Engineering Overview
International Fusion Materials Irradiation Facility

J. Rathke
Advanced Energy Systems, Inc.

FESAC Subcommittee Review
January 14, 2003
San Diego, CA

Acknowledgements:

The presenter wishes to thank all members of the IFMIF team for their contribution to the material presented here

Outline

- **Background of IFMIF Program**
- **Conceptual Design Activity**
  - **Design Overview**
  - **Cost and Schedule Overview**
- **Reduced Cost Design**
  - **Design Overview**
  - **Cost and Schedule Overview**
- **Current Program Status**
- **Technology & Achievements Overview**
  - **Test Facilities**
  - **Target System**
  - **Accelerator System**
- **Overview of LEDA Facility at Los Alamos**
- **Summary**

Why a Dedicated Fusion Neutron Source?

- **There is presently no neutron source that combines:**
  - **fusion similar spectrum**
  - **high fluence for accelerated testing**
  - **sufficiently large test volume**

- **ITER testing is limited because fluence accumulation is restricted to <5 dpa and the mode of operation is very different from DEMO (e.g. low temperature, strongly pulsed operation)**

  However it is a valuable test bed for integral testing of components like TBM's in the low fluence regime

- **Reliable materials development for DEMO reactors (~80-150 dpa) cannot be done in fission reactors, spallation sources, or next-step fusion devices**

History (and Future?) of IFMIF

International Fusion Materials Irradiation Facility

1975-1985	**FMIT**
1985-1993	**International Studies of Various Neutron Source Options**
1988	**ESNIT - Japan**
1989	**IEA Workshop - San Diego Sets Requirements**
1992	**International Decision for Accelerator Based D-Li Neutron Source (Karlsruhe)**
1993	**Moscow Workshop on High Flux Source Options Confirms D-Li decision**
1994-1996	**IFMIF Conceptual Design Activity under IEA** US Funding for IFMFI CDA ~$5 Million (ORNL, LANL, ANL, Grumman Team)
	US Funding After IFMFI CDA ~0.5-1.0 FTE/yr
1997-1998	**IFMIF Conceptual Design Evaluation**
1999	**IFMIF Reduced Cost Design** (Japanese Led Effort)
2000-2002	**IFMIF Key Element Technology Phase (KEP)**
2003	**IFMIF Transition Phase**
2004-2008	**IFMIF EVEDA** (Planning based on $72M over 5 years)

Intense Fusion Neutron Source

Mission:
- Qualification of candidate materials up to about full lifetime of anticipated use in a fusion DEMO reactor
- Calibration and validation of data generated from fission reactors and particle accelerators
- Identify possible new phenomena which might occur due to the high energy neutron exposure

Requirements *(IEA workshop in San Diego 1989)*:

- **Neutron flux/volume relation**: Equivalent to 2 MW/m^2 in 10 l volume *
- **Neutron spectrum**: Should meet FW spectrum as near as possible
  Criteria include PKA spectrum, H, He, He/dpa
- **Neutron fluence accumulation**: DEMO fluence ~150 dpa in few years
- **Neutron flux gradient:** ≤10%/cm *
- **Machine availability:** 70%
- **Time structure:** Quasi continuous operation
- **Good accessibility of irradiation volume**

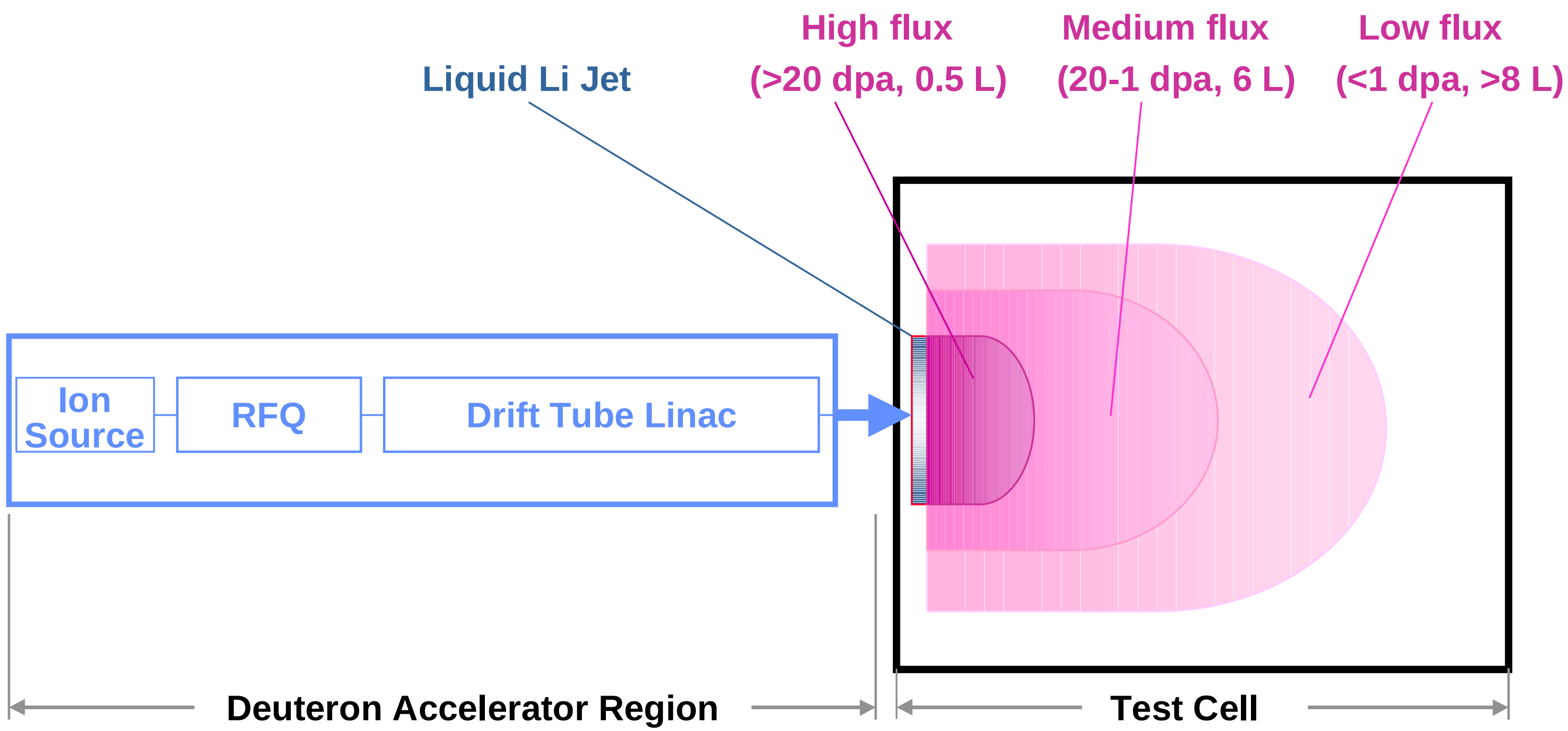
* **requires use of qualified miniaturized specimens**

Anatomy of IFMIF

International Fusion Materials Irradiation Facility

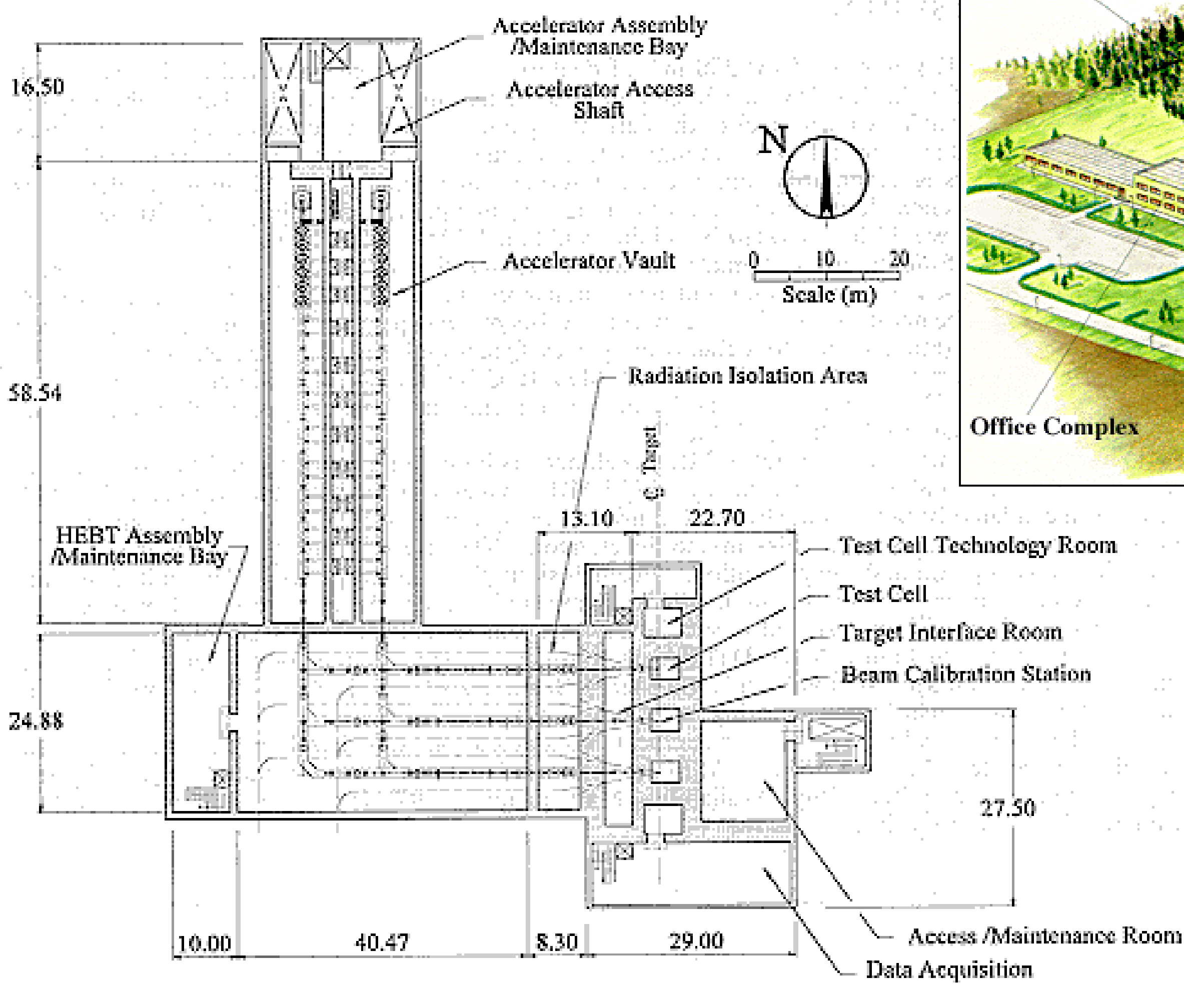
Typical Reactions: $^{7}Li(d,2n)^{7}Be$ $^{6}Li(d,n)^{7}Be$ $^{6}Li(n,T)^{4}He$

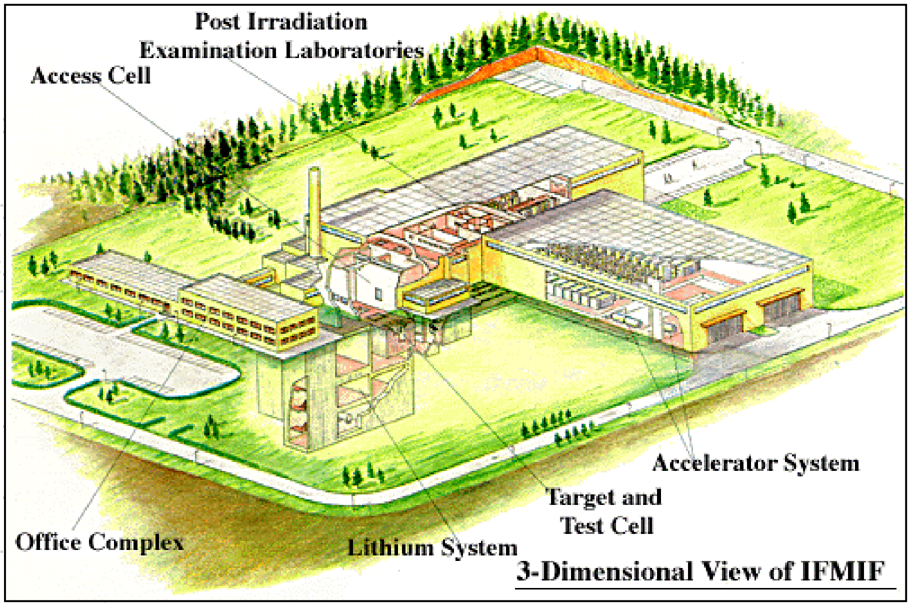
Deuterons: 32, 36, <u>40 MeV</u> 2x 125 mA Beam footprint 5x20 cm^{2}



