ECH Systems

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by

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on behalf of CPI, GA, MIT,

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Outline

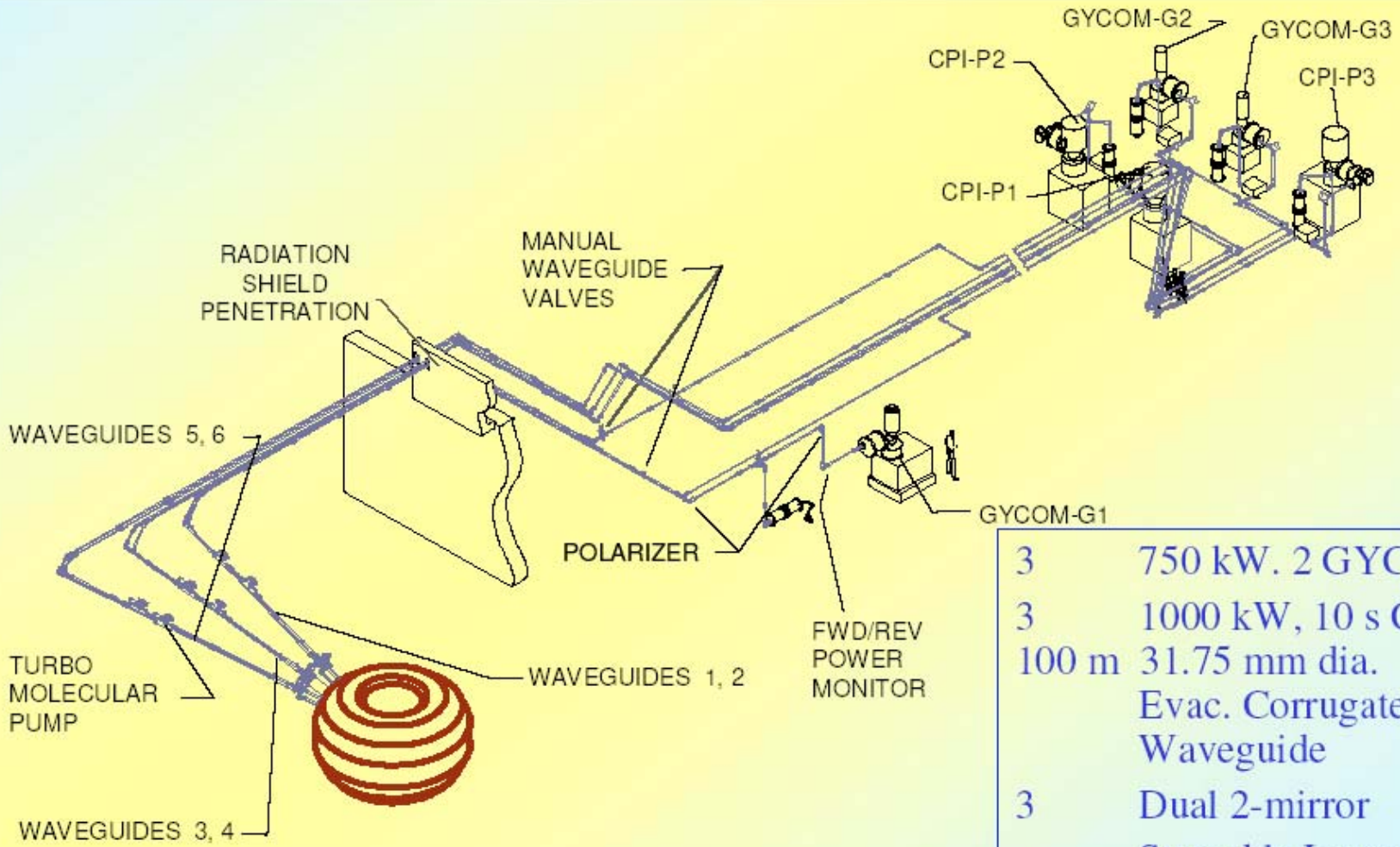
- ECH Mission / Scope
- FY03 / FY04 Technical Highlights / Accomplishments
- Proposed FY05 Tasks
- Proposed FY06 Tasks
- FY05 and FY06 Tasks supported by ITER Project
- Key concerns / issues
- Summary

ECH Mission / Scope

- Develop advanced, reliable technology for ECH, ECCD, EBW
  - Gyrotrons, Windows, Transmission Lines and Antennas.
- Support near term and burning plasma ECH experiments.
- Foster international collaboration.

- Increase the reliability, power and efficiency of gyrotrons.
  - Develop tunable gyrotrons for use at a range of B field values.
- Develop efficient mode converters to Gaussian beams.
- Increase the efficiency of transmission lines.
- Develop remote, steerable launchers.
- Develop the theory and design tools for the accurate design of new gyrotrons and transmission line components.
- Reduce the cost of all gyrotron system components.
- Develop a low cost gyrotron power supply system.

