shop Testing and Inspection													
	Pressure and Leak Tests	CVM201	Shop Manufacturing Labor	9,000	mhr				\$576	(5)	15	\$576	(5)	15
	Clean and Vacuum Leak Test	CVM201	Shop Manufacturing Labor	9,000	mhr				\$576	(5)	15	\$576	(5)	15
	Inspect and Pack for Shipment	CVM201	Shop Manufacturing Labor	10,200	mhr				\$653	(5)	15	\$653	(5)	15
	SUB-TOTALS					\$8,119	(5)	30	\$10,810	(5)	15	\$18,930	(5)	21
15.B.01	Blanket Cooling Water External Piping System from Top Ports :		"Will Price Later When Design Sufficiently Developed"			\$0	---	---	\$0	---	---	\$0	---	---
	SUB-TOTALS					\$0	---	---	\$0	---	---	\$0	---	---

ITER EDA PHASE
PROJECT COST ESTIMATE (Rev. 1)
U.S. TEAM RE & C AND CB & I

PORT ASSEMBLIES FOR VACUUM VESSEL
SHOP FABRICATION
ITER TASK No. 8

Account No.	Account Description	Comd. Code	Commodity Description	Qty.	Unit	Material Cost (K\$)	Material Cost Uncert.		Labor Cost (K\$)	Labor Cost Uncert.		Total Cost (K\$)	Total Cost Uncert.	
							(-%)	(+%)		(-%)	(+%)		(-%)	(+%)
15.B.02	Inner Port Extensions, at Middle and Lower Ports :													
15.B.02.1	Manufacturing Engineering													
	Manuf. Drawings & Procedures	CVE101	Engineering Drawings Labor	1,320	mhr				\$86	(5)	20	\$86	(5)	20
15.B.02.2	Material Procurement													
	Inconel 625 Plate Material	N/A	Contr. Material (10,30,50 mm)	570	ton	\$13,125	(5)	30				\$13,125	(5)	30
	Polish Inside Surface of Plates	N/A	Finish to 32 rms		sqm	\$12	(5)	10				\$12	(5)	10
	Welding Consumables	N/A	Contract Material	20	ton	\$499	(5)	25				\$499	(5)	25
15.B.02.3	Shop Manufacturing Fabrication													
	Cut, Bevel, and Form Plates	CVM201	Shop Manufacturing Labor	20,000	mhr				\$1,280	(5)	15	\$1,280	(5)	15
	Assemble Port Cover Assm's	CVM201	Shop Manufacturing Labor	39,200	mhr				\$2,509	(5)	15	\$2,509	(5)	15
15.B.02.4	Shop Testing and Inspection													
	Pressure and Leak Tests	CVM201	Shop Manufacturing Labor	4,000	mhr				\$256	(5)	15	\$256	(5)	15
	Clean and Vacuum Leak Test	CVM201	Shop Manufacturing Labor	4,000	mhr				\$256	(5)	15	\$256	(5)	15
	Inspect and Pack for Shipment	CVM201	Shop Manufacturing Labor	4,800	mhr				\$307	(5)	15	\$307	(5)	15
	SUB-TOTALS					\$13,637	(5)	30	\$4,694	(5)	15	\$18,331	(5)	26
15.B.02	Outer Port Extensions (Ducts), at Middle and Lower Ports :													
15.B.02.1	Manufacturing Engineering													
	Manuf. Drawings & Procedures	CVE101	Engineering Drawings Labor	180	mhr				\$12	(5)	20	\$12	(5)	20
15.B.02.2	Material Procurement													
	Inconel 625 Plate Material	N/A	Contract Material (50 mm)	510	ton	\$12,295	(5)	30				\$12,295	(5)	30
	Polish Inside Surface of Plates	N/A	Finish to 32 rms		sqm	\$12	(5)	10				\$12	(5)	10
15.B.02.3	Shop Manufacturing Fabrication													
	Fabr & Weld Single Wall Ducts	CVM201	Shop Manufacturing Labor	25,000	mhr				\$1,600	(5)	15	\$1,600	(5)	15
15.B.02.4	Shop Testing and Inspection													
	Clean and Vacuum Leak Test	CVM201	Shop Manufacturing Labor	4,000	mhr				\$256	(5)	15	\$256	(5)	15
	Inspect and Pack for Shipment	CVM201	Shop Manufacturing Labor	4,000	mhr				\$256	(5)	15	\$256	(5)	15
	SUB-TOTALS					\$12,308	(5)	30	\$2,124	(5)	15	\$14,431	(5)	28

Account No.	Account Description	Comd. Code	Commodity Description	Qty.	Unit	Material Cost (K\$)	Material Cost Uncert. (-%) (+%)	Labor Cost (K\$)	Labor Cost Uncert. (-%) (+%)	Total Cost (K\$)	Total Cost Uncert. (-%) (+%)
15.B.02	Shield Doors, at Middle and Lower Ports :										
15.B.02.1	Manufacturing Engineering										
	Manuf. Drawings & Procedures	CVE101	Engineering Drawings Labor	300	mhr			\$20	(5) 15	\$20	(5) 15
15.B.02.2	Material Procurement										
	Inconel 625 Plate & Pipe Material	N/A	Contract Material (50 mm)	540	ton	\$12,670	(5) 30			\$12,670	(5) 30
15.B.02.3	Shop Manufacturing Fabrication										
	Fabr & Assemble Shield Doors	CVM201	Shop Manufacturing Labor	30,000	mhr			\$1,920	(5) 15	\$1,920	(5) 15
15.B.02.4	Shop Testing and Inspection										
	Prepare and Pack for Shipment	CVM201	Shop Manufacturing Labor	17,000	mhr			\$1,088	(5) 15	\$1,088	(5) 15
	SUB-TOTALS					\$12,670	(5) 30	\$3,028	(5) 15	\$15,697	(5) 27
15.B.03	Bellows, at Middle and Lower Ports :										
15.B.03.1	Manufacturing Engineering										
	Manuf. Drawings & Procedures	CVE101	Engineering Drawings Labor	240	mhr			\$16	(5) 15	\$16	(5) 15
	Bellows Vendor Inspections	CVM202	Shop Project Management	280	mhr			\$14	(5) 15	\$14	(5) 15
15.B.03.2	Material Procurement										
	Purchase Complete from Vendor	N/A	Contract Material (Inconel)	100	ton	\$2,995	(5) 30			\$2,995	(5) 30
15.B.03.4	Shop Testing and Inspection										
	Inspect and Pack for Shipment	CVM201	Shop Manufacturing Labor	480	mhr			\$31	(5) 15	\$31	(5) 15
	SUB-TOTALS					\$2,995	(5) 30	\$60	(5) 15	\$3,056	(5) 30
15.B.04	Instrumentation Ports in Vacuum Vessel :										
15.B.02.1	Manufacturing Engineering										
	Manuf. Drawings & Procedures	CVE101	Engineering Drawings Labor	60	mhr			\$4	(5) 15	\$4	(5) 15
15.B.02.2	Material Procurement										
	Inconel 625 Pipe (2 cm dia)	N/A	Contract Material	10	ton	\$250	(5) 15			\$250	(5) 15
15.B.02.3	Shop Manufacturing Fabrication										
	Fabricate and Weld Penetrations	CVM201	Shop Manufacturing Labor	120	mhr			\$8	(5) 15	\$8	(5) 15
	SUB-TOTALS					\$250	(5) 15	\$12	(5) 15	\$261	(5) 15

ITER EDA PHASE
PROJECT COST ESTIMATE (Rev. 1)
U.S. TEAM RE & C AND CB & I

SUPPORT ATTACHMENTS TO VACUUM VESSEL
SHOP FABRICATION
ITER TASK No. 8

Account No.	Account Description	Comd. Code	Commodity Description	Qty.	Unit	Material Cost (K\$)	Material Cost Uncert.		Labor Cost (K\$)	Labor Cost Uncert.		Total Cost (K\$)	Total Cost Uncert.	
							(-%)	(+%)		(-%)	(+%)		(-%)	(+%)
15.C	Support Structures, Attached to Vacuum Vessel (Total for 24 Segments)			850	ton	\$17,709	(5)	30	\$5,440	(5)	15	\$23,149	(5)	26
				83,530	mhr									
15.C.01	Internal Blanket to Vessel Supports :													
	(24) Bottom Inboard Double Assemblies and (48) Bottom Outboard Single Assemblies													
15.C.01.1	Manufacturing Engineering													
	Manuf. Drawings & Procedures	CVE101	Engineering Drawings Labor	720	mhr				\$47	(5)	20	\$47	(5)	20
15.C.01.2	Material Procurement													
	Inconel 625 Plate/Forging Material	N/A	Contr. Material (30 & 250 mm)	190	ton	\$4,534	(5)	30				\$4,534	(5)	30
	Polish Inside Surface of Plates	N/A	Finish to 32 rms		sqm	\$7	(5)	10				\$7	(5)	10
	Welding Consumables	N/A	Contract Material	5	ton	\$94	(5)	25				\$94	(5)	25
15.C.01.3	Shop Manufacturing Fabrication													
	Fabr, Assm, and Attach to Vessel	CVM201	Shop Manufacturing Labor	28,070	mhr				\$1,796	(5)	15	\$1,796	(5)	15
	Final Machine Sliding Surfaces	CVM201	Shop Manufacturing Labor	5,000	mhr				\$320	(5)	15	\$320	(5)	15
15.C.01.4	Shop Testing and Inspection													
	Dimensional Inspection	CVM201	Shop Manufacturing Labor	500	mhr				\$32	(5)	15	\$32	(5)	15
	SUB-TOTALS					\$4,635	(5)	30	\$2,195	(5)	15	\$6,830	(5)	25

ITER EDA PHASE
PROJECT COST ESTIMATE (Rev. 1)
U.S. TEAM RE & C AND CB & I

SUPPORT ATTACHMENTS TO VACUUM VESSEL
SHOP FABRICATION
ITER TASK No. 8

Account No.	Account Description	Comd. Code	Commodity Description	Qty.	Unit	Material Cost (K\$)		Material Cost Uncert.	Labor Cost (K\$)	Labor Cost Uncert.		Total Cost (K\$)	Total Cost Uncert.	
						(-%)	(+%)			(-%)	(+%)		(-%)	(+%)
15.C.02	External Vessel Support Points Structures:													
	(24) Pairs of Upper Support Assemblies and (24) Pairs of Lower Support Assemblies													
15.C.02.1	Manufacturing Engineering													
	Manuf. Drawings & Procedures	CVE101	Engineering Drawings Labor	480	mhr				\$31	(5)	20	\$31	(5)	20
15.C.02.2	Material Procurement													
	Inconel 625 Plate Material	N/A	Contract Material (30 mm)	350	ton	\$7,151	(5)	30				\$7,151	(5)	30
	Polish Inside Surface of Plates	N/A	Finish to 32 rms		sqm	\$6	(5)	10				\$6	(5)	10
	Welding Consumables	N/A	Contract Material	5	ton	\$156	(5)	25				\$156	(5)	25
15.C.02.3	Shop Manufacturing Fabrication													
	Fabricate Assemblies	CVM201	Shop Manufacturing Labor	43,300	mhr				\$2,771	(5)	15	\$2,771	(5)	15
15.C.02.4	Shop Testing and Inspection													
	Inspect and Pack for Shipment	CVM201	Shop Manufacturing Labor	4,000	mhr				\$256	(5)	15	\$256	(5)	15
	SUB-TOTALS					\$7,313	(5)	30	\$3,058	(5)	15	\$10,372	(5)	26
15.C.03	Internal Divertor Supports From Vessel :													
	(2) Square Supports Which will Extend Around the Inside of the Vessel in the Toroidal Direction													
15.C.03.1	Manufacturing Engineering													
	Manuf. Drawings & Procedures	CVE101	Engineering Drawings Labor	240	mhr				\$16	(5)	20	\$16	(5)	20
15.C.03.2	Material Procurement													
	Inconel 625 Forging Material	N/A	Contr Material (120 mm sq.)	300	ton	\$5,761	(5)	30				\$5,761	(5)	30
15.C.03.3	Shop Manufacturing Fabrication													
	Fabricate, Machine, Polish Bars	CVM201	Shop Manufacturing Labor	2,500	mhr				\$160	(5)	15	\$160	(5)	15
15.C.03.4	Shop Testing and Inspection													
	Inspect and Pack for Shipment	CVM201	Shop Manufacturing Labor	160	mhr				\$10	(5)	15	\$10	(5)	15
	SUB-TOTALS					\$5,761	(5)	30	\$186	(5)	15	\$5,947	(5)	30

ITER EDA PHASE
PROJECT COST ESTIMATE (Rev. 1)
U.S. TEAM RE & C AND CB & I

Pb/B4C SHIELDING FOR VACUUM VESSEL
SHOP FABRICATION
ITER TASK No. 8

Account No.	Account Description	Comd. Code	Commodity Description	Qty.	Unit	Material Cost (K\$)	Material Cost Uncert.		Labor Cost (K\$)	Labor Cost Uncert.		Total Cost (K\$)	Total Cost Uncert.	
							(-%)	(+%)		(-%)	(+%)		(-%)	(+%)
15.D	External Pb/B4C Vessel Shielding (Total for 24 Segments)			590	ton									
				129,910	mhr	\$12,917	(5)	24	\$8,431	(5)	15	\$21,348	(5)	21
15.D.01	Pb/B4C Vessel Shielding :													
15.D.01.1	Manufacturing Engineering													
	Manuf. Drawings & Procedures	CVE101	Engineering Drawings Labor	1,560	mhr				\$101	(5)	20	\$101	(5)	20
15.D.01.2	Material Procurement													
	304 S.S. Sheeting for Boxes	N/A	Contract Material (2 mm thick)	75	ton	\$569	(5)	30				\$569	(5)	30
	Lead (Pb) Shielding Material	N/A	Componets Would be Powder	340	ton	\$796	(5)	10				\$796	(5)	10
	B4C Shielding Material	N/A	Mixed at 2 Parts B4C to 3 Parts of Pb.	170	ton	\$11,291	(5)	25				\$11,291	(5)	25
15.D.01.3	Shop Manufacturing Fabrication													
	Fabricate Special S.S. Boxes:	CVM201	Shop Manufacturing Labor	50,000	mhr				\$3,200	(5)	15	\$3,200	(5)	15
	(30 mm thick around Vessel and 50 mm thick around 2.5 M of Ports)													
	Install Pb/B4C into Boxes	CVM201	Shop Manufacturing Labor	40,850	mhr				\$2,614	(5)	15	\$2,614	(5)	15
	Trial Fit Shielding to a Segment	CVM201	Shop Manufacturing Labor	31,700	mhr				\$2,029	(5)	15	\$2,029	(5)	15
15.D.01.4	Shop Testing and Inspection													
	Inspect and Pack for Shipment	CVM201	Shop Manufacturing Labor	7,340	mhr				\$470	(5)	15	\$470	(5)	15
	SUB-TOTALS					\$12,656	(5)	24	\$8,414	(5)	15	\$21,070	(5)	21
15.D.02	Mounting System for Shielding :													
15.D.02.1	Manufacturing Engineering													
	Manuf. Drawings & Procedures	CVE101	Engineering Drawings Labor	240	mhr				\$16	(5)	20	\$16	(5)	20
15.D.02.2	Material Procurement													
	Inconel 625 Weld Studs w/ misc	N/A	Contract Material	5	ton	\$261	(5)	30				\$261	(5)	30
15.D.02.4	Shop Testing and Inspection													
	Inspect and Pack for Shipment	CVM201	Shop Manufacturing Labor	20	mhr				\$1	(5)	15	\$1	(5)	15
	SUB-TOTALS					\$261	(5)	30	\$17	(5)	20	\$278	(5)	29