IFMIF - CDA Design

International Fusion Materials Irradiation Facility



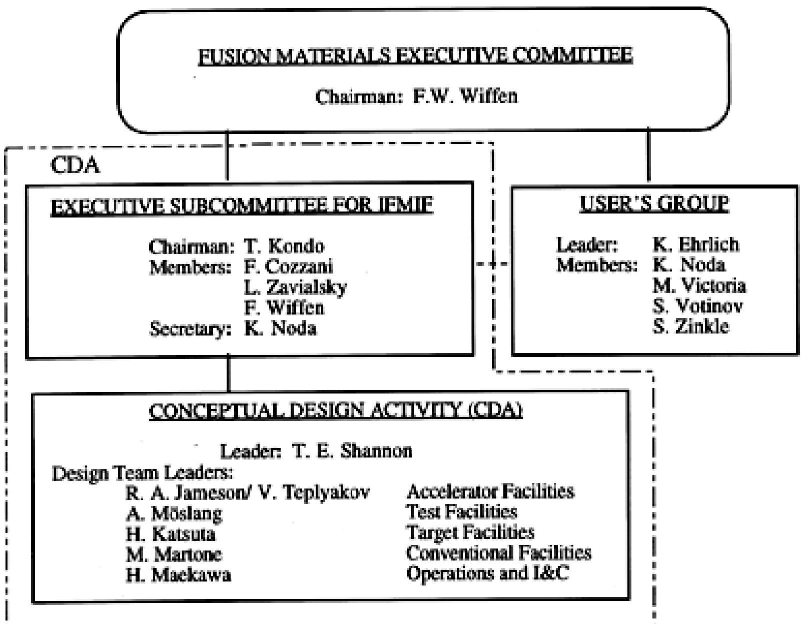


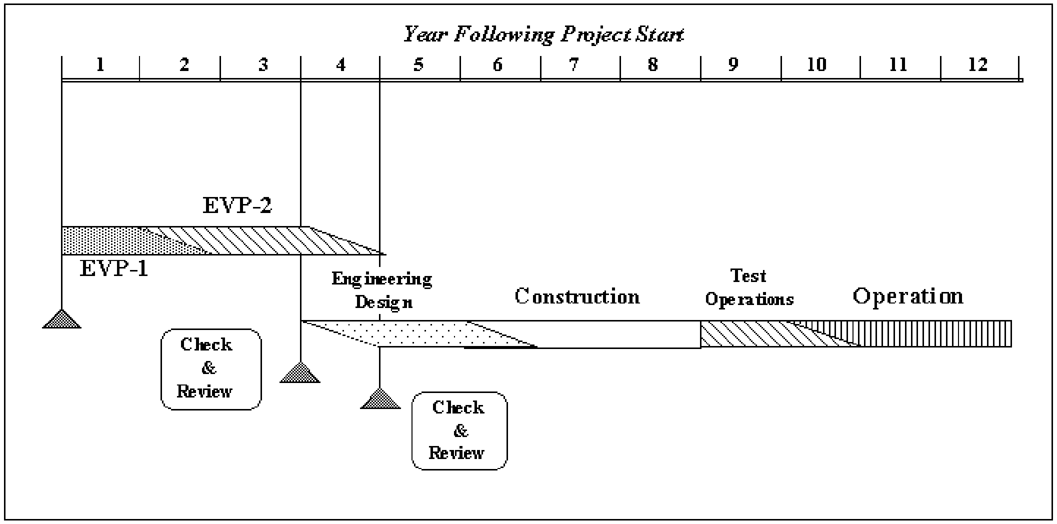
- **Two 175 MHz Accelerators (250 mA) Expandable to Four Accelerators (500 mA)**
- **Selectable Output Energy 32, 36, and 40 MeV**
- **2 Targets & Test Cells**
- **Fixed Beam Calibration Beam Stop**

CDA Organization, Cost and Schedule

International Fusion Materials Irradiation Facility

IFMIF CDA Cost (1996 estimate)				
WBS	Subsystem	Estimated Cost (MICF)	AFI (MICF)	Total Estimated Cost (MICF)
1.0	Project Management	52.0	0.0	52.0
2.0	Test Facility	89.1	17.5	106.6
3.0	Target Facility	92.8	22.4	115.2
4.0	Accelerator Facility	339.0	70.0	409.0
5.0	Conventional Facilities	75.7	14.7	90.4
6.0	Central Control	21.9	2.1	24.0
	TOTALS	**670.5**	**126.7**	**797.2**
			18.9%	



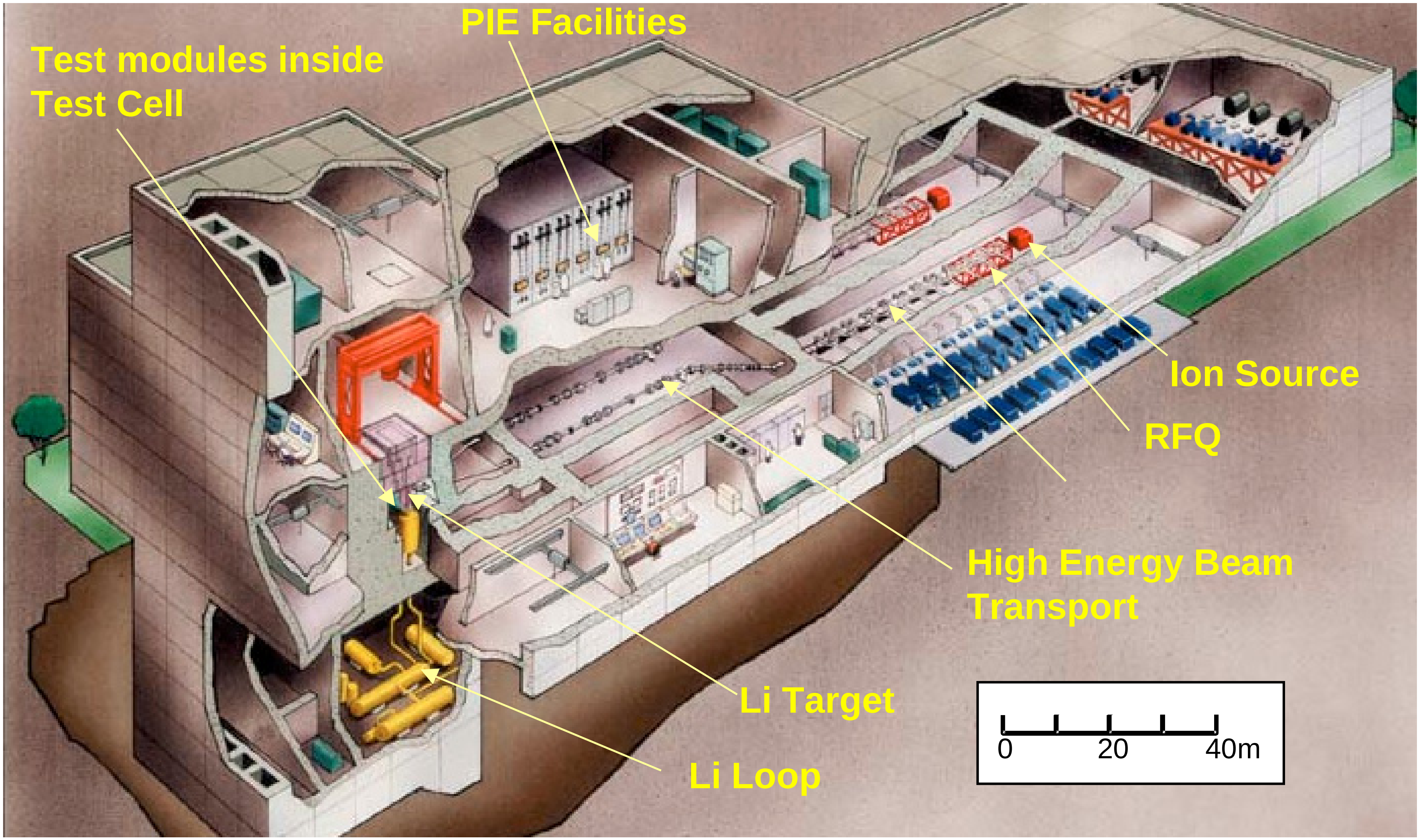


IFMIF Reduced Cost Design

- **28th FPCC meeting - January 1999 requested a review of IFMIF for potential cost reductions**
- **Due to reduced effort in US and Europe, Japanese colleagues took the lead in this effort**
  - **Japan took lead role in Design Integration**
- **Result:**
  - **Design with reduced capability/expandability**
    - **Single target/test cell**
    - **No fixed beam calibration station**
    - **No upgrade path to 500 mA**
  - **Staged approach to construction**
    - **Phase 1 - One accelerator operating at 50 mA on target**
    - **Phase 2 - One accelerator operating at 125 mA on target**
    - **Phase 3 - Two accelerators operating at 250 mA on target**

IFMIF Reduced Cost Design

International Fusion Materials Irradiation Facility



Reduced Cost IFMIF

International Fusion Materials Irradiation Facility

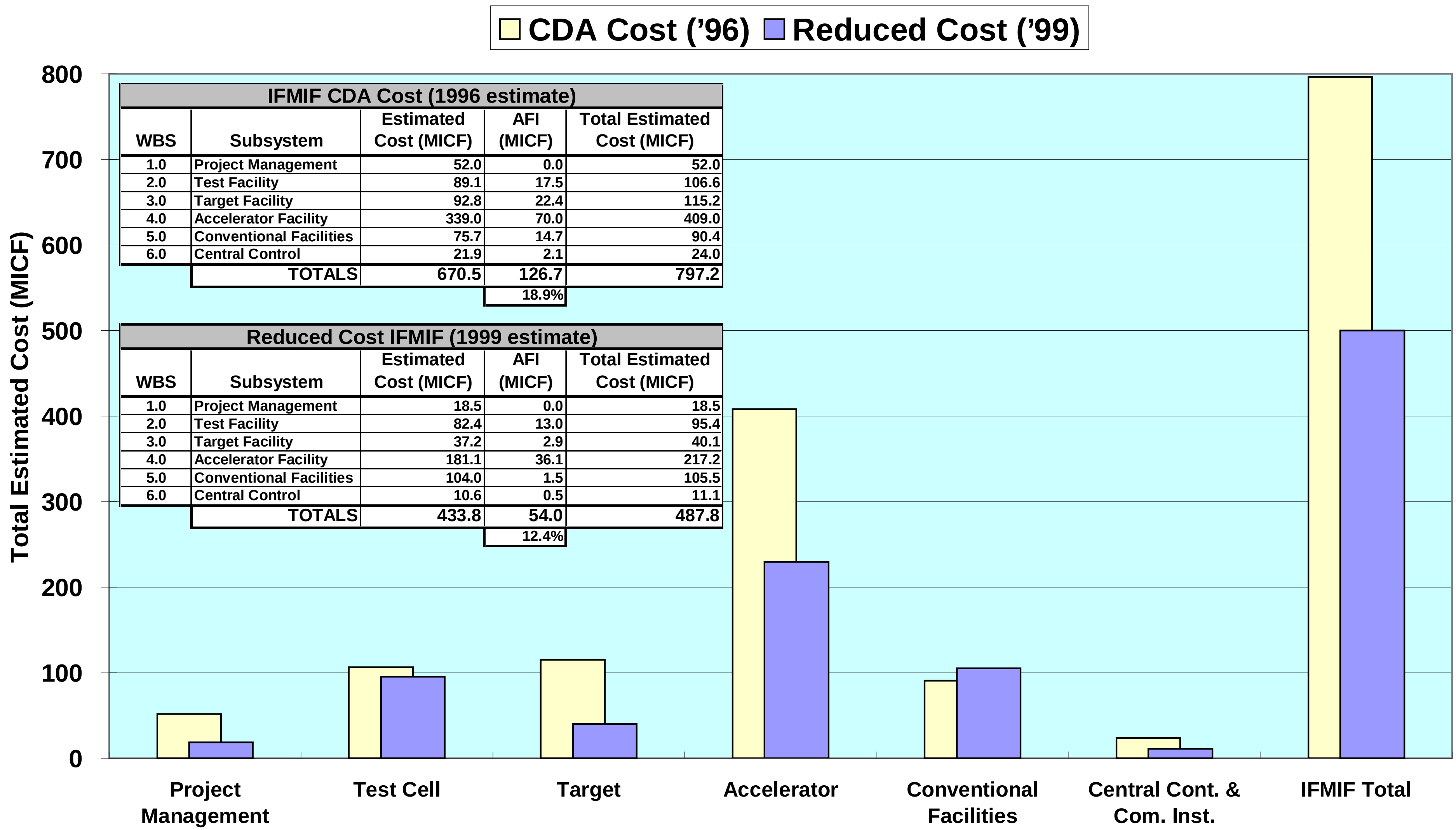
Reduced Cost IFMIF (1999 estimate)				
WBS	Subsystem	Estimated Cost (MICF)	AFI (MICF)	Total Estimated Cost (MICF)
1.0	Project Management	18.5	0.0	18.5
2.0	Test Facility	82.4	13.0	95.4
3.0	Target Facility	37.2	2.9	40.1
4.0	Accelerator Facility	181.1	36.1	217.2
5.0	Conventional Facilities	104.0	1.5	105.5
6.0	Central Control	10.6	0.5	11.1
	TOTALS	433.8	54.0	487.8
			12.4%	