DIII-D 110 GHz 6 GYROTRON ECH SYSTEM

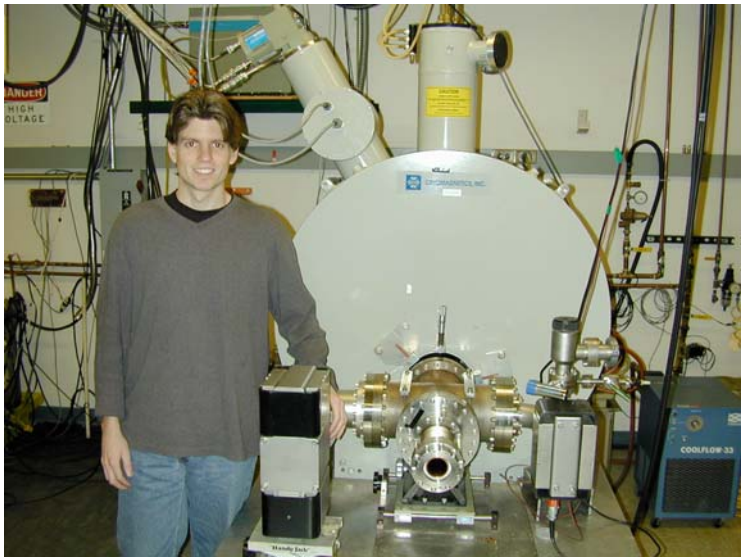


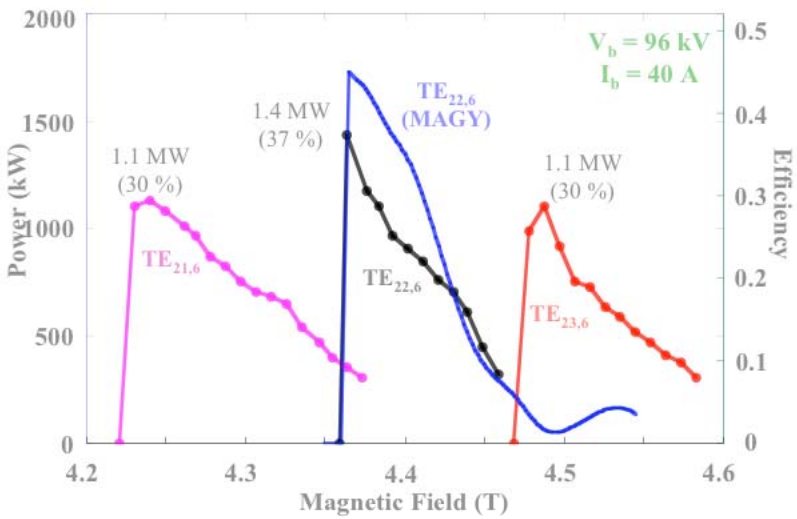
3	750 kW. 2 GYCOM
3	1000 kW, 10 s CPI
100 m	31.75 mm dia. Evac. Corrugated Waveguide
3	Dual 2-mirror Steerable Launcher

DIII-D NATIONAL FUSION FACILITY SAN DIEGO

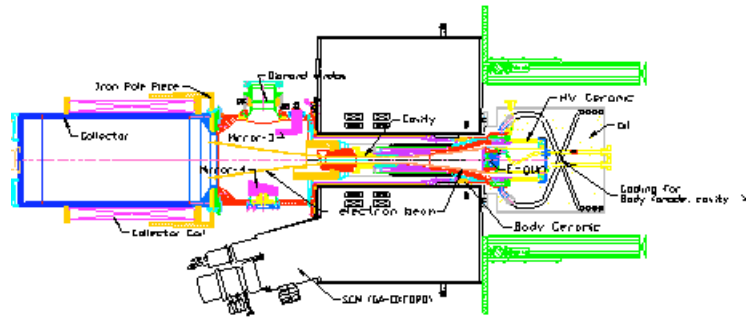
GENERAL ATOMICS

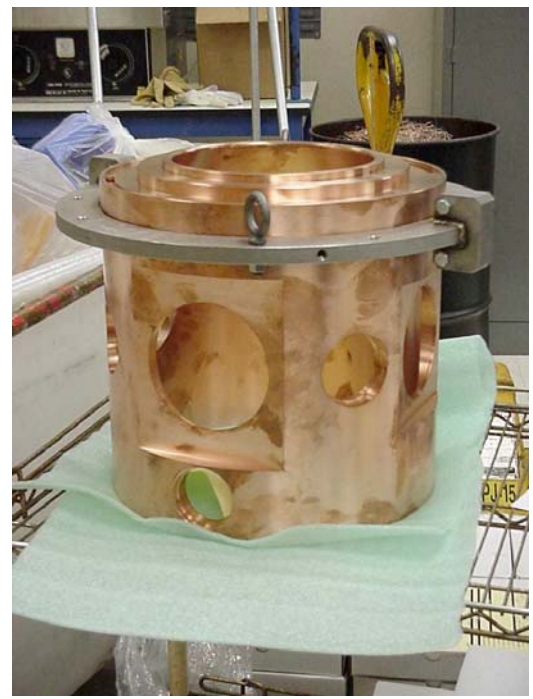
FY03 / FY04: 1.5 MW, 110 GHz Gyrotron





Demonstration of 1.4 MW at Short Pulse Lengths (MIT)