ITER EDA PHASE
PROJECT COST ESTIMATE (Rev. 1)
U.S. TEAM RE & C AND CB & I

SPECIAL JIGS & FIXTURES, AND MAJOR EQUIPMENT
SHOP FABRICATION AND FIELD CONSTRUCTION
ITER TASK No. 8

Account No.	Account Description	Comd. Code	Commodity Description	Qty.	Unit	Material Cost (K\$)	Material Cost Uncert.		Labor Cost (K\$)	Labor Cost Uncert.		Total Cost (K\$)	Total Cost Uncert.	
							(-%)	(+%)		(-%)	(+%)		(-%)	(+%)
15.E	Total Special Jigs & Fixtures, and Major Const Equipment			---	---	\$13,967	(5)	16	---	---	---	\$13,967	(5)	16
15.E.1	Special Jigs and Fixtures For Shop Fabrication :													
	"Refer to the Attached List"	N/A				\$11,532	(5)	15				\$11,532	(5)	15
	SUB-TOTALS					\$11,532	(5)	15	---	---	---	\$11,532	(5)	15
15.E.1	Special Jigs and Fixtures, And Major Equipment For Field Construction :													
	"Refer to the Attached List"	N/A				\$2,435	(5)	20				\$2,435	(5)	20
	SUB-TOTALS					\$2,435	(5)	20	---	---	---	\$2,435	(5)	20

ITER EDA PHASE
PROJECT COST ESTIMATE (Rev. 1)
U.S. TEAM RE & C AND CB & I

VACUUM VESSEL ASSEMBLY AND TEST AT THE SITE
FIELD CONSTRUCTION
ITER TASK No. 8

Account No.	Account Description	Comd. Code	Commodity Description	Qty.	Unit	Material Cost (K\$)	Material Cost Uncert.		Labor Cost (K\$)	Labor Cost Uncert.		Total Cost (K\$)	Total Cost Uncert.	
							(-%)	(+%)		(-%)	(+%)		(-%)	(+%)
15.F	Vacuum Vessel Assembly and Test at the Site (Total for 24 Segments, Plus Ports and Attachments)			238,100	mhr									
				48,000	mhr	\$0	—	—	\$21,150	(5)	17	\$21,150	(5)	17
15.F.01	Vacuum Vessel Main Assembly :													
15.F.01.1	Construction Engineering													
	Assembly and Test Drawings	CVE101	Engineering Drawings Labor	3,000	mhr				\$195	(5)	20	\$195	(5)	20
	QA, Weld, NDE, Test, etc Proc's	CVE102	Engineering Design Labor	2,000	mhr				\$180	(5)	20	\$180	(5)	20
	Project Management	XL0022	Site Project Management	48,000	mhr				\$4,653	(5)	20	\$4,653	(5)	20
15.F.01.2	Sub-Assembly at Site													
	Mobilize, Set-Up Equipment, etc	XL0006	Site Construction Labor	4,800	mhr				\$325	(5)	15	\$325	(5)	15
	Receive and Store All Materials	XL0006	Site Construction Labor	4,400	mhr				\$298	(5)	15	\$298	(5)	15
	Install V.V. Segments Inside of T.F.													
	Coils and Temp. Support	XL0006	Site Construction Labor	5,760	mhr				\$390	(5)	20	\$390	(5)	20
15.F.01.3	Vacuum Vessel Assembly on Permenant Support Structure													
	Rig and Set V.V. Segments In-Place	XL0006	Site Construction Labor	4,800	mhr				\$325	(5)	15	\$325	(5)	15
	Final Fit Outer Wall Seams and													
	Restrain Segments Together	XL0006	Site Construction Labor	7,800	mhr				\$528	(5)	15	\$528	(5)	15
	Rotate Entire Vessel 7.5 Degrees													
	and Perform Final Alignment	XL0006	Site Construction Labor	1,800	mhr				\$122	(5)	25	\$122	(5)	25
	Weld and NDE Outer Shell Joints	XL0006	Site Construction Labor	21,840	mhr				\$1,479	(5)	15	\$1,479	(5)	15
	Fit, Weld, and NDE Inner Shell													
	Closure Plates	XL0006	Site Construction Labor	52,420	mhr				\$3,549	(5)	15	\$3,549	(5)	15
	Install S.S. Shielding Balls Inside of													
	Walls at Field Closing Seams	XL0006	Site Construction Labor	5,380	mhr				\$364	(5)	15	\$364	(5)	15
	Remove Internal Restraint Spiders	XL0006	Site Construction Labor	19,200	mhr				\$1,300	(5)	15	\$1,300	(5)	15
	Prepare Inside of Vacuum Vessel													
	for Test and as a Clean Room	XL0006	Site Construction Labor	800	mhr				\$54	(5)	15	\$54	(5)	15
	Polish and Final Clean Interior													
	Surfaces of Vessel	XL0006	Site Construction Labor	17,280	mhr				\$1,170	(5)	20	\$1,170	(5)	20
	Field Run Cooling Water Piping (S.S.)													
	From V.V. Walls to Cryostat	XL0006	Site Construction Labor	6,000	mhr				\$406	(5)	15	\$406	(5)	15

ITER EDA PHASE
PROJECT COST ESTIMATE (Rev. 1)
U.S. TEAM RE & C AND CB & I

VACUUM VESSEL ASSEMBLY AND TEST AT THE SITE
FIELD CONSTRUCTION
ITER TASK No. 8

Account No.	Account Description	Comd. Code	Commodity Description	Qty.	Unit	Material Cost (K\$)	Material Cost Uncert.		Labor Cost (K\$)	Labor Cost Uncert.		Total Cost (K\$)	Total Cost Uncert.	
							(-%)	(+%)		(-%)	(+%)		(-%)	(+%)
15.F.01.4	Testing and Inspection													
	Dimensional Inspections	XL0006	Site Construction Labor	1,200	mhr				\$81	(5)	15	\$81	(5)	15
	Pressure, Leak, Flow Tests of Annulars at Field Closing Seams	XL0006	Site Construction Labor	5,380	mhr				\$364	(5)	15	\$364	(5)	15
	Perform Final Vacuum Leak Rate Test of Vacuum Vessel	XL0006	Site Construction Labor	1,920	mhr				\$130	(5)	15	\$130	(5)	15
	Final Turn Over of V.V. to Customer	XL0006	Site Construction Labor	200	mhr				\$14	(5)	15	\$14	(5)	15
	Clean-Up & Demobilize Site	XL0006	Site Construction Labor	1,920	mhr				\$130	(5)	15	\$130	(5)	15
	SUB-TOTALS					\$0	—	—	\$16,058	(5)	17	\$16,058	(5)	17
15.F.02	Port Assemblies for Vacuum Vessel :													
15.F.02.3	Installation of Lower and Middle Port Assemblies													
	Install Inner Port Extensions to Outer Wall of Vacuum Vessel	XL0006	Site Construction Labor	19,200	mhr				\$1,300	(5)	15	\$1,300	(5)	15
	Install Outer Port Extensions (Ducts) to Cryostat Nozzles	XL0006	Site Construction Labor	5,760	mhr				\$390	(5)	15	\$390	(5)	15
	Install Port Extension Bellows	XL0006	Site Construction Labor	7,680	mhr				\$520	(5)	15	\$520	(5)	15
	Install Shield Doors in Port Extensions (48) Total Required	XL0006	Site Construction Labor	2,880	mhr				\$195	(5)	15	\$195	(5)	15
15.F.02.3	Installation of the Other Port and Related Assemblies													
	Install Top Port Cover Structures	XL0006	Site Construction Labor	8,070	mhr				\$546	(5)	15	\$546	(5)	15
	Install Blanket Cooling Water External Piping System from Top Ports to the Manifold at the Cryostat	"Will Price Later When Design Sufficiently Developed"												
15.F.02.3	Polish and Final Clean Interior Surfaces of All Port Assemblies	XL0006	Site Construction Labor	3,120	mhr				\$211	(5)	20	\$211	(5)	20
15.F.02.4	Testing and Inspection													
	Dimensional Inspections	XL0006	Site Construction Labor	480	mhr				\$33	(5)	15	\$33	(5)	15
	Pressure and Leak Tests of Port Assemblies	XL0006	Site Construction Labor	2,400	mhr				\$163	(5)	15	\$163	(5)	15
	SUB-TOTALS					\$0	—	—	\$3,358	(5)	15	\$3,358	(5)	15

ITER EDA PHASE
PROJECT COST ESTIMATE (Rev. 1)
U.S. TEAM RE & C AND CB & I

VACUUM VESSEL ASSEMBLY AND TEST AT THE SITE
FIELD CONSTRUCTION
ITER TASK No. 8

Account No.	Account Description	Comd. Code	Commodity Description	Qty.	Unit	Material Cost (K\$)	Material Cost Uncert.		Labor Cost (K\$)	Labor Cost Uncert.		Total Cost (K\$)	Total Cost Uncert.	
							(-%)	(+%)		(-%)	(+%)		(-%)	(+%)
15.F.03	Support Structures Attached to Vacuum Vessel :													
15.F.03.3	Installation of External Main Vessel Support Attachment Assemblies													
	Attach (48) Pairs of Upper and Lower Support Structures	XL0006	Site Construction Labor	2,880	mhr				\$195	(5)	15	\$195	(5)	15
15.F.03.3	Installation of Internal Divertor Support Attachments													
	Attach (2) Square Supports to the Inside of the Vessel, All Around the Toroidal Direction	XL0006	Site Construction Labor	1,080	mhr				\$73	(5)	15	\$73	(5)	15
	Polish and Clean the Supports	XL0006	Site Construction Labor	330	mhr				\$22	(5)	15	\$22	(5)	15
15.F.03.4	Testing and Inspection													
	Dimensional Inspections	XL0006	Site Construction Labor	40	mhr				\$3	(5)	15	\$3	(5)	15
	SUB-TOTALS					\$0	—	—	\$293	(5)	15	\$293	(5)	15
15.F.04	External Pb/B4C Vessel Shielding													
	Complete Installation Must be to Exterior of Vacuum Vessel Segments, Prior to Installing Each Inside A.T.F. Coil													
15.F.04.2	Sub-Assembly at Site													
	Weld Inconel Studs to Exterior of Vacuum Vessel Segments	XL0006	Site Construction Labor	1,920	mhr				\$130	(5)	15	\$130	(5)	15
	Final Install Shielding Panels to Vessel Segments	XL0006	Site Construction Labor	19,200	mhr				\$1,300	(5)	15	\$1,300	(5)	15
15.F.04.4	Testing and Inspection													
	Dimensional Inspections	XL0006	Site Construction Labor	160	mhr				\$11	(5)	15	\$11	(5)	15
	SUB-TOTALS					\$0	—	—	\$1,441	(5)	15	\$1,441	(5)	15

SPECIAL JIGS AND FIXTURES BUDGET ESTIMATE FOR SHOP FABRICATION OF THE "ITER" VACUUM VESSEL

REF. No.	DESCRIPTION	TOTAL COST
1	Plasma Arc Cutter, with C.N.C. Control Unit and Water Table	\$374
2	Press Forming Dies for Inner Shell Plates	\$329
3	Press Forming Dies for Port Penetration Plates	\$112
4	Water Jet Cutting Unit, with C.N.C. Control Unit, (4) Heads, and Water Table	\$499
		\$0
5	(3) Sets of Initial Fit-Up Floor Plates: 60' x 40'	\$512
6	Temporary Stiffening for Cutting and Welding Port Openings in Inner Shell	\$100
7	Water Jet Tracking Unit for Cutting Port Openings	\$25
8	(6) Tilt Tables with Saddles, for Welding Main Vacuum Vessel Segments Together	\$749
9	(24) Sets of Internal Spider Restraint Framing: for Shop Dimensional Control and Shipping	\$1,797
10	(2) Sets of Segment Lifting and Turning Spreaders with Slings	\$300
11	Hysraulic Man Lift	\$62
12	Tube and Clamp Type Scaffolding	\$112
13	Ultrasonic Inspection Equipment	\$22
14	Optical / Laser Measuring and Alignment Equipment	\$94
15	Clearance Check Box Templates for Ports	\$15
16	Special Inert Gas and Electric Heated Furnace for Dim. Stability PWHT's and 300 Degrees Leak Tests	\$649
17	Plate Stiffener Gussets for Stabilizing Field Weld Joint Areas	\$102
18	Rotating Table for Water Cutting of Final Field Weld Joint Edge Preps	\$250
19	Water Jet Adapter Set-Up for Cutting Final Field Weld Joint Edge Preps	\$94
20	Backing Frames for Segment Support at Horizontal Milling Machine	\$250
21	Steel Fabr Containers for Shipping and Storage of S.S. Shielding Balls (Shop and Jobsite)	\$250
22	Hoppers with Hoses, etc for Installation of S.S. Shielding Balls Within the Segment Walls	\$549

SPECIAL JIGS AND FIXTURES BUDGET ESTIMATE FOR SHOP FABRICATION OF THE "ITER" VACUUM VESSEL

[illegible]

SPECIAL JIGS AND FIXTURES BUDGET ESTIMATE FOR FIELD ASSEMBLY OF THE "ITER" VACUUM VESSEL

REF. No.	DESCRIPTION	TOTAL COST
1	(2) Sets of V.V. Segment Lifting and Turning Spreaders with Slings	\$300
2	All Required Crannage: Assm. Area and at Machine	S.B.O.
3	Heavy Haul Transporter	S.B.O.
4	Electric Power, Including Main Distribution Panels	S.B.O.
5	Compressed Air Supply	S.B.O.
6	Special 650 Amp Electric Welding Machines	\$271
7	(2) Plasma Arc Cutting Machines	\$62
8	Ultrasonic Inspection Equipment	\$34
9	Optical / Laser Measuring and Alignment Equipment	\$112
10	Tube and Clamp Type Scaffolding	\$212
11	Combination Lifting Frame for T.F. Coil, and Lift / Holding Frame for T.F. Coil with V.V. Segment	S.B.O.
12	Fixture to Rotate V.V. Segment Into a T.F. Coil	\$349
13	Fixture to Temp. Support V.V. Segment Inside a T.F. Coil	\$120
14	Fixtures to Align and Fit-Up V.V. Segments Together, and Restrain Field Weld Joint Areas	\$90
15	Inside Vacuum Vessel Access Platforms	\$150
16	Fixtures and Actuators to Rotate "Entire Fit-Up Vacuum Vessel" 7.5 Degrees to Its Final Position	S.B.O.
17	Hoppers with Hoses, etc for Installation of S.S. Shielding Balls Within the Field Seam Walls	\$137
18	Temp. Pins to Maintain Alignment of Holes in Exterior Vessel Support Lugs During Welding	\$45
19	Lifting and Alignment Fixtures for Handling Port Extensions, Bellows, Ducts	\$75
20	Misc. for Air Pressure Testing of the Field Seam Annular Space Areas	\$12

SPECIAL JIGS AND FIXTURES BUDGET ESTIMATE FOR FIELD ASSEMBLY OF THE "ITER" VACUUM VESSEL

REF. No.	DESCRIPTION	TOTAL COST
21	Forced Hot Air System for Testing of the Field Seam Annular Space Areas	\$90
22	Tank, Pump, Flow Meter, Deionized Water, etc for Water Flow Testing of Field Seam Annular Areas	\$31
23	Additional Temp. Covers for Vacuum Testing of the Completed Vacuum Vessel	\$45
24	Vacuum Vessel Air Ventilation System	\$262
25	Vacuum Vessel Access Cabin for Clean Entry	\$37
26	All In-Service Remote Maintance (R.H.) Fixtures, Rigging, Tools, etc.	Not in Scope of Vacuum Vessel
"S.B.O. : Assumed to be Supplied by Others"		
TOTAL COSTS (K\$: 1993 BASIS)		\$2,435

Part D**Assessment of Type 316LN Stainless Steel as Alternative
Vacuum Vessel Material****Table of Contents**

D.1. Introduction.....	1
D.2. Scope.....	1
D.3. Type 316LN Stainless Steel Material Assessment.....	2
D.3.1 Availability and Mill Surface Finish	2
D.3.2 Sizing and Forming	2
D.3.3 Machinability.....	3
D.3.4 Weldability.....	3
D.3.5 Nondestructive Examination (NDE)	3
D.3.6 Heat Treatment	3
D.3.7 Vacuum Service Applicability	3
D.3.8 Manufacturing	4
D.3.9 Cost Differences.....	4
D.3.10 Summary and Recommendations	4

D.1. Introduction

The Part A Vacuum Vessel Fabrication Assessment provided a vacuum vessel manufacturing overview and plan for Alloy 625 material. The JCT has indicated however, that Type 316LN stainless steel is being considered as an alternative vessel material.

