SAND2007-2644C

Z-IFE (Z-Pinch Inertial Fusion Energy)

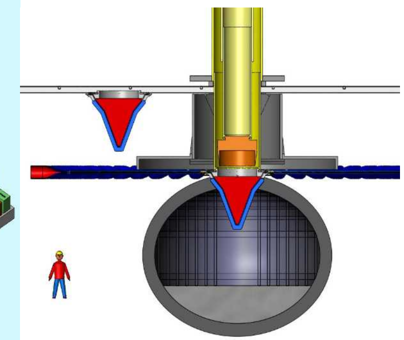
Z-IFE Results
Current Status and Near-Term Plans
Long-Range Vision
Funding needs to move to the next step

RTL

LTD driver

Shock Mitigation

Z-PoP



Chamber

Craig L. Olson
Z-IFE Program Manager

IFE Science & Technology Strategic Planning Workshop
Marriott Hotel
San Ramon, California
April 24-27, 2007

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

The Z-Pinch IFE Team (FY06)

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15) Institute of High Current Electronics, Tomsk, Russia
16) Kurchatov Institute, Moscow, Russia

Z-Pinch is the newest of the three major drivers for IFE

1999 Snowmass Fusion Summer Study, IAEA CRP on IFE Power Plants,
2002 Snowmass Fusion Summer Study, FESAC 35-year plan Panel Report (2003),
FESAC IFE Panel Report (2003)

Major drivers:

Laser	Heavy ion	Z-pinch
(KrF, DPSSL)	(induction linac)	(pulsed power)
	GeV, kA	MV, MA

Targets:

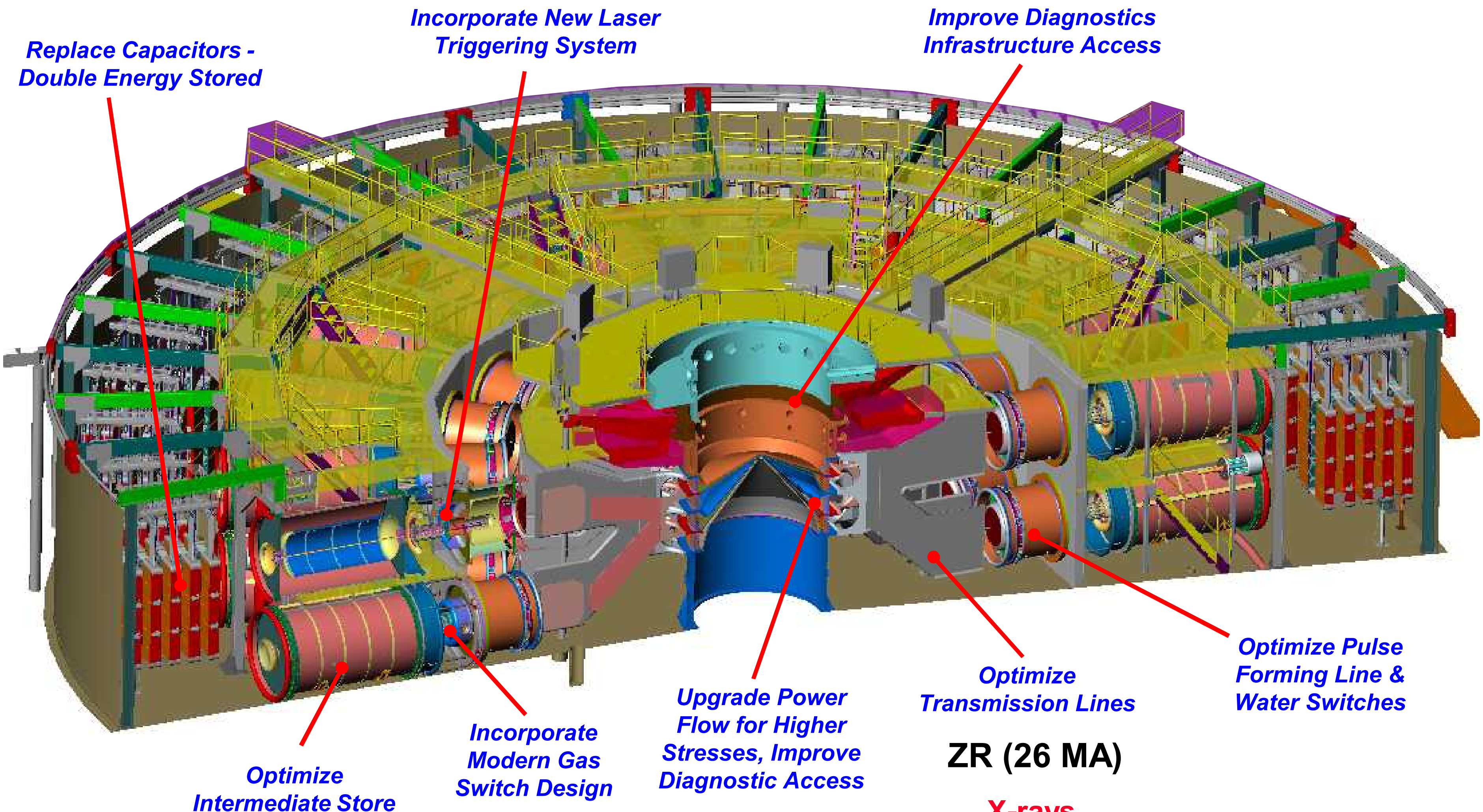
Direct-drive	Indirect-drive	Fast Igniter option (major driver + PW laser)

Chambers:

Dry-wall	Wetted-wall	Thick-liquid wall	Solid/voids

Thick liquid walls essentially eliminate the "first wall" problem, and lead to a faster development path: no new neutron test facilities required

ZR - Refurbishing the Entire Accelerator

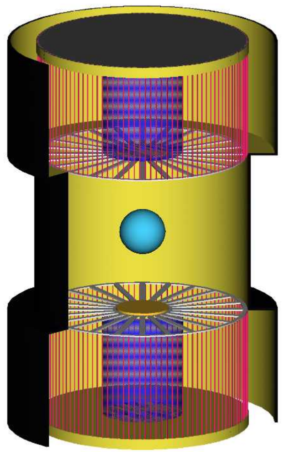


ZR (26 MA)

X-rays
~2.7 MJ
~350 TW

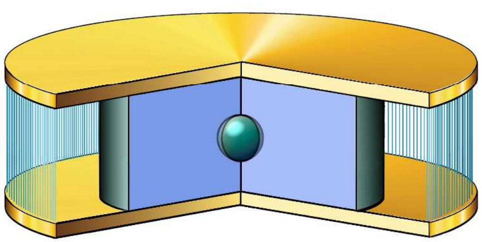
Simulation results and scaling of Z-pinch indirect-drive target concepts for high-yield ICF and Z-IFE

Double-Ended Hohlraum



	ICF → IFE
Peak current	2 x (62 – 116) MA
Energy delivered to pinches	2 x (19 – 67) MJ
Z-pinch x-ray energy output	2 x (9 – 33) MJ
Capsule absorbed energy	1.2 – 8.6 MJ
Capsule yield	400 – 4500 MJ
	G~11 G~34

Dynamic Hohlraum



Peak current	56 – 95 MA
Energy delivered to pinch	14 – 42 MJ
Capsule absorbed energy	2.4 – 7.2 MJ
Capsule yield	530 – 4600 MJ
	G~38 G~110

J. Hammer, M. Tabak (LLNL) J. Lash, S. Slutz, R. Vesey, W. Stygar

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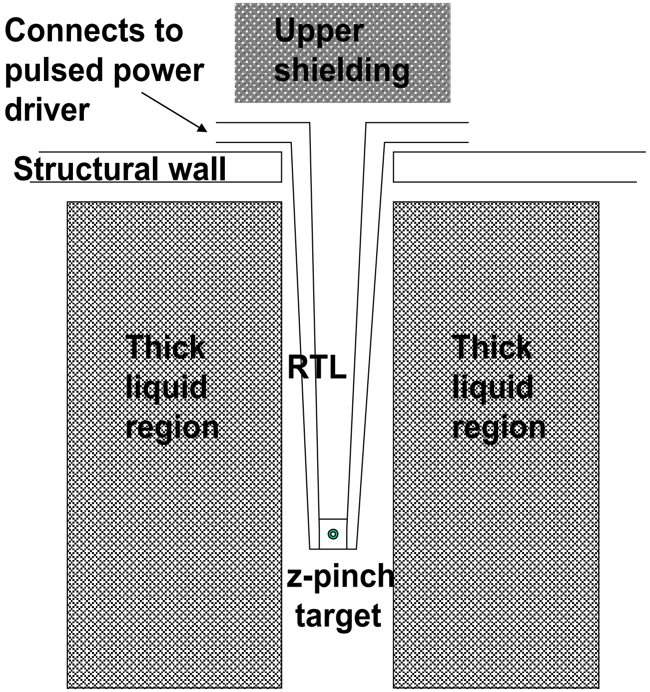
Recyclable Transmission Line (RTL) Concept for Z-Pinch IFE



Yield and Rep-Rate: few GJ every 3-10 seconds per chamber (0.1 Hz - 0.3 Hz)
Thick liquid wall chamber: only one opening (at top) for driver; nominal pressure (10-20 Torr)
RTL entrance hole is only 1% of the chamber surface area (for R = 5 m, r = 1 m)
Flibe absorbs neutron energy, breeds tritium, shields structural wall from neutrons
Neutronics studies indicate 40 year wall lifetimes
Activation studies indicate 1-1.5 days cool-down time for RTLs
Studies of waste steam analysis, RTL manufacturing, heat cycle, etc. in progress

- Eliminates problems of final optic, pointing and tracking N beams, and high-speed target injection
- Requires development of RTL

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Z-Pinch IFE Power Plant has a Matrix of Possibilities

Repetitive Z-Pinch Driver:

- Marx generator/ water line technology
- magnetic switching (RHEPP technology)
- linear transformer driver (LTD technology)

RTL (Recyclable Transmission Line):

- frozen coolant (e.g., Flibe/ electrical coating)
- immiscible material (e. g., carbon steel)

Target:

- double-pinch
- dynamic hohlraum
- advanced targets
- fast ignition

Chamber:

- dry-wall
- wetted-wall
- thick-liquid wall
- solid/voids (e. g., Flibe foam)

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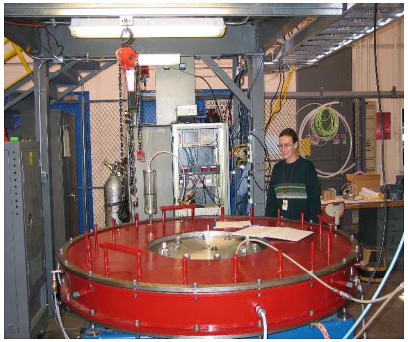
Recent Results in Z-IFE

1. RTLs
   - simulations (> 5 MA/cm works)
   - experiments (> 5 MA/cm works)
   - fabrication of PoP-size RTLs and pressure testing

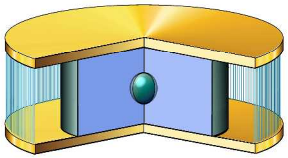
2. LTD repetitive driver
   - 0.5 MA, 100 kV LTD cavity fires every 10 seconds
   - 1.0 MA, 100 kV LTD cavities (5) voltage-adder tests
   - full IFE driver architectures



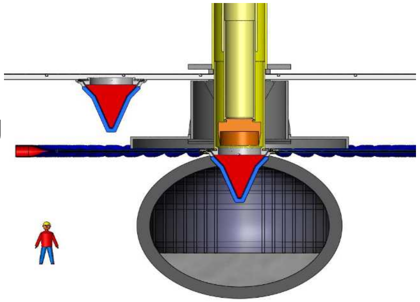
3. Shock mitigation
   - theory
   - experiments: water ring/explosives
     foamed liquids
     shock tube/foams
   - simulations

4. Z-PoP planning
   - vacuum/electrical connections
   - overhead automation animations
   - costing

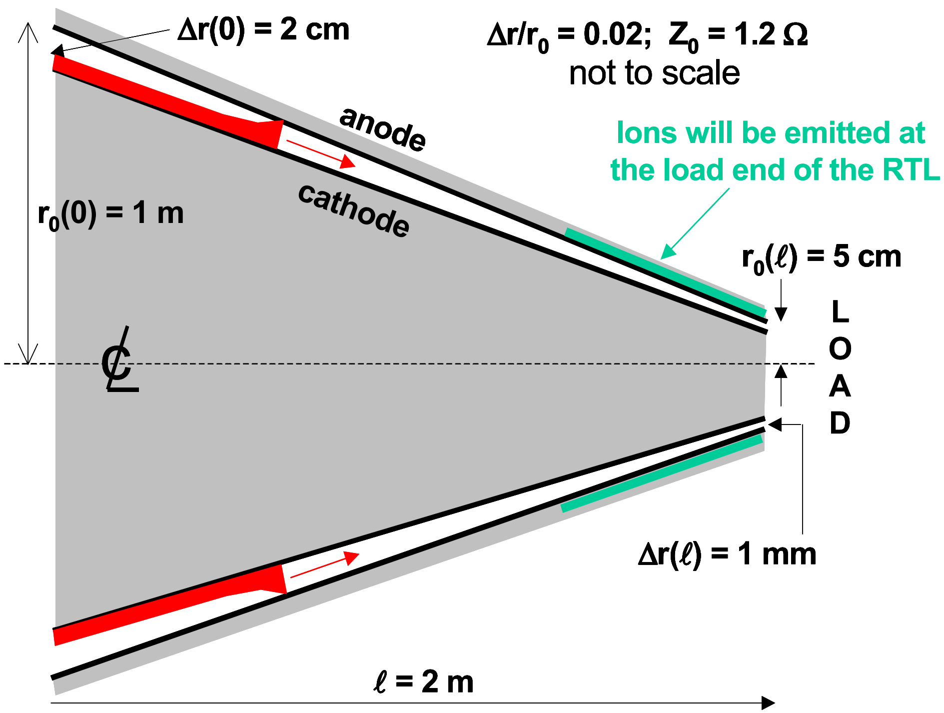
5. Z-IFE targets for 3 GJ yields
   - gains ~ 50-100
   - double-pinch/dynamic hohlraum
   - advanced targets
   - scaling studies



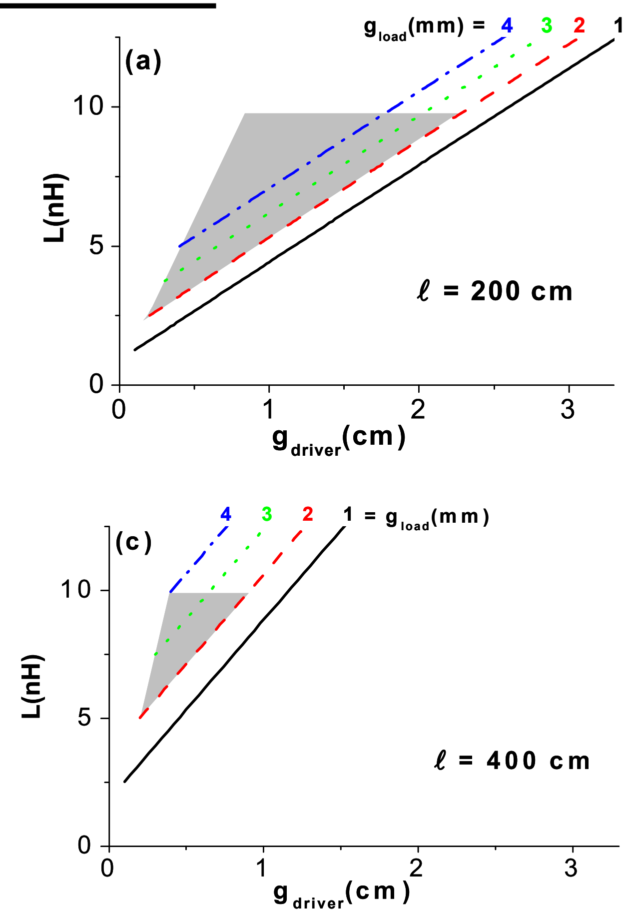
6. Z-IFE power Plant
   - RTL manufacturing/costing
   - wall activation studies: 40 year lifetime
   - power plant design +GNEP, transmutation



