Department of Energy

Assessment

of the

ITER Project Cost Estimate

November 2002

EXECUTIVE SUMMARY

The Department of Energy (DOE) Assessment of the ITER Project Cost Estimate was conducted on November 21-25, 2002, at the request of Dr. Raymond L. Orbach, Director of the DOE Office of Science. The purpose of this review was to assess in summary fashion the cost estimate that has been prepared by the ITER Team, emphasizing reasonableness of project cost and schedule assumptions and, to the extent possible, the construction and technical management assumptions.

The mission of ITER is to demonstrate the scientific and technological feasibility of fusion energy for peaceful purposes. Fusion energy is a potential major new source of energy with attractive features of no greenhouse gas emissions, no production of long-lived radioactive products, abundant and widely distributed sources of fuel (seawater and lithium), inherent safety features to shut down easily with no possibility of fuel meltdown, continuous mode of operation to meet demand, and manageable waste.

Currently, the ITER project is at the stage where the final design is essentially complete, and the R&D that provides the technical basis for the design and for hardware fabrication is also essentially complete. Four government "Parties", namely, the European Union, Japan, the Russian Federation, and Canada are negotiating necessary international arrangements and terms for proceeding with ITER construction, and they are assessing candidate construction sites at Cadarache, France; Vandellos, Spain; Rokkasho, Japan; and Clarington, Canada. Decisions on these matters by the participating governments are expected in 2003.

The Committee concluded that the ITER Team has prepared a complete cost estimate that is based on sound management and engineering principles, and is credible as a basis for establishing relative contributions by the Parties to the construction of ITER. The estimate is a synthesis by the ITER Team of multiple international industrial cost estimates for each of 85 procurement packages covering essentially the entire project; it includes a normalization of material and labor cost rates in various countries, and it emphasizes the value of individual components relative to each other. It is not comparable to a traditional DOE construction project cost estimate. The credibility of such a value estimate is supported by the design and R&D results that are unusually mature for a science project facing the decision to fund construction.

Because multiple Parties would construct the ITER project, with each responsible for procurements of in-kind hardware in its own territory with its own currency, a direct conversion of the ITER value estimate into a single currency is not particularly relevant; nevertheless, it is possible. Converting to U.S. dollars, the total would be about $5 billion (constant 2002 dollars) for the base estimate consisting of about $4 billion for ITER hardware, initial spares, buildings, and installation and assembly of the hardware into the buildings plus about $1 billion for project management and engineering support during construction, R&D during construction, and commissioning. The U.S. considers commissioning to be part of the project period while the current ITER Parties consider it to be part of the operation period.

Several of the current Parties have gone beyond the direct conversion process and prepared their own full cost estimate. European Union personnel presented the conclusions of their cost estimate to the Committee. Their analysis indicated close agreement with the ITER value estimate to within a few percent, although individual component costs varied by somewhat larger percentages.

The current ITER Parties agree that the ITER value estimate is appropriate for establishing relative contributions by the Parties to the construction of ITER. They are now negotiating an arrangement for sharing project scope on that basis, with the understanding that each Party would be financially responsible for their in-kind hardware contributions.

In light of the above, the Committee concluded that in the event the U.S. decides to join the current negotiations, it should prepare, as soon as possible, its own cost estimate for a set of procurement packages for components the U.S. would be interested in providing. Such a cost estimate should conform to current DOE project management procedures, including appropriate contingency and escalation cost. In addition, similar cost estimates should be prepared for the other types of potential U.S. contributions to ITER for common expenses such as personnel assigned to the Central Team and Field Team and common procurements. These latter estimates should also include appropriate contingency and escalation cost.

The proposed construction schedule for the project is ten years beginning with establishment of an ITER legal entity and ending with first plasma. A critical path has been identified, and tasks not on the critical path have been scheduled to level the spending profile. The construction schedule seems generally reasonable; however, there is inevitable uncertainty in estimating the duration of the governmental approval process that is a prerequisite to starting the construction of the project.

The Committee was informed of some of the options being considered by the negotiators for management of the ITER construction project. These include roles for a government level Council, Director General, various advisory groups, Central Team, Field Teams that provide technical management of procurements in the Parties' territories, and Domestic Agencies that award contracts. The results of the ongoing negotiations will establish the management and organization structure to be used for project construction. Since management will be the key to the ultimate success of the project, the Committee believes that for a complex international project such as ITER, a strong line-management approach will be in the best interest of the Parties.

In summary, the Committee concluded that the ITER Team has prepared a complete cost estimate that is based on sound management and engineering principles, and is credible as a basis for establishing relative contributions by the Parties to the construction of ITER. The proposed schedule developed by the ITER Team is reasonable. The management arrangements now being negotiated are critical to the project's success.

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Appendices

1. INTRODUCTION

1.1 Background

The mission of ITER is to demonstrate the scientific and technological feasibility of fusion energy for peaceful purposes. Currently, the European Union, Japan, the Russian Federation, and Canada are negotiating the arrangements and terms for construction, operation, and decommissioning of ITER for subsequent decisions by participating governments.

In his remarks to the Conference of G-8 Energy Ministers in Detroit, Michigan on May 2, 2002, Energy Secretary Spencer Abraham told the audience that President Bush is interested in the potential of ITER and has asked DOE to seriously consider American participation.

Since that time, the U.S. fusion community completed a two-week Summer Study in July 2002 that confirmed the need for burning plasma fusion research, and that resulted in a uniform technical assessment of the three leading proposals for a burning plasma experiment, one of which was ITER. Building upon the results of the Summer Study, a Fusion Energy Sciences Advisory Committee (FESAC) Panel completed a report in September 2002 that was provided a burning plasma program strategy to advance fusion energy. The Panel report was subsequently endorsed by FESAC. ITER is an important part of the recommended strategy.

The Department of Energy (DOE) is sponsoring a study by the National Research Council to provide a further review from the broader perspective of the larger U.S. science community of the burning plasma strategy of the U.S. fusion program. Interim findings are expected in December 2002.

A FESAC Panel on the Fusion Development Path is developing a plan for starting operation of a fusion demonstration facility in 35 years, and ITER is a key element of the plan. An interim report will be available early in December 2002.

The results of all of these efforts, including results from the DOE Assessment of the ITER Cost Estimate will enable DOE to respond to the President's request for "DOE to seriously consider American participation (in ITER)."

1.2 Charge to the DOE ITER Cost Assessment Committee

Because of the size of a potential U.S. investment in ITER, the importance of ITER in advancing fusion science and the potential for ITER to serve as a model for future international science projects, the Office of Science will need to be able to substantiate to Congress and the Administration, that any investment in ITER is reasonable and likely to achieve expected results.

In an October 31, 2002, memorandum (Appendix A), Raymond L. Orbach, Director of the DOE Office of Science (SC) established a review committee with the following charge:

> "…I request that you assemble a Review Committee to assess in summary fashion the cost estimate that has been prepared by the ITER Project Team. The assessment should emphasize the reasonableness of the project cost and schedule assumptions and, to the extent possible, the construction and technical management assumptions."

The Director asked for a written review report by December 2, 2002.

1.3 Membership of the Committee

The Committee was chaired by Daniel R. Lehman, Director of SC's Construction Management Support Division. Its members were primarily drawn from DOE National Laboratories, and DOE Site and Project Offices. Two advisors were chosen to assist the Committee in their understanding of ITER technology, design, construction, and planned operations. In addition, the Committee included observers from DOE and the White House Office of Science and Technology Policy. The Committee participants are shown in Appendix B.

1.4 The Assessment Process

Recognizing that the U.S. is reconsidering its participation in ITER, Dr. Robert Aymar, the leader of the ITER International Team, along with his staff, graciously offered to meet with the Committee in November 2002. Development of a mutually agreeable agenda was carried out with the close cooperation of Dr. Aymar. The Committee would like to express its gratitude for the excellent cooperation and hospitality received from its ITER hosts.

The assessment took place November 21-25, 2002 at ITER offices located at the Max Planck Institute of Plasma Physics in Garching, Germany. The agenda is provided in Appendix C. The first day was largely devoted, in plenary session, to project technical overview presentations by ITER staff members. On the second day, the Committee met and began technical, cost, and management discussions with Dr. Aymar. Late in the afternoon, the team met with a representative of the European Fusion Development Agreement, Dr. Roberto Andreani, who recently completed an independent estimate of ITER project costs. Discussions with Dr. Aymar continued into the third day. The next two days focused on committee working sessions, committee deliberations, and drafting the Committee's report. Each Committee member met with Dr. Aymar to discuss initial findings and comments in his respective areas of expertise and assigned ITER system. The preliminary results of the assessment were discussed with Dr. Aymar.

The basis for the assessment of the ITER cost estimate involved expert opinion by the committee members relying on information made available by Dr. Aymar and his staff and published ITER documentation. The Committee considered cost factors such as maturity of project scope definition, quality of the bases of estimates, identification of major cost drivers and sensitivities, and areas of risk and uncertainty. The Committee also considered observations and comments from previous ITER reviews and assessments.

Four candidate sites for ITER have been proposed for consideration within the ongoing ITER negotiations. Europe has proposed two sites—one in France and one in Spain. Japan has proposed a site in the northern end of its main island, and Canada has proposed a site near Toronto. The negotiators from these Parties and the Russian Federation are expected to finish their reports on these sites by or around February 2003, at which time the participating governments would consider the reports of the negotiators and subsequently reach a decision on the preferred site and other key subjects such as cost sharing and selection of a director. Subsequently, a Joint Implementing Agreement would be updated to reflect the site selection, and the agreement would be initialed for approval by the participating governments later in 2003.

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2. ITER DESIGN OVERVIEW

2.1 Background on Fusion

Fusion energy is a potential major new source of energy. The fusion energy process involves the fusion of deuterium and tritium fuels to generate heat that can be used for the production of electricity and possibly for the production of hydrogen as a fuel. The U.S. DOE Office of Science has the lead role in the U.S. for pursuing fusion energy research.

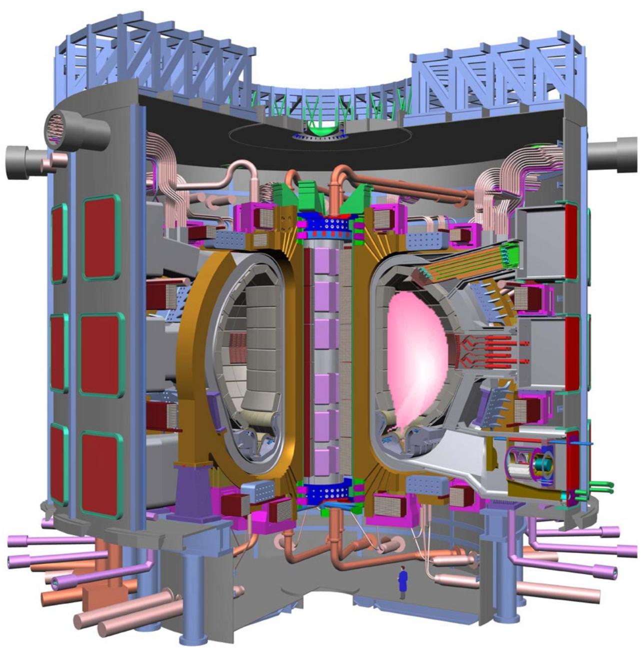
The attractive features of a fusion power plant would be no greenhouse gas emissions, no production of long-lived radioactive products, abundant and widely distributed sources of fuel (seawater and lithium), inherent safety features to shut down easily with no possibility of fuel meltdown, a continuous mode of operation to meet demand, and manageable waste.

Since the late 1950's, scientists and engineers from the U.S., Europe, Russia, and Japan (the major fusion programs) have conducted fusion research with an ultimate goal of developing such a new source of energy. Excellent progress has been made as a result of continuously improved fusion plasma research experiments with major advances in scientific diagnostics, modeling, and computation. Today, fusion research is at the threshold of exploration of "burning plasma" in which sufficient heat from the fusion reaction is retained within the plasma and sustains the reaction for long duration. Such exploration is a necessary step toward the realization of a fusion energy source; it must be done to establish the confidence in proceeding with demonstrations of practical fusion energy. Construction of ITER and implementation of the ITER research program would provide for such exploration. Due to its significant performance capability, ITER would advance the fusion energy goal in a major way.

2.2 Background on ITER Design Activities

The U.S. participated in the ITER Conceptual Design Activity with Europe, Japan, and the Soviet Union from its inception in 1986, at the recommendation of President Reagan and General Secretary Gorbachev, until its completion in 1990. The U.S. participated in the ITER Engineering Design Activity with Europe, Japan, and the Russian Federation from mid-1992 until mid-1998, during which time the initial ITER design was prepared including extensive supporting R&D. In early 1998, the U.S. participated in an ITER Special Working Group to reconsider the ITER design with the purpose of reducing its cost and increasing its likelihood of success against modified scientific and technological goals—while retaining the overall programmatic objective of demonstrating “the scientific and technological feasibility of fusion energy for peaceful purposes.” At the formal conclusion of the Engineering Design Activity, the U.S. left the ITER activities because of Congressional concerns that the project would not be constructed and would not work.

After the U.S. departure, the other ITER Parties continued in the direction proposed by the Special Working Group. The subsequent design effort was quite successful and has resulted in the present ITER design (see Appendix D for design decriptions), which retains the overall programmatic objective, but with some performance reduction and significantly lower cost relative to the initial device. The redesign, coupled with theoretical and experimental advances, has given the fusion scientific community confidence that the new ITER will meet its scientific and technological goals.



ITER Final Design

3. ITER COST ESTIMATE OVERVIEW

3.1 Estimate Purpose and End Use

The purpose of the cost estimate developed by the ITER Team is to provide a consistent, comprehensive, and realistic basis to assist the ITER Parties in determining the nature and scope of their involvement in the construction of ITER. This estimate is not a project budget or control estimate in the traditional cost engineering sense. The estimate is a synthesis of multiple international cost estimates for each of 85 procurement packages covering essentially the entire project. In addition, the ITER Team provided detailed backup information to the Parties including physical quantities for all systems, as well as labor hours and normalized labor rates so that the Parties could perform their own estimates. The Parties have accepted the ITER Team's value estimate as an appropriate mechanism for understanding, with a common basis, the nature and value of the contributions to be made by each individual Party.

The current ITER value estimate is a product of significant project efforts leading to a new design that achieves a 50 percent reduction in the ITER value estimate of the direct capital cost of the previous 1998 ITER design. The process for collecting cost data from industries to complete the new valuation followed the same process that was used to develop the 1998 ITER value estimate. Procurement packages, providing technical descriptions and standard cost categories were sent to the Parties' industries with specific instructions for estimating the cost and quantity of equipment, materials, tooling, and labor. The data collected from the responses were evaluated, normalized, and converted to a common cost basis—ITER Units of Account (IUA), where IUA = $1,000 U.S. (January 1989 value). The procurement packages were not sent to Canada because Canada became a negotiating Party at a later date. The normalized estimates were summarized in the ITER Technical Basis (International Atomic Energy Agency, ITER Engineering Design Activity Documentation Series No. 24) and are provided as Attachment E.

The newly developed value estimate is supported by a large engineering design effort (approximately $500 million) that resulted in an essentially final design for ITER, and an unusually large R&D effort (approximately $1 billion) both of which have been conducted over the past decade. The ITER value estimate did not include contingency and escalation that would reflect the additional cost of materials and labor based on the currently proposed construction schedule (approximately ten years). In addition, the project has identified the value estimates of project management and engineering support during construction, R&D during construction, and integrated commissioning to achieve first plasma.

The overall ITER management approach and specific procurement and contracting practices have not been determined, although Dr. Aymar described the current models being considered by the negotiators, and a Host Party has not been selected. These features as discussed in Section 6 could have a significant impact on the cost of constructing ITER.

