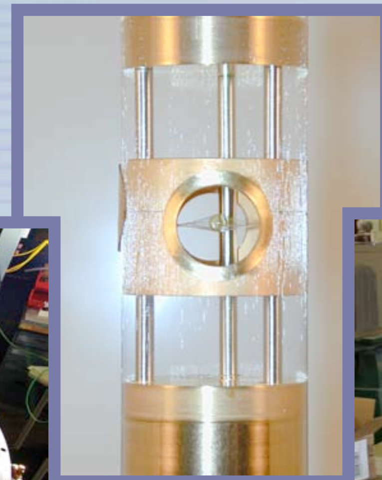
Z-Pinch Inertial Fusion Energy

LTD Cavity



Hohlraum

Recyclable Transmission Line

Fusion Power Associates Annual Meeting and Symposium

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Outline

- **Refurbished *Z***
- **Pulsed power fusion**
- **Linear Transformer Driver technology**
- **Pulsed power IFE**

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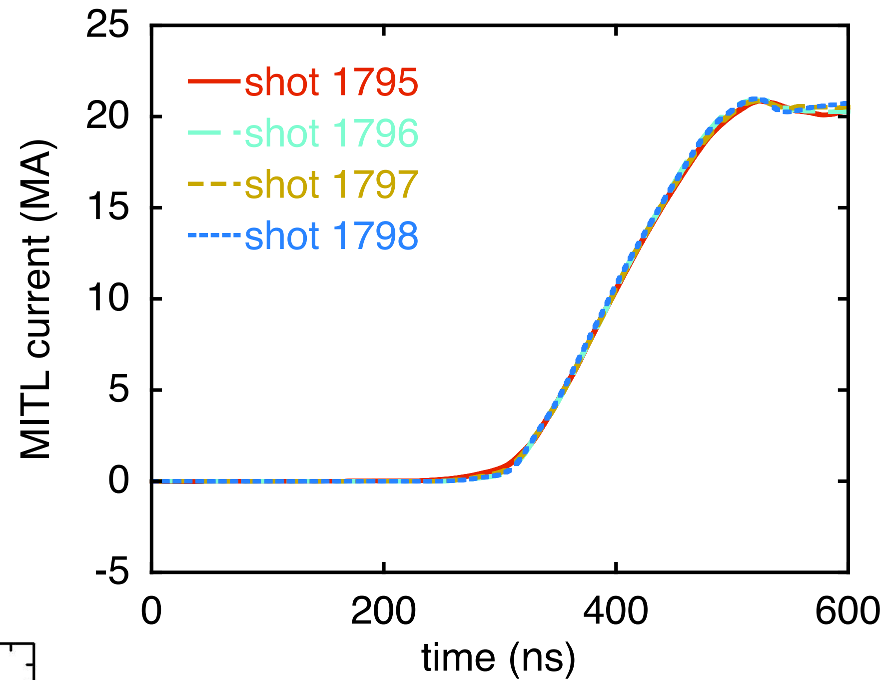
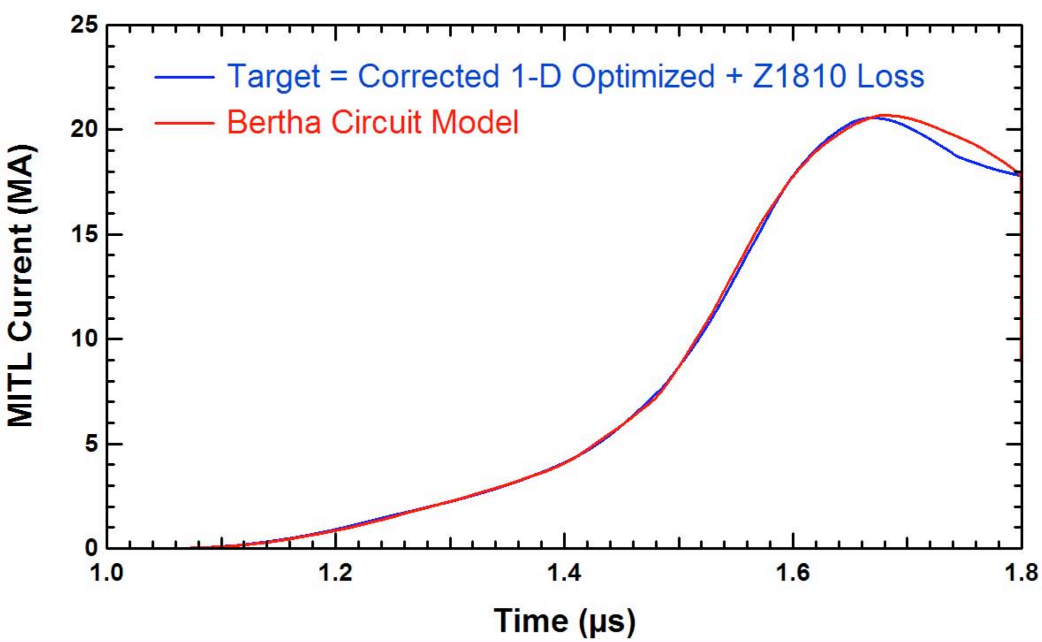
We demonstrated accurate pulse shaping and that th peak MITL current can be reproduced to within 1%

