Direct Conversion in a Z-Pinch IFE Reactor

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Abstract

Recently, a world's record x-ray power of 0.28 PW has been measured from a Z-pinch driven imploding plasma at Sandia National Laboratory, Albuquerque, NM. This result immediately led to detailed calculations showing high fusion energy gain from a Z-pinch indirectly driven DT fusion capsule. This has fueled interest in a practical Z-pinch fusion reactor. Formidable technological obstacles must be overcome to make a practical Z-pinch driven reactor. The pulsed power system must be capable of delivering 10^7 to 10^8 pulses of energy 20-50 MJ to the load with high efficiency (> 0.1) at a rate of ~ 0.3 pulses/s. The reactor chamber must be protected from fusion reactions and byproducts. The components destroyed must be cheap enough (~$2/module).

An attractive scheme uses a MHD generator to directly convert most of the fusion energy with residual energy recovery by a steam bottoming cycle. A compact blanket absorbs most of the fusion energy and creates low temperature plasma that is used to drive a MHD generator. Rather low yields are required to convert the blanket to the ~ 1 eV plasma required to optimally drive the MHD generator. For example, a 5 GJ yield requires a flibe blanket with a thickness of only ~ 20 cm and a mass of ~ 70 kg to absorb more that 1/2 of the fusion energy.