Estimate in 1996$

- **Estimate prepared in Japan and presented to US, EU, and RF at Design Integration Meeting, Lausanne, 1999.**
- **Estimate reflects assumptions for project implementation in Japan**
- **International group has not yet officially revised CDA estimates**
- **Goal for 2003 - Rationalize the Cost Estimate & Design Baseline**

IFMIF Cost Comparison

International Fusion Materials Irradiation Facility



IFMIF CDA Cost (1996 estimate)

WBS	Subsystem	Estimated Cost (MICF)	AFI (MICF)	Total Estimated Cost (MICF)
1.0	Project Management	52.0	0.0	52.0
2.0	Test Facility	89.1	17.5	106.6
3.0	Target Facility	92.8	22.4	115.2
4.0	Accelerator Facility	339.0	70.0	409.0
5.0	Conventional Facilities	75.7	14.7	90.4
6.0	Central Control	21.9	2.1	24.0
	TOTALS	670.5	126.7	797.2
			18.9%	

Reduced Cost IFMIF (1999 estimate)

WBS	Subsystem	Estimated Cost (MICF)	AFI (MICF)	Total Estimated Cost (MICF)
1.0	Project Management	18.5	0.0	18.5
2.0	Test Facility	82.4	13.0	95.4
3.0	Target Facility	37.2	2.9	40.1
4.0	Accelerator Facility	181.1	36.1	217.2
5.0	Conventional Facilities	104.0	1.5	105.5
6.0	Central Control	10.6	0.5	11.1
	TOTALS	433.8	54.0	487.8
			12.4%	

IFMIF Operating Costs

International Fusion Materials Irradiation Facility

- Detailed estimate prepared for CDA (2 accelerator option) - No update for the Reduced Cost IFMIF
- RC IFMIF may be somewhat less due to reduced equipment requiring maintenance - Power usage the same
- Electric Power cost drives number - Assumes 43.4 MW Full Load. Rates: .066 ICF/kWh min., .131 ICF/kWh max.
- Staff - 183 Total, 60 day shift, 41 shifts 2, 3 & 4

IFMIF CDA Operating Cost Estimate 1996 (MICF/yr)					
Category	Estimate	AFI	Total	Maximum	Minimum
Personnel	23.0	2.3	25.3	25.3	25.3
Electric Power	31.6		31.6	42.1	20.3
Utilities	0.7	0.2	0.9	0.9	0.9
Maintenance	8.0		8.0	8.0	8.0
Waste Disposal	0.5	0.1	0.6	0.6	0.6
Miscellaneous	1.0		1.0	1.0	1.0
		TOTALS	67.4	77.9	56.1

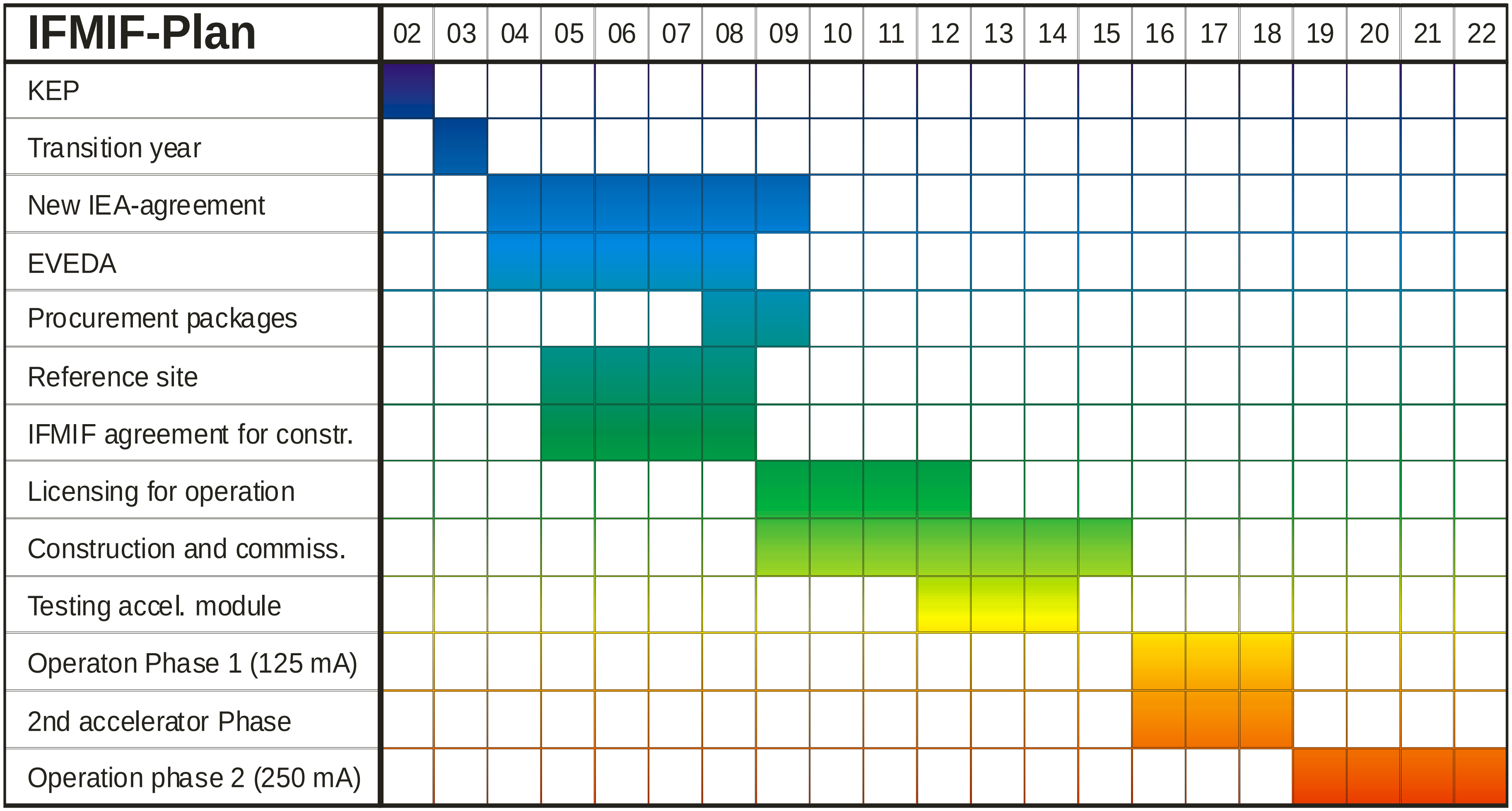
Design/Program Status

- **Major elements of the Reduced Cost Design have been adopted**
  - **Limited to 2 accelerators, single target, no beam calibration station**
  - **Simplified beam transport system**
- **Staged approach has been reduced to 2 stages**
  - **Stage 1 - One accelerator operation at 125 mA**
  - **Stage 2 - Two accelerator operation at 250 mA**
- **Agreement on Fast Track Schedule between funded parties (EU and JA)**
  - **2003 - Transition Year - Organize Central Team**
  - **2004-2008 - Engineering Validation and Engineering Design Activity, Site Selection**
  - **2009 - Construction Start**

