IFE Engineering Test Facility (ETF) - Opportunities for Reducing Fusion Development Costs

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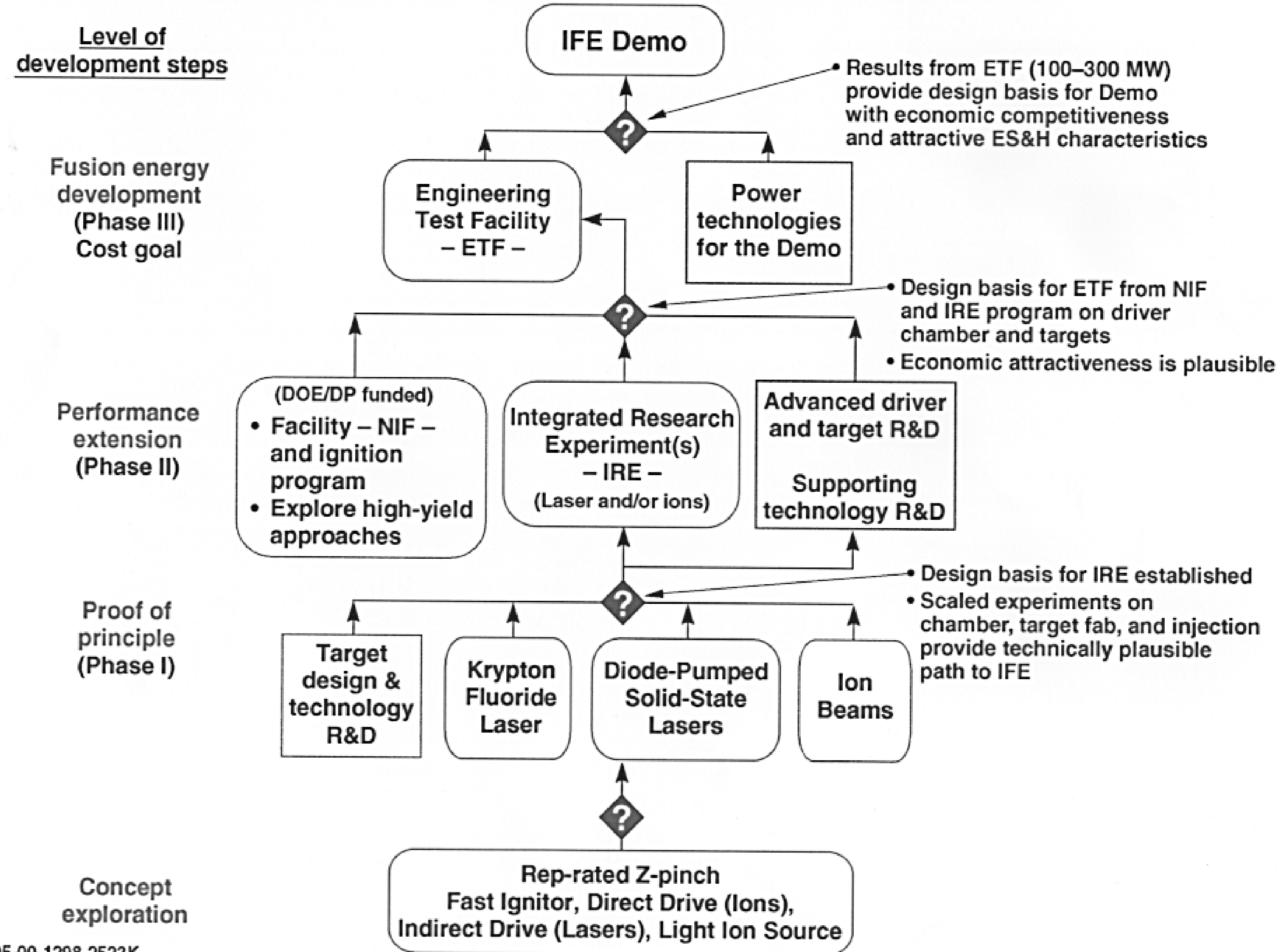
July 15, 1999
1999 Fusion Summer Study
Snowmass, CO

