Recent Results of ICF and IFE Z-Pinch Research at the University of Wisconsin

R.R. Peterson, D. Kammer, D.A. Haynes,

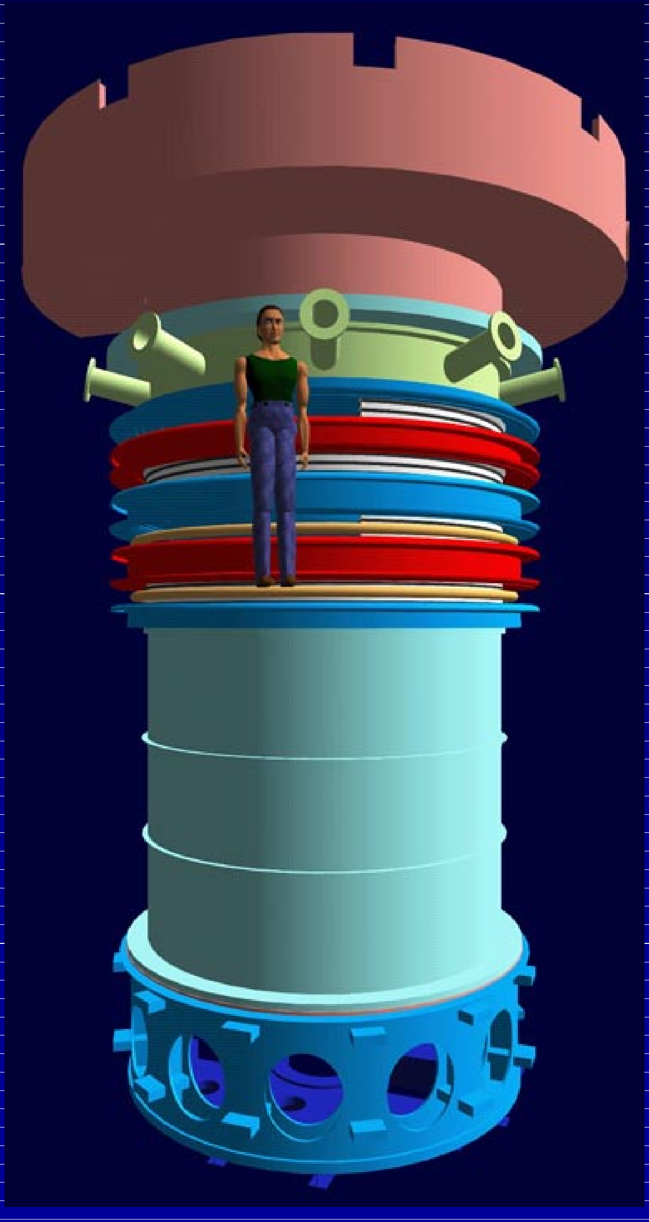
D. Williamson, J.P. Blanchard, A. Kostuch,

I.N. Sviatoslavsky, H.Y. Khater, G.A. Moses,

G.A. Rochau, M.E. Sawan, J. Yuan,

P. McKenna, T.J. Tautges,

G. Shanmugasundar, and G.L. Kulcinski



Outline of Presentation

- Background of UW-SNL Collaborations
- ICF Physics and Near Term Z-Pinch Related Research
    - **Computer Simulations of X-Ray Neutron Output from X-1 Targets**
    - **Computer Simulation of Hole Closure in Z-Pinch Hohlraums**
    - **Computer Simulations of Debris Production from Current Return Cans**
    - **Computer Simulations of Al Contained EOS Experiments**
    - **Experiments on Z to Simulate IFE Target Chamber Phenomena**
    - **Experiments on Z of Radiation Transport in Foams**
- Engineering and Intermediate Term Z-Pinch Structural Related Research
    - **Preliminary Finite Element Structural Modeling and Analysis of Z**
    - **Design of a System to Catch and Contain Debris from EOS Experiments**
    - **Shielding for the X-1 Target Chamber**
    - **Activation of X-1 Target Chamber**
- IFE Related Research