D.2. Scope

Part D Assessment of Type 316LN Stainless Steel as Alternative Vacuum Vessel Material presents a comparative summation of the Part A material and manufacturing assessment considering Type 316LN as an alternative vessel material. Similarities and differences in manufacturing processes using Type 316LN stainless steel versus Alloy 625 are presented.

Generally, the design basis (ITER design documents and Raytheon/CB&I sketches) and manufacturing characteristics presented in the Part A Vacuum Vessel Fabrication Assessment for the Alloy 625 have been used for the assessment of the Type 316LN vessel material alternative. Consistent with the Part A discussions, the following topics are addressed:

- material availability and mill surface finish,
- sizing and forming,
- machinability,
- weldability,
- nondestructive examination,
- heat treatment,
- vacuum service applicability, and
- manufacturing.

Manufacturing process differences and the potential effect on overall vessel costs are briefly discussed. An assessment summary is also presented.

D.3. Type 316LN Stainless Steel Material Assessment

This section addresses the use of Type 316LN austenitic stainless steel as an alternative to Alloy 625. At the direction of the ITER JCT (Table 1 Reference 9), the vessel design basis described in ITER Garching Joint Work Site Memo (Draft #9 - G15 MD 01 94-17-05 W 1) is applicable to a Type 316LN vessel with the following material thickness revisions.

Vessel Component	Alloy 625 Material Thickness	Type 316LN Material Thickness
Vessel Segment Inner Shell	30 mm	40 mm
Vessel Segment Outer Shell	30 mm	40 mm
Shell Reinforcement	40 mm	50 mm
Ribs	30 mm	40 mm
Port Structure	50 mm	60 mm
Port Structure Reinforcement	50 mm	60 mm

D.3.1 Availability and Mill Surface Finish

Discussions with mill suppliers have indicated that Type 316LN is not as readily available as the standard grade of Type 316 stainless steel. Suppliers do not anticipate however, any difficulty with supplying the material in the required quantities.

Similar to the Alloy 625 material, an achievable mill surface finish for the Type 316LN sheet and plate materials is a No. 4 polished finish (381-635 micro mm). As with the Alloy 625 material, additional surface finish specification requirements will necessitate additional finishing operations. Type 316LN will be more susceptible to surface scratching than Alloy 625 and therefore, additional care to prevent damage to the polished surfaces during shipping and handling will be necessary with this material.

D.3.2 Sizing and Forming

The lower yield and tensile strengths of the Type 316LN material requires less power during forming. This requirement may be offset by the heavier cross-section (i.e. increased plate thicknesses) identified for the stainless steel materials. The net anticipated power requirements are expected to be roughly equivalent to that required for Alloy 625.

The magnetic permeability of Type 316LN stainless steel tends to increase during forming or cold-working. Although this increase could potentially have an adverse effect on the suitability of the material for the intended vacuum vessel service, the use of this material on the Tokamak Fusion Test Reactor (TFTR) should preclude any concerns regarding its intended vacuum vessel application.

D.3.3 Machinability

Type 316 is more readily machined than Alloy 625. This advantage however, may be offset by the increased machining due to the greater thickness of the shell segment plates and port assembly components.

D.3.4 Weldability

Weldability of Type 316LN stainless steel is similar to Alloy 625 and may be performed using the same welding processes. There is greater industry experience with welding of the austenitic stainless steels and weld shop productivity is estimated to be approximately 20% greater when welding austenitic stainless steels vs. Alloy 625.

The greater material thickness will significantly increase the volume of weld metal and the potential for weld-induced distortion. Higher costs associated with additional welding time and welding filler metal can therefore be expected.

Austenitic stainless steel deposited weld metal is generally specified to contain a minimum amount of delta ferrite (typically in the range of 2-5%), to preclude the occurrence of microfissuring. Delta ferrite is slightly magnetic, which is undesirable for vacuum vessel service. Also there will be added costs for the required QC measures to verify conformance of the Type 316 vessel with the required minimum delta ferrite and maximum magnetic permeability criteria. Correlation between % ferrite and magnetic permeability (μ) are available for these purposes.

D.3.5 Nondestructive Examination (NDE)

No significant differences are anticipated between the weld NDE techniques applicable to Type 316LN stainless steel vs. Alloy 625. Increased time and costs associated with the examination procedures for a greater volume of stainless steel weld metal are expected.

D.3.6 Heat Treatment

Post-forming or postweld heat treatment is not normally required for fabrication of Alloy 625 or Type 316LN stainless steel vessels. A 'dimensional stability heat treatment' was performed on the Type 316LN vessel segments for TFTR. The need for such a requirement for the ITER vessel segments needs to be further investigated to the extent that it may be necessary for maintenance of critical tolerances during vessel bake-out.

D.3.7 Vacuum Service Applicability

Vacuum service applicability of Type 316LN stainless steel material' has been demonstrated by its record of satisfactory service in major fusion devices such as the

TFTR vacuum vessel. The specified ITER vessel segment leak rate of 1×10^{-9} std cc/sec. is not expected to present any significant concerns for a Type 316LN vessel.

D.3.8 Manufacturing

The Type 316LN stainless steel increased plate thickness, estimated to be of the order of 20% to 33% or 10 mm greater than the equivalent Alloy 625 vessel material will proportionately increase the vacuum vessel weight. This increased weight may potentially impact the required fixturing and handling of the vessel components at both the manufacturing facility and in the field.

Weld joint details to be used for Type 316 stainless steel are similar to those used for welding of Alloy 625. The greater volume however, of the stainless steel weld joints introduces additional associated material, welding, QC, and inspection costs. The increased weld material deposition and resultant distortion as a result of weld shrinkage could adversely affect the maintenance of the specified dimensional tolerances.

D.3.9 Cost Differences

Detailed cost spreadsheets similar to those provided in the Part C "Cost Estimate" have not been formally prepared for an alternate Type 316LN vessel. Estimated costs by WBS accounts however, have been evaluated and are tabulated for this report. The estimated costs provided within the following Table identify a net cost reduction for an alternate Type 316LN vessel of \$75 million. (Material cost reductions are estimated at \$80 million while labor cost increases on the order of \$5 million are anticipated.) Specific factors associated with these estimated costs include:

- potential lower cost of Type 316LN plate material,
- lower costs of welding filler metal material,
- higher costs associated with additional welding time and quantity of welding filler metal,
- higher NDE costs for volumetric examinations,
- additional heat treatment costs if it is determined that a "dimensional stability heat treatment" as was performed for TFTR is required, and
- potential for additional machining operations as necessary after welding to maintain critical dimensional tolerances.

D.3.10 Summary and Recommendations

In summary, the proposed low-carbon, nitrogen strengthened austenitic stainless Type 316LN material should present no unusual manufacturing problems to experienced fabricators of high alloy materials. The Task No. 8 assessment presented in this Section provides an overview of the manufacturing differences between an Alloy 625 and Type 316LN vessel. Notable Type 316LN material issues identified during this assessment include:

- increased thickness and associated vessel manufacture costs may offset any reduced material cost advantages,
- increased vessel weight due to greater material thickness may present additional shop handling and field assembly concerns,
- greater magnetic permeability of the base metal after forming and working may be undesirable, and
- increased weld metal volume may adversely impact the capability to control distortion and maintain specified tolerances.

It is recommended that the impact of these issues on the fabricability of the ITER vacuum vessel be assessed prior to any decision related to the selection of this alternative material. A follow-on assessment to this Task No. 8 should be considered to address these issues.

VACUUM VESSEL SHOP FABRICATION AND SITE ASSEMBLY (STAINLESS STEEL 316LN MATERIAL)

ALTERNATE PROJECT COST ESTIMATE SUMMARY (REV. 1)

I.T.E.R. TASK NO. 8

**I.T.E.R. ENGINEERING DESIGN ACTIVITY PHASE U.S. TEAM
RAYTHEON ENGR. & CONSTR. AND CHICAGO BRIDGE & IRON**

WBS ACCOUNT NO.	ACCOUNT DESCRIPTION	MATERIAL COST (K\$)	MATERIAL COST UNCERTAINTY		LABOR COST (K\$)	LABOR COST UNCERTAINTY		TOTAL COST (K\$)	TOTAL COST UNCERTAINTY	
			(-%)	(+%)		(-%)	(+%)		(-%)	(+%)
15. A	VACUUM VESSEL MAIN ASSEMBLY: VENDOR SHOP FABRICATION	\$107,665	---	---	\$47,496	---	---	\$155,161	---	---
15. B	V.V. PORT ASSEMBLIES: VENDOR SHOP FABRICATION	\$26,670	---	---	\$21,536	---	---	\$48,206	---	---
15. C	V.V. SUPPORT ATTACHMENTS: VENDOR SHOP FABRICATION	\$8,604	---	---	\$6,025	---	---	\$14,629	---	---
15. D	V.V. Pb-B4C EXTERNAL SHIELDING: VENDOR SHOP FABRICATION	\$12,917	---	---	\$8,431	---	---	\$21,348	---	---
15. E	SPECIAL JIGS & FIXTURES, AND MAJOR EQUIPMENT	\$13,967	---	---	\$0	---	---	\$13,967	---	---
15. F	VACUUM VESSEL ASSEMBLY AND TESTING AT THE JOBSITE	\$0	---	---	\$22,120	---	---	\$22,120	---	---
15	VACUUM VESSEL: TOTAL COST	\$169,823	0	18	\$105,608	0	25	\$275,431	0	21

NOTES: 1) ALL ABOVE COST FIGURES ARE IN (K\$): 1,000'S OF U.S. DOLLARS.

2) ALL ABOVE FIGURES ARE ON THE BASIS OF 1993 COSTS, WITHOUT ANY PROVISION FOR ESCALATION.

3) ABOVE IS A SUMMARY OF THE TOTAL ESTIMATE FOR THE ALTERNATE 316LN STAINLESS STEEL MATERIAL.

4) THE ALTERNATE S.S. MATERIAL REQUIRES 1,460 MTONS OF ADDITIONAL SHIP WEIGHT FROM THE SHOP (12,665 VS. 11,205)

ITER TASK NO. 8

VACUUM VESSEL FABRICATION PLAN & COST STUDY (D68)

VACUUM VESSEL SKETCH SUMMARY

SK1001	15° SEGMENT WITH PORTS AND
SK1002	15° VESSEL SEGMENT ASSEMBL
SK1003	VERTICAL PORT COVER & INNE
SK1004	15° VESSEL SEGMENT OUTER S
SK1005	15° VESSEL SEGMENT ASSEMBL
SK1006	15° VESSEL SEGMENT RIB ASSE
SK1007	VESSEL RIB DETAILS
SK1008	INNER SHELL DEVELOPMENT
SK1009	ELEVATION VESSEL SHELL WIT
SK1010	VESSEL SHELL PLAN & ELEVAT
SK1011	VESSEL SHELL PROFILES
SK1012	VESSEL SHELL TYPICAL WELD
SK1013	ASSEMBLY OF 3-15° VESSEL SI
SK1014	FIELD CLOSURE JOINT DETAIL
SK1015	PORT CONNECTION & WELD DET
SK1016	PORT STRUCTURE SHIELD DOOR
SK1017	(DRAWING NOT USED)
SK1018	BLANKET SUPPORT DETAILS
SK1019	TYPICAL SEGMENT SUPPORT LL
SK1020	SECTION THRU HORIZONTAL PO

BLANKET SUPPORTS
Y ISOMETRIC
R PORT EXTENSIONS
HELL CLOSURE PLATES
Y ISOMETRIC OUTER SHELL REMOVED
SEMBLY

H PORTS
ION

DETAILS
EGMENTS

AILS

GS UPPER & LOWER
RT

RAYTHEON ENGINEERS AND CONSTRUCTORS	
ITER VACUUM VESSEL TASK 8	
REF NO. G 15 SP 06 94-05-16 W I	
MEMO DRAFT 9 (20-9-94)	
SK 1000	01-10-95

VESSEL SEGMENT
SK1002

SCALE
0 100 200 300 400 500 600 700 800 900 1000

INNER BLANKET
SUPPORTS
SK 1018

15° VESSEL SEGMENT WITH PORTS AND BLANKET SUP

RAYTHEON ENGINEERS AND CONSTRUCTORS	
ITER VACUUM VESSEL TASK 8	
REF NO. G 15 SP 06 94-05-16 W 1	
MEMO DRAFT 9 (20-9-94)	
SK 1001	01-10-95

INNER BLANKET SUPPORT
SKI018
(SHOP INSTALLED)

15° VESSEL SEGMENT
ASSEMBLY ISOMETRIC

SUPPORTS TO STRUCTURE
SKI019
(FIELD INSTALLED)

RAYTHEON ENGINEERS AND CONSTRUCTORS	
ITER VACUUM VESSEL TASK 8	
REF NO. G 15 MD 01 94-17-05 W 1	
MEMO DRAFT 9 (20-9-94)	
SK 1002	01-10-95

DIVERTER I
EXTENSION
(FIELD IN)

(VERTICAL PORT COVER & INNER PORT

VERTICAL PORT COVER
(FIELD INSTALLED)