We were required to demonstrate 3% reproducibility for an NNSA milestone

The stretch goal was 2%

We've demonstrated 1%





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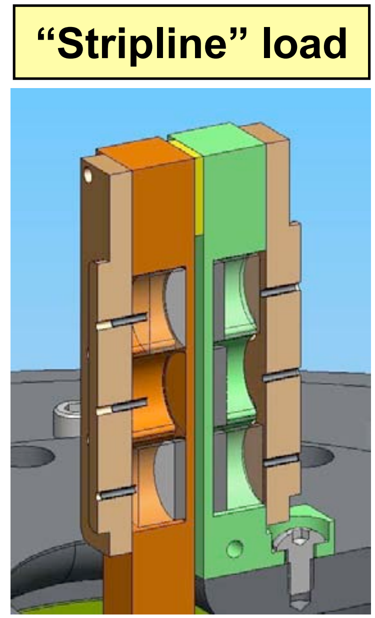
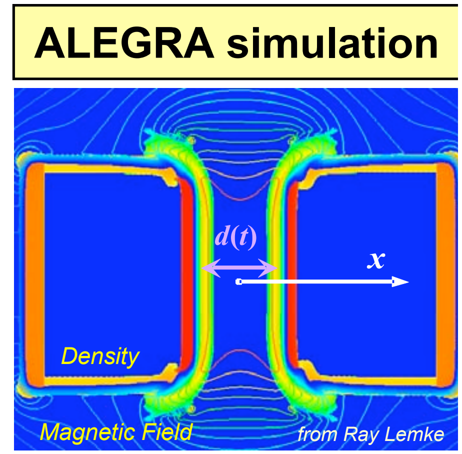
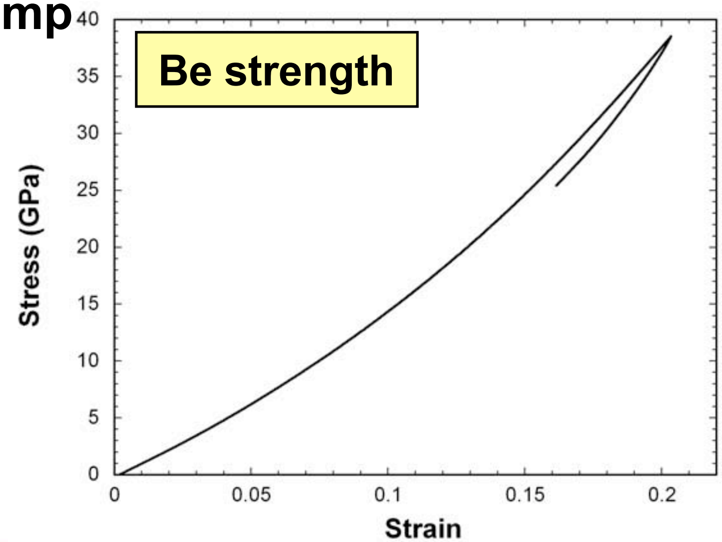
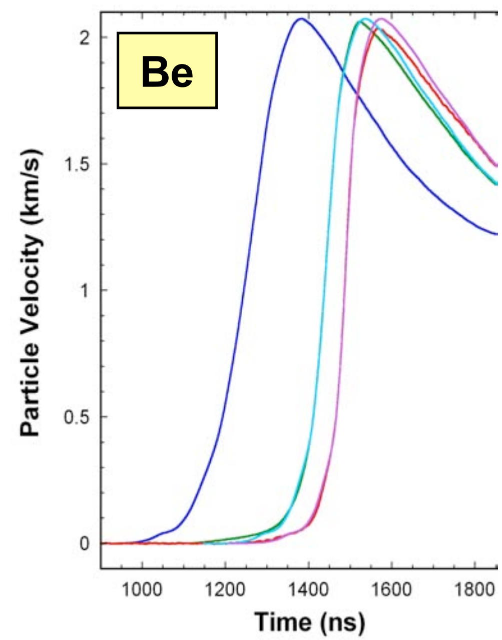
The Z platform provides extremely accurate measurements of material isentropes and Hugoniots

- **Magnetic ramp compression is enabling new regions of a material's phase diagram to be explored under dynamic compression**
- **Refurbished Z significantly increases capability, leading to new and exciting experiments in high-pressure material dynamics**
- **Future direction will be to couple advanced capabilities to ramp compression facilities**
  - Pre-heat capability
  - Sample recovery
  - Advanced diagnostics
    - » pyrometry
    - » x-ray diffraction

