SAND2006-7381C

Z-Pinch Inertial Fusion Energy (Z-IFE) Program

Z-IFE Recent Results

***long-term goals*: Power production, Hydrogen production**

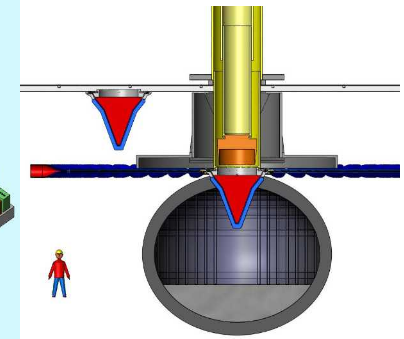
***nearer-term goals*: GNEP, Nuclear waste transmutation**

RTL

LTD driver

Shock Mitigation

Z-PoP



Chamber

Craig L. Olson + Z-IFE Team
Sandia National Laboratories
Albuquerque, NM 87185

17th TOFE
Albuquerque, NM
November 13-15, 2006

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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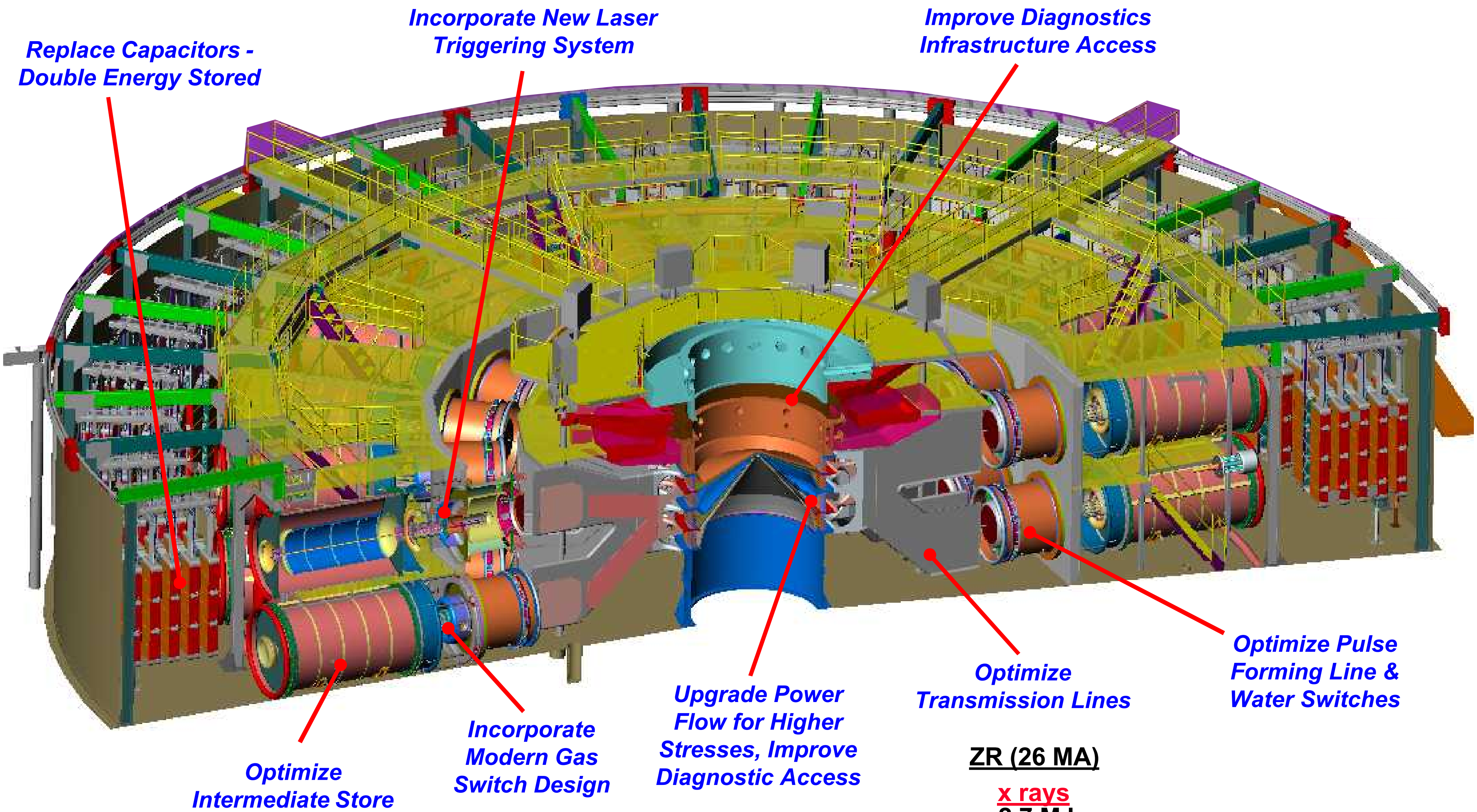
ZR - Refurbishing the Entire Accelerator



ZR (26 MA)

x rays
~2.7 MJ
~350 TW

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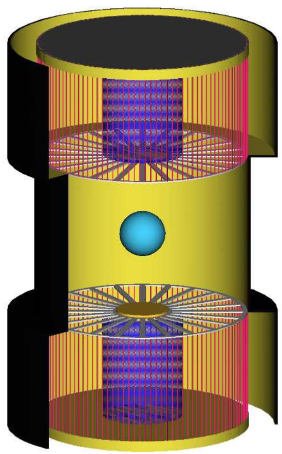
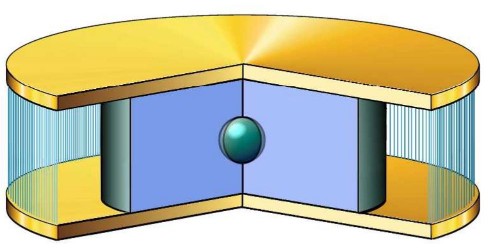
Simulation results and scaling of Z-pinch indirect-drive target concepts for high-yield ICF and Z-IFE

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

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

J. Hammer, M. Tabak *J. Lash, S. Slutz, R. Vesey, W. Stygar*

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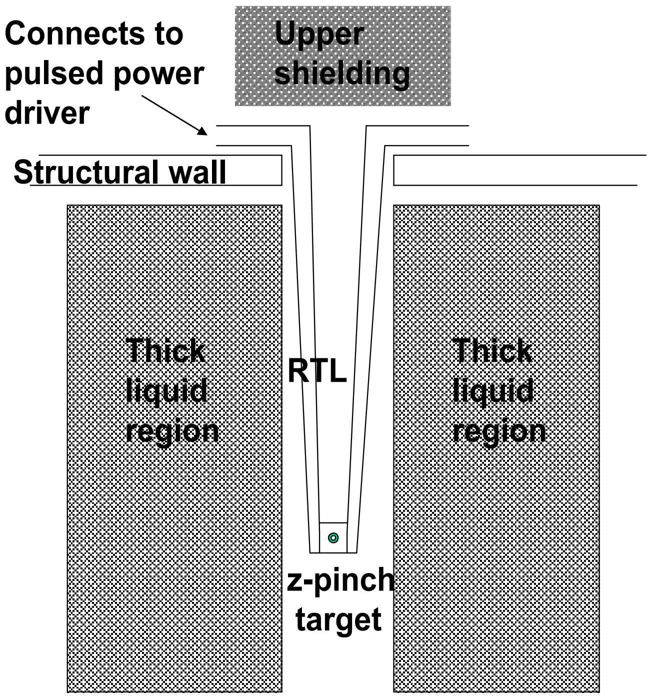
Recyclable Transmission Line (RTL) Concept for Z-Pinch IFE



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
- Thick liquid walls essentially alleviate the “first wall” problem.
  No new neutron test facilities required.

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Recent Results in Z-IFE

1. <u>RTLs</u>

   simulations (> 5 MA/cm works)

   experiments (> 5 MA/cm works)

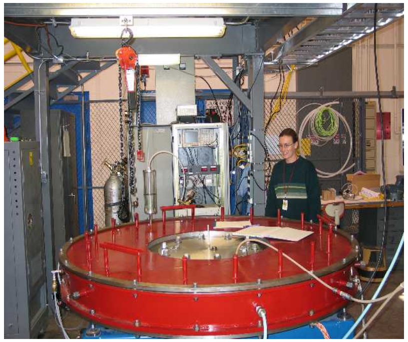
   fabrication of PoP-size RTLs and pressure testing