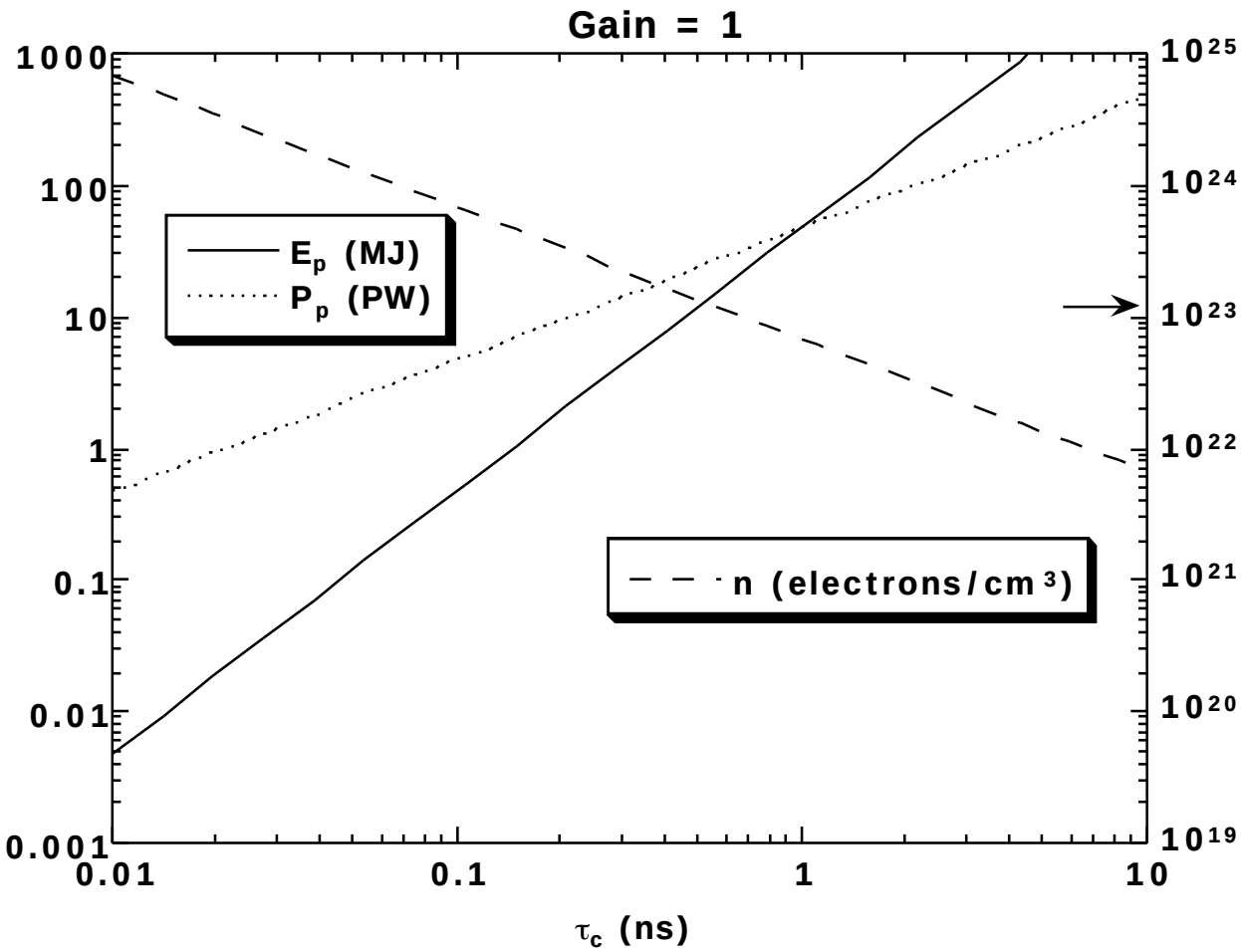
Summary

- **The key issues to be solved to produce a Z-pinch driven IFE reactor are:**
  - **Accelerator requirements**
    - **Rep rate ~ 0.1-1 pulse/sec.**
    - **Energy to pinch > 20MJ.**
  - **Fusion Yield > 4 GJ.**
    - **High gain is required (G > 150).**
    - **Current Rise time as long as possible.**
      - **Longer current rise time reduces the stress on accelerator design and allows higher load inductance.**
  - **Recyclable transmission line (RTL) and load must be cheap enough!**
    - **Key requirement < $2-3/pulse for RTL plus load.**
  - **Direct conversion is an attractive option**

The competition is tough!

- Natural gas power plant (to be installed in Northern California)
  - Very low cost of electricity, COE ~ 3¢/kWh!
    - HYLIFE, COE ~9¢/kWh (1988)
  - Low plant capital costs ~ 0.6$/W!
    - HYLIFE, ~ 3$/W (1988)
  - System efficiency ~ 60%
  - We can not count on the greenhouse argument
    - The carbon dioxide emission from natural gas plants has been reduced!
      - Carbon dioxide reduction increases the COE to 5¢/kWh
- Wind generators are also in the running.
  - COE ~ 5¢/kWh

PW drivers are required IFE!



Achievable accelerator output characteristics

- **Energy delivered to pinch ≤ 50 MJ.**
- **Wallplug Efficiency ~ 10-20%.**
- **Rep. Rate = 0.1 - 1 pulse/sec.**
- **Long life (~ 10^7 pulses).**

Z-pinch IFE reactor requirements

- **Accelerator requirements**
  - **Rep rate ~ 0.1 -1/sec.**
  - **Energy to pinch > 20MJ.**
- **Fusion Yield > 1 GJ.**
  - **High gain is required (G > 150).**
  - **Current Rise time as long as possible.**
    - **Longer current rise time reduces the stress on accelerator design and allows higher load inductance**
- **RTL and load must be cheap enough!**
  - **Key requirement ~ $2/pulse for RTL and target.**
  - **The present z-pinch experiments use wire arrays**
    - **Wire arrays are probably to expensive to use in a reactor**
    - **The wire arrays can be replaced by cheaper liners or gas puffs in the higher current reactor.**

The fusion gain must be high enough!