IFMIF ‘Fast Track’ Schedule

International Fusion Materials Irradiation Facility

EFDA

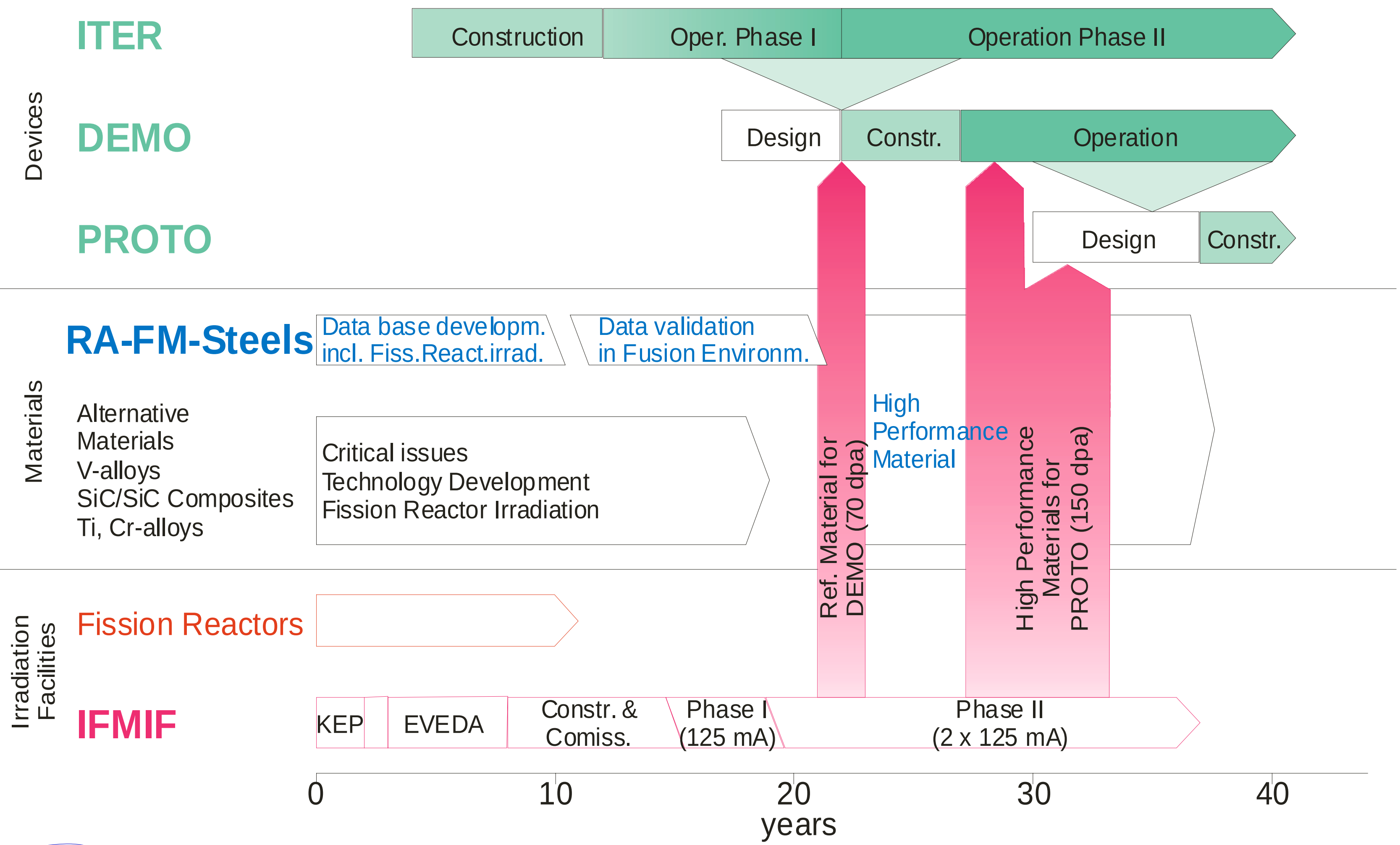


M. Gasparotto, IFMIF Design Integration Meeting, Garching, Germany, Nov., 2002

IFMIF and Fusion Road Map

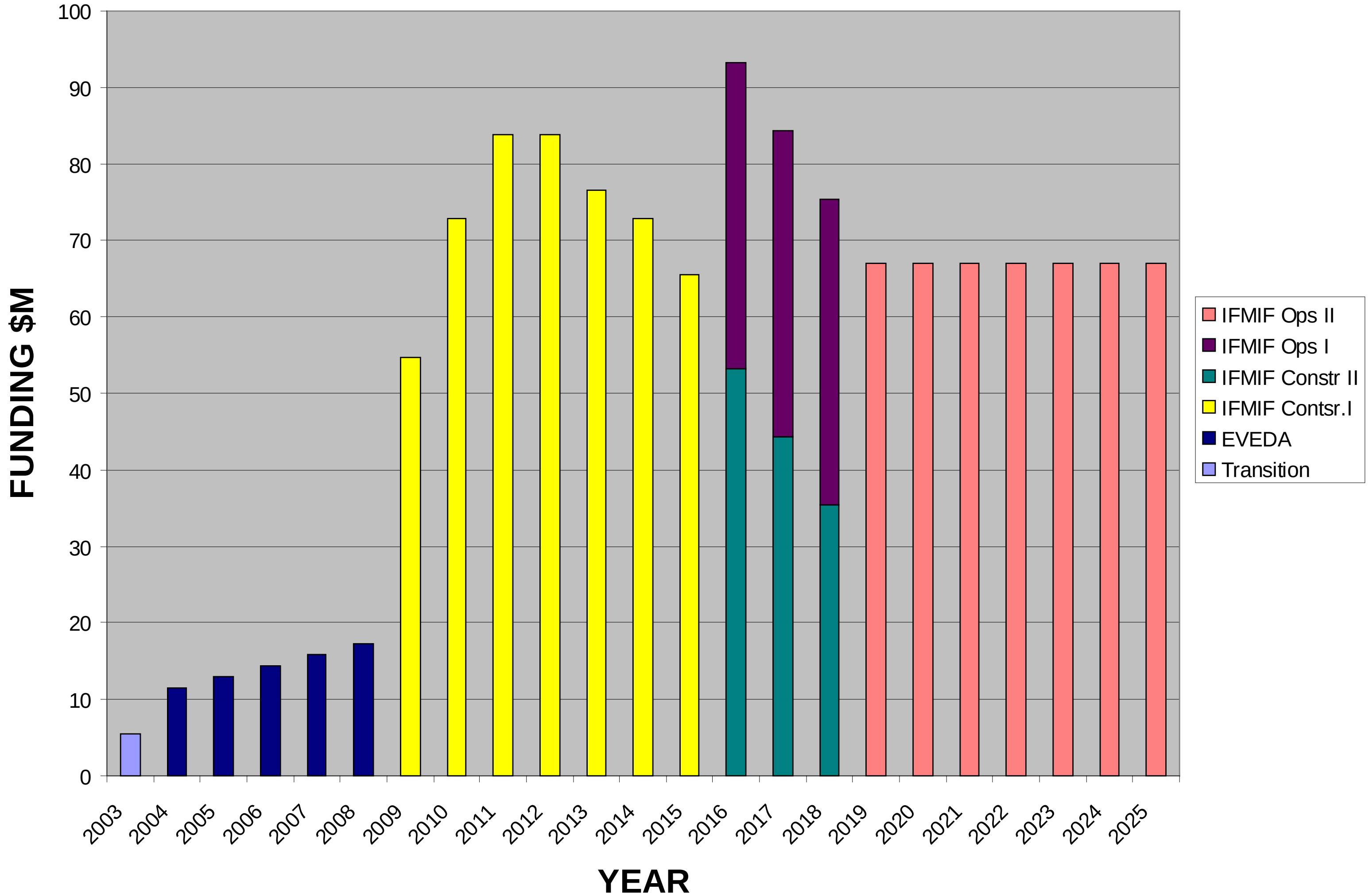
International Fusion Materials Irradiation Facility

EFDA



Funding Profile Total Program

Profile reflects costs as shown previously except Construction & Commissioning is at $643 M - This is a guess at where the 2003 cost rationalization will arrive



Commitment of Parties

- **Europe** (M. Gasparotto, 11/02)
  - Funding for 2003 Transition in-place at 3 MEuro
  - Plan for EVEDA Phase (included in 6th Framework)

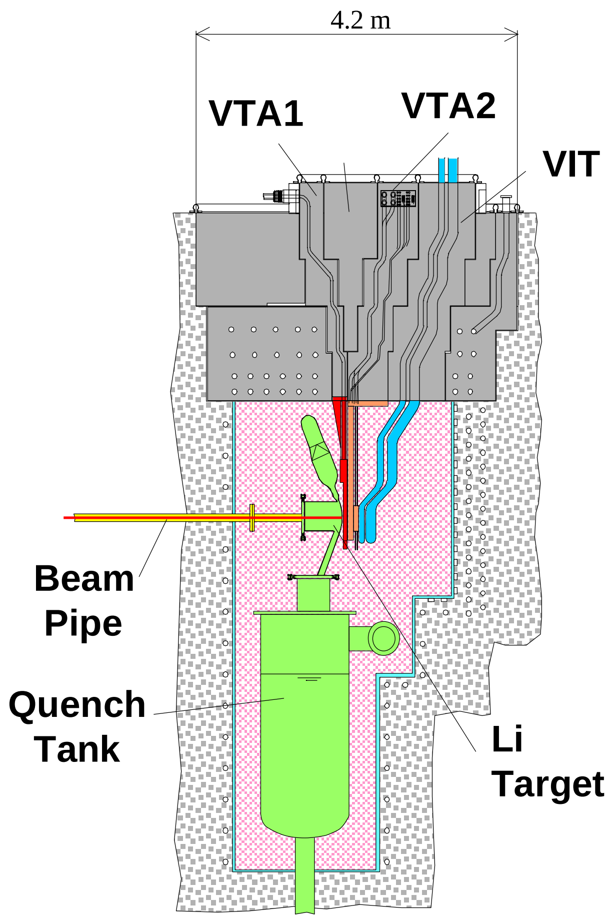
IFMIF - EVEDA - Costs (MEuro)				
Tasks	R&D	Design	Sub-total	EU Contribution
Design Integration	0	5	5	50%
Accelerator	27	5	32	30-35%
Li-Target	17	4	21	10-15%
Test Facilities	9	5	14	80-90%
TOTAL	53	19	72	35-40%

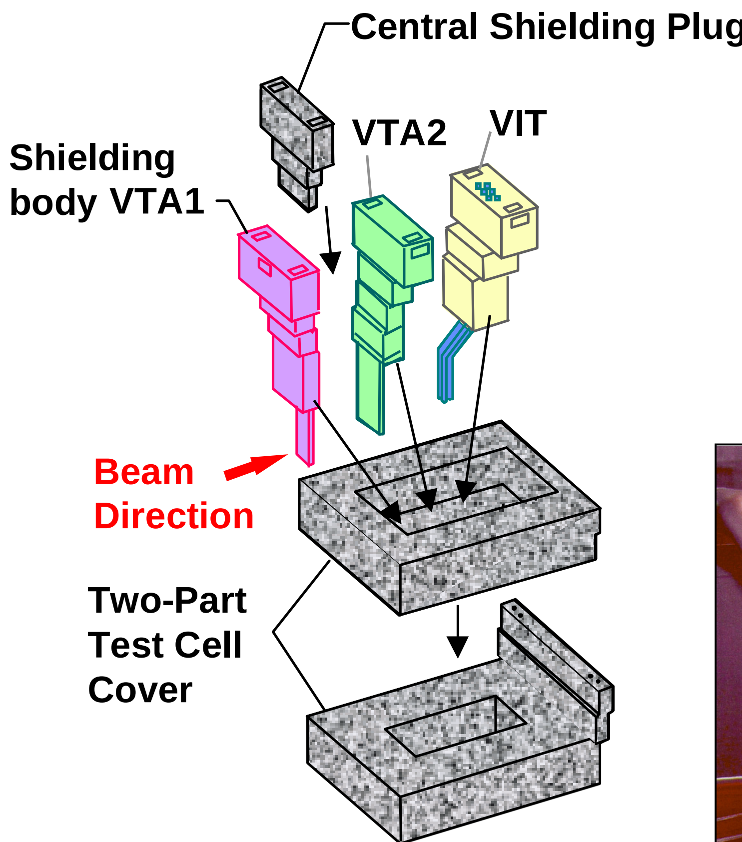
- **Japan** (H. Nakamura, 1/03)
  - Work conducted jointly by JAERI and University/NIFS
  - Funding for 2003 Transition maintains KEP level (~10 FTE)
  - Necessary steps are being followed nationally supposing start of EVEDA Phase
  - IFMIF schedule beyond 2003 will be discussed in upcoming IFMIF meeting (March 2003, Tokyo)

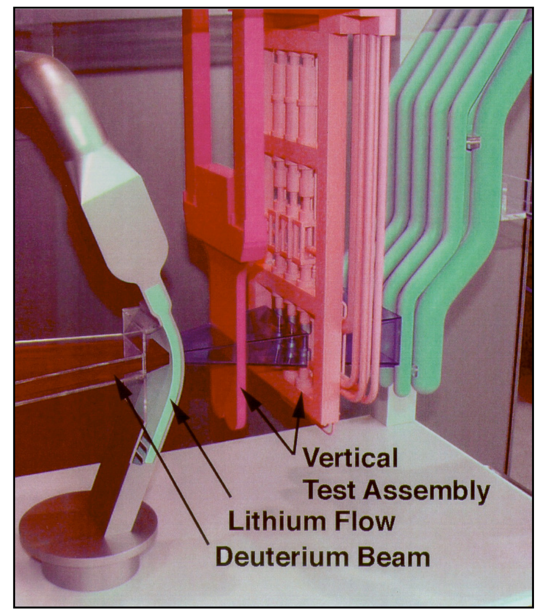
Technology Assessment

Test Cell Design

International Fusion Materials Irradiation Facility







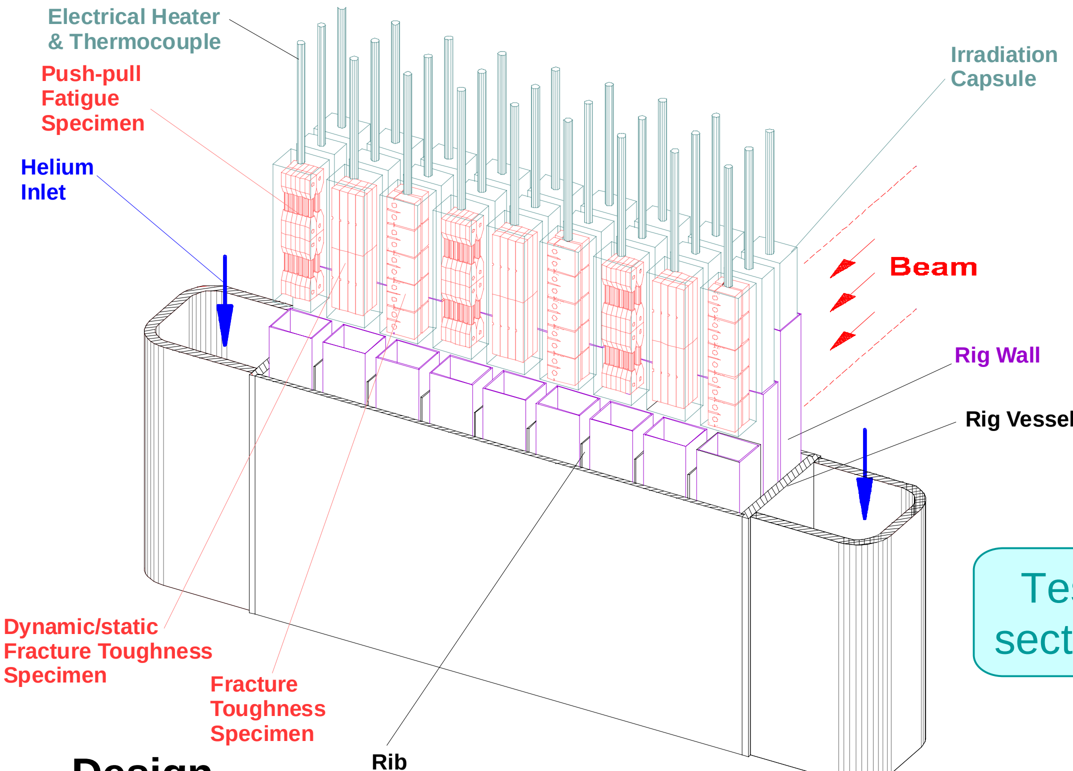
Model of Li target and test modules

Baseline design concept:

- Gas coolant systems for all test modules
- Modular and highly flexible
- Easy user access
- Capacity for upgrades

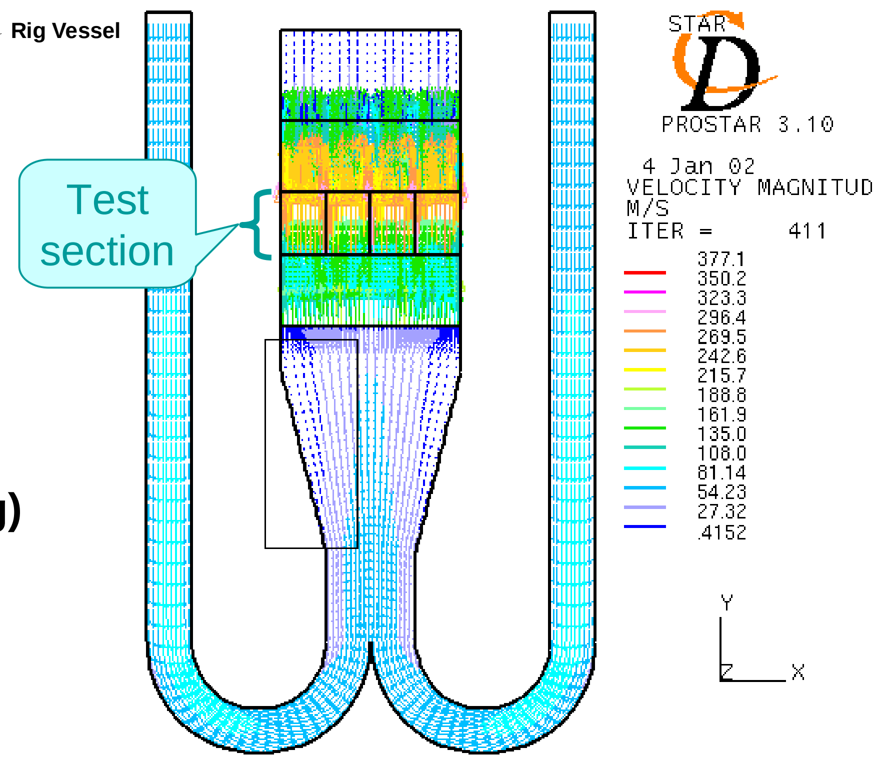
Test Cell Achievements

International Fusion Materials Irradiation Facility



Thermal Hydraulics

- Flat T distribution within entire capsule 356-366 °C
- Sufficiently homogeneous He gas distribution



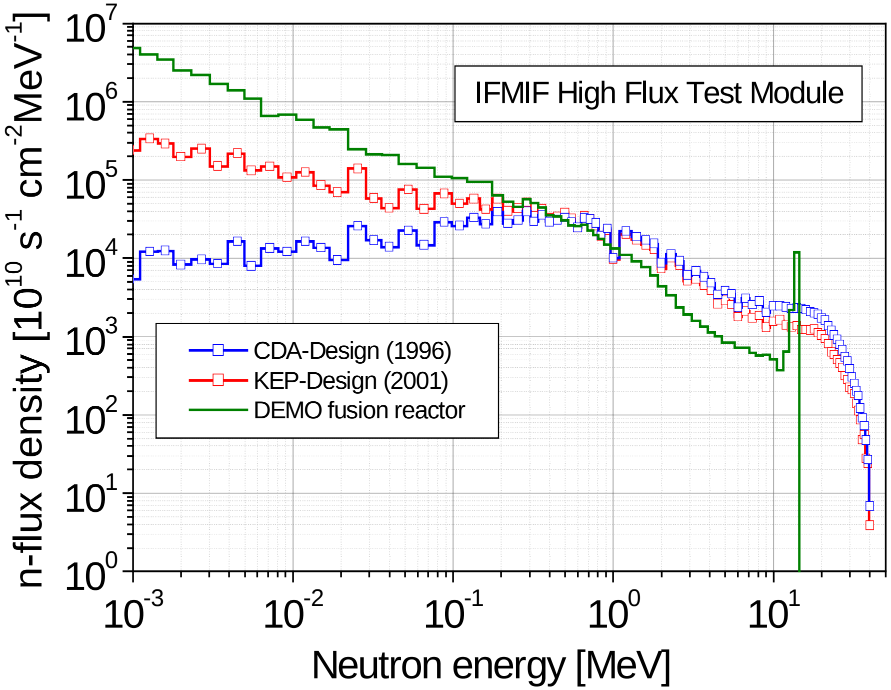
Design

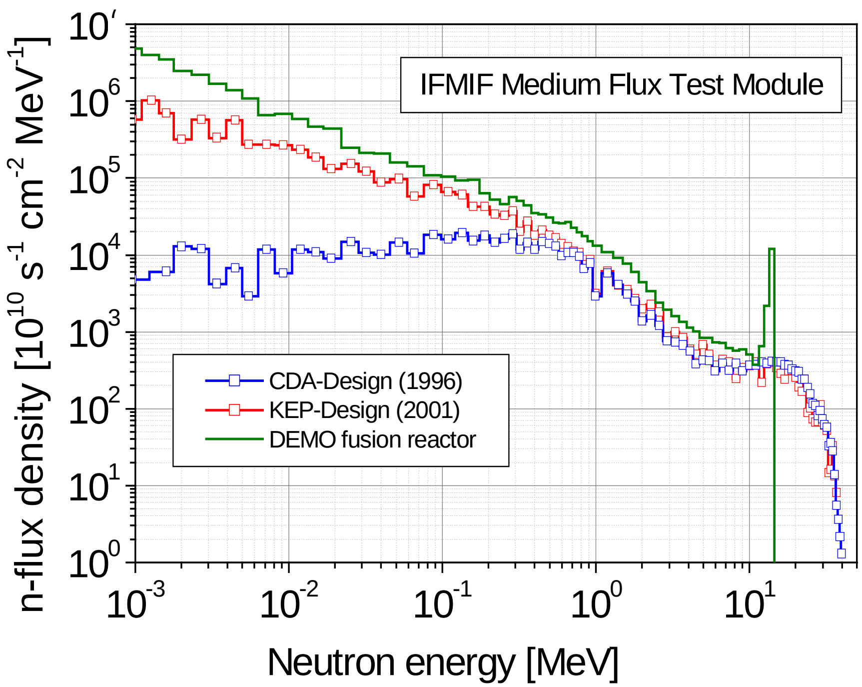
- 27 rigs, He-gas cooled
- Individual rig temperatures (ohmic heating)
- T_{irr}: 300 - 1000 °C
- SSTT:
  - 7 specimen types
  - 400-700 specimens

IFMIF Neutronics - Achievements

International Fusion Materials Irradiation Facility

Improvement of neutron spectra with moderator/reflector





- Moderator/reflector: → Substantial improvements in neutron spectrum adaption
→ Irradiation volume increase by ~20%

IFMIF Neutronics - Achievements

International Fusion Materials Irradiation Facility

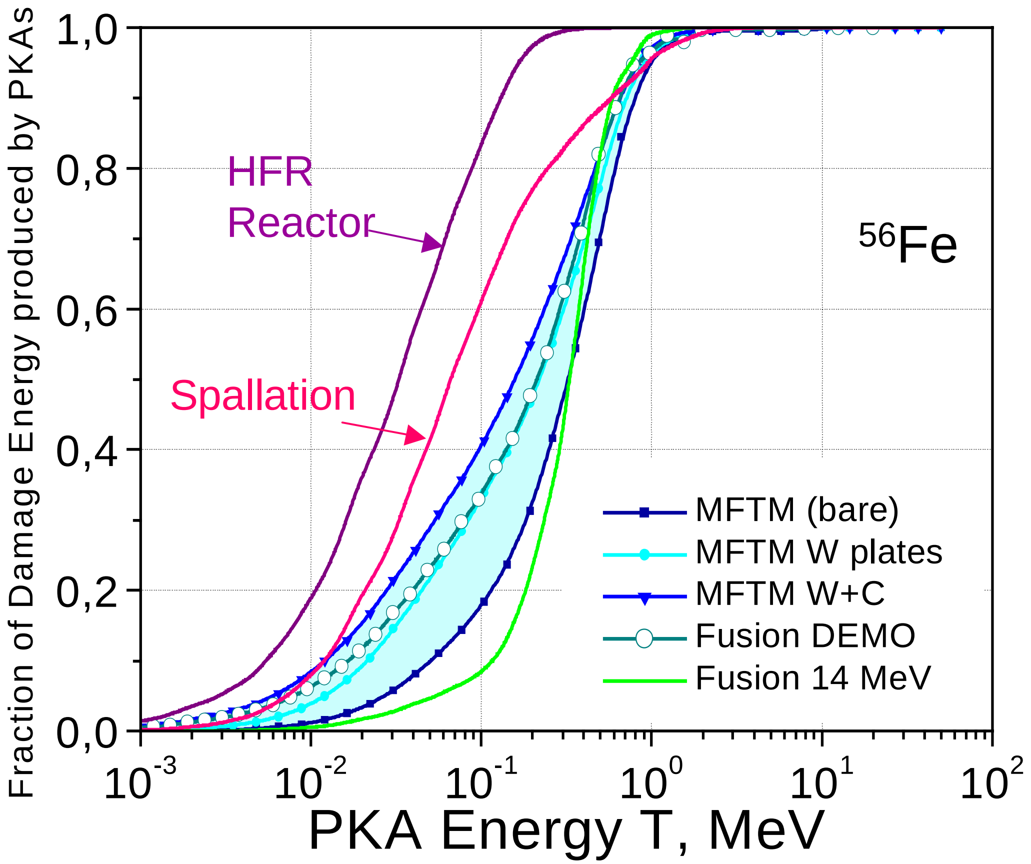
Irradiation Parameter	DEMO	ITER	IFMIF HFTM	IFMIF MFTM
Total n-flux, $(n/(cm^2\ s)$	$1.3 \cdot 10^{15}$	$4 \cdot 10^{14}$	$(4 \div 10) \cdot 10^{14}$	$(2 \div 6) \cdot 10^{14}$
H production, (appm/fpy)	1200	500	1000÷1500	300÷500
He production, (appm/fpy)	300	120	250÷600	70÷120
Displacement damage production, (dpa/fpy)	30	12	20÷55	7÷10
H per dpa, (appm/dpa)	40	45	40÷50	30÷50
He per dpa, (appm/dpa)	10	11	10÷12	8÷14

- Correct scaling of He, H and dpa production
- Accelerated irradiation in limited volume

IFMIF Neutronics - Achievements

International Fusion Materials Irradiation Facility

Sensitivity of neutron spectrum to recoil energy distribution



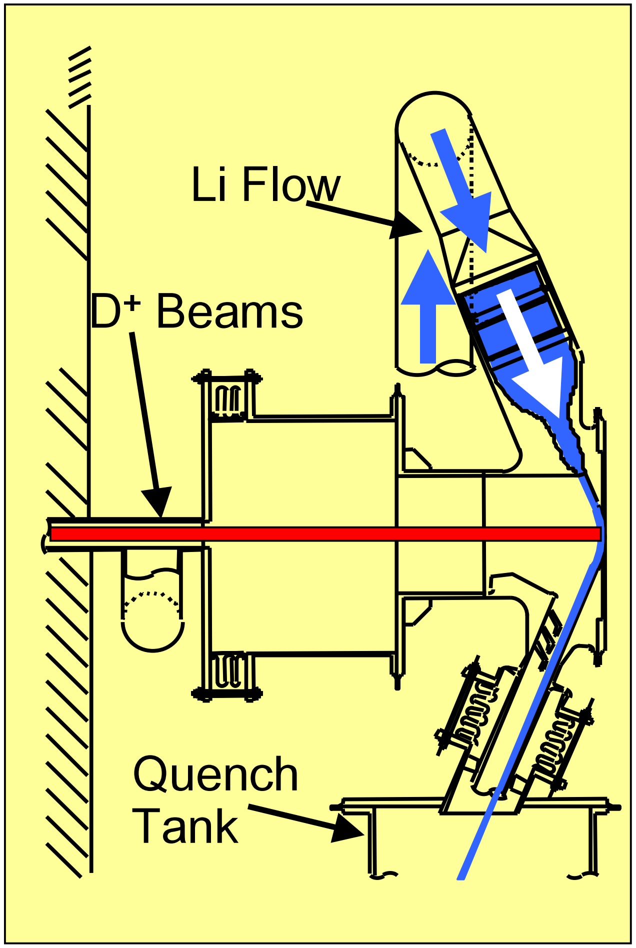
IFMIF (hatched area) meets perfectly the conditions of DEMO-reactor blankets