The project cost for ITER determined by any specific Party in their unique currency and their accounting practices will likely vary from the ITER valuation. Such a Party-specific cost estimate would be a summation of the costs of the defined scope of work using the standards and accepted estimating and accounting practices of the specific Party. For instance, if the U.S. were to develop an independent estimate for the entire ITER scope, it should take the following steps:

1. Evaluate the project scope and validate the ITER assumptions making any changes necessary (equipment, materials, labor, support costs, etc.) to meet the technical specifications required for a particular component required by ITER using the U.S. methods and practices.
2. Include all support costs such as management, engineering, procurement, and other relevant project costs (R&D/Commissioning).
3. Establish and include contingency to address uncertainty in the estimate.
4. Escalate the total cost to reflect the increase in cost of materials and labor based on appropriate escalation rates over the currently proposed construction schedule.

However, no ITER Party will ever be responsible for the entire project scope. Therefore, it would be more appropriate for the U.S. to estimate only the cost for ITER components under consideration by the U.S. using the previously described step-wise process.

3.2 Estimate Classification and Characteristics

The ITER value estimate for the direct items closely resembles a typical Class 1 cost estimate as defined by the International Association for the Advancement of Cost Engineering (AACE International). Class 1 estimates are based on full project definition, supported by deterministic cost estimating methods, and are the result of significant efforts focused on cost estimate preparation.

The estimate documentation associated with the procurement packages have many elements of best practices in cost estimating: standard formats, clear bases of estimates, well-defined scopes of work, defined labor hours and rates, documented quantities, and well-defined descriptions of cost categories used for all cost estimates.

Several reviews by outside groups have been conducted recently. In the U.S., a committee of the 2002 Snowmass Summer Study examined ITER's cost estimate as part of a comparative analysis examining the estimates of ITER, FIRE, and IGNITOR. The Snowmass committee identified items not included in the estimate and highlighted areas of risk and uncertainty. Overall, the Snowmass committee found the ITER estimate to be reasonable as a basis of comparison to facilitate international negotiations on task sharing.

In January 2001, the European Union contracted (approximately $1 million) with a consortium of European industrial firms to develop an independent costing of ITER using European standards and practices. After a four-month study, the estimate developed by the consortium confirmed the ITER estimate with an overall discrepancy of a few percent for the total cost.

The Committee learned that the Russian Federation and the Japanese have also developed independent estimates for all or a portion of the ITER valuation in their respective cost estimating and accounting systems. The Committee was not able to obtain information about the outcomes of these efforts, due to time limitations.

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4. COST ESTIMATE ASSESSMENT

The Committee concluded that the ITER Team has prepared a complete value estimate that is based on sound management and engineering principles, and is credible as a basis for establishing relative contributions by the Parties to the construction of ITER. The major part of the value estimate is judgment by the ITER Team based on multiple international industrial cost estimates for each of 85 procurement packages covering essentially the entire project; it is not comparable to a traditional DOE construction project cost estimate. The credibility of the estimate is supported by the design and R&D results that are unusually mature for a science project facing the decision to fund construction.

Items of cost deliberately not included in the estimate have been noted by the Committee. These items include: transportations costs of large components from the fabricator's closest port to a potential site and expatriation charges for industry personnel to assist with installation. Site-specific costs for items outside the generic design criteria, e.g., potential additional cost for seismic requirements, will be borne by the host. Detailed design and R&D for Diagnostics and Heating and Current Drive Systems are not part of the estimate and are expected to be paid by the contributing Party as part of on-going R&D programs. As previously mentioned, contingency and escalation have not been determined or included in the estimate.

A summary of the Committee's assessment is provided in Table 4-1. A more detailed version of this table addressing the major ITER systems is included as Appendix F.

Table 4-1. Summary of Review Committee Assessment

Element of ITER Project Value	kIUA[1]	$M2002[2]	Committee Assessment
ITER Direct Items	2,754.7	3,955.7	**Machine Core** design essentially complete, good detail in estimates. **Auxiliary Systems** designs are mature, many conventional components, good est. details. **Heating and Current Drive Systems** designs are preliminary. **Diagnostics** are conceptual and based on 1998 ITER Design. **CODAC** estimate is reasonable based on engineering judgment.
Construction Management and Engineering Support	477.0	685.0	Generally, reasonable; Physics support not included.
Contingency	Not Relevant for ITER Value	TBD	Not included as part of ITER valuation; would be included in USDOE estimate for any component.
Other Project Costs (R&D, Commissioning)	169.9	244.0	**R&D** is reasonable/ recognizes ~$1B spent. **Commissioning** is reasonable, Physics support is not included.
Escalation	Not Relevant for ITER Value	TBD	Not included as part of the ITER valuation; would be included in USDOE estimate for any component.
ITER Value Estimate	3,401.6	4,884.7	Credible as a basis for establishing relative contributions.

[1] ITER Units of Account (IUA) where 1 IUA = $1,000 January 1989 dollars, IUA is a common basis determined as a result of the ITER process for normalizing estimates from different international parties.
[2] kIUAs converted to $M2002 (kIUA x 1.436); see Appendix H for methodology.
[3] Costs for supporting work expected to be conducted under the Parties' ongoing programs are not included. These costs include diagnostic development; experiment planning and analysis; plasma heating technology, etc.

4.1 Direct Cost Summary

4.1.1 Machine Core

4.1.1.1 Magnet System

This system's cost estimate is credible, based on sound management and engineering principles and can be used as a basis for establishing relative contributions by the Parties. ITER superconducting magnet costing is based on a complete set of project work packages and budgetary estimates from competent industrial vendors among the ITER Parties. It is further supported by the successful completion of the toroidal field (TF) and central solenoid (CS) model coil facilities and tests of insert coils, representing the original ITER design, all of which met or exceeded specified performance. ITER risk is further reduced by ongoing research by the ITER Parties, particularly in strand development.

The conductor temperature margin and conduit tensile fatigue for the new ITER design are considered marginal. This is being addressed by changes in the conductor and conductor materials, as well as a strand development program. These measures are likely to restore design margins, while qualifying as many Nb_3Sn vendors as possible in order to avoid possible impact on the project schedule.

System Description

The ITER magnet system consists of the TF magnet system, CS magnets, the poloidal field (PF) system, the field error correction coils (CC), the cold structure connecting the TF, CS, PF and CC systems, and the superconducting current feeders (FF).

The 18 TF magnets provide a toroidal flux density of 5.3 T at the 6.2-meter plasma major radius. The maximum flux density at the TF magnets is 11.8 T and the conductor current is 68 KA. The TF conductors are circular 1,082-strand Nb_3Sn cable-in-conduit (CICC) superconductors with a central cooling channel. They are pancake-wound in seven radial stainless steel plates. The circular conductors are insulated from the plates by epoxy-impregnated polyimide. The TF winding pack is enclosed by a stainless steel structural case. The TF cases are wedged at the inner leg to support overturning loads. Overturning of the outer legs is resisted by bolted shear panels.

The CS magnet system is a vertical stack of six independently driven winding pack modules, hung in a single assembly from the top of the TF coils. The modules are preloaded in compression by tie-plates at the inner and outer diameters of the CS stack. The CS conductors are 1,152-strand Nb_3Sn CICC with a peak flux density of 13.5 T.

The PF coils, used for plasma position and shape control, are six separate solenoids, mounted from the TF cases. The conductors are approximately 1,000-strand NbTi CICC's in a square, stainless steel conduit with a central cooling channel. PF mounting plates prevent bending shear in the PF winding packs by allowing radial motion.

The 18 CCs are mounted outside the TF in three independent sets of six coils at the top, bottom, and equator of the tokamak. The CCs correct error fields due to coil asymmetries. The CICC is a NbTi cable with approximately 300 strands, a square, stainless steel conduit, and no central cooling channel. The conductors carry up to 10 kA at 5 T.

The Feeders are the 26 superconducting bus lines, feeding current to the superconducting magnets from the cold end of the vapor-cooled leads. They include three coolant feeders for cold structure, two instrumentation feeders, cryostat feedthroughs, and a coil terminal box outside the cryostat.

All of the superconducting coils are cooled by the forced circulation of supercritical helium with inlet pressures of 0.6 MPa and inlet temperatures of 4.4-4.7 K.

Scope Definition and Maturity

The system must provide a central flux density of 5.3 T, a plasma current of 15 MA, and a volt-second swing of 314 Wb, as well as all of the plasma positioning, shaping, and field error cancellation. The coil system has a total stored energy of approximately 50.2 GJ and the cold mass is 10,135 tonnes.

ITER98 was a highly mature design, with a complete set of drawings and supporting analysis to submit to industry for budgetary estimates. The downsized ITER magnet system is very mature, but some parts of the coil system have changed topologically. The most significant change in the magnet system since ITER98 was that from layer-wound to a pancake-wound and segmented CS coil. The joints changed from praying hands to clasping hands. Structurally, the CS coil is no longer bucked against the TF coil. The necessary changes have been made on the drawings, but drawings of joints and breakouts were not supported by finite element analyses in the Design Description Document (DDD). According to the Director, most of this analysis has since been completed.

Basis of Estimate

The magnet system estimate of $1,094 million is based on six work packages that were developed and sent to industries in the countries of the three ITER partners. The magnet work packages included: 1) Toroidal Field Coils and Windings, 2) Magnet Structures, 3) Poloidal Field Coil and Correction Coils, 4) Central Solenoid Coil, 5) Feeders, and 6) Conductor. The Feeders only received a single budgetary estimate. The other five major subsystems received full budgetary estimates from each of the three ITER Parties.

A summary of the six magnet work packages was reviewed. All of the components and manufacturing steps needed to produce the magnets and deliver them to the ITER site were included. It is noted that magnet cold testing is not planned.

Major Cost Drivers and Sensitivities

The magnet system cost is dominated by the superconductor, the magnet structures, and the Toroidal Field Coil and Winding. They represent 47, 22, and 15 percent of total magnet system cost, respectively.

Risk and Uncertainty

The superconductor is the largest source of cost and schedule uncertainty in the magnet system. Negative schedule and cost uncertainty comes from the possibility that the design will probably require the parallel efforts of all the Nb_3Sn vendors in the world, possibly generating noncompetitive pricing or bottlenecks. Performance uncertainty comes from strain degradation of critical properties, creating low design margins, and the requirement for low flaw sizes, due to high cyclic stresses.

Low design margins in superconductor critical properties and allowable conduit flaw sizes are being addressed by re-optimization of the conductor design, qualification of high toughness conduit material, and the development of Nb_3Sn with higher critical current density. The Nb_3Sn strand development program, if successful, should restore adequate design margins. Since the higher performance specifications cannot be met by some existing technology, ITER is attempting to qualify enough vendors for quantity production to avoid a significant impact on schedule.

4.1.1.2 Vacuum Vessel

The vacuum vessel cost estimate is credible, based on sound management and engineering principles and can be used as a basis for establishing relative contributions by the Parties. The relatively minor design changes made since the estimate was compiled should not affect the cost significantly. There is no evidence of significant technical or schedule risks that would adversely affect the construction costs. The Committee has reviewed a summary of this package.

System Description

The vacuum vessel is a large toroidal chamber that provides both the plasma vacuum and tritium containment functions. The vessel measures almost 20 meters in diameter at the outer extent of the torus and weighs about 5,400 tonnes. It is a double-wall structure, composed of 60-

mm 316LN stainless steel face sheets and 40-mm poloidal ribs. The vessel is fabricated in nine toroidal sectors. There are 18 sets of upper and equatorial ports and nine sets of lower ports for access. The vessel is supported from the lower port ducts. Port duct extensions connect the vessel ports to the cryostat. Neutron shielding consisting of steel plates and water is provided between the double walls, including ferritic material to reduce the toroidal magnetic field ripple. The vessel is protected from radiation damage by a set of approximately 0.45-meter-thick blanket modules, such that the vessel field joints can be re-welded at any time during the life of the experiment. The vessel walls and lower, outboard blanket support frames provide enough conducting material for passive stabilization of the plasma without relying on additional copper plates or in-vessel active control coils. The vessel is highly loaded during plasma disruption events, but has been thoroughly analyzed and shown to safely resist all design loading conditions.

Scope Definition and Maturity

The vessel is almost completely designed, with full CAD models and supporting analysis. The complete specification and drawings needed for a procurement package will be available in July 2003. In addition, two full-scale, half sectors of the vessel were constructed in Japan as part of the Engineering Design Activity (EDA) R&D activities and demonstrated the feasibility of the all manufacturing methods, tolerance requirements (+/- ten mm), and sector-to-sector assembly welding techniques.

Basis of Estimate

The vessel fabrication estimate of approximately $330 million is a “build-to-print” estimate and is divided into two parts: the main vessel and the port assemblies. The main vessel estimate includes the double wall torus, vessel supports, shielding between the vessel walls, integral blanket interfaces, and instrumentation sensors. The port assemblies’ estimate includes the port duct extensions and connecting ducts. Both estimates include manufacturing engineering. Two Parties estimated the vessel and port assemblies, while one Party estimated only the port assemblies. The estimate includes the labor for all manufacturing and inspection operations based on known quantities such as mass of raw material, mass of weld deposited, material removed by machining, etc.

Major Cost Drivers and Sensitivities

The vessel cost is dominated by the large amount of welding, the relatively high geometric accuracy, and the ultra high vacuum requirements. The complexity and cost of the vessel have increased from the EDA design due to the incorporation of attachment features for a large number (421) of blanket/shield modules. However, attachment of the blanket modules to the vessel eliminated an expensive, separately cooled, backplate structure that was part of the EDA design.

Risk and Uncertainty

No major risk or uncertainties are apparent. Additional R&D is proposed to fabricate a small section of torus containing one or two typical blanket attachment interfaces to assess local weld distortion.

4.1.1.3 Blanket System

The Blanket System fabrication cost estimate is credible, based on sound management and engineering principles, and can be used as a basis for establishing relative contributions by the Parties. Some detailed design work remains to fully characterize all of the unique blanket shapes. No major design changes have been made since the estimate was compiled and none are expected to be made prior to release of procurement packages that would affect the cost significantly. There is no evidence of significant technical or schedule risks that would adversely affect the construction costs. The Committee has reviewed parts of this package.

System Description

The blanket/shield system is designed to absorb most of the fusion power (up to 700 MW) and consists of 421 water-cooled, stainless-steel modules weighing about four tonnes each. The modules are mounted on the plasma side of the vacuum vessel via adjustable, flexible titanium supports. The plasma facing surface of each module is faced with four, separately cooled, independently removable panels consisting of a copper alloy heat sink and a ten-mm-thick beryllium surface layer. Manifolds mounted to the vessel provide cooling water, and all connections are made from the plasma side of the modules with short bore welding tools. The modules are highly loaded during plasma disruption events, but have been thoroughly analyzed and shown to transmit all design loading conditions to the vacuum vessel without damage. However, the modules are also designed for remote removal and replacement via the in-vessel remote handling system. The entire outboard array of modules can be replaced with tritium breeding modules as an upgrade if outside sources of tritium are not available. The fully remote handling and accurate placement of similar-sized modules has been demonstrated as part of the EDA R&D program.

Scope Definition and Maturity

The blanket system is fully defined, but the detailed configuration of all the various module shapes must still be completed. The complete specification and drawings needed for a procurement package are planned to be available coincident with overall start of project construction.

Basis of Estimate

The blanket hardware estimate of approximately $237 million is a "build-to-print" estimate and is divided into four packages: the blanket manifolds and filler shields, the first wall/shield modules, the port limiters, and the blanket module connections. Full or partial estimates were provided for all four packages by all three Parties. The manifold estimate includes the custom piping inside the vessel, as well as a few small filler blocks in gaps between modules. The first wall and shield module package consists of the separable first wall assemblies and the large shield blocks and include about five percent overage or spares. Two port limiters are included, as well as one spare. The blanket connectors include both the mechanical and electrical connection pieces. All the estimates include material, shop engineering, and the labor for all manufacturing and inspection operations based on known quantities such as forming operations, mass of weld deposited, material removed by machining, etc. The estimates were based on a composite of manufacturing methods developed during an extensive R&D program. Powder hot isostatic pressing (HIPping), casting, and forging/drilling were all successfully prototyped for the blanket modules. Several different prototypical first wall panel fabrication methods were successfully demonstrated.