HORIZONTAL PORT
EXTENSION
(FIELD INSTALLED)

PORT
(INSTALLED)

(EXTENSIONS)

RAYTHEON ENGINEERS AND CONSTRUCTORS	
ITER VACUUM VESSEL TASK 8	
REF NO. G 15 SP 06 94-05-16 W 1	
MEMO DRAFT 9 (20-9-94)	
SK 1003	01-10-95

15° VESSEL SEGMENT
(OUTER SHELL CLOSURE PLATES)

ACCESS HOLES FOR
SHIELD BALLS
INSTALLED IN SHOP
(TYPICAL ALL PLATES)

RAYTHEON ENGINEERS AND CONSTRUCTORS	
ITER VACUUM VESSEL TASK 8	
REF NO. G 15 MD 01 94-17-05 W 1	
MEMO DRAFT 9 (20-9-94)	
SK 1004	01-10-95

INNER BLANKET SUPPORT
SHOP INSTALLED
SK1018

15° VESSEL SEGMENT
ASSEMBLY ISOMETRIC
OUTER SHELL REMOVED

SUPPORTS TO STRUCTURE
FIELD INSTALLED
SK1019

RAYTHEON ENGINEERS AND CONSTRUCTORS	
ITER VACUUM VESSEL TASK 8	
REF NO. G 15 MD 01 94-17-05 W 1	
MEMO DRAFT 9 (20-9-94)	
SK 1005	01-10-95

RIB 9

RIB 10

RIB 11

RIB

RIB

RIB

15° VESSEL SEGMENT
RIB ASSEMBLY

RAYTHEON ENGINEERS AND CONSTRUCTORS	
ITER VACUUM VESSEL TASK 8	
REF NO. G 15 MD 01 94-17-05 W 1	
MEMO DRAFT 9 (20-9-94)	
SK 1006	01-10-95

RIB 1

RIB 2

RIB 3

RIB 6

RIB 7

RIB

VESSEL RIB DETAILS

LENGTH
17468.320 MM

LENGTH
4251.786 MM

LENGTH
4233.638 MM

LENGTH
4077.501 MM

LENGTH
30338.730 MM

LENGTH
9244.561 MM

LENGTH
9249.942 MM

LENGTH
23546.016 MM

LENGTH
4117.710 MM

LENGTH
6782.882 MM

LENGTH
4482.827 MM

RIB 4

RIB 5

LENGTH
4117.710 MM

LENGTH
2394.395 MM

RIB 9

RIB 10

RIB 11

SCALE
0MM 500MM 1M 2M

RAYTHEON ENGINEERS AND CONSTRUCTORS	
ITER VACUUM VESSEL TASK 8	
REF NO. G 15 MD 01 94-17-05 W 1	
MEMO DRAFT 9 (20-9-94)	
SK 1007	01-10-95

32.598
828.8

366.165
9300.6

242.981
6171.7

78.727
1999.7

115.079
2923.0

86.183
2189.0

171.722
4361.7

125.491
3187.5

1417.594
36006.9

SCALE
1" = 10' 0"

INNER SHELL DEVELOPMENT

RAYTHEON ENGINEERS AND CONSTRUCTORS	
ITER VACUUM VESSEL TASK 8	
REF NO. G 15 MD 01 94-17-05 W 1	
MEMO DRAFT 9 (20-9-94)	
SK 1008	01-10-95

SCALE
0M 500MM 1M 2M

ELEVATION - VESS

L SHELL WITH PORTS

RAYTHEON ENGINEERS AND CONSTRUCTORS
ITER VACUUM VESSEL TASK 8
REF NO. G 15 MD 01 94-17-05 W 1
MEMO DRAFT 9 (20-9-94)
SK 1009 01-10-95

SCALE
0MM 500MM 1M 2M

VESSEL SHELLS (PLAN & ELEVATION)

RAYTHEON ENGINEERS AND CONSTRUCTORS	
ITER VACUUM VESSEL TASK 8	
REF NO, G 15 MD 01 94-17-05 W 1	
MEMO DRAFT 9 (20-9-94)	
SK 1010	01-10-95

INNER SHELL

POINT	COORDINATES	
	INCHES	MILLIMETERS
A	384.311,159.449	9761.500,4050.000
B	270.709,113.465	6876.000,2882.000
C	273.819,111.693	6955.000,2837.000
D	151.890,12.362	3858.000,314.000
E	186.260,-2.165	4731.000,-55.000
F	274.409,-114.764	6970.000,-2915.000
G	384.311,-153.780	9761.500,-3906
H	338.110,-240.039	8588.000,-6097.000
J	254.572,192.403	6466.145,4887.039
K	257.036,186.608	6528.703,4739.832
L	235.295,26.289	5976.497,667.729
M	234.251,25.889	5949.975,657.569
N	235.521,-29.947	5982.235,-760.651
P	317.980,-180.766	8076.701,-4591.453
R	262.919,-187.484	6678.138,-4762.083
S	234.563,-187.975	5957.908,-4774.557
T	290.301,169.511	7373.637,4305.567

SCALE
0 1500MM 2M

OUTER SHELL

DUAL DIMENSIONS ARE
INCHES OVER MILLIMETERS

TYPICAL SHELL THICKNESS 30MM

VESSEL SHELL ELEVATION

EL SHELLS PROFILES

RAYTHEON ENGINEERS AND CONSTRUCTORS	
ITER VACUUM VESSEL TASK 8	
REF NO. G 15 SP 06 94-05-16 W I	
MEMO DRAFT 9 (20-9-94)	
SK 1011	01-10-95

DETAIL A

VESSEL SHELL
 TYPICAL WELD DET

BACKING BAR DETAIL

INNER SHELL
TYPICAL GROOVE WELD

INNER SHELL OF
VACUUM VESSEL

DETAIL D

DETAILS

RAYTHEON ENGINEERS AND CONSTRUCTORS	
ITER VACUUM VESSEL TASK 8	
REF NO. G 15 SP 06 94-05-16 W 1	
MEMO DRAFT 9 (20-9-94)	
SK 1012	01-10-95

ASSEMBLY (3) 15° VESSEL SEGMENTS

RAYTHEON ENGINEERS AND CONSTRUCTORS	
ITER VACUUM VESSEL TASK 8	
REF NO. 6 15 SP 06 94-05-16 W 1	
MEMO DRAFT 9 (20-9-94)	
SK 1013	01-10-95

15° VESSEL SEGMENT

FIELD CLOSURE

OPTIONAL BACKING BAR DESIGN

NOTE 1-

RIB DOES NOT PENETRATE
OUTER SHELL AT FIELD
CLOSURE JOINT LOCATION

PRE JOINT DETAIL

RAYTHEON ENGINEERS AND CONSTRUCTORS	
ITER VACUUM VESSEL TASK 8	
REF NO. G 15 MD 01 94-17-05 W 1	
MEMO DRAFT 9 (20-9-94)	
SK 1014	01-10-95

SECTION

PORT STRUCTURE SHIELD
(TYPICAL AT MIDDLE AND LOWER INNER

A-A

SCALE

DOOR
PORT EXTENSIONS)

RAYTHEON ENGINEERS AND CONSTRUCTORS	
ITER VACUUM VESSEL TASK 8	
REF NO. G 15 MD 01 94-17-05 W 1	
MEMO DRAFT 9 (20-9-94)	
SK 1016	01-10-95

OUTER
BLANKET
SUPPORT

INNER
BLANKET
SUPPORT

PLAN VIEW

ELEVATION VIEW

RIGHT VIEW

LANKET SUPPORT DETAILS

RAYTHEON ENGINEERS AND CONSTRUCTORS	
ITER VACUUM VESSEL TASK 8	
REF NO. G 15 SP 06 94-05-16 W 1	
MEMO DRAFT 9 (20-9-94)	
SK 1018	01-10-95

SECTION A-A

TYPICAL SEGMENT

T SUPPORT LUGS UPPER & LOWER

RAYTHEON ENGINEERS AND CONSTRUCTORS	
ITER VACUUM VESSEL TASK 8	
REF NO. G 15 MD 01 94-17-05 W 1	
MEMO DRAFT 9 (20-9-94)	
SK 1019	01-10-95

SECTION TH

RU HORIZONTAL PORT

RAYTHEON ENGINEERS AND CONSTRUCTORS	
ITER VACUUM VESSEL TASK 8	
REF NO. G 15 MD 01 94-17-05 W 1	
MEMO DRAFT 9 (20-9-94)	
SK 1020	01-10-95

DRAFT # 9 (20/ 9/ 94)

ITER
Garching Joint Work Site

MEMO

TO: D-68 Task Officers

FROM: G. Johnson and K. Ioki

SUBJECT: Vacuum Vessel Fabrication Plan and Cost Study (Task D68) - Detail Guidance

REF. NO.: G 15 MD 01 94-17-05 W 1

DATE: 20 September 1994

In order to insure consistency and help make the results easier to compare and analyse, we are providing a common cost structure and format for the vessel cost study results (Task D68). The overall cost structure should follow the vacuum vessel WBS (Work Breakdown Structure), which is included in appendix A. The cost results should be summarised on spread sheets similar to those shown in appendix B. Also included in appendix B is information on how the enclosed spread sheets are set-up and can be used. Completed spread sheet examples are included in appendix C. A list of general costing assumptions and guidelines is given in appendix D.

Specifications have been generated for each major vessel system. These specifications include drawings, sketches, and assumptions to be used as a technical basis for the estimates. The information included in these specifications will be frozen at a date in late September or early October. The specification numbers and titles are listed below:

WBS No.	Spec. No.	Title
15.A	G 15 SP 01 94-05-16 W 1	Vacuum Vessel Main Assembly
15.B	G 15 SP 02 94-05-16 W 1	Port Assemblies
15.C	G 15 SP 03 94-05-16 W 1	Support Structures
15.D	G 15 SP 04 94-05-16 W 1	Add. Pb/B4C Shielding For TF Coils
15.E	G 15 SP 05 94-05-16 W 1	Assembly and Special Fixtures
15.F	G 15 SP 06 94-05-16 W 1	Vacuum Vessel Assembly and Test at the Site

In order to assist in our efforts to monitor the progress of this activity, a schedule of requested input from each home team has been developed and is listed below.

Nov. 7, 1994 - A 1-2 page progress report.

Dec. 30, 1994 - Two bound copies of the final report including an executive summary,

A copy of each report specified above is to be sent to G. Johnson at the Garching site by the requested date.

Appendix A
(Vacuum Vessel - WBS)

Vacuum Vessel

WBS (Work Breakdown Structure)

- 15 Vacuum Vessel**
 - 15.A Vacuum Vessel Main Assembly**
 - 15.A.01 Inner and Outer Shell**
 - 15.A.02 Leak Detection System**
 - 15.A.03 Shielding for V. V.**
 - 15.A.04 Cooling Piping**
 - 15.A.05 Wall Conditioning System**
 - 15.B Port Assemblies**
 - 15.B.01 Port Structures**
 - 15.B.02 Port Extensions**
 - 15.B.03 Port Bellows Assy's**
 - 15.B.04 Special Access Ports & Bellows**
 - 15.C Support Structures**
 - 15.C.01 Blanket to VV Support**
 - 15.C.02 VV to Structure Supports**
 - 15.C.03 Divertor to VV Supports**
 - 15.D Add. Pb/B4C Shielding for TF Coil**
 - 15.D.01 Pb/B4C Shielding**
 - 15.D.02 Support Structure**
 - 15.E Assembly and Special Fixtures**
 - 15.E.01 Assembly Fixtures**
 - 15.E.02 Alignment Fixtures**

Appendix B
(Spread Sheet for Cost Results)

ESTIMATE												
ACCOUNT NAME	Rel. Key	Commod. Code	Commodity Name	QTY	Quantity	Uncertainty	UNIT	Material Cost	Cost	Labour Cost	Cost	Uncert.
					(-%)	(+%)		(K\$)	(-%)	(+%)	(K\$)	(-%)
VACUUM VESSEL - TOTAL												
Vacuum Vessel Main Assembly												
Port Assemblies												
Support Structures												
Op Shielding												
Assembly and Special Fixtures												
Vacuum Vessel - Assy & Test at Site												

[illegible]

[illegible]

ESTIMATE	Ref. Key	Commod Code	Commodity Name	QTY	Quantity Uncertainty (-%)	Quantity Uncertainty (+%)	PORT ASSEMBLIES										Total Cost (\$K)	Total Cost Uncert. (-%)	Total Cost Uncert. (+%)	#VALUE!	#VALUE!	
							UNIT	Material Cost (\$K)	Material Cost Uncert. (-%)	Material Cost Uncert. (+%)	Labour Cost (\$K)	Labour Cost Uncert. (-%)	Labour Cost Uncert. (+%)	#VALUE!	#VALUE!	#VALUE!						#VALUE!
ACCOUNT NAME																						
Port Assemblies																						
(Total for 24 Sectors)																						
Port Structures																						
Manufacturing Engineering																						
Manufacturing Drawings																						
Project Engineering																						
Quality Assurance																						
Quality Control																						
TPI (Third Party Inspection)																						
Manufacturing & Assembly																						
Top port structures																						
Middle port structures																						
Lower port structures																						
Top port cover plates																						
Shield doors																						
Testing & Inspection																						
Leak & Pressure Tests																						
Dimensional Inspection																						
SUBTOTAL																						
Port Extensions																						
Manufacturing Engineering																						
Manufacturing Drawings																						
Project Engineering																						
Quality Assurance																						
Quality Control																						
TPI (Third Party Inspection)																						
Manufacturing & Assembly																						
Field port extensions																						
Over port extensions																						
Testing & Inspection																						

OST ESTIMATE

SI ESTIMATE	Ref. Key	Commod Code	Commodity Name	QTY	Quantity Uncertainty (-%)	Quantity Uncertainty (+%)	Pb / B4C SHIELDING						Total Cost (\$K)	Total Cost Uncert. (-%)	Total Cost Uncert. (+%)
							Material Cost (\$K)	Material Cost Uncert. (-%)	Material Cost Uncert. (+%)	Labour Cost (\$K)	Labour Cost Uncert. (-%)	Labour Cost Uncert. (+%)			
							UNIT	#VALUE!	#VALUE!	#N/A	#VALUE!	#VALUE!	#N/A	#VALUE!	#VALUE!
ACCOUNT NAME															
Pb / B4C Shielding															
(Total for 24 Sectors)															
Pb / B4C Shielding															
Manufacturing Engineering															
Manufacturing Drawings															
Project Engineering															
Quality Assurance															
Quality Control															
TPI (Third Party Inspection)															
Manufacturing & Assembly															
Pb shielding															
B4C shielding															
SS boxes															
Testing & Inspection															
Dimensional Inspection															
SUBTOTAL															
Structure Supports															
Manufacturing Engineering															
Manufacturing Drawings															
Project Engineering															
Quality Assurance															
Quality Control															
TPI (Third Party Inspection)															
Manufacturing & Assembly															
Support Structures															
Testing & Inspection															
Dimensional Inspection															
SUBTOTAL															