2. <u>LTD repetitive driver</u>

   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. <u>Shock mitigation</u>

   theory

   experiments: water ring/explosives
   foamed liquids
   shock tube/foams

   simulations

4. <u>Z-PoP planning</u>

   vacuum/electrical connections
   overhead automation
   animations

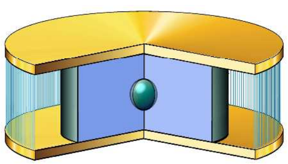
   costing

5. <u>Z-IFE targets for 3 GJ yields</u>

   gains ~ 50-100

   double-pinch/dynamic hohlraum

   scaling studies

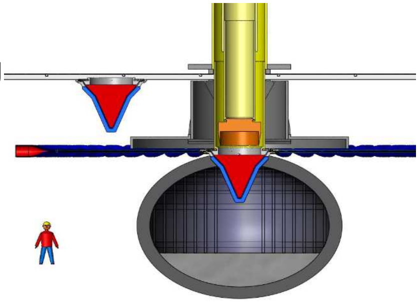


6. <u>Z-IFE power Plant</u>

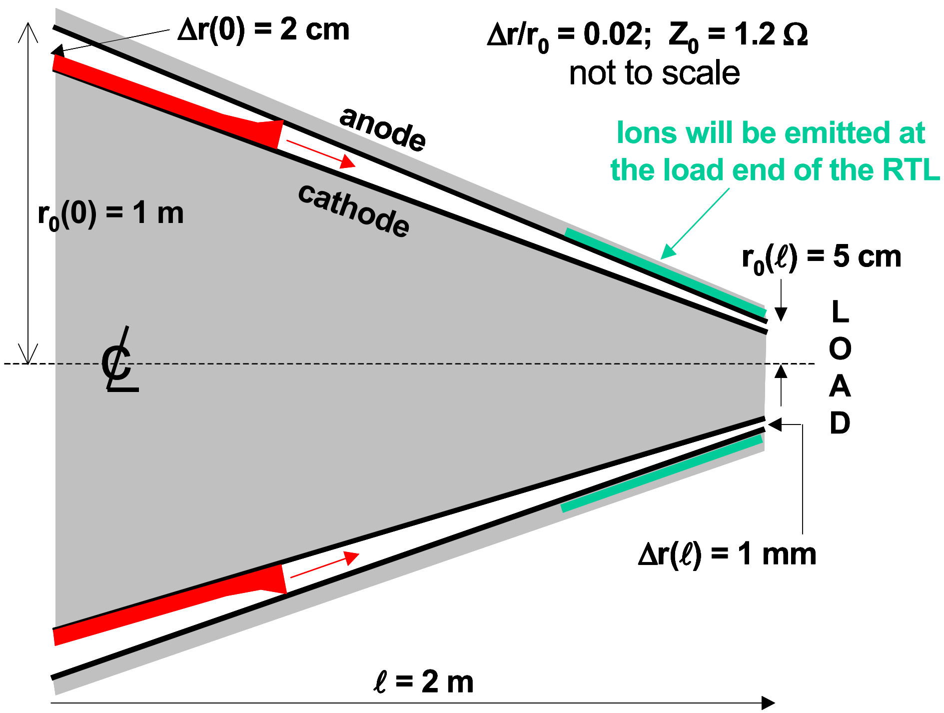
   RTL manufacturing/costing

   wall activation studies: 40 year lifetime

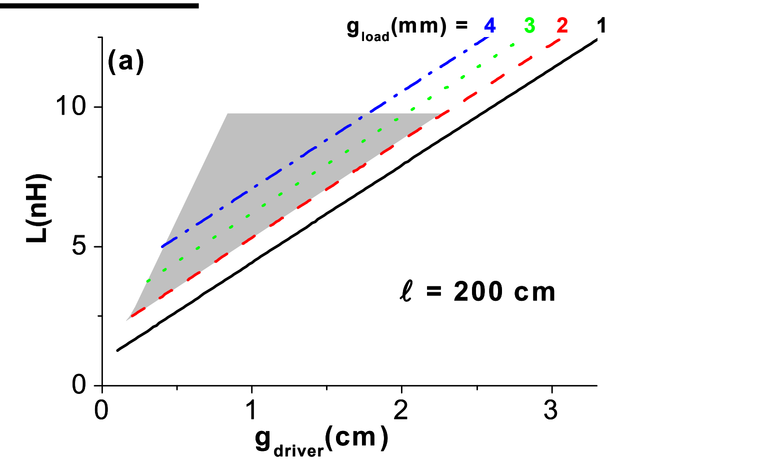
   power plant design +GNEP, transmutation

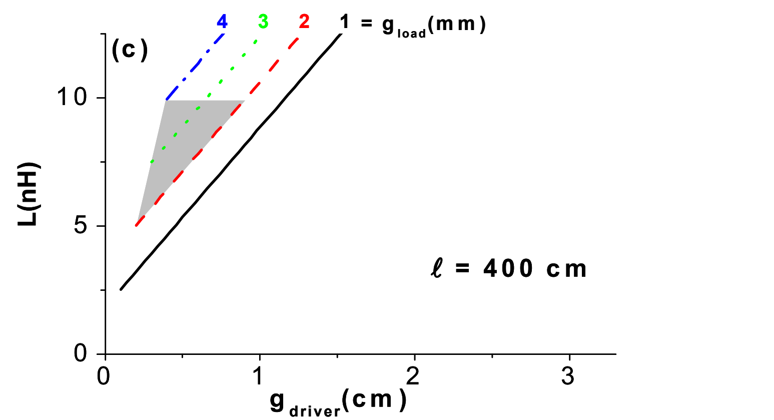


The physics of electron and ion flow in RTLs has been studied analytically and with LSP simulations: AK gaps at the load should be ≥ 2 mm



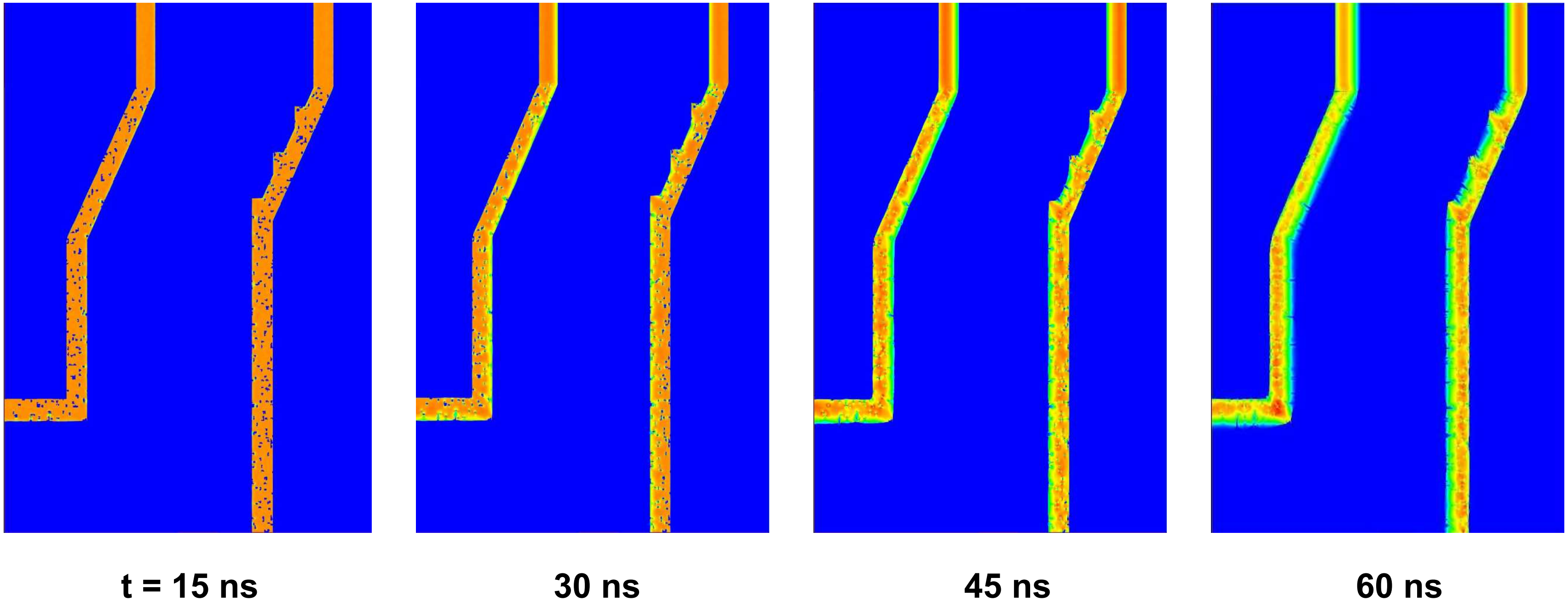
Conical tapered RTL for the baseline Z-IFE design. Power is fed in from the left.



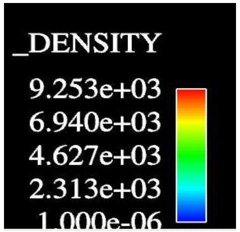


RTL inductance as a function of AK gap at the input end for various values of AK gap at the load. Shaded area are allowed design areas.

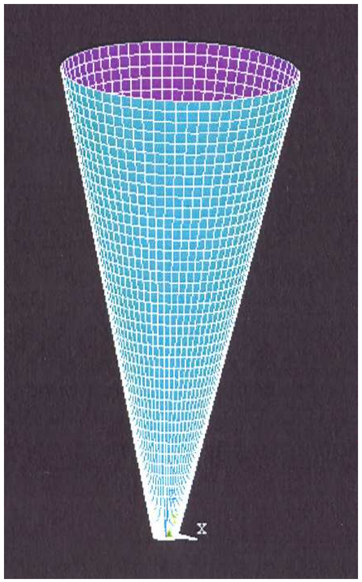
ALEGRA simulations of RTL with random imperfections still shows robust power flow



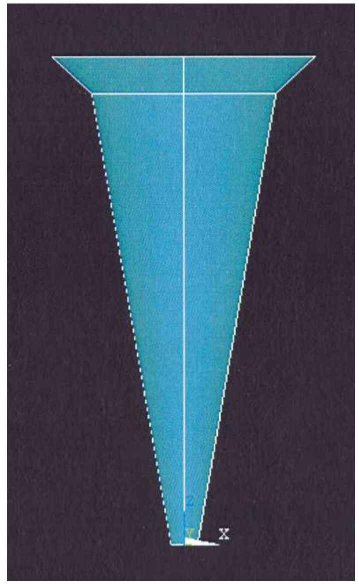
AK gap: 2 mm
RTL wall thickness: 0.025 inches = 635 microns
Power pulse: rising to 60 MA in 100 ns



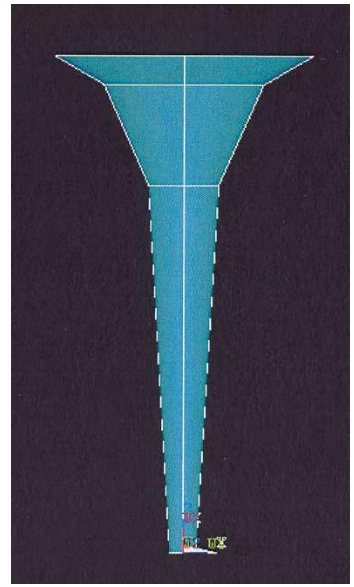
RTL buckling mode analysis leads to optimized RTL shape, that permits lower mass RTLs