Major Cost Drivers and Sensitivities

The blanket cost is dominated by the large number of blanket modules and associated first wall panels. There is also some penalty for the complexity of the shapes required to accommodate the neutral beam openings, resulting in a large number (31) of unique module shapes. The first wall panel design is dictated by both the direct heating and the large disruption loads that require division of the first wall into four panels per blanket module and a strong attachment between the panels and the module. Two designs are currently being considered and, in principle, both could be used for the production units. The other cost driver is the beryllium coating on the first wall. Large differences in the cost of beryllium were uncovered during the estimating process, but a median value was used in the estimate rather than the lowest value.

Risk and Uncertainty

No major construction risks or uncertainties are apparent. The blanket modules are not on the critical path, the design is nearly complete, and several different fabrication processes have been successfully developed.

4.1.1.4 Divertor

The Divertor System cost estimate is credible, based on sound management and engineering principles and can be used as a basis for establishing relative contributions by the Parties. The detailed design work is completed but the complete specification is not prepared. No major design changes have been made since the estimate's compilation, nor are any expected prior to bid that would affect the cost significantly. There is no evidence of significant technical or schedule risks that would adversely affect the construction costs, and the technical decision on the material choice (carbon or tungsten) of the high heat flux targets has been finalized. The Committee has reviewed parts of this package.

System Description

The divertor system consists of 54 water-cooled, stainless-steel cassette assemblies weighing about 12 tonnes each. Each cassette is fitted with plasma facing surfaces capable of absorbing very high local heat flux of more than 10 MW/m^2. The cassettes are mounted on rails at the bottom of the vacuum vessel and form a complete toroidal ring. The plasma facing surfaces of each cassette are separately cooled and independently removable in a hot cell to facilitate maintenance and minimize waste. The inner and outer targets are a combination of tungsten and carbon fiber composite (CFC) integrated with a copper alloy heat sink and steel strongback in the form of "fingers" oriented in the poloidal direction. Manifolds mounted behind the cassettes provide cooling water, and all connections are made with in-pipe welding tools. The plasma facing components are highly loaded thermally and mechanically during plasma disruption events, but have been thoroughly analyzed and shown to transmit all design loading conditions through the cassettes to the vacuum vessel without damage. The divertor is designed for remote removal and replacement several times during the operating phase. The fully remote handling, water connections, and accurate placement of full scale cassettes have been demonstrated as part of the EDA R&D program.

Scope Definition and Maturity

The divertor system is fully defined, and the detailed drawings and specification needed for a procurement package will be completed prior to start of construction. Some concerns about tritium retention in the CFC may require a switch to tungsten for the entire surface, and this issue is the subject of ongoing R&D. In any event, both CFC and tungsten targets have been successfully fabricated and tested in all Parties. A full-scale partial cassette body was constructed and integrated with the targets as part of the EDA R&D program.

Basis of Estimate

The divertor estimate of approximately $109 million is a "build-to-print" estimate and is divided into two packages: cassette integration and testing, and plasma facing (high heat flux) components. Full or partial estimates for both packages were provided by two Parties, while one Party provided a full estimate only for the plasma facing components. All the estimates include material, shop engineering, and the labor for all manufacturing and inspection operations based on known quantities such as forming and brazing operations, mass of weld deposited, material removed by machining, etc. The estimates were based on a composite of manufacturing methods developed during the extensive R&D program.

Major Cost Drivers and Sensitivities

The divertor cost is dominated by the large number of high heat flux "fingers" that must be reliably fabricated to very high quality.

Risk and Uncertainty

While there has been an extensive R&D program, there is still some concern that the manufacturing reliability may need modifications or optimization during large-scale production fabrication. However, the divertor modules are not on the critical path and several fabrication processes have been successfully developed.

4.1.1.5 Machine Assembly

The Machine Assembly is a complex series of operations requiring a large number of labor hours, as well as significant special tooling and fixtures. The cost estimate is credible, based on sound management and engineering principles and can be used as a basis for establishing relative contributions by the Parties. The overall planning is complete to the extent that all operations have been identified and estimated, and detailed concepts have been developed for all major tools. The very precise manipulation and placement of very heavy (up to 1,200 tonnes) loads will be difficult. However, there is no evidence that there is some feasibility issue or other technical risk that can be immediately identified that would adversely affect the construction costs. The Committee has reviewed parts of this package.

System Description

Machine Assembly includes all operations associated with installation of the cryostat and all systems inside the cryostat, including:

- Cryostat and penetrations;
- Cryostat lid and frame for bioshield;
- Magnet system, including toroidal field coils and structures, gravity supports, poloidal field coils and supports, central solenoid and supports, correction coils and supports, and in-cryostat feeders;
- Vacuum vessel, including vacuum vessel ports, vacuum vessel gravity supports;
- Thermal shields, including vacuum vessel thermal shields, cryostat thermal shields, transition thermal shields;
- In-vessel components, including divertor and blanket modules;
- In-port components, including cryopumps, diagnostics, test blanket modules, and additional heating systems; and
- All associated in-cryostat piping, instrumentation, and cabling.

The above tasks require a number of large transporters, lifting fixtures, subassembly stands, platforms, special purpose welding, inspection and measurement tools, as well as the two large overhead cranes.

Scope Definition and Maturity

The assembly steps are defined in a detailed assembly plan and all the major tools and fixtures are defined at the advanced conceptual level. The fully detailed plans, drawings, and specification needed for a procurement package will be completed about one year after start of construction.

Basis of Estimate

The Machine Assembly estimate of approximately $133 million is an advanced conceptual design estimate and is divided into two packages: assembly operations and assembly tooling. Full estimates were provided for both packages by all three Parties. All the estimates are based on physical quantities such as material, mass of weld deposited, number of connections, etc. and include shop engineering and the labor for all tooling manufacturing, assembly, and inspection operations. Detailed plans and detailed concepts for the major tooling and fixtures were used for the estimate, but resource-loaded schedules and details of the minor tools remain to be developed.

Major Cost Drivers and Sensitivities

The assembly cost is dominated by the large number of operations and the extensive welding to be performed. For example, the nine vacuum vessel field assembly joints each require four, full-poloidal welds in the 60-mm-thick facesheets. There are also many kilometers of piping to install, weld, and inspect, as well as numerous large vacuum port connections.

Risk and Uncertainty

The primary risk of the assembly operations appears to be the manipulation and very accurate placement of very heavy loads, including the TF/VV sub-assemblies that weigh more than 1,000 tones each and the Central Solenoid assembly that weighs more than 1,100 tones.

4.1.1.6 Cryostat

The Cryostat cost estimate is credible, based on sound management and engineering principles and can be used as a basis for establishing relative contributions by the Parties.

System Description

The cryostat provides the vacuum boundary required for thermal insulation, as well as a secondary containment barrier. The cryostat consists of a large, fully welded stainless steel vacuum vessel 28 meters in diameter and 24-meters tall with a total weight of over 3,000 tonnes. Both the lid and base are reinforced, flat structures, with the lid supported by an integrated carbon steel framework that includes the bio-shielding and the base supported by the building. Numerous penetrations are provided in correspondence to the vacuum vessel ports and for coil service lines. The cryostat must be assembled on site from pre-formed subassemblies. The vacuum vessel pressure suppression system (VVPSS) consists of a simple cylindrical tank designed to condense steam produced by leaks in the in-vessel components and protect the vacuum vessel from overpressure.

Scope Definition and Maturity

The cryostat and VVPSS are defined, and the detailed drawings and specification needed for a procurement package will be completed about one year after start of construction.

Basis of Estimate

The cryostat estimate of approximately $109 million is a "build-to-print" estimate and includes both the cryostat and vacuum vessel pressure suppression system in one procurement package. Complete cost estimates were provided for this package by two Parties. The estimates include material, shop engineering, and the labor for all manufacturing and inspection operations based on known quantities such as forming operations, mass of weld deposited, material removed by machining, etc.

Major Cost Drivers and Sensitivities

The cryostat cost is dominated by its large size, numerous penetrations, and the large quantity of field welding required.

Risk and Uncertainty

No major construction risks or uncertainties were apparent. The cryostat is not on the critical path, the design is for the most part is complete and it is of conventional construction.

4.1.1.7 Thermal Shields

The thermal shield cost estimate is credible, based on sound management and engineering principles and can be used as a basis for establishing relative contributions by the Parties.

System Description

The thermal shield system reduces the heat load on the magnets and other structures operating at liquid helium temperatures by providing a radiation barrier actively cooled to 80K with helium gas. The shield is divided into several regions, including the region immediately between the vacuum vessel and magnet system, the regions around the ports and the region adjacent to the interior surface of the cryostat. The shields consist of stainless steel panels with a low emissivity silver coating. Electrical breaks are provided to minimize eddy currents and resultant forces during transients. The thermal shields are almost impossible to repair in some areas, so all the panels are designed with fully redundant cooling.

Scope Definition and Maturity

The thermal shield system is fully defined, but the complete drawings and specifications are not needed for a procurement package until after start of construction.

Basis of Estimate

The thermal shield estimate of approximately $41million is a “build-to-print” estimate in one procurement package. Complete estimates were provided by all three Parties. All the estimates include material, shop engineering, and the labor for all manufacturing and inspection operations based on known quantities such as forming operations, mass of weld deposited, leak checking, etc.

Major Cost Drivers and Sensitivities

The thermal shield cost is dominated by the large number of pieces and associated helium trace lines, as well as the required geometric complexity and tight tolerances (few mm).

Risk and Uncertainty

The primary risk for the thermal shield is a failure that causes an excessive thermal radiation load on the magnets or cold structure. This is extremely unlikely since the cooling circuits are not constructed from tubes but from heavy extrusions and are fully inspected. In addition, there are two circuits per shield panel for redundancy.

4.1.1.8 Vacuum Pumping and Fueling System

The Vacuum Pumping and Fueling System cost estimate is credible, based on sound management and engineering principles and can be used as a basis for establishing relative contributions by the Parties. However, some of the estimates were performed only by the JCT in consultation with experts and not by industrial vendors.

System Description

The vacuum pumping system provides the necessary vacuum conditions in the vacuum vessel for the conduct of plasma experiments. The system is comprised of a roughing system, torus pumping system, cryostat vacuum pumping system, heating and current drive vacuum pumping systems, guard and service vacuum pumping system, diagnostic vacuum pumping system, and lead detection systems. The main torus pumping system uses up to ten batch-perated cryopumps, although only six will be initially supplied. The fueling system comprises a main gas supply system, the pellet injection system, the local gas supply system for the neutral beam injectors and diagnostic neutral beam, and the fusion power shutdown system. Each of the two pellet injectors are centrifugal-type capable of steady state operation.

Scope Definition and Maturity

The vacuum pumping system is relatively well defined, but the detailed drawings and specifications required for a procurement package are not needed until several years after start of construction.

Basis of Estimate

The Vacuum Pumping and Fueling estimate of approximately $49 million is based on a combination of functional and "build to print" procurement packages. The estimate is divided among seven packages, including the non-standard cryopumps and related equipment, roughing pump sets and change-over boxes, leak detection stations, standard components, pellet injector, gas injector valve boxes, and the glow discharge cleaning system. Full estimates were provided for the cryopumps, roughing pump sets, and the glow discharge cleaning system by two Parties, but the balance of the estimate was done internally by the JCT.

Major Cost Drivers and Sensitivities

The vacuum pumping and fueling system cost is dominated by the large mass flow and requirement for steady-state capability. In addition, due to the large number of separate systems serviced by the various vacuum and leak detection systems, there will be a significant number of interfaces.

Risk and Uncertainty

No major construction risks or uncertainties were apparent. The pumping system and fueling systems are both based on existing technology and confirmed by prototype tests.

4.1.2 Auxiliary Systems

4.1.2.1 Remote Handling Equipment

The estimate for the Remote Handling Equipment is credible, based on sound management and engineering principles and can be used as a basis for establishing relative contributions by the Parties. The current design is mature and augmented with R&D, which has already demonstrated two full-scale prototypes for the remote handling of blanket modules and divertor cassettes. The Committee has reviewed this package.

System Description

Due to neutron activation, the repair, inspection or maintenance of ITER in-vessel components has to be carried out remotely. In-vessel first wall components are subject to plasma-wall interaction leading to erosion. This requires regular or infrequent refurbishment, depending on the erosion rate. Furthermore, components may need to be replaced due to unexpected failure. This requires the introduction of common and dedicated remote handling (RH) equipment into the vacuum vessel. Components have been classified according to the frequency with which they are expected to require remote repair or replacement.

- RH class 1 pertains to components requiring regular planned replacement (e.g., divertor cassettes, test blanket modules).
- RH class 2 applies to those that are likely to require repair or replacement (e.g., blanket modules and diagnostics port modules).
- RH class 3 applies to components that are not expected to require maintenance or replacement during the lifetime of ITER but would need to be replaced remotely should they fail (e.g., vacuum vessel).
- RH class 4 is for components that do not require remote handling.

All in-cryostat components are RH class 3, although it is expected that up to the end of ITER operations, short-term personnel access will be feasible within the cryostat for simple repair operations.

The repair of in-vessel components can, in principle, either be accomplished by in-situ operations, or by removing the component and replacing it by a new one or re-installing the component after repair or refurbishment in a hot cell. However, studies have shown that, mainly due to access problems, in-situ repair operations are generally not feasible. The ITER strategy is therefore based on the removal of components from the vacuum vessel, and remote transfer to the hot cell where the components will be either repaired by common and dedicated RH equipment or replaced with new components.

Scope Definition and Maturity

The overall scope is well defined. The current status ranges from conceptual design to full-scale prototype development and testing.

Remote handling demonstrations for the shielding blanket (RH class 1), divertor (RH class 2), and horizontal port systems (RH class 1) have been completed. The capability to accomplish these remote maintenance operations has been demonstrated at or nearly full-scale in representative mockup simulations.

The blanket RH capabilities were demonstrated with a prototypical rail system, manipulators, end effectors, and viewing systems. A mockup of the port arrangement and several locations of blanket module simulators were built and used in the RH demonstrations. The remote handling equipment demonstrated the necessary operations to release a blanket module at several locations, remove the module to the port, bring in a new module, and re-attach the module.

The divertor RH maintenance systems were validated with a mockup of the lower port and divertor rail system. The operations included installing and removing divertor cassettes.

Basis of Estimate

The Remote Handling Equipment estimate of $88 million is supported by the successful development and testing of a full-scale manipulator for a blanket module and full-scale handling equipment with rail and port mock-up for a divertor cassette. Complete estimates were provided by two of the three Parties for all scope except for the viewing/metrology systems where there was one full estimate and one partial estimate.

Major Cost Drivers and Sensitivities

The assembly and maintenance of the ITER machine will be affected from the very beginning by the presence of in-vessel components made of, or coated with, beryllium. Because of the health hazards associated with beryllium dust, such components must be handled in a controlled way, starting from the machine assembly stage, to ensure that plant workers are not exposed to unacceptable levels of beryllium. During plasma operation, the machine components will be activated and the in-vessel components will be both activated, and contaminated with tritium. Because of the beta and gamma activation of the component bulk and surface dust (beryllium, carbon, tungsten), and because of the presence of tritium, special handling techniques during machine maintenance periods will also be required. Tritium and dust contamination must therefore be confined during the transfer of components between the machine and the hot cell.

Risk and Uncertainty

The risks associated with the RH class 1 and 2 operations have been mitigated to acceptable levels by full size demonstrations to validate the proposed RH equipment, software, and procedures. Further studies and developments are required to verify the feasibility of the disassembly and re-assembly of large components that are designated as RH class 3 (i.e., toroidal field coils and vacuum vessel segments) to a level appropriate to highly unlikely operations.

4.1.2.2 Cooling Water

The estimate for the Cooling Water System is credible, based on sound management and engineering principles and can be used as a basis for establishing relative contributions by the Parties. The current design, based on conventional technology, is mature and augmented with detailed analysis and includes well-defined interfaces. The Committee has reviewed this package.