The Engineering Test Facility is the primary “fusion energy development” step



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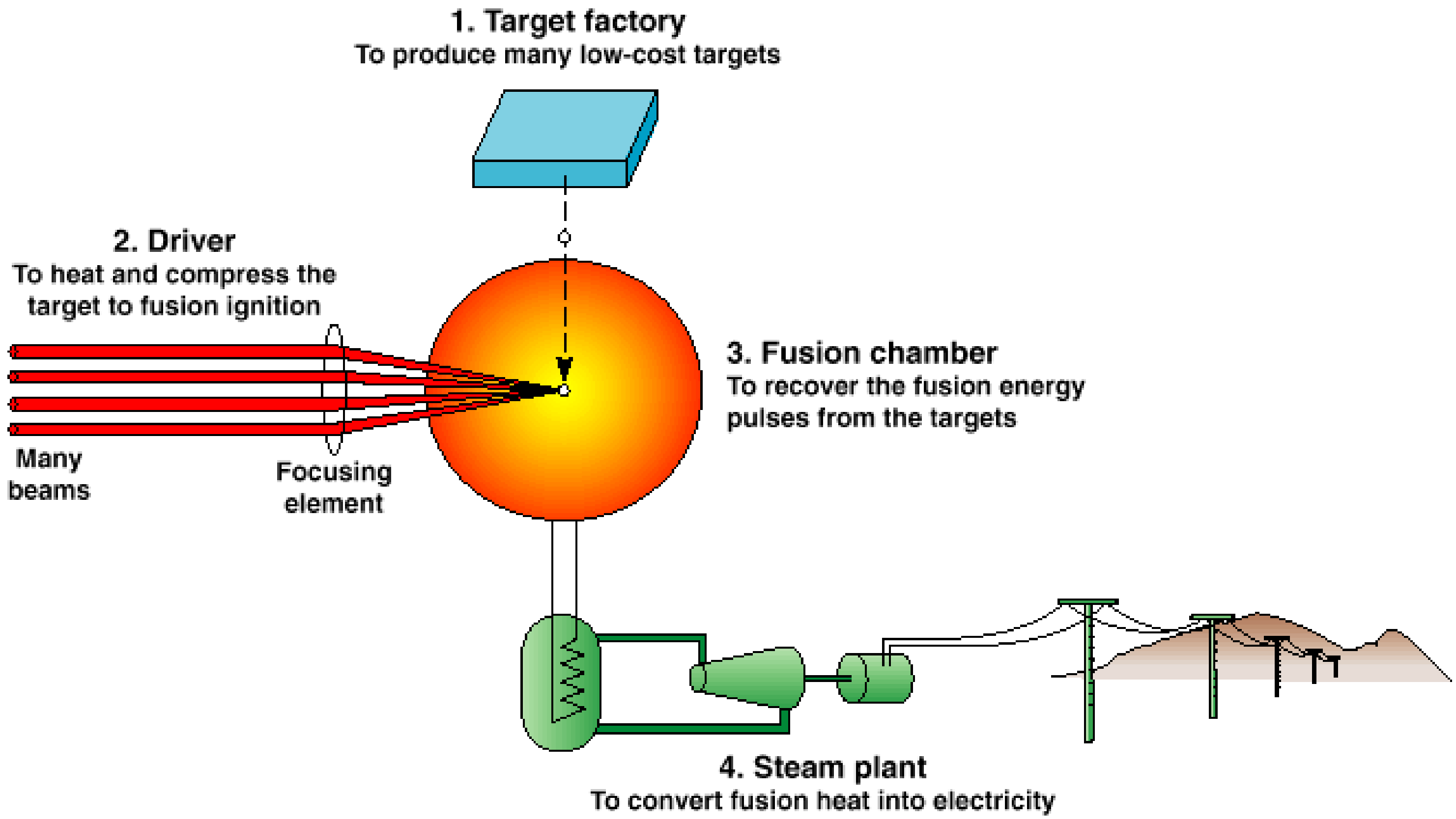
Proposed ETF construction and operating strategy will reduce development costs