Assy & Special Fixtures

ESTIMATE

ESTIMATE																
ACCOUNT NAME	Ref. Key	Commod Code	Commodity Name	QTY	Quantity Uncertainty		UNIT	Material Cost (K\$)	Material Cost Uncert.		Labour Cost (K\$)	Labour Cost Uncert.		Total Cost (K\$)	Total Cost Uncert.	
					(-%)	(++)			(-%)	(++)		(-%)	(++)		(-%)	(++)

VACUUM VESSEL- Assy & Test at Site																
COST ESTIMATE																
ACCOUNT NAME	Ref. Key	Commod Code	Commodity Name	QTY	Quantity Uncertainty		UNIT	Material Cost (K\$)	Material Cost Uncert.		Labour Cost (K\$)	Labour Cost Uncert.		Total Cost (K\$)	Total Cost Uncert.	
					(-%)	(+%)			(-%)	(+%)		(-%)	(+%)		(-%)	(+%)
Vacuum Vessel Assy & Test at Site								#N/A	#VALUE!	#VALUE!	#N/A	#VALUE!	#VALUE!	#N/A	#VALUE!	#VALUE!
(Total for 24 Sectors)																
Vacuum Vessel Main Assy																
Manufacturing Engineering																
Manufacturing Drawings			#N/A				#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Project Engineering			#N/A				#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Quality Assurance			#N/A				#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Quality Control			#N/A				#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
TPI (Third Party Inspection)			#N/A				#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Assembly (At site)																
Test assy on mechanical structure			#N/A				#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Final assy on mech. structure			#N/A				#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Rotating & positioning vessel			#N/A				#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Welding on vessel ports			#N/A				#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Installing balls at field joints			#N/A				#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Testing																
Pressure Tests			#N/A				#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Leak Tests			#N/A				#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Flow Tests			#N/A				#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Inspections (At site)																
Dimensional			#N/A				#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
SUBTOTAL								#N/A	#VALUE!	#VALUE!	#N/A	#VALUE!	#VALUE!	#N/A	#VALUE!	#VALUE!
Leak Detection System																
Manufacturing Engineering																
Manufacturing Drawings			#N/A				#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Project Engineering			#N/A				#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Quality Assurance			#N/A				#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Quality Control			#N/A				#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
TPI (Third Party Inspection)			#N/A				#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Assembly (At site)																
Assy & welding of port bellows			#N/A				#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Assy & welding of port extensions			#N/A				#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

[illegible]

[illegible]

Notes on using Cost Spreadsheets

1. There are two types of files: Cost spreadsheets which are files named "Cost Est - ..." and commodity spreadsheets which are files named "commod" for costing and commodities respectively. Do not change the names of these files (keep a backup copy in its own folder somewhere).
2. There is a cost spreadsheet for each vessel subsystem. The list of account names along the left side of each cost sheet is a proposed breakdown of cost, but can be added to or reduced as is felt appropriate. There is only one commodity table and the information on it will automatically be added to a cost spread sheet when the commodity code is listed on the spreadsheet. Some proposed commodities are listed on the commodity table but others can be added or values changed as appropriate.
3. Begin by defining additional commodity data if needed. You choose all codes, names, units and values.
4. Now open the costing spreadsheet. You need to define the structure in the unshaded columns. Wherever possible use the following guidelines:
 - (a) Break down the cost of each component into the following main headings: 1. Engineering; 2. Manufacture and Assembly; 3. Testing and Inspection.
 - (b) These all refer to the subcomponent manufacture, so any integration work involving different components should be shown as a separate cost heading, appropriately broken down.
 - (c) There are two ways of handling special raw materials:
 - (i) define a commodity table entry, if you wish to repeatedly refer to the cost under several sub-components, e.g. special quality steel;
 - (ii) if you only need to use it once in the estimate, include the material as a line item under (2), e.g. 1m² Be tiles.
 - (d) "2. Manufacture and Assembly" could be broken down e.g. into sub-components, or into sub-elements, e.g. materials and processes, or a mix, as appropriate.
 - (e) Try to get the line items in the costing spreadsheet to fit as closely as possible to the eventual contracts and their subdivisions.
5. You don't need to specify numbers in the shaded columns - these are all calculated from formulae for you. You will need to copy the row to the appropriate line of your spreadsheet before filling in the commodity code and quantity details, to ensure the formulae are also copied. If an uncertainty value is zero, enter zero or leave blank. You can override formulae by entering a value.

6. Two columns are given for +/- uncertainties, to allow you to specify unequal percentages at this stage of R&D. However, the core of the estimate should be the most likely value you expect in 1998.
7. You will need to adjust the formulae in the subtotals line after copying it into place, to indicate the range of line numbers to be covered. Use the example "subtotal" line to see how this is done.

Method of costing

1. Each costing line should wherever possible be calculated based on a "commodity", with its associated material and labour costs, and a unique cost driving parameter. These are documented in the Commodity Table, at present defined by the estimator.
2. The commodity table on which the cost estimate is based should typically consist of costs of different materials (both raw and already assembled equipment), and costs of different types of manpower. Some commodities will contain both material and labour elements.
3. The costing line items should be broken up to such an extent that they use as far as possible conventional items, to allow standardisation across the whole cost estimate.
4. Use a referencable cost source wherever possible, preferably industry, and seek confirmatory quotations.

Cost Breakdown Structure

1. At the top level the CBS should use the WBS/CI 2-digit code.
2. Below this level the breakdown is up to the cost estimator.
3. The lowest level should as far as possible be a breakdown into the cost elements of the final work packages to industry.

Standard ITER On-Site Labor Rates

The cost estimates prepared during the EDA include a number of parameters which will require adjustment after the site is selected. The table below provides a set of labor rates for both field construction and shop manufacturing operations. These rates are to be used by all estimators for site operations until such time as the site has been selected and actual site labor rates can be developed. When creating a commodity which includes a labor content, the estimator should use these rates, multiplied by the number of man-hours per commodity unit, to calculate the labor content value. These data have been embedded in the EXCEL spreadsheets in the attached files.

Ref. Key	Commodity Code	Description	Base Labor Cost	Fringe Cost	Total Direct Labor Cost	Support Cost	Total Cost
1	XL0001	Site Construction Labor-Architectural	\$17.23	\$4.82	\$22.05	\$32.27	\$54.32
1	XL0002	Site Construction Labor-Concrete	\$17.32	\$7.22	\$24.54	\$27.63	\$52.17
1	XL0004	Site Construction Labor-Earthwork	\$16.80	\$8.24	\$25.04	\$28.61	\$53.65
1	XL0003	Site Construction Labor-Electrical	\$21.58	\$5.39	\$26.97	\$29.82	\$56.79
1	XL0005	Site Construction Labor-Instrument	\$20.02	\$7.96	\$27.98	\$31.31	\$59.29
1	XL0006	Site Construction Labor-Mechanical	\$20.76	\$6.96	\$27.72	\$39.99	\$67.71
1	XL0007	Site Construction Labor-Piping	\$20.02	\$7.96	\$27.98	\$31.31	\$59.29
1	XL0008	Site Construction Labor-Startup	\$19.50	\$8.00	\$27.50	\$30.00	\$57.50
1	XL0009	Site Construction Labor-Structural	\$19.09	\$7.01	\$26.10	\$32.27	\$58.37
2	XL0010	Shop direct Labor - Crane Operator	\$17.00	\$6.97	\$23.97	\$23.97	\$47.94
2	XL0011	Shop direct Labor - Electrical	\$19.50	\$8.00	\$27.50	\$27.50	\$54.99
2	XL0012	Shop direct Labor - Fluids testing	\$20.00	\$8.20	\$28.20	\$28.20	\$56.40
2	XL0013	Shop direct Labor - Foreman	\$21.50	\$8.82	\$30.32	\$30.32	\$60.63
2	XL0014	Shop direct Labor - Mechanical	\$19.50	\$8.00	\$27.50	\$27.50	\$54.99
2	XL0015	Shop direct labor - Millwright	\$17.50	\$7.18	\$24.68	\$24.68	\$49.35
2	XL0016	Shop direct Labor - NC Machine Op.	\$16.50	\$6.77	\$23.27	\$23.27	\$46.53

Ref. Key	Commodity Code	Description	Base Labor Cost	Fringe Cost	Total Direct Labor Cost	Support Cost	Total Cost
2	XL0017	Shop direct Labor - NC Machine Prog.	\$20.00	\$8.20	\$28.20	\$28.20	\$56.40
3	XL0018	Shop direct labor - QC Inspector	\$16.50	\$6.77	\$23.27	\$23.27	\$46.53
3	XL0019	Shop direct labor - QC Supervisor	\$17.50	\$7.18	\$24.68	\$24.68	\$49.35
2	XL0020	Shop direct Labor - Rigger	\$16.00	\$6.56	\$22.56	\$22.56	\$45.12
2	XL0021	Shop direct Labor - Welding	\$25.00	\$10.25	\$35.25	\$35.25	\$70.50
4	XL0022	Field Design Engineering	\$27.50	\$11.28	\$38.78	\$58.16	\$96.94

These data have been drawn from the sources identified below.

Table B References

Key

1. R.S. Means, 30 City Average, January 1993. Fringe benefit package includes employer's contribution to taxes, health benefits, vacation benefits if any, and related employer-paid labor cost items. Crews are identified with the type of work performed. Composite crew rates are made up from various crafts, whose rates are documented by R. S. Means. The assumed percentage of specific crafts in each crew are as listed below:

COMPOSITE CREW:	AR	CN	EW	EL	IN	ME	PI	SU	ST
Craft Mix									
Boilermaker						15			
Carpenter	35	40		2					5
Electrician	35			96	70			50	
Iron Worker	25	20				10			75
Laborer		30	60	1					5
Millwright						25		15	
Operating Engineer		5	35	1	2	12	15		15
Pipe fitter	5				28	35	80	35	
Teamster			5			3	5		
Other		5							
Total	100	100	100	100	100	100	100	100	100

Support cost includes the experience based cost of temporary facilities, field supervision, field tools, equipment, consumables, contractor paid permits, fees, taxes, other overheads, and profit. Values in this table are based on data provided by Ebasco Services, Inc.

2. (1) Employment and Earnings, US Dept. of Labor, December 1993; Table C2- Average earnings ... private nonfarm payrolls and (2) TPX estimate for Poloidal Field Magnet Construction, Bechtel Group, Inc. Fringe benefit package was not specified, and has been estimated using 41% of direct gross wages. Support cost includes the cost of shop supervision, management, consumables other overheads, and profit. It specifically excludes the cost of facilities and equipment. These cost elements will be owned by the ITER project and will be estimated separately, under their own account numbers. Special purpose tools and equipment are also excluded from this rate. Support costs have been estimated assuming that they are equal to 100% of the total direct labor cost.
3. (1) American Electronics Association 1993 Benchmark Compensation Survey and (2) TPX estimate for Poloidal Field Magnet Construction, Bechtel Group, Inc. Fringe benefit package was not specified, and has been estimated using 41% of direct gross wages. Support cost includes the cost of shop supervision, management, equipment, consumables other overheads, and profit. It specifically excludes the cost of facilities and equipment. These cost elements will be owned by the ITER project and will be estimated separately, under their own account numbers. Special purpose tools and equipment are also excluded from this rate. Support costs have been estimated assuming that they are equal to 100% of the total direct labor cost.
4. Experience based estimate provided by Bechtel Group, Inc. Fringe benefit package was not specified, and has been estimated using 41% of direct gross wages. Support cost includes the cost of facilities, management, supervision, office equipment, other overheads, and profit. These costs have been estimated assuming that they are equal to 150% of the total direct labor cost.
5. Experience based estimate provided by Bechtel Group, Inc. Fringe benefit package was not specified, and has been estimated using 41% of direct gross wages. Support cost includes the cost of facilities, management, supervision, office equipment, other overheads, and profit. These costs have been estimated assuming that they are equal to 200% of the total direct labor cost.

Appendix C

(Spread Sheet Examples)

VACUUM VESSEL MAIN ASSY.

VACUUM VESSEL MAIN ASSY.																
ESTIMATE																
ACCOUNT NAME	Ref. Key	Commod Code	Commodity Name	QTY	Quantity Uncertainty		UNIT	Material Cost (K\$)	Material Cost Uncert.		Labour Cost (K\$)	Labour Cost Uncert.		Total Cost (K\$)	Total Cost Uncert.	
					(-%)	(+%)			(-%)	(+%)		(-%)	(+%)		(-%)	(+%)
Vacuum Vessel Main Assy (Total for 24 Sectors)								74882	-15	15	176281	-24	24	251163	-21	22
Inner and Outer Shell																
Manufacturing Engineering																
Manufacturing Drawings		A0001	CAD Operator (Vender Sho	50000	-20	20	h	0	0	0	3000	-24	26	3000	-24	26
Project Engineering		A0002	Project / Design Engineer (	20000	-20	20	h	0	0	0	1800	-24	26	1800	-24	26
Quality Assurance		A0002	Project / Design Engineer (	500	-20	20	h	0	0	0	45	-24	26	45	-24	26
Quality Control		XL001B	Shop direct labor - Inspecto	1000	-20	20	h	0	0	0	47	-24	26	47	-24	26
TPI (Third Party Inspection)		XL001B	Shop direct labor - Inspecto	1000	-20	20	h	0	0	0	47	-24	26	47	-24	26
Manufacturing & Assembly																
Outer Skin-3 cm Inconel 625			#N/A	420	-10	10	ton	8800	-15	15	42000	-20	20	50800	-19	19
Inner Skin-3 cm Inconel 625			#N/A	290	-10	10	ton	6076	-15	15	29000	-20	20	35076	-19	19
Ribbs-3cm plate Inconel 625			#N/A	470	-10	10	ton	9848	-15	15	47000	-20	20	56848	-19	19
Reinforcement			#N/A	250	-20	20	ton	5238	-25	25	25000	-20	20	30238	-21	21
Welding skin, ribbs, etc.		XL0021	Shop direct labor - Welder	50000	-40	40	h	0	0	0	10000	-43	47	10000	-43	47
Testing & Inspection																
Leak & Pressure Tests		XL0012	Shop direct labor - Fluids te	500	-30	40	h	0	0	0	28	-34	47	28	-34	47
Dimensional Inspection		XL001B	Shop direct labor - Inspecto	400	-20	20	h	0	0	0	19	-24	26	19	-24	26
SUBTOTAL																
								29962	-16	16	157985	-21	21	187947	-20	21
Leak Detection System																
Manufacturing Engineering																
Manufacturing Drawings		A0001	CAD Operator (Vender Sho	800	-20	20	h	0	0	0	48	-24	26	48	-24	26
Project Engineering		A0002	Project / Design Engineer (	320	-20	20	h	0	0	0	29	-24	26	29	-24	26
Quality Assurance		A0002	Project / Design Engineer (	40	-20	20	h	0	0	0	4	-24	26	4	-24	26
Quality Control		XL001B	Shop direct labor - Inspecto	40	-20	20	h	0	0	0	2	-24	26	2	-24	26
TPI (Third Party Inspection)		XL001B	Shop direct labor - Inspecto	60	-20	20	h	0	0	0	3	-24	26	3	-24	26
Manufacturing & Assembly																
Weld cover plates & welding			#N/A	5000	-30	30	m	10	-36	36	100	-36	36	110	-36	36
Tubing (0.5 cm dia.)			#N/A	20000	-30	30	m	40	-36	36	50	-36	36	90	-36	36
Feedthroughs			#N/A	344	-15	15	ea	90	-21	21	25	-21	21	115	-21	21
Testing & Inspection																