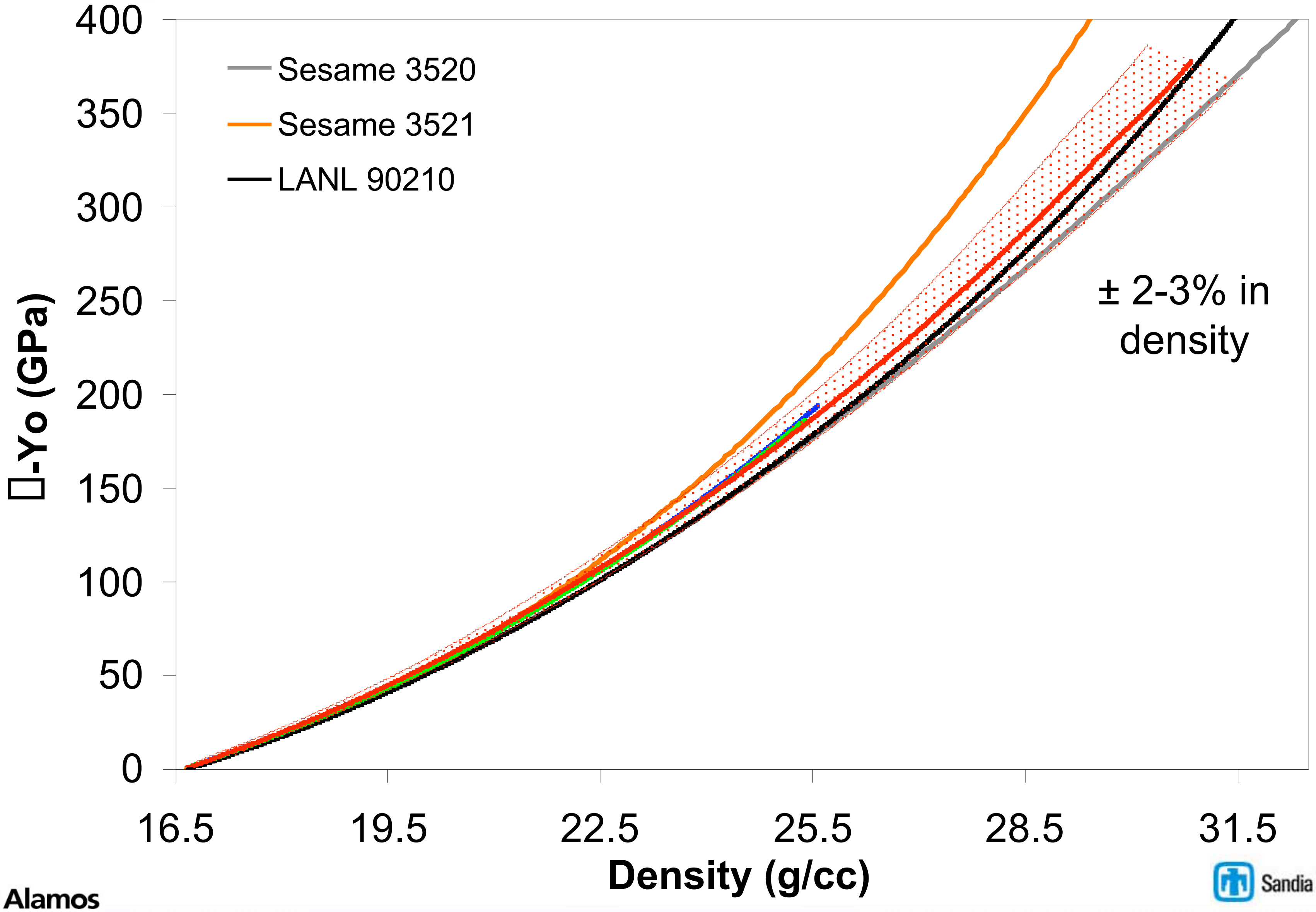








The extracted isentrope discriminates between various tabular equations of state for Ta



Los Alamos

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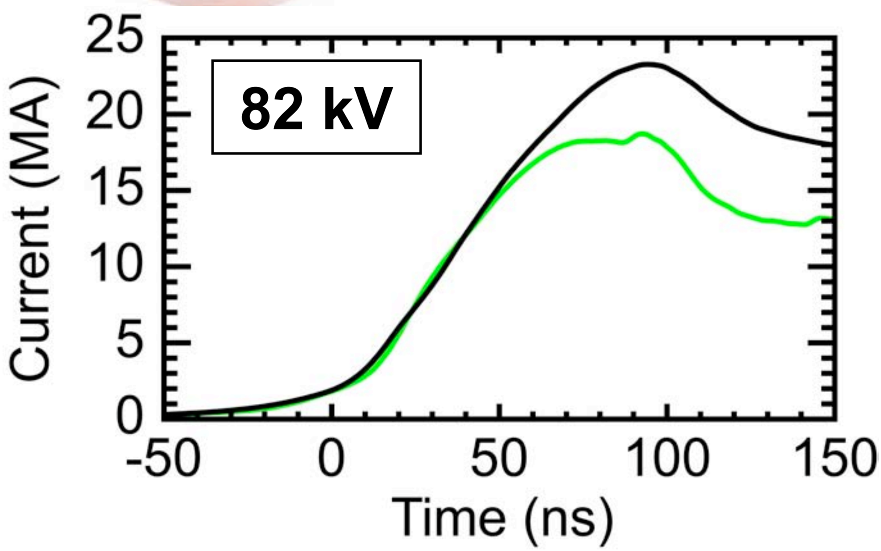
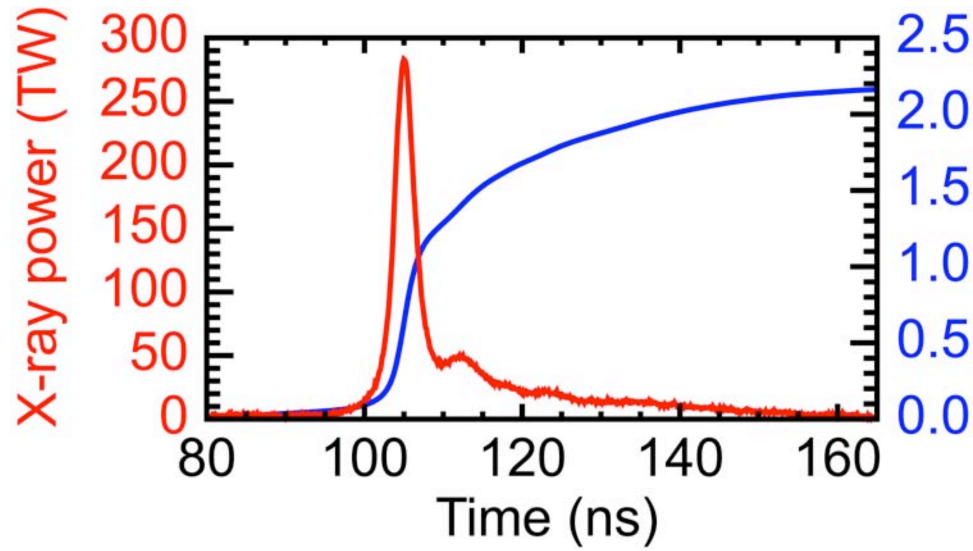
We are establishing radiation effects testing platforms at record x-ray powers and energies





- Large diameter stainless steel wire array implosions are being investigated for ~7 keV K-shell x-ray production
  - 70 kJ, 20 TW of K-shell x-rays on 3 recent shots
- Optimal stainless steel wire arrays on Z previously generated
  - 1 MJ, 150 TW of total soft x-ray radiation
  - 50 kJ, 10 TW of K-shell x-ray radiation