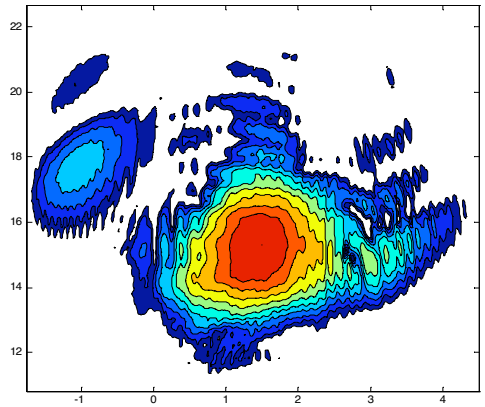




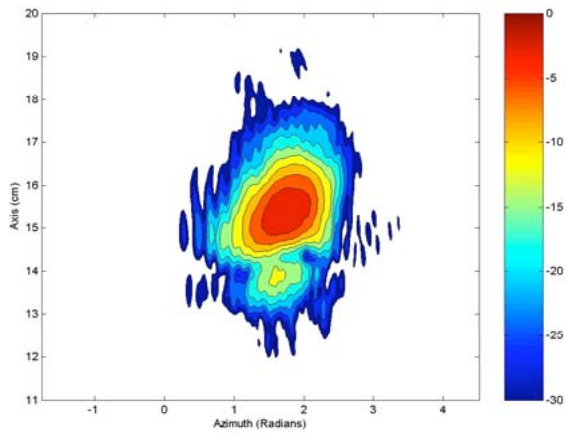
CW Tube will operate in 3/04 (CPI)

FY03 / FY04: Mode Converters/Antennas

Launcher radiation patterns measured at UW.

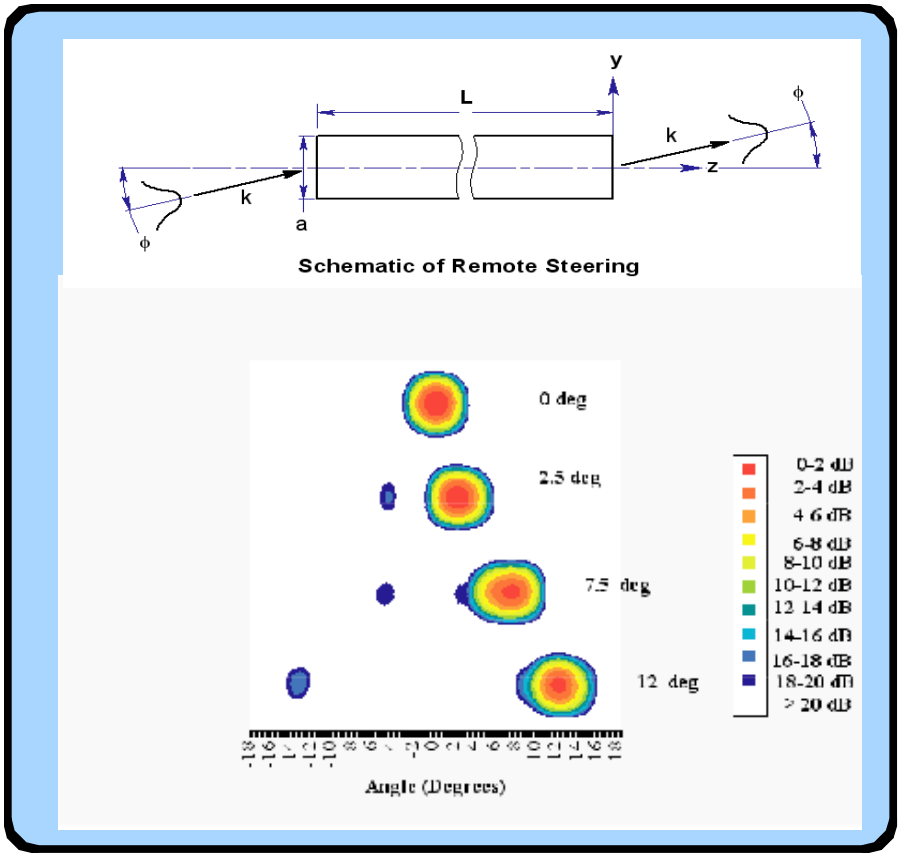


Old launcher radiation pattern.



New launcher radiation pattern.

Improved Mode Converter (UW,CCR)



Remote Steerable Launcher (GA)

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- FY03 / FY04 Technical Highlights / Accomplishments
- **Proposed FY05 Tasks**
- Proposed FY06 Tasks
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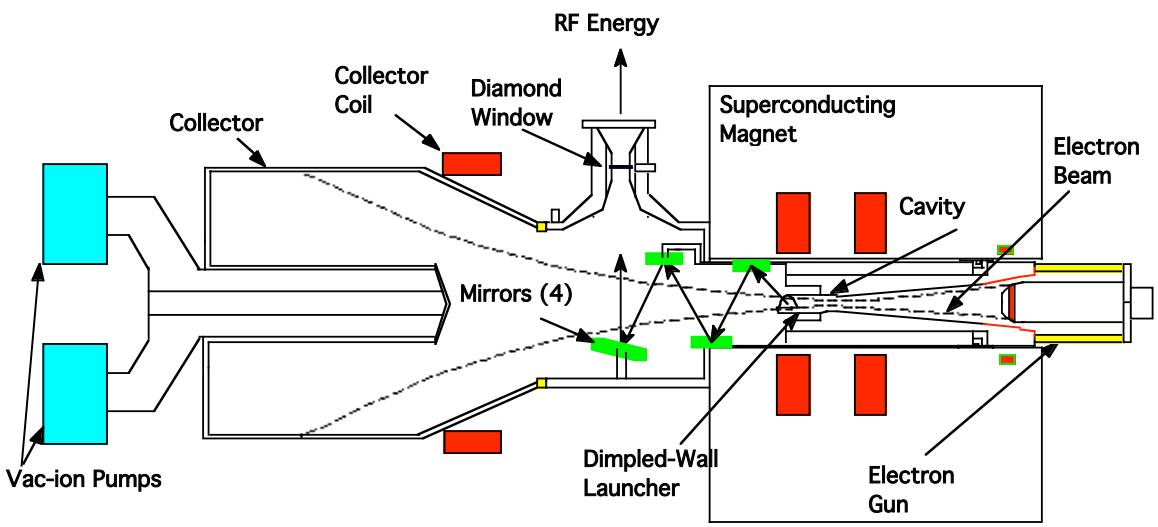
Proposed FY05 Tasks: 1