System Description

The cooling water system (CWS) consists of the tokamak cooling water system (TCWS), the component cooling water system (CCWS), the chilled water system (CHWS), and the heat rejection system (HRS) capable of 750 MW. The CWS has the following functions:

Tokamak Cooling Water System

- Remove the heat deposited in the in-vessel components and VV during a plasma pulse to the HRS by way of the WCSs, or directly to air
- Control the coolant temperature, flow rate and pressure for the in-vessel components and VV during normal operation as required
- Remove decay heat from the in-vessel components and the VV after plasma shutdown
- Provide the ability to bake the in-vessel components and the VV
- Provide safe confinement of the radioactive inventory of the coolant
- Confine radioactive materials from the tokamak following any failure of in-vessel component boundaries
- Measure the heat removed from the in-vessel components and VV to contribute to the determination of the overall fusion power balance
- Control the water chemistry in the in-vessel components and VV
- Allow in-vessel components to be isolated to facilitate leak localization

Component Cooling Water System

- Remove the heat from components to the CHWS or to the HRS
- Control the coolant temperature, flow rate, and pressure for components as required
- Control the water chemistry in the components

Chilled Water System

- Provide low temperature coolant for the components
- Remove the heat from components to the heat rejection system

Heat Rejection System

- Provide heat rejection system coolant for the TCWS, CCWS and CHWS
- Remove the heat from the TCWS, CCWS and CHWS, and release it to the environment

Scope Definition and Maturity

The system requirements and definition of standard, existing components have been established. The envisioned equipments are considered to be currently available with a well-documented database. The system specifications and functional requirements are well understood and defined for the procurement packages. The procuring parties must develop detailed specifications for the system components.

Basis of Estimate

The Cooling Water estimate of $189 million is based on a design consisting of conventional technology and equipment. Full estimates were provided by two of the three Parties for all scope.

Major Cost Drivers and Sensitivities

The main drivers of the CWS design are cost reduction, segmentation, and standardization of the in-vessel components, facilitation of installation and maintenance, staged procurement, and acceptable impact on the building of pressure loading following an ex-vessel coolant leak.

Risk and Uncertainty

No specific risks or uncertainties were identified. In addition to site-specific design, further activity is desirable in the following areas to improve plant performance, to support an operating license application, and to optimize the system design:

- Demonstration and measurement of data validating the natural convection characteristics of VV PHTS
- Plant operation/control system design (including plant shutdown sequence after off-normal events)
  - Optimization of layout considering facilitation of installation and maintenance, particularly for the upper pipe chase (including the pipe freeze method for leak localization)
  - Clarification of requirements for drying such as the maximum number of in-vessel components to be dried concurrently, and drying duration
  - Clarification of counter current flow limiting correlation for the blanket module and divertor cassette configuration, and optimization of the system to blow-out the residual water after gravity drainage

4.1.2.3 Tritium Plant

The estimate for the Tritium Plant is credible, based on sound management and engineering principles and can be used as a basis for establishing relative contributions by the Parties. The current design, based on well-proven technology, is mature and has been augmented with R&D performed with a fully integrated system. The Committee has reviewed this package.

System Description

The functions of the tritium plant can be summarized as: 1) processing all tritiated gas streams from sources within the plant to produce the gas streams for fuelling (at specified flow rates and isotopic compositions), 2) confinement of tritium with multiple barriers (such as a primary component, secondary enclosures and rooms), and 3) detritiation of a number of tritium-containing waste streams, contaminated room air, and tritiated waste water to reject the detritiated remnants to the environment.

Scope Definition and Maturity

The scope is well defined. The design is essentially complete with layout and detail drawings.

Basis of Estimate

The Tritium Plant estimate of $53 million is based on detailed functional analyses over the full range of anticipated parameters for the tritium fuel cycle. Full estimates were provided by two of the three Parties for all scope.

Major Cost Drivers and Sensitivities

The main design guidelines for the tritium plant are: 1) minimization of tritium inventories, 2) reduction of occupational exposure, 3) low generation of effluents and wastes, and 4) reduction of costs by standardization of components.

Risk and Uncertainty

None identified. The design is based upon well-proven technology to ensure high reliability and the safe handling and credible accountancy of tritium. R&D has been performed on a fully integrated system for 100 grams of tritium.

4.1.2.4 Cryodistribution

The estimate for the Cryodistribution system is credible, based on sound management and engineering principles and can be used as a basis for establishing relative contributions by the Parties. The current design, based on mostly conventional technology, is mature and augmented with appropriate system analyses. The Committee has reviewed this package.

System Description

The ITER cryogenic system is subdivided into three parts: 1) a 55-kilowatt liquid helium cryogenic plant, 2) a cryogenic distribution components, and 3) a system of cryogenic lines/manifolds.

Scope Definition and Maturity

The scope is well defined. The design is mature and includes detailed system drawings.

Basis of Estimate

The Cryodistribution estimate of $128 million reflects a design that is based mostly on conventional technology and equipment. Full estimates were provided by two of the three Parties for all scope.

Major Cost Drivers and Sensitivities

The smoothing of the pulsed heat load, maintenance of stable operation over the wide range of plasma scenarios, as well as cost minimization by using standardized components, are the main guidelines for the design of the ITER cryogenic system.

Risk and Uncertainty

None identified. The design is based on conventional technology.

4.1.2.5 Power Supplies and Distribution

The estimate for the Power Supplies and Distribution is credible, based on sound management and engineering principles and can be used as a basis for establishing relative contributions by the Parties. The current design, based on conventional technology, is mature and augmented by analyses of performance characteristics and fault modes and includes R&D, which has demonstrated operation of the high current switchers. The Committee has reviewed this package.

System Description

The pulsed and steady state power supplies consist of the following four major systems: 1) a 500 MW/400 MVar pulsed power distribution system, 2) oil power supplies, 3) AC power distribution for the heating and current drive (H&CD) power supplies (PS), and 4) 110 MW/78 MVar steady state electric power network (SSEPN).

The pulsed power distribution system will supply ac power to the coil PS and H&CD PS, while the SSEPN will provide AC power to different loads (mainly motors) within the plant systems, such as the cooling water system and cryogenic plant. The coil PS and H&CD PS will supply their corresponding loads, the magnet coils and H&CD systems, in general with DC power.

The main general functions of the pulsed power distribution system PS systems are: 1) supply the ITER machine and ITER plant systems with electric power, 2) protect them in case of electric faults, and 3) provide proper grounding of the machine and power supply components.

Scope Definition and Maturity

The scope is well defined. The design is essentially complete with system drawings augmented with substantial analyses.

Basis of Estimate

The Power Supplies and Distribution estimate of $308 million reflects a design based on somewhat conventional and/or well-proven technology with the possible exception of sophisticated fault protection for the superconducting coil set. R&D has been performed on 66 and 170 kA switchers and breakers. Full estimates were provided by two of the three Parties for the high voltage substation/AC power distribution and AC/DC converters/reactive power compensators/harmonic filters. All three Parties provided full estimates for the switching networks/discharge circuits/DC distribution/instrumentation and steady state electrical power network.

Major Cost Drivers and Sensitivities

Intensive studies have been carried out to define extreme conditions in case of faults. For the magnet coils, one of the most important parameters is over-voltage on the coil terminals that can cause an insulation breakdown and trigger a chain of other fault events.

Risk and Uncertainty

None Identified. Computer simulation studies of the entire AC/DC conversion plant, including pulsed AC power supply, have been performed. The results show that, with the selected parameters of the reactive power compensation and harmonic filter system, the level of reactive power, and the content of harmonics in the reference HV grid, do not exceed specified limits.

Motor generators may be needed for energy storage and/or power factor correction depending on the site. These are not included in the estimate, they would be provided by the host, if needed.

4.1.2.6 Buildings

The estimate for the Buildings is credible, based on sound management and engineering principles and can be used as a basis for establishing relative contributions by the Parties. The current design, based on known technology, is mature for the most important buildings and is augmented by appropriate analyses (e.g., seismic). The Committee has reviewed this package.

System Description

ITER buildings house, support, protect, control access to, provide suitable environmental conditions for, and provide services to the components, systems, and operations that are selected to be located within them. The ITER buildings have been optimized to provide the lowest cost design solution that adequately meets the mission requirements and the appropriate standards for the public and workers, as well as investment protection. The ITER buildings can be grouped in two main classes: radiologically-controlled buildings and conventional buildings.

Scope Definition and Maturity

The scope is well defined. The non site-specific design is essentially complete for the radiological buildings.

Basis of Estimate

The Buildings estimate of $546 million is based on "commodity rates", a concept that was previously agreed to during U.S. prior participation in the EDA in 1997. The site and building structures, except for the nuclear-related buildings, are relatively conventional in design and construction technology for industrial buildings. There are no site or building problems with these buildings that require extraordinary efforts. Full estimates were provided by two of the three Parties for all scope. Cost of the site and buildings will be borne by the host Party.

Major Cost Drivers and Sensitivities

The layout has been designed for the minimum floor area, to reduce the complexity of system interfaces, and to minimize the connection distances, by following these key design strategies:

- **A general layout policy**. To avoid the crossing of different service types, such as electrical power, cooling water, and waste handling—clearly, the extent to which services can be segregated decreases as they get closer to the tokamak;
- **Separation of services.** With the tokamak building located in the center, the site is arranged so that electrical services enter from the west, cooling systems are located on the east, personnel-related functions are concentrated on the south, and waste management functions are located on the north (these directions are for identification purposes only);
- **Staged construction and expandability**: To the maximum extent possible, the design of systems, buildings, and the site will be such that future additions in system capacity are not precluded.

There will be some variability due to material, labor, and licensing costs for the selected site.

Risk and Uncertainty

No specific risks or uncertainties were identified. The design of the ITER site and buildings is appropriate for the function.

Those buildings that are involved with the tokamak machine, those that house the systems and the components that interact directly with the machine, and those that are required for close support of the tokamak machine, have received the greatest degree of attention. These buildings, in order of highest degree of design completion to lowest, are the: 1) Tokamak building, 2) tritium, vacuum, fuelling and services building, 3) hot cell building, 4) low-level radwaste building, and 5) personnel access control building.

Other buildings that are also associated with the above, have received preliminary and detailed design attention, but will need to be studied further, include: the Laydown, cryohalls, assembly and RF heating building, and the Diagnostic Building. The remaining buildings have received only preliminary design attention.

4.1.2.7 Waste Treatment and Storage

The estimate for Waste Treatment and Storage is credible, based on sound management and engineering principles and can be used as a basis for establishing relative contributions by the Parties. The current design, based on known technology, is preliminary and is appropriate for budgeting purposes. The Committee has not reviewed this package although it is assumed it reflects the same level of completeness as those that were reviewed.

System Description

Sources of potential effluents (including tritium, activated dust, activated corrosion products, etc.) have been identified, discharge pathways determined, and design features and active discharge control systems assessed for expected end of life conditions which are assumed to include extensive maintenance and refurbishment in the hot cell. Conservative assumptions are made so as not to underestimate potential effluents. Effluent pathways are controlled and monitored through the plant exhaust, the liquid discharge pathways, and the heat rejection system.

Scope Definition and Maturity

The scope is well defined.

Basis of Estimate

The Waste Treatment and Storage estimate of $3 million (plus $7 million in deferred cost) is based on conventional and/or well-proven technology and equipment. Full estimates were provided by one of the three Parties for all scope.

Major Cost Drivers and Sensitivities

The concept of "clearance" for free release of low-level radiological material is the guiding principle. Not all countries subscribe to this concept, so the applicability of this assumption will be site-specific.

Risk and Uncertainty

No particular risks or uncertainties were identified. The design is based on conventional and/or well-proven technology.

4.1.2.8 Radiological Protection

The estimate for Radiological Protection is credible, based on sound management and engineering principles and can be used as a basis for establishing relative contributions by the Parties. The current design, based on known technology, is preliminary and appropriate for budgeting purposes. The Committee has reviewed this package.

System Description

The radiological monitoring system for a generic site, according to present assumptions, provides the following specific functions: 1) personnel dosimetry for all radiation and contamination hazards appropriate for the radiation zones, and 2) dedicated radiation and contamination monitors, separate from others that are located at strategic points in the ITER plant, and specified to remain functional during and after postulated accidents.

The latter are to provide an assessment of the conditions as part of an emergency preparedness program. In particular, air radiation monitoring is provided in all areas where tritium is handled, processed, or stored. The tritium monitoring system in the plant gaseous exhaust is redundant and is designed to remain operable under accidents and loss of normal electrical power. It provides real-time indication of tritium releases. The sensitivity of the monitors enables the detection levels of tritium in air as low as 10^{-6} Ci/m3.

Scope Definition and Maturity

The scope is well defined.

Basis of Estimate

The Radiological Protection estimate of $1 million (plus $3 million in deferred costs) is based on conventional and/or well-proven technology and equipment. Full estimates were provided by two of the three Parties for all scope.

Major Cost Drivers and Sensitivities

"As Low As Reasonably Achievable" (ALARA) is the guiding principle.

Risk and Uncertainty

None identified. The design is based on conventional and/or well-proven technology.

4.1.3 Heating and Current Drive Systems

4.1.3.1 Ion Cyclotron

The estimate for Ion Cyclotron Heating and Current Drive (H&CD) is credible, based on sound management and engineering principles and can be used as a basis for establishing relative contributions by the Parties. The current design is preliminary and dependent upon incomplete R&D. The Committee has reviewed this package.

System Description

The 20 MW of power and operating frequency range of 40 to 55 MHz encompasses all the ion cyclotron physics scenarios and allows operation at a 70 percent reduced toroidal field. An extension of the frequency range from 35 to 60 MHz would be desirable for improved flexibility, and would be possible at somewhat reduced performance.

Scope Definition and Maturity

The scope is well defined. The design is at the preliminary design stage augmented with advanced analyses, system-level drawings and R&D.

Basis of Estimate

The Ion Cyclotron H&CD estimate of $46 million does not include detailed engineering design of the launcher. R&D work is ongoing and also not included in the estimate. Full estimates were provided by one of the three Parties for all scope.

Major Cost Drivers and Sensitivities

The design of these systems has been developed with the aim of providing: 1) a credible high-level power performance associated with a high reliability, 2) modular construction and identical interfaces wherever possible, 3) interchangeable in-vessel assemblies, 4) standardized control systems (with an unique man-machine interface) and operation. The design is dependent upon ongoing R&D.

Risk and Uncertainty

There is uncertainty in the development of a launcher design. A launcher design typical of that necessary for ITER has been developed for testing on JET.

4.1.3.2 Electron Cyclotron

The estimate for Electron Cyclotron H&CD is credible, based on sound management and engineering principles and can be used as a basis for establishing relative contributions by the Parties. The current design is preliminary and dependent upon incomplete R&D. The Committee has reviewed this package.

System Description

The nominal injection power is 20 MW at 170 GHz and 2 MW at 120 GHz (startup). The RF power at 170 GHz is switched between the upper launcher and the equatorial launcher by changing of waveguide connections. The RF power used for the assisted startup is transmitted by three waveguides also used for the main H&CD. The power sources at 120 and 170 GHz are switched during a plasma discharge.

Scope Definition and Maturity

The scope is well defined. The system is at the preliminary design stage and includes advanced analyses, system-level drawings and R&D.

Basis of Estimate

The Electron Cyclotron H&CD estimate of $111 million does not include required R&D or detailed launcher design. R&D work is ongoing. Full estimates were provided by two of the three Parties for the equatorial launcher, upper launcher, and power supply. All three Parties provided full estimates for the transmission line and RF Power sources and controls.

Major Cost Drivers and Sensitivities

The design of these systems has been developed with the aim of providing: 1) a credible high-level power performance associated with a high reliability, 2) modular construction and identical interfaces wherever possible, 3) interchangeable in-vessel assemblies, 4) standardized control systems (with an unique man-machine interface) and operation. The design is dependent upon ongoing R&D.

Risk and Uncertainty

The design is based on R&D objectives that have not yet been achieved.

4.1.3.3 Neutral Beam

The estimate for Neutral Beam H&CD is credible, based on sound management and engineering principles and can be used as a basis for establishing relative contributions by the Parties. The estimate is based on the present preliminary design that is dependent upon incomplete R&D. The Committee has not reviewed this package although it is assumed it reflects the same level of completeness as those that were reviewed.

System Description

The neutral beam (NB) system design consists at present of two H&CD injectors and one diagnostic neutral beam (DNB) injector. Each H&CD injector will deliver a deuterium beam of

16.5 MW (total 33 MW), with energy of 1 MeV, and will be able to operate for long pulses (up to 3,600 seconds for steady state operation). A system based on negative (D-) ions is necessary, primarily, for better energy efficiency due to its high neutralization efficiency.