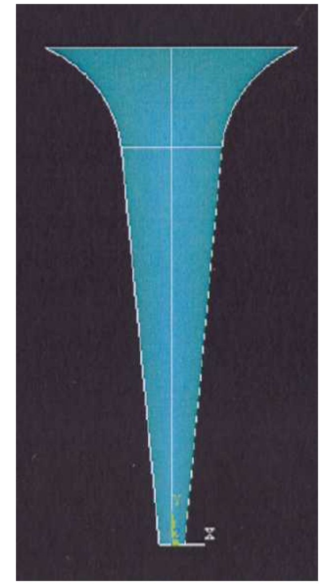
Single segment RTL



Two-segment RTL



Three-segment RTL



Curved RTL

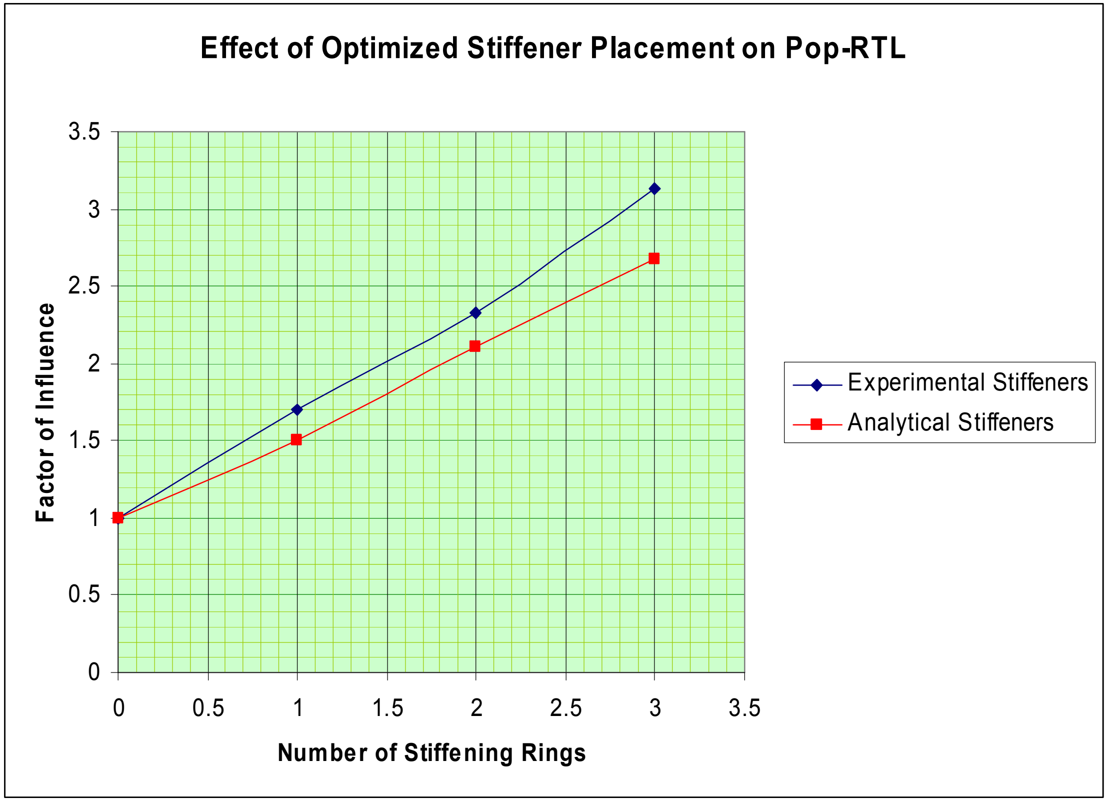
RTL design	Eigenbuckling Pressure (dyne/cm^3)	Enhancement over single-segment
single-segment	249,755	1.0
two-segment	490,117	1.96
three-segment	730,507	2.92
curved	748,966	3.00

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

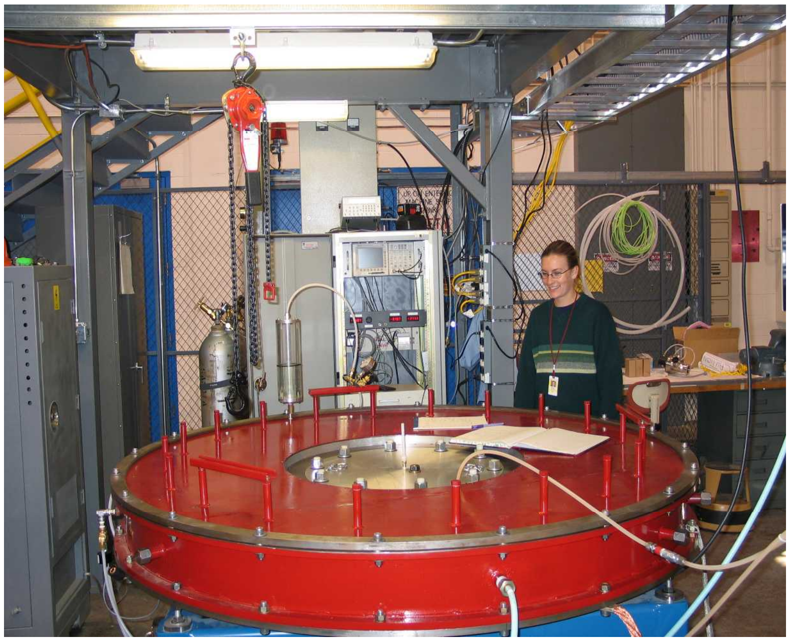


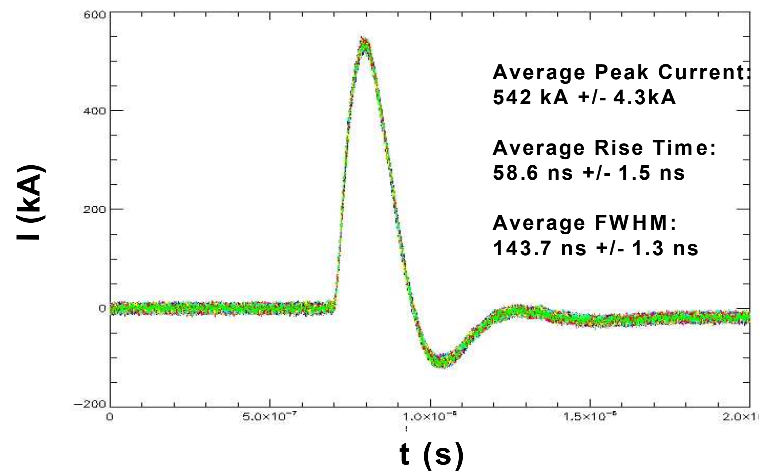
Stiffeners significantly increase the structural performance of the PoP-RTL without adding significant mass

SNL, U. Alabama

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

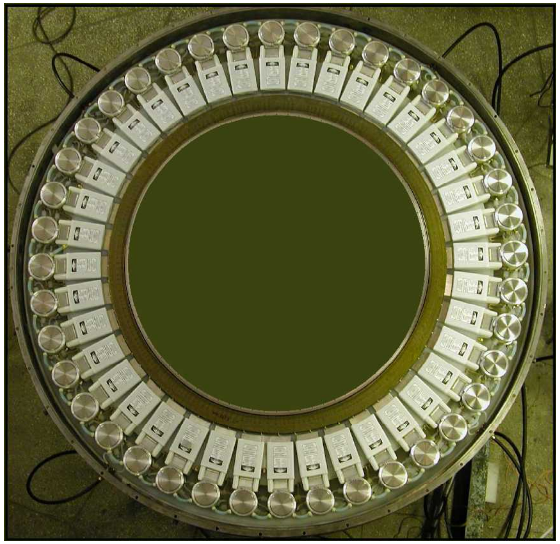
40 Maxwell 31165 caps,
20 switches, ±100 kV
0.2 Ohm load 0.05TW

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)

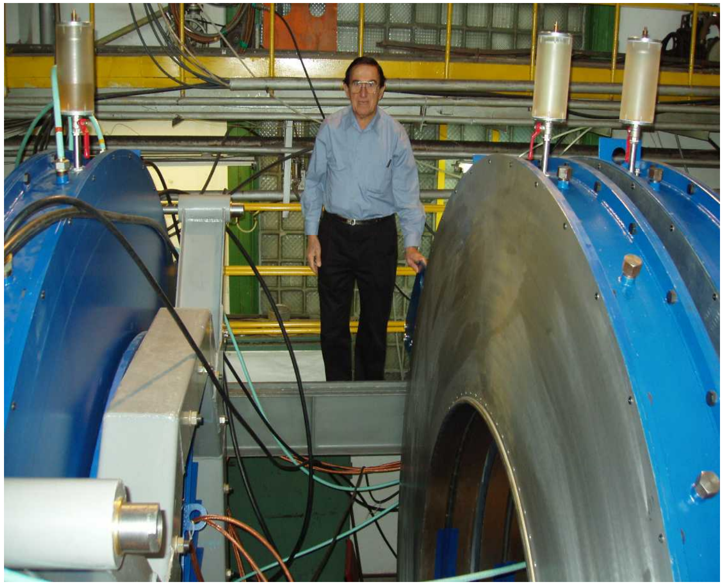
Five 1.0 MA LTD cavities have been built in Tomsk, Russia (this is the building block for Z-PoP and future Z-IFE drivers)