Leak & Pressure Tests		#N/A	1	0	0	ea	0	0	0	100	-30	30	100	-30	30
SUBTOTAL							140	-26	26	360	-30	30	500	-29	29
Shielding for VV															
Manufacturing Engineering															
Manufacturing Drawings	A0001	CAD Operator (Vender Sho	100	-20	20	h	0	0	0	6	-24	26	6	-24	26
Project Engineering	A0002	Project / Design Engineer (	50	-20	20	h	0	0	0	5	-24	26	5	-24	26
Quality Assurance	A0002	Project / Design Engineer (	10	-20	20	h	0	0	0	1	-24	26	1	-24	26
Quality Control	XL0018	Shop direct labor - Inspecto	10	-20	20	h	0	0	0	0	-24	26	0	-24	26
TPI (Third Party Inspection)	XL0018	Shop direct labor - Inspecto	25	-20	20	h	0	0	0	1	-24	26	1	-24	26
Manufacturing & Assembly															
Balls(20 mm dia)		#N/A	4600	-10	10	ton	43000	-15	15	250	-44	44	43250	-15	15
Ball coating (Al2O3)		#N/A	130	-50	50	ton	130	-57	57	5000	-120	120	5130	-118	118
Testing & Inspection															
		#N/A	0	0	0	#N/A	0	0	0	0	0	0	0	0	0
SUBTOTAL							43130	-15	15	5263	-116	116	48393	-26	26
Cooling Piping															
Manufacturing Engineering															
Manufacturing Drawings	A0001	CAD Operator (Vender Sho	400	-20	20	h	0	0	0	24	-24	26	24	-24	26
Project Engineering	A0002	Project / Design Engineer (	150	-20	20	h	0	0	0	14	-24	26	14	-24	26
Quality Assurance	A0002	Project / Design Engineer (	100	-20	20	h	0	0	0	9	-24	26	9	-24	26
Quality Control	XL0018	Shop direct labor - Inspecto	100	-20	20	h	0	0	0	5	-24	26	5	-24	26
TPI (Third Party Inspection)	XL0018	Shop direct labor - Inspecto	50	-20	20	h	0	0	0	2	-24	26	2	-24	26
Manufacturing & Assembly															
Feeder Pipes (300 mm dia)		#N/A	100	-20	20	m	150	-24	25	5000	-25	25	5150	-25	25
Manifolds		#N/A	48	-20	20	ea	1500	-25	25	4800	-25	25	6300	-25	25
Testing & Inspection															
Leak & Pressure Tests	XL0012	Shop direct labor - Fluids te	50	-30	40	h	0	0	0	2820	-34	47	2820	-34	47
SUBTOTAL							1650	-24	25	12673	-26	29	14323	-26	29
Full Conditioning System															
SUBTOTAL							0	0	0	0	0	0	0	0	0

[illegible]

Appendix D

(Costing Assumptions and Guidelines)

Summary of Costing Guidelines

Assumptions

1. US\$ of 1.1.93.
2. ITER Standard Site Requirements.
3. Eight-hour, single-shift, five-day working week.
4. Casual overtime limited to 5% of total labour workhours.
5. Multiple shift work will be used only where technically essential.
6. Allowances for work stoppages of 10 working days per year.
7. Construction begins in mid1998 and ends by mid-2005, except long lead items, which should be indicated (with start dates).
8. Include costs of fabrication, vendor engineering, initial spare parts, packing and shipping (to the nearest port), manuals , etc., and vendor required services.
9. Exclude ocean freight, export duties, taxes and extended warranties.
10. Include design and R&D work not completed during the EDA, as separate line items. (This will be done by the JCT.)
11. The cost estimate should have a 50-50 confidence level. If there are additional unknown cost elements which will be resolved during the EDA, these should appear as a separate line item labelled UCE.
12. Exclude Construction Management Team (CMT) (\$725M or 2900 PMY); Construction Phase R&D (\$340M) and Startup Operations Team (SOT) (\$120M) (1989 values).
13. Costs are to include all design, material, fabrication, assembly, testing, reassembly, and inspection required to certify the complete vessel at the site. It is to be assumed that each system is defined with a detail design specification (Including detail interface drawings. Note: These drawings are in sufficient detail to define all key aspects of the design but are not fabrication or shop drawings.) and all detail fabrication drawings and procedures and generated by the vendor. Costs should exclude estimates for design optimization.
14. Alternative options (schedule, location, process, labour source) should be freely suggested and costed, with a view to obtaining the best overall cost and schedule for the construction of the project.
15. Manufacturers in a chain for a particular component must provide all necessary handling, inspection, storage, and maintenance of raw materials for their part of the manufacture.
16. Include any necessary "assembly/check fit-up" of complete assemblies both prior to shipment to the ITER site and at the ITER site itself.

17. , Indicate what test facilities are assumed to be available (cost free) on-site for acceptance testing, and the usage expected (hours).
18. If new facilities are required, add a new line item on the spreadsheet so that these costs are kept separate.
19. Include all design specific tools, fixtures and jigs, which will become the property of ITER at the conclusion of the manufacture.
20. At the end of each activity (i.e.: design, fabrication, assembly, testing, inspection, etc.) the vendor is to generate a report and complete documentation package (including CAD files), defining the activity just completed.
21. It should be assumed that each vendor is required to generate a QA plan addressing each phase of his activity (i.e.: design, fabrication, assembly, testing, inspection, etc.). this plan must specify how the quality of the activity is to be assured.
22. It should be assumed that the vendor for each component or system will be fully responsible for demonstrating that the component or system satisfies the specification. After this has been done and the system accepted by ITER, the vendor will still be responsible for deficiencies for a period of 1 year.

Draft # 9 (20-9-94)

ITER

DESCRIPTION OF WORK

ACCOUNT NUMBER: 15.A

Rev. No.: 0

Date: 16 May 94

ACCOUNT TITLE: Vacuum Vessel Main Assembly

Account Class: Vacuum Vessel

REFERENCE NO.: G 15 SP 01 94-05-16 W 1

1.0 Scope of Work:

The Vacuum Vessel Main Assembly consists of the toroidal vessel inner and outer shell (including ribs between the shells), heating and cooling piping to the shell, interfaces for vessel support structures (i.e.: mounting points), in wall shielding (balls and plates), leak detection lines and accommodations, and structural support points for all internal hardware. The vacuum vessel also includes provisions for remote maintenance.

2.0 Design Basis

The vacuum vessel main assembly is a major safety barrier and must be designed to support electromagnetic loads during plasma disruptions and vertical displacement events (VDE) and to withstand plausible accidents without losing confinement. The vacuum vessel must provide for high quality vacuum and high electrical resistivity at high temperature. The maximum outlet temperature of the vacuum vessel coolant is required to be not higher than 200 °C. The total electrical resistance of the vacuum vessel and the blanket structure should be approximately 8 $\mu\Omega$ to limit the induced eddy current flow. Such relatively low values help to provide plasma vertical stability. The vacuum vessel design is a water cooled, double wall structure joined by poloidal ribs. The inner and outer shells are made of welded plates, 30-40 mm in each thickness. The field welded joint design will allow the monitoring of tritium leaks. The plate material envisaged is Inconel 625, however low activation Inconels are also being considered. Shielding materials are installed between the inner and outer shells. The vessel design, in principal, is consistent with a fully remote replacement of any vacuum vessel sector.

Cost Calculation Input Assumptions:

Drawings, sketches, and assumptions to be used as a bases for the estimate are listed below. These will be updated and forwarded to each home team, as the design progresses.

15.A Vessel Assy / Main Chamber

15.A.01 Inner and Outer Shell (Reference drawings of shell & ribs- see appendix A)

1. The primary vessel material is Inconel 625.
2. The inner and outer shell thickness is mainly 3 cm with some areas 4 cm (20 % of shell -primarily around ports and vessel support points).
3. The ribs are 3 cm thick.
4. Each sector is assumed to have two facets on the inner shell and three facets on the outer shell
5. All fabrication, testing, inspection, and certification activities are to comply with the requirements of the ASME Code Section III (Class 2). All welding is to be assumed to be by the TIG process. It should be assumed that all pressure boundary butt welds on the inner and outer shell will be radiographically inspected. Welds between the ribs and the inner and outer shell will be dye - penetrant inspected only.

3. The port structure cooling pipe is ~50 mm in diameter (inside). The piping for six ports is connected in series. Piping for each set of six ports is routed through the cryostat.

15.A.05 Wall Conditioning System (No drawings available)

1. Cooling system piping will accommodate the gas or steam used for wall conditioning and no additional hardware coats will be incurred.

3.0 Cost Basis

The costs for the vacuum vessel main assemble is estimated on the basis of the following parameters:

1. There is one (1) vessel that is made up 24-15 deg. slices.
2. Spare slices or other components are not part of this cost account.

Cost option (cost seperately)

3. Assumming that the vessel design is the same as the one described above, provide a cost estimate for a vessel made of SS 316 LN.

4.0 Class

The classifications of the systems in this account (per the ITER Technical & Quality Classifications - Manual) are as follows:

System	Safety Class	Quality Class
15.A Vessel Assy / Main Chamber	1	1
15.A.01 Inner and Outer Shield	1	1
15.A.02 Leak Detection System	4	3
15.A.03 Shielding for V. V.	2	1
15.A.04 Cooling Piping	2	1
15.A.05 Wall Conditioning System	4	3

5.0 Attached Drawings

Figure No.	Drw. Title
15.A-1	Schematic View of VV Assembly
15.A-2	Toroidal Cross Section of VV Assembly
15.A-3	Schematic View of VV Sector
15.A-4	Toroidal Section of VV
15.A-5	Plan Sections of VV
15.A-6	Basic Geometry of VV
15.A-7	Section through VV at Middle Port
15.A-8	Sector Assembly Concept
15.A-9	Sector Field Weld Design Concepts
15.A-10	Sector Installation and Maintenance Concept
15.A-11	Poloidal Stiffening Ribs Concept
15.A-12	Schematic View of Double Wall Concept
15.A-13	View of Stiffening Rib Concept
15.A-14	Schematic Rib Layouts

6. Tolerance assumptions (values are to be considered best effort targets):
 - A. Sector overall height - ± 20 mm
 - B. Sector overall width - ± 20 mm
 - C. Sector wall thickness (distance from inner to the outer wall) - ± 5 mm
 - D. Shell plate thickness - ± 0.1 mm
7. The leak rate of a sector must be less than 1×10^{-9} Std. cc/sec.
8. It should be assumed that a sector can be shipped to the site as an assembly.
9. The shield balls are installed at the vendors factory before shipment to the site for all circuits except in the area of the field joints.
10. As a minimum, the following tests and inspections should be done at the vendors factory before shipment to the site:
 - A. Sector Tests and Inspections (before balls are installed)
 - i. Water channel pressure test
 - ii. Water channel leak test (room temp.)
 - iii. Water channel leak test (300 C - furnace or heating method provided by vendor)
 - iv. Dimensional inspection
 - B. Sector Tests and Inspections (after balls are installed)
 - i. Water channel pressure test
 - ii. Water channel leak test (room temp.)
 - iii. Water channel leak test (300 C - furnace or heating method provided by vendor)
 - iv. Dimensional inspection
 - v. Pressure drop and flow tests of water through the cooling circuits
11. The vendor will be responsible for providing all test equipment at both the vendors factory and the ITER site.

15.A.02 Leak Detection System (No drawings available)

1. All leak detection lines between the field welds cover plates and the pump room (20 m from the cryostat) are in this cost account but not the leak detector itself. The system consists of thin SS covers over the field welds (seal welded in place) that are connected to 3-4 mm diameter tubing used to route He to the field weld.
2. Total no. of lines is ~ 172 (25×4 sector field joints + 24×3 port field joints)
3. Feedthroughs for the tubes through the cryostat are included in this cost account.

15.A.03 Shielding for V.V. (No drawings available)

1. All of the vessel shielding volume is filled with S.S. balls (non magnetic). Shielding plate is not used.
2. Tungsten carbide balls are not used in this system.
3. The ball diameter is assumed to be 20 mm.
4. The balls are coated with .025 cm thick Al_2O_3 .
5. The vessel is not coated.

15.A.04 Cooling Piping (No drawings available)

1. The cooling piping included in this cost account extends to the cryostat vessel. Piping for both the main vessel and port structures is included in this element.
2. The vessel shell cooling pipe is ~ 300 mm in diameter (inside). The piping for vessel sector pairs are connected in series. Piping for each pair is routed through the cryostat.

Appendix A
(Reference Drawings - Vessel Shell)

Figure 15.A-2 Toroidal Cross Section of VV Assembly

Figure 15.A-3 Schematic View of VV Sector

POINT	COORDINATE
A	9761.5, 4050
B	6876, 2882
C	6955, 2837
D	3858, 314
E	4731, -55
F	6970, -2915
G	9761.5, -3906
H	8588, -6097
J	6466.145, 4887.039
K	6528.703, 4739.832
L	5976.497, 667.729
M	5949.975, 657.568
N	5982.235, -760.651
P	8076.701, -4591.453
R	6678.138, -4762.083
S	5957.908, -4774.557
T	7373.637, 4305.567

OUTER SKIN DIMENSIONS

INNER SKIN DIMENSIONS

SECTION A-A (SEE SH. 2)

Figure 15.A-4 Toroidal Section of VV

NOTES.

- 1/ ALL DIMENSIONS IN millimetres UNLESS STATED
- 2/ DIMENSIONS RELATE TO OPERATING TEMPERATURE
- 3/ REFER TO DOCUMENT G 15 CD10 0001 FOR CLASS AND QUALITY LEVELS

TITLE			
TOROIDAL SECTION OF VACUUM VESSEL			
ISSUE	94.05.20.12	CO-ORDINATION APPROVAL	94.07.18
NEXT ASSY XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX			
XXXXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX XXXXXX			

DRG FRAME SIZE 564 x 390			
STATUS	DRM	CHK'D	R.O.
F	DJL	NAME	KEL
NAME OF ORGANISATION			
GARCHING J.W.S.			

ITER-EDA.	
NOT FOR PUBLICATION	
The information on this drawing is confidential under the terms of the ITER EDA agreement. This information shall not be transmitted to anyone who is not authorized to receive it.

Figure 15.A-5 Plan Sections of VV

NOTES.