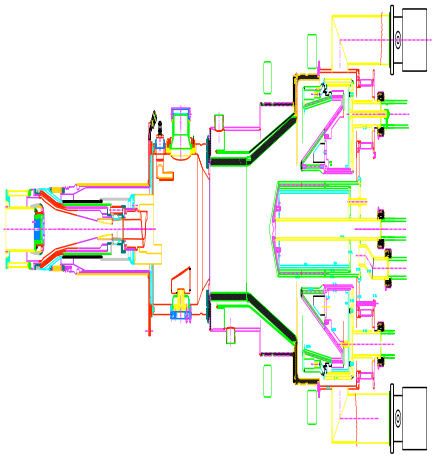
- **ITER 1 MW, 120 GHz Gyrotron**
  - Start-up gyrotrons for ITER.
  - Power level of 1.2 to 1.5 MW will be design goal, to assure that >1.0 MW is produced and coupled to the corrugated waveguide.
  - Based on successful 1 MW and 1.5 MW, 110 GHz gyrotrons for DIII-D.
  - **Milestone: Complete design by September, 2005.**
- CPI will lead the study and will produce the engineering drawings.
- MIT will participate in the design study, validating the design of the electron gun and other key components.
- Univ. MD will analyze mode interactions and mode competition.
- Univ. WI will complete a preliminary design of the mode converter system for this gyrotron.



Proposed FY05 Tasks: 2

- **1.5 MW, 110 GHz Gyrotron with a two-stage depressed collector**.
  - **Milestone: Fabricate and test by September, 2005**

- Two stage depressed collector is available from SBIR program funding at Calabazas Creek Research.
- CPI will rebuild existing single-stage depressed collector tube into a two-stage depressed collector tube.
- Univ. MD will help in analyzing the operation of the two-stage collector.
- MIT will help with modeling the gyrotron operation.



Proposed FY05 Tasks: Other

- **3.** Design Study of **ITER transmission line system** – preliminary design at GA – Sept., 2005
- **4.** Design study of **Next Step Gyrotron**, which may be increased in power to 2 MW, or in frequency, to 170 GHz; first design with ECH community input at MIT – Sept., 2005.
- **5.** Advances in **remotely steerable launcher** design will be made to permit steering at larger angles and the incorporation of miter bends at GA – September 2005.
- **6.** Complete an improved design code for the **launcher-reflector** system for MW gyrotrons at Univ. WI – January, 2005.
- **7.** Modification of the **code MAGY** for coaxial configurations of future CW gyrotrons operating at a multi-MW power level at Univ. MD - March 2005.
- **8.** Modify **MIT test stand** to conduct tests of gyrotrons at the 2 MW power level – September, 2005.
- **9. Improved Modeling Tools** – improved codes for designing gyrotrons and transmission lines – Sept. 2005.

FY05 ECH Tasks - Funding

Task	Total	ITER
1. ITER 1 MW, 120 GHz Gyrotron	$475k	$475k
2. 1.5 MW, 110 GHz, 2-stage Depr. Coll. Gyrotron	$368k	
3. ITER Transmission Line	$75k	$75k
4. Next Step Gyrotron Research	$120k	
5. ITER Remotely Steerable Launcher	$25k	$25k
6. Launcher – Reflector Research	$50k	$25k
7. MAGY Code R&D	$70k	$20k
8. MIT Test Stand	$75k	
9. Improved Modeling Tools	$160k	$30k
Total	$1418k	$650k

* No ITER Project Funds in FY05

FY05 Incremental Funding Request

- Incremental Task Request: Improvement of CPI Test Stand for continuous operation of 1 to 2 MW gyrotrons with depressed collectors: $700k.
  - Needed to test gyrotrons at CPI rather than GA.
  - Saves $$$$$.

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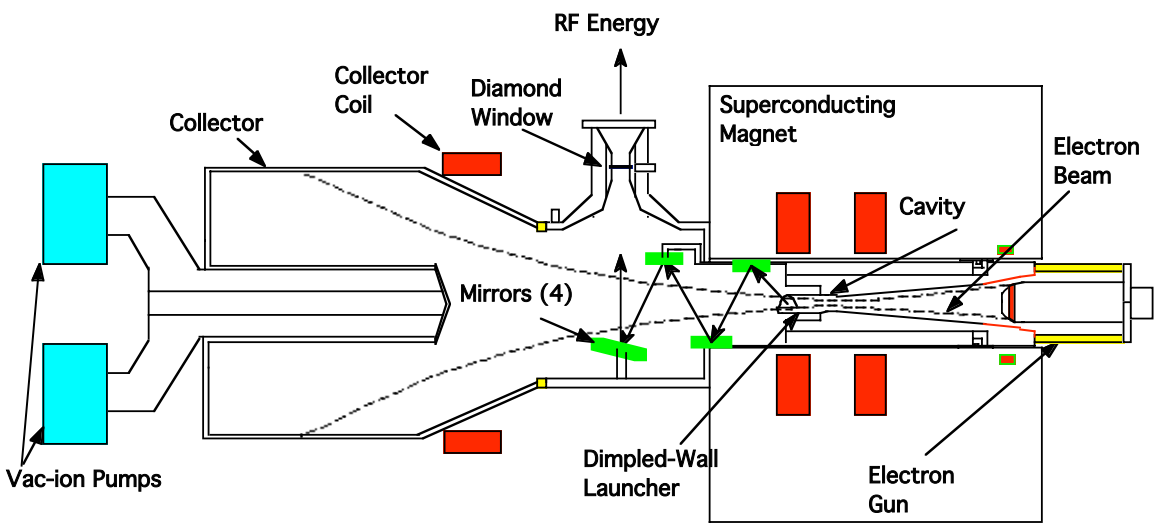
Proposed FY06 Tasks: 1

