Status of Advanced Design Studies and Overview of ARIES-AT Study

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Electronic copy: http://aries.ucsd.edu/najmabadi/TALKS

ARIES Web Site: http://aries.ucsd.edu/ARIES

Role of Fusion in a Sustainable Global Energy Strategy

- Most of the socioeconomic studies were launched in FY 99:
  - * Study of options to deploy large fusion power plant including hydrogen production and co-generation. (ORNL & Partners). Completed in 12/99. (Presentation by L. Waganer)
  - * Establish the merits and address issues associated with fusion implementation (PPPL). (Presentation by J. Schmidt)
  - * Macro-economics modeling of global energy market and role of fusion (PNL) (Continuation of previous work).
  - * Comparison of various sources of energy based on equivalent CO_2 emission (U. Wisc.). (Presentation by J. Kulckinski)

National Power Plant Studies Program Initiated Two-years Projects in 1/99

- **Fusion Neutron Source Study:**
  - Non-electric applications of fusion, specially those resulting in near-term products may lead to new clients and to additional resources for fusion.
  - A concept definition study was performed to identify promising concepts and provide necessary information for proceeding further.
- **ARIES-AT:**
  - Assess impact of advanced technologies as well new physics understanding & modeling capabilities on the performance of advanced tokamak power plants.
- **Integrated IFE Chamber Study: (to start in 4/2000)**
  - Identify and explore design window for IFE chambers.

Non-Electric Applications of Fusion Neutrons

- Typical applications (~10^{19}-10^{21} n/s) :
  - * Transmutation of fission waste (Actinides);
  - * Hybrids for fuel and/or energy production;
  - * Fusion materials and engineering testing.
- Post-cold-war additions:
  - * Tritium production;
  - * Burning of plutonium from dismantled weapons.
- Recent application (~10^{11}-10^{13} n/s)
  - * Radioisotope production;
  - * Medical radiotherapy;
  - * Detection of explosives.

Focus Areas

Key Conclusions of Neutron Source Study

- There are many different transmutation fuel cycles and many different blankets proposed.
- There is no established set of criteria. Most concepts can be re-optimized based on different criteria, so comparison is difficult.
- Work by other communities has focused on performance (cost, electricity production, burn through) not on safety, licensing, reliability, cost, etc.
- Most performance parameters mainly depend on blanket and fuel cycle choices (spectrum of external source matters little).

Key Conclusions of Neutron Source Study

- The most fundamental distinction is the existence of an external neutron source leading to critical versus sub-critical blanket operation.
  - Fission (near-term technology)
  - Fusion & accelerator (sub-critical operation and deeper burn)
- The cost of the external neutron source is an added cost. Trade-off of sub-critical operation and deeper burn versus cost difficult in the absence of established criteria. Compared to accelerators, fusion has the added difficulty of the need to breed tritium.
- This is NOT a near-term option for fusion because of the safety and licensing issues and the associated need for component data base and reliability. Same is true for accelerator-based systems.
- Both ATW and fusion-based system are technically viable long-term options.

ARIES-RS Study Sets the goals and Direction of Research for ARIES-AT

	ARIES-RS Performance	ARIES-AT Goals
Economics		
Power Density	Reversed-shear Plasma Radiative divertor Li-V blanket with insulating coatings	Higher performance RS Plasma, High T_c superconductors
Efficiency	610^o C outlet (including divertor) Low recirculating power	> 1000^o C coolant outlet > 90% bootstrap fraction
Availability	Full-sector maintenance Simple, low-pressure design	Same or better
Manufacturing		Advanced manufacturing techniques
Safety and Environmental attractiveness	Low afterheat V-alloy No Be, no water, Inert atmosphere Radial segmentation of fusion core to minimize waste quantity	SiC Composites Further attempts to minimize waste quantity

Main Features of ARIES-AT^2
(Advanced Technology & Advanced Tokamak)

- **High Performance Very Low-Activation Blanket:** New high-temperature SiC composite/LiPb blanket design capable of achieving ~60% thermal conversion efficiency with small nuclear-grade boundary and excellent safety & waste characterization.
- **Higher Performance Physics:** reversed-shear equilibria have been developed with up to 50% higher β than ARIES-RS and reduced current-drive power.
- **Higher Performance Magnets:** High-T_c superconductors.

$\Rightarrow$ Present strawman operates at the same power density as ARIES-RS, higher β was used to reduce the peak field at the magnet.