There Has Been a Long and Productive History of Collaboration Between Sandia and the University of Wisconsin

Start Date	Duration	Project
1978	1	Cavity and First Wall Design for REB Fusion Reactors
1979	2	Cavity and First Wall Design for Non-Symmetric Blast Waves
1981	1	LIB Fusion Reactor Design
1982	5	LIF Target Development Facility
1983	1	Blast Wave Phenomena in LIF Target Chambers
1983	1	PBFA-II Coupled n & γ Transport Calculations
1986	1	Probability Risk Assessment-Recovery Action Effects
1987	10	LIBRA Commercial Reactor Fusion Design (with KfK)
1991	5	Theory of Emission Spectra from LIB Created Plasmas
1992	1	Computer Simulation of Tokamak Disruptions
1993	1	Jupiter Project
1994	1	LIB Channel Analysis
1996	1	Spectroscopy Analysis of Dynamic Hohlraums
1997	3*	X-1, ZX High Yield Test Chamber Design and Analysis
1999	2*	IFE Power Concepts for Z-Pinch Technology

* Current

University of Wisconsin Fusion Ph.D. Graduates Employed by Sandia National Laboratories

Poukey, J. W.	**1966**
Chaffin, R. C.	**1967**
Kuswa, G. W.	**1970**
Hunter, T. O.	**1978**
Whitley, J. B.	**1978**
Watson, R. D.	**1981**
O'Brien, K.	**1985**
Pong, L.	**1985**
Croessmann, C. D.	**1986**
Bartel, T.	**1987**
Sniegowski, J. J.	**1991**
Castro, J. P.	**1995**
Crowell, J.	**1999 (Livermore, CA)**

R.R. Peterson

University of Wisconsin-Madison

Sandia National Laboratories
November 6, 2000

ICF Physics and Near Term Z-pinch Related Projects at The University of Wisconsin

Fusion Technology Institute University of Wisconsin - Madison

1. Computer Simulations of X-Ray Neutron Output from X-1 Targets
2. Computer Simulations of NIF Indirect Drive Capsules
3. Computer Simulations of Hole Closure in Z-Pinch Hohlraum Experiments on Z
4. Computer Simulations of Debris Production From Current Return Cans in Wire Array Implosions*
5. Computer Simulations of Aluminum Contained EOS Experiments
6. Experiments on Z to Simulate IFE Target Chamber Phenomena*
7. Radiation Transport in Foams: Experiments and Simulations
8. Time-resolved X-ray Imaging Diagnostic (EST) on Z
9. Modeling of Response of Materials to Ion Beams

* Non-SNL funding

Computer Simulations of X-Ray Neutron Output from X-1 Targets

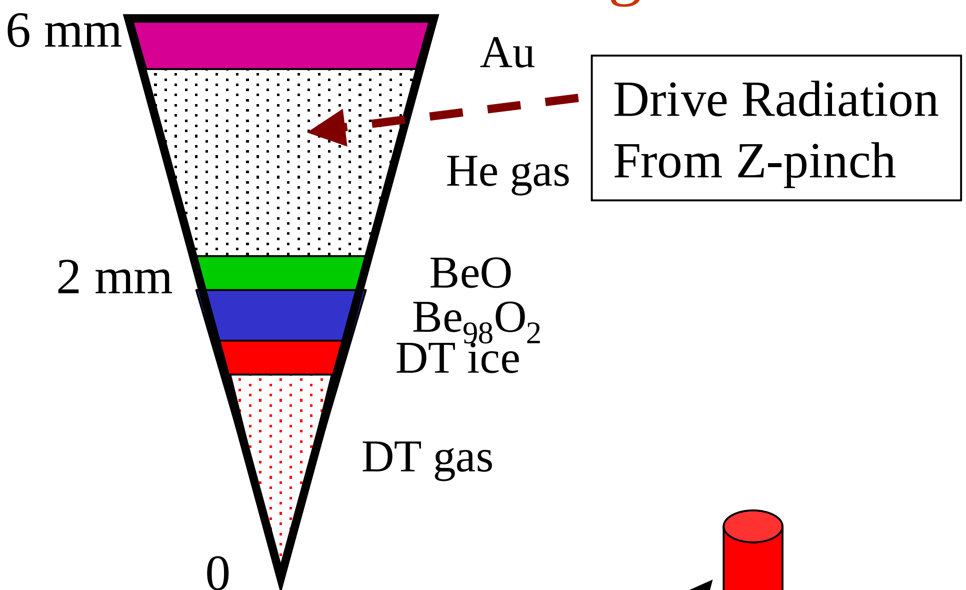
R.R. Peterson and D.A. Haynes
University of Wisconsin-Madison