- **ITER 1 MW, 120 GHz Gyrotron**
  - **Milestone: Fabricate long lead time major gyrotron tube components by September, 2006.**
- CPI will lead the development and will fabricate the major tube parts, including all long lead time items.
- MIT will participate by validating the design of the cavity and other key components.
- Univ. MD will further analyze mode interactions and mode competition.
- Univ. WI will finish the design of the mode converter system for this gyrotron.



Proposed FY06 Tasks: Other

- **2.** Improved design of **ITER transmission line** and first design of DC power supplies at GA – Sept., 2006.
- **3.** Studies of **Gyrotron Reliability** including enhanced cooling and improved brazing at CPI – Sept., 2006.
- **4.** Final design of **Next Step Gyrotron** at MIT and ordering of new electron gun at MIT – Sept. 2006.
- **5.** Advances in **remotely steerable launcher** design will be implemented and tested at GA – September 2006.
- **6.** Demonstrate a new concept for measuring the **loss tangent** of CVD diamond disks even after they are installed on a gyrotron at GA – September 2006.
- **7.** Complete a final design of a **launcher-reflector system** for the 1 MW, 120 GHz gyrotron at UW – Sept., 2006.
- **8.** Analysis of **space charge instabilities** in high-power gyrotrons with depressed collectors at U MD – Sept., 2006.
- **9. Improved Modeling Tools** – improved codes for designing gyrotrons and transmission lines – Sept. 2006.

FY06 ECH Tasks/Funding –10% Case

Task	Funding	(ITER Support)
1. ITER 1 MW, 120 GHz Gyrotron	$625k	$625k
2. ITER Transmission Line	$50k	$50k
3. Gyrotron Reliability Studies	$100k	$100k
4. Next Step Gyrotron Research	$200k	
5. ITER Remotely Steerable Launcher	$25k	$25k
6. Loss Tangent Measurement	$15k	$15k
7. Launcher – Reflector System	$52k	$30k
8. Space Charge Instabilities	$70k	$35k
9. Improved Modeling Tools	$139k	$70k
Totals	$1276k	$950k

FY06 Incremental Tasks: Level Funding Case

- Incremental Task Request 1: Stronger program to support and speed up the 1 MW, 120 GHz gyrotron development by CPI, MIT, U MD and U WI: $132k.
- Incremental Task Request 2: Stronger effort on loss tangent measurement system at GA: $10k.
- Total incremental request to reach the leveling funding case is $142k, bringing total FY06 budget request from $1276k to $1418k (same as FY05).

FY06 ECH Tasks/Level Funding Case

Task	Funding	(ITER Support)
1. ITER 1 MW, 120 GHz Gyrotron	$757k	$757k
2. ITER Transmission Line	$50k	$50k
3. Gyrotron Reliability Studies	$100k	$100k
4. Next Step Gyrotron Research	$200k	
5. ITER Remotely Steerable Launcher	$25k	$25k
6. Loss Tangent Measurement	$25k	$25k
7. Launcher – Reflector System	$52k	$30k
8. Space Charge Instabilities	$70k	$35k
9. Improved Modeling Tools	$139k	$70k
Totals	$1418k	$1092k

FY06 Incremental Funding Request

- Incremental Task Request 1: Funding to complete fabrication of all parts of the ITER 1 MW, 120 GHz gyrotron at CPI : $400k.

- Incremental Task Request 2: Enhanced research program for remotely steerable launcher at GA, to develop high average power models: $250k.