The physics of electron and ion flow in RTLs has been studied analytically and with LSP simulations: AK gaps at the load should be ≥ 2 mm



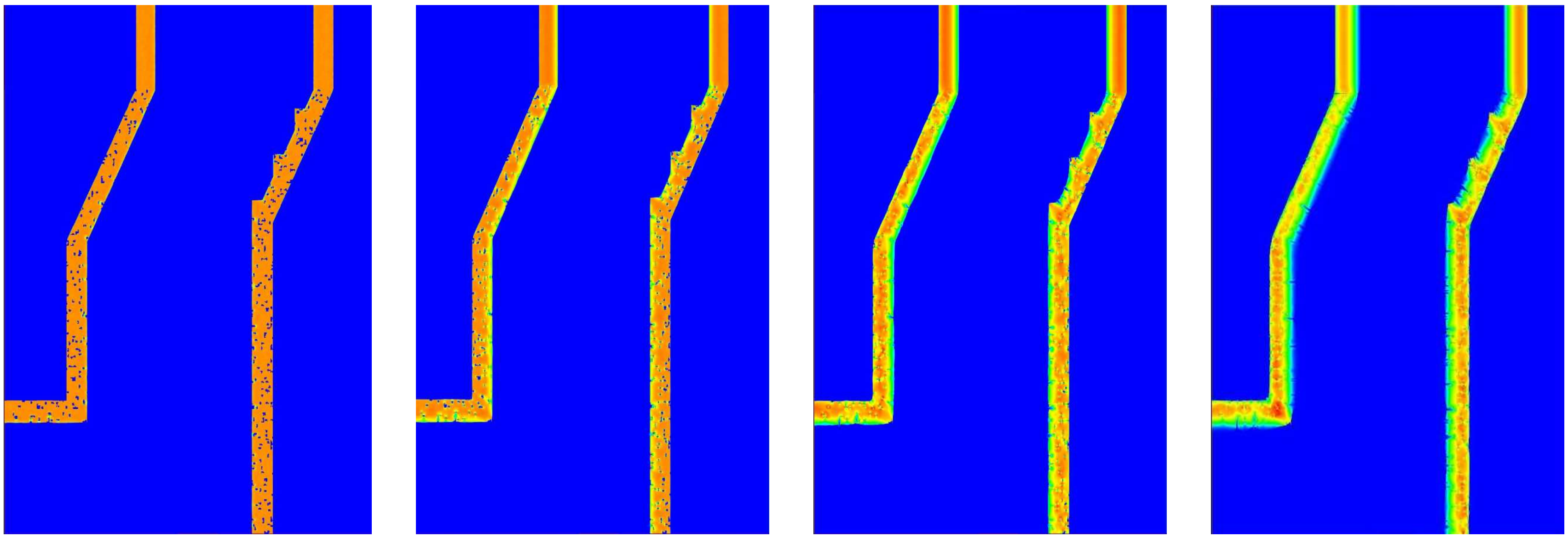
Conical tapered RTL for the baseline Z-IFE design. Power is fed in from the left.



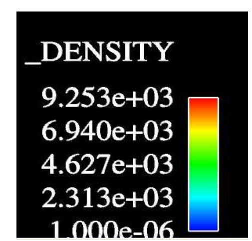
RTL inductance as a function of AK gap at the input end for various values of AK gap at the load. Shaded area are allowed design areas.

P. Ottinger, J. Schumer (NRL)

ALEGRA simulations of RTL with random imperfections still shows robust power flow



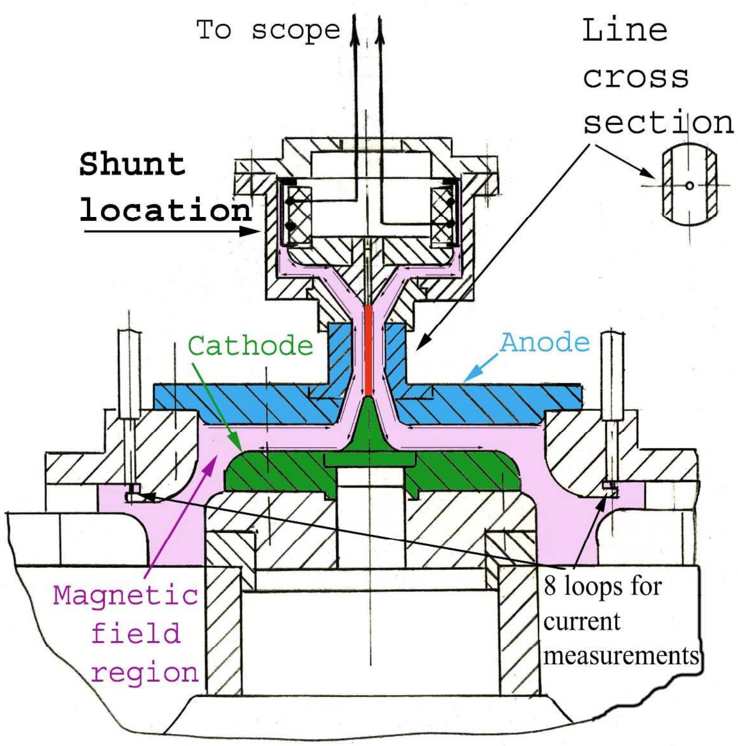
t = 15 ns | 30 ns | 45 ns | 60 ns



AK gap: 2 mm
RTL wall thickness: 0.025 inches = 635 microns
Power pulse: rising to 60 MA in 100 ns

S. Rosenthal, K. Cochrane (SNL)

Experiments and simulations at Kurchatov show plasma formation does not result in gap closure at 6 MA/cm.



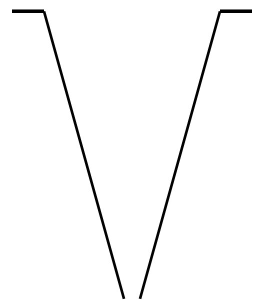
Experiment on S-300 at Kurchatov Institute, Moscow, Russia

The series of experiments has been carried out aimed at the investigation of the MITL section at the linear current densities up to 6 MA/cm that is typical of the Pulsed Power Fusion Energy plant. The temporal behavior of both input and output current in the MITL section is identical up to 220-260 ns. At this stage, it has been found that the plasma formed as a result of electrodes surface explosion, did not reconnect the MITL gap. The process of electrodes explosion and subsequent dense plasma dynamics fairly corresponds to the predictions of numerical simulations based on the 1-D MHD NPINCH code taking into account EOS for metals and plasmas.

V. Smirnov, A. Kingsep, et al. (Kurchatov, Moscow)

RTL sizes

Power Plant



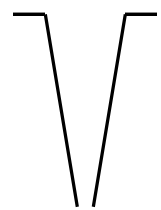
R = 100 cm

L = 200 – 500 cm

r = 5 cm

Test RTLs

Fabricated and pressure tested



R = 50 cm

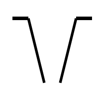
L = 200 cm

r = 5 cm

thickness: 0.025 inches (635 microns)

Z-PoP

Fabricated and pressure tested



R = 16 cm

L = 64 cm

r = 2-5 cm

(For 10 module Z-Pop, with10 MA, gives 0.1 MA/cm at clamp – same as for 60 MA with R = 100 cm)

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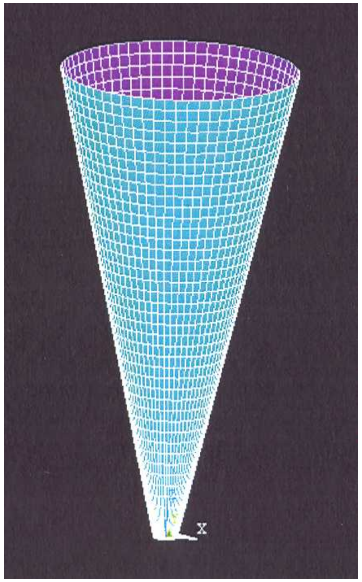
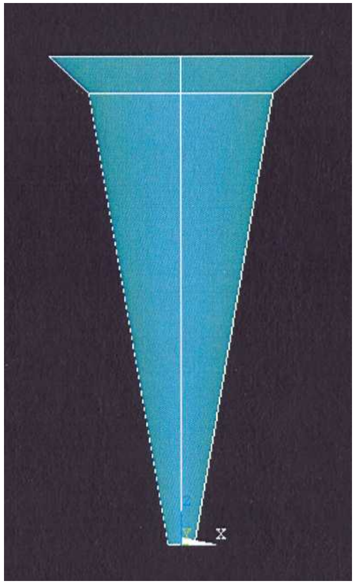
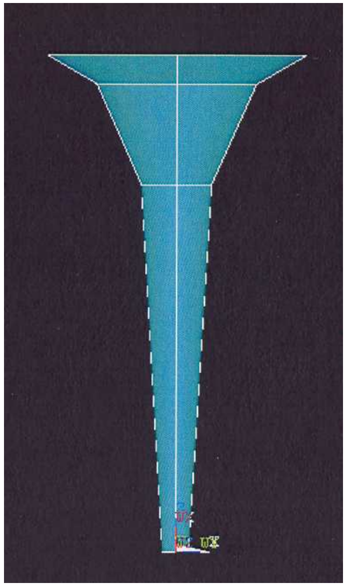
RTL buckling mode analysis leads to optimized RTL shape, that permits lower mass RTLs



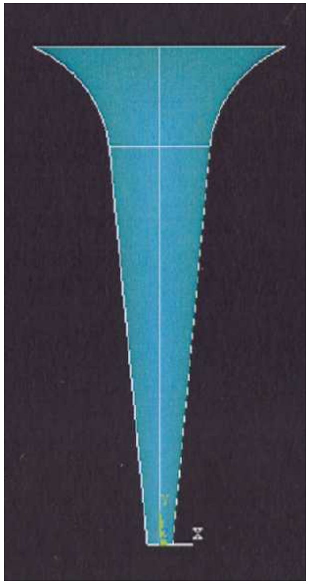
Single segment RTL



Two-segment RTL



Three-segment RTL



Curved RTL

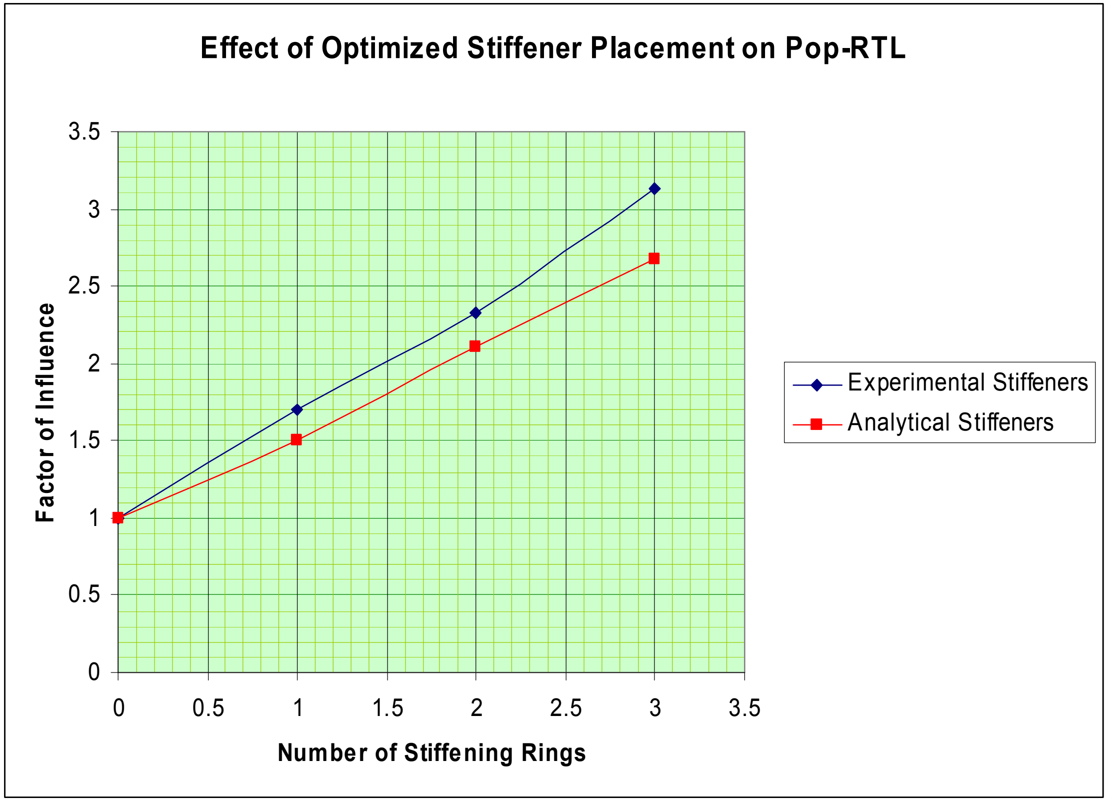
RTL design	Eigenbuckling Pressure (dyne/cm^3)	Enhancement over single-segment
single-segment	249,755	1.0
two-segment	490,117	1.96
three-segment	730,507	2.92
curved	748,966	3.00

D. Kammer, B. Wilson (University of Wisconsin)

(22) PoP-RTLs were constructed and pressure tested to buckling with various stiffening rings

PoP-RTL cone made by Toledo Metal Spinning

Stiffening rings mounted to PoP- RTL cone

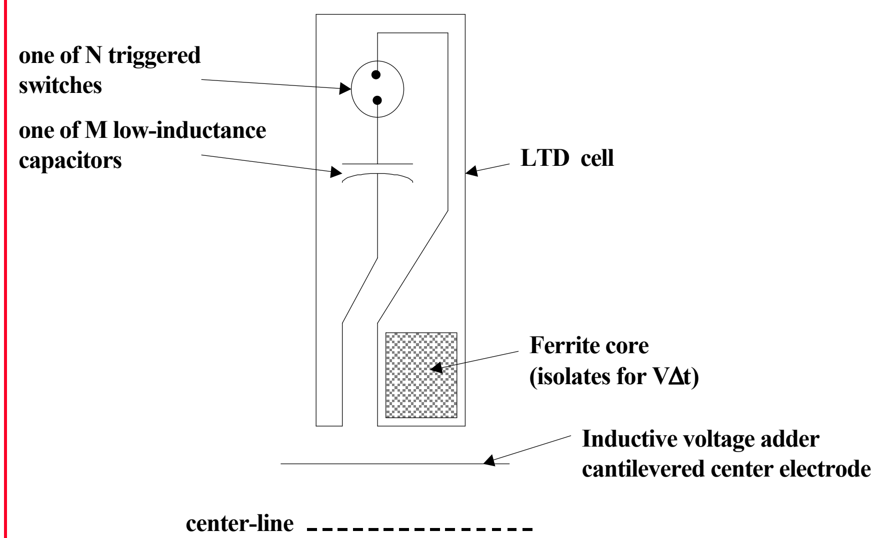


Stiffeners significantly increase the structural performance of the PoP-RTL without adding significant mass