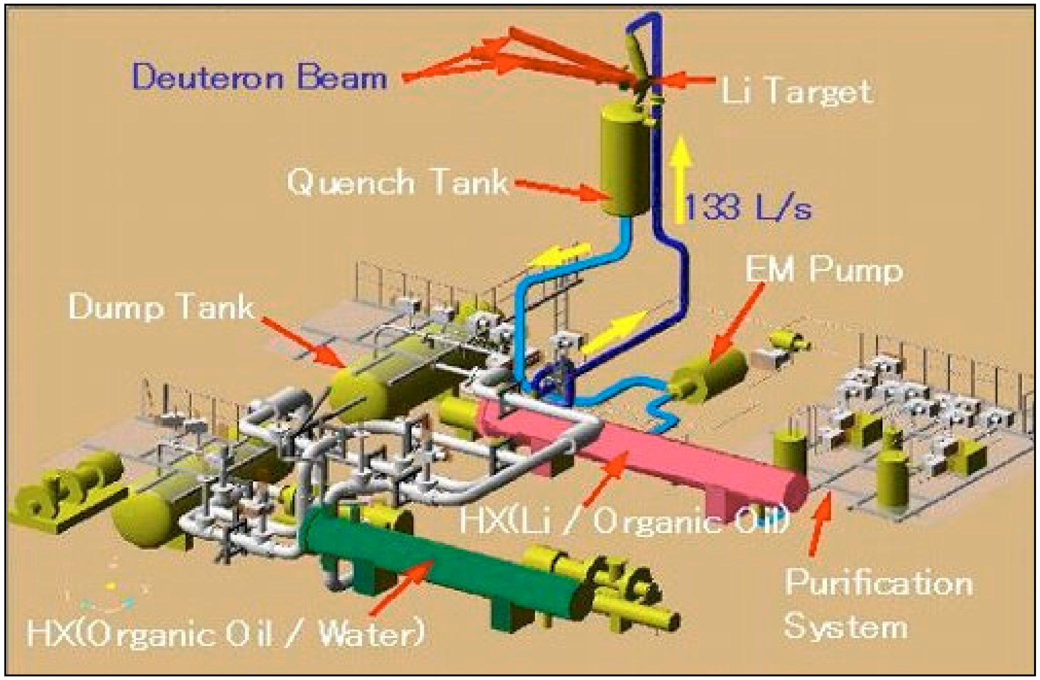
Lithium Target System

International Fusion Materials Irradiation Facility

Function;

- Obtain stable and high speed liquid Li flow under 10MW Deuterium beam.



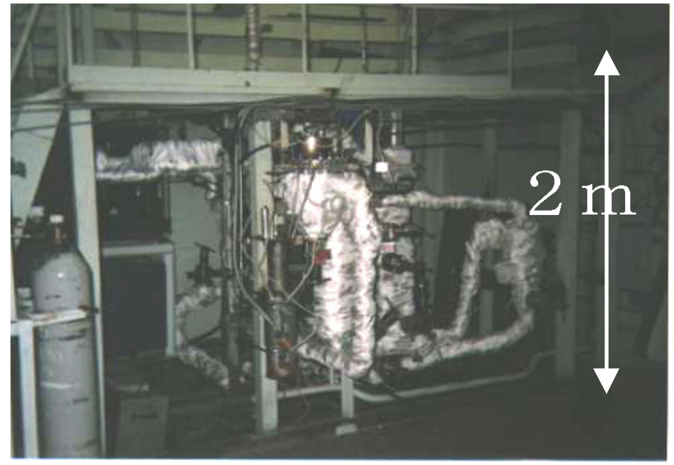


Major Specifications;

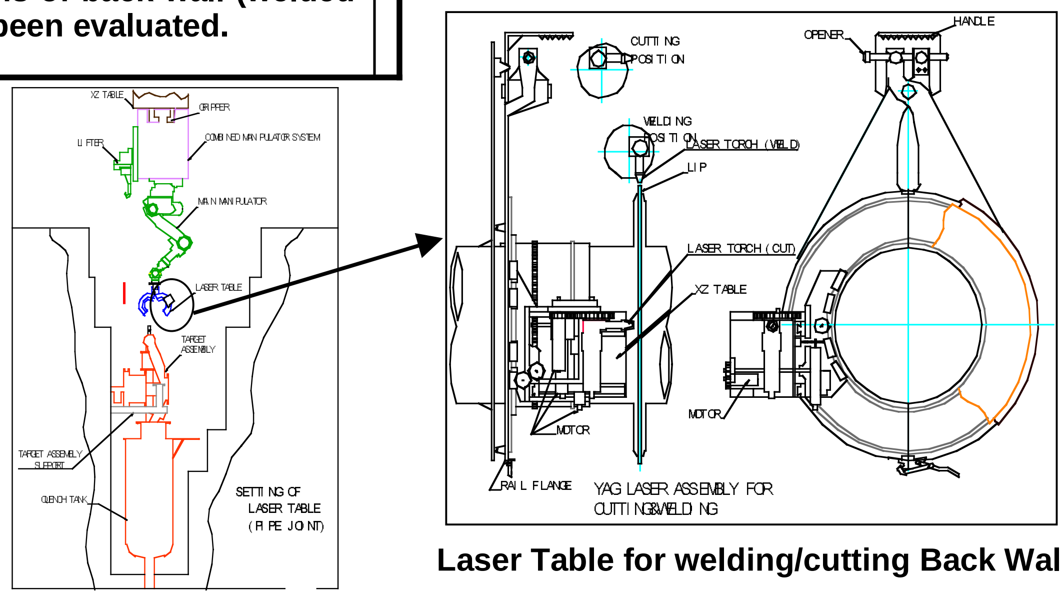
- Heat flux by beam : 1 GW/m^2
- Li flow : 15(range10 - 20) m/s
- Width/Thickness of Li : 26/2.5 cm
- Inlet, Outlet, Peak Li temp. : 250, 300, 450 ℃
- Tritium generation rate : 7g/year
- Impurity contents :10 wppm (C, N, O: each)

Target System Achievements

Task Area	Achievements
Li Jet Flow stability	**Water jet experiment has validated stable high speed flow (20m/s). Set-up for study of effect of “stair” of back plate on stability is prepared. Li loop experiment is started and 14 m/s Li flow is achieved.**
Impurity & corrosion	**Characterization of nitrogen gettering materials has been done. Evaluation of impurity monitors and traps have been done. Corrosion loop is completed.**
Safety analysis	**Transient characteristics of Li loop at beam trip has been clarified. In safety analysis, target safety is fulfilled. System failure probability estimated.**
Remote handling	**Remote handling of two options of back wall (welded type and “bayonet” type) has been evaluated.**



Li Loop in Russia
Impurity control and corrosion testing



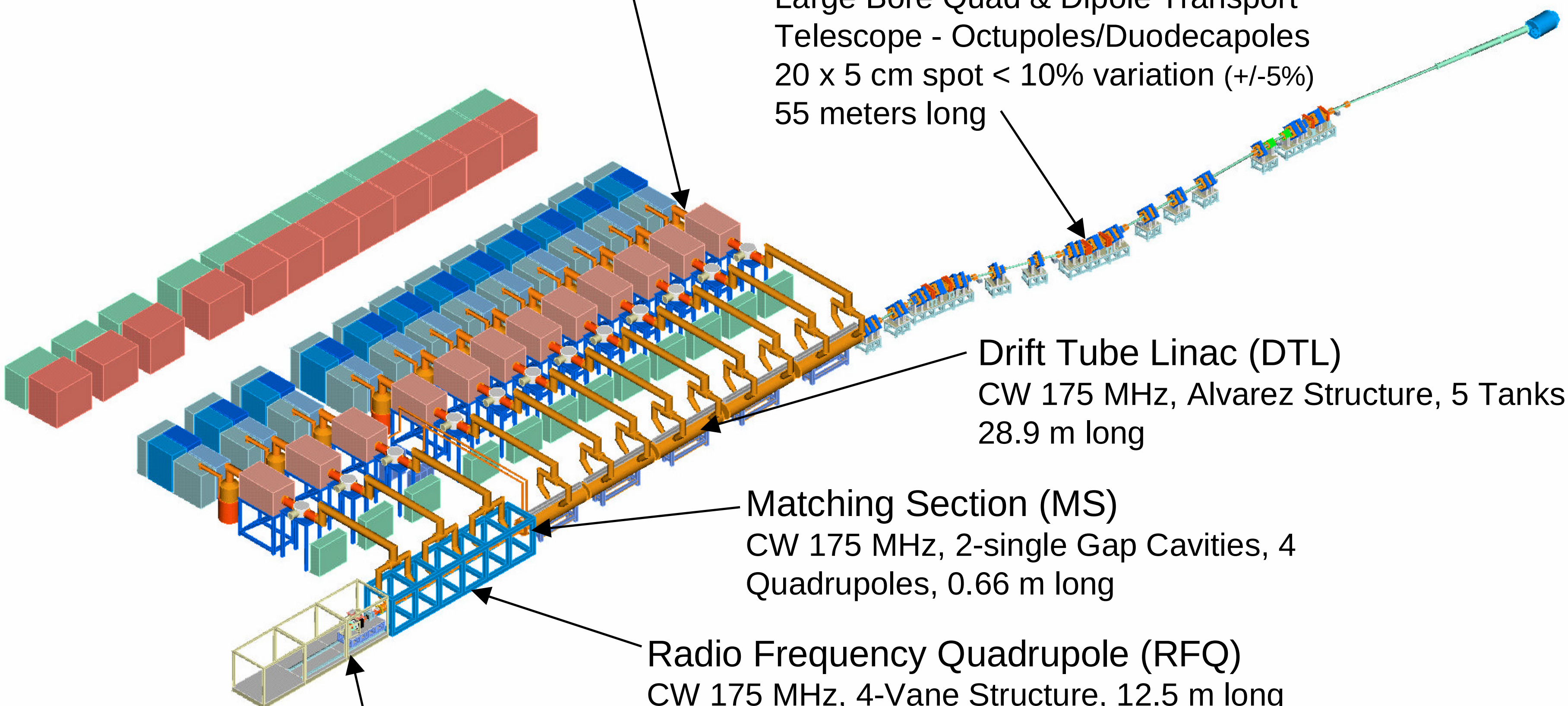
Laser Table for welding/cutting Back Wall

IFMIF Accelerator System - Baseline

International Fusion Materials Irradiation Facility

RF Power System - 12 Required
Thales Diacrode - 1MW CW at 175 MHz

High Energy Beam Transport (HEBT)
Large Bore Quad & Dipole Transport
Telescope - Octupoles/Duodecapoles
20 x 5 cm spot < 10% variation (+/-5%)
55 meters long