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  - **No FY05 Tasks, only FY06 Tasks**
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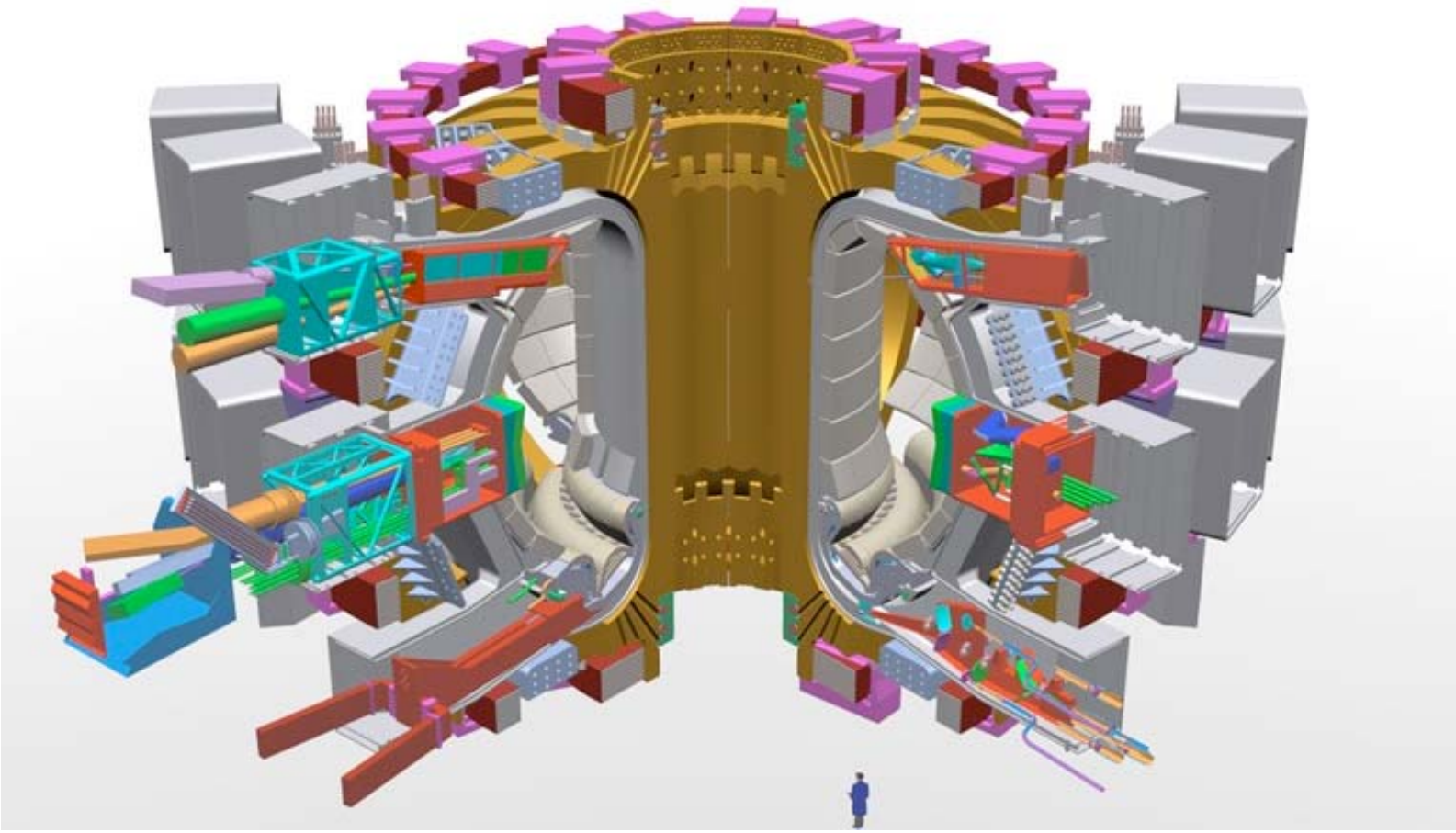
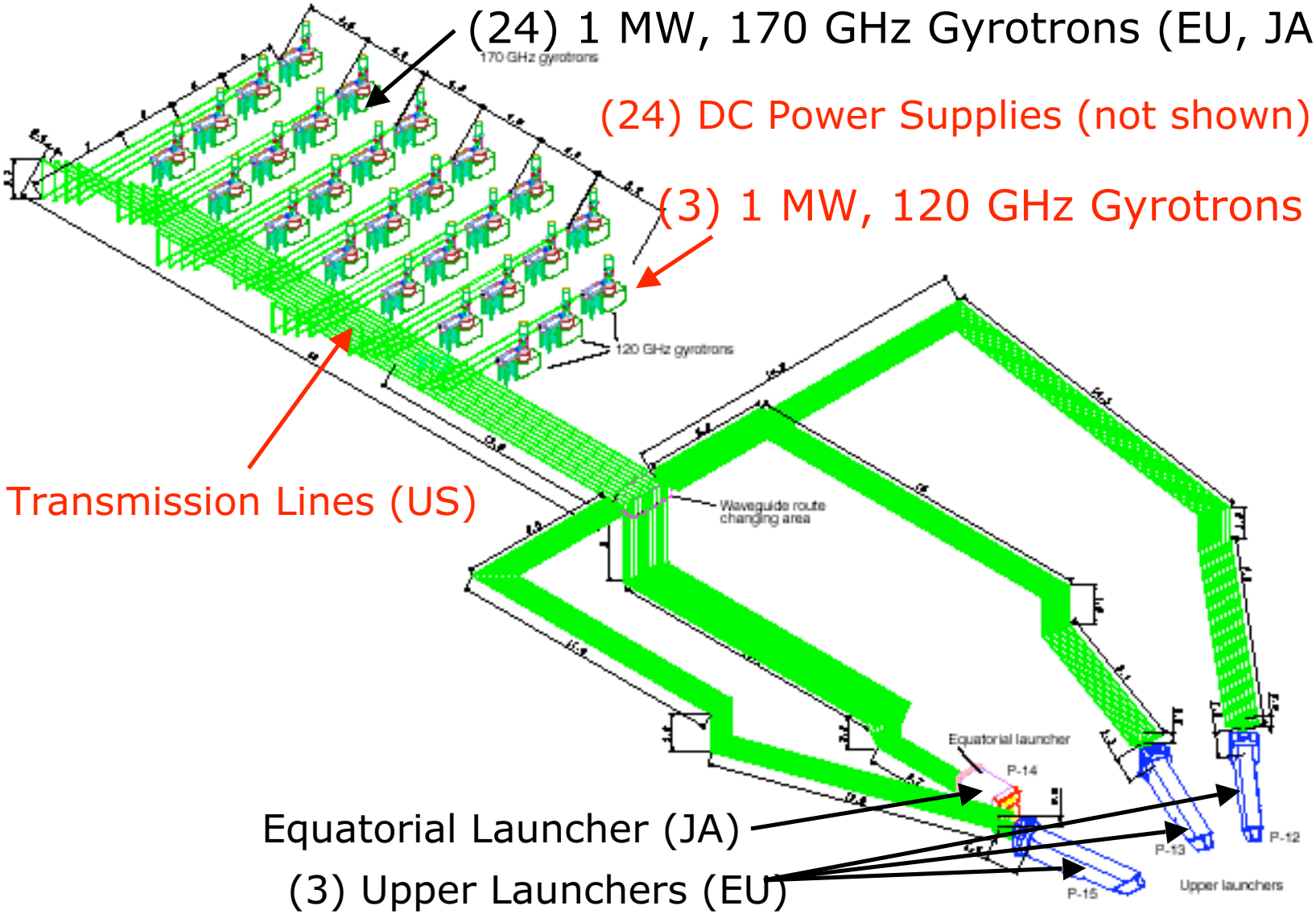
ECH on ITER