M. Turgeon (SNL), M. Barkey (U. Alabama)

Linear Transformer Driver (LTD) technology is compact and easily rep-rateable

- LTD uses parallel-charged capacitors in a cylindrical geometry, with close multiple triggered switches, to directly drive inductive gaps for an inductive voltage adder driver (Hermes III is a 20 MV inductive voltage adder accelerator at SNL)
- LTD requires no oil tanks or water tanks
- LTD accelerator volume about 1/4 -1/3 the volume of Marx/water line technology (as used in Saturn and Z)
- LTD pioneered at Institute of High Current Electronics in Tomsk, Russia



Modular

High Efficiency

Low Cost (estimates are ~1/2 that for Marx/water line technology)

Easily made repetitive for 0.1 Hz

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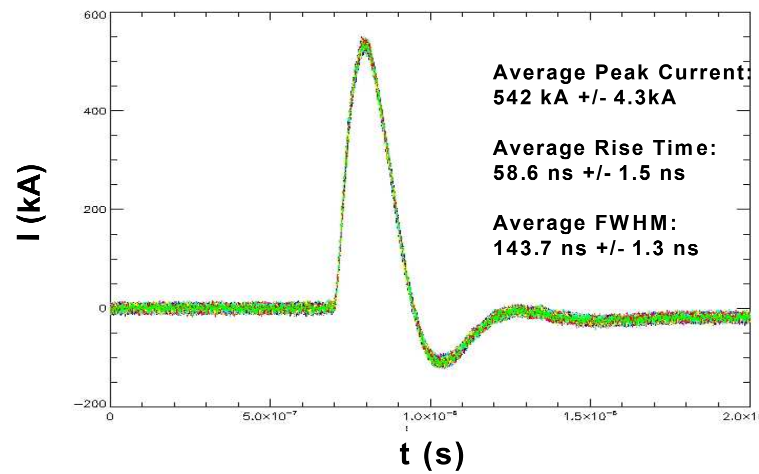
Repetitive, 0.5 MA, 100-kV LTD Cavity is in operation at SNL

SNL high current LTD Laboratory



Overlay of 100 shots at 0.03 Hz
for 90 kV charging

40 Maxwell 31165 caps,
20 switches, ±100 kV
0.2 Ohm load   0.05TW

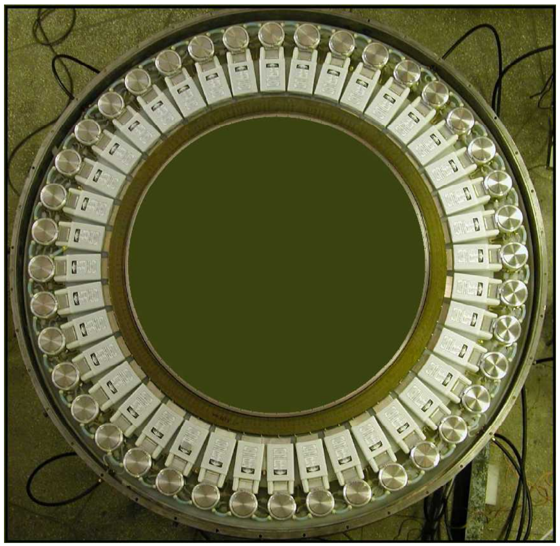
At SNL: This 0.5 MA cavity has been fired in repetitive mode for ~3000 shots; the last set of 50 shots with one shot every 10.25 seconds (~0.1 Hz)

At Tomsk: One switch has been fired 37,000 shots with one shot every 12 seconds (~0.08 Hz)

M. Mazarakis, W. Fowler, R. Sharpe (SNL)   A. Kim (HCEI, Tomsk)

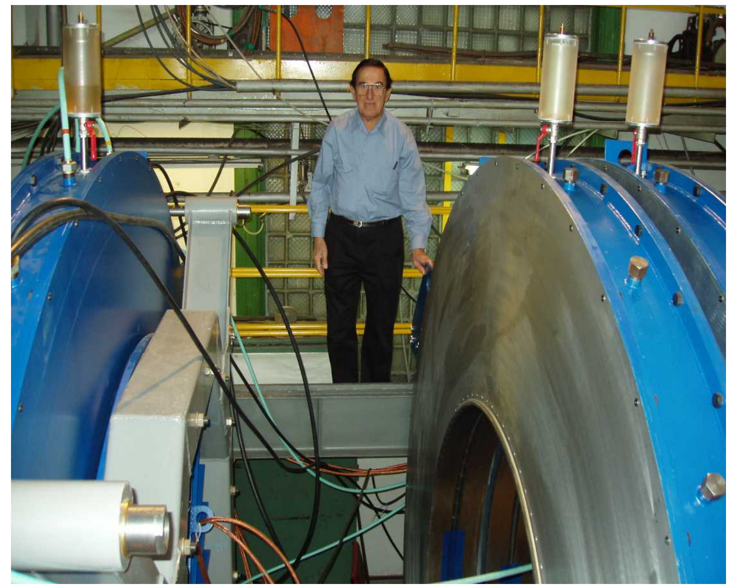
Five 1.0 MA LTD cavities have been built in Tomsk, Russia (this is the building block for Z-PoP and future Z-IFE drivers)

3-m



1-MA, 100kV, 70ns LTD cavity (top flange removed)

80 Maxwell 31165 caps,
40 switches, ±100 kV
0.1 Ohm load 0.1TW



Test stand for Voltage adder testing of five 1.0 MA LTD cavities (High Current Electonics Institute – Tomsk, Russia)

September 2006

M. Mazarakis, et al. (SNL) A. Kim, et al. (HCEI, Tomsk)

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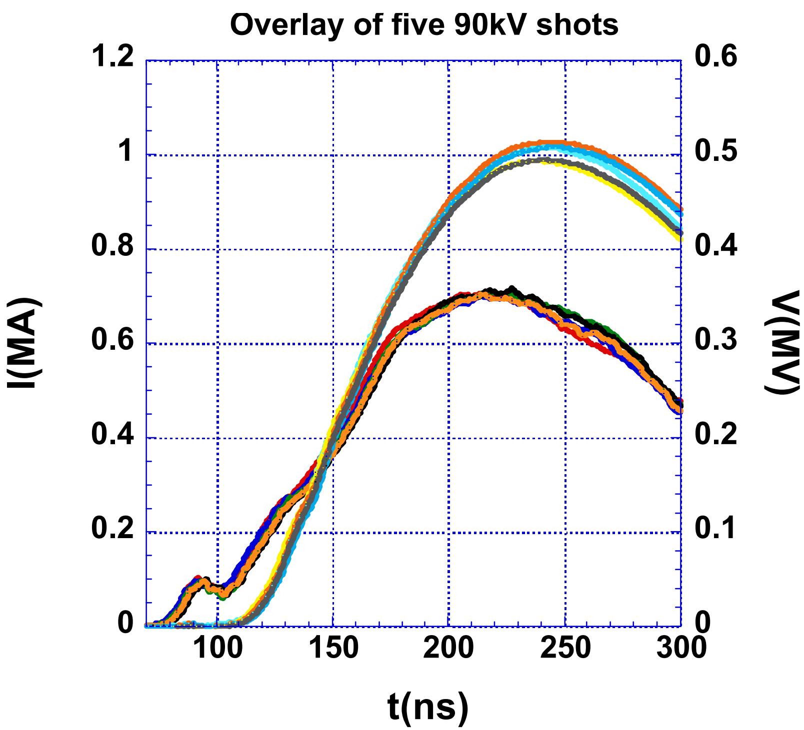
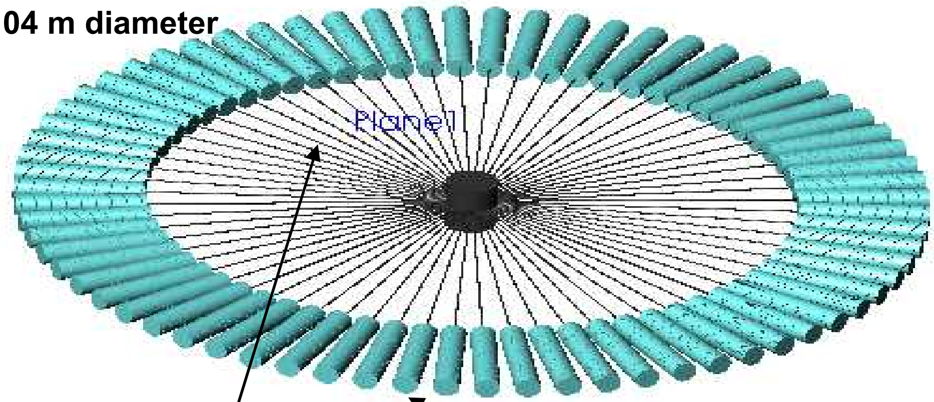
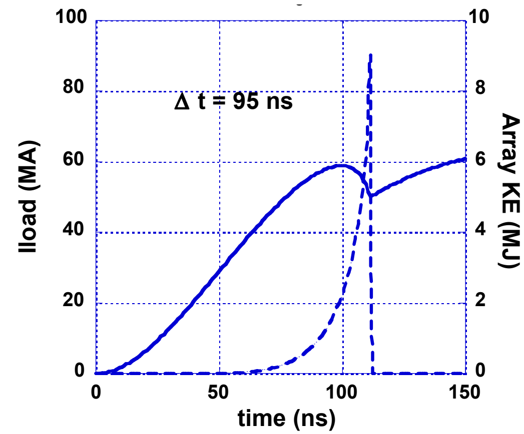
Five 1 MA LTD cavities were tested in a voltage-adder configuration at HCEI, Tomsk



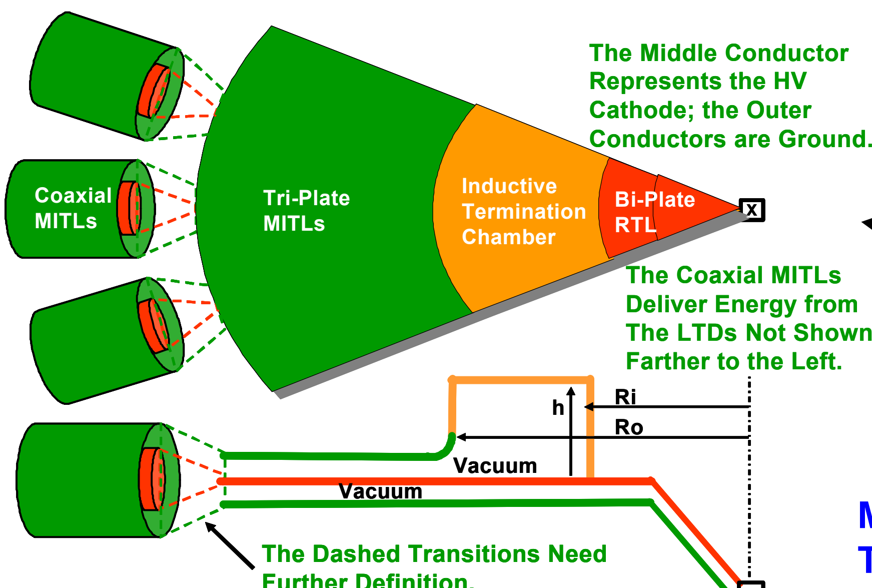
M. Mazarakis, et al. (SNL)   A. Kim, et al. (HCEI, Tomsk)

An IFE driver (60 MA), with seventy 1-MA voltage-adder modules, each with 70 LTD cavities (SNL)





55 mg array load



Top pie-section and side views of the Coaxial to Tri-Plate to Bi-Plate transition geometry

M. Mazarakis, D. Smith,
T. Pointon, W. Langston (SNL)

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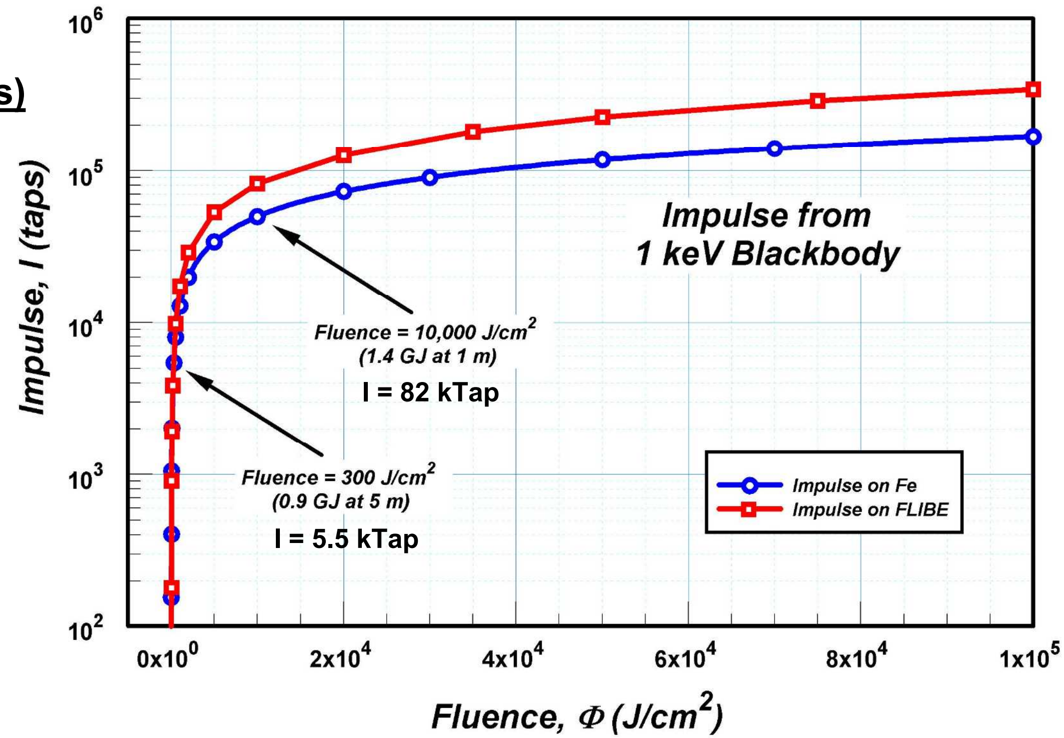
Shock mitigation methods are being investigated to reduce the x-ray shock impulse on the thick liquid wall before it reaches the structural wall

Example: 3 GJ yield (0.9 GJ in x-rays)

Flibe at 1 m radius:
X-ray fluence is 7 kJ/cm^2
Peak pressure is 45 Mbar
Impulse is 34 kTap

Flibe at 5 m radius:
X-ray fluence is 300 J/cm^2
Peak pressure is 1.8 Mbar
Impulse is 1.4 kTap



Typical Lethality Response Levels:
- Light-weight structure (*e.g.*, satellite)
  - > 1 to 10 ktaps *
- Medium-weight structure (*e.g.*, airframe)
  - > 10 to 30 ktaps
- Robust structure (*e.g.*, RV)
  - > 30 to 80 ktaps

Impulse needs to be reduced by a small factor (1.5 or more) before it reaches the structural wall

(1 kTap = 100 Pa s = 1 Mbar ns)