- 1/. ALL DIMENSIONS IN millimetres UNLESS STATED
- 2/. DIMENSIONS RELATE TO OPERATING TEMPERATURE
- 3/. REFER TO DOCUMENT G 15 CD10 0001 FOR CLASS AND QUALITY LEVELS

TITLE PLAN SECTIONS OF VACUUM VESSEL				DRG FRAME SIZE 564 x 390			
ISSUE 94.03.15.13				CO-ORDINATION APPROVAL 94.02.18			
STATUS F				DRM DJL			
CHK'D NAME				R.O. K11			
NAME OF ORGANISATION GARCHING J.W.S.							
DO NOT TAKE MEASUREMENTS USE ONLY DIMENSIONS GIVEN				THIRD ANGLE PROJECTION Φ			
1.5.0.0.1.70.11S10.11A.S.S.YI

<u>SURFACE AREA</u>	: 1800m ² (INNER)
	: 2000m ² (OUTER)
<u>VESSEL INTERNAL VOLUME</u>	: 4500m ³
<u>WEIGHT OF VACUUM VESSEL WALLS (STIFFENING RIBS INCLUDED)</u>	: 2000ton
<u>SHIELDING MATERIALS</u>	: 5100ton

Figure 15.A-6 Basic Geometry of VV

NOTE

1. DIM 134 IS TO ALLOW FOR 114mm WIDE SCISSOR KEY PLUS 10mm CLEARANCE EACH SIDE.
2. DIM 90 IS TO ALLOW 2 x 30mm LONG MATERIAL FOR 2 CUT AND REWELD OPERATIONS PLUS 30mm CLEARANCE TO RIB.

DIMENSIONS RELATE TO OPERATING TEMPERATURE

Figure 15.A-7 Section through VV at Middle Port

Figure 15.A-8 Sector Assembly Concept

PLAIN OPTION

STEPPED OPTION

Figure 15.A-9 Sector Field Weld Design Concepts

Figure 15.A-10 Sector Installation and Maintenance Concept

Figure 15A-11 Poloidal Stiffening Ribs and Divertor

Figure 15.A-12 Schematic View of Double Wall Concept

Figure 15.A-13

View of Stiffening Rib Concept

19373.83

38807.98

19434.15

SCHEMATIC RIB LAYOUT - UPPER

SCHEMATIC RIB LAYOUT - LOWER

Draft #9 (20-9-94)

ITER

DESCRIPTION OF WORK

ACCOUNT NUMBER: 15.B

Rev. No.: 1

Date: 16 May 94

ACCOUNT TITLE: Port Assemblies

Account Class: Vacuum Vessel

REFERENCE NO.: G 15 SP 02 94-05-16 W 1

1.0 Scope of Work:

The port assemblies include the vessel ports, the port ducts, and the bellows. The vessel port structures are an integral part of the vacuum vessel. The upper ports are used to install and remove the blanket and provide the feedthrough point for all blanket cooling lines. The feedthrough point for these lines must reliably isolate the inside of the vessel from the cryostat, and accommodate movement of the blanket relative to the vessel. The mid plane and divertor ports are used for equipment installation and maintenance, utility feedthroughs, and vacuum pumping. Bellows are a critical part of these port assemblies. One end of a bellows assembly connects to a vessel port and the other end connects to a port duct. The port duct fills the remaining space between the vessel and the cryostat. The cryostat ports are not part of this system.

2.0 Design Basis

The port assemblies, like the vacuum vessel main assembly, are major safety barriers and must be designed to support electromagnetic loads during plasma disruptions and vertical displacement events (VDE) and to withstand plausible accidents without losing confinement. The field welded joint design around the port assemblies must allow the monitoring of tritium leaks. The port assembly design, in principal, is consistent with a fully remote replacement of any vacuum vessel sector.

Cost Calculation Input Assumptions:

Drawings, sketches, and assumptions to be used as a bases for the estimate are listed below. These will be updated and forwarded to each home team, as the design progresses.

15.B Port Assemblies

15.B.01 Port Structures (Reference drawings of ports - see appendix A)

1. The primary port structural material is Inconel 625.
2. Each port structure (this is the structural part of each port that is located between the vessel inner and outer shell) is made from 5 cm thick plate, where the structure is welded to the vessel shell and along the inside of the port between the vessel shells. The area between the vessel shells is reinforced with a second 5 cm thick plate, spaced several centimeters from the outer plate.
3. The top port has a cover plate that is a double wall design similar to the vessel (3 cm thick plates are used). This plate has two chimneys which enclose six pipes for blanket cooling. The pipes are attached to an enclosure, through an intermediate bellows. The enclosure extends to the cryostat and the pipes pass through the cryostat to a manifold.
4. The middle and lower ports do not have cover plates.
5. All fabrication, testing, inspection, and certification activities are to comply with the requirements of the ASME Code Section III (Class 2). All

welding is to be assumed to be by the TIG process. It should be assumed that all pressure boundary butt welds on the port assemblies and welds between the port structures and the vessel shell will be radiographically inspected.

6. Tolerance assumptions (values are to be considered best effort targets):
 - A. Port structure overall height & width - ± 2 mm
 - B. Port structure overall thickness (distance from inner to the outer wall) - ± 2 mm

15.B.02 Port Extensions

1. A port extension is installed on each middle and lower port. The port extensions consist of two parts. The inner part is welded to the port structure and extends 1 to 2 m to the port bellows. Between the port bellows and the cryostat is the outer part of the port extension.
2. The primary port extension material is Inconel 625.
3. The port extension is a double wall design with the inner wall 5 cm thick and the outer wall 1 cm thick. There are 3 cm thick stiffening ribs between the walls and the walls are separated by a distance of 20 cm. Additional shielding is not required between the duct walls.
4. The port extensions are water cooled. (Piping is included in element 15.A.04)
5. The cross-section of a port extension is the same as the vessel port.
6. All fabrication, testing, inspection, and certification activities are to comply with the requirements of the ASME Code Section III (Class 2). All welding is to be assumed to be by the TIG process. It should be assumed that all pressure boundary butt welds on the port extensions will be radiographically inspected. Welds between the port structure ribs and the inner and outer shells of the extensions will be dye - penetrant inspected only.
7. A shield door is installed for each middle and lower vessel port extension. These doors are welded to the inner wall of the port extensions in a manner that allows the weld to be cut and the doors removed as required. Each door is 60 cm thick S.S. with 38% of the thickness open for water passages. Each door will have 24 - 10 cm dia. holes for water and electrical feedthroughs.
8. Tolerance assumptions (values are to be considered best effort targets):
 - A. Port extension overall height & width - ± 2 mm
 - B. Extension wall thickness (distance from inner to the outer wall) - ± 2 mm
 - D. Shell plate thickness - ± 0.1 mm
9. The leak rate of a sector must be less than 1×10^{-9} Std. cc/sec.

15.B.03 Port Bellows Assy (No drawings are available)

1. The center and lower vessel ports have 1.5 m long non circular bellows between the inner and outer port extensions.
2. The bellows are a single wall design made from Inconel 625.
3. The cross-section of the bellows is the same as the vessel port.
4. All fabrication, testing, inspection, and certification activities are to comply with the requirements of the ASME Code Section III (Class 2). All welding is to be assumed to be by the TIG process. It should be assumed that all pressure boundary butt welds on the bellows assemblies will be radiographically inspected.
6. Tolerance assumptions (values are to be considered best effort targets):
 - A. Port bellows overall height & width - ± 2 mm
 - B. Sector wall thickness (distance from inner to the outer wall) - ± 2 mm
 - D. Shell plate thickness - ± 0.1 mm
7. The leak rate of a sector must be less than 1×10^{-9} Std. cc/sec.

15.B.04 Special Access Ports & Bellows Assy's (No drawings are available)

1. Each vessel segment has three 2 cm diameter ports for instrumentation and diagnostics.
2. All special access ports and bellows assemblies are made of Inconel 625.

3.0 Cost Basis

The costs for the vacuum vessel port assemblies is estimated on the basis of the following parameters:

1. There are 24 upper port structures.
2. There are 24 middle port structures.
3. There are 24 lower port structures.
4. There are bellows and port extensions on all of the middle and lower ports.
5. Spare bellows or other components are not part of this cost account.
6. There are a total of 72 - 2 cm diameter ports for instrumentation and diagnostics.

Cost option (cost separately):

7. An option is for there to be a total of 4 - NBI ports. Each port is 30 cm in inside dia. and penetrates the vessel wall at an angle of 45 deg. from normal. Each port also has a bellows and port extension which extends to the cryostat.

Cost option (cost separately)

8. Assuming that the design of all port assemblies are the same as those described above, provide a cost estimate for these parts made from SS 316 LN.

4.0 Class

The classification of the systems in this account (per the ITER Technical & Quality Classifications - Manual) are as follows:

System	Safety Class	Quality Class
15.B Port Assemblies	1	1
15.B.01 Port Structures	1	1
15.B.02 Port Extensions	1	1
15.B.03 Port Bellows Assy	1	1
15.B.04 Special Access Ports & Bellows Assy's	1	1

5.0 Attached Drawings

Figure No.	Drw. Title
15.B-1	Upper port Details
15.B-2	Upper Port Header Concept
15.B-3	Upper Port Top View
15.B-4	Upper Port Structure Concept
15.B-5	Blanket Header Routing - Isometric
15.B-6	Blanket Header Routing - Side View
15.B-7	Blanket Header Details #1
15.B-8	Blanket Header Details #2
15.B-9	Horizontal Port Concept
15.B-10	Horizontal Port Cooling Option
15.B-11	Divertor Port Option

Appendix A
(Reference Drawings - Vessel Ports)

Figure 15.B-1 Upper port Details

DIMENSIONS RELATE TO OPERATING TEMPERATURE
THIS IS PROVISIONAL WORKING INFORMATION ONLY.
BASIC CONCEPT OF VERTICAL PORT

ITER

WORKING PROPOSAL
LEVEL : SKETCH

DATE: 26-MAY-94
D.J. LIGHTONLERS

CALIFORNIA CO. 00000

Figure 15.B-2 Upper Port Header Concept

DIMENSIONS RELATE TO OPERATING TEMPERATURE

Figure 15.B-4 Upper Port Structure Concept

DIMENSIONS RELATE TO OPERATING TEMPERATURE

THIS IS PROVISIONAL WORKING INFORMATION ONLY.

VERTICAL PORT STRUCTURE - COVER PLATE WITH "CHIMNIES"

SCALE: NTS

DI/KS/VAC_VES VERTICAL PORT STRUCTURE S/R VERSION/01

ITER

DATE: 29-JUN-94
D.J. LIGHTONER

WORKING PROPOSAL
LEVEL: SKETCH

GARCHING CO-CENTER

Figure 15.B-6 Blanket Header Routing - Side View

9000410RS03_T-S_
3A7E217_VEE_PHE_
CHILLING-PIPE-STUDY

NOTES:
 1. T.F. COIL SIZE AND POSITION ASSUMED FROM MODEL No.:
 90002501S01_I_S_94011817_IAC_PHR_OVERVIEW_OF_17ER
 _CONFIGURATION_IAC_4

Figure 15.B-9 Horizontal Port Concept

DIMENSIONS RELATE TO OPERATING TEMPERATURE

THIS IS PROVISIONAL WORKING INFORMATION ONLY.

BASIC CONCEPT OF HORIZONTAL PORT

SECTION Y-Y

SECTION X-X

3D VIEW

Figure 15.B-10 Horizontal Port Cooling Option

Figure 15.B-11 Divertor Port Option

NOTES.

1. T.F.COIL SIZE AND POSITION ASSUMED FROM MODEL No:
90002501S01_T_S_94011817_TAC_PHR_OVERVIEW_OF_ITER
_CONFIGURATION_TAC_4

DIMENSIONS RELATE TO OPERATING TEMPERATURE

THIS IS PROVISIONAL WORKING INFORMATION ONLY.

BASIC CONCEPT OF DIVERTOR PORT

ITER

WORKING PROPOSAL
LEVEL 1 SKETCH

DATE: 26-MAY-91
D.J. LIGHTONERS

ITER

DESCRIPTION OF WORK

ACCOUNT NUMBER: 15.C

Rev. No.: 1

Date: 16 May 94

ACCOUNT TITLE: Support Structures
Account Class: Vacuum Vessel

REFERENCE NO.: G 15 SP 03 94-05-16 W 1

1.0 Scope of Work:

The support structures consist of the support points for the vacuum vessel, which are the support brackets on the vessel used to connect to the structural links supported from the coil support structure (structural links are not part of this element), and the supports for the divertor and blanket on the inside of the vessel which are mounted from the vessel wall.

2.0 Design Basis

The support structures are used to mechanically support the vacuum vessel main assembly, the blanket, and the divertor and must withstand structural loads due to gravity and induced electromagnetic loads. These structures have an important safety function.

Cost Calculation Input Assumptions:

Drawings, sketches, and assumptions to be used as a bases for the estimate are listed below. These will be updated and forwarded to each home team, as the design progresses.

1.5.C Support Structures

15.C.01 Blanket to VV Support (Reference drawings of supports - see appendix A)

1. The primary support material is Inconel 625.
2. All fabrication, testing, inspection, and certification activities are to comply with the requirements of the ASME Code Section III (Class 2).
3. The support concept to be costed is the sliding concept. (Other concepts may be costed as options if desired.) It should be assumed that the support is water cooled and provides an insulation break between the blanket and the vessel.

15.C.02 VV to Mechanical Structure (There are no costs in this element.)

1. The pin and link to the main mechanical structure (WBS 1.4) is part of that structure and not included here.
2. The part of this structure that is welded to the vessel shell is part of the Vacuum Vessel Main Assembly.

15.C.03 Divertor to VV Support (No drawings are available)

1. The primary support material is Inconel 625.
2. All fabrication, testing, inspection, and certification activities are to comply with the requirements of the ASME Code Section III (Class 2).
3. The primary divertor support is provided by a pair of square bars (120 mm * 120 mm in cross-section) that extend around the vessel in the toroidal direction. These bars are welded to the vessel inner wall and must be machined after welding. (Final machining costs are included in WBS 1.7.)

3.0 Cost Basis

The costs for the vacuum vessel support structures is estimated on the basis of the following parameters:

1. There are 96 blanket to VV support structures.
2. There are 2 divertor to VV support bars that extend around the vessel.
3. Spare supports or other components are not part of this cost account.

Cost option (cost separately)

4. Assuming that the support designs are the same as the ones described above, provide a cost estimate for supports made of SS 316 LN.

4.0 Class

The classification of the systems in this account (per the ITER Technical & Quality Classifications - Manual) are as follows:

System	Safety Class	Quality Class
15.C Support Structures	1	1
15.C.01 Blanket to VV Support	3	1
15.C.02 VV to Mechanical Structure	1	1
15.C.03 Divertor to VV Support	3	1

5.0 Attached Drawings

Figure No.	Drw. Title
15.C-1	Toroidal Cross Section of VV Assembly
15.C-2	Schematic View of VV Sector
15.C-3	Sliding Blanket Support Assy. Concept
15.C-4	Blanket Support Views

Appendix A
(Reference Drawings - Vessel Supports)

Figure 15.C-1 Toroidal Cross Section of VV Assembly

Figure 15.C-2 Schematic View of VV Sector

STAGE 1

POSITIONING OF VACUUM VESSEL
PREPARATION FOR INSTALLING SLIDING PARTS
MEASUREMENT OF SUPPORT POSITIONS

STAGE 2

ASSEMBLY OF SLIDING PARTS

STAGE 3

INSTALLATION OF INBOARD BLANKET MODULES
INSTALLATION OF TEMPORARY SUPPORTS FOR MODULES

STAGE 4

INSTALLATION OF OUTER BLANKET MODULES
INSTALLATION OF TEMPORARY SUPPORTS FOR MODULES

STAGE 5

WELDING OF BACK AND FRONT PLATES
REMOVAL OF TEMPORARY SUPPORTS AFTER INSPECTION
CORRECTION OF COOLING PIPES FOR SLIDING SUPPORTS
INSTALLATION OF DIVERTOR CASSETTES

3D VIEW OF INBOARD
BLANKET SUPPORTS

Figure 15.C-3 Sliding Blanket Support Assy. Concept

THIS IS PROVISIONAL WORKING INFORMATION ONLY.