- EC Current Drive (ECCD), off-axis.
- EC Heating (ECH), including start-up.
- Neoclassical Tearing Mode (NTM) stabilization.

ECH System / Allocations



(24) 1 MW, 170 GHz Gyrotrons (EU, JA, RF)

(24) DC Power Supplies (not shown) (US)

(3) 1 MW, 120 GHz Gyrotrons (US)

Transmission Lines (US)

Equatorial Launcher (JA)

(3) Upper Launchers (EU)

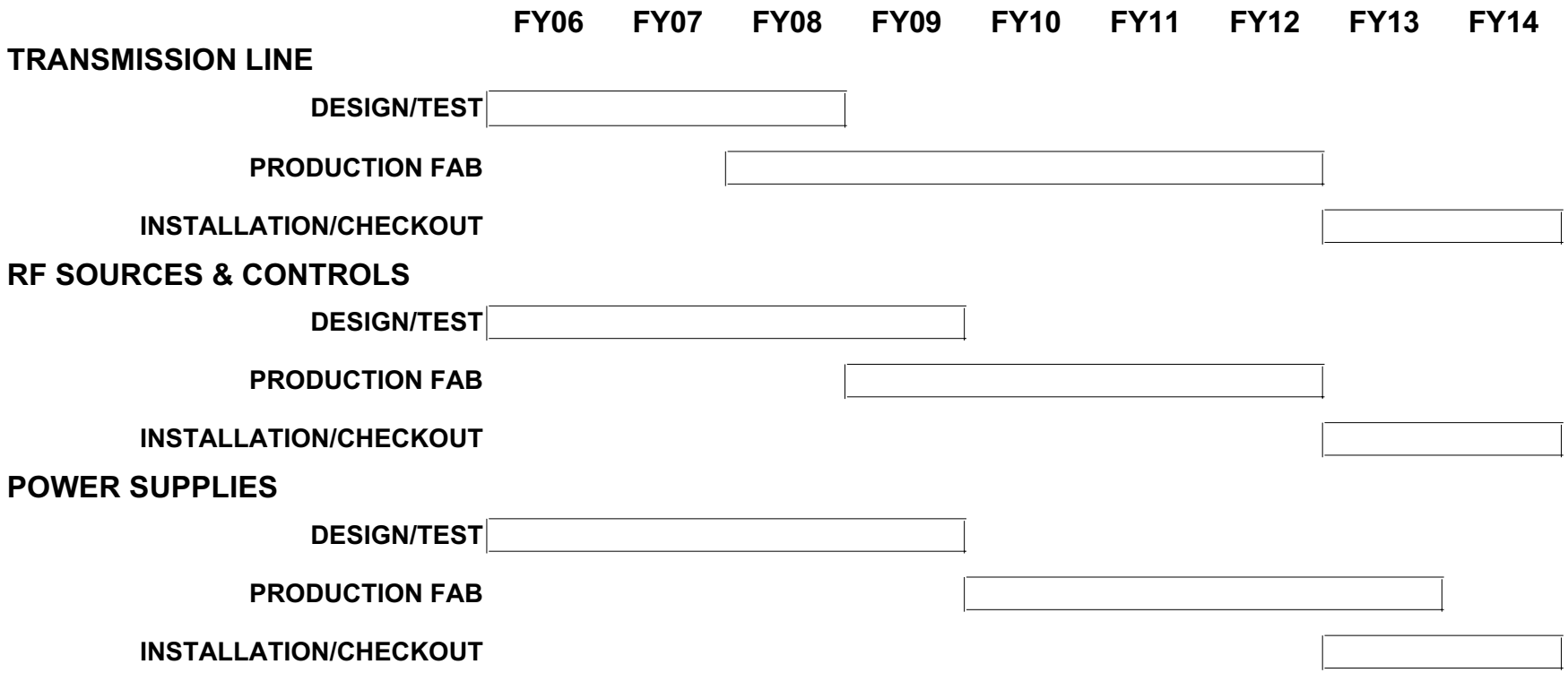
ECH&CD Cost Overview

	Trans Lines	DC Supplies	RF Source & Controls	Total
Total	$41,730	$26,280	$14,530	$82,540