J. Lawrence, L. Chabildas (SNL)

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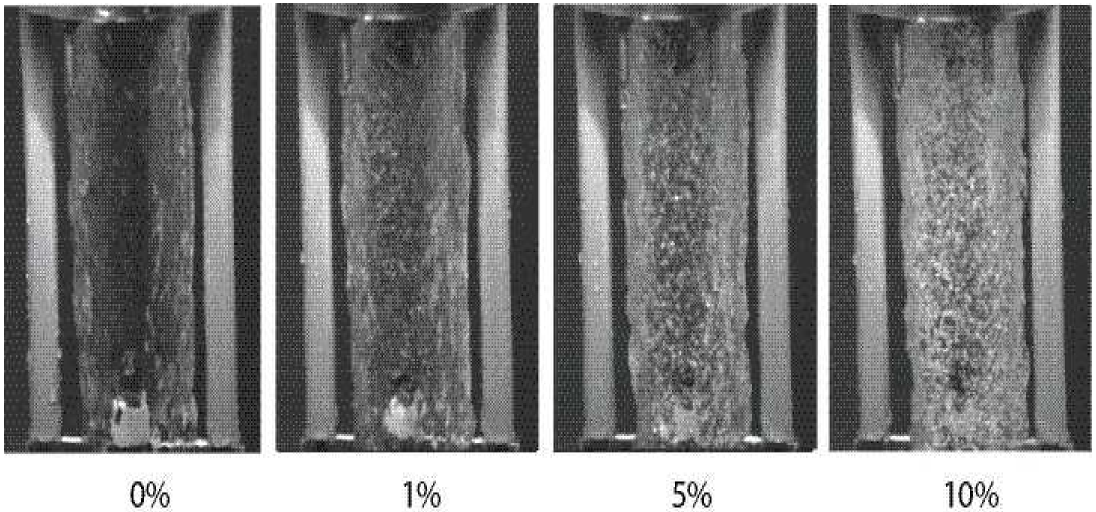
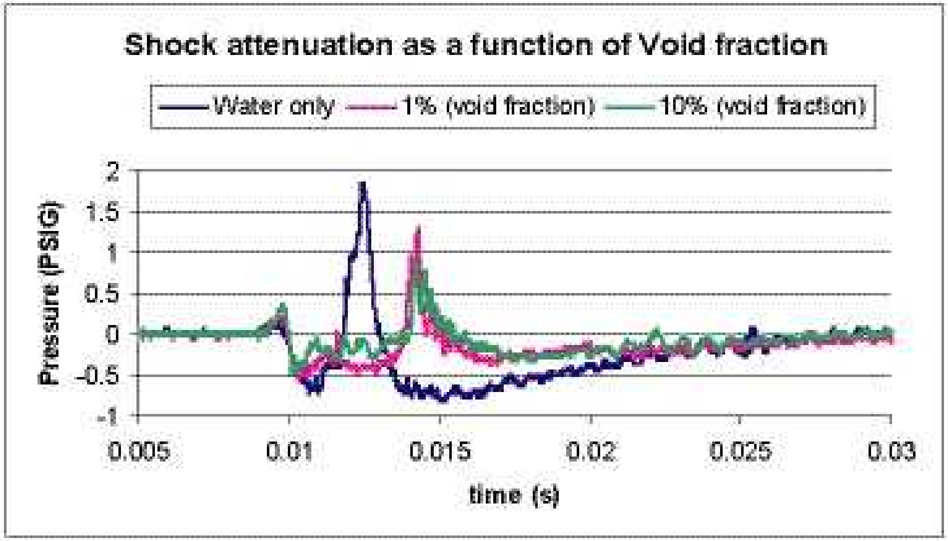
Annular water jets with an exploding wire on axis are used to study shock mitigation for thick liquid walls



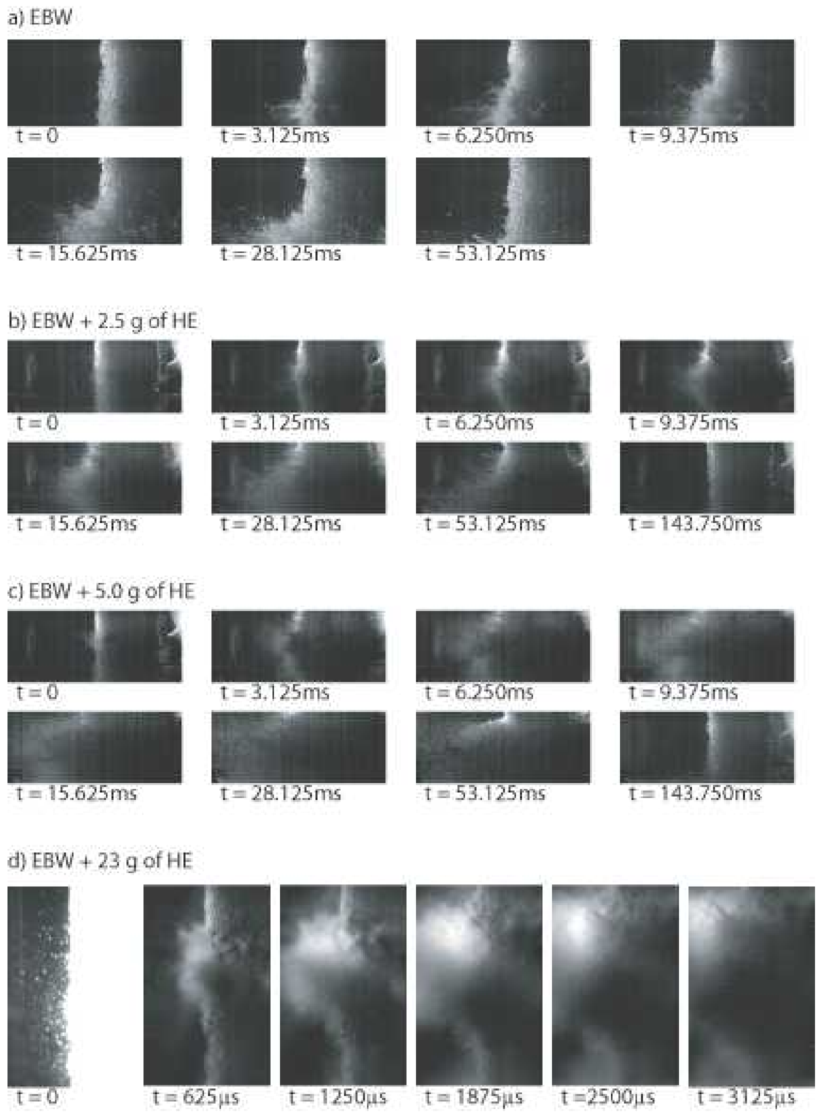
Photographs showing near-field behavior of two-phase annular jets with different void fractions (liquid superficial velocity v = 2 m/s)



Shock impulse attenuated by factor of 1.4

S. Abdel-Khalik, et al. (Georgia-Tech)

Annular water jet + high explosives used to investigate shock mitigation for thick liquid walls (VHEX facility)



<u>**Exploding bridge wire (EBW)**</u>
Peak pressure: 4.5 atmospheres
Impulse duration: 180 μs
Raw integrated impulse: 22 Pa.s

EBW + 2.5 g of HE (C4)
Peak pressue: 21 atmospheres
Impulse duration: 140 μs
Raw integrated impulse: 55 Pa.s

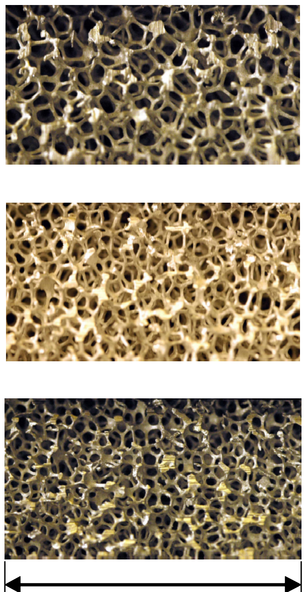
<u>**EBW + 5 g of HE (C4)**</u>
Peak pressure: 105 atmospheres
Impulse duration: 80 μs
Raw integrated impulse: 100 Pa.s

<u>**EBW + 23 g of HE (C4)**</u>

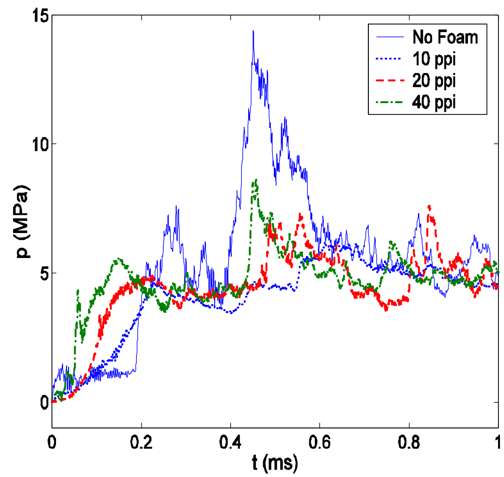
Crushing of porous liquid structures transfers momentum uniformly into the blanket mass without jetting or spall

P. Peterson, et al., UCB

Shock Mitigation is studied with metallic foams and two-phase liquids at the shock tube facility at U. Wisconsin

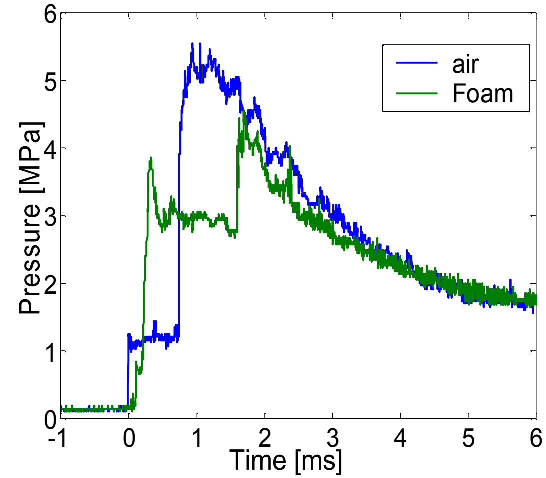

3 cm

Open cell morpholgy for Al foams as a function of pore size; (a) 10 ppi, (b) 20 ppi, (c) 40 ppi



Pressure traces from transducer located 3.81 cm above endwall for Al foams

Impulse was reduced 25%, 19.5%, 14% for 10, 20, 40 ppi solid foams



Pressure traces from a transducer located 1 m below the surface of a very low density liquid foam.

Impulse was reduced 22%.

G. Kulcinski, M. Anderson, et al. (U. Wisconsin)

Z-PoP

• Z-PoP (Proof-of-Principle) is an experiment designed to demonstrate proof-of-principle of the repetitive pulsed power operations necessary for a pulsed power driven IFE power plant.

•Z-PoP will consist of a Linear Transformer Driver (LTD) pulsed power driver, connected to a Recyclable Transmission Line (RTL), which in turn is connected to a Z-pinch load.

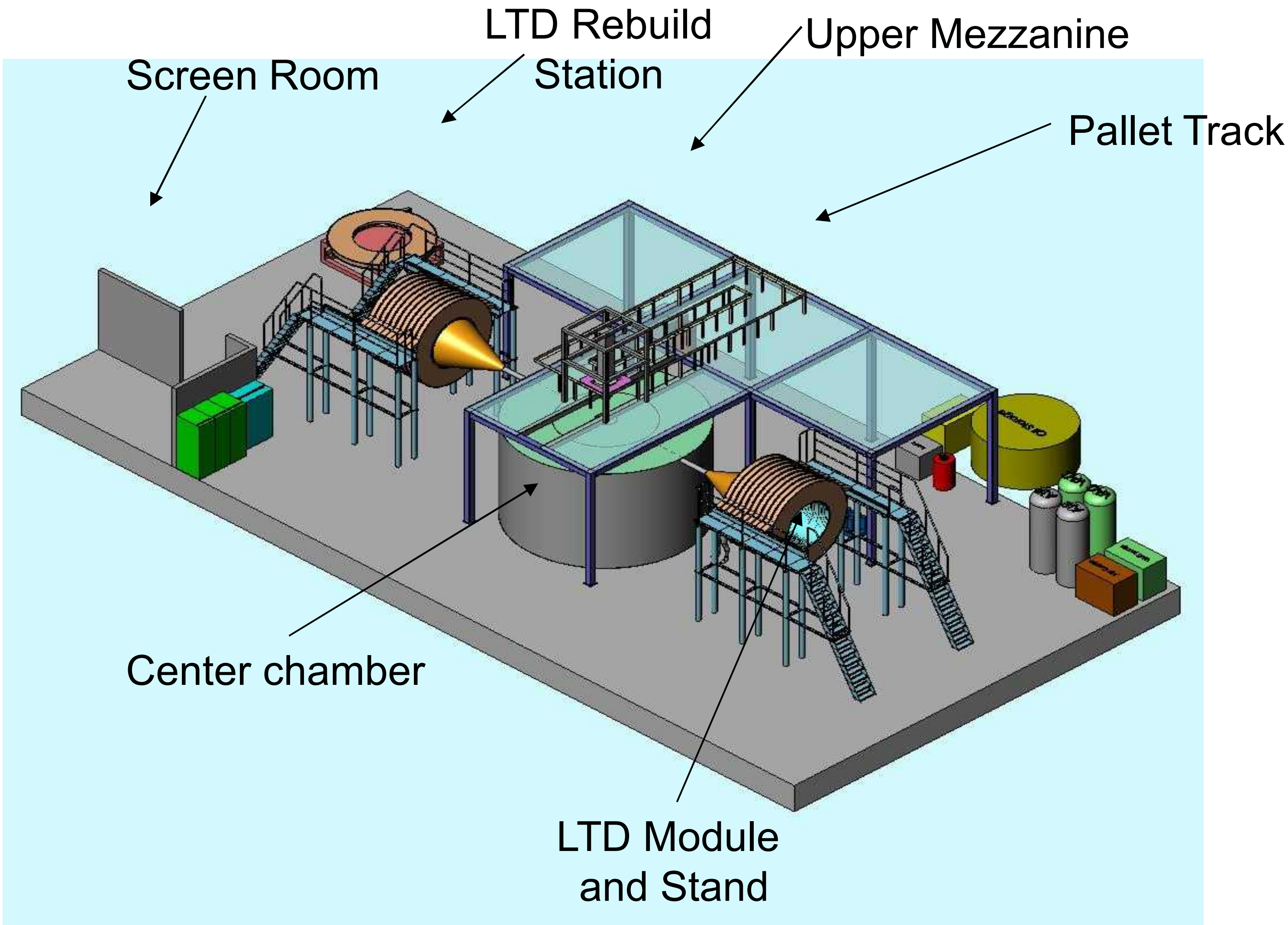
•After each shot, an automated system will remove the RTL/z-pinch load and replace it with a new RTL/Z-pinch load.

•The sequence will repeat at about 0.1 Hz (i.e., every 10 seconds), the same as envisioned for an IFE power plant

•Z-PoP will be the first demonstration of a repetitive high current z-pinch, as would be used in an IFE power plant.