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

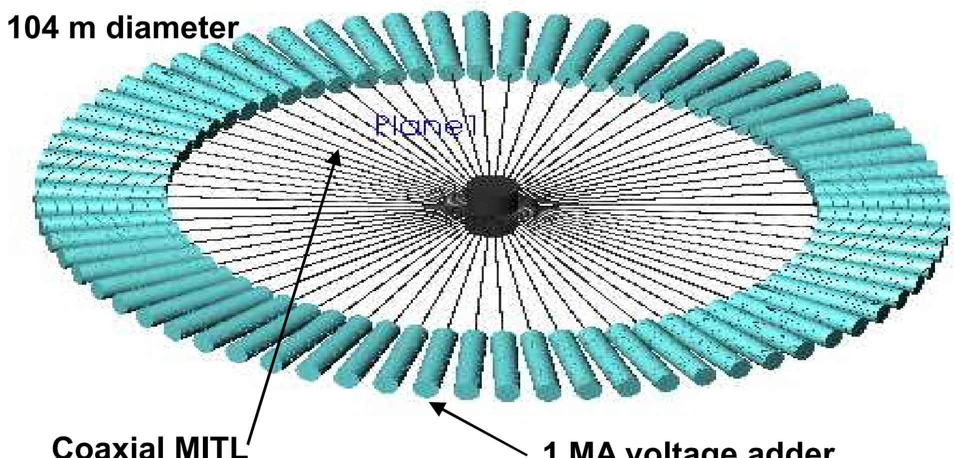


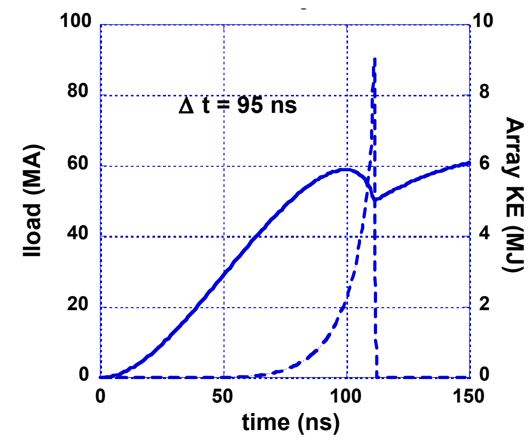
Test stand for Voltage adder testing of five 1.0 MA LTD cavities (High Current Electonics Institute – Tomsk, Russia)

September 2006

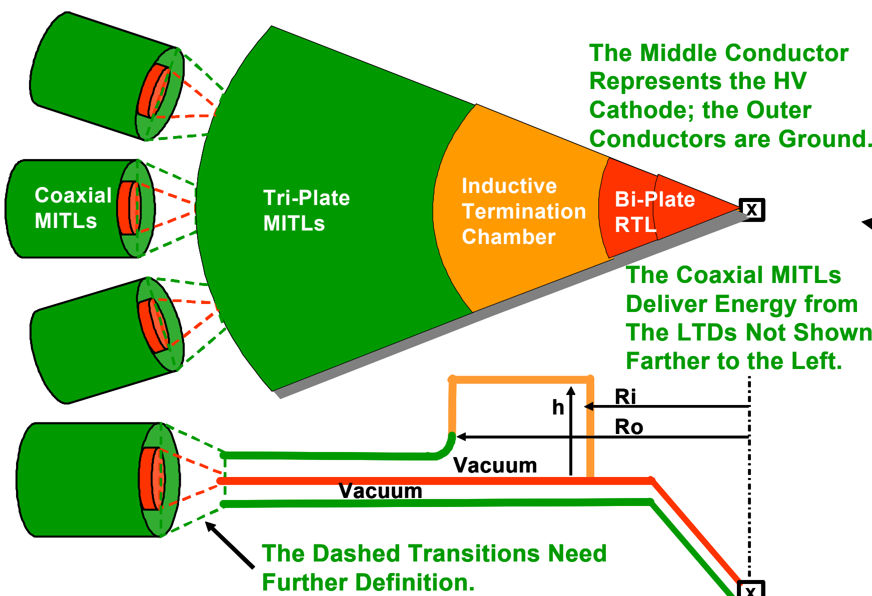
SNL, Tomsk

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





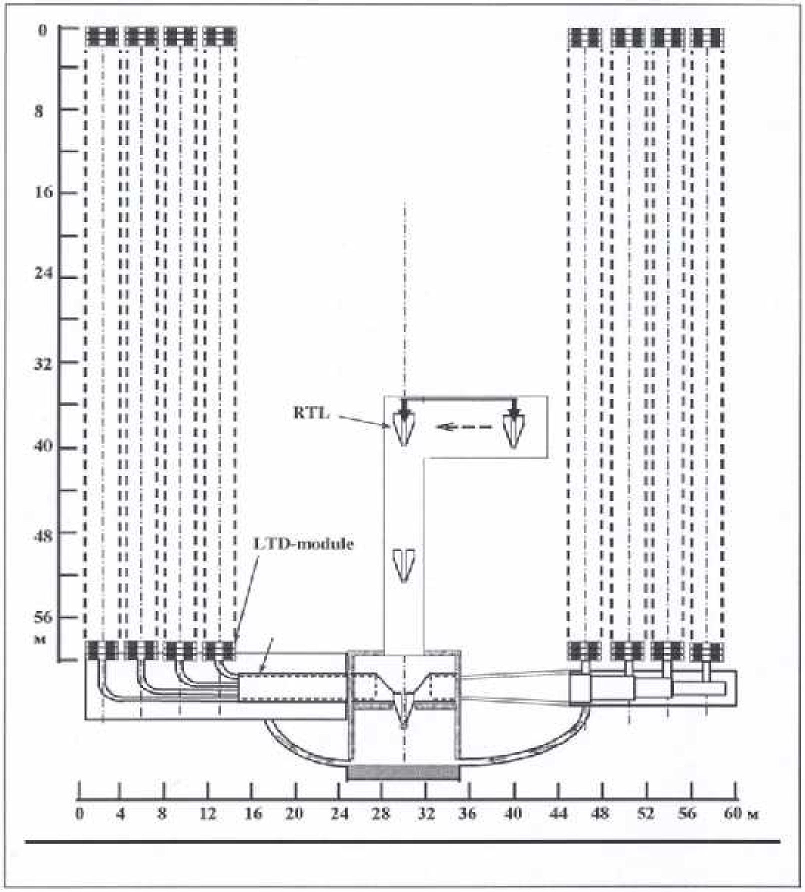
55 mg array load



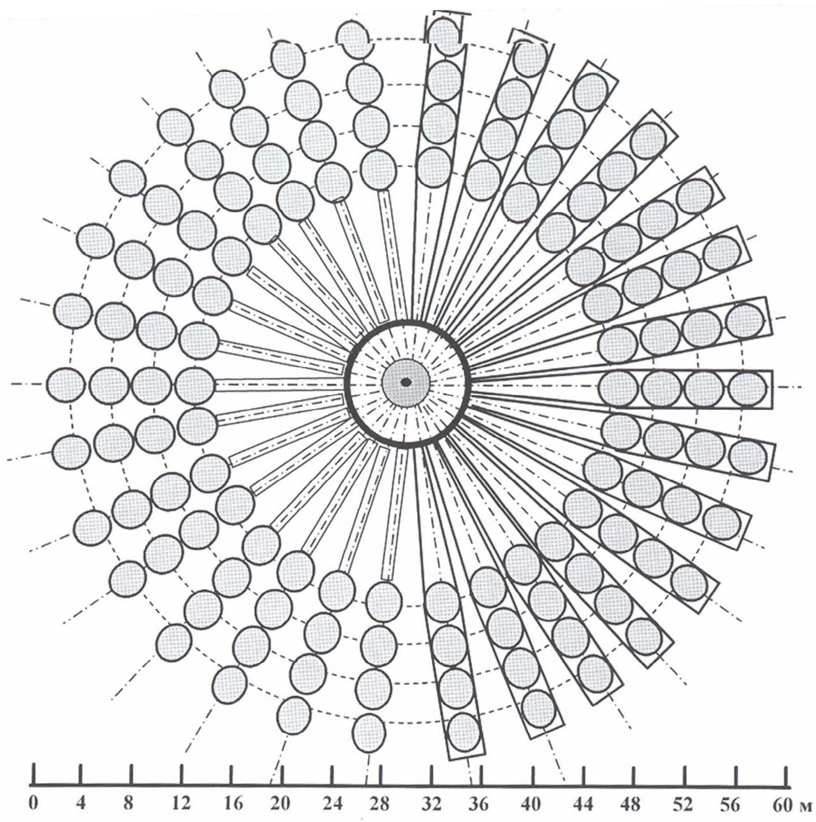
Top pie-section and side views of the Coaxial to Tri-Plate to Bi-Plate transition geometry

An IFE driver (90 MA) with 120 LTD modules

(Kurchatov – Moscow, Russia)