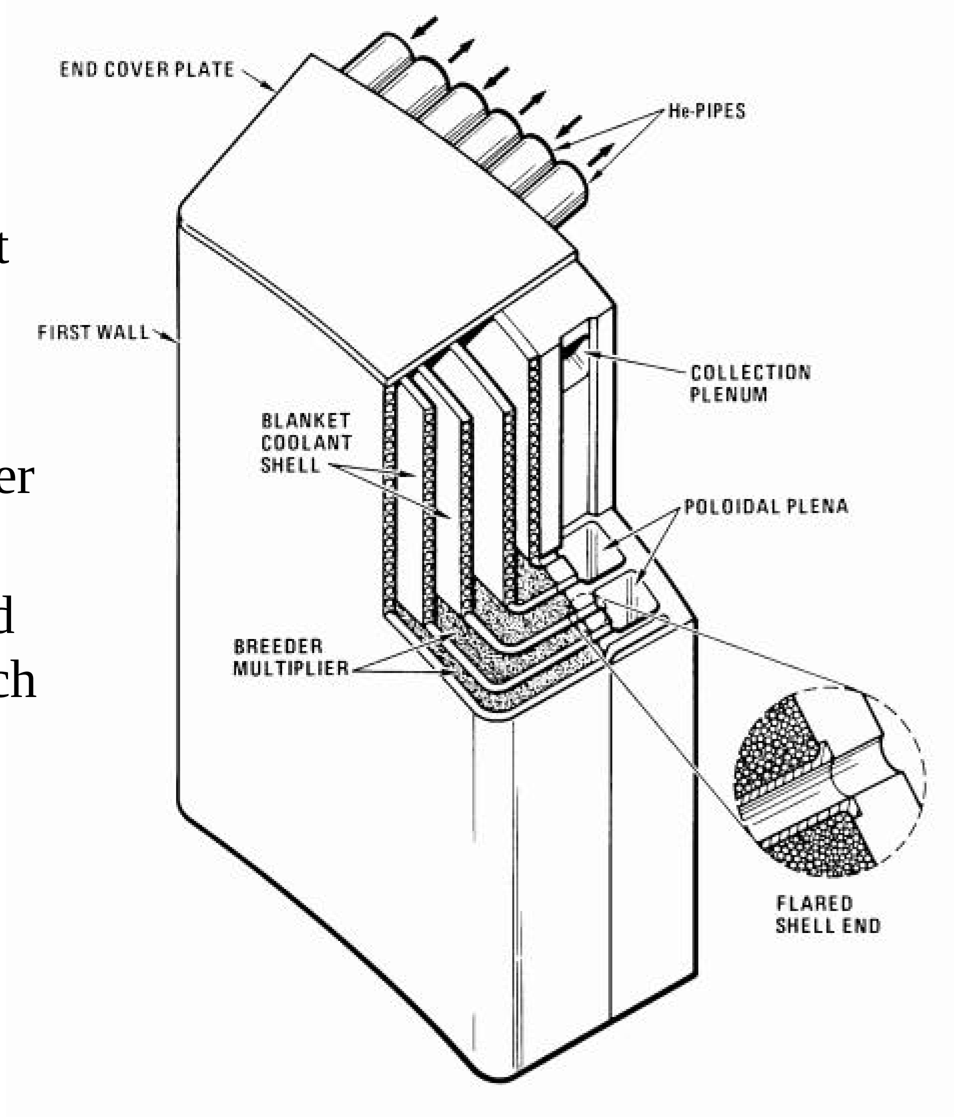
- Reduce unit cost of components through **advanced manufacturing techniques.**

ARIES-AT^2: Physics Highlights

- Use the lessons learned in ARIES-ST optimization to reach a higher performance plasma;
  - Using > 99% flux surface from free-boundary plasma equilibria rather than 95% flux surface used in ARIES-RS leads to larger elongation and triangularity and higher stable β.
- Eliminate HHFW current drive and use only lower hybrid for off-axis current drive.
- Perform detailed, self-consistent analysis of plasma MHD, current drive and divertor (using finite edge density, finite p', impurity radiation, etc.)
- ARIES-AT blanket allows vertical stabilizing shell closer to the plasma, leading to higher elongation and higher β.