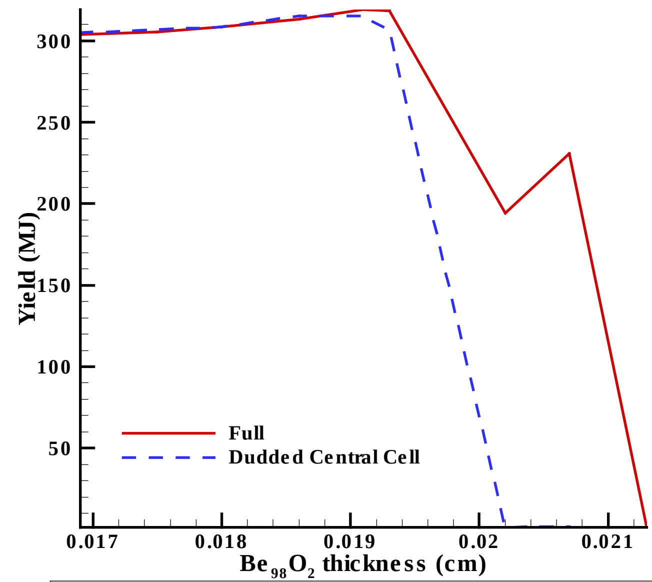
Sandia National Laboratories
November 6, 2000

Study of X-1 Indirect-Drive Target With 1-D BUCKY Code

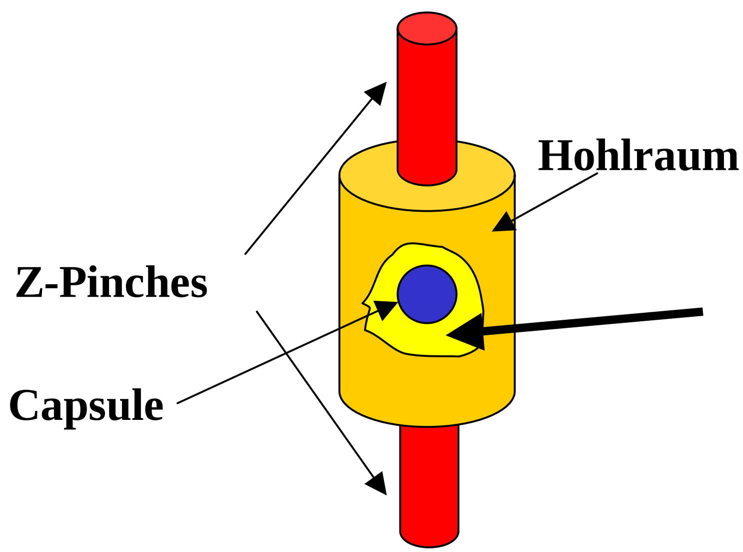
Fusion Technology Institute University of Wisconsin - Madison