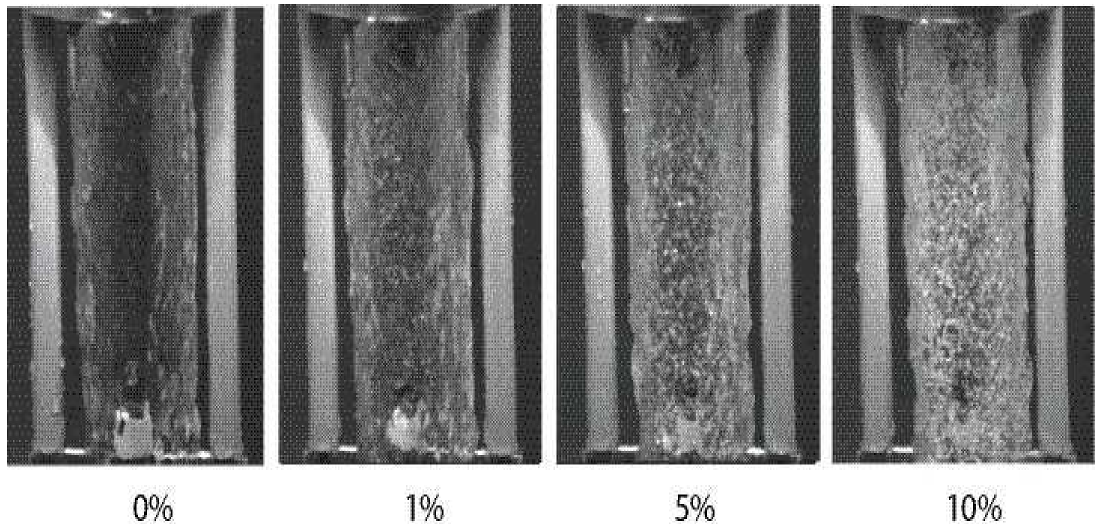


General conceptual scheme of LTD generator and reactor chamber for ZP-3R

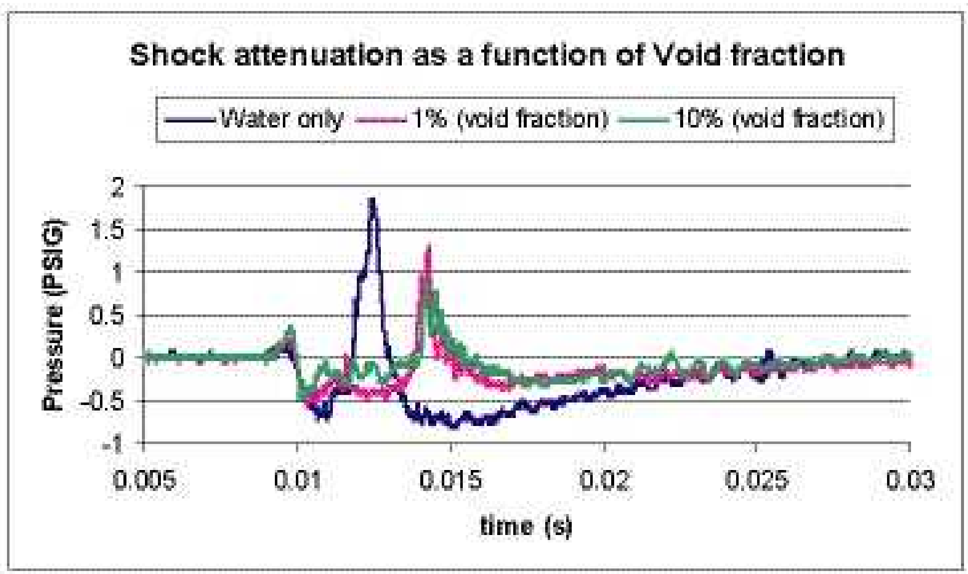


Top view of LTD modules of ZP-3R

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

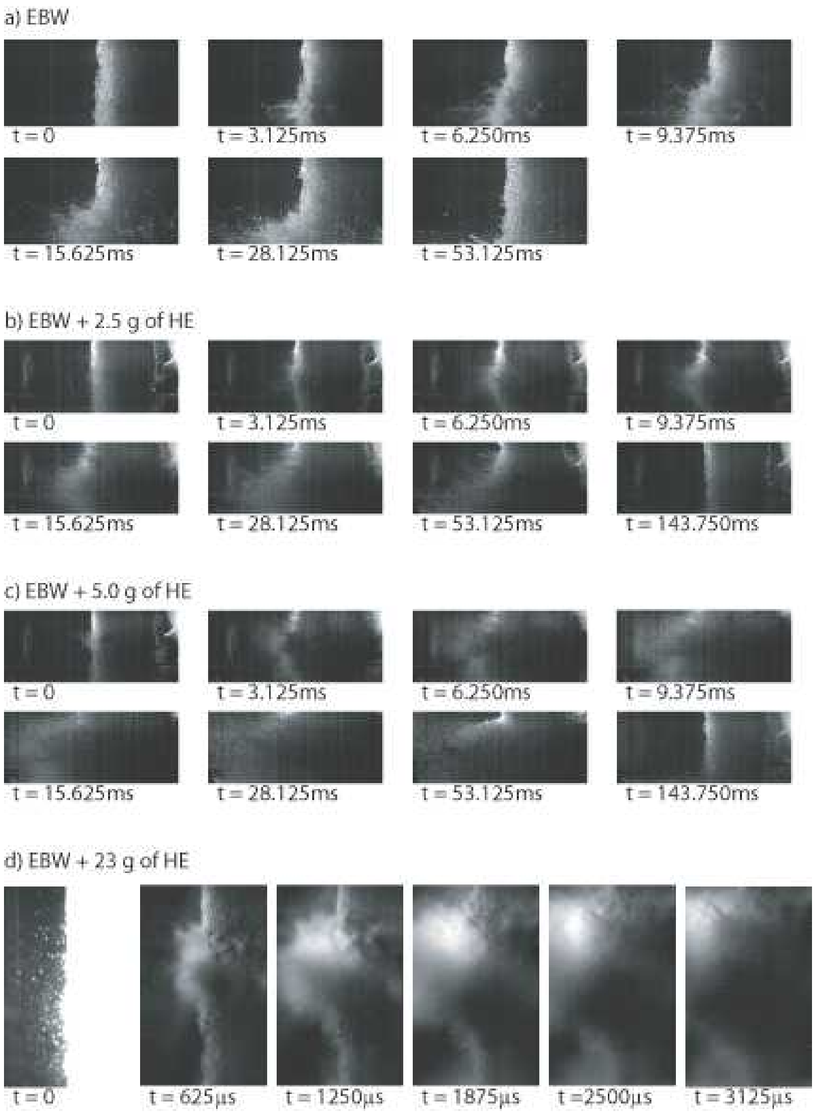


Photographs showing near-field behavior of two-phase annular jets with different void fractions (liquid superficial velocity v = 2 m/s)



Georgia-Tech

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



Exploding bridge wire (EBW)
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

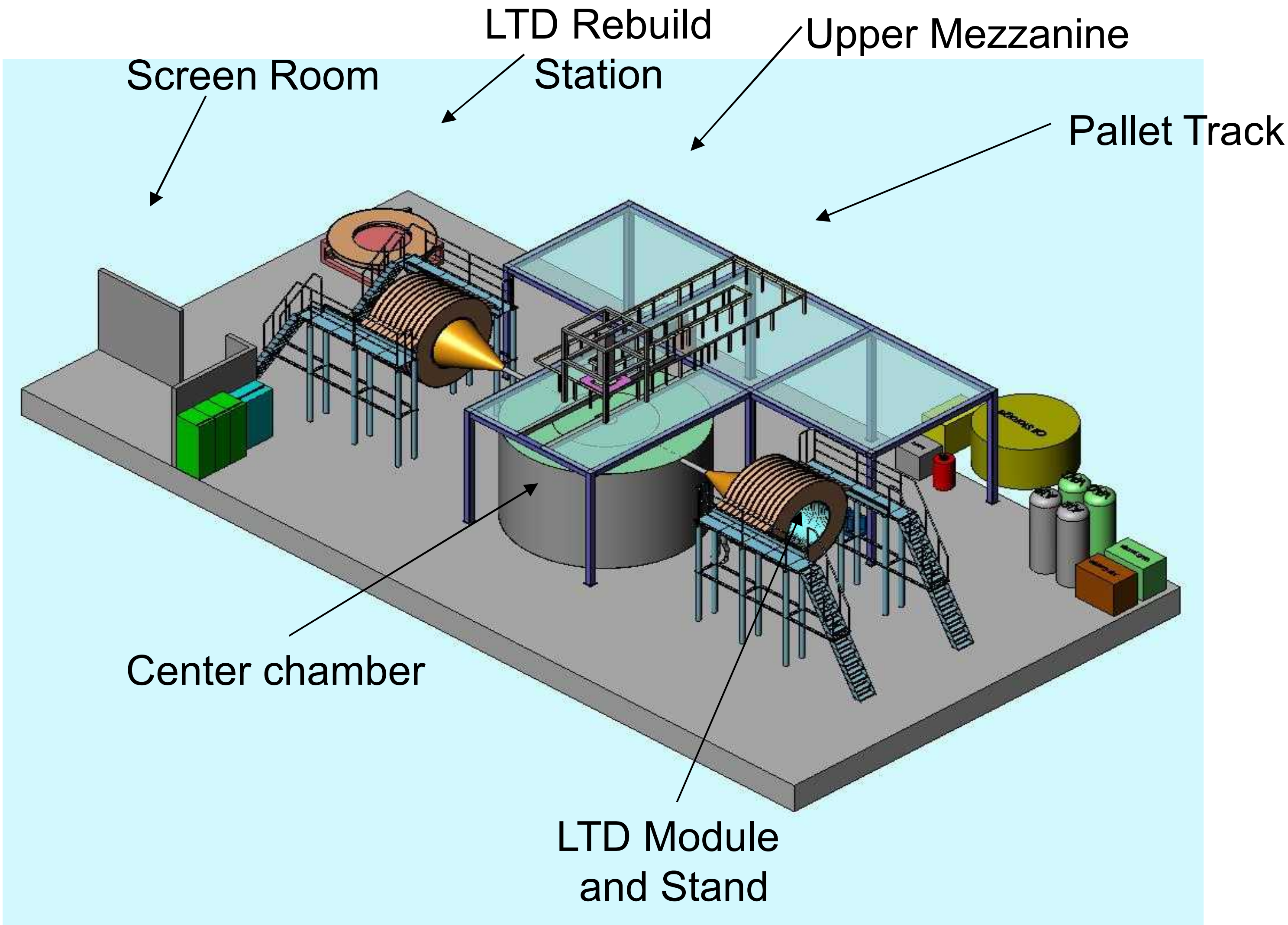
EBW + 5 g of HE (C4)
Peak pressure: 105 atmospheres
Impulse duration: 80 μs
Raw integrated impulse: 100 Pa.s

EBW + 23 g of HE (C4)

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

UCB

Z – PoP (two 1 MA legs)