Strategy is to take advantage of as many of the following as possible:

- **Separability of driver, target systems, and fusion chamber**
- **Modularity (drivers, heat transfer equipment)**
- **Ability to switch beams to different chambers**
- **Ability to test chambers at reduced scale**
- **Ability to vary rep-rate and target yield to control power**
- **Develop/test subsystems in series of increasingly difficult steps**
- **Possibility of upgrading driver for subsequent demo phase**

Inertial Fusion Energy (IFE) power plants of the future will consist of four parts



A power-plant driver would fire about five targets per second to produce as much electricity as today's 1000-megawatt power plant

Objectives of ETF

- **System Integration** – Integrate all the major subsystems required for an inertial fusion power plant (driver, target production and injection systems, and fusion chamber, and heat removal system)
- **Driver Efficiency** – Demonstrate driver efficiency needed for economical power
- **High Gain** – Demonstrate target gain high enough for attractive economics (acceptable recirculating power fraction)
- **High Yield** – Demonstrate targets at near full yield in single shot tests
- **High Rep-Rate** – Operate at full rep-rate with reduced yield (and thus power) to demonstrate target injection and tracking, chamber recovery between shots, and heat removal
- **Safety** – Demonstrate ability for safe operation including recovery of tritium

ETF will progress through a series of increasingly difficult tests

- High rep-rate driver operation with required efficiency (or scaleable to power plant requirement)

- Single shot, high gain target experiments to optimize designs
  - first demonstration for heavy ion driver

- Short duration (minutes), burst mode tests at low yield to prove and optimize chamber designs
  - beam switching to test multiple chamber if desired
  - tritium breeding not required
  - batch production of targets

- Steady state, average power tests for days to weeks
  - include tritium breeding and recovery
  - automated target production
  - include heat removal and steam generation
  - produce electricity?

- Upgrade driver and plant components to demo scale?

How large must the ETF driver be?

Several factors to consider:

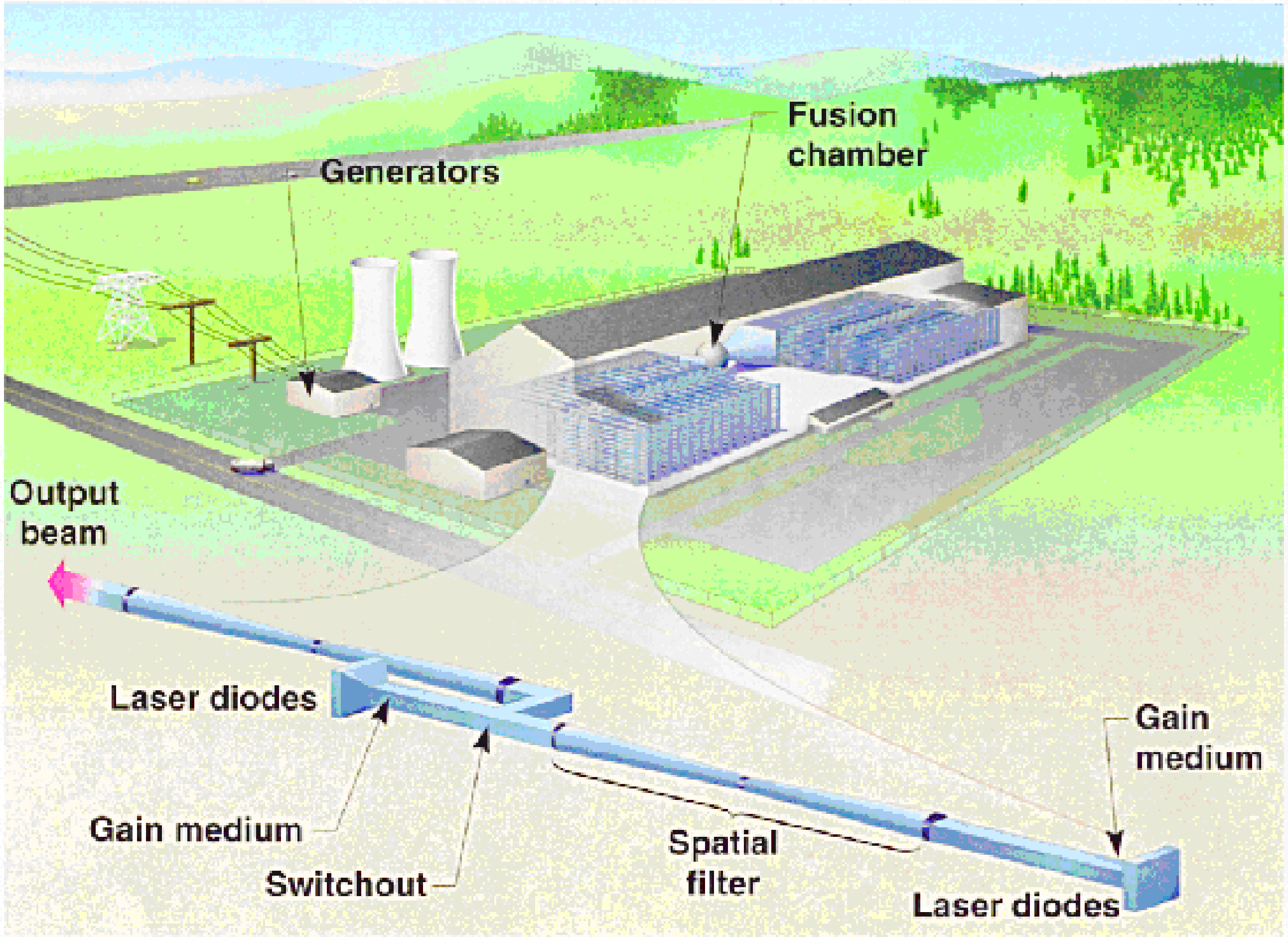
Could be as low as 1-2 MJ depending on gain curve and driver efficiency