R. McKee, Larry Shipers, Finis Long, James Jones,
Jeff McDonald, Pete Wakeland (SNL)

Z – PoP (two 1 MA legs)



Cost Estimate: two lines in three years: $15 M in FY05 $

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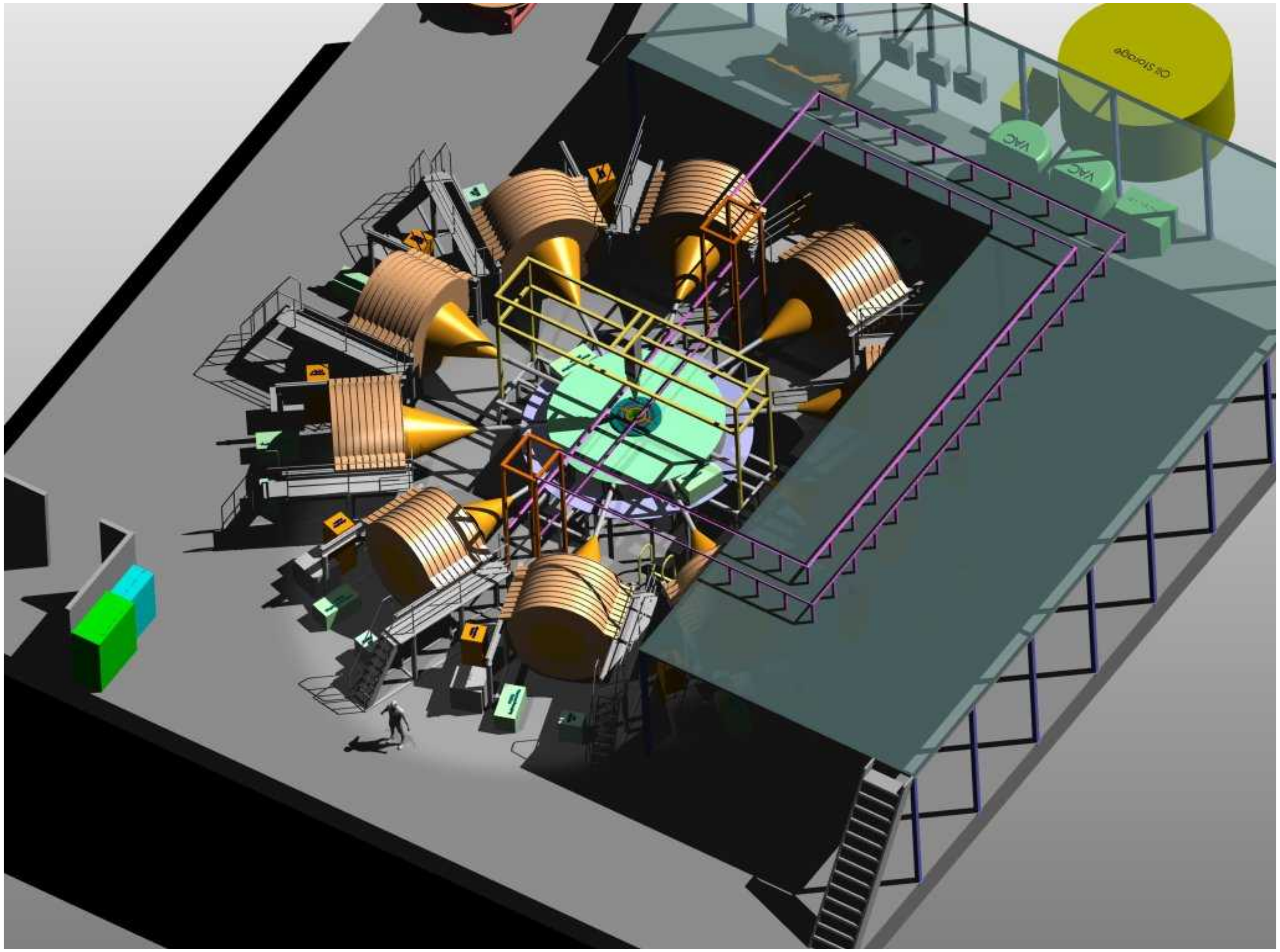
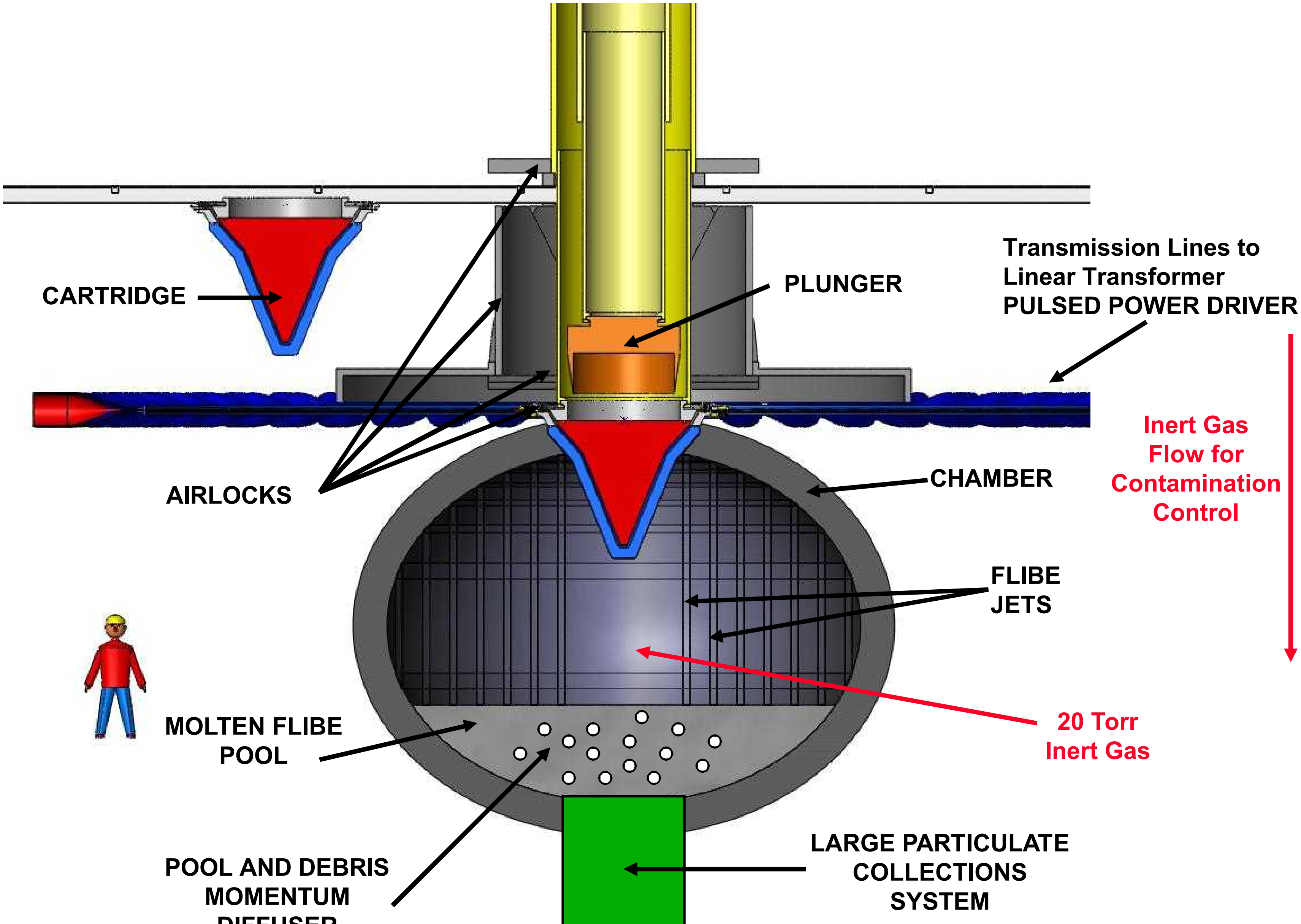
Z – PoP (ten 1 MA legs)

comparable to a rep-rated Saturn at 10 MA



Cost Estimate: ten lines in five years: $35.2 M in FY05 $

BASE Z-IFE Power Plant UNIT



G. Rochau, J. Cook, B. Cipiti, et al. (SNL)

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

Chamber

Shape	Spherical or Ellipsoidal
Dimension	4 m internal radius
Material	F82H Steel
Wall Thickness	15-30 cm

Coolant

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

Tritium Recovery

Breeding Ratio	1.1
Tritium Recovered per Shot	0.017 g
Extraction Type	Countercurrent

RTL

RTL Material	1004 Carbon Steel
Cone Dimensions	1 m Ø x 0.1 m Ø x 2 m h
Outer Cone Thickness	0.9 mm → 0.52 mm
Inner Cone Thickness	0.52 mm
Mass per RTL (2 cones)	50 kg → 34 kg

RTL Manufacturing

Furnace	Electric Arc
Production	Sheet Metal to Deep Draw
Energy Demand	184 MW for ten chambers

G. Rochau, J. Cook, B. Cipiti, et al. (SNL)

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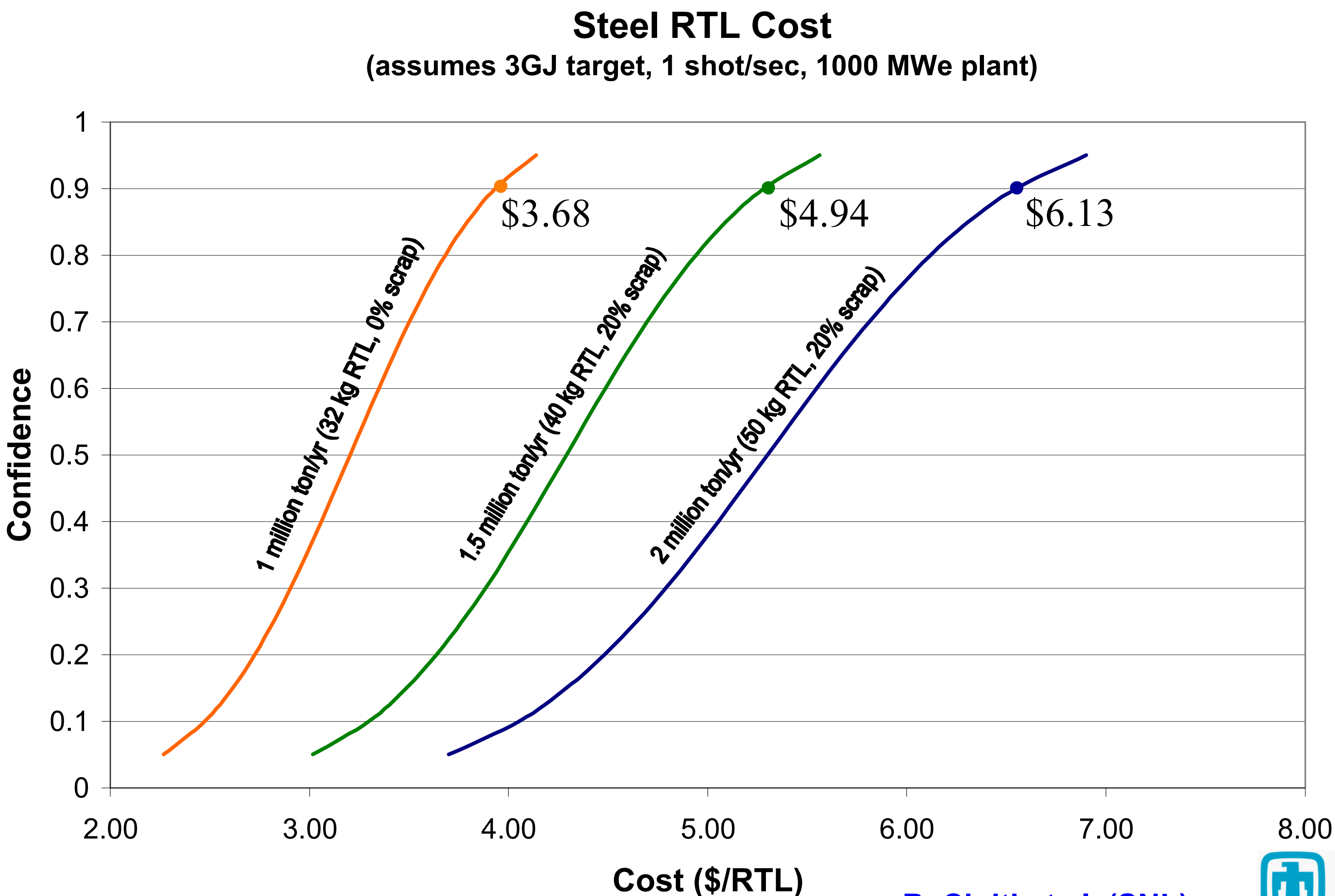
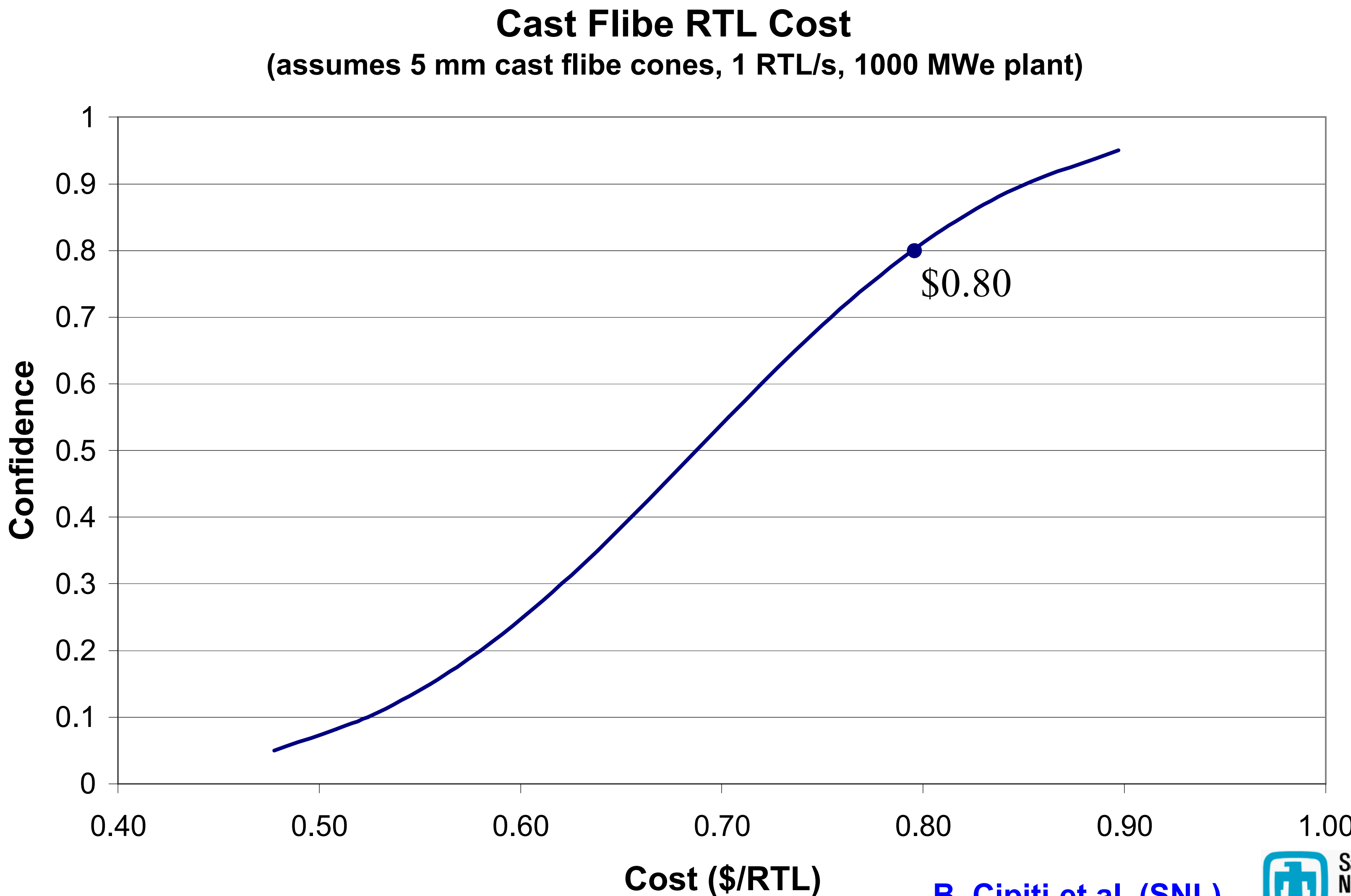
Steel RTL Cost is Driven by Mass