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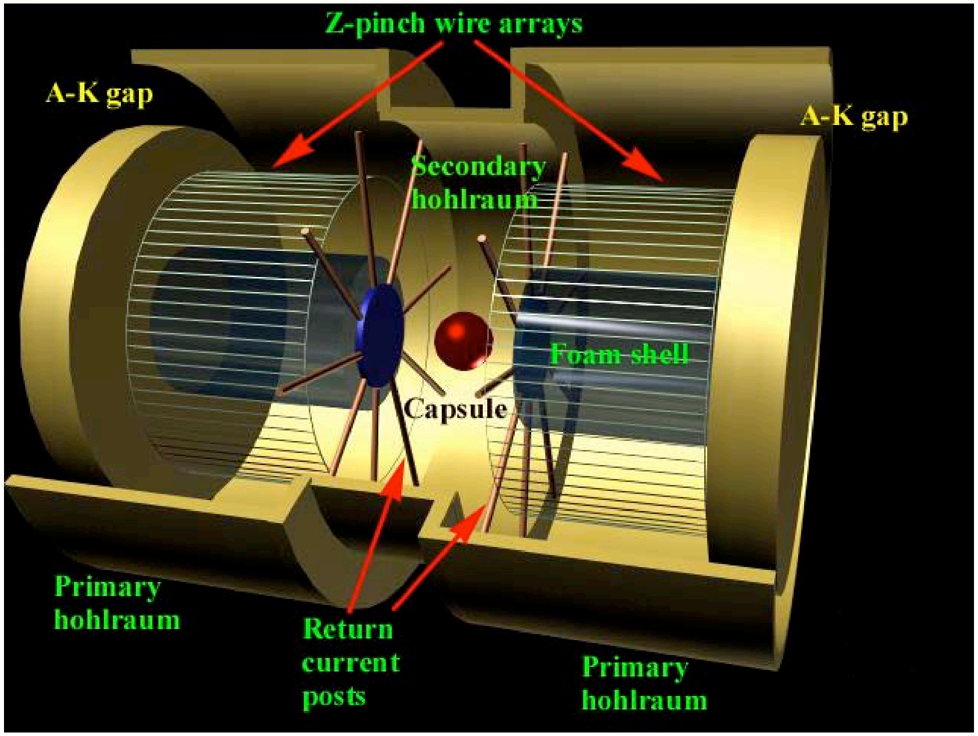
Outline



- Refurbished *Z*
- **Pulsed power fusion**
- Advances in pulsed power technology
- Z-pinch IFE

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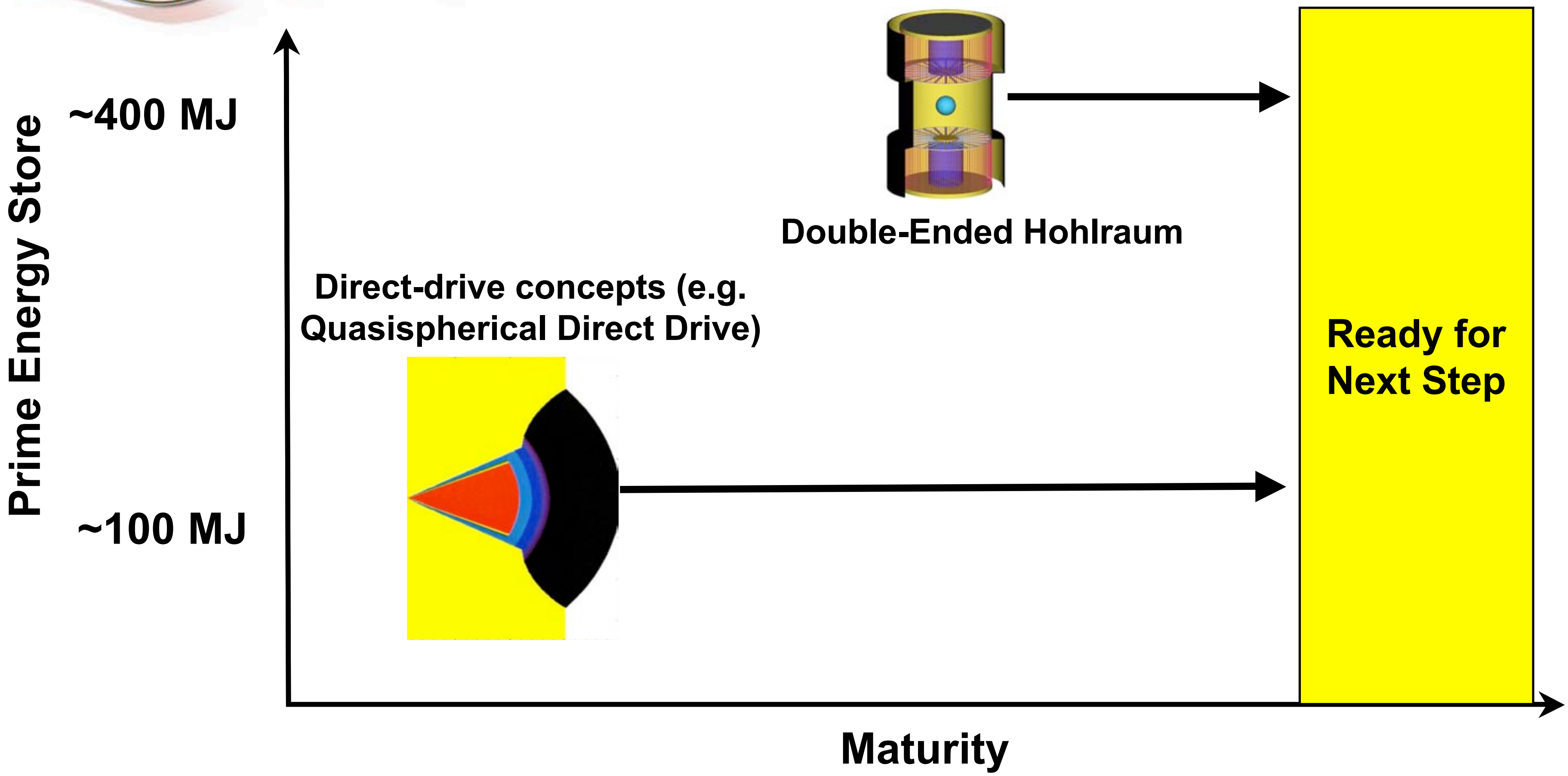
The goal of the pulsed power fusion program is to validate a target design and a machine architecture for a high yield facili