Driver technology leading to the ETF – modularity is an important feature

- Laser drivers with 10's to 100's of parallel beam lines will be able to demonstrate driver scale technology at small beam energy (i.e., build a single ~ 10-100 of kJ beamline)

- Heavy ion demonstration will likely be front-end of full scale driver (multi-beam injector, acceleration to 10-100's of MeV)
  - Important since low energy section is considered most difficult
  - Full-scale components of high energy section (e.g., cores, multi-beam quad arrays, etc.) can be developed and tested prior to ETF driver to give confidence in design

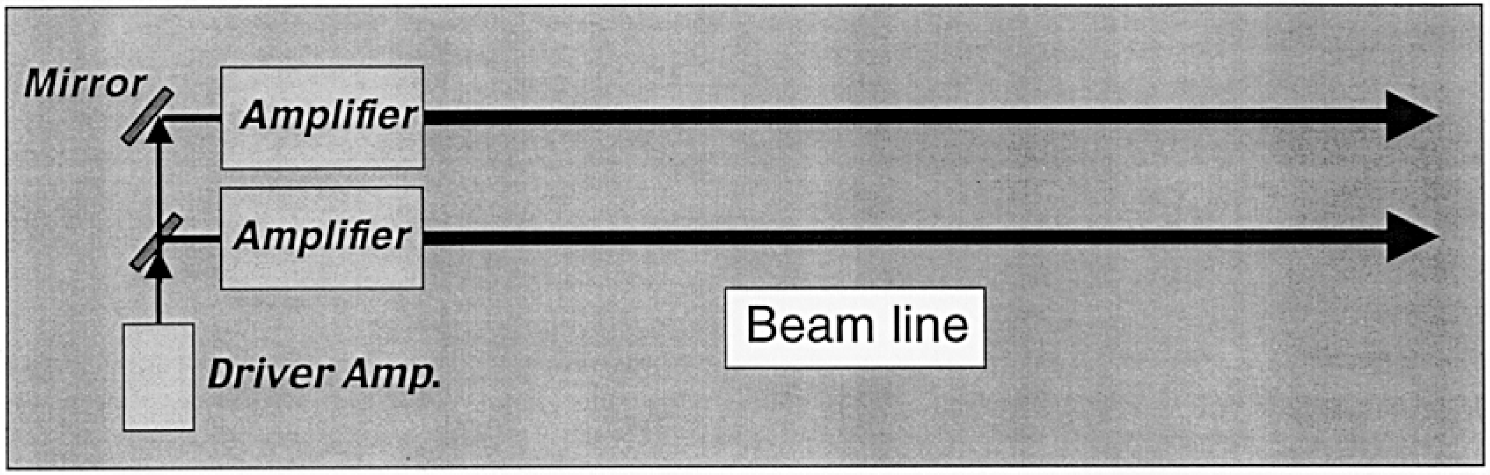
An IFE power plant with a DPSSL driver