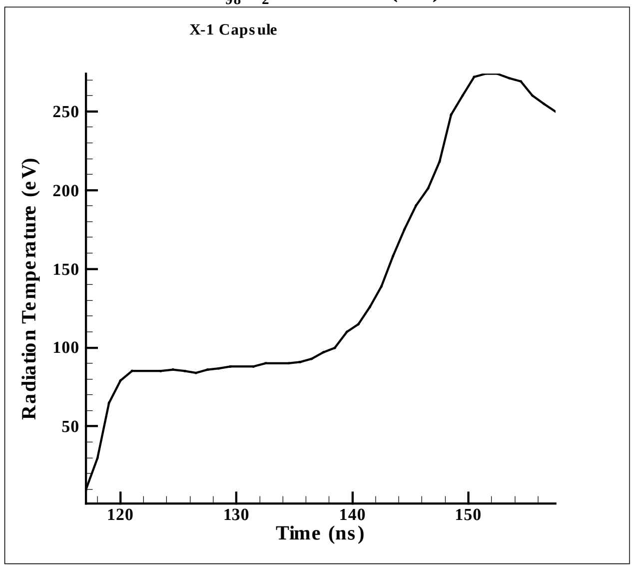
BUCKY 1-D X-1 Target





Static Wall Z-pinch-driven Hohlraum Target





BUCKY is a Flexible 1-D Radiation-Hydrodynamics Computer Code

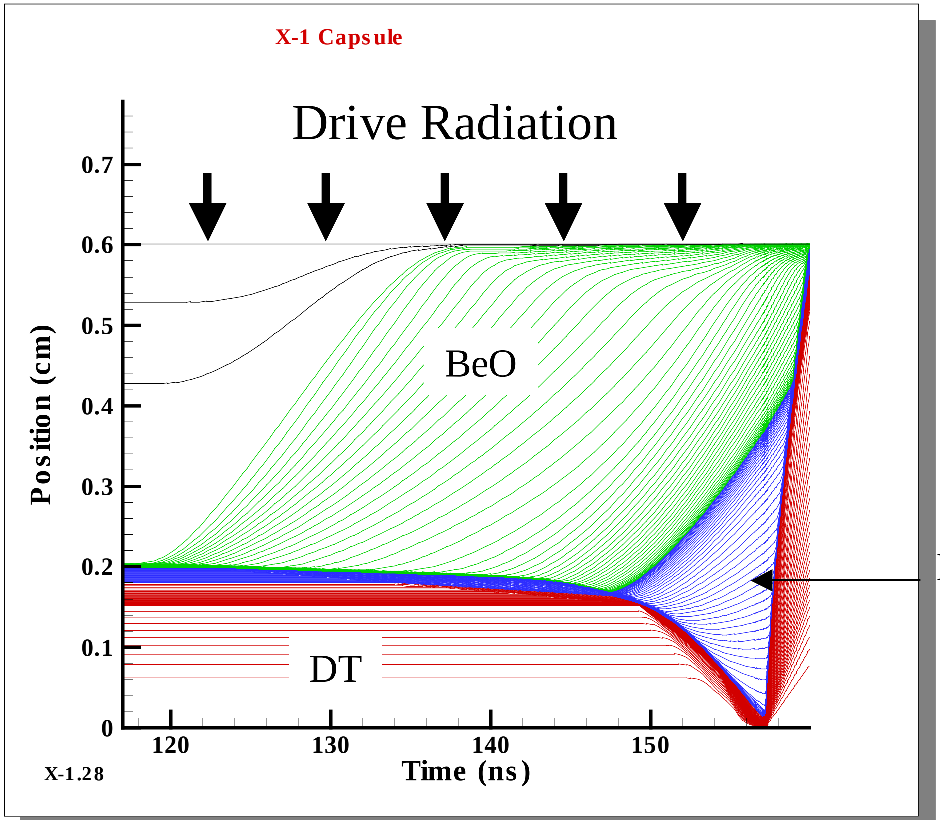
- **1-D Lagrangian MHD (spherical, cylindrical or slab).**
- **Thermal conduction with diffusion.**
- **Applied electrical current with magnetic field and pressure calculation.**
- **Radiation transport with multi-group flux-limited diffusion, method of short characteristics, and variable Eddington.**
- **Non-LTE CRE line transport.**
- **Opacities and equations of state from EOSOPA or SESAME.**
- **Equilibrium electrical conductivities**
- **Thermonuclear burn (DT,DD,DHe^3) with in-flight reactions.**
- **Fusion product transport; time-dependent charged particle tracking, neutron energy deposition.**
- **Applied energy sources: time and energy dependent ions, electrons, and x-rays.**
- **Moderate energy density physics: melting, vaporization, and thermal conduction in solids and liquids.**
- **Benchmarking: x-ray burn-through and shock experiments on Nova and Omega, x-ray vaporization, RHEPP melting and vaporization, PBFA-II K_α emission, …**
- **Platforms: UNIX, PC, MAC**