Scope Definition and Maturity

The scope is well defined. The design is at the preliminary stage. Advanced analysis, system-level drawings and R&D have been performed.

Basis of Estimate

The Neutron Beam H&CD estimate of $138 million does not include the required R&D. R&D work is ongoing. Full estimates were provided by two of the three Parties for the assembly and testing, pressure/vacuum vessels/drift duct/passive magnetic shielding, active core compensation coils, and power supply. All three Parties provided full estimates for the beam source/high voltage bushing and beamline components.

Major Cost Drivers and Sensitivities

The size of the ion source and the required deuterium current density should not require large extrapolations from the largest operational negative-ion-based NB injection systems (JT-60U and LHD) in physics (plasma uniformity and negative ion current density) or in engineering (manufacturing, assembly, and maintenance).

The acceleration voltage remains the only free variable. For the H&CD injectors, higher voltages could permit an increase of the power and the current drive efficiency. On the other hand, higher voltages imply larger insulation distances (both in gas and vacuum) and higher beam shine-through through the plasma. Moreover, the maximum acceleration voltage of the two existing test beds, at Naka and at Cadarache, is 1 MV in both cases. Considering ITER dimensions, 1 MV is considered a good compromise.

Risk and Uncertainty

The design is based on R&D objectives that have not yet been achieved.

4.1.4 Diagnostics

The diagnostics valuation is based on a scaling of diagnostics planned and fully estimated during the EDA. It appears credible and can be used as a basis for establishing relative contributions by the Parties. The Committee has reviewed parts of this package.

System Description

To meet the requirements for plasma and first wall measurements, an extensive diagnostic set of about 40 individual measurement systems is required. Not all of the diagnostics will be built during the machine construction phase. However, it is necessary to assess the interface, space, and service requirements of each diagnostic that will eventually be used, and make any necessary provisions during machine construction to avoid expensive modification costs later. Diagnostics required at the start of DT operation and that must be addressed include:

- **Magnetic Diagnostics**. Vessel Wall Sensors, Divertor Magnetics, Continuous Rogowski Coils, Diamagnetic Loops
- **Neutron Diagnostics**. Radial Neutron Camera, Vertical Neutron Camera, Micro-fission chambers, Neutron Flux Monitors, Gamma-Ray Spectrometer, Activation System, Lost Alpha Detectors, Knock-on Tail Neutron Spectrometer
- **Optical/IR(Infra-Red) Systems**. Core Thomson Scattering, Edge Thomson Scattering, X-Point Thomson Scattering, Divertor Thomson Scattering, Toroidal Interferometer/ Polarimeter, Collective Scattering System
- **Bolometric Systems**. Arrays for Main Plasma, Arrays for Divertor
- **Spectroscopic and Neutral Particle Analyzer Systems**. H Alpha Spectroscopy, Visible Continuum Array, Main Plasma and Divertor Impurity Monitors, X-ray Crystal Spectrometers, Charge eXchange Recombination Spectroscopy based on DNB, Motional Stark Effect based on heating beam, Soft X-Ray Array, Neutral Particle Analyzers, Laser Induced Fluorescence
- **Microwave Diagnostics**. Electron Cyclotron Emission, Main Plasma Reflectometer, Plasma Position Reflectometer, Divertor Reflectometer, Divertor EC absorption, Main Plasma Microwave Scattering, Fast Wave Reflectometry
- **Plasma-Facing Components and Operational Diagnostics**. IR/Visible Cameras, Thermocouples, Pressure Gauges, Residual Gas Analyzers, IR Thermography (Divertor), Langmuir Probes
- **Diagnostic Neutral Beam**

Scope Definition and Maturity

The diagnostic systems are functionally well defined, but the detailed R&D, drawings and specifications have not been completed and will be the responsibility of the Parties.

Basis of Estimate

The Diagnostic work package estimate of approximately $170 million (plus $42 million in deferred cost) is an approximate estimate of the diagnostic hardware. The estimate is grouped in ten packages, including magnetic diagnostics, neutron systems, optical systems, bolometry, spectroscopic systems, microwave systems, operational systems, standard diagnostics, diagnostic neutral beam, and the diagnostic neutral beam power supply. Full estimates were provided by two Parties for the diagnostic neutral beam and power supplies, and by only one Party for the bolometry and standard diagnostics. The balance of the estimate was done internally by the JCT. The estimates were based on scaling of diagnostics from previous estimates made during the EDA phase. The estimates include only the hardware costs. The JCT will assist in integrating the diagnostics with shielding into, for example, a port plug. However, it is assumed that the Parties taking responsibility for a given diagnostic will do the necessary design and R&D outside the ITER construction budget.

Major Cost Drivers and Sensitivities

The diagnostic cost is dominated by the radiation flux and fluence and by the requirement for remote handling.

Risk and Uncertainty

The primary risks are the technical uncertainty of diagnostic operation in the high radiation environment, integration or radiation shielding, and the capability for remote maintenance.

4.1.5 Control, Data Acquisition, and Communications

The control, data acquisition, and communications (CODAC) system cost estimate is an informed allotment since this system will not be defined in detail for five or more years. However, the estimate appears credible compared with similar, albeit smaller, systems estimated or purchased recently and can be used as a basis for establishing relative contributions by the Parties.

System Description

The CODAC system provides the integrated computer control of all the various systems, as well as the data acquisition system. The system is structured around a supervisory control system (SCS) and individual dedicated control subsystems. It has not been designed, but a common architecture will be specified to define the requirements of all interfaces to the system. It is hoped that real-time simulation can be used to optimize control of the plasma.

Scope Definition and Maturity

This CODAC system design philosophy and functions have been defined in detail, but the specific hardware and software will not be specified until needed (perhaps not for five years) to take advantage of possible future advances in computer technology.

Basis of Estimate

The CODAC estimate of approximately $72 million is a consensus of expert opinion and is not based on a particular set of software and hardware.

Major Cost Drivers and Sensitivities

The primary cost drivers are the amount of data to be collected and complexity of processing.

Risk and Uncertainty

The cost of this system may be conservative due to rapid advances in computer technology.

4.2 Construction Management and Engineering Support

This estimate covers the management structure, consisting of a Central Team at the ITER project site and Field Teams for each Party. Their responsibility is successful completion of the project. The Committee concluded that the methodology to develop the cost estimate was credible, and the estimate can be used as a basis for establishing the relative contributions of the Parties. The estimate would be re-assessed after the actual management structure for ITER is established.

It is expected that the ITER project will be managed through a line organization composed of a Central Team at the ITER site, and Field Teams at the Parties' locations. As described in the Management section, this management organization is responsible for technical integration, business and quality management of the subcontracts, and management oversight of all ITER activities.

The current ITER estimate provides for staffing the management organization over the life of the construction project as indicated by person-years (PY) in Table 4-2. The intent is that this covers direct project staff and not the administrative support that would be provided by the home institutions of the Parties.

Table 4-2. Staff of Management Organization

Organization	Professional PY	Support PY
Central Team (at the site)	840	840
Field Teams (distributed)	960	1920

Until the decisions are made concerning the scope to be undertaken by each of the Parties, a further breakdown of the Field Teams cannot be made.

This estimate was developed based on overall management judgment, not from a detailed organizational staffing plan with associated staffing by function by year. Subsequently, a detailed analysis was prepared that generally confirmed this estimate.

Total cost of this effort is estimated to be $685 million. The cost estimates assume 150 IUA per year for professional staff and 75 IUA per year for support staff. (When converted to 2002 dollars, this is equivalent to $216 K per year and $108 K per year, respectively). ITER management considers that this will cover direct staff at minimum levels. While these rates may be sufficiently high to cover some level of administrative support, the estimate does not explicitly include administrative support (procurement, accounting, clerical, etc.) that would be subcontracted or provided by host institutions. This is reasonable for European and Japanese laboratories, where the institution receives separate funding for basic staff, but may not be true for the U.S.

In total, the estimate is about 17 percent of the direct costs, which seems reasonable; however, this would need to be re-assessed after the actual management structure is established.

4.3 Other Project Costs Summary

This element covers activities necessary to support the construction project. In DOE terminology, the construction project Total Estimated Cost (TEC) plus Other Project Costs (OPC) equals the Total Project Cost (TPC).

4.3.1 R&D During Construction

The Committee concluded that the methodology to develop the cost estimate of $115 million for R&D during construction was credible, and the estimate can be used as a basis for establishing the relative contributions of the Parties. However, it should be noted that certain scientific activities, such as R&D for diagnostics and plasma heating technologies are not included within this scope.

It must first be recognized that about $1 billion has been invested over the past ten years to develop the technologies and reliability of manufacturing methods necessary to construct ITER. This is approximately 25 percent of the direct cost of the facility. Essentially all critical components have been prototyped at a scale relevant to the current design.

The estimate provides $115 million to support any remaining fabrication development that might be necessary to build ITER. This was described as an informed management judgment rather than the result of a detailed estimate. It is not believed that any further technology development is necessary.

It should be recognized that R&D in support of plasma diagnostics and plasma heating technologies (e.g., neutral beams, ICRH, ECRH, LH) are not included because the Parties are developing these technologies as part of their domestic fusion programs.

4.3.2 Commissioning

Overall, the Committee concluded that the methodology for development of the $130 million estimate for integrated commissioning was credible, and the estimate can be used as a basis for establishing the relative contributions of the Parties. This recognizes that this commissioning scope is only that necessary to support the first plasma milestone, commissioning of individual supporting systems is budgeted directly in those accounts, and scientific support is provided and budgeted by the ongoing fusion programs of the Parties.

The ITER plan calls for integrated commissioning of all subsystems, controls, and interfaces between subsystems during the year prior to first plasma. These activities will qualify the operating staff and establish the readiness for experimental research.

The operating staff in place at the end of this period is 600 people, matching their estimate for the hydrogen operations phase of the project. This does not include the visiting scientific personnel who will perform theory, modeling, experimental research, etc. This is expected to require up to 400 additional staff. It is planned that maintenance and many other support services will be subcontracted.

The integrated commissioning phase is conducted during a one-year period at the end of the construction project. The operations plan identifies an additional three years of hydrogen operations in preparation for nuclear operations. It should be noted that DOE normally considers "commissioning" as a part of the project. ITER considers this integrated commissioning as part of the operations phase.

Intentionally Blank

5. SCHEDULE and FUNDING ASSESSMENT

The schedule duration of ten years for ITER construction after project start seems generally reasonable; however, there is considerable uncertainty regarding the near-term decisions that precede project start.

The ITER schedule from this point forward can be described in terms of four phases:

1. **ITER Transition Arrangements**. The period between January 2003 and the time when the ITER legal organization is established.
2. **Construction Project**. The period for completion of R&D, vendor design, construction of facilities, fabrication/assembly of components, and installation/commissioning (using DOE definitions).
3. **Operations**. This period begins with "first plasma" (i.e., operations with hydrogen—again using the DOE convention), and proceeds through the full range of D-T burning plasma experiments and engineering experiments to meet the ITER objectives.
4. **Decommissioning**. Dismantling of the experiment and associated equipment, including waste disposal.

Negotiations are currently underway among the present ITER Parties concerning site selection, arrangements for organization and management, and many other issues that are necessarily complex for an international undertaking of this magnitude. The timing of the key decisions has not been established; however, there is a goal to present recommendation(s) at the G-8 Summit in June 2003. Detailed plans and funding for the ITER Transition Arrangements phase have not been established. For these reasons, the establishment of the ITER Legal Entity and Project Start cannot be reliably projected.

The construction phase is projected to be about ten years. This assumes that long-lead procurements not connected to site specific safety issues can be initiated prior to receiving regulatory approval. The schedule is paced by superconductor manufacture, followed by coil fabrication, machine assembly, and installation and commissioning. The Committee concluded that this schedule is generally reasonable.

Key milestones are as follows (see also Appendix G):

1.	Establish the ITER Legal Entity	Project Start
2.	Receive license and begin site construction	two years
3.	Start Tokamak Assembly	six years
4.	First plasma	ten years

The sequence of non-critical path elements is designed to level the funding profile as much as possible. The result is that the budget outlay requirements (not escalated) from the fourth through the ninth year of the project are roughly constant for the overall project, although not necessarily for each participant.

The Committee did not review the operations or decommissioning schedules.

6. MANAGEMENT APPROACH

Negotiations between the ITER Parties will define the organization and management structure to be used for construction. The Committee agrees with the present Leader of the ITER International Team, that a strong, line management approach will be in the best interests of all Parties. The management of a Party's work packages is also a critical element in any management scheme under consideration.

The Director General for the ITER construction project will impact plans for executing the project. The Director General and ITER management team must assume full technical ownership and exercise control at a very early stage of the project. Progress towards the start of construction will be slow until there is an approved Director General and management approach.

The Committee discussed potential organizational arrangements with the Leader of the ITER International Team. He described the attributes of these arrangements and it is clear that he has given considerable thought to the organization. However, the documentation available to the Committee did not include details on the management arrangements for the construction effort. This is now under discussion with the existing Parties and will depend on the outcome of the negotiations and the appointment of the Director General.

Managing ITER construction would be the responsibility of the ITER International Fusion Energy Organization, an entity to be formed by international agreement. The Director General of this organization would be responsible for the successful completion of the project and would report to a governing council formed by the various Parties to the agreement. The Director General and this Council would provide the direct line of accountability incorporating all participants into a single organization. The organization would include a Central Team at the ITER site that would have overall responsibility for meeting the project objectives, establishing the technical specifications, controlling realization, and implementing a quality assurance program to satisfy the requirements from the licensing safety authorities of the Host Country. In addition to the Central Team, the organization would include Field Teams located within each Party contributing "in-kind" ITER components as "work packages". The Central Team and the Field Teams all report to the Director General. The technical scope of ITER construction is defined in about 85 work packages. The majority of work packages are proposed to be in-kind contributions by the ITER Parties. The successful completion of these work packages would be managed directly by the Field Teams under the supervision and coordination of the Central Team, which would provide overall management. In addition, each Party would have a "Domestic

Agency" that is responsible to the Party for the work package contracts. Work packages not covered in this manner would be procured by the ITER Team using direct contracts and funded by cash contributions from all Parties. Together with the basic site infrastructure, the Host Party would contribute all "non-transportable" ITER components.

The assignment of work packages will be the result of international negotiations currently underway. The ITER construction work packages fall into three primary categories. The largest category is the high technology components to be delivered to the ITER construction site by the Parties (e.g., toroidal field magnets). The current estimate is that 65-75 percent of the total ITER value estimate is in this category. The next largest category in total value includes items to be contributed by the host (e.g., site infrastructure—10-25 percent). The third category includes items that are not assigned to individual Parties for which a centrally managed fund would be used (10-15 percent). The actual costs (not ITER value) would be shared among the ITER Parties.

The Committee offers a number of comments on ITER management given that the actual management of the construction project will have a significant impact on the cost, schedule, and technical performance of the project.

Launching a large international science construction project is a formidable challenge. The ITER Director General is obviously an extremely important position and it should be expected that the Director General will impact the detailed plans for ITER construction. Indeed the Director General and the full project team will need to be established and take technical ownership at a very early stage in the project preparation. They must have significant authority and resources if they are to be capable of exercising control over the project. The Director General should be appointed soon and produce a plan that describes the detailed management arrangements.

The ITER International Fusion Energy Organization must establish explicit roles and responsibilities of the various elements of the organization, in particular, the relationship between the Central Team on-site and the various Field Teams located in the Parties. In addition to advisory bodies to the Council, the Director General will need to establish his/her own advisory arrangements that can provide independent critique, analysis, and advice. These advisory bodies would assess scientific, technical, cost, schedule, and management aspects of the construction project.

The construction of ITER would continue and extend a trend toward international collaborative science facilities. ITER presents new management challenges. Configuration control, progress reporting, quality assurance, and general integration activities will be difficult at best, and therefore require early implementation of capabilities to carry out these functions.

The extensive R&D program conducted over the last decade has resulted in a mature technical understanding of the various ITER components and manufacturing processes. The mature design and supporting R&D are conducive to the industrial procurement oriented approach contemplated for construction. This approach will work well if there are few technical changes during the construction period.