B. Cipiti et al. (SNL)

Cast Flibe RTLs Cost Considerably Less



B. Cipiti et al. (SNL)

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RTL activation

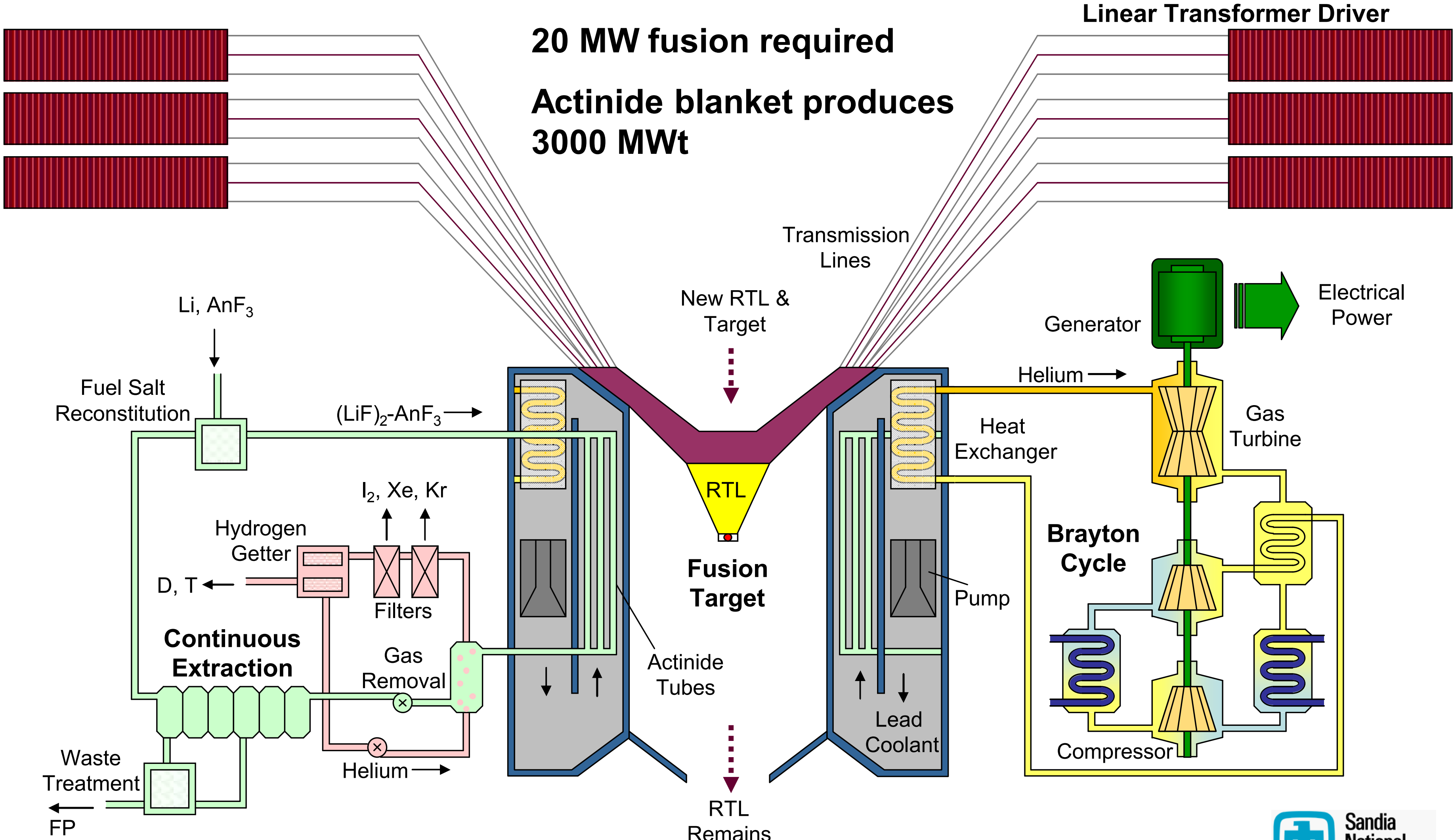
Carbon steel RTL (preferred) — L. El-Guebaly (U. Wisconsin)

- recycle remotely in ~ 1.5 day
- after 35 years, material can be released for reuse (clearance index <1)
- RTL dose peaks at 160 Sv/hr, and drops to 1 Sv/hr in one hour
- advanced remote handling can have up to 3000 Sv/hr
  - (so should have large safety margin)

Iron, or frozen Flibe — W. Meier et al. (LLNL)

- analyzed each element in periodic chart
- considered 1 day recycle with WDR < 1
- contact dose rate in range of 10-100 Gy/hr for iron
- acceptable lifetime dose to machinery for < 114 Gy/hr
  - (so should have some safety margin)

In-Zinerator Power Plant Concept: A Fusion-Fission Hybrid: A sub-critical blanket burns actinides – produces transmutation of waste and produces power



B. Cipiti et al. (SNL)

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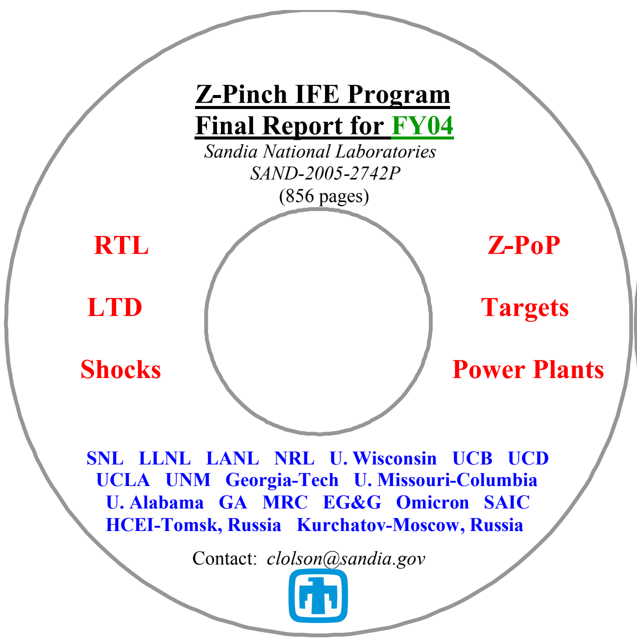
Current Status and Near-Term Plans

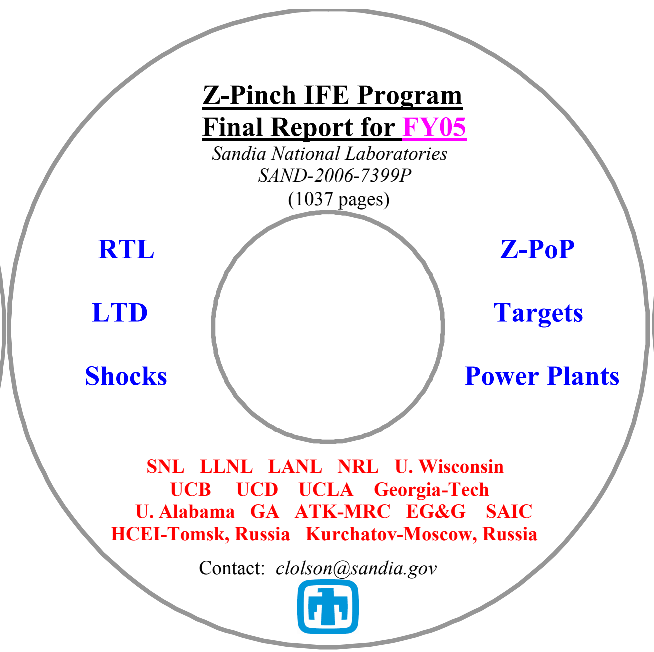
Three CDs summarize Z-IFE R&D

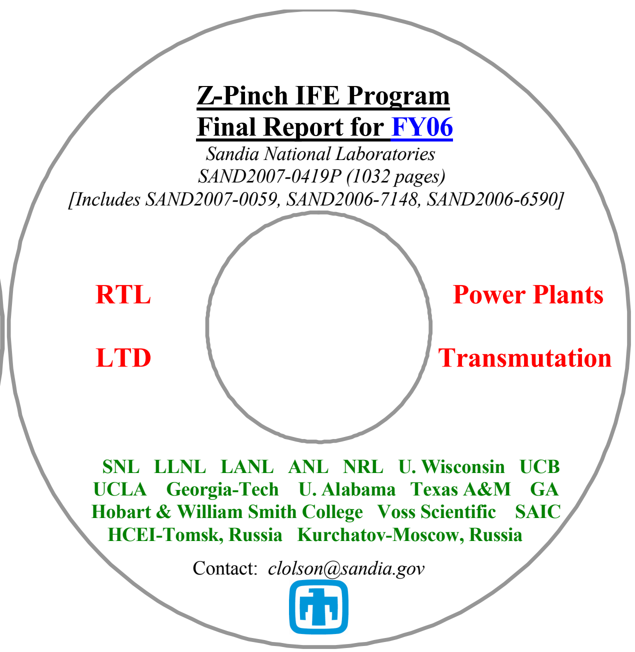
Z-IFE Final Report FY04 ***SAND-2005-2742P*** **(856 pages)**

Z-IFE Final Report FY05 ***SAND-2006-7399P*** **(1037 pages)**

Z-IFE Final Report FY06 ***SAND-2007-0419P*** **(1032 pages)**







Three Sandia Reports are the core of the FY06 Z-IFE Results

included in the FY06 CD

SANDIA REPORT
SAND2007-0059
Unlimited Release
Printed January 2007

Recyclable Transmission Line (RTL) and Linear Transformer Driver (LTD) Development for Z-Pinch Inertial Fusion Energy (Z-IFE) and High Yield

Craig L. Olson, Michael G. Mazarakis, William E. Fowler, Robin A. Sharpe, David L. Smith, Matthew C. Turgeon, William L. Langston, Timothy D. Pointon, Paul F. Ottinger, Joseph W. Schumer, Dale R. Welch, David V. Rose, Thomas C. Genoni, Nicki L. Bruner, Carsten Thoma, Mark E. Barkey, Michael Guthrie, Daniel C. Kammer, Gerald L. Kulcinski, Yuri G. Kalinin, Alexander S. Kingsep, Sergei L. Nedoseev, Valentin P. Smirnov, and Alexander Kim

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000.

Sandia National Laboratories

SANDIA REPORT
SAND2006-7148
Unlimited Release
Printed November 2006

Z-Inertial Fusion Energy: Power Plant Final Report FY 2006

Jason T. Cook, Gary E. Rochau, Benjamin B. Cipiti , Charles W. Morrow, Salvador B. Rodriguez, Cathy O. Farnum, Marcos A. Modesto-Beato, Samuel Durbin, James D. Smith, Paul E. McConnell, Dannelle P. Sierra, Craig L. Olson, Wayne Meier, Ralph Moir, Per F. Peterson, Philippe M. Bardet, Chris Campen, James Franklin, Haihua Zhao, Gerald L. Kulcinski, Mark Anderson, Jason Oakley, Ed Marriott, Jesse Gudmundson, Kumar Sridharan, Riccardo Bonazza, Virginia L. Vigil, Mohamed A. Abdou, Lothar Schmitz, Alice Ying, Tomas Sketchley, Yu Tajima, Said I. Abdel-Khalik, Brian Kern, Said.M. Ghiaasiaan

Prepared by
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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000.

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SANDIA REPORT
SAND2006-6590
Unlimited Release
Printed November 2006

Fusion Transmutation of Waste: Design and Analysis of the In-Zinerator Concept

B.B. Cipiti, V.D. Cleary, J.T. Cook, S. Durbin, R.L. Keith, T.A. Mehlhorn, C.W. Morrow, C.L. Olson, G.E. Rochau, J.D. Smith, M. Turgeon, M. Young, L. El-Guebaly, R. Grady, P. Phruksarojanakun, I. Sviatoslavsky, P. Wilson, A.B. Alajo, A. Guild-Bingham, P. Tsvetkov, M. Youssef, W. Meier, F. Venneri, T.R. Johnson, J.L. Willit, T.E. Drennen, W. Kamery

Prepared by
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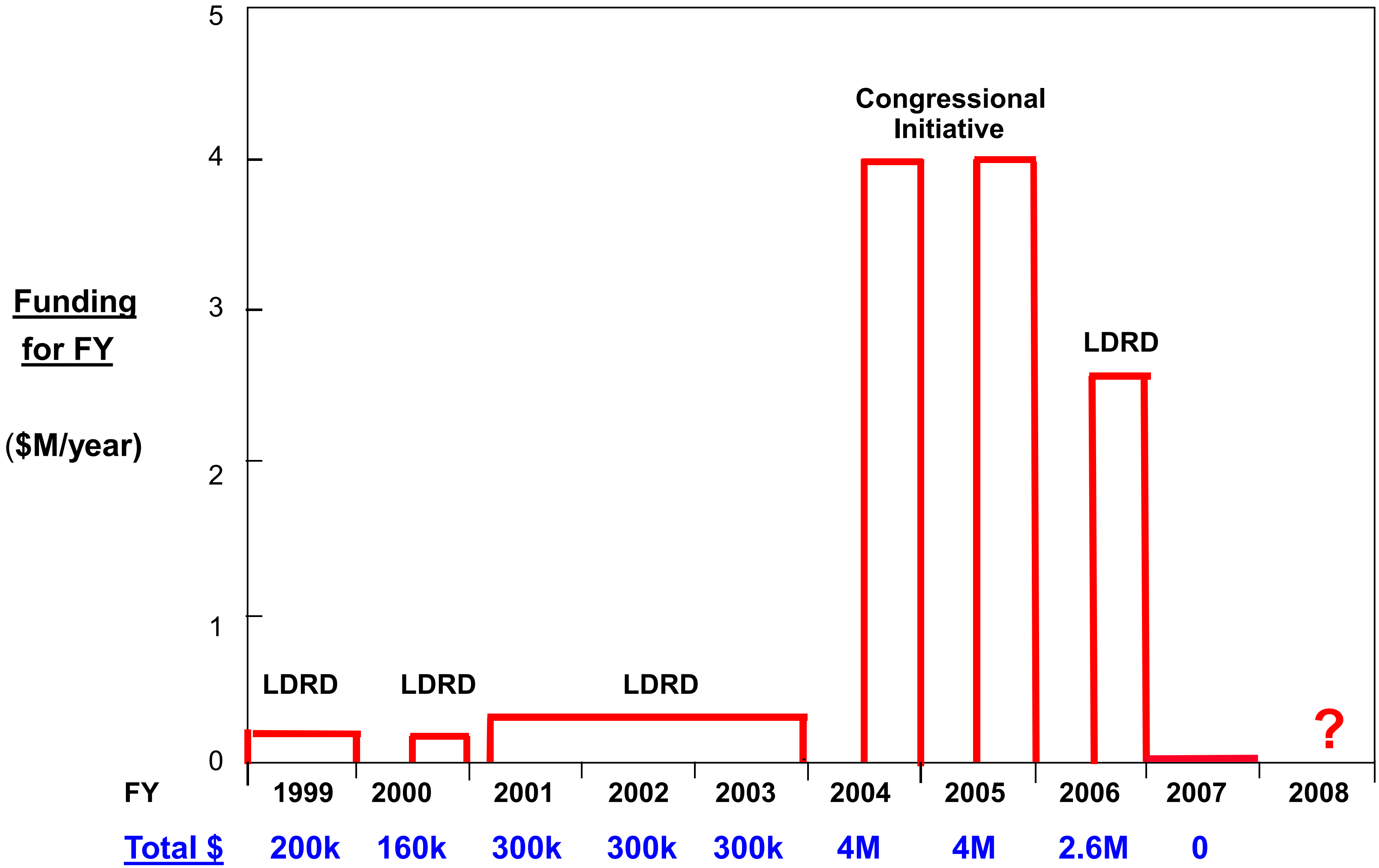
Z-IFE Funding



FY07 related work on nuclear blankets and transmutation is in the final year of a Grand Challenge LDRD (FY05-FY07)

GC LDRD Title: Advanced Fusion Concepts: Neutrons for Testing and Energy

GC LDRD Mission:

- study advanced pulsed power fusion targets on Z
- design an externally-driven nuclear assembly (Z-EDNA) driven by Z fusion neutrons for DP testing
- develop a Z-fusion nuclear waste transmutation concept

GC LDRD End States:

- enable an ICF program decision on making advanced fusion concept part of the baseline program
- enable a Sandia decision on building & fielding a Z-EDNA on ZR for DP neutron testing.
- enable Sandia to participate in international transmutation research

Z-IFE comments re: Next Step Pulsed Power Facility

DOE NNSA DP charter for SNL ICF program is to assess High Yield

A High-Yield Driver Facility should be compact, efficient, cost effective, potentially rep-rateable, and have minimum activation issues. An attractive candidate for High Yield is to:

- **Use LTD technology (Kurchatov agrees)**
- **Use RTLs (allows higher shot rate)**
- **Use single-shot thick liquid wall chamber (alleviates chamber activation issues)**

Possible Options for supporting Z-IFE in FY07

Create a "home" for IFE in DOE	not in FY07
Congressional Initiative	not in FY07
LDRD (Z-IFE is in all parts of the SNL Science of Extreme Environments LDRD call)	not in FY07
DP (do parts related to High Yield)	not in FY07
Senate mark – proposed HED Office for IFE, etc.	not in FY07
Private industry (power utilities)	too early
?	