ARIES-I Introduced SiC Composites as A High-Performance Structural Material for Fusion

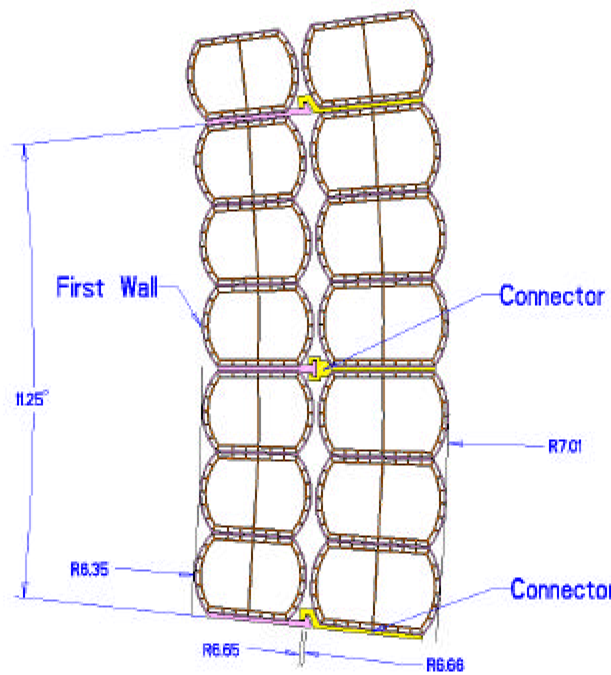
- Excellent safety & environmental characteristics (very low activation and very low afterheat).
- High performance due to high strength at high temperatures (>1000^{o}C).
- Large world-wide program in SiC:
  - New SiC composite fibers with proper stoichiometry and small O content.
  - New manufacturing techniques based on polymer infiltration results in much improved performance and cheaper components.
  - Recent results show composite thermal conductivity (under irradiation) close to 15 W/mK which was used for ARIES-I.

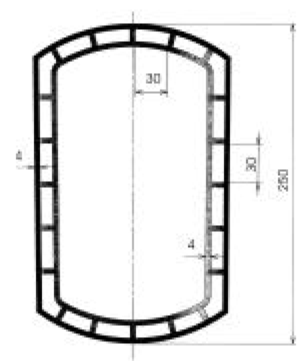


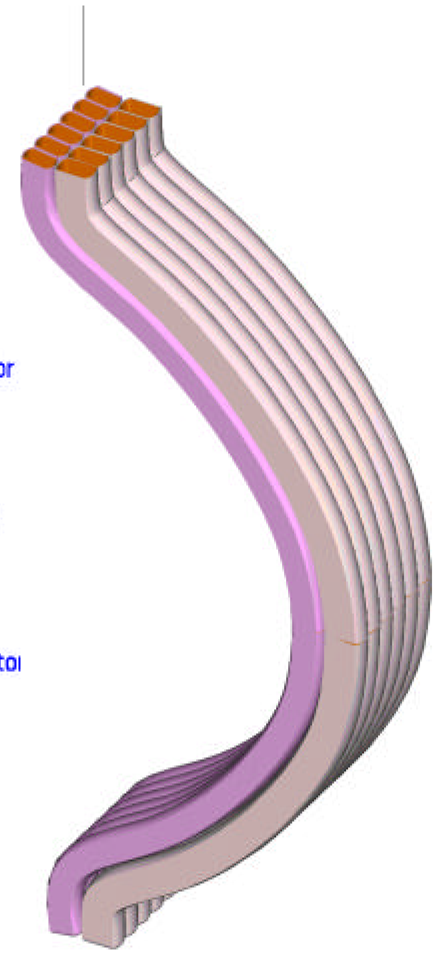
ARIES-AT^2: SiC Composite Blankets

- Simple, low pressure design with SiC structure and LiPb coolant and breeder.
- High LiPb outlet temperature (~1100^{o}C) and high thermal efficiency of ~60%.
- Simple manufacturing technique.
- Very low afterheat.
- Class C waste by a wide margin.