- An inertial fusion energy (IFE) power plant entails $>10^5 \times$ the repetition rate and total thermonuclear yield compared to the National Ignition Facility (NIF)

The laser technology can be developed without building the entire system

An IFE laser would consist of a number of identical parallel beam lines--



One <u>possible</u> IFE laser architecture:

10 parallel beam lines, each of output 120 kJ (1.2 MJ total)

Each 120 kJ beam line would consist of four identical 30 kJ amplifiers

To develop and evaluate KrF lasers requires we build one 30 kJ amplifier

i.e. <u>*one part*</u> of <u>*one line*</u>

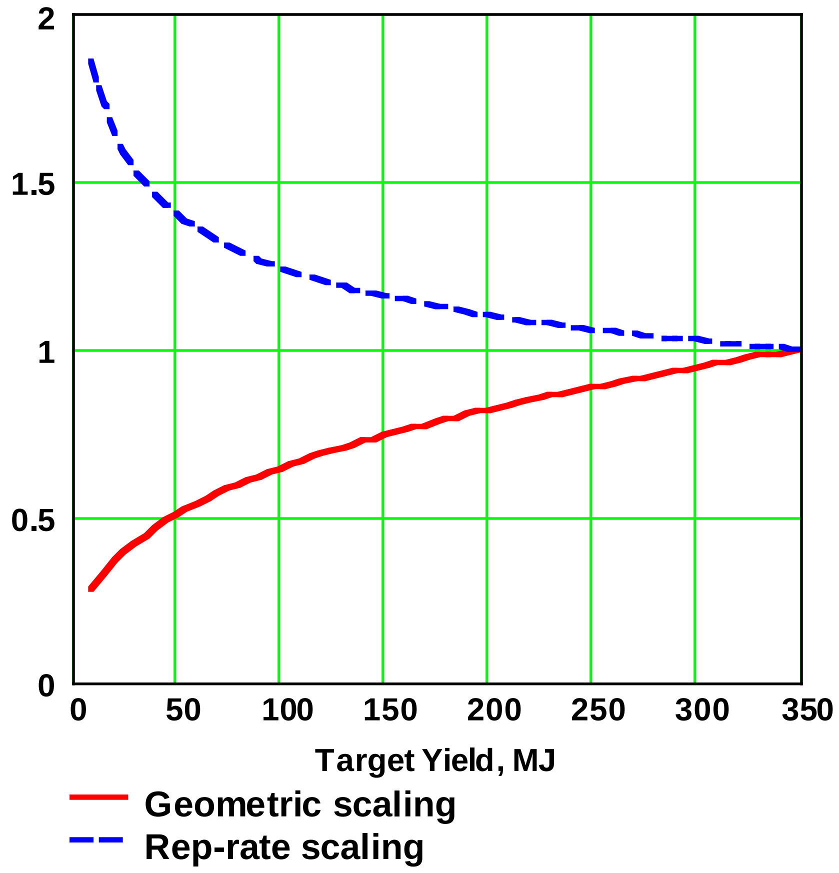
This modular nature leads to relatively low development costs.

Livermore's ATA induction linac accelerated more than 10 kA of electrons.