- **The fusion gain must satisfy:**

$$\eta_E G_{fusion} \eta_{x-ray} \eta_A f = 1$$

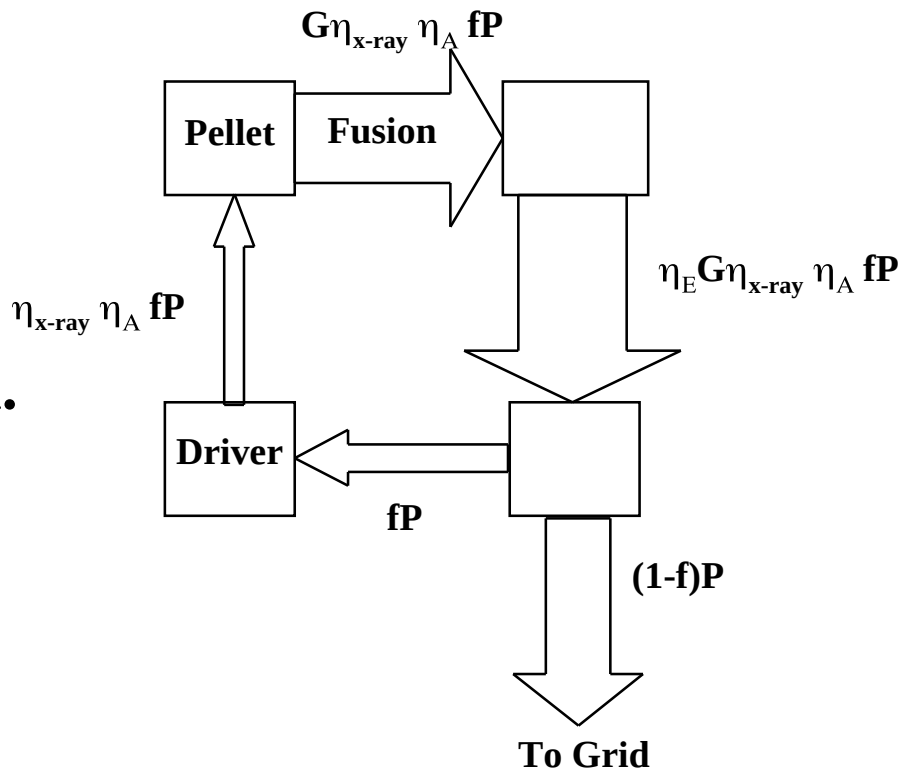
$\eta_{x-ray} = 0.8$

$\eta_E = 0.4$, Electrical energy/thermal energy.

$\eta_A = 0.1$, Accelerator efficiency, pinch energy/accelerator energy.

$f = 0.2$, Recirculating power fraction.