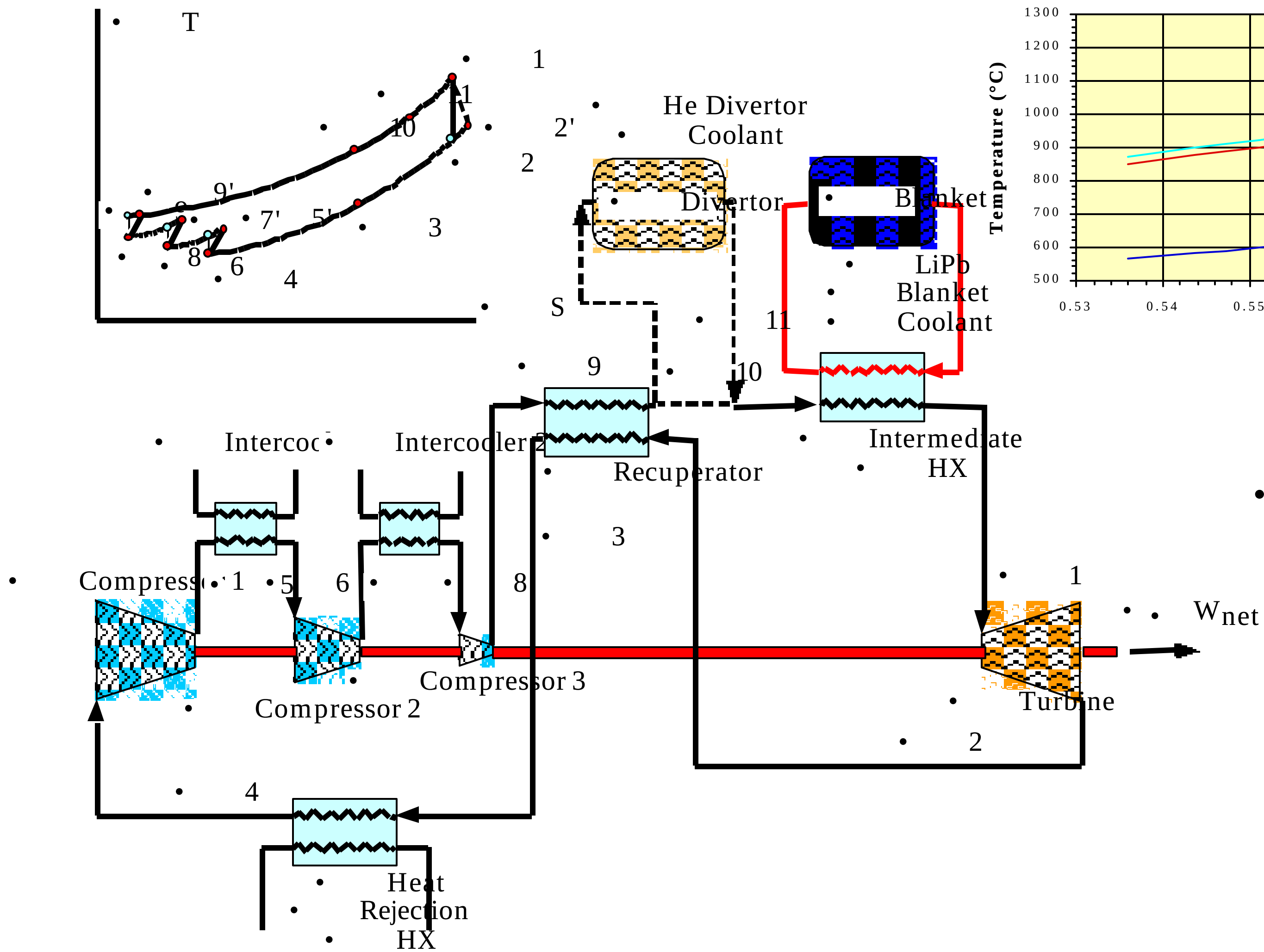
Outboard blanket & first wall

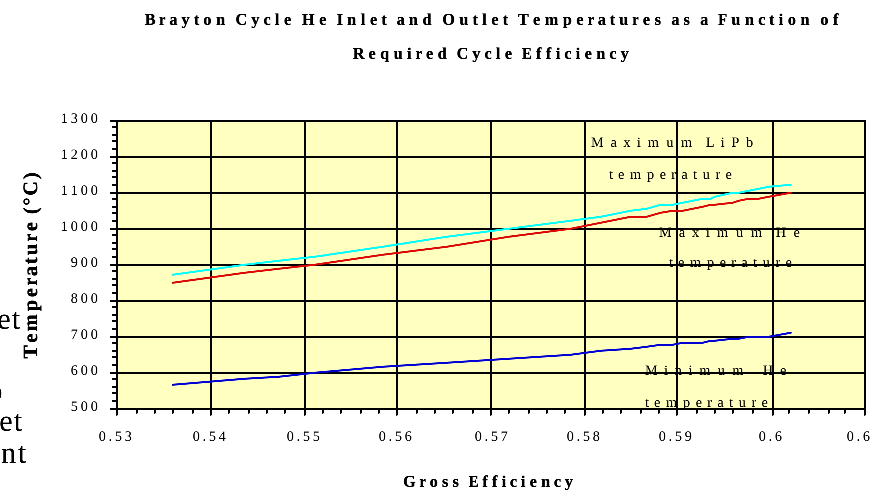






Recent Advances in Brayton Cycle Leads to Power Cycles With High Efficiency