50 MeV, 70 ns, 1 kHz burst repetition rate, adequate current for fusion

Chambers can be tested at less than full scale

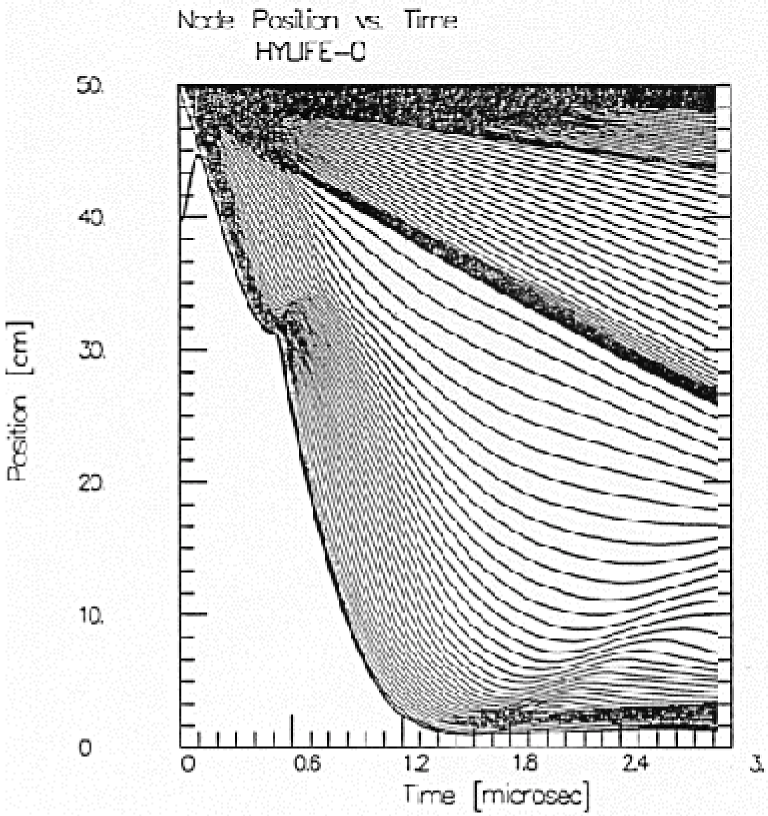
- **To preserve key hydraulic phenomena related to chamber clearing (including effects of impulse loading) HYLIFE-II dimensions scale as (target yield)$^{0.35}$ and rep-rate as (dimension)$^{-1/2}$ (P. Peterson, UCB)**



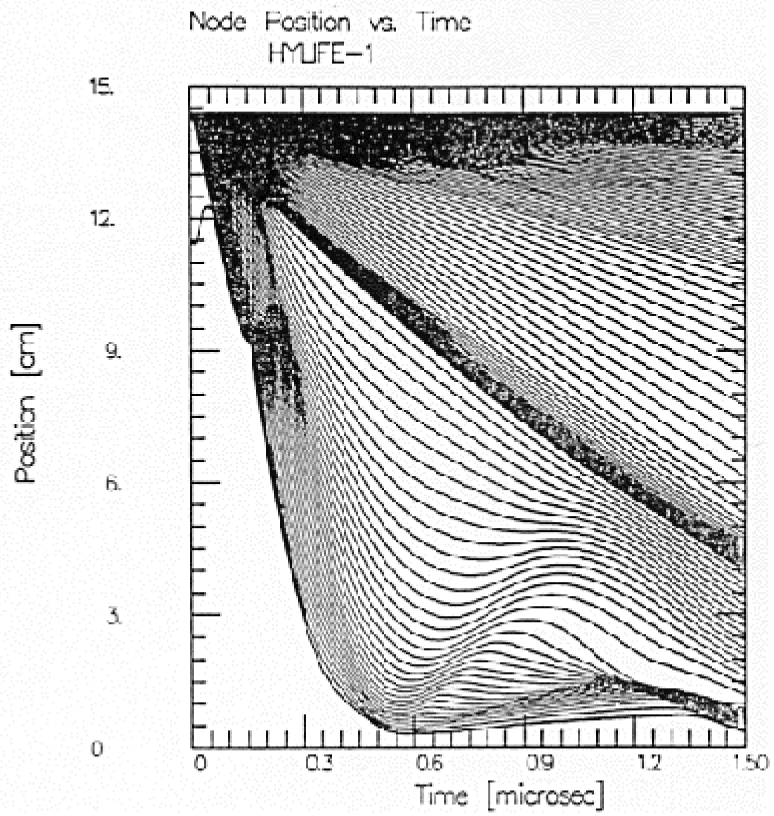
Vapor blow-off from HYLIFE-II first surface is similar in full-size and ITF-scale chambers