Drift Tube Linac (DTL)
CW 175 MHz, Alvarez Structure, 5 Tanks
28.9 m long

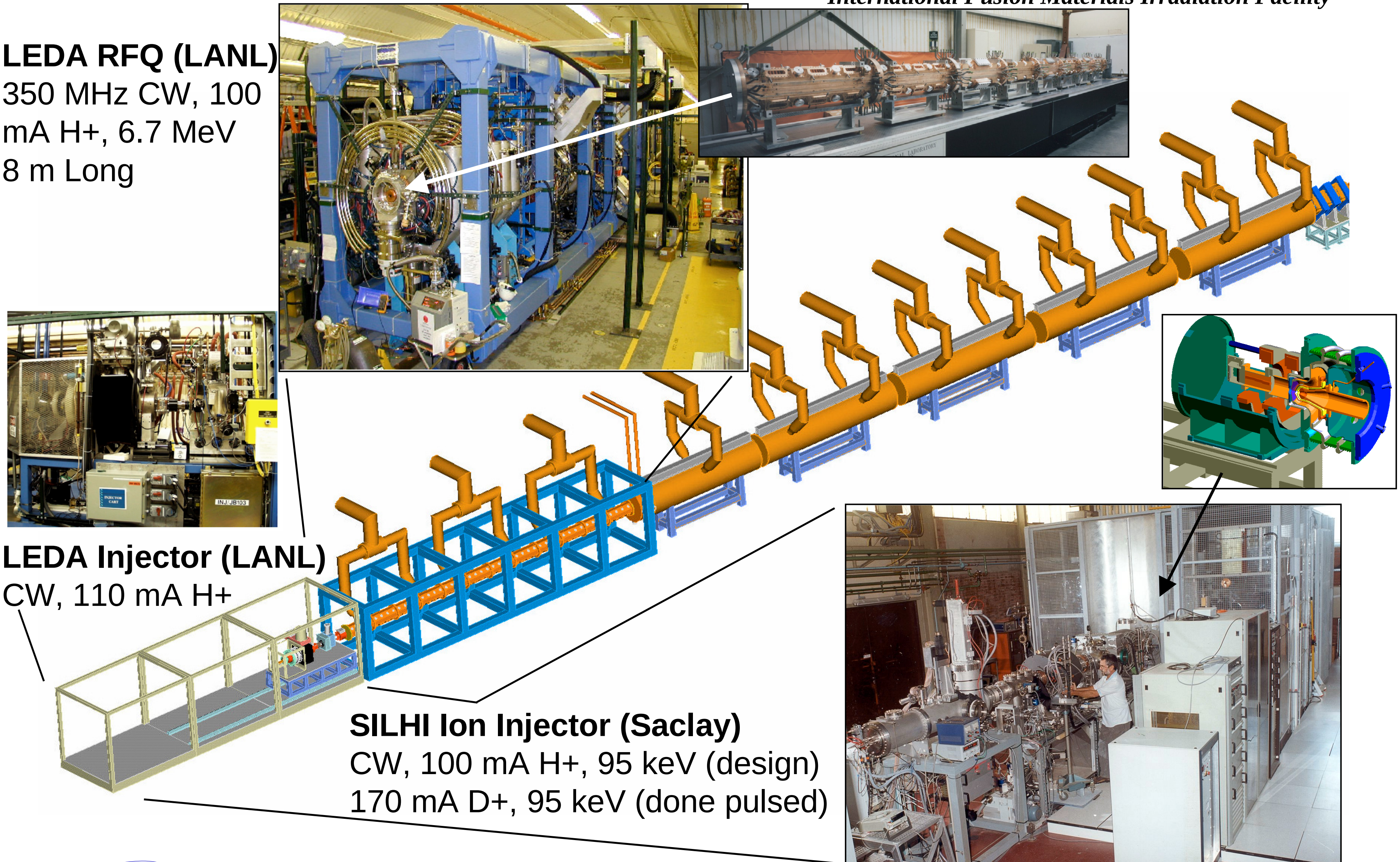
Matching Section (MS)
CW 175 MHz, 2-single Gap Cavities, 4 Quadrupoles, 0.66 m long

Radio Frequency Quadrupole (RFQ)
CW 175 MHz, 4-Vane Structure, 12.5 m long
Brazed copper structure - water cooled

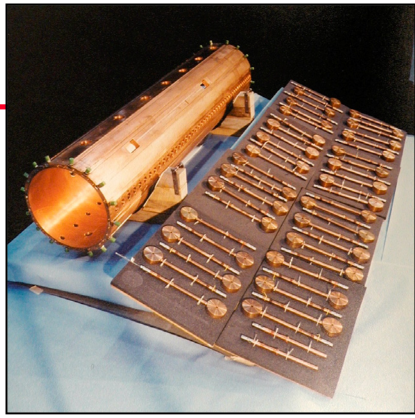
Ion Injector
CW ECR Source, 155 mA D+, 95 keV
Magnetic Low Energy Beam Transport to RFQ

IFMIF Accelerator System - Achievements

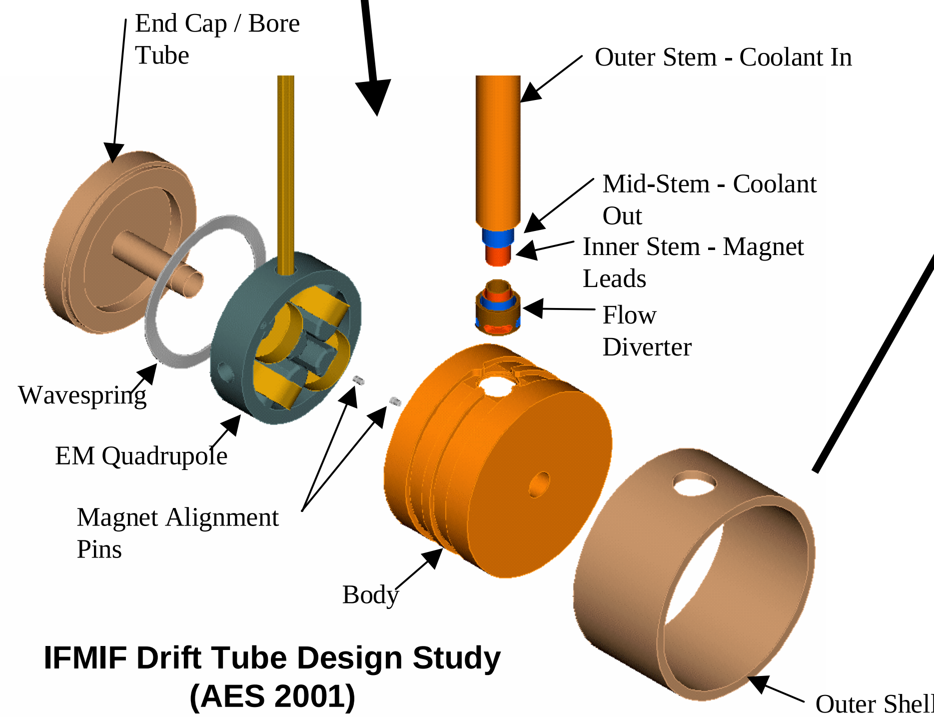
International Fusion Materials Irradiation Facility



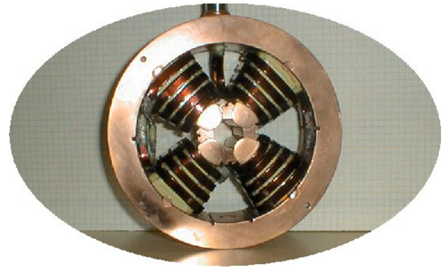
DTL Achievements



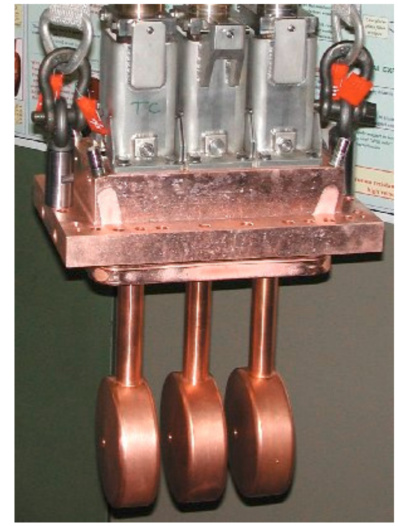
Continuous Wave Deuterium Demonstrator Drift Tube Linac Tank & Drift Tubes (AES 1992)

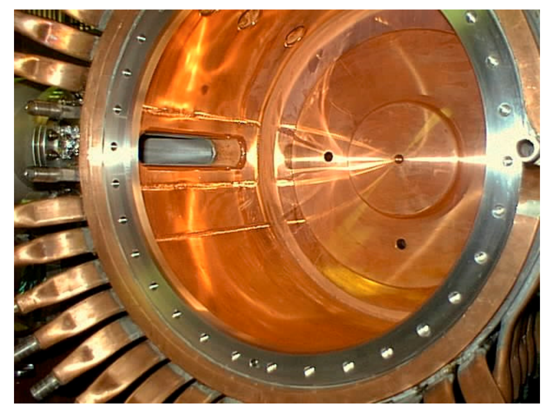


IFMIF Drift Tube Design Study (AES 2001)



IPHI DTL Prototype (Saclay 1997 - Present)

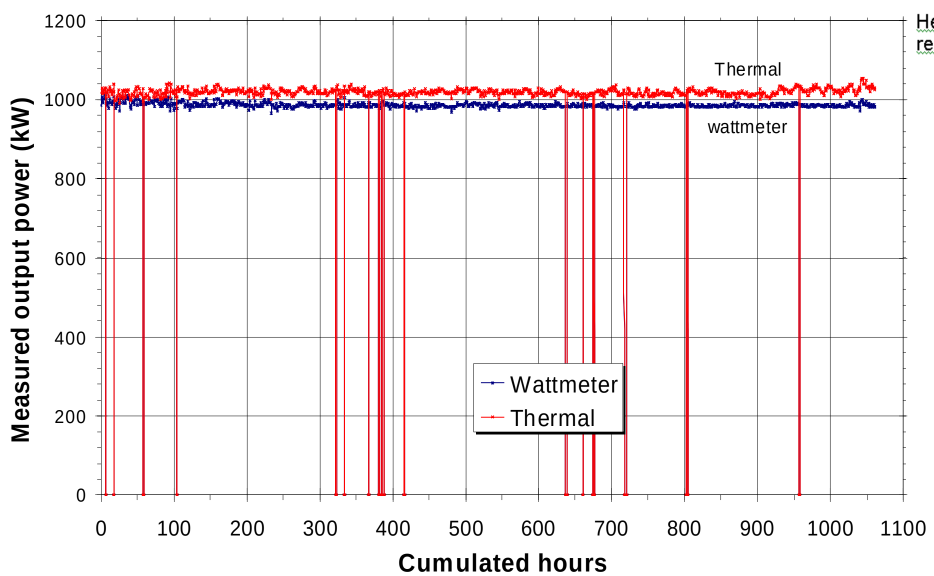


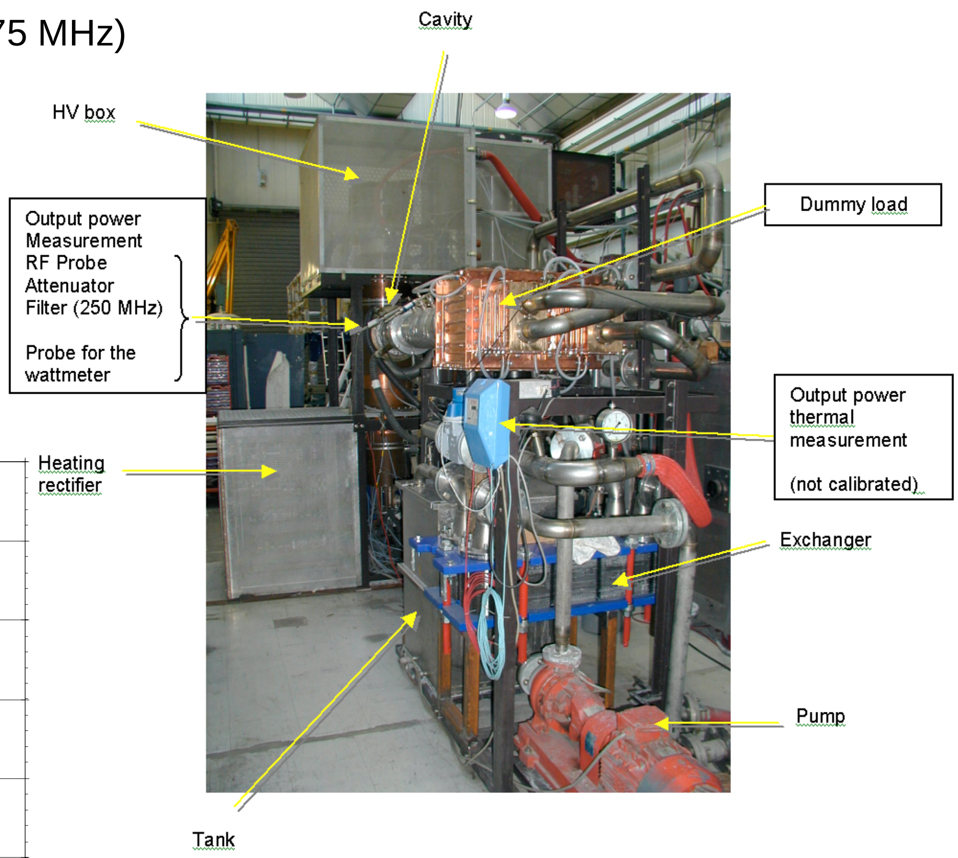


RF Power Achievements

Thales TH628 Diacrode Long Run Test

- **1 MW RF Output at 200 MHz** (more difficult than 175 MHz)
- **1061.7 hours test, 1047.5 RF hours**
- **Longest period : 220.25 h**
- **98.66% On, 1.3% Off**
- **MTBF: 52 h, MTTR: 47 min.**