Indirect-Drive Target Output is Dominated by Neutrons and X-rays

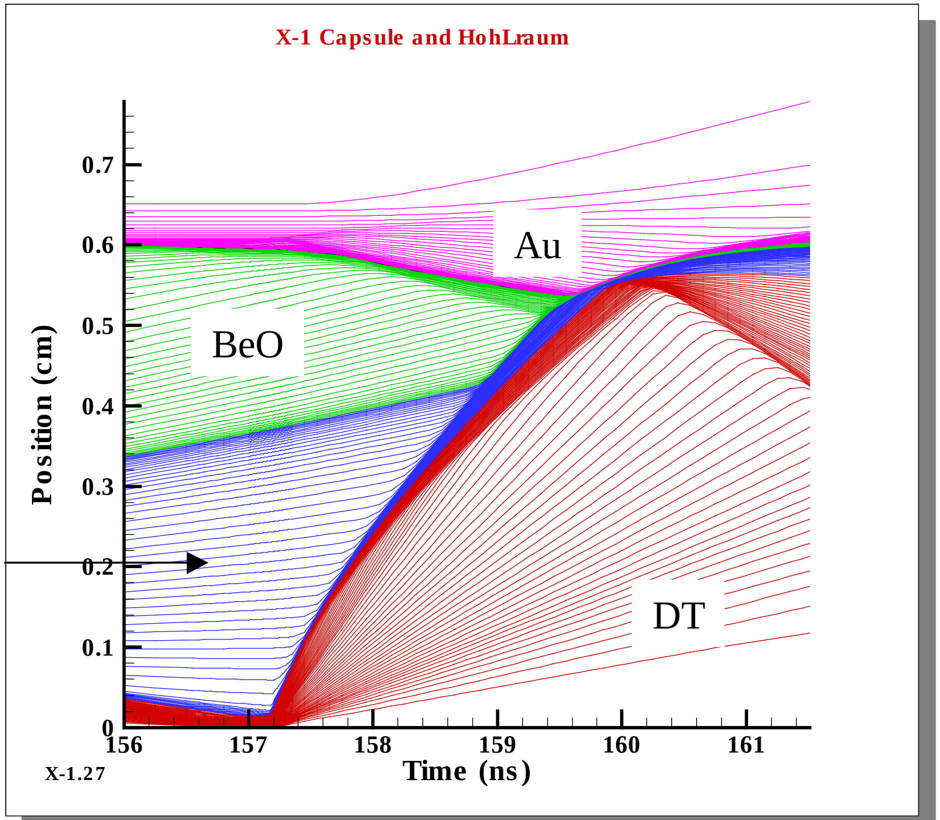
Fusion Technology Institute University of Wisconsin - Madison

Implosion without hohlraum; radiation drive
Used to design capsule and study sensitivity to variations in fabrication.
Run time, a few hours (HP C-180).

Final implosion and burn with hohlraum; no drive
Used to simulate x-ray and ion debris output
Run time, a few days (HP C-180).