- Demonstrated ~500 MJ yield in 2D hohlraum + capsule simulations
- Robustness of 220 eV capsules is suitable for Z-pinch driven hohlraum
- Developed strategy to control time-dependent hohlraum symmetry
- Capsule absorbs 7% of the z-pinch-generated x-ray energy

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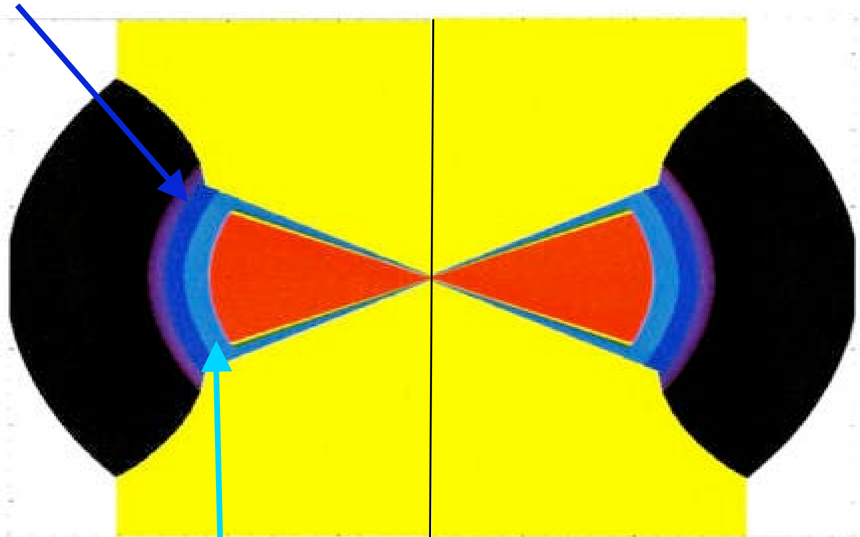
Magnetically driven implosions of a conductor containin fusion fuel could lead to higher coupling efficiency

~2.5 mm radius and
~0.1 mm thick Beryllium
Conductor/Pusher



1.8 mg Cryo DT

Quasispherical Direct Drive concept

- Quasispherical Direct Drive (QSDD) uses magnetic pressure to implode a capsule containing fusion fuel
- Efficient at coupling prime energy to the fusion fuel (as much as ~0.5 - 1%)
- Double Ended Hohlraum is ~0.04% efficient
- QSDD is susceptible to Magneto-Rayleigh-Taylor instabilities
- Calculating a QSDD implosion correctly puts stringent demands on the simulation tools

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Linear Transformer Driver cavity

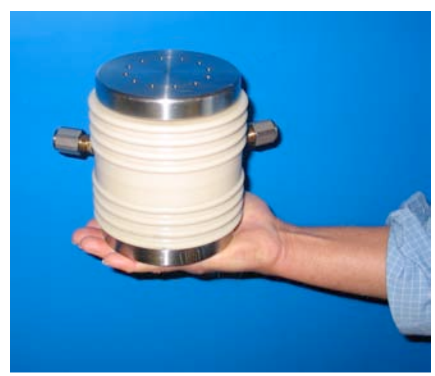
Linear Transformer Drivers (LTDs) are a major advance in pulsed power technology

LTD cavity

- rise time ≥ 70 nsec
- timing jitter = 2 ns (1σ)
- voltage and current reproducibility = 0.3% (1σ)
- peak power = 0.1 TW
- output energy = 11.3 kJ

- LTDs compress stored electrical energy to the desired pulse length in a single stage
- LTDs are composed of simple modules of fast capacitors and 200-kV switches
- LTDs have an efficiency of 70% and can be fired once every 10 seconds

LTD switch



LTD capacitor

We have the hardware to assemble and test a 1-MV, 1-MA LTD module

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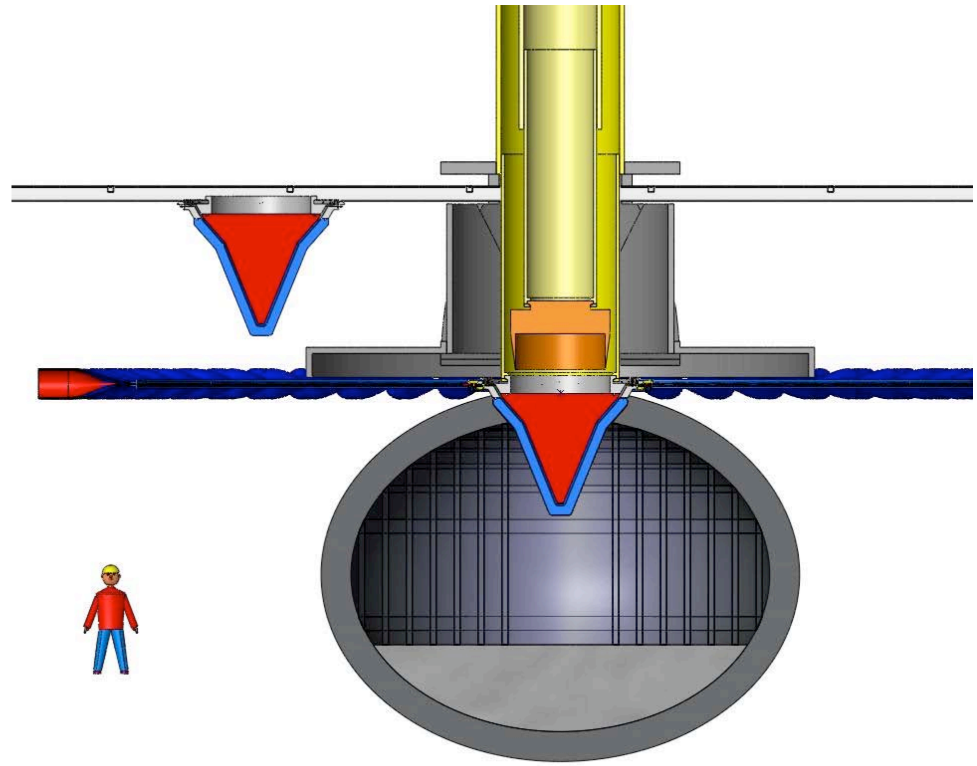