Test Set-up

IFMIF Accelerator Technology

International Fusion Materials Irradiation Facility

- **Ion Injector - 140 mA, D+, CW beam matched to RFQ at ~100 keV**
  - Comprises ECR ion source, extraction grids, low energy beam transport
  - US, EU, and JA have test stands (LEDA in US is basis for Saclay design)
    - Saclay has demonstrated ~98% availability at high current for long runs
    - Saclay has demonstrated D+ extraction at IFMIF current levels (pulsed for radiation)
- **Radio Frequency Quadrupole (RFQ) - 125 mA CW beam at 5 MeV**
  - ~12.5 meter structure, 1.6 MW RF Power (3 Supplies), transmission 98.3%
  - LEDA RFQ (350 MHz CW, 6.7 MeV, 100 mA, H^+) has operated for 100's of hours and demonstrated virtually all engineering parameters; benchmark for physics
  - Saclay currently fabricating 5 MeV, CW proton RFQ
- **Matching Section - 2 single gap cavities plus 4 quadrupole magnets**
  - Matches beam from RFQ to DTL, minimizes losses. No technology issues
- **Drift Tube Linac (DTL) - 125 mA CW to 40 MeV**
  - ~29 meters in 5 separate tanks. Requires 9 RF power supplies
  - Design basis from CW, 80 mA D^- DTL designed for the SDI program (Grumman-AES)
  - Prototype CW, H^+ DTL Fabricated and undergoing test by Saclay
- **RF Power - 1 MW output at 175 MHz - 9 systems required**
  - Thales TH628 Diacrode long run test successful

Low Energy Demonstration Accelerator at Los Alamos

The LEDA facility at Los Alamos is the premiere CW ion accelerator facility in the world. With a CW, 100 mA H+ injector and 6.7 MeV RFQ Accelerator it is one of the most powerful linacs in the world. A great deal of the design basis for the IFMIF ties directly to work at LEDA.

Unique Features and Capabilities

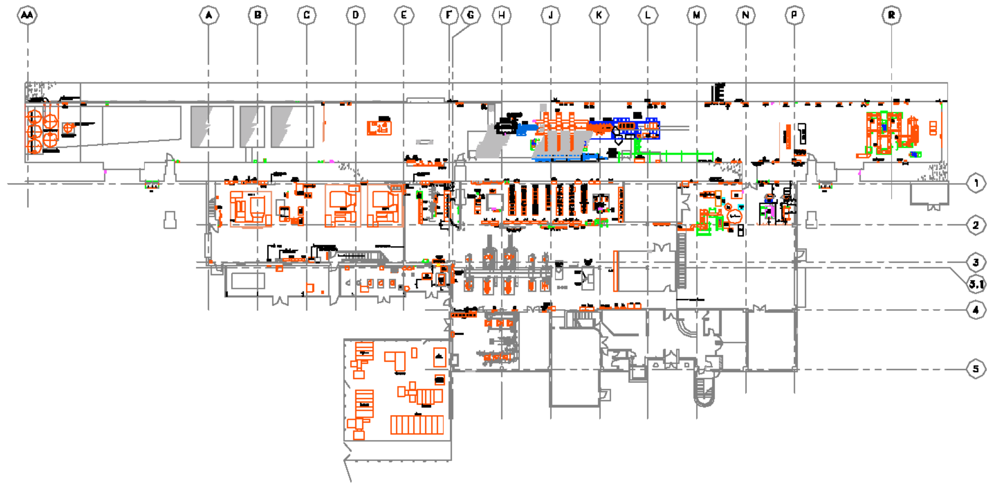
- A 100-mA capable proton accelerator (at 6.7-MeV,cw)
- Well-shielded 150-m long beam tunnel, with personnel access control
- Six 1-MW RF power generators
- 13 MVA of input ac power (easily expandable to 25 MW – capable of supporting a 100 MeV proton beam at 100 mA)
- 15--20 MW of cooling capability
- 12 separate cooling systems (including 50°F chilled water)
- High-power experimental and test areas
- Equipped control room, instrumentation area, power supplies
- Integral machine shop, storage areas, cranes, high-bay, small labs, >30 office spaces, meeting rooms, & computer vault.
- $170M has been invested in the LEDA facility

Current Status - Cold Storage

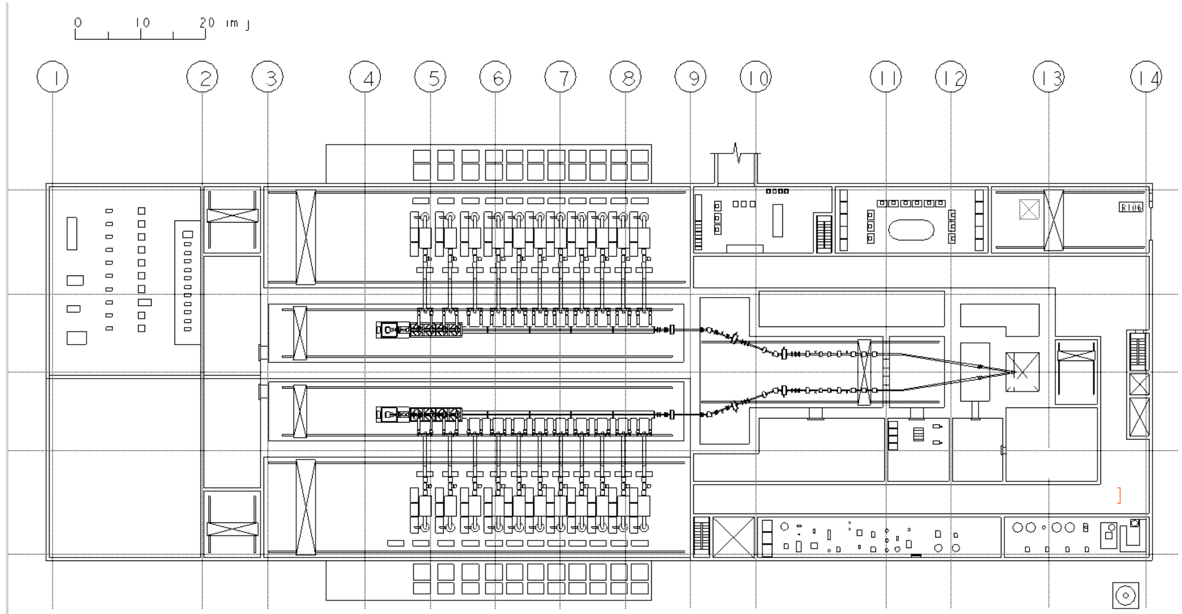
- Scheduled & Funded for Dismantling starting in 2003

LEDA and IFMIF

International Fusion Materials Irradiation Facility



LEDA



IFMIF

LEDA Facility

International Fusion Materials Irradiation Facility

Water Systems

RF Power Gallery

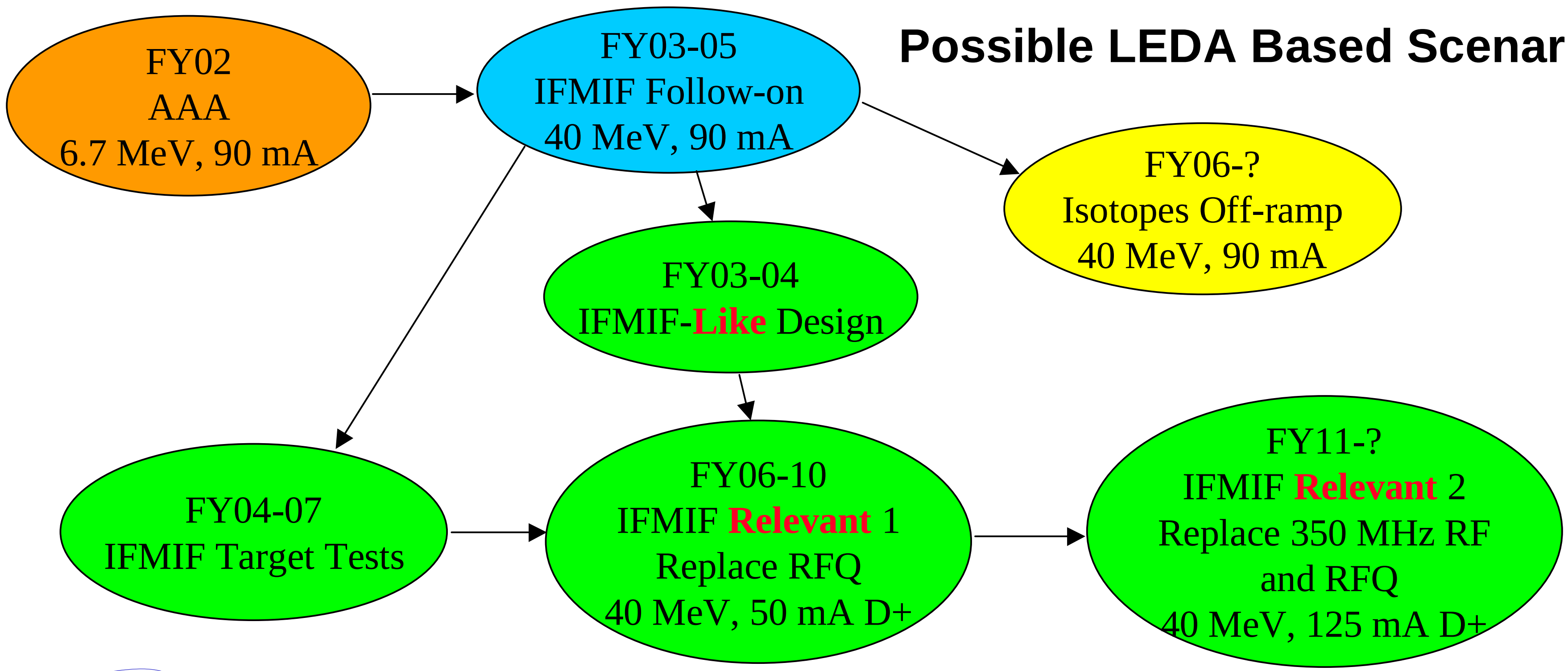
Roles for LEDA?

International Fusion Materials Irradiation Facility

Irradiation Volumes for 1 to > 20 dpa/yr using ^{7}Li target with LEDA

- 0.5 lit for 40 mA (use installed 350 MHz but new RFQ) D^{+} current at 40 MeV on ^{7}Li.
- 2 lit for 125 mA (requires 175 MHz RFQ) deuteron current at 40 MeV on ^{7}Li.
- Reference IFMIF case -
  - 6 lit for 250 mA deuteron current at 40 MeV on ^{7}Li.

Possible LEDA Based Scenarios



Summary

- **IFMIF Conceptual Design is well developed**
- **No serious technology issues**
  - **Ready to proceed to prototyping and engineering design**
- **Europe is very focussed and ready to proceed to EVEDA (Fast Track)**
- **Japan is in process of "transition" to EVEDA phase, also appear serious about proceeding promptly**
- **It seems clear that EVEDA cannot proceed without significant US involvement**
  - **US maintains excellent capability in accelerator technology - could re-assume leadership in this area**
  - **Accelerator (R. Jameson) and Design Integration (T. Shannon) continue to have US group leaders**
  - **LEDA facility at Los Alamos available to contribute on many levels**
- **IFMIF is also subject to decisions on ITER**