The staffing level estimates (perhaps not their cost) to manage the construction of the device (central and field teams) presented in the ITER design report appear minimal, in particular when one considers the need to establish an operating laboratory, and the actual level will depend on the organization established. Staffing levels may require augmentation to meet the full needs of the construction project. These costs will be shared by the Parties in accordance with their level of participation in the construction and some contingency planning should be considered for these needs.

The process used by the ITER Central Team to determine the value of the various work packages was reasonable and produced a credible *relative* valuation of the different work packages. These relative value estimates of the various work packages provide an adequate basis for negotiations. Each Party would need to establish from these value estimates (that use normalized standard unit costs for material and labor) the actual costs in its own currency and its own industrial environment and contractual procedures.

Substantial R&D, engineering analysis, and design work is complete on essentially all of the ITER work packages. This body of work is a solid technical basis for a decision to proceed with construction. Adjustments to the design are required for a few systems, and most systems require additional effort to complete detailed drawings with full dimensioning. The existing ITER Team is concentrating on completing these activities for the critical path systems as soon as possible. The other systems will be completed by the Central Team during the construction period. It is likely that the U.S., if it becomes a Party, will need to complete additional engineering studies and prepare work packages so that they are ready for industrial contracts. It is difficult to estimate the total effort required but funding plans should include resources for this work.

DOE project management practice requires explicit recognition of cost risk by contingency budgets. The ITER valuation method does not produce a cost estimate that is in accordance with any Party's actual costs and does not include cost risk analysis. Cost risks to an ITER Party fall into the following general categories:

1. Risks associated with a work package including any additional R&D, engineering, and design effort that may be required to prepare a domestic industrial firm not already involved during the Engineering Design Activity for construction;
2. Risks associated with the staffing levels for managing the work packages (field teams and procurement management) and interfacing with the ITER site organization;
3. Cost risks associated with common projects; and
4. Cost risks associated with unforeseen scope.

An evaluation of the absolute cost and the cost risk in the U.S. to accomplish a given work package would require the preparation of a detailed U.S. cost estimate for the work package. If the U.S. were to join ITER negotiations, the U.S. would need to complete a detailed study of work packages under consideration and complete a U.S. cost estimate before making a commitment to undertake a given work package.

The proposed organizational structure under consideration envisions significant roles and responsibilities for the Parties. If the U.S. were to join ITER negotiations, the U.S. would need to organize the U.S. component contributions in full recognition of the ITER management structure agreed upon in the negotiations and in a manner that is compatible (as much as possible) with the traditional DOE approach to managing the construction of large science projects. This approach would help to mitigate U.S. risk exposure on work packages assigned to the U.S. There is still, however, a certain level of cost risk in the items that are not direct contributions of the U.S., such as common items shared by the Parties and staffing at the ITER site.

Appendix A: Charge

October 31, 2002

MEMORANDUM TO:	DANIEL R. LEHMAN DIRECTOR CONSTRUCTION MANAGEMENT SUPPORT DIVISION
FROM:	DR. RAYMOND ORBACH DIRECTOR OFFICE OF SCIENCE
SUBJECT:	Assessment of ITER Cost Estimate

In his remarks to the Conference of G8 Energy Ministers in Detroit, Michigan on May 2, 2002, Secretary Abraham announced that President Bush is interested in the potential of the international fusion energy research effort known as ITER, and has asked DOE to seriously consider American participation.

Because of the size of a potential U.S. investment in ITER, the importance of ITER in advancing fusion science and the potential for ITER to serve as a model for future international science projects, the Office of Science will need to be able to substantiate to Congress and the Administration, that any investment in ITER is reasonable and likely to achieve expected results.

Therefore, I request that you assemble a Review Committee to assess in summary fashion the cost estimate that has been prepared by the ITER project team. The assessment should emphasize the reasonableness of project cost and schedule assumptions and, to the extent possible, the construction and technical management assumptions.

Recognizing that the U.S. is reconsidering its position on ITER, Robert Aymar, the project Director, along with his staff, has graciously offered to meet with the Review Committee in Garching, Germany in mid-November 2002.

The Office of Fusion Energy Sciences of the Office of Science will provide support to you as required for this endeavor.

Please provide me your written review report by December 2, 2002.

cc:
J. Decker, SC-2
M. Johnson, SC-3
T. Vanek, SC-4
N. Davies, SC-50
M. Holland, OSTP
R. Aymar, ITER (Garching)

Appendix B

Department of Energy Assessment
of the

ITER Project Cost Estimate

REVIEW COMMITTEE PARTICIPANTS

<u>Department of Energy</u>

Daniel Lehman, DOE/SC, Chair
Stephen Meador, DOE/SC

Consultants

Michael Harrison, BNL
Brad Nelson, ORNL
Lester Price, DOE/ORO
Michael Williams, PPPL
James Yeck, DOE/CH

Advisors

Joel Schultz, MIT
Lester Waganer, Boeing

Observers

Warren Marton, DOE/SC
Michael Holland, OSTP [part-time]

Appendix C

Department of Energy Assessment of the

ITER Project Cost Estimate

DRAFT AGENDA

Thursday, November 21, 2002—ITER Building A, Room 054

8:00 am	DOE Executive Session	Lehman
9:00 am	Technical Overview Discussions	TBD—Chuyanov/Ioki
12:00 pm	Lunch	
1:00 pm	Technical Overview Discussions	TBD—Chuyanov/Ioki
2:30 pm	Break	
5:00 pm	DOE Executive Session	

Friday, November 22, 2002

8:00 am	Cost, Schedule, and Management Discussion	Aymar
10:00 am	Break	
12:00 pm	Lunch	
1:00 pm	Cost, Schedule, and Management Discussion	Aymar
4:00 pm	European Union Validation of ITER Cost Estimate	Andreani
5:00 pm	DOE Executive Session	

Saturday, November 23, 2002

8:00 am	Cost, Schedule, and Management Discussion	Aymar
12:00 pm	Lunch	
1:00 pm	Cost, Schedule, and Management Discussion	Aymar
4:30 pm	DOE Executive Session	
6:30 pm	Adjourn	

Sunday, November 24, 2002

8:00 am	Subcommittee Working Sessions and Report Writing
12:00 pm	Lunch
1:00 pm	Subcommittee Working Sessions
2:00 pm	DOE Executive Session
7:30 pm	Adjourn

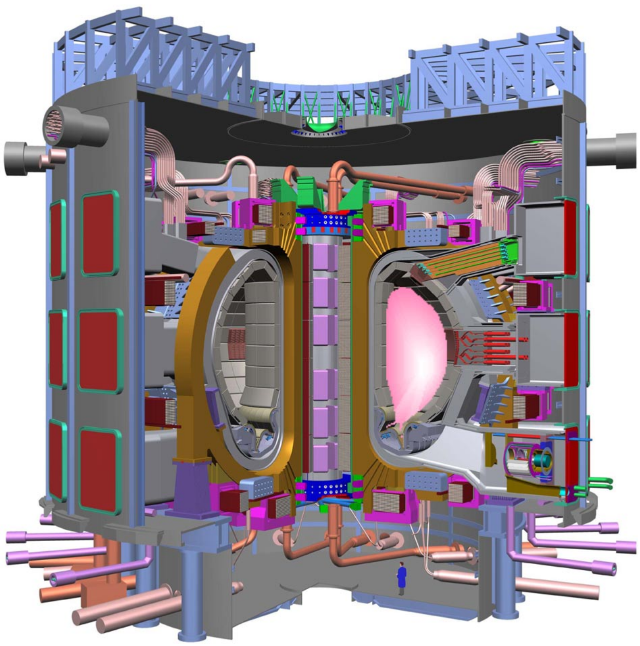
Monday, November 25, 2002

8:00 am	Subcommittee Working Sessions and Report Writing
12:00 pm	Lunch

6:30 pm ***Adjourn***

Appendix D

Current ITER Design



ITER Final Design

ITER has been designed to provide major advances in all of the key areas of plasma science. It will enter new scientific research frontiers in all of these areas. Because of ITER's large size and magnetic field, it will allow study of plasma stability and transport in regimes unexplored by any existing fusion research facility worldwide. Due to the intense plasma heating by fusion products, it will also access previously unexplored regimes of energetic particle physics. Because of the very strong heat and particle fluxes emerging from ITER plasmas, it will extend regimes of plasma-boundary interaction well beyond previous experience. The new regimes of plasma physics that can be explored for long duration, and the interactions amongst the anticipated phenomena, are characterized together as the new regime of "burning plasma physics."

ITER also represents a major advance in essentially all areas of fusion technology. Plasma facing components will be pressed to previously unexplored limits in heat flux and fluence (flux over time). ITER will be a testbed for initial studies of the behavior of fusion blanket modules. The performance of large-scale, high-field superconducting magnets will be demonstrated. In addition, a whole class of important technologies needed for heating and fueling plasmas, as well as for driving plasma current, will be brought up to the next level of development. All of these systems will be challenged to perform in a high duty factor (ratio of plasma burn time to time between pulses) fusion environment. ITER will also provide a practical test of remote maintenance technologies.

The integration of the ITER plasma science capability with technology features typical of those envisioned for a fusion power source will provide, for the first time, an opportunity to demonstrate the scientific and technological feasibility of fusion.

Performance Objectives

Fusion power, nominally 500 Mega Watts.

Strong internal plasma heating from alpha particles produced by the fusion reaction with gain =10, where gain is the fusion power produced within the plasma divided by the external power added to the plasma.

Long duration pulses of fusion power, each nominally 400 seconds with a maximum duration of 3600 seconds.

Broad experimental range for inductive and non-inductive drive of the plasma current.

Technology required in a fusion power source including superconducting magnets, high heat flux plasma facing materials, tritium fuel handling systems, diagnostics for understanding plasma behavior.

Capability for initial testing of fusion blanket modules.

Description of Major Components of ITER Design

The following ITER design information is excerpted from the IAEA ITER documents #22 Summary of ITER Final Design Report and #24 ITER Technical Basis.

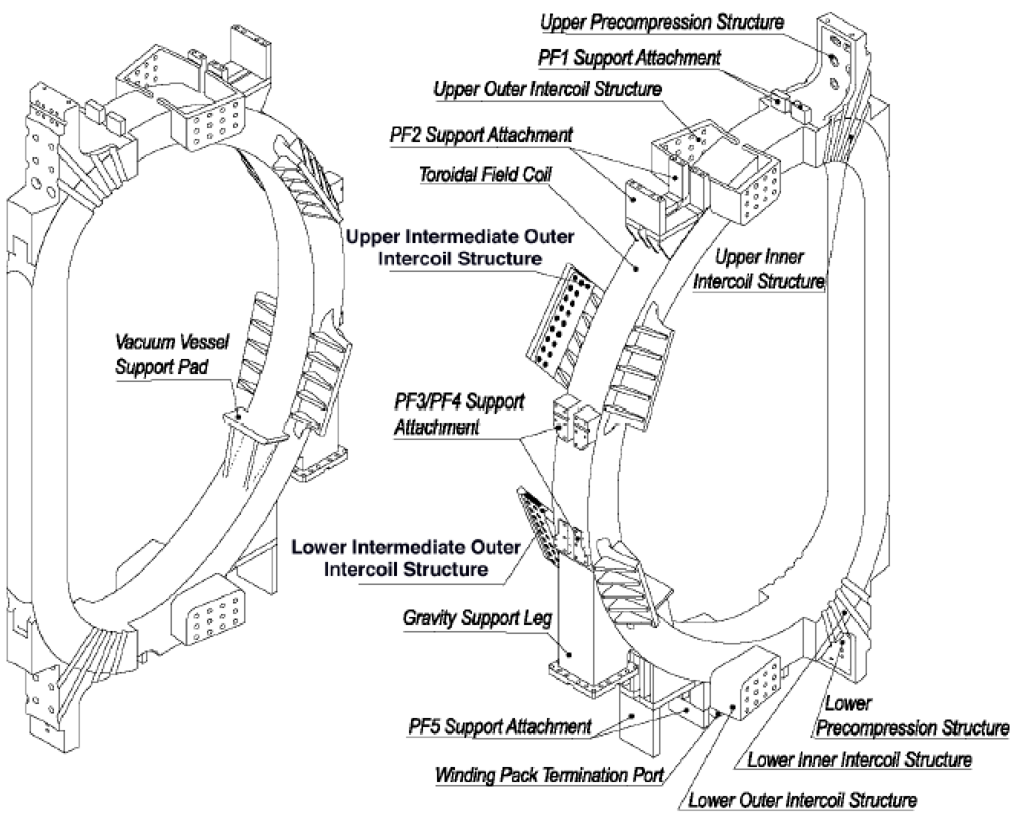
1. Magnets

The plasma is confined and shaped by a combination of magnetic fields from three main origins: toroidal field coils, poloidal field coils and plasma currents. Aiming in ITER at steady-state operation, all the coils are superconducting: copper coils would require too large an electric power to be acceptable for ITER as well as for a future reactor.

Toroidal Field (TF) Coils

The toroidal magnetic field value on the plasma axis is 5.3T, which leads to a maximum field on the conductor $\leq$ 12 T. Because of this high field value, Nb_3Sn is used as superconducting material, cooled at 4.5K by a flow of supercritical helium at approximately 0.6 Mpa. The total magnetic energy in the toroidal field is around 40 GJ, the confinement of which leads to significant forces on each of the 18 coils.

The coils are connected together by bolted structures, and by two compression rings made of unidirectional glass fibres. A Toroidal Field Coil structure is shown below.



Poloidal Field (PF) Coils

The Poloidal Field Coils consist of the six modules of the central solenoid (CS) and the six large PF coils placed outside the TF coils. Currents within these coils control the plasma shape and position. All these axissymmetric coils use superconductors cooled by a flow of supercritical helium at 4.5K and 0.6 Mpa. Nb_3Sn is used in the CS modules whereas less expensive NbTi can be used in the PF coils since the maximum field value is lower than 6T. Redundant turns are built into the trapped coils to allow for failures.

The PF coils and additional Error Field Correction Coils are shown below.

Error Field Correction Coils

The need to correct imperfections in the magnetic field symmetry, due to the imperfect positioning of the TF, CS and PF coil currents, requires the use of "correction coils", able to provide a helical field of a few 10^{-5} times the TF value. These coils are composed of three sets of six saddle coils and are shown below.

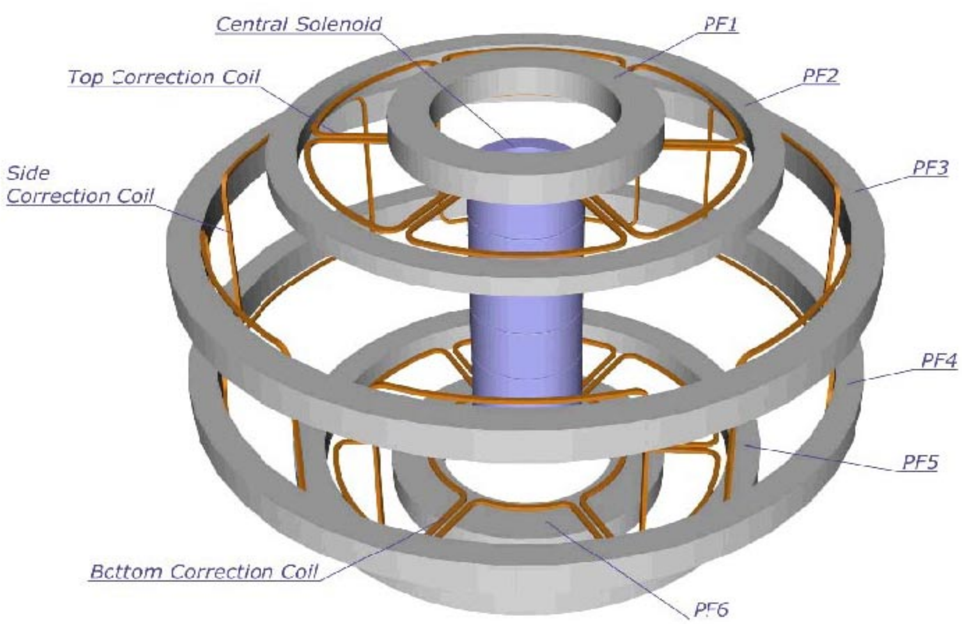


Figure 4.1-3 ITER Poloidal Field Coils and Error Field Correction Coils

Superconducting Coil Protection

The superconductor of all coils is protected against local overheating, should the coil current continue to flow after a local transition from superconducting to normal conducting state due to an off-normal local energy dump.