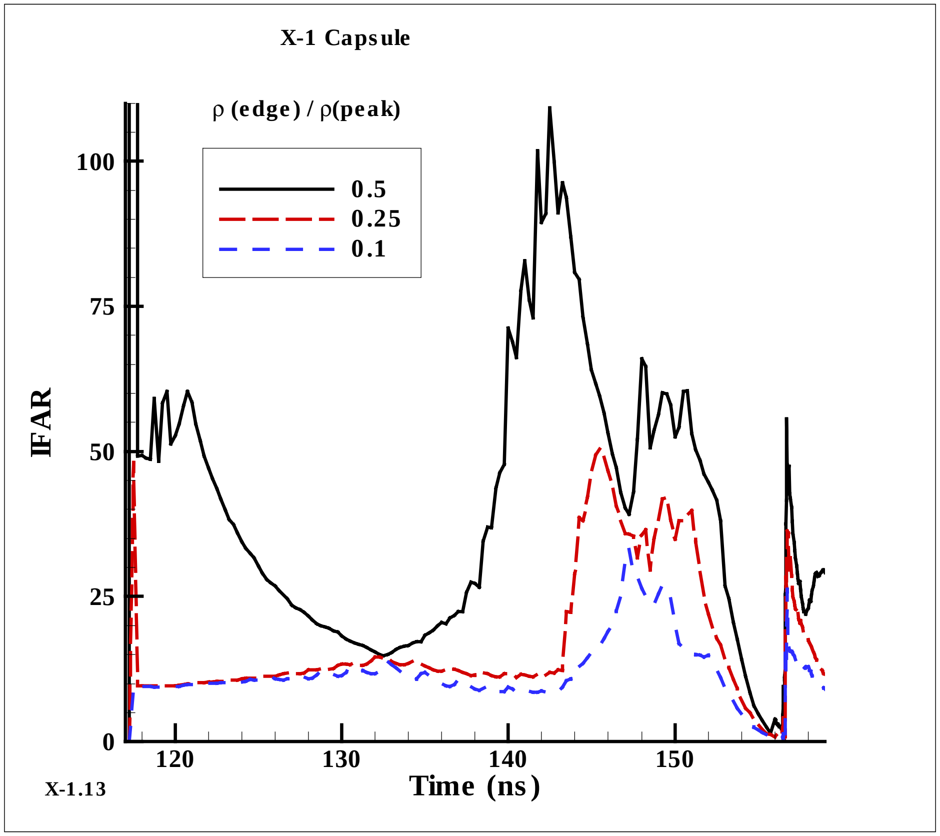
$Be_{98}O_2$

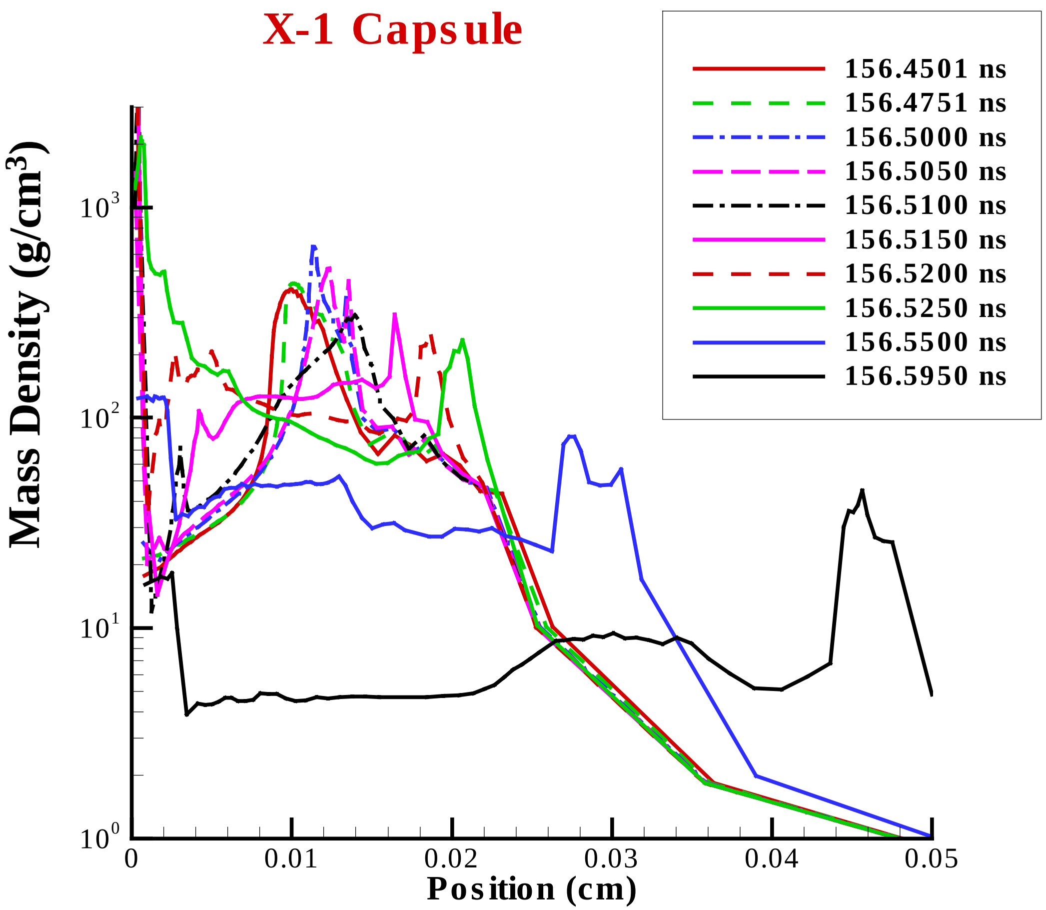


Mass Density Profiles in X-1 Target Change During Burn

Fusion Technology Institute University of Wisconsin - Madison

- •Fuel Is Highly Compressed Near Ignition Time.
- •Fuel Density Is High Enough to Re-absorb Some Neutrons and Soften Their Spectra.
- •Density Is Rapidly Changing.