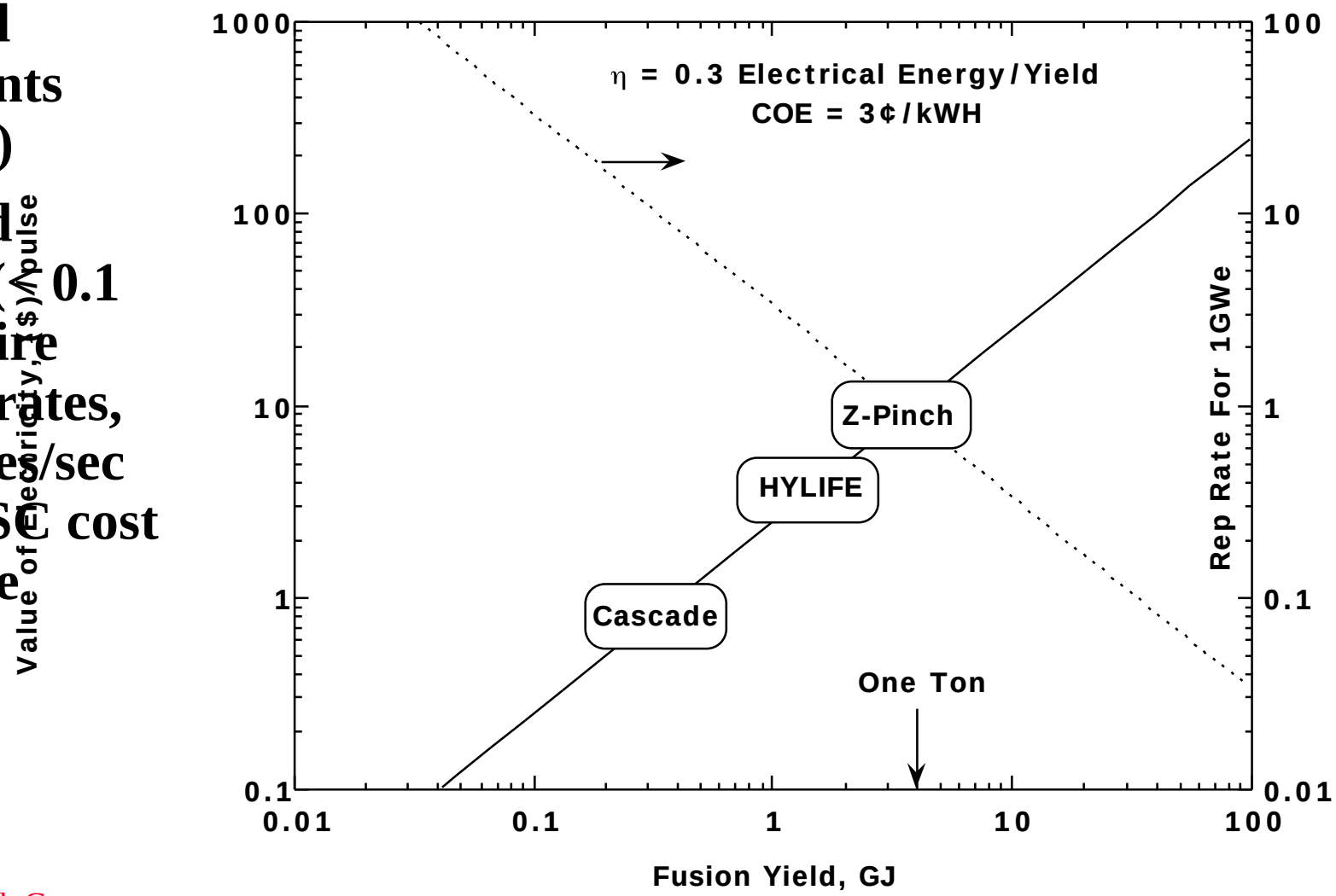
$G_{fusion} > 150$



- **High gain (G > 150) is required.**

High yield increases the allowed sacrificial component cost

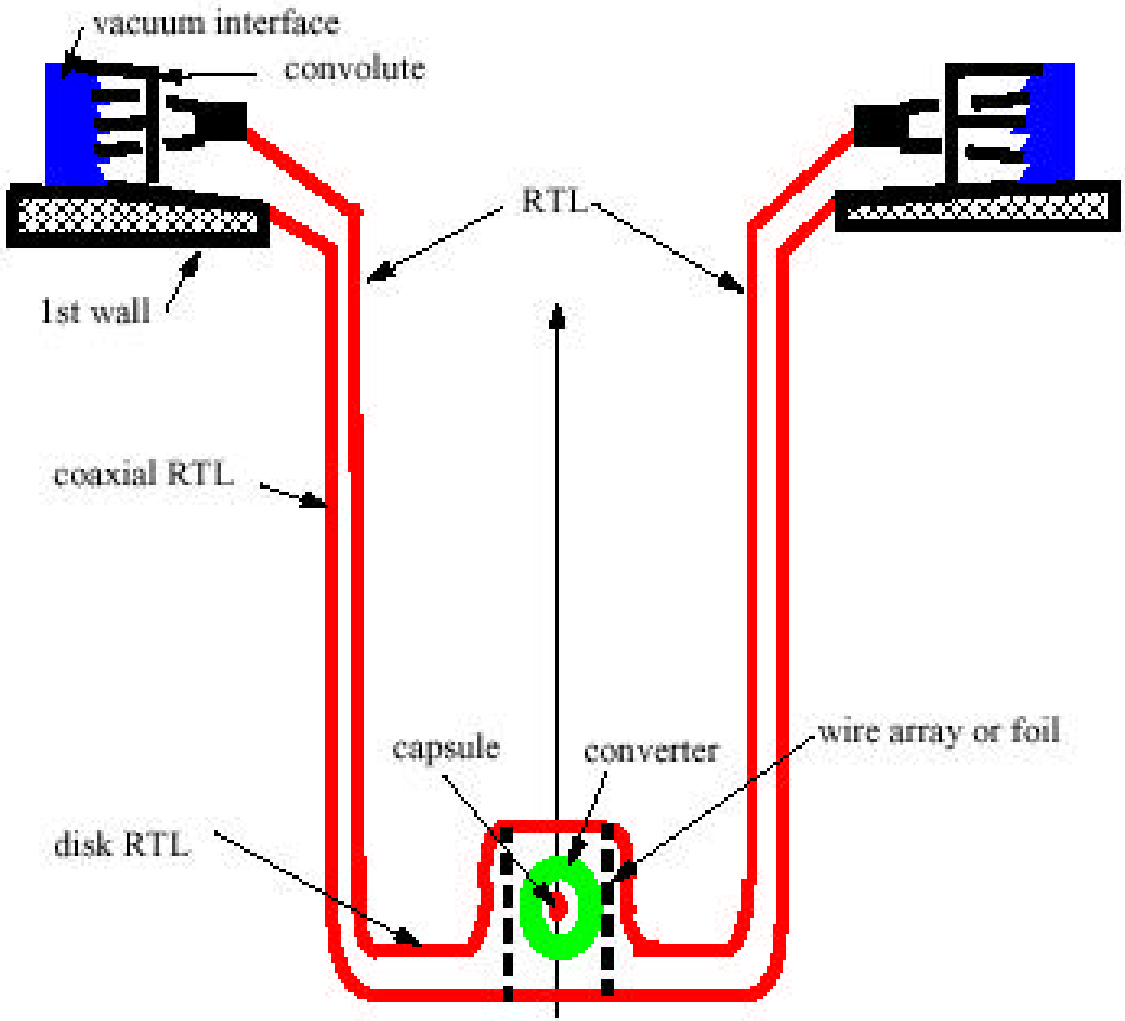
- < $2/pulse for sacrificial components (SC/V~ 5)
- Low yield schemes (< 0.1 GJ) require high rep rates, > 30 pulses/sec and low SC cost < 5¢/pulse