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

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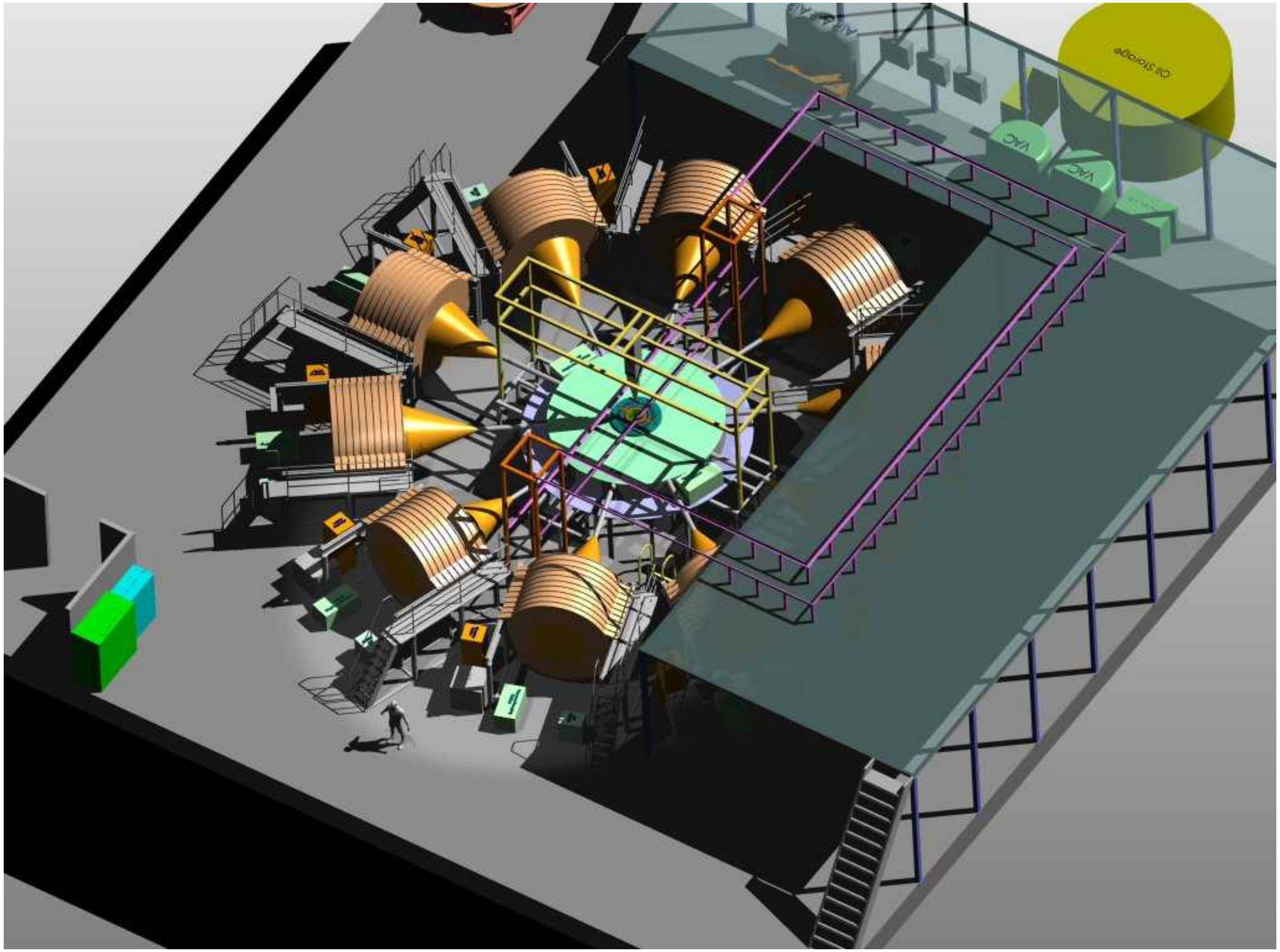
Z – PoP (ten 1 MA legs)

comparable to a rep-rated Saturn at 10 MA



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

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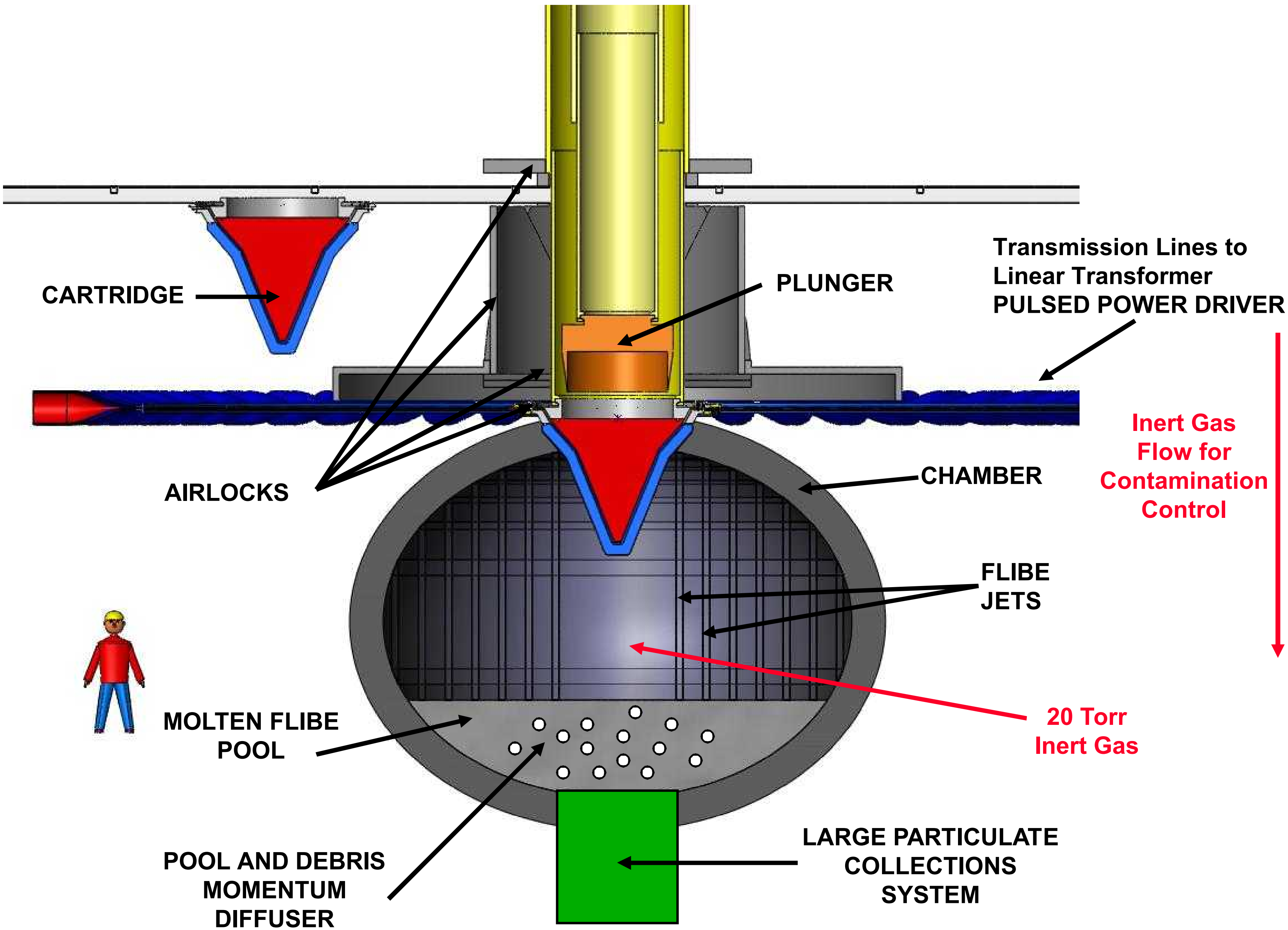
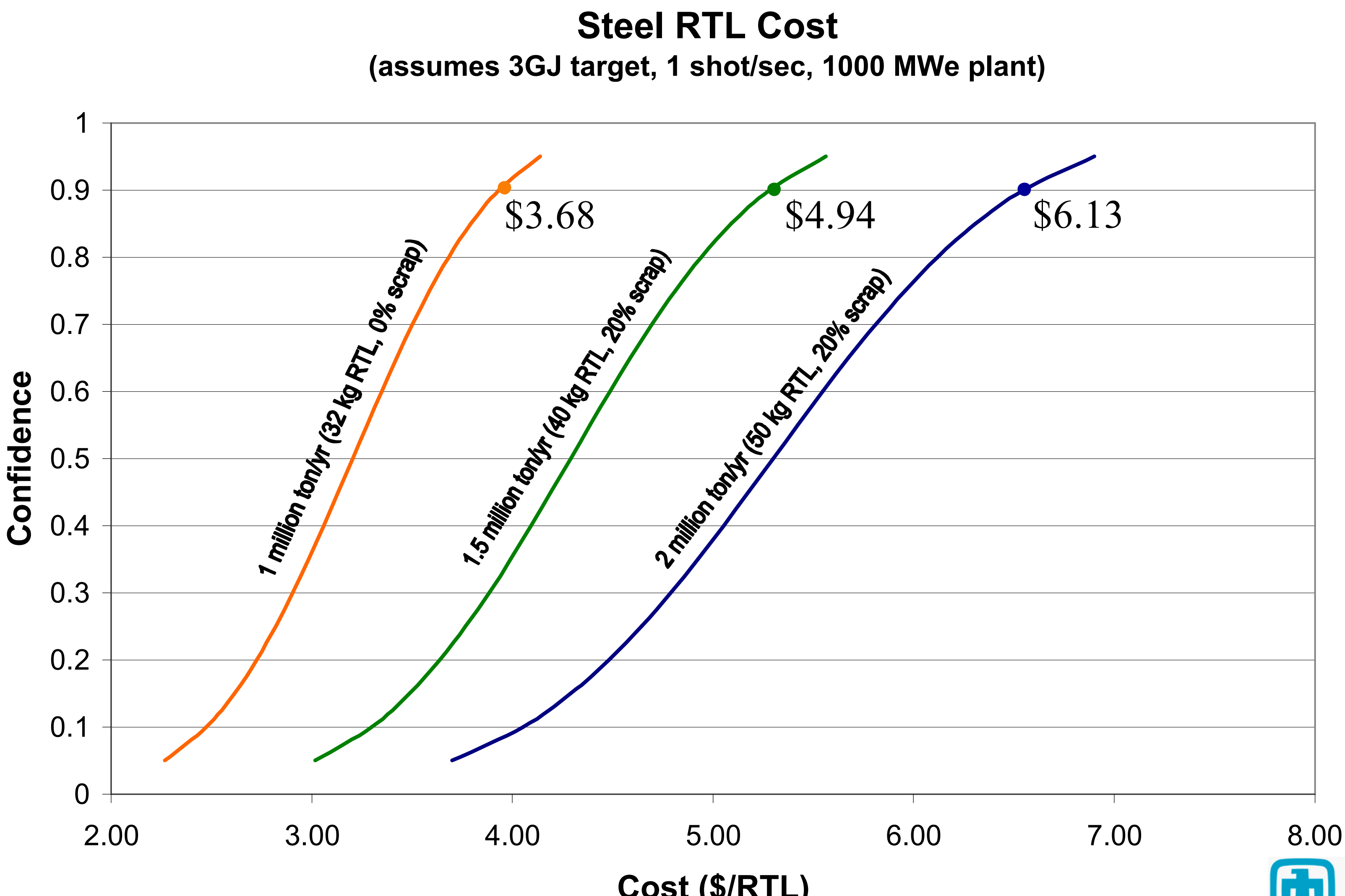
BASE Z-IFE UNIT