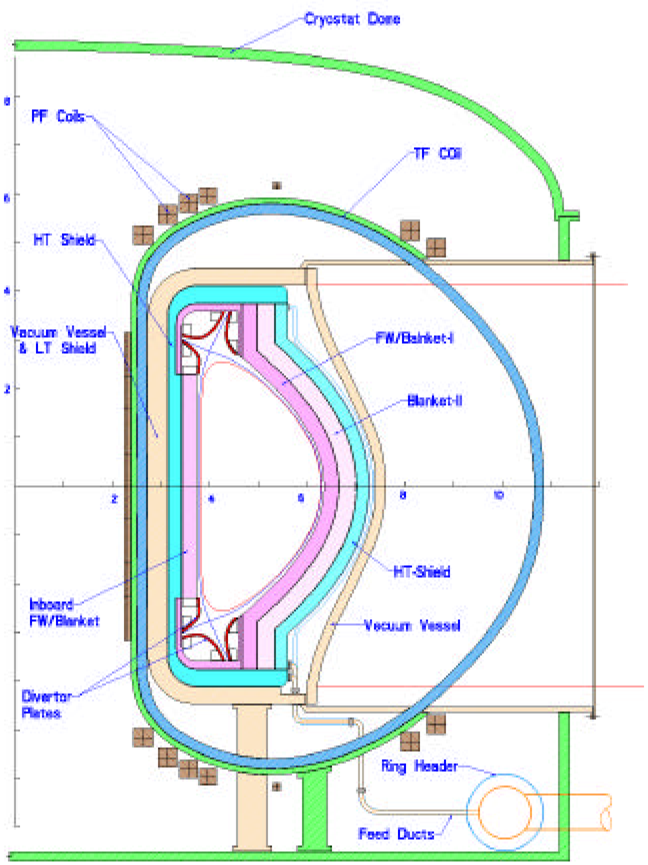




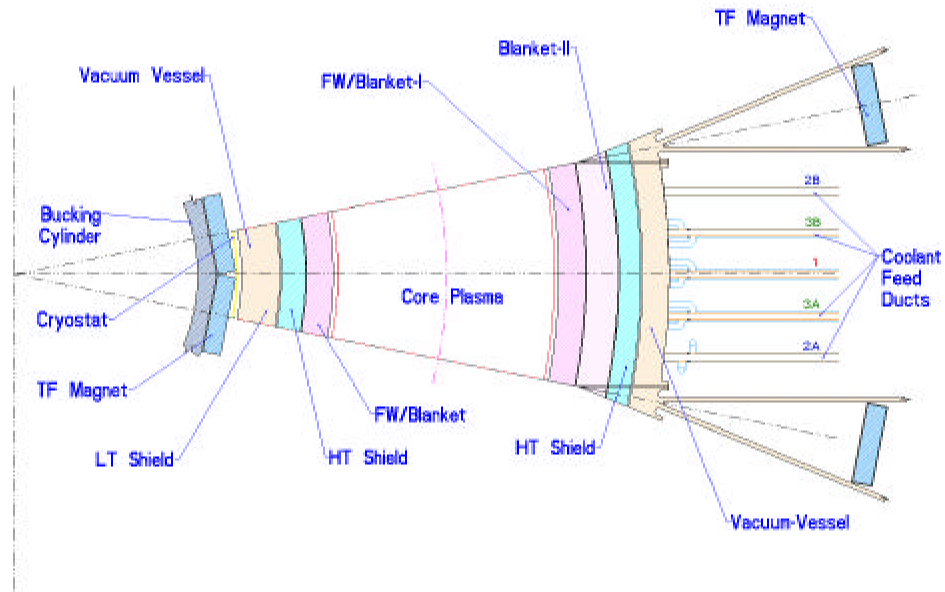
- Key improvement is the development of cheap, high-efficiency recuperators.