High gain Z-pinch driven IFE capsules have been designed

- **Z-pinch driven hohlraum design (**J. H. Hammer, M. Tabak, S. C. Wilks, J. D. Lindl, D. S. Bailey, P. W. Rambo, A. Toor, and G. B. Zimmerman, "High Yield Inertial Confinement Fusion Target Design for a Z-pinch Driven Hohlraum," Phys. Plasmas **6**, 2129 (1999))**) has a gain of 75.**
  - **Accelerator requirements**
    - **100 ns current risetime**
    - **60MA peak current**
  - **~ 16MJ of x-rays from pinch required**
  - **1.2 GJ Yield**
  - **Higher gain is required**

Schematic of recyclable transmission line



Direct energy MHD conversion is an attractive option

- **The scheme:**
  - **Deposit the fusion energy in a compact blanket.**
  - **Vaporize/ionize the blanket to produce a highly conductive plasma (T ~ 1 eV).**
  - **The plasma is expanded through a nozzle and a MHD generator to directly produce electricity.**
- **References**

1. **E. P. Velikov, V. S. Golubev, V. V. Chernukha, Soviet Atomic Energy 36, 258 (1974).**
2. **G. P. Lasche, Unpublished UCD Ph. D. dissertation, UCRL 53434, LLNL (1983).**

Compact Fusion Advanced Rankine MHD Conversion (Grant Logan)