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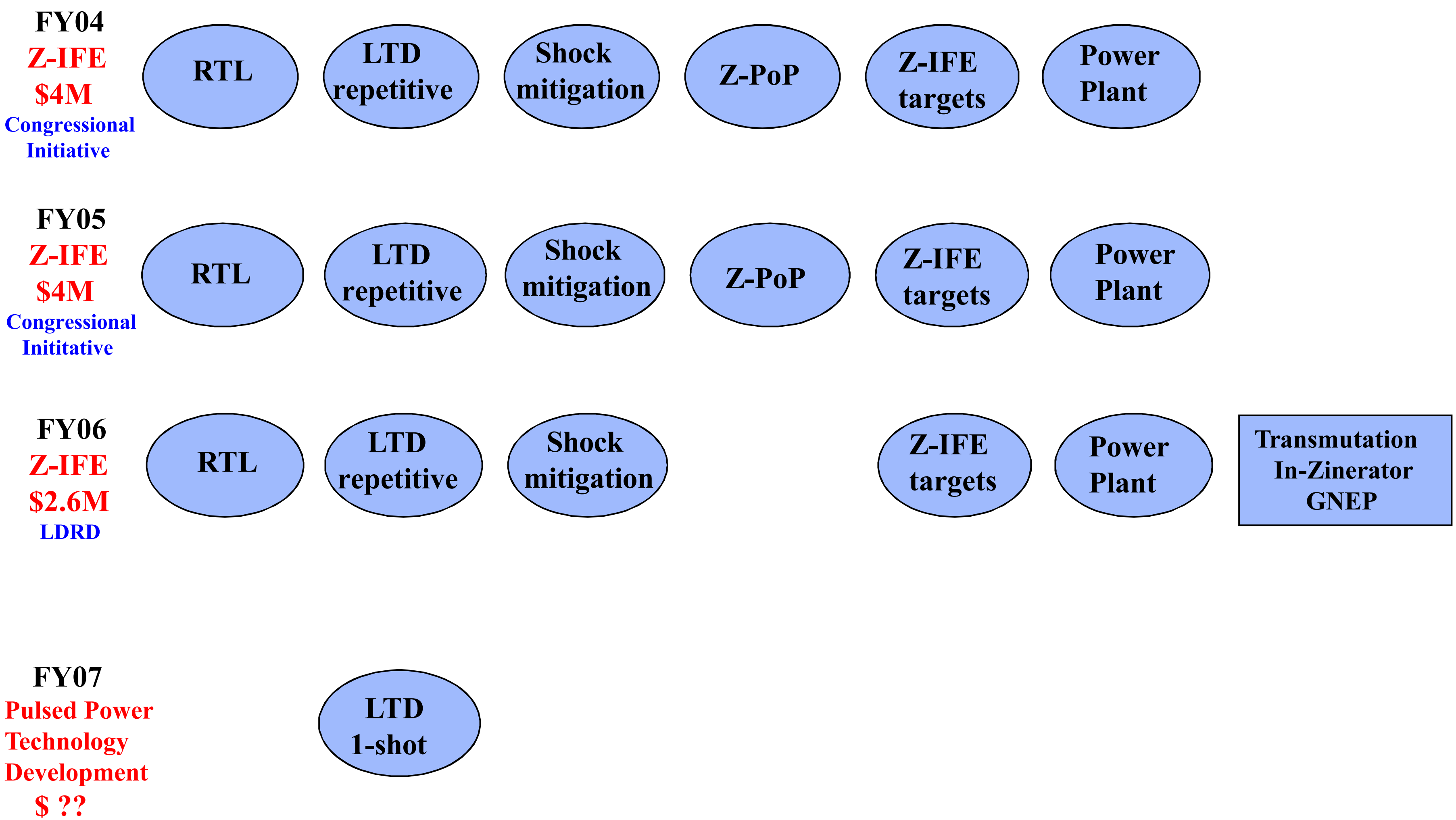
Of the six task areas for Z-IFE, only LTD (for a single-shot, next-step driver) will have some support in FY07



Cost of ending Z-IFE Program in FY07

Loses momentum for Z-IFE gained over last 6 years

Loses expertise of 19-member Z-IFE collaboration

Loses Z-IFE constituency in fusion community

Ends Z-IFE development in all 6 task areas

Removes pressure on DOE to establish home for IFE

Loses community enthusiasm for Z-IFE

Ends University Ph.D. Thesis projects on Z-IFE (left unfinished)

Loses opportunity to be ready to capitalize for energy on NIF success

How do you see Z-IFE evolving beyond the near term?

Z-IFE is on hold, and will not evolve unless there is a change in the U.S. “un-written” policy on IFE.

Only the LTD task area may continue under NNSA support.

The potential intermediate step of transmutation will continue to be examined with final GC LDRD funding in FY07.

What needs to be accomplished to move forward?

The U.S. needs to have a "written policy" on IFE that honors the FESAC recommendations on IFE.

DOE needs to have a home and funding for IFE.

Z-IFE needs to have continuous support (not picket fence funding).

What are potential landscape-changing developments?

NIF demonstrates ignition

Energy crisis

Global warming concerns escalate dramatically

Breakthrough target results on ZR

What are the technical issues for Z-IFE?

RTL power flow, electrical conductivity (Flibe vs. steel), mass (strength vs. cost)

LTD development and demonstration

Thick liquid walls and shock mitigation

Z-IFE targets with high yield and high gain

Power plant engineering and economics

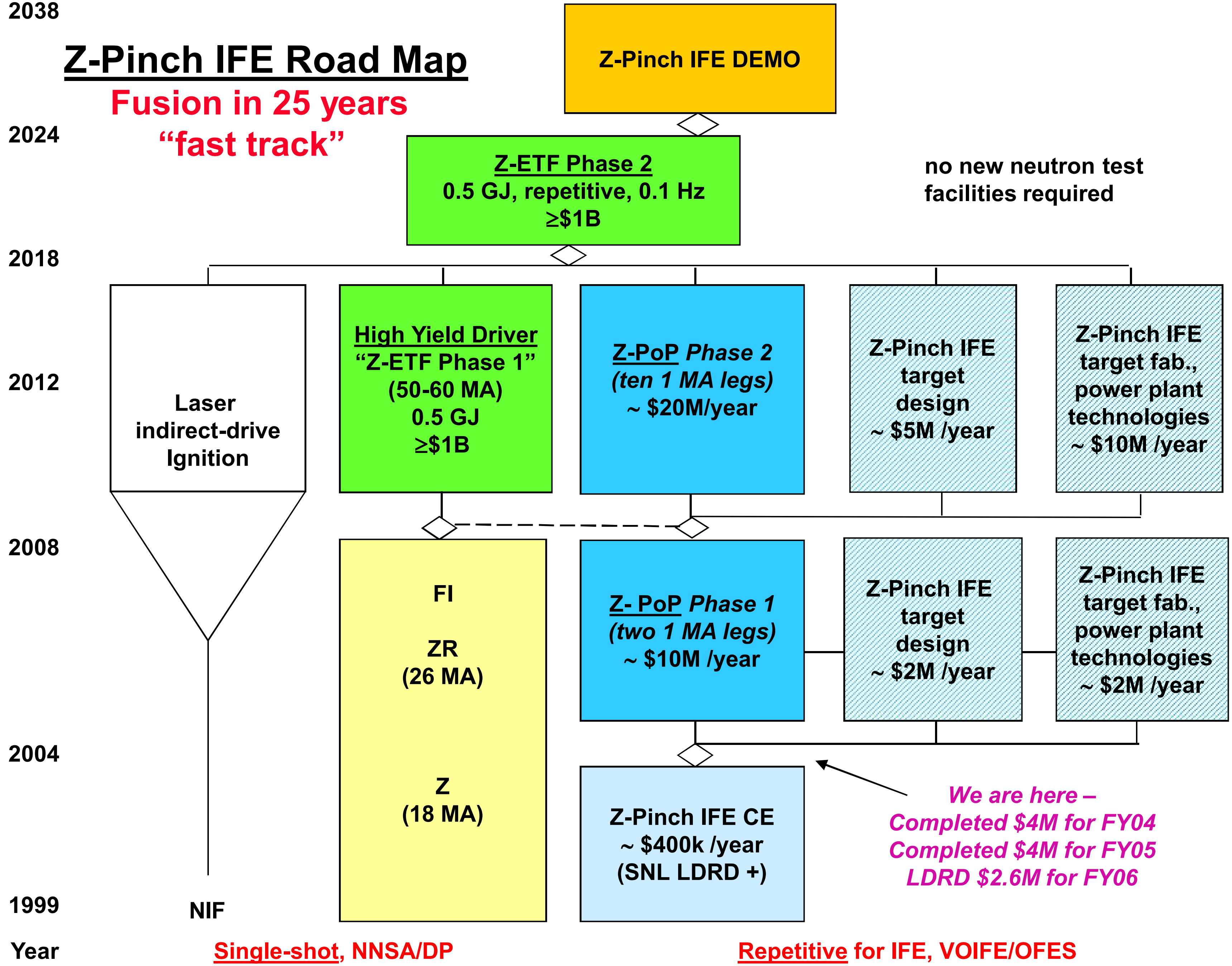
What is the present situation for Z-IFE?

- Z-IFE is on hold indefinitely
- ICF & Pulsed Power Technology programs may enable future Z-IFE
  - ICF: increase target gain "G" by advanced target design & experiments
  - Pulsed Power Technology & ICF: increase driver efficiency "η" by LTD development
- Proposed LDRD investments:
  - Fusion technology R&D, including blanket multiplication "M"
  - Power plant technology – conversion cycle efficiency "η_T"
  - System studies of yield, rep-rate and containment technology
- Be prepared for a "landscape-changing event" to re-initiate interest in Z-IFE

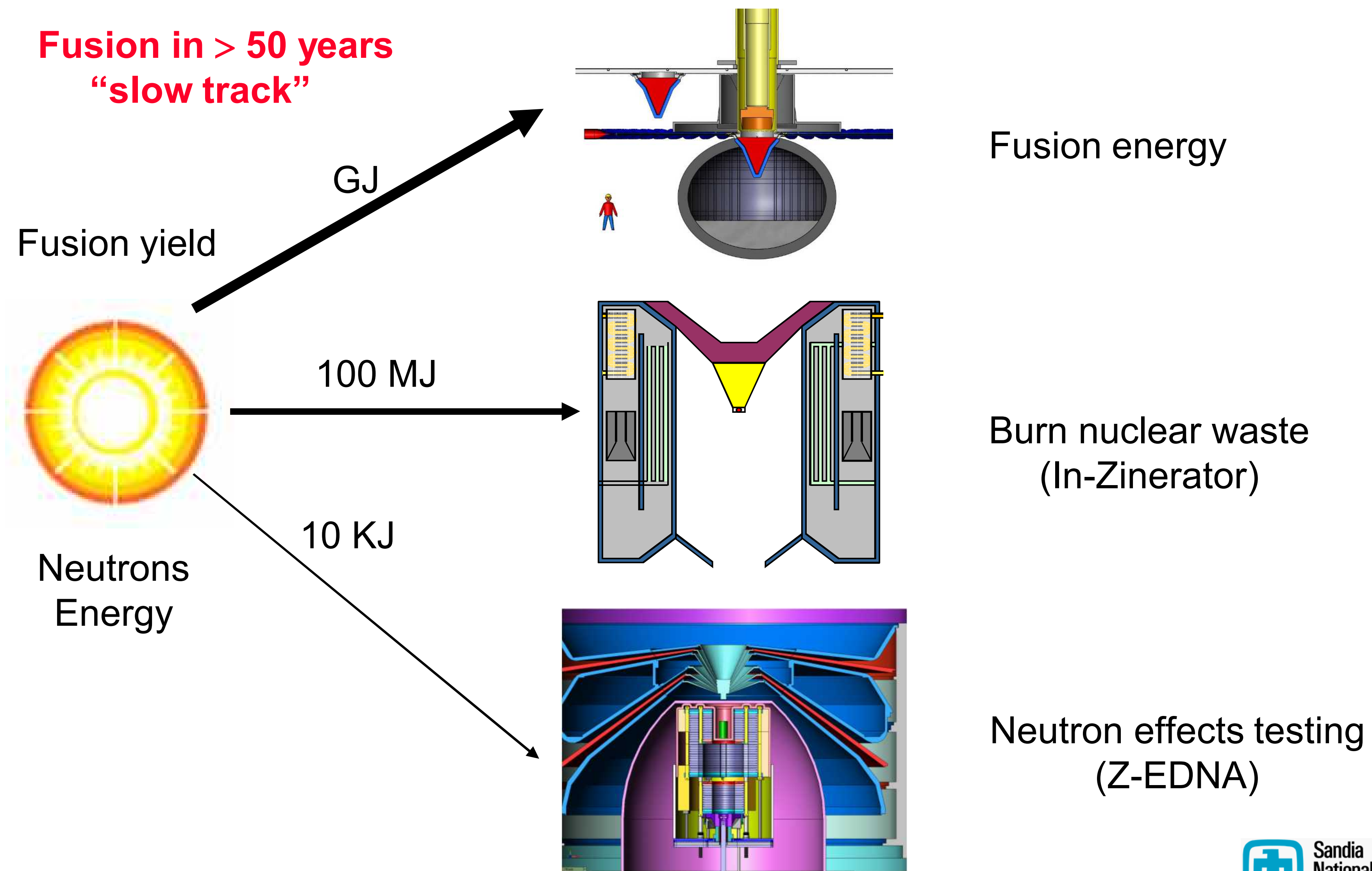
Long-Range Vision

Z-Pinch IFE Road Map

Fusion in 25 years
"fast track"