ARIE-AT also Uses A Full-Sector Maintenance Scheme

Cross-Section of ARIES-AT Power Core



Plan View of ARIES-AT Power Core(1/16 Sector)



Major Parameters of ARIES-RS and ARIES-AT

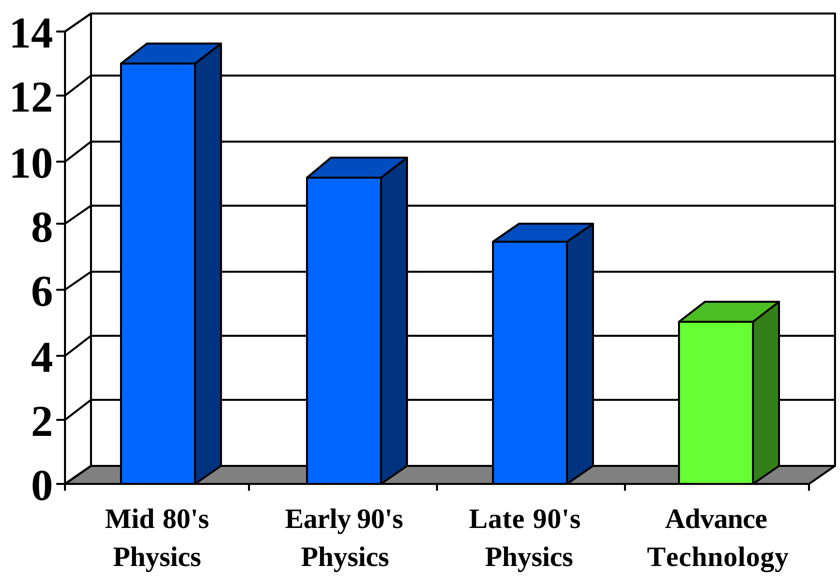
	ARIES-RS	ARIES-AT
Aspect ratio	4.0	4.0
Major toroidal radius (m)	5.5	5.2
Plasma minor radius (m)	1.4	1.3
Plasma elongation (κ_x)	1.9	2.2
Plasma triangularity (δ_x)	0.77	0.86
Toroidal β	5%	9.2%
Electron density (10^{20} m^{-3})	2.1	2.25
ITER-89P scaling multiplier	2.3	2.7
Plasma current	11	13

Major Parameters of ARIES-RS and ARIES-AT

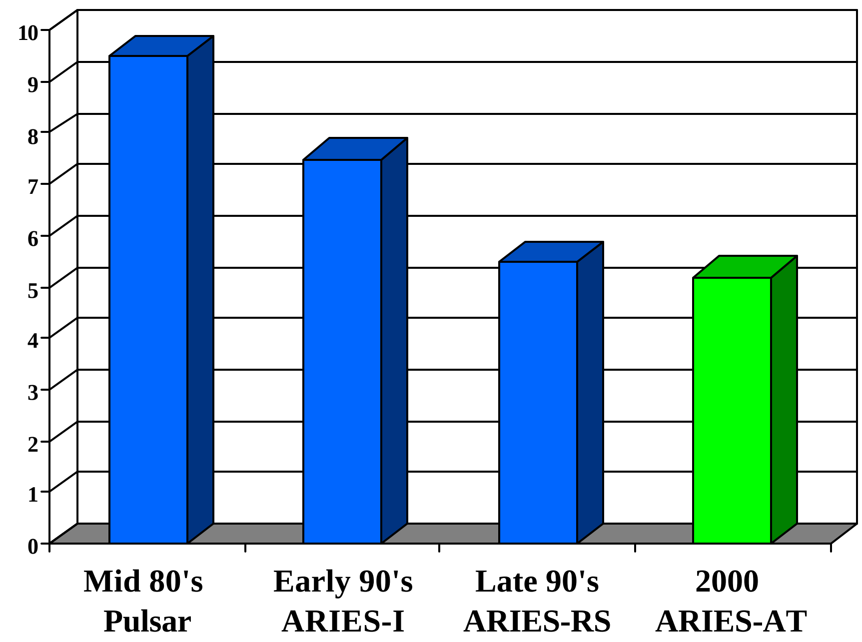
	ARIES-RS	ARIES-AT
On-axis toroidal field (T)	8	6
Peak field at TF coil (T)	16	11
Current-drive power to plasma (MW)	81	25
Peak/Avg. neutron wall load (MW/m^2)	5.4/ 4	4.7/3.8
Fusion power (MW)	2,170	1,720
Thermal efficiency	0.46	0.59
Gross electric power (MW)	1,200	1,136
Recirculating power fraction	0.17	0.12
Cost of electricity (mill/kWh)	76	53