Steel RTL Cost is Driven by Mass



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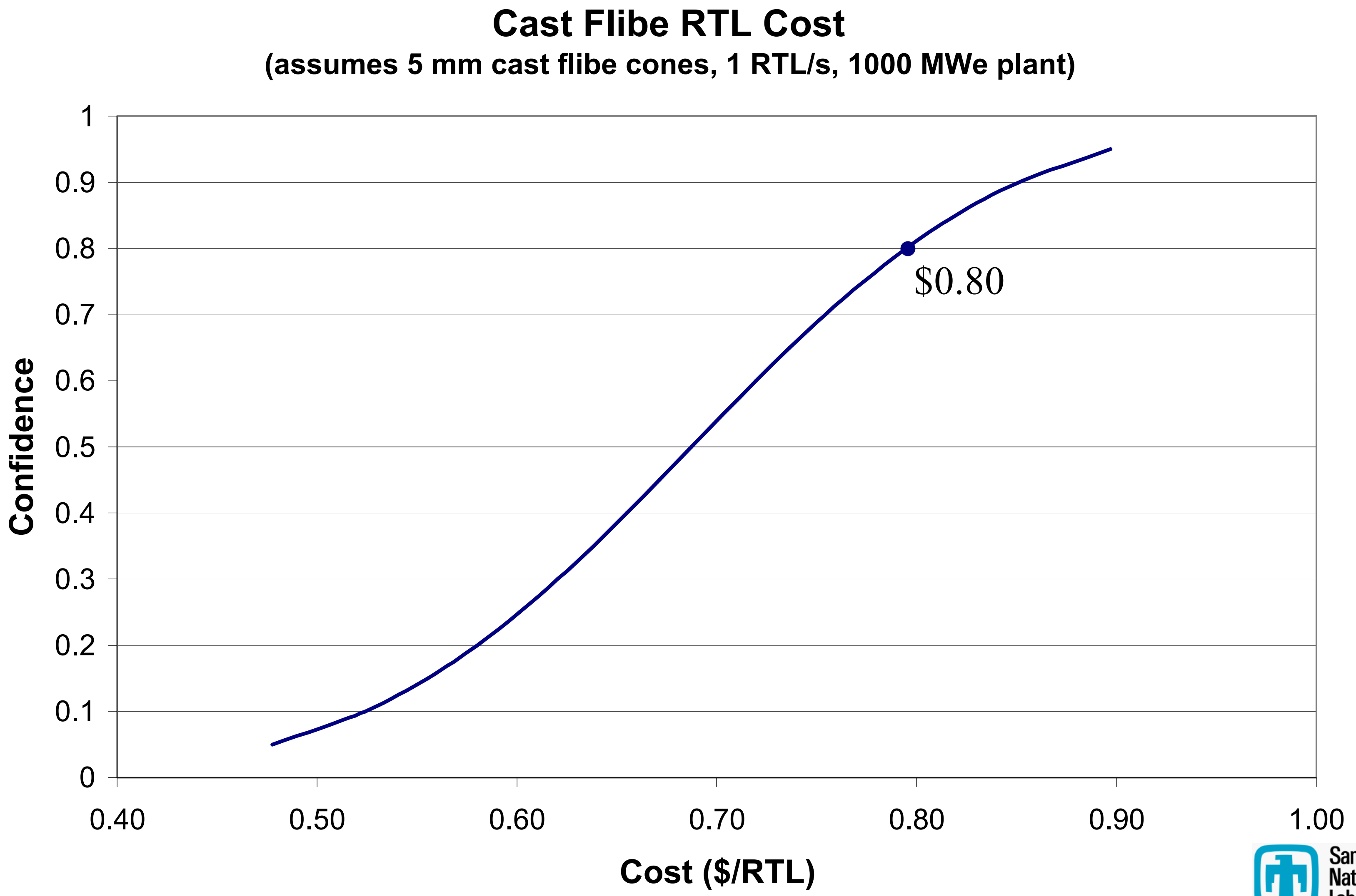
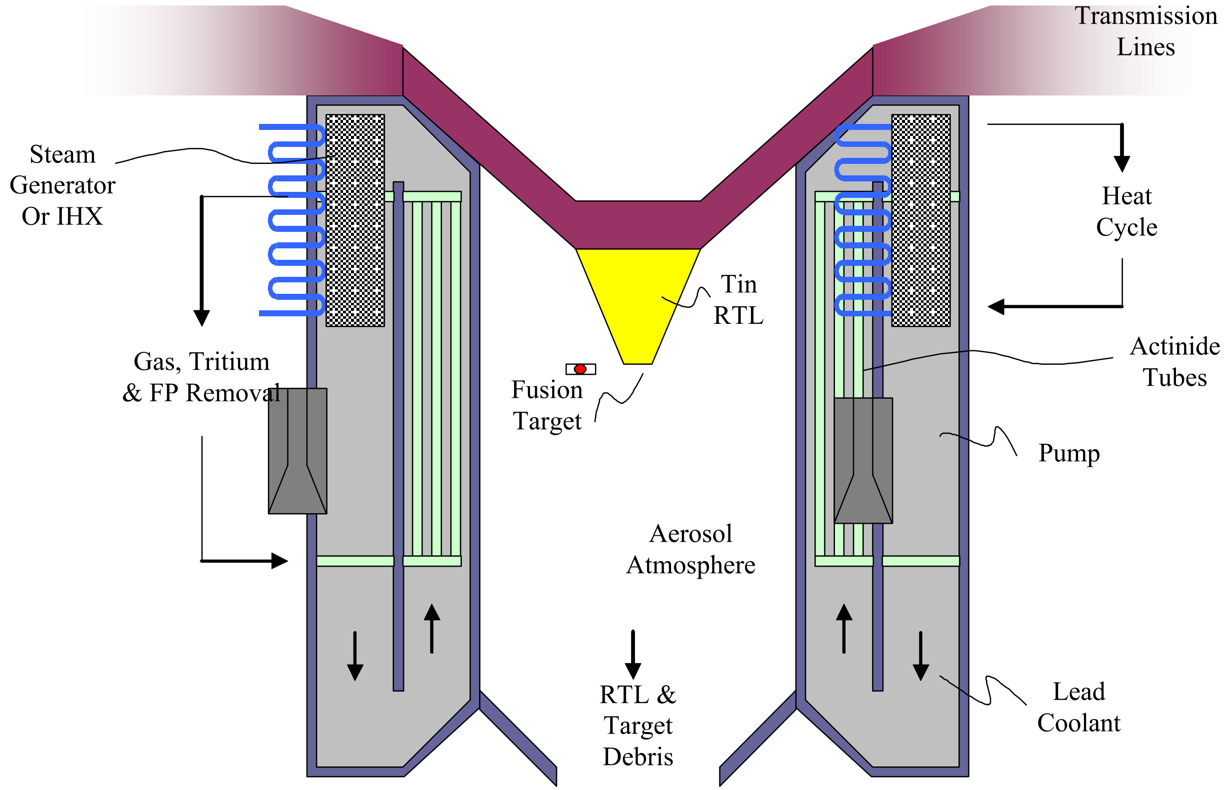
Cast Flibe RTLs Cost Considerably Less



In-Zinerator includes a sub-critical blanket to burn actinides – produces transmutation of waste and produces power



In-Zinerator Power Plant

Z-Pinch parameters for: Z-IFE Power Plant Transmutation Plant

Parameter	Z-IFE Power Plant	In-Zinerator
Fusion Target Yield	3,000 MJ	200 MJ
Repetition Rate	0.1 Hz	0.1 Hz
Power per Chamber	390 MWth	3,000 MWth
Transmutation Rate	N/A	1,200 kg/yr
k_{eff}	N/A	0.97
Energy Multiplication	N/A	150
Number of Chambers	10	1
RTL & Target		
RTL Material	1006 carbon steel	Tin ??
Cone Dimensions	1m Ø x 0.1m Ø x 2m H	1m Ø x 0.1m Ø x 1m H
Mass per RTL	34 kg	93 kg
Chamber Design		
Shape	Spherical	Cylindrical
Dimension	5.9 m outer radius	3.2 m outer radius
Chamber Material	F82H	F82H or Hasteloy-N
Wall Thickness	35 cm	5 cm
Blanket		
Actinide Mixture	N/A	$(LiF)_2$-AmF_3
Coolant	Flibe	Lead
Coolant Configuration	Jet and Pool	Shell & Tube (contained)
First Wall Configuration	Thick liquid wall	Structural Wall
Shock Mitigation	Thick, voided coolant	Argon Aerosol
Coolant Operating Temperature	950 K	950 K
Heat Cycle	Rankine	Rankine