In addition, all these coils must be protected against the heat coming from their surroundings. Therefore, a large cryostat vessel places all the coils in a vacuum good enough to limit convective heat transfers. Additionally a thermal shield (VVTS), cooled at about 80 K by a flow of helium, is provided between the coils and hot parts to shield against radiative heat transfer.

Superconducting Coil Cryogenic Cooling

On top of the steady state cryogenic heat load there is a significant pulsed heat load on the coils from two separate sources: the neutron flux produced by the fusion reaction and attenuated by the blanket and vessel shields, and eddy currents induced by any field change in the coil superconductor and steel cases during the operational scenario of the plasma pulse (or even more during a plasma disruption). Since the cryogenic plant is essentially a steady state system, between the coils and the cryogenic plant, an energy storage is present to cushion the pulsed loads. In effect, this energy storage is mainly provided by the large steel mass of the TF coil cases, and by the temperature variation of the liquid helium bath that cools the supercritical helium flow through heat exchangers.

2. Vessel and In-Vessel Systems

Vacuum Vessel

The vacuum vessel is a component with multiple functions, namely it:

- provides a boundary consistent with the generation and maintenance of a high quality vacuum, necessary for limiting impurity influx into the plasma;
- supports the in-vessel components and their resultant mechanical loads;
- participates in shielding against neutrons, and in removing the corresponding power during a pulse, and moreover in removing the decay heat of all in-vessel components in case of there being no other coolant available;
- provides a continuous conductive shell for plasma MHD with a toroidal one turn resistance of ~8μΩ;
- provides all access to the plasma through ports, for diagnostics, heating systems, pumping, water piping, etc.;
- provides the first confinement barrier for tritium and activated dust with a very high reliability.

All these functions are central to the operation of ITER and thus require a very robust mechanical design analyzed for stresses in all possible normal and off-normal conditions. The vessel is built with two shells linked by ribs and fitted with nuclear radiation shielding material, and ferromagnetic inserts in the shadow of the TF coils to reduce the TF ripple value.

To ensure reliable water cooling, two independent loops are used. These can remove by natural convection the decay heat from all in-vessel components (if they are not cooled directly).

Neutron Shielding

The 14 MeV neutrons, i.e., 80 percent of the fusion energy produced in the plasma, transfer energy to the water coolant, and subsequently to the environment, by colliding with the materials present around the plasma (mostly steel and water) in the blanket modules and in the vacuum vessel. The small neutron energy, not absorbed in these two shields, is released in the cold TF coil structure, and should be absolutely minimized.

Blanket Modules

The shielding blanket is divided into two parts. The back part with a radial thickness of around 30 cm is a pure shield made of steel and water. The front part, the "first wall", includes diverse materials: one-cm thick beryllium armour protection, one-cm thick copper to diffuse the heat load as much as possible, and around ten cm of steel structure. This component will become the most activated and tritium-contaminated in the entire ITER device. It could be in contact with the plasma in off-normal conditions, and thus can suffer damage from the large heat locally deposited, and may have to be repaired or possibly changed.

In order to allow a practical method of maintenance, the blanket wall is modular (approximately 420 in total) with a maximum weight of 4.0 t (and about 1.5 m2 facing the plasma) and moreover the front part of each module is divided in four-six first wall panels. Each module is attached to the vessel by four flexible links, radially stiff but pliant against toroidal or poloidal motions.

Blanket Maintenance

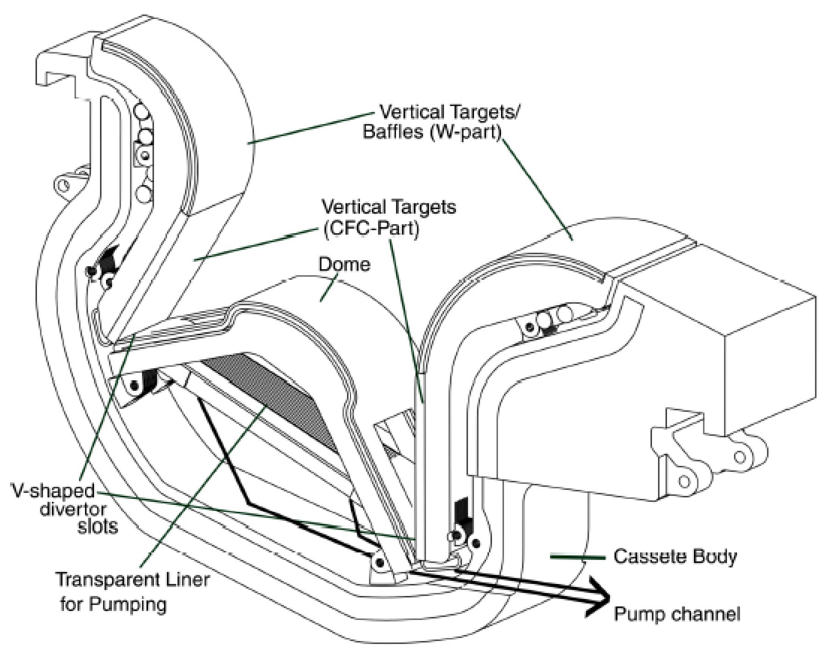
The maintenance and repair of a blanket module is performed by first removing it from the vessel. For this purpose, a vehicle, equipped with an end gripper, is positioned along a toroidal rail deployed along the vessel torus centreline. The end gripper is engineered to cut the connection to the water pipe feeders and to unbolt the module, and to bring it to an equatorial maintenance door. At this location it will be transferred into a cask, and subsequently to the hot cell for repair or replacement. The cask operates by docking and undocking to the ports of the vessel and of the hot cell, avoiding contamination to the environment. Similar casks are used for removal of any equipment installed in any equatorial or upper port of the vessel, i.e., heating launcher, diagnostics, or tritium breeding test blanket.

Divertor

The divertor shares with the blanket a similar modular philosophy and maintenance procedure. The cassettes (54 in total) are removed from the vessel at three lower access ports, to which they are conveyed by a toroidal mover mounted on annular rails attached to the vessel floor. These rails also act as the mounting point of the cassettes during operation.

Besides providing shielding of the vessel, the modular cassettes (Figure 4.2-2) support the divertor target plates, a set of particularly high heat flux components, built with high conductivity armour of carbon fibre composite (CFC) and tungsten.

Figure 4.2-2
Divertor Cassette



In-Vessel Component Water Cooling

Each divertor cassette is separately cooled by water, with feeder pipes connecting to the manifold outside the vessel and cryostat. Groups of two or three blanket modules are similarly fed by separate pipes installed on the plasma side of the inner shell of the vacuum vessel. This arrangement leads to handling a large number of small size pipes, but (e.g., by "spiking" specific coolant channels with tracer elements) allows the identification of possible modules or cassettes leaking water, from tests outside the cryostat, a crucial procedure to be able to rapidly localize the leaks in vacuum.

Cryogenic Pumps

Well recessed and shielded from neutrons, but inside the divertor port, are the torus cryogenic pumps operating at 4.5 K. These have the capacity to pump hydrogenic atoms, as well as helium by adsorption and condensation. The pumping performance can be varied and the condensed gases can be removed by heating the pumping panels to 80 K and pumping away the gas released using a roughing pump after a shutter towards the vacuum chamber has been closed.

3. Cryostat

The cryostat provides the vacuum environment to stop convective heat transfer to the superconducting magnets and cold structures, and forms the secondary confinement barrier for the radioactive inventory inside the vacuum vessel. The cryostat is a single wall cylindrical shell with flat top and bottom. Its diameter, 28 m is determined by the dimension of the largest component located inside, the poloidal field coils. Its height, 24 m internal, is determined by the size of components inside, as well as by the need to provide adequate vertical space for penetrations through the cryostat shell.

4. Vacuum Pumping and Fueling

Vacuum Pumping System

The vacuum pumping system provides the necessary vacuum conditions in the vacuum vessel for the conduct of plasma experiments. The system is comprised of a roughing system, torus pumping system, cryostat vacuum pumping system, heating and current drive vacuum pumping systems, guard and service vacuum pumping system, diagnostic vacuum pumping system, and lead detection systems.

Fueling System

The fueling system comprises a main gas supply system, the pellet injection system, the local gas supply system for the neutral beam injectors and diagnostic neutral beam, and the fusion power shutdown system.

5. Remote Handling Equipment

Due to neutron activation, the repair, inspection or maintenance of ITER in-vessel components has to be carried out remotely. In addition, in-vessel first wall components are subject to plasma-wall interaction leading to erosion. This requires regular or infrequent refurbishment, depending on the erosion rate. Furthermore, components may need to be replaced due to unexpected failure. This requires the introduction of common and dedicated remote handling equipment into the vacuum vessel. All ITER components have been designated into a remote handling category, and the required remote handling equipment will be provided within the project scope.

6. Cooling Water System

The cooling water system provides for the rejection of heat from a variety of ITER systems and consists of the tokamak cooling water system, the component cooling water system, the chilled water system, and the heat rejection system.

7. Tritium Plant and Fuel Cycle

The tritium used in ITER will be supplied by external sources. During plasma operation, in order to generate 500 MW of total fusion power, about 0.1 g of tritium will be burnt every 100 s. However, considering the divertor/plasma-purity operational conditions that call for maximum pumping speed and un-burnt fuel recalculation, more than 25 g of tritium will be injected into and pumped from the vessel during the same 100 s. The tritium plans is comprised of a variety of tritium handling and processing systems to process the pumped gases on line, to remove impurities and separate the tritium, and to store it for recycling back into the tokamak.

Segregation of tritium-containing equipment in separated structures, with limitation of the local inventory and robust confinement barriers, is appropriate for safety reasons. The storage of D_2, DT and T_2 is achieved in many parallel canisters, and adsorbed on ZrCo beds, which can deliver rapidly the required flow for plasma fuelling. Their tritium content is measured by calorimetry with around one percent accuracy.

8. Cryoplant and Distribution

The ITER cryogenic system is subdivided into three parts: the cryoplant, the cryodistribution system and the system of cryogenic lines and manifolds. As in any large cryogenic plant, the desire is to operate in a steady state cooling mode. Because the ITER heat load of the magnet system is largely deposited in pulses due to magnetic field variations during the pulses and the DT neutron production, the ITER cryosystem must smooth the pulsed heat load and maintain stable operation over a wide range of plasma operating scenarios.

9. Power Supplies and Distribution

A wide variety of power supplies and distribution systems are incorporated into the ITER design. They consist of the four major systems: pulsed power distribution system, coil power supplies, heating and current drive power supplies, and steady state electric power network. The reference design for drawing power from the local electric grid assumes the availability of sufficient grid capacity to meet the ITER pulsed and steady power needs. In the event the grid cannot meet all of the ITER needs in real time, an alternate design provides for the use of motor-generators to store some of the needed energy for use during the ITER experimental pulses.

10. Tokamak and Other Buildings

The ITER buildings should provide the volumes and controlled atmosphere required for assembly and operation. In addition, the tokamak building is important for its contribution to safety, for the following reasons:

- A biological shield of borated concrete is provided around the cryostat to limit the radiation levels outside the pit to values insignificant for the activation of components, even if human presence will not be allowed during plasma pulses.

- Part of the building is essential as a further confinement barrier (even containment in this case), forming two concrete leak tight vaults around the neutral beam injectors and the water cooling system, or even as a third confinement barrier in the case of the tritium building (the metallic equipment inside glove boxes provide the first and second barriers in this case).

- A differential pressure (Figure 4.5-1) is maintained in the different zones around the tokamak, according to the risk of being contaminated by an accidental release of tritium or activated material during operation or maintenance. In this way, the atmosphere will move only from lower to higher contamination levels. These differential pressures are maintained by the air conditioning system. The design arrangement of a separate cell around each vessel port access allows the atmosphere of each cell to be maintained through a venting system capable of detritiation and filtering. This is especially justified during the maintenance procedure when removing components from the vessel occurs.

- The concrete walls provide appropriate shielding against emission from activated components, during their automatic transport via cask from one vessel port to the hot cell (and back) through the galleries.

The very robust structure of the tokamak and tritium buildings is based on the existence of a common stiff basemat designed to react seismic conditions. Should the actual site have much more severe conditions than the generic site used in the design, the common basemat will be put on isolators and the acceleration amplification suffered by the components above will be maintained below the accepted design level.

Other principal buildings are included for hot cell and radwaste, power supplies. Cryoplant, laboratory support, and control including laboratory/office.

11. Miscellaneous Plant Systems

The ITER plant has a number of miscellaneous systems that are required to support the operations of the plant. These include radiological and environmental monitoring, potable and fire protection water, sewage, steam, condensate and demineralized water, compressed air, breathing air, nitrogen, helium and other special gases and plant sampling.

12. Heating and Current Drive Systems

A variety of heating and current drive systems are available to heat the plasma and thereby enable the fusion process and to help drive a current in the plasma. Each of these systems has unique characteristics to achieve specific objectives within the plasma. The systems are: neutral beam injection, radio-frequency systems, electron cyclotron systems, and ion cyclotron systems.

13. Diagnostics

Included in the scope of the project are a variety of plasma diagnostics that are needed to start up the machine, form and control an initial plasma, and carry out an initial set of plasma experiments. During the operations phase, additional diagnostics will be added in support of specific experiments to be performed.

14. Plant Control

A highly integrated plant control and data acquisition system is necessary for the efficient operation of the ITER device. A variety of specialized systems are included in the scope of the project to enable ITER to achieve its objectives.