Z is focused on single-shot HED & fusion research; fusion energy is the goal

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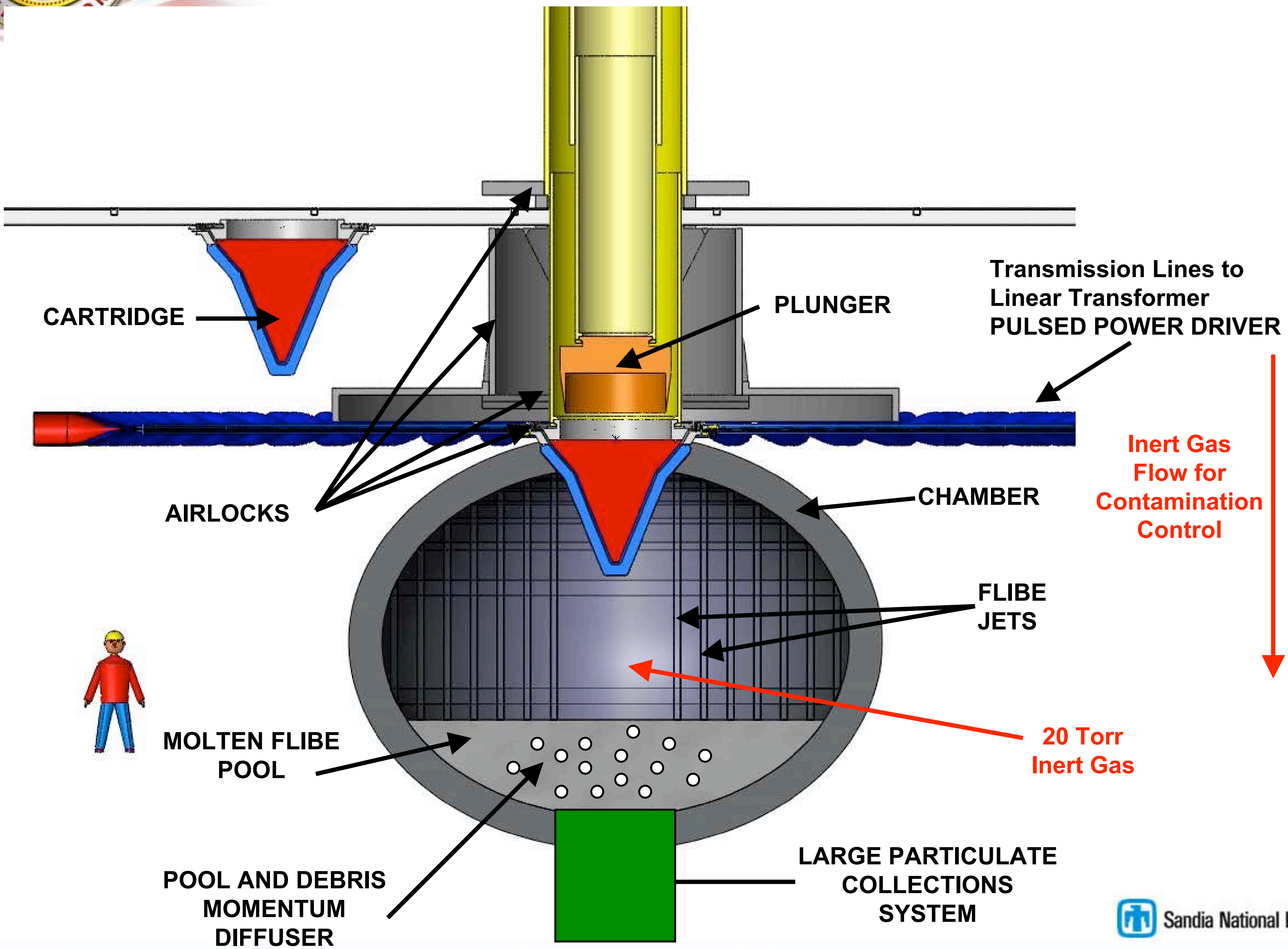
We have invested about $13M on z-pinch related energy research in the last decade