Our Vision of Magnetic Fusion Power Systems Has Improved Dramatically in the Last Decade, and Is Directly Tied to Advances in Fusion Science & Technology

Estimated Cost of Electricity (c/kWh)



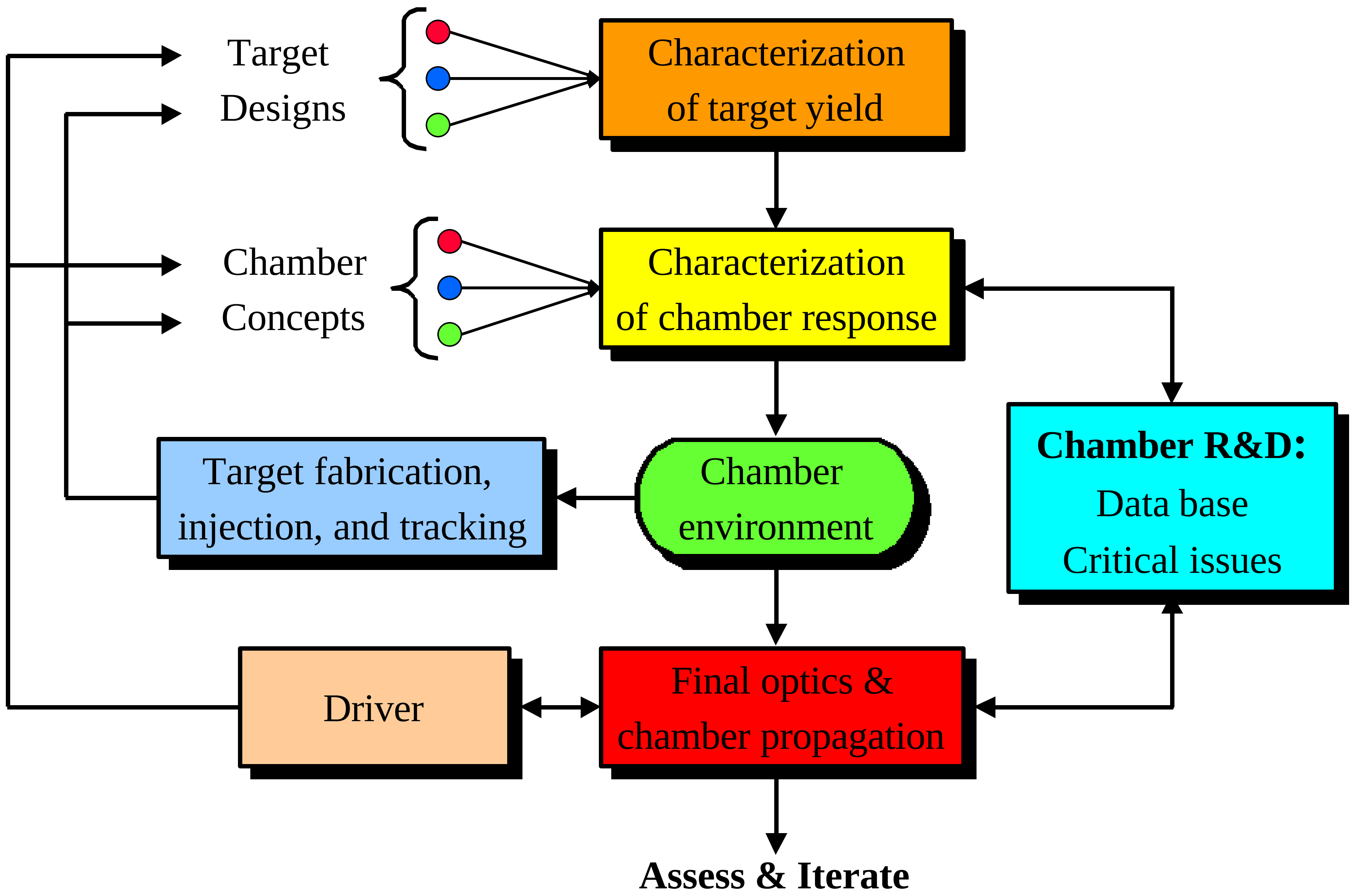
Major radius (m)