WJS4-

Full-size chamber, Y = 350 MJ, R = 50 cm

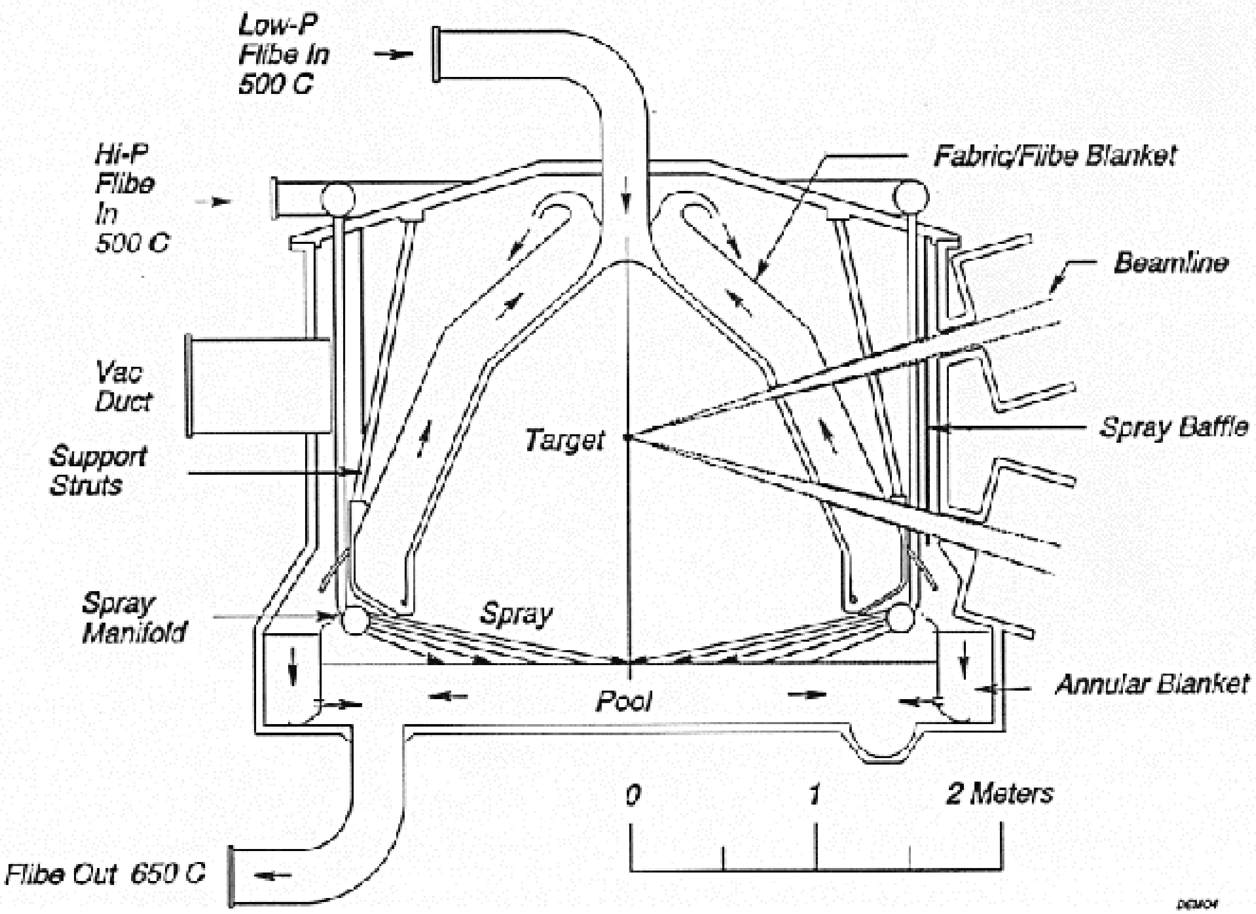


ITF chamber, Y = 31.5 MJ, R = 14.4 cm

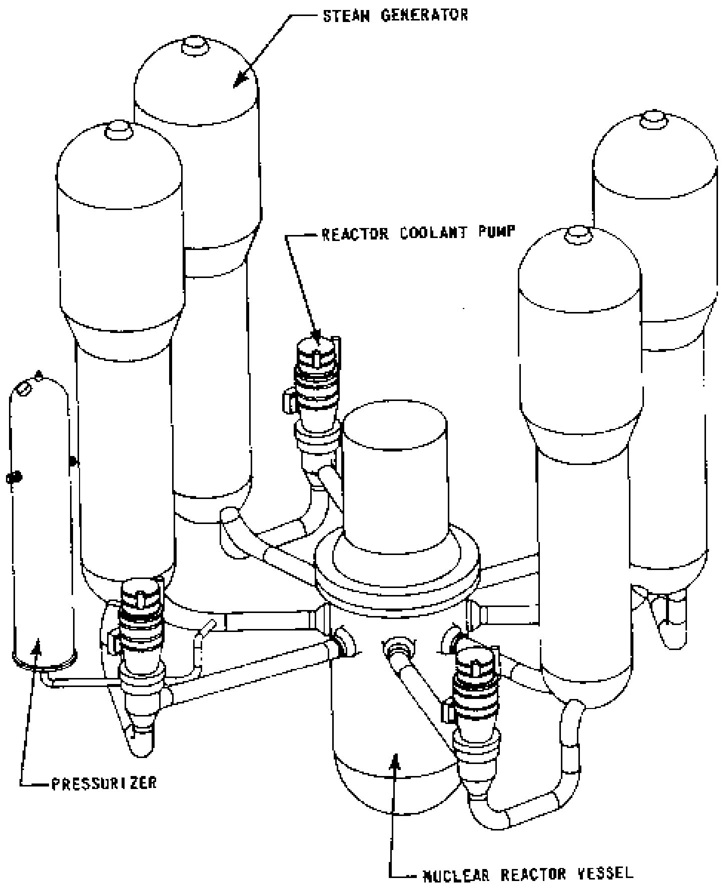


GENERAL ATOMICS

OSIRIS READILY SCALES DOWN TO A SMALL DEMO: THIS ONE IS FOR 20 MJ, 5 Hz, and 100 MW_{fusion}



Power plants typically have 2 - 4 primary heat transfer loops



Westinghouse 4-Loop Reactor Coolant System

Size of heat transfer (HT) components is set by scale-up requirements

One Example:

Power Plant

- Four full scale HT loops = 675 MWt per loop
- Total power = 2700 MWt
- Generates electricity ~ 1 GWe

Demo Plant

- One or two HT loops at 2/3 power plant scale = 450 MWt
- Total power = 450-900 MWt
- Generates electricity ~ 150-300 MWe

ETF

- One HT loop at 2/3 demo scale = 300 MWt
- Total power = 300 MWt
- Produces required steam conditions but no electricity

Automated target systems will be needed for ETF

- Production and injection technologies developed off-line prior to ETF (proceeding from room temp surrogates to cryogenic prototypes)
- Production techniques will leverage off of ICF Program work where possible
- Batch mode production should be adequate for burst mode tests during early ETF phase (300/minute of test at 5 Hz)
- Automated production required for average power tests (1 week at 5 Hz = 3 million targets!)

The ETF can be a cost effective step in development of IFE

- 1 - 2 MJ driver may be adequate
- Single driver used to optimize target designs and test one or more chamber designs
- Chambers can be tested to small scale (10% of full scale cost)
- Heat transfer components tested at ~ 10% of full scale, electric power production not necessary
- Target technologies continue to leverage off ICF Program where possible

A successful ETF will provide a convincing case to proceed to a Demo

- High gain, high yield targets
- High rep-rate driver with adequate efficiency
- High rep-rate target production and injection
- High rep-rate chamber operation
- Heat removal
- Tritium breeding and recovery
- Safe operation