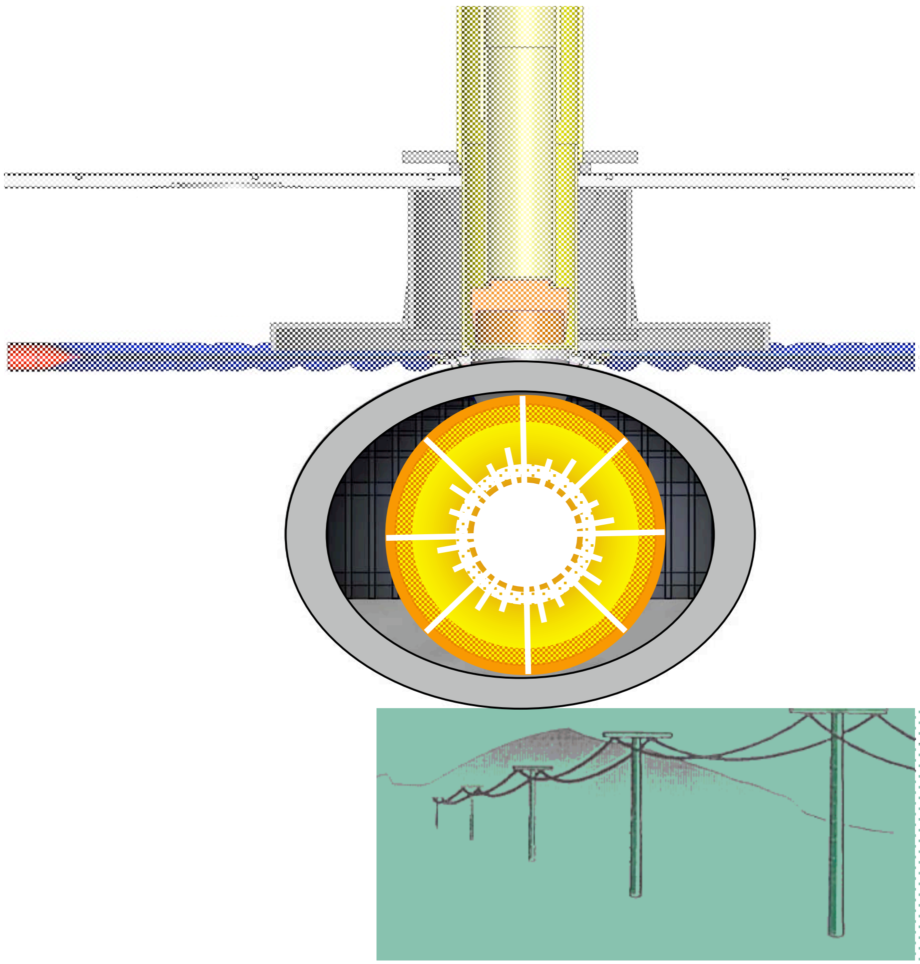
- **Z-Pinch IFE LDRDs/Congressional Initiatives (1999–2006, $11.8M):**
  - repetitive pulsed power drivers
  - recyclable transmission lines
  - high-yield targets
  - thick-liquid wall chamber power plants

- **Z-Pinch Driven Fusion Systems for IFE, Transmutation, and GNEP LDRD (2004-2006, $1.2M):**
  - developed a Z-fusion nuclear waste transmutation concept

The Z-pinch IFE concept uses low rep-rate recyclable transmission lines, high yield targets, and thick liquid walls



Z-Pinch Power Plant Baseline Parameters



Target Yield	3 GJ
Rep. Rate (per chamber)	0.1 Hz
Fusion Power per chamber	300 MWth
Number of Chambers	10
<u>Chamber</u>	
Shape	Spherical or Ellipsoidal
Dimension	4 m internal radius
Material	F82H Steel
Wall Thickness	15-30 cm
<u>Coolant</u>	
Coolant Choice	Flibe
Jet Design	Circular Array
Standoff (Target to First Jet)	0-2 m
Void Fraction	0.05 – 0.67
Curtain Operating Temperature	950 K
Average Curtain Coolant Flow	12 m^3/s
Heat Exchanger Coolant Flow	0.47 m^3/s
Heat Exchanger Temp. Drop	133 K
Pumping Power	1.3 MW/chamber
Heat Cycle	Rankine
Heat Exchanger Type	Shell and Tube

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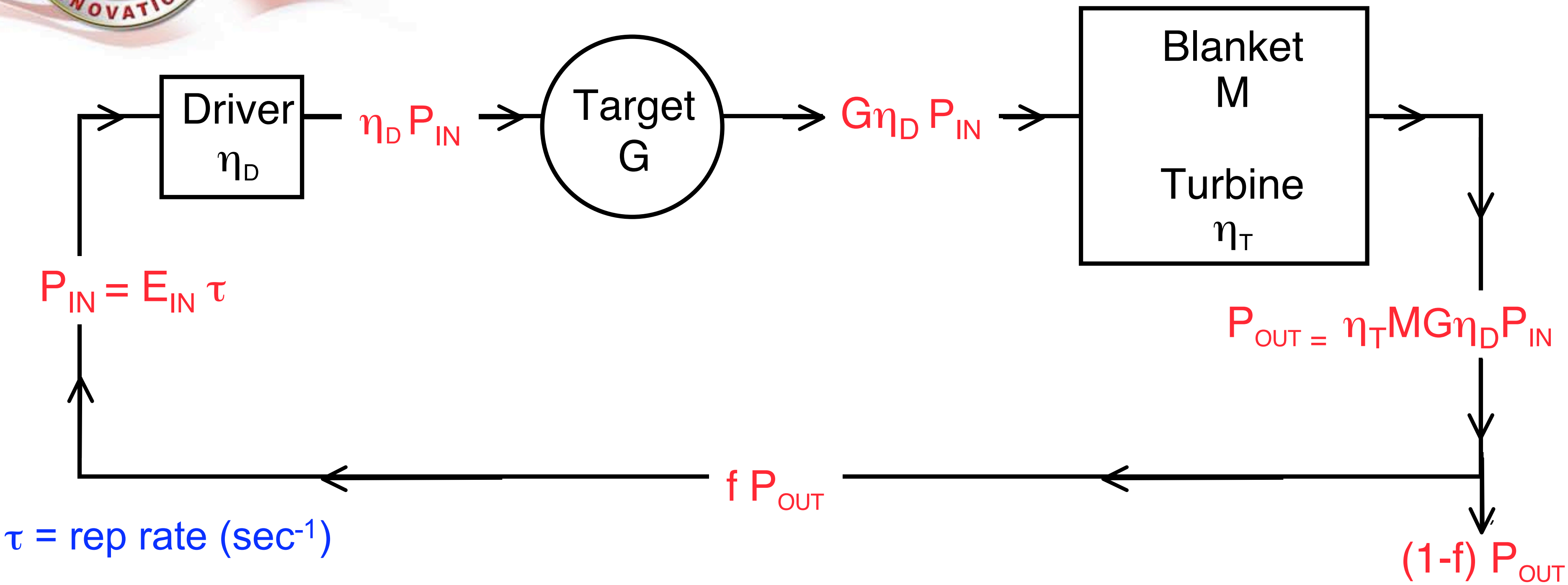
The power cycle of an IFE reactor is described by six parameters: E_{IN}, η_D, τ, G, M, η_T