Proposed FY06 ITER Tasks ($3.3M)

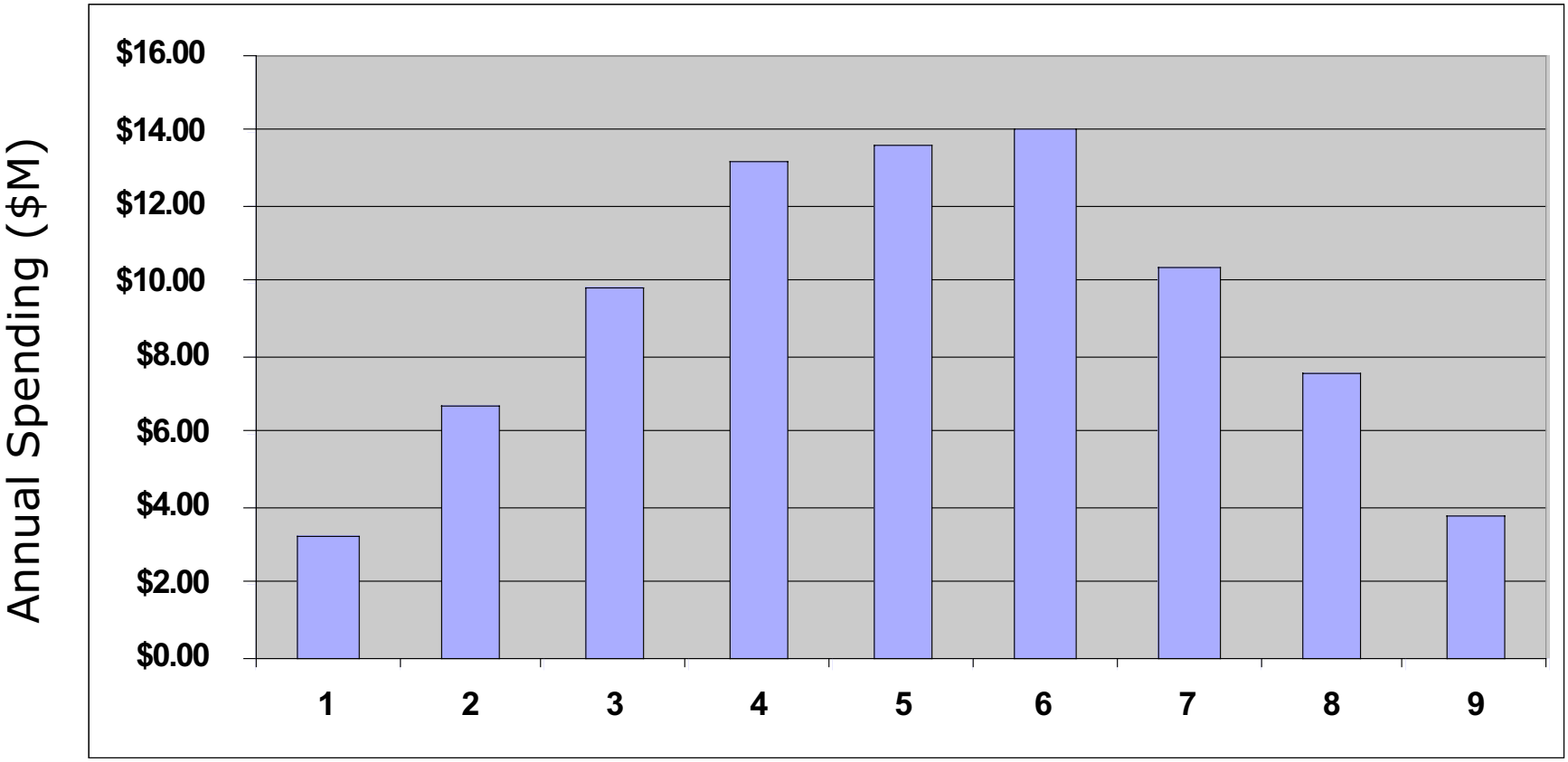
- TRANSMISSION LINES
  - Design of transmission line components completed.
  - Start fabrication of new cw prototype components.
  - Perform proof of principle tests on new components.
  - Funding of $1.1M
- RF SOURCES & CONTROLS
  - Complete the first prototype of a 1 MW 120 GHz gyrotron, procure magnet, start testing.
  - Complete the design of the gyrotron control system.
  - Complete the design of the gyrotron support system.
  - Order long lead items for full prototype system.
  - Funding of $1.1M
- POWER SUPPLIES
  - Complete the system conceptual design.
  - Funding of $1.1M

ITER ECH Project Plan



This project plan was developed by GA.

Spending Profile for ITER ECH



Project Year (1 = 2006; 9 = 2014)

- Total cost of ECH System is $82.54M

Concerns / Issues

- Spending profile for ITER tasks has too small a level of funding in FY06. Additional funding needed to increase speed of prototype development, in order to reduce risk.
  - Recommended level of funding for FY06 ITER ECH tasks is $6M.

Conclusions

- FY05 and FY06 ECH Technology program plans provide strong support for Heating and Current Drive Physics research both in the US program and for ITER.
  - FY05 budget provides 46% direct ITER task support.
  - FY06 budget provides 77% direct ITER task support.
- FY06 ECH ITER program should initiate all three areas – RF Sources (Gyrotrons and Controls), Transmission Lines and ECH DC Power Supplies.
- Early start to technology development essential to reducing total cost and risk!