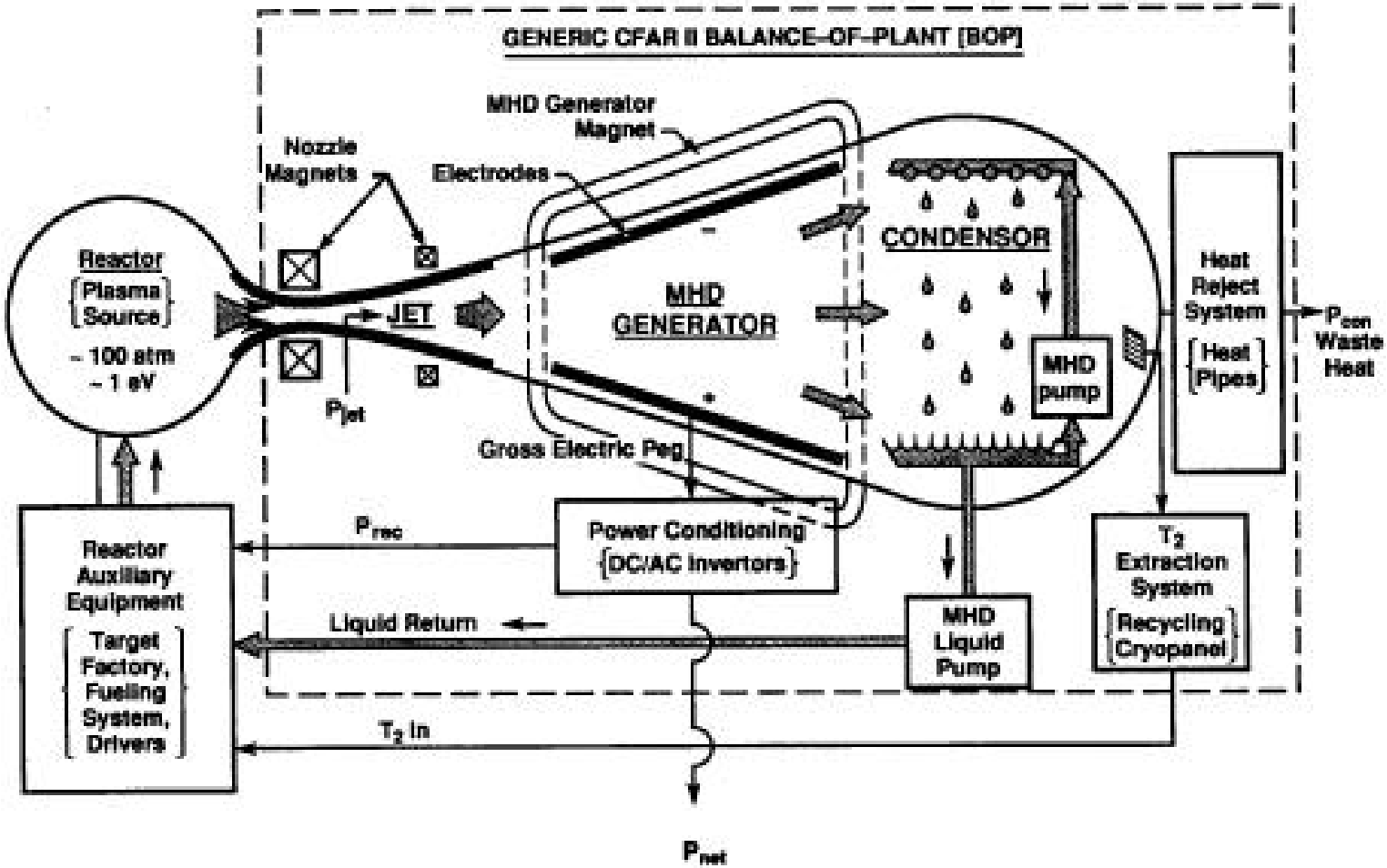


Figure 1 General scheme for Compact Fusion Advanced Rankine (CFARII) MHD-power-conversion cycle

The optimum Flibe blanket outer radius varies slowly with yield

- **The optimum Flibe (fluorine, lithium, and berylium) blanket thickness varies slowly with yield.**

Yield	Blanket Outer Radius r_{outer}	Mass	Energy Capture Fc	COE
5GJ	18cm	50kg	.55	38 (mills/kWe)
10	20	68kg	.60	33
20	25	132kg	.75	30