SLIDING BLANKET SUPPORT ASSEMBLY PROCEDURE

ITER

WORKING PROPOSAL
LEVEL 1 SKETCH

DATE: 18-JAN-94
D.J. LIGHTOVLERS

Figure 15.C-4 Blanket Support Views

THIS IS PROVISIONAL WORKING INFORMATION ONLY.

BLANKET SUPPORT STUDY

ITER
WORKING PROPOSAL
LEVEL : SKETCH

DATE: 07-DEC-90
D.J. LIGHTOWLERS

ITER

DESCRIPTION OF WORK

ACCOUNT NUMBER: 15.D

Rev. No.: 1

Date: 16 May 94

ACCOUNT TITLE: Add. Pb/B4C Shielding For TF Coils

Account Class: Vacuum Vessel

REFERENCE NO.: G 15 SP 04 94-05-16 W 1

1.0 Scope of Work:

This system consists of the Pb/B4C shield material to be mounted on the outer surface of the vessel and the mounting structure for this shielding.

2.0 Design Basis

The outer surface of the vacuum vessel is covered by additional lead shielding for the TF coils. This shield is primarily a gamma shield but also shields neutrons. The lead is enclosed by thin stainless steel to preclude its loss by melting during accident conditions.

Cost Calculation Input Assumptions:

Drawings, sketches, and assumptions to be used as a bases for the estimate are listed below. These will be updated and forwarded to each home team, as the design progresses.

15.D Add. Pb/B4C Shielding For TF Coils

15.D.01 Pb/B4C Shielding (Reference drawings of shielding - see appendix A)

1. The B4C/Pb shielding is 30 mm thick around the vessel and 50 mm thick around the ports. The ratio of B4C to Pb is 2/3. (Alternate materials that could replace Pb, such as PbO₂ or Pb - 10 Cu should be costed as options)
2. The lead is contained in S.S. boxes that are 500 mm by 2500 mm and divided into five compartments. The boxes have a 1 mm wall thickness.
3. The lead shielding does not require water cooling.

15.D.02 Structure Support

1. Figure 15.D-2 shows a concept for this mounting system.

3.0 Cost Basis

The costs for the vacuum vessel Pb / B4C shielding is estimated on the basis of the following parameters:

1. Shielding covers all surfaces of the vessel and the perimeter of the ports and port extensions for a distance of 2.5 m from the vessel. Beyond 2.5 m, no shielding is required.
2. Spare shielding or other components are not part of this cost account.

4.0 Class

The classification of the systems in this account (per the ITER Technical & Quality Classifications - Manual) are as follows:

System	Safety Class	Quality Class
15.D Add. Pb/B4C Shielding For TF Coils	3	1

15.D.01 Pb/B4C Shielding	3	1
15.D.02 Structure Support	3	1

5.0 Attached Drawings

Figure No.	Drw. Title
15.D-1	Gamma Shield Module Layout Concept
15.D-2	Gamma Shield Module Concept

Appendix A
(Reference Drawings - Vessel Pb/B4C Shield)

DEVELOPED VACUUM VESSEL
OUTER SKIN

Figure 15.D-1 Gamma Shield Module Layout Concept

Draft # 9 (20-9-94)

ITER

DESCRIPTION OF WORK

ACCOUNT NUMBER: 15.E

Rev. No.: 1

Date: 16 May 94

ACCOUNT TITLE: Assembly and Special Fixtures
Account Class: Vacuum Vessel

REFERENCE NO.: G 15 SP 05 94-05-16 W 1

1.0 Scope of Work:

The assembly and special fixtures include assembly and alignment fixtures required during fabrication and assembly. The fixtures to rotate the vessel assembly and RH fixtures are not part of this system.

2.0 Design Basis

During the assembly of vacuum vessel systems, special handling, assembly, and alignment fixtures will be required. These fixtures are included in this WBS element. The fixtures to rotate the vessel assembly and RH fixtures are not part of this system.

Cost Calculation Input Assumptions:

Drawings, sketches, and assumptions to be used as a bases for the estimate are listed below. These will be updated and forwarded to each home team, as the design progresses.

15.E Assembly and Special Fixtures

15.E.01 Assembly Fixtures (Reference drawings of fixtures - see appendix A)

1. Special fixtures to lift the vessel assy are not included in the cost account.
2. Assembly fixtures to be included are as follows:
 - a. Vessel segment assy. fixture
 - b. Port bellows assy. fixture
 - c. Ball installation fixture
 - d. Support structure assy. fixture
 - e. Ph/B4C assy. fixture
 - f. Misc. welding fixtures
3. Remote handling fixtures to be included are as follows:
 - a. Remote welding head for making the vessel field weld joint. The arm that supports this head and the welder itself are not part of this element. The welding technique is assumed to be TIG.
 - b. Remote cutting heads for cutting the vessel at the point of the field weld joint. The arm that supports these heads and the cutting machines themselves are not part of this element. The cutting process will involve two steps. The first step is plasma gouge cutting (cuts through most of the wall thickness) followed by YAG laser cutting. A separate head is to be provided for each cutting method.
 - c. Remote inspection head for inspecting the vessel field weld joint. The arm that supports this head and the inspection machine itself are not part of this element. The inspection technique is assumed to be RT for the initial assembly.

15.E.02 Alignment Fixtures (No drawings are available)

1. Alignment fixtures to be included are as follows
 - a. Vessel segment alignment fixture

b. Misc. alignment fixtures

3.0 Cost Basis

The costs for the vacuum vessel port assemblies is estimated on the basis of the following parameters:

1. It is assumed that there is only one of each type of fixture.

4.0 Class

The classification of the systems in this account (per the ITER Technical & Quality Classifications - Manual) are as follows:

System	Safety Class	Quality Class
15.E Assembly and Special Fixtures	1	3
15.E.01 Assembly Fixtures	1	3
15.E.02 Alignment Fixtures	4	3

5.0 Attached Drawings

Figure No.	Drw. Title
15.E-1	Vessel Sector Transport Fixture
15.E-2	Vessel Sector Transport Fixture - Side View

Appendix A
(Reference Drawings - Assembly & Special Fixtures)

Figure 15.E-1 Vessel Sector Transport Fixture

ITER
 DATE: 20-JAN-91
 D.J. LICHTENBERG
 WORKING PROPOSAL
 LEVEL : SKETCH

THIS IS PROVISIONAL WORKING INFORMATION ONLY.

VACUUM VESSEL FIXTURE AND TOOLING STUDY

Figure 15.E-2 Vessel Sector Transport Fixture - Side View

THIS IS PROVISIONAL WORKING INFORMATION.

VAC_VES_FIXTURE_AND_TOOLING_STUDY

ITER

18-JAN-94
D.J. LIGHTOWLERS

WORKING PROPOSAL
LEVEL : SKETCH

GARCHING CO-CENTRE

Draft # 9 (20-9-94)

ITER

DESCRIPTION OF WORK

ACCOUNT NUMBER: 15.F

Rev. No.: 0

Date: 16 May 94

ACCOUNT TITLE: Vacuum Vessel Assembly and Testing at the Site

Account Class: Vacuum Vessel

REFERENCE NO.: G 15 SP 06 94-05-16 W 1

1.0 Scope of Work:

The vacuum vessel consists of five sub components as follows: 1) Vacuum Vessel Main Assembly which consists primarily of the vessel inner and outer shield and the in wall shielding, 2) Port Assemblies which consists primarily of the port structures, port extensions, and bellows assemblies, 3) Support Structures for the blanket/shield, and divertor, 4) Additional Pb/B4C Shielding for the TF Coils, and 5) Assembly and Special Fixtures required to assemble and align these components.

After the components and assemblies have been shipped to the site, the subassemblies must be brought together and assembled and tested. This specification describes these activities.

2.0 Design Basis

The vessel assembly is a major safety barrier and must be designed to support electromagnetic loads during plasma disruptions and vertical displacement events (VDE) and to withstand plausible accidents without losing confinement. The vacuum vessel must provide for high quality vacuum and high electrical resistivity at high temperature. The maximum outlet temperature of the vacuum vessel coolant is required to be not higher than 200 °C. The total electrical resistance of the vacuum vessel and the blanket structure should be approximately 8 $\mu\Omega$ to limit the induced eddy current flow. Such relatively low values help to provide plasma vertical stability. The vacuum vessel design is a double wall structure joined by poloidal ribs. The inner and outer shells are made of welded plates, 30-40 mm in each thickness. The plate material envisaged is Inconel 625. Shielding materials are installed between the inner and outer shells.

The support structures are used to mechanically support the blanket and divertor and must withstand structural loads due to gravity and induced electromagnetic loads.

The outer surface of the vacuum vessel is covered by additional lead shielding for the TF coils. This shield is primarily a gamma shield but also shields neutrons. The lead is enclosed by thin stainless steel to preclude its loss by melting during accident conditions.

The thermal shield is installed on the outside of the gamma shield to provide a thermal barrier between the vessel and the coils. The thermal shield will have two parallel independent coolant circuits.

The special fixtures include assembly and alignment fixtures required during fabrication and assembly. The fixtures to rotate the vessel assembly and RH fixtures are not part of this system.

Cost Calculation Input Assumptions:

Drawings, sketches, and assumptions to be used as a bases for the estimate are listed below. These will be updated and forwarded to each home team, as the design progresses.

15.F Vacuum Vessel Assembly and Testing at the Site

15.F.01 Vacuum Vessel Main Assembly - Assembly and test activities and assumptions for the site are given below:

1. Assembly costs to be included are as follows:
 - A. Test assembly of the 24 sectors on the mechanical structure (Coils are not in place for this test)
 - B. Final assembly of the sectors on the mechanical structure and making the field weld joint between sectors.
 - C. Rotating the vessel and performing final positioning
 - D. Welding on the vessel ports
 - E. Installing balls in the field joint circuits
2. As a minimum, the following tests and inspections should be done at the site:
 - A. Sector Tests and Inspections
 - i. Water channel pressure test
 - ii. Water channel leak test (room temp.)
 - iii. Water channel leak test (300 C - furnace provided)
 - iv. Dimensional inspection
 - B. Vessel Assembly Tests and Inspections (items iii. - ix. will focus on the vessel field joints)
 - i. Preassembly of all 24 sectors on the coil support structure to check vessel position and interfaces and determine the dimensions of the filler plates between sectors. (Coils are not in place at this time.)
 - ii. Final vessel position and dimensional inspection
 - iii. Water channel pressure test
 - iv. Water channel leak test (room temp.)
 - v. Pressure test of vessel interior (pressure TBD)
 - vi. Pressure test of vessel exterior (pressure TBD)
 - vii. Leak test of vessel interior (room temp.)
 - viii. Leak test of vessel exterior (room temp.)
 - ix. Pressure drop and flow tests after ball installation in the circuit with the field joint.
3. All fabrication, testing, inspection, and certification activities at the site are to comply with the requirements of the ASME Code Section III (Class 2). All field joint welding is to be assumed to be by the TIG process. The inspection method is to be RT.
4. Tolerance assumptions for the vessel assembly (assembly including 24 sectors / values are to be considered best effort targets):
 - i. Position - ± 10 mm (reference is a vessel center line TBD)
 - ii. Angle - ± 0.025 deg. (reference is a vessel center line TBD) This is intended to position the vessel level within ± 5 mm.
5. The leak rate of vessel assembly must be less than 1×10^{-9} Std. cc/sec.
6. The vendor will be responsible for providing all test equipment at the ITER site.

15.F.02 Port Assemblies - Assembly and test activities and assumptions for the site are given below:

1. Assembly costs to be included are as follows:

- A. Final assembly and welding of the port bellows and port extensions for the middle and lower ports (between the vessel ports and the cryostat)
- 2. As a minimum, the following tests and inspections should be done at the site:
 - A. Port extension Tests and Inspections
 - i. Water channel pressure test
 - ii. Water channel leak test (room temp.)
 - iii. Water channel leak test (300 C - furnace provided)
 - iv. Dimensional inspection
 - B. Bellows Tests and Inspections
 - i. Bellows pressure test
 - ii. Bellows leak test (room temp.)
 - iii. Bellows leak test (300 C - furnace provided)
 - iv. Dimensional inspection
- 3. All fabrication, testing, inspection, and certification activities at the site are to comply with the requirements of the ASME Code Section III (Class 2). All field welding is to be assumed to be by the TIG process. The inspection method is to be RT.
- 4. Tolerance assumptions for the bellows and port extensions (values are to be considered best effort targets):
 - i. Position - ± 2 mm (reference is a vessel center line TBD)
 - ii. Angle - ± 0.5 deg. (reference is a port center line TBD)

15.F.04 Support Structure Assembly - Assembly and test activities and assumptions for the site are given below:

- 1. Assembly costs to be included are as follows:
 - A. Installation of the blanket and divertor support structures in the vessel
 - B. Welding on the support structures to the vessel
- 2. Dimensional inspection of installation position.
- 3. All fabrication, testing, inspection, and certification activities at the site are to comply with the requirements of the ASME Code Section III (Class 2). All field welding is to be assumed to be by the TIG process. The inspection method is to be RT.
- 4. Tolerance assumptions for the support structures :
 - i. Position - ± 0.5 mm (reference is a vessel center line TBD)

15.F.04 Add. Pb/B4C Shielding Assembly - Assembly and test activities and assumptions for the site are given below:

- 1. Assembly costs to be included are as follows:
 - A. Installation of the Pb / B4C shielding on the vessel
 - B. Welding on the support structures to the vessel
- 2. Dimensional inspection of installation position.
- 3. All fabrication, testing, inspection, and certification activities at the site are to comply with the requirements of the ASME Code Section III (Class 2). All field welding is to be assumed to be by the TIG process. The inspection method is to be RT.
- 4. Tolerance assumptions for the support structures :
 - i. Position - ± 1 mm

3.0 Cost Basis

After the vessel components and assemblies have been shipped to the site, all integrated assembly and test activities are costed in this category. Assembly and test of non vessel systems are not included.

4.0 Class

The classifications of the systems in this account (per the ITER Technical & Quality Classifications - Manual) are as follows:

System	Safety Class	Quality Class
15.F.01 Vessel Assy / Main Chamber	1	1
15.F.02 Port Assemblies	1	1
15.F.03 Support Structures	1	1
15.F.04 Add. Pb / B4C Shielding	3	1
15.F.05 Assembly and Special Fixt.	1	3

5.0 Attached Drawings

Figure No.	Drw. Title
15.F-1	Schematic View of VV Assembly
15.F-2	Toroidal Cross Section of VV Assembly

Appendix A

(Reference Drawings - Vessel Assembly)

Figure 15.F-2 Toroidal Cross Section of VV Assembly

Figure 15 F-1 Schematic View of VV Assembly