We want —. With $\eta_T \approx 0.4 \Rightarrow$

Pulsed Power IFE issues and strategy

Pulsed power technology

Increase pulsed power efficiency
(presently 10-15% on Z)
e.g. LTD drivers

Fusion technology

Increase blanket multiplication
(baseline value = 1)
e.g. fission/fusion hybrids

$$f = \frac{1}{\eta_D G M \eta_T}$$

ICF target physics

Increase target gain
(baseline value ~500)
e.g. direct implosions

Power plant technology

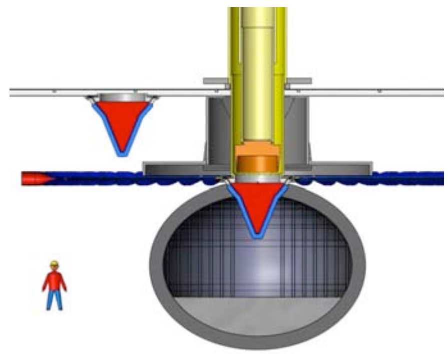
Increase conversion efficiency
(baseline value = 0.35)
e.g. Brayton vs Carnot cycle

Fission-fusion hybrids could provide a technology maturation path to fusion energy

Fusion yield

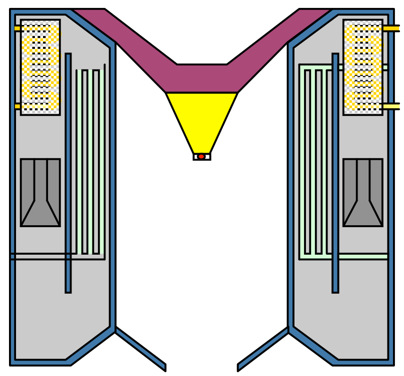
Neutrons
Energy

GJ



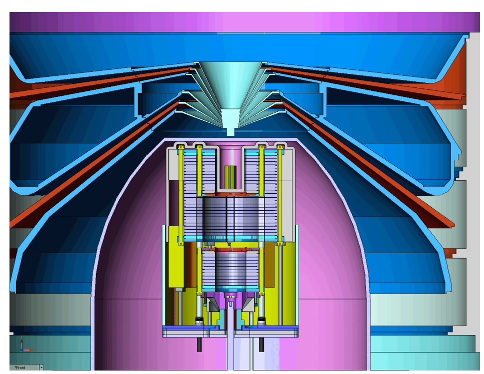
Fusion energy

100 MJ



Burn nuclear waste

10 kJ



Neutron effects testing

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The In-Zinerator requires a modest fusion power (20 MW) and extracts energy from LWR spent fuel

Overall Parameters

Fusion Target Yield	200 MJ
Repetition Rate	0.1 Hz
K_{eff}	0.97
Power per Chamber	3,000 MWth
Transmutation Rate	1,280 kg/yr
Number of Chambers	1

RTL & Target

RTL Material	Tin (or Steel)
RTL Cone Dimensions	1 mØ x 0.1 mØ x 2 m h
Mass per RTL	93 kg (Tin)
Tritium per Target	1.35 m

Chamber Design

Shape	Cylindrical
Dimension	3.2 m outer radius
Chamber Material	Hastelloy-N
Wall Thickness	5 cm

Blanket

Actinide Mixture	$(LiF)_2$-AnF_3
Coolant	Lead
Coolant Configuration	Shell & Tube
First Wall Configuration	Structural Wall
Shock Mitigation	Argon gas & aerosol
Coolant Temperature	950 K
Heat Cycle	Rankine or Brayton

Reports:
- SAND2006-6590 Fusion Transmutation of Waste: Design and Analysis of the In-Zinerator Concept, B. Cipiti et. al, November 2006.
- SAND2007-6487 The Role of Z-Pinch Fusion Transmutation of Waste in the Nuclear Fuel Cycle, B. Cipiti et. al, October 2007.
- Fusion-Fission Hybrids for Nuclear Waste Transmutation: A synergistic Step Between Gen-IV Fission and Fusion Reactors, T. Mehlhorn et. al, Fusion Engineering and Design 2008.

Summary

- The *Z* Refurbishment Project was completed over a year ago; the *Z* facility has been dedicated to weapons science experiments
- Integrated 2D calculations predict pulsed power hot-spot ignition fusion yields in excess of 500 MJ; our near-term focus is now on alternative targets that increase the efficiency of coupling energy to the fusion fuel
- Complementary work on repetitive drivers, target chamber dynamics, and new target concepts strengthen the inertial fusion energy program
- Fission-fusion hybrids offer a science and technology maturation path to inertial fusion energy
- Pulsed power provides a complementary path to fusion energy through
  - Alternative fusion target concepts
  - Efficient, repetitive driver technology
  - A unique approach to couple the driver to the target