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



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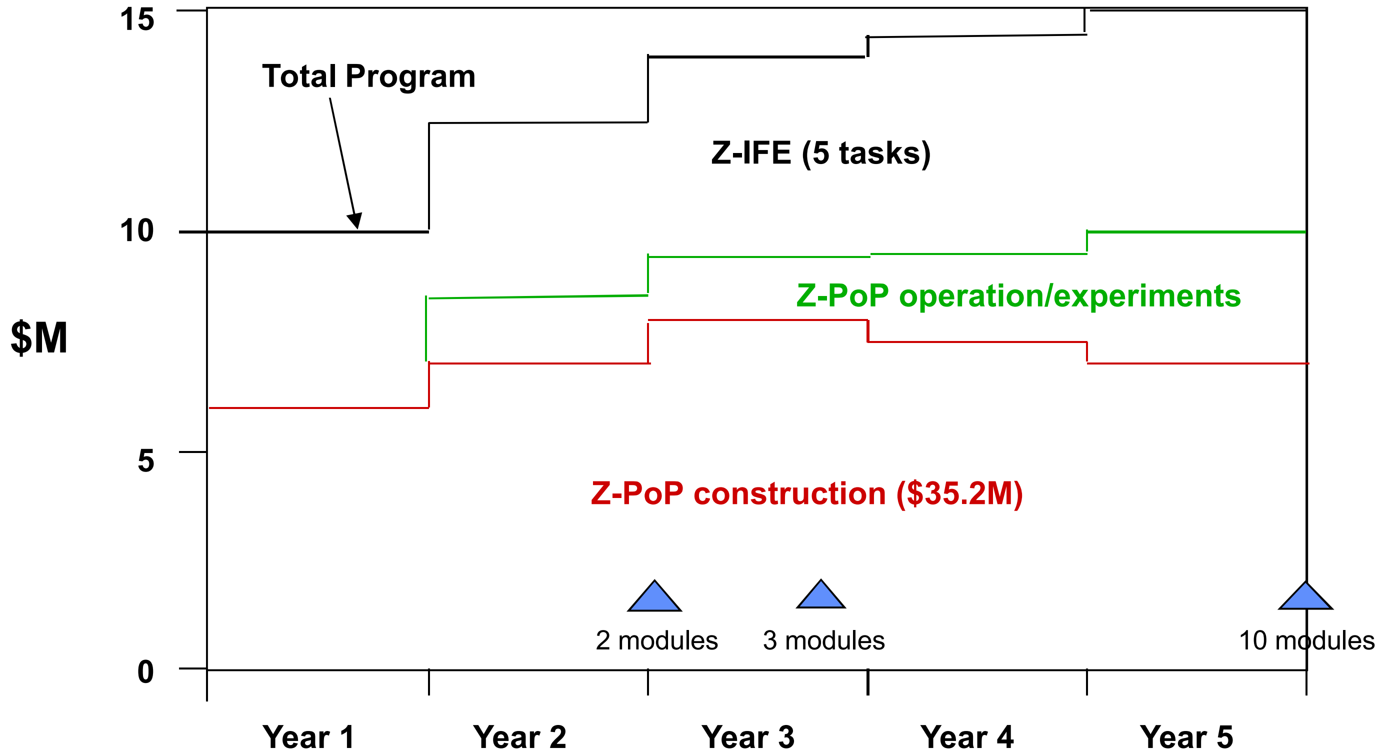
Funding needs for Z-IFE to move to next step:

- **minimal program: $2.6M – $4M per year**

- **robust program including Z-PoP:**
  ~ $12M/year

Z-IFE / Z-PoP Funding Profile



Z-IFE (Z-Pinch Inertial Fusion Energy)

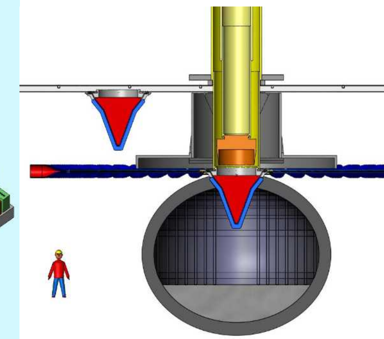
Z-IFE Results
Current Status and Near-Term Plans
Long-Range Vision
Funding needs to move to the next step


RTL


LTD driver


Shock Mitigation

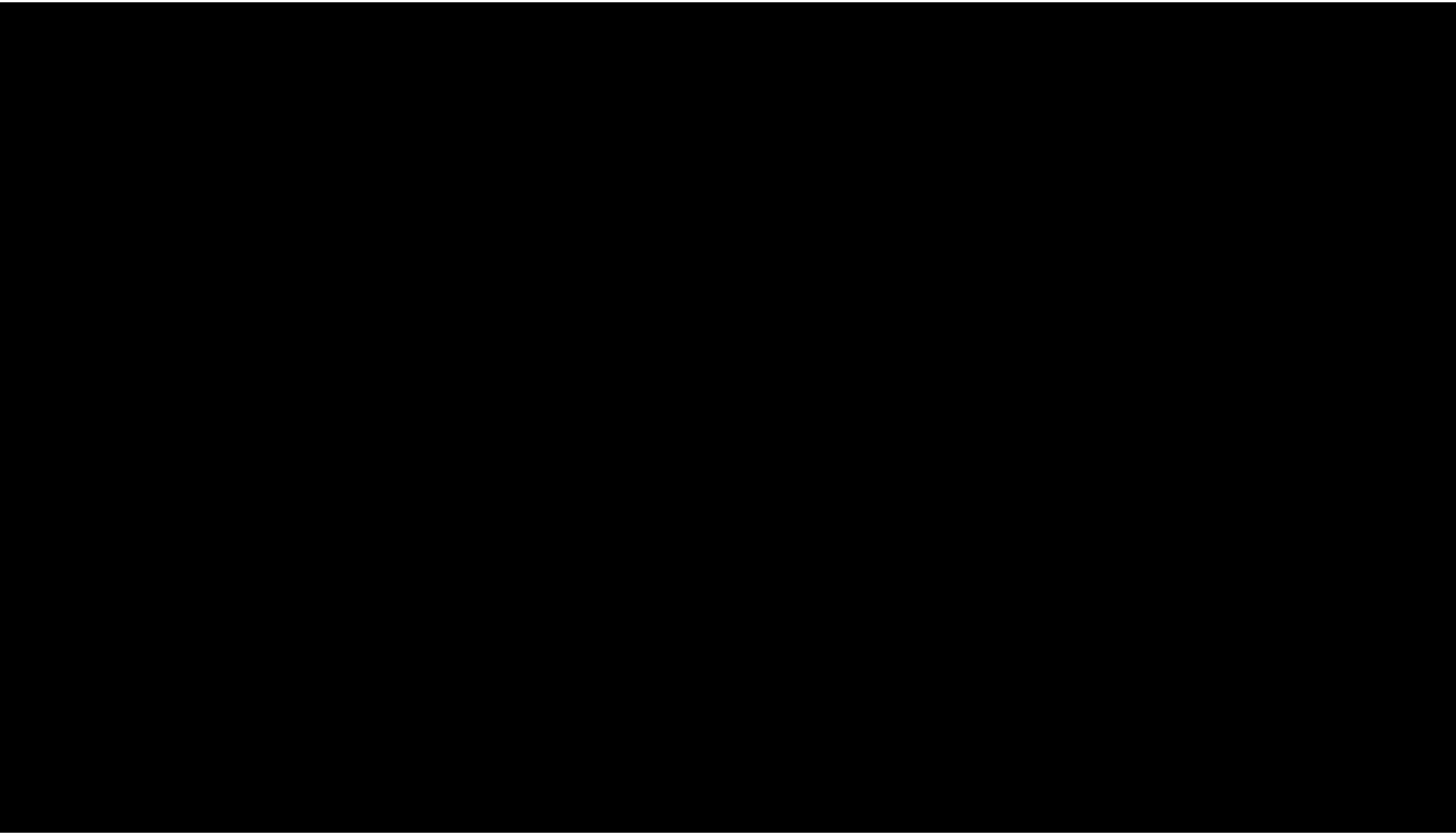

Z-PoP


Chamber

Present results (three CDs) assure us that Z-IFE is on a sound scientific and engineering basis.   The rate at which Z-IFE may be realized depends on the importance the U.S. places on IFE.

Extra View-Graphs

Z-PoP Movie



Z-IFE Presentations at ANS TOFE (November 2006)

(1) "Z-Pinch Inertial Fusion Energy (Z-IFE) Program"
Craig L. Olson, SNL (**Invited** Plenary)

(2) "Keeping the Cryogenic Targets Layered Until Shot Time in a Z-Pinch IFE Power Plant"
Remy Gallix, et al., GA

(3) "Modeling of Z-IFE Hydrogen Plants with MELCOR-H2"
Sal Rodriguez, et al., SNL, Purdue, and Omicron

(4) "Systems Modeling for Z-IFE Power Plants"
Wayne R. Meier, LLNL

(5) "Shock Mitigation Using Compressible Two-Phase Jets for Z-Pinch IFE Reactor" Applications"
Celine C. Lascar, et al., Georgia-Tech

(6) "Void Fraction Distribution in Two-Phase Jets for Z-Pinch IFE Reactor Applications"
Brian J. Kern, et al., Georgia-Tech

(7) "Shock Mitigation Studies in Voided Liquids for Fusion Chamber Protection"
Virginia L. Vigil, et al., SNL and University of Wisconsin

(8) "Activation and Waste Stream Analysis for RTL of Z-Pinch Power Plant"
Laila A. El-Guebaly, et al., University of Wisconsin

(9) "The 500 kA, 100 ns LTD Cavity Has Reached the 0.1 Hz Repetition Rate Z-Pinch IFE Goal"
William E. Fowler, et al., SNL

(10) "Z-Pinch Fusion Driven Systems for IFE, Transmutation, and GNEP"
Gary E. Rochau, SNL (**Invited**)

(11) "Z-Pinch Chamber Assessment and Design"
Igor Sviatoslavsky, et al., University of Wisconsin

(12) "Engineering Issues Facing Transmutation of Actinides in a Z-Pinch Fusion Power Plant"
Paul P. H. Wilson, et al., University of Wisconsin

(13) "The Sandia High Current High Voltage Z-Pinch IFE Driver Program"
Michael G. Mazarakis, et al., SNL and HCEI, Tomsk, Russia (**Invited**)

(14) "Power Flow Constraints for a Recyclable Transmission Line for Z-Pinch IFE"
Joseph W. Schumer, et al., NRL and SNL

(15) "Driver Transition Geometries and Inductance Considerations Leading to Design Guidelines for a Z-IFE Power Plant"
David L. Smith, et al., SNL

(16) "Transmutation of Actinides Using Z-Pinch Fusion"
Benjamin B. Cipiti, et al., SNL and University of Wisconsin (**Invited**)

(17) "Isotopic Anaylsis of the In-Zinerator Actinide Management System"
Phiphat Phruksarojanakun, et al., University of Wisconsin and SNL (**Invited**)

(18) "Parametric Analysis of Z-Pinch Driven Nuclear Waste Incineration System"
Avery A. Guild-Bingham, SNL and Texas A&M

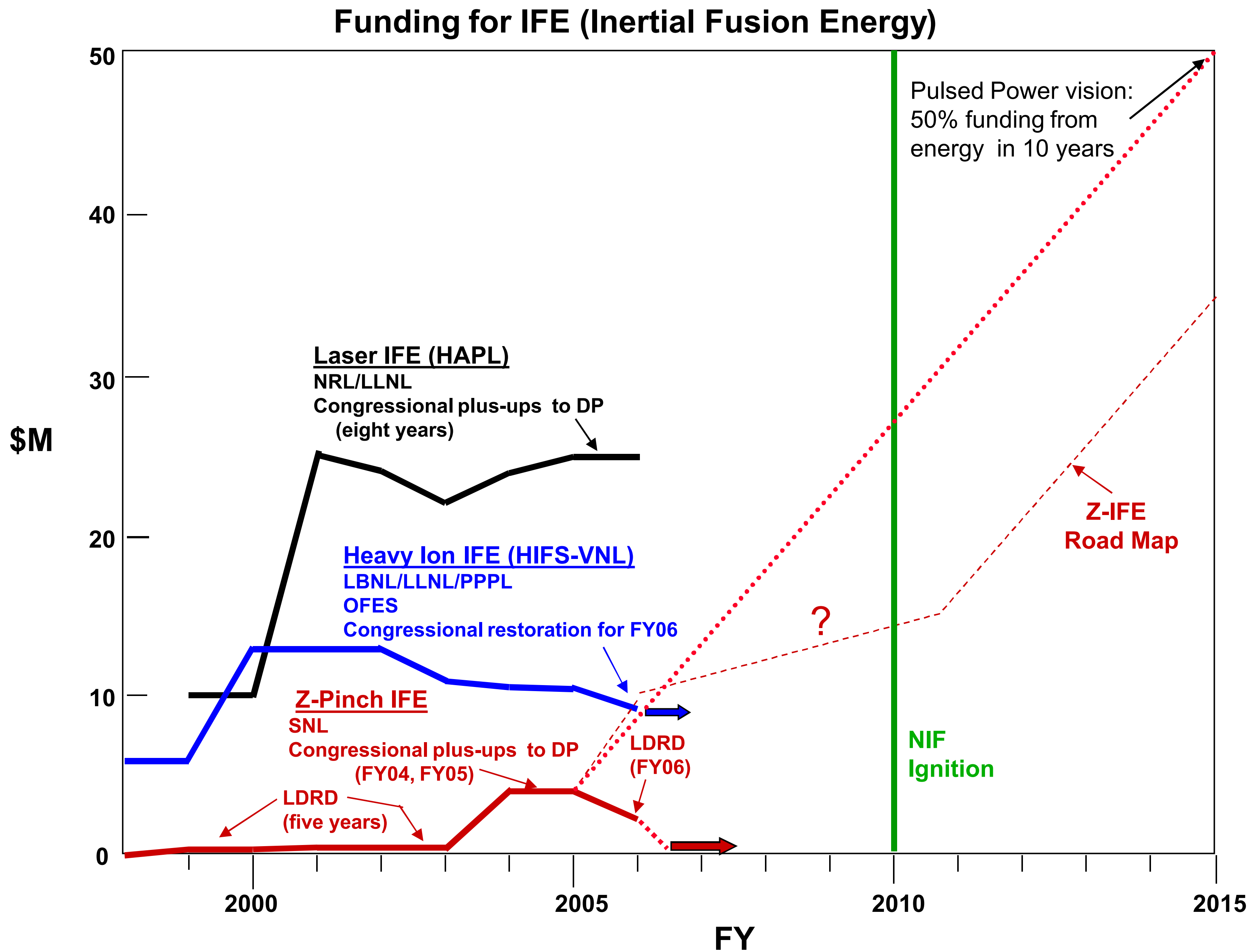
(19) "Three-Dimensional Nuclear Assessment for the Chamber of Z-Pinch Power Plant"
Mohamed E. Sawan, et al., University of Wisconsin (**Invited**)

(20) "Investigation of Argon and Xenon as Potential Shock Attenuators in Z-IFE Chambers Using ALEGRA"
Sal Rodriguez, et al., SNL

(21) "Simple Models for the Dynamic Response Associated with IFE Shock Mitigation"
R. Jeffrey Lawrence, et. al., SNL

(22) "Experimental Investigation of Z-Pinch IFE Chamber Liquid Structure Response"
Per F. Peterson, et al., UCB and LLNL

(23) "Fusion Power Plant Tritium Production and Recovery"
Rodney L. Keith, SNL


Funding for IFE (Inertial Fusion Energy)
$M
50
40
30
20
10
0
2000
2005
2010
2015
FY
Pulsed Power vision:
50% funding from
energy in 10 years
Laser IFE (HAPL)
NRL/LLNL
Congressional plus-ups to DP
(eight years)
Heavy Ion IFE (HIFS-VNL)
LBNL/LLNL/PPPL
OFES
Congressional restoration for FY06
Z-Pinch IFE
SNL
Congressional plus-ups to DP
(FY04, FY05)
LDRD
(five years)
LDRD
(FY06)
?
Z-IFE
Road Map
NIF
Ignition