Appendix E: ITER Cost Estimate Summary

ITER Cost Estimate Summary

WBS No.	Procurement Package	No.		HT Cost Estimate EU	JA	RF	Direct Capital Cost (1) (kIUA)	Percentage / Total	Spares deferred Investment (2) (kIUA)	Ratio of (1) / (3) %	Direct capital cost (3) (kIUA)	Deferred Investment (4) (kIUA)
				O : full estimate; P : partial estimate; X : no estimate								
1.1	Magnet Systems	1	Toroidal Field Coils Windings	O	O	O	117.0		4.0			
		2	Magnet Structures	O	O	O	168.3		5.4			
		3	Poloidal Field Coil & Correction Coils	O	O	O	49.7		0.0			
		4	Central Solenoid Coil	O	O	O	31.1		3.4			
		5	Feeders	X	O	X	41.0		3.2			
		6	Conductor	O	O	O	355.0		24.2			
			Subtotal				**762.1**	27.7	**40.2**	42.3	1800.0	
1.5	Vacuum Vessel	1	Main Vessel	O	O	X	155.0		0.0			
		2	Port Assemblies	O	O	O	75.0		0.0			
			Subtotal				**230.0**	8.4	**0.0**	113.0	203.0	
1.6	Blanket System	1	Blanket Manifolds, Filler Shields	O	O	O	6.0		0.0			
		2-1	FW/Blanket Shield Modules	O	O	P	142.6		7.3			
		2-2	Port Limiters	O	O	O	6.1		1.3			
		3	Blanket Module Connections	P	O	O	10.5		0.0			
			Subtotal				**165.2**	6.0	**8.6**	38.6	428.5	
1.7	Divertor	1	Cassette Integration & Testing	O	P	X	10.7		0.5			
		2	Plasma Facing Components	O	O	O	65.3		6.4			
			Subtotal				**76.0**	2.8	**6.9**	34.5	220.6	
2.2	Machine Assembly	1	Assembly Operations	O	O	O	50.3		0.0			
		2	Assembly Tooling	O	O	O	42.4		0.0			
			Subtotal				**92.7**	3.4	**0.0**	71.0	130.5	
2.4	Cryostat	1	Cryostat & VV Pressure Suppr. System	O	O	X	**75.8**	2.8	**0.0**	70.6	107.4	
2.7	Thermal Shields	1	Thermal Shield System	O	O	O	**28.8**	1.0	**0.0**	75.2	38.3	
3.1	Vacuum Pumping & Fueling System	1	Non-standard Cryopumps & Related Equipment	O	O	X	8.9		2.3			
		2	Roughing Pump Sets & Change-over Boxes	O	O	X	6.7		0.0			
		3	Leak Detection Stations	X	X	X	5.0		0.0			
		4	Standard Components	X	X	X	5.3		0.0			
		5	Pellet Injector	X	X	X	2.5		2.5			
		6	Gas Injector Valve Boxes	X	X	X	4.3		1.3			
		7	GDC Conditioning System	O	O	X	1.5		0.6			
			Subtotal				**34.2**	**1.2**	**6.8**	36.7	93.3	
	Machine Core		*Subtotal*				*1464.8*	*53.2*	*62.5*	*48.5*	*3021.6*	*0*

WBS No.	Procurement Package	No.		HT Cost Estimate (O : full estimate, P : partial estimate, X : no estimate) EU	JA	RF	Direct Capital Cost (1) (kIUA)	Percentage / Total	Spares deferred Investment (2) (kIUA)	Ratio of (1) / (3) %	Direct capital cost (3) (kIUA)	Deferred Investment (4) (kIUA)
2.3	R/H Equipment		Blanket RH Equipment	O	O	X	27.1		0.8			
			In-Vessel Div. Maintenance Equipment	O	O	X	11.7		0.3			
			Transfer Cask System	O	O	X	10.0		6.4			
			Viewing/Metrology Systems	O	P	X	6.0		0.8			
			Neutral Beam RH Equipment	O	O	X	0.6		5.4			
			Hot Cell Repair/Maintenance Equipment	O	O	X	5.7		38.6			
			Subtotal				**61.1**	**2.2**	**52.3**	34.0	180.0	87.4
2.6	Cooling water	1	PHTS and CVCS	O	O	X	71.0		2.6			
		2	Heat Rejection System	O	O	X	37.4		10.8			
		3	Component Cooling & CW Systems	O	O	X	23.1		3.4			
			Subtotal				**131.5**	**4.8**	**16.8**	38.7	339.4	10
3.2	**Tritium Plant**	1	Tokamak Exhaust Processing System	O	O	X	6.1		6.9			
		2	Storage & Delivery, Long Term Storage System	O	O	X	11.9		2.6			
		3	HTD Isotope Separation	O	O	X	0.0		6.2			
		4	Atmosphere Detritiation	O	O	X	12.8		17.4			
		5	Water Detritiation	O	O	X	3.7		10.8			
		6	Tritium Plant Analytical System	O	O	X	1.0		0.6			
		7	Tritium Plant Automatic Control System	O	O	X	1.1		0.8			
			Subtotal				**36.6**	**1.3**	**45.2**	47.2	77.6	98
3.4	**Cryodistribution**		Cryoplant	O	O	X	60.5		2.5			
			Cryolines	O	O	X	12.2		4.0			
			Cryodistribution Components	O	O	X	16.2		1.4			
			Subtotal				**88.9**	**3.2**	**7.9**	61.7	144.2	24.2
4.1	**Power Supplies & Distribution**	1	High Voltage Substation and AC Distribution System	O	O	X	26.6		0.4			
		2	AC/DC Converters, Reactive Power Compensators and Harmonic Filters	O	O	X	81.2		1.0			
		3	Switching Networks, Discharge Circuits, DC Distribution and Instrumentation	O	O	O	67.2		1.8			
			Subtotal				**175.0**	**6.4**	**3.2**	54.2	323.0	0
4.1		8	Steady State Electrical Power Network	O	O	O						
			Subtotal				**39.7**	**1.4**	**0.3**	53.1	74.7	0

WBS No.	Procurement Package	No.		HT Cost Estimate (O : full estimate, P : partial estimate, X : no estimate) EU	JA	RF	Direct Capital Cost (1) (kIUA)	Percentage / Total	Spares deferred Investment (2) (kIUA)	Ratio of (1) / (3) %	Direct capital cost (3) (kIUA)	Deferred Investment (4) (kIUA)
6.2	**Buildings**	1	Reinforced Concrete and Site Infrastructure Elements	O	O	X	311.5		0.0			
		2	Steel Frame Buildings	O	O	X	68.8		0.0			
			Subtotal				**380.3**	**13.8**	**12.0**	46.5	818.1	11.4
6.3	**Waste Treatment and Storage**	1	Waste Treatment and Storage	O	X	X	**2.1**		**7.0**		87.4	0
6.4	**Radiological Protection**	1	Radiological Protection	O	O	X	**1.0**		**3.2**		7.4	0
	Auxiliaries		*Subtotal*				*916.2*	*33.3*	*148.0*	44.7	*2051.8*	*231*
5.1	**IC H&CD**	1	Antenna Arrays and Vacuum Transm. Lines	O	X	X	4.5		0.0			
		2	Main Transm. Line and Matching System	O	X	X	4.8		0.0			
		3	RF Power Sources & RF Monitoring Control	O	X	X	16.0		2.0			
		4	Power Supply	O	X	X	6.9		0.0			
			Subtotal				**32.2**	**1.2**	**2.0**	0.0	0.0	0
5.2	**EC H&CD**	1A	Equatorial Launcher	X	O	O	7.3		0.0			
		1B	Upper Launcher	X	O	O	8.9		0.0			
		2	Transmission Line	O	O	O	17.9		0.0			
		3	RF Power Sources and Controls	O	O	O	29.5		3.0			
		4	Power Supply	O	O	X	13.9		0.0			
			Subtotal				**77.5**	**2.8**	**3.0**	45.8	169.2	0
5.3	**NB H&CD**	1	Assembly and Testing	O	O	X	3.8		0.0			
		2	Beam Source and High voltage Bushing	O	O	O	9.5		0.0			
		3	Beamline Components	O	O	O	3.9		0.0			
		4	Pressure/Vacuum Vessels, Drift Duct and Passive Magnetic Shielding	O	O	X	11.9		0.0			
		5a	Active Corr./Compensation Coils	O	O	X	4.4		0.0			
		6	Power Supply	O	O	X	62.5		0.0			
			Subtotal				**96.0**	**3.5**	**0.2**	60.0	160.0	0
	H and CD		*73MW (100MW in 1998)*				*205.7*	*7.4*	*5.2*	*62.5*	*329.2*	*0*

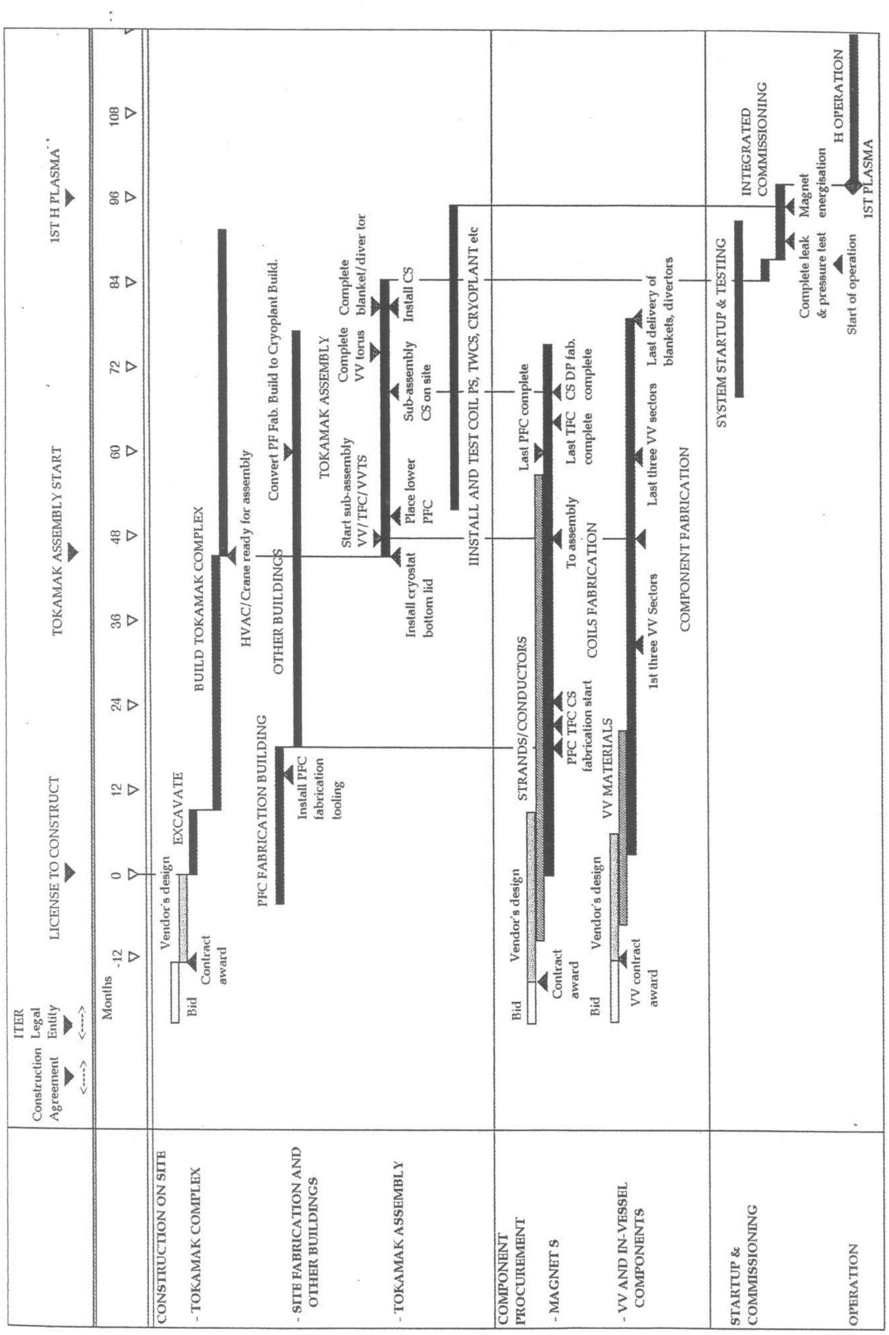
WBS	Procurement Package			HT Cost Estimate			Direct Capital Cost (1)	Percentage / Total	Spares deferred Investment (2)	Ratio of (1) / (3) %	Direct capital cost (3)	Deferred Investment (4)
No.				O : full estimate								
				P : partial estimate								
				X : no estimate			(kIUA)		(kIUA)		(kIUA)	(kIUA)
		No.		EU	JA	RF						
5.5	Diagnostics	A	Diagnostics. Magnetics	X	X	P	3.3		0.0			
		B	Neutron Systems	X	P	P	3.9		6.2			
		C	Optical Systems	X	X	P	16.9		8.8			
		D	Bolometry	O	X	X	6.7		0.0			
		E	Spectroscopic Systems	X	P	P	8.9		13.6			
		F	Microwave Systems	X	X	X	8.3		9.4			
		G	Operational Systems	X	X	X	11.0		0.0			
		N	Standard Diagnostics	O	X	X	36.3		4.2			
			Diagnostic Neutral Beam:Line	O	O	X	13.0		0.1			
			Diagnostic Neutral Beam:Power Supply	O	O	X	9.7		0.0			
			Subtotal				**118.0**	**4.3**	**42.3**	78.2	150.8	71
	CODAC		Hardware and Software (rough estimate)				**50**	**1.8**	**0.0**		50.0	0
			Grand Total				**2754.7**	**99.9**	**258.0**	**49.2**	**5603.4**	**302**

Appendix F ITER Value Estimate and Committee Assessment

Element of ITER Value Estimate	kIUA[1]	$M 2002[2]	Committee Assessment
ITER Direct Items			
Machine Core	*1,464.8*	2,103.5	
Magnet Systems	762.1	1,094.4	Detailed design essentially complete; Conductor strand/conduit change - addressed by R&D
Vacuum Vessel	230.0	330.3	Detailed design essentially complete; Full-scale sector prototypes built, Good detail in estimate
Blanket System	165.2	237.2	Design and R&D complete for representative modules; Good detail in estimate
Divertor	76.0	109.1	Design mature; successful R&D, minor changes possible - no cost impact; Good detail in estimate
Machine Assembly	92.7	133.1	Advanced conceptual level plan and tooling design for all core elements inside cryostat
Cryostat	75.8	108.9	Design mature; Conventional construction
Thermal Shields	28.8	41.4	Detailed design essentially complete
Vacuum Pumping & Fuel System	34.2	49.1	Design mature; Pellet injection R&D ongoing; Balance is conventional construction
Auxillary Systems	*916.2*	1,315.7	
Remote Handling Equipment	61.1	87.7	Design mature for divertor and blanket; prototypes demonstrated (except full cask transfer and hot cell operations)
Cooling Water	131.5	188.8	Design essentially complete; system composed of conventional components
Tritium Plant	36.6	52.6	Design essentially complete; Well proven technology
Cryodistribution	88.9	127.7	Design essentially complete; system composed of conventional components
Power Supplies & Distribution	214.7	308.3	Design essentially complete with supporting analysis and R&D
Buildings	380.3	546.1	Design essentially complete (not site-specific); Well understood construction techniques
Waste Treatment and Storage	2.1	3.0	Preliminary design
Radiological Protection	1.0	1.4	Preliminary design
Heating and Current Drive Systems (H&CD)	*205.7*	295.4	
Ion Cyclotron H&CD	32.2	46.2	Preliminary level design; R&D and detailed design excluded
Electron Cyclotron H&CD	77.5	111.3	Preliminary level design; R&D and detailed design excluded
Neutral Beam H&CD	96.0	137.9	Preliminary level design; R&D and detailed design excluded
Diagnostics	*118.0*	169.5	Conceptual level design definition based on 1998 design; R&D and detailed design excluded from estimate
Control, Data Acquisition, Communications	*50.0*	71.8	Reasonable estimate; Based on budgetary allotment
Subtotal ITER Direct Items	**2,754.7**	**3,955.7**	Sum of estimates based on ITER's 85 procurement packages
CM & Engineering Support	**477.0**	**685.0**	Generally reasonable; Physics and institutional support not included
Contingency	**Not Applicable**	**TBD**	Not in ITER valuation, but would be included in USDOE estimate
Other Project Costs	**169.9**	**244.0**	
R&D during construction	*79.9*	114.8	Reasonable; Recognizes $1B already spent; Diagnostics R&D and Plasma Heating not included
Integrated Commissioning	*90.0*	129.2	Reasonable; Physics Support not included
Escalation	**Not Applicable**	**TBD**	Not in ITER valuation, but would be included in USDOE estimate once construction is scheduled
Total ITER Value Estimate	**3,401.6**	**4,884.7**	
(Spares and Deferred Items)	258.0	370.5	Will be apportioned to Parties consistent with ITER procurement strategy

[1] ITER Units of Account (kIUA) where 1kIUA = $1,000 (January 1989 Dollars) a common basis determined as a result of the ITER process for normalizing estimates from different international parties
[2] kIUAs converted to $2002 (kIUA x 1.436)

Appendix G ITER Schedule



Appendix H

US Gross Domestic Product Implicit Price Level Deflators
(Escalation methodology prepared as part of 2002 Snowmass Summer Study)

IPLD* = Implicit Price Level Deflator for US Gross Domestic Product

Year	IPLD*	Quarter	IPLD*	FY	IPLD*
		4	103.65		
1999	104.69	1	104.12	FY99	**104.28**
		2	104.51		
		3	104.83		
		4	105.27		
2000	106.89	1	106.07	FY2000	106.29
		2	106.68		
		3	107.12		
		4	107.68		
2001	109.42	1	108.65	FY2001	108.89
		2	109.32		
		3	109.92		
		4	109.78	*extrapolated data**	
2002	***110.58***	1	110.05	*FY2002*	*110.25*
		2	110.40		
		3	110.76		
		4	*111.12*		

** Extrapolated data based on inflation rate similar to last four quarters* *1.29%*

ITER Conversion Rate = 1.39 to convert from 1q1989$ to 2000$ (mid-point)

per ITER escalation groundrules	1.39
GDP escalation from 2000$ to 2002$ =	1.033
Combined escl. from 1q1989$ to 2002$ is 1.39 x GDP escl =	**1.436**