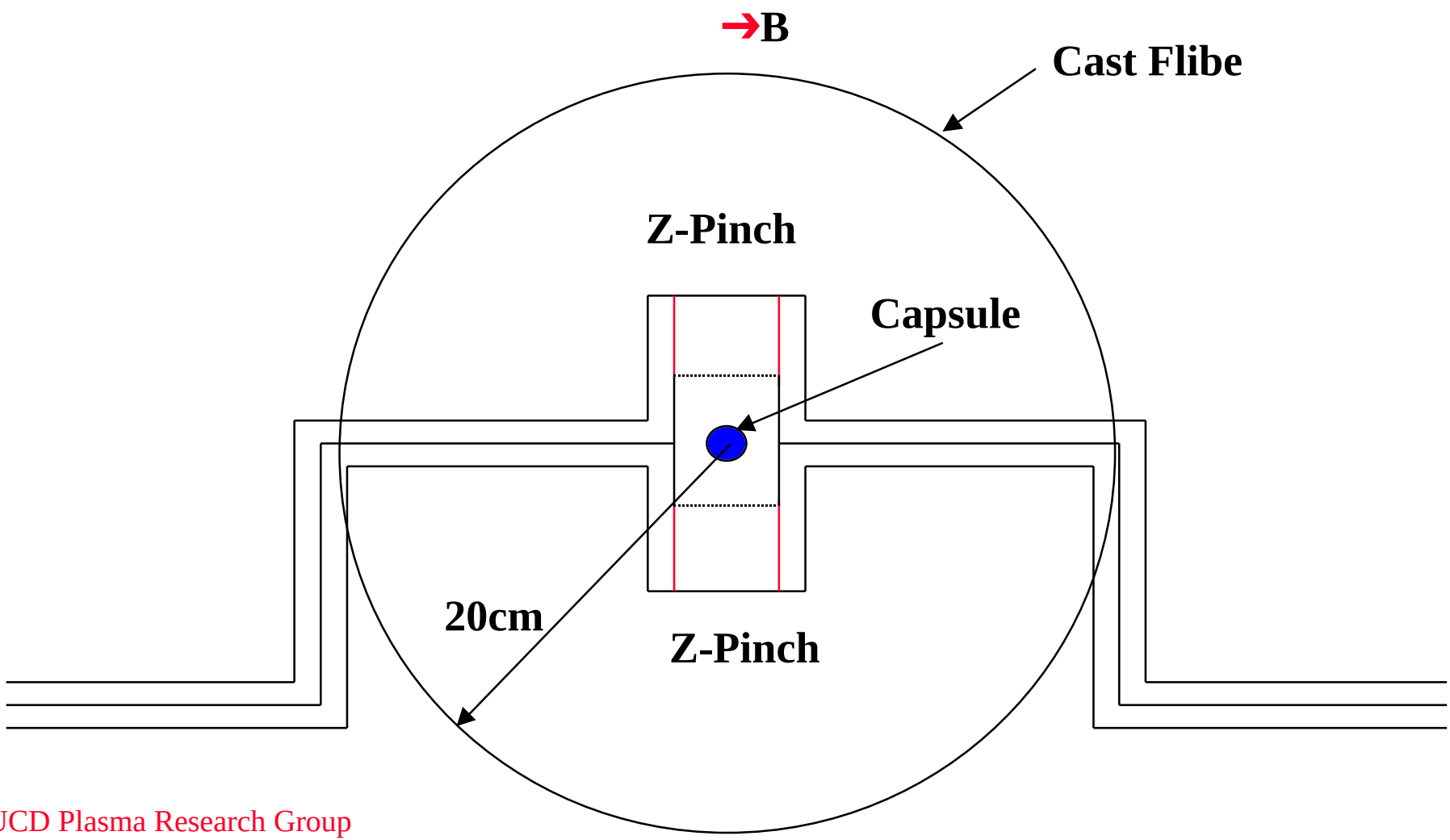
P_{fusion} = 4GW, Fusion Target Gain = 1000, Driver cost = 4$/J
Driver efficiency = 0.2

From: B. G. Logan, Low cost, High Yield IFE Reactors: Revisiting Velikhov's Vaporizing Blankets, Fusion Technology, 21, 1784 (1992).

See also: B. G. Logan, Inertial fusion reactors using Compact Fusion Advanced Rankine (CFARII) MHD conversion, Fusion Engineering and Design 22, 151 (1993).

Most of the fusion energy is deposited in the compact blanket

- Compact blanket



UC Davis z-pinch IFE research program

- **The Plasma Research Group will evaluate the impact of the RTL on power plant design**
  - **The RTL is connected to the target to drive the imploding z-pinch load.**
    - **The connection of the RTL to the permanent MITL must survive.**
    - **The RTL close to the target (fusion capsule + hohlraum) will be transformed into hot plasma and shrapnel.**
    - **The power plant must be designed so that the reactor components are protected from the shrapnel.**
  - **We will calculate**
    - **Neutron and x-ray emission from the high temperature plasma.**
    - **Molecular dynamics calculations of the size distribution of the shrapnel.**
    - **The effect of the shrapnel on the reactor components.**
- **We will also evaluate the viability of direct conversion.**