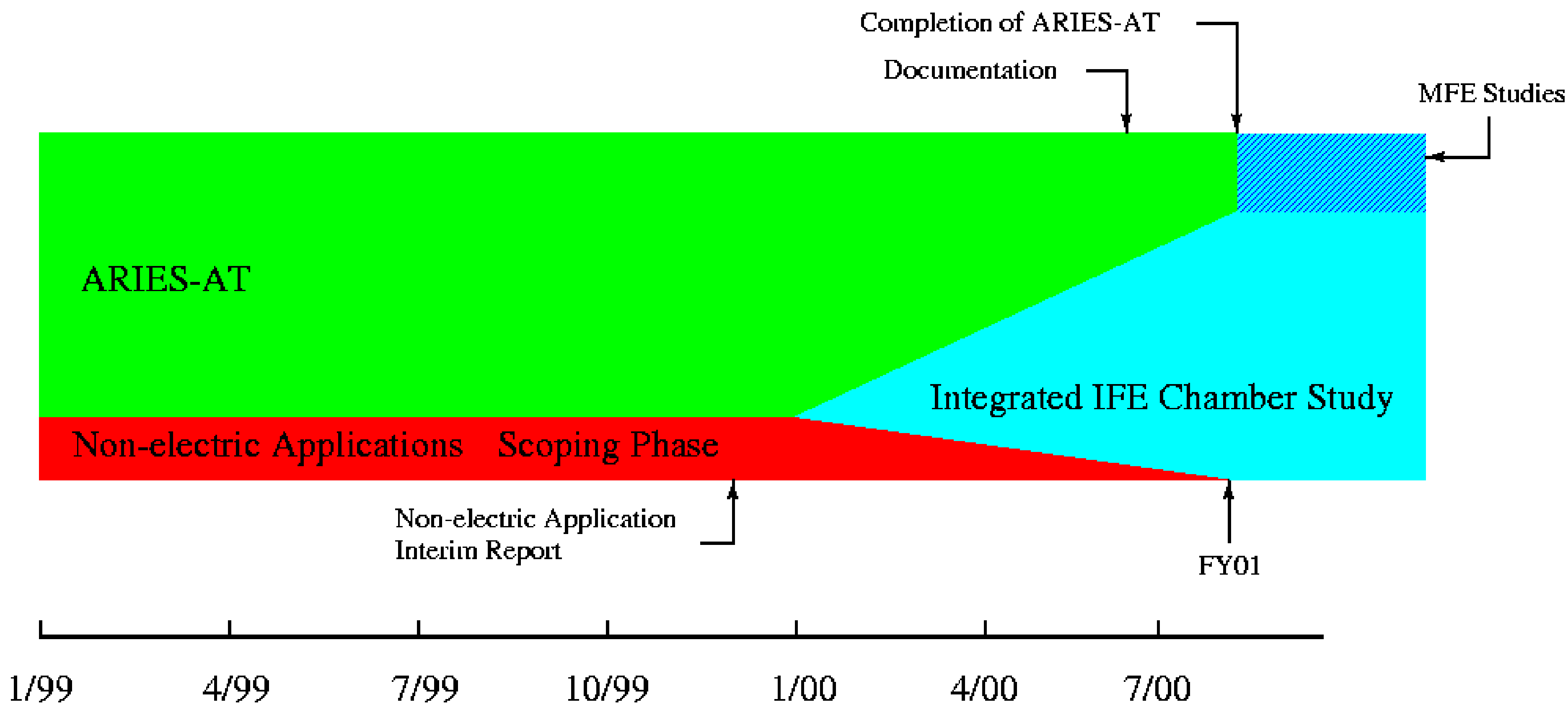
Present ARIES-AT parameters:

Major radius:	5.2 m	Fusion Power	1,720 MW
Toroidal β:	9.2%	Net Electric	1,000 MW
Wall Loading:	4.75 MW/m^2	COE	5.3 c/kWh

The Integrated IFE Study Will Identify and Explore the Design Window for IFE chambers & Define R&D Needs



National Power Plant Studies Program
Plan for FY 2000



- The scope and relative size of the MFE and IFE studies in FY01 depends to program budget and outcome of congressional process.