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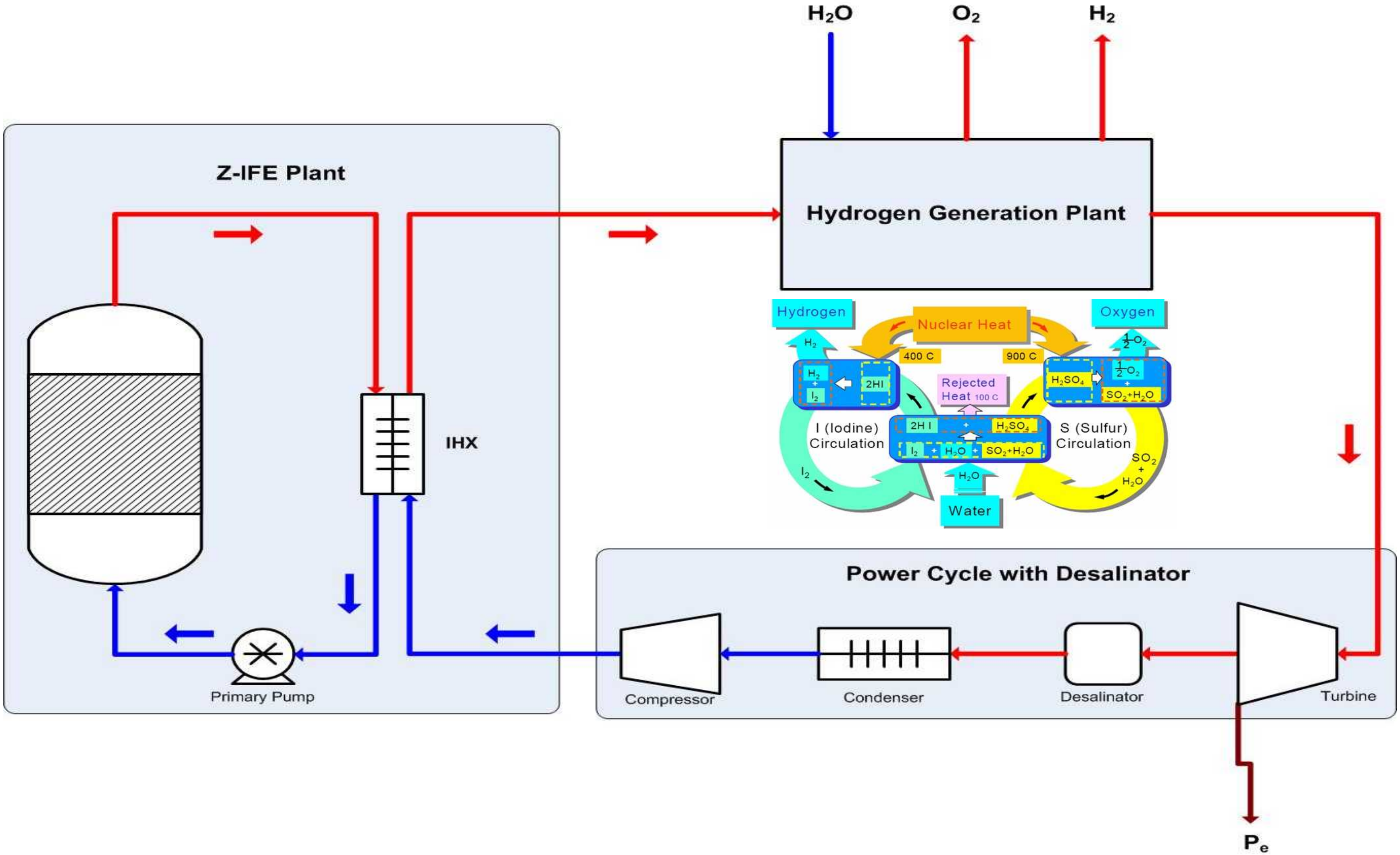
Overall System for Hydrogen Production using Z-Pinch IFE



Hydrogen Production Costs for Various Methods

Production method (Ref. 1)	Cost ($/kg)
Coal gasification	0.68
Non-catalytic partial oxidation	1.69
Thermo-chemical nuclear (fission) (Ref.2)	1.38
Thermo-chemical nuclear (fusion) z-pinch driven	1.62-2.23
Steam methane reformation	1.12-1.76
Electrolysis (depends on cost of electricity)	1.98-5.64

Ref. 1. T.E. Drennen, et al., "The Hydrogen Futures Simulation Model (H2Sim) Technical Description," Sandia Report SAND2004-4937 (2005).

Ref. 2. K.R. Schultz, et al., "Large-Scale Production of Hydrogen by Nuclear Energy for the Hydrogen Economy," National Hydrogen Assoc. Annual Conference, Washington, DC, March 5, 2003.

Unique features of z-pinch driven fusion hydrogen production:

- essentially unlimited source of energy
- no greenhouse gases
- no long-lived radioactive waste

Z-IFE Presentations at TOFE

(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**)

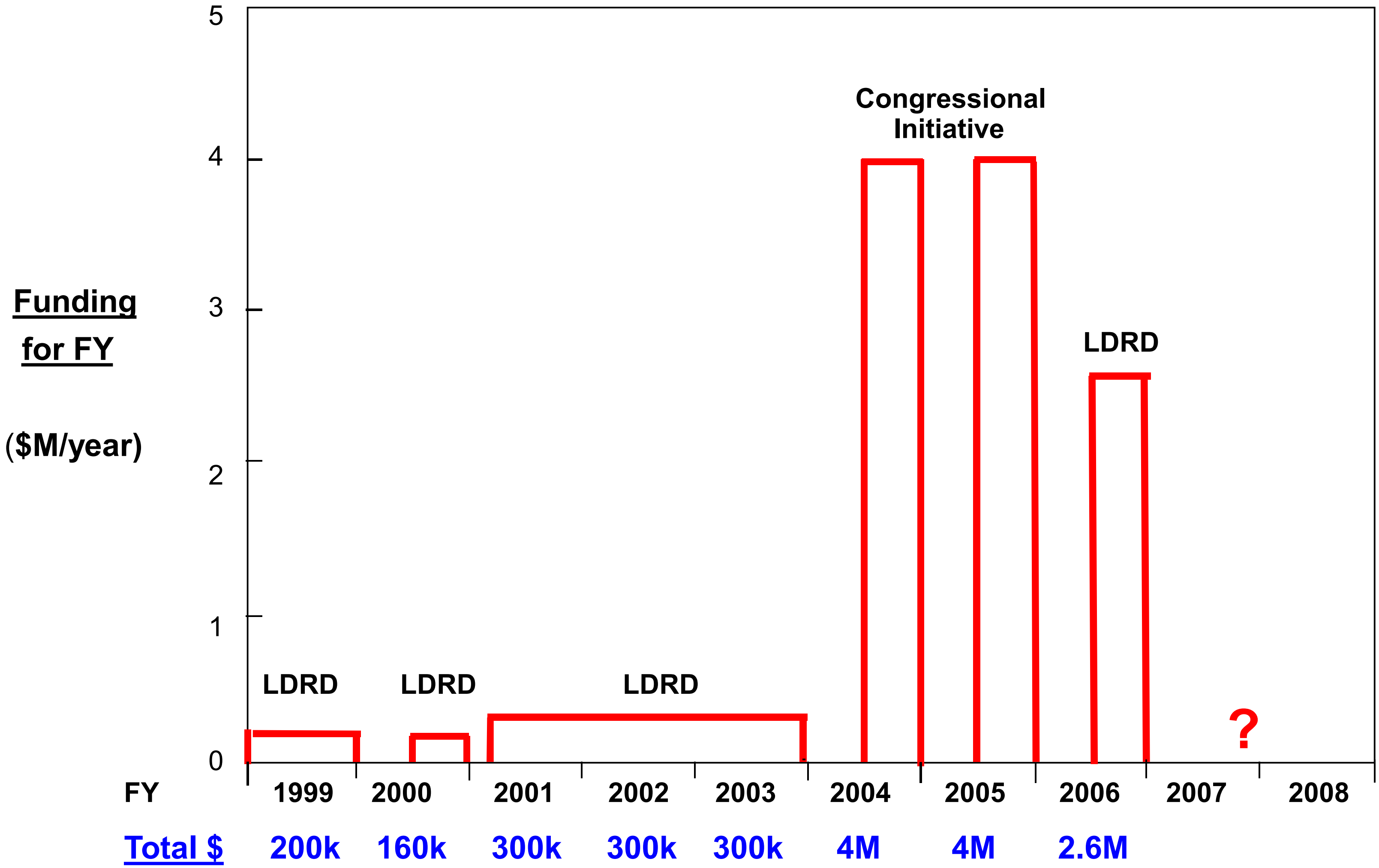
(20) "Investigation of Argon and Xenon as Potential Shock Attenuators in Z-IFE Chambers Using ALEGRA"
Sal Rodriguez, et al., SNL

(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

Z-IFE Funding



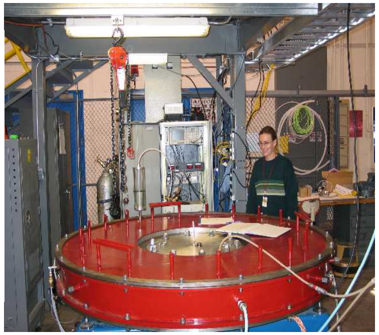
Z-IFE Program

Z-IFE Recent Results

long-term goals: Power production, Hydrogen production

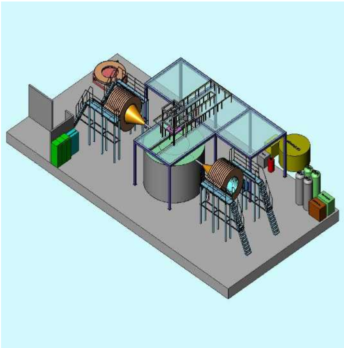
nearer-term goals: GNEP, Nuclear waste transmutation

RTL

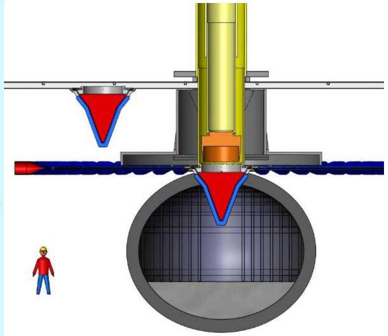


LTD driver

Shock Mitigation



Z-PoP



Chamber

- Substantial Progress is being made in all areas of Z-IFE
- Future of Z-IFE is uncertain

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.

Z-PoP Movie