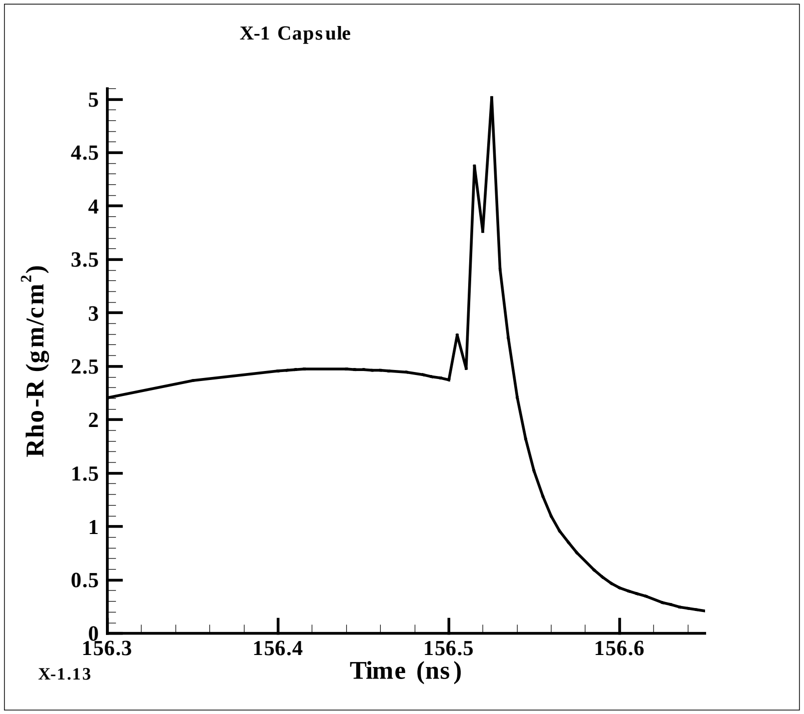


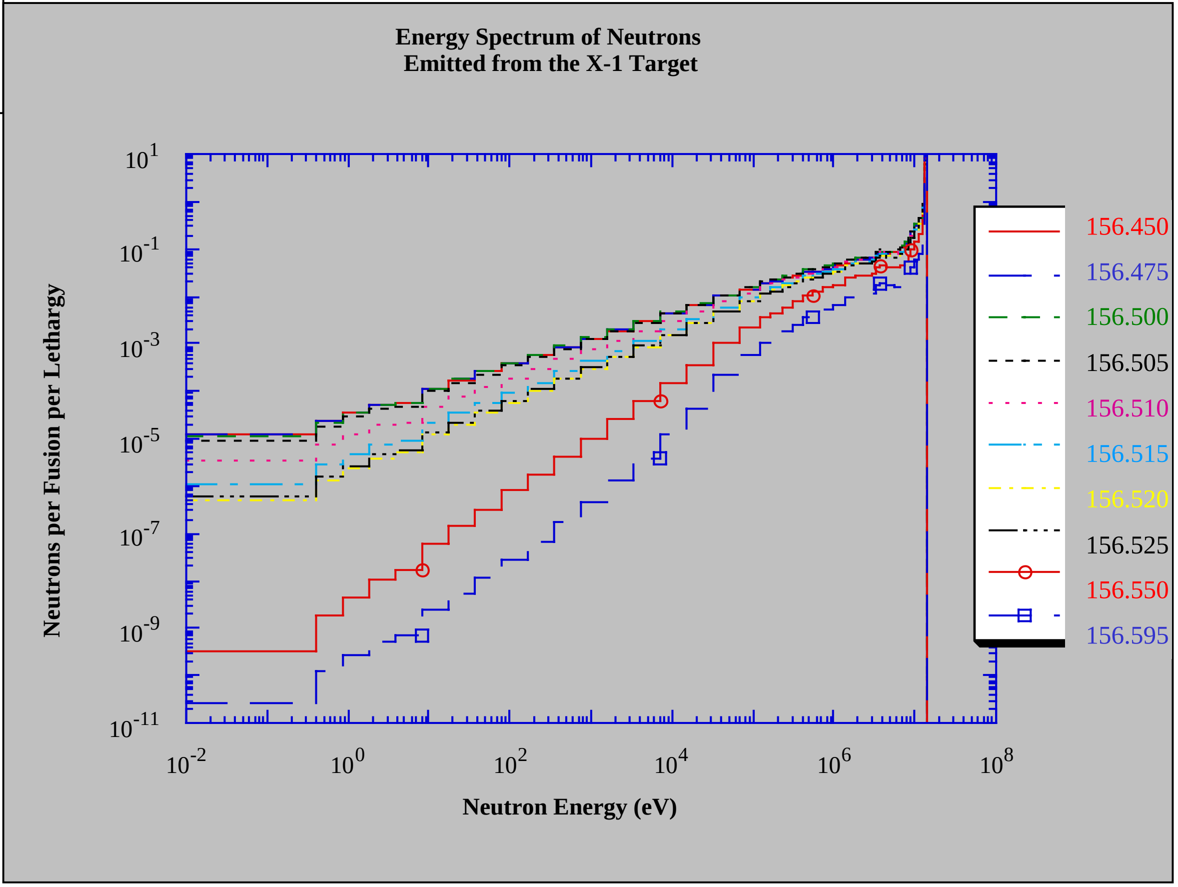


Fuel Density-Radius Product (ρR) is High Enough to Absorb Some Neutrons and Soften Spectrum

Fusion Technology Institute University of Wisconsin - Madison

X-1 Energy Partition		**Fluence on 650 cm Wall**
Neutrons:	220 MJ (69.22%)	41.4 J/cm^2
Gammas:	0.95 MJ (.03%)	0.18 J/cm^2
X-rays:	61.3 MJ (19.3%)	11.5 J/cm^2
Ions:	28.6 MJ (9.0%)	5.4 J/cm^2
Endoergic:	7.8 MJ (2.45%)	-----------
Total:	**318 MJ**	**58.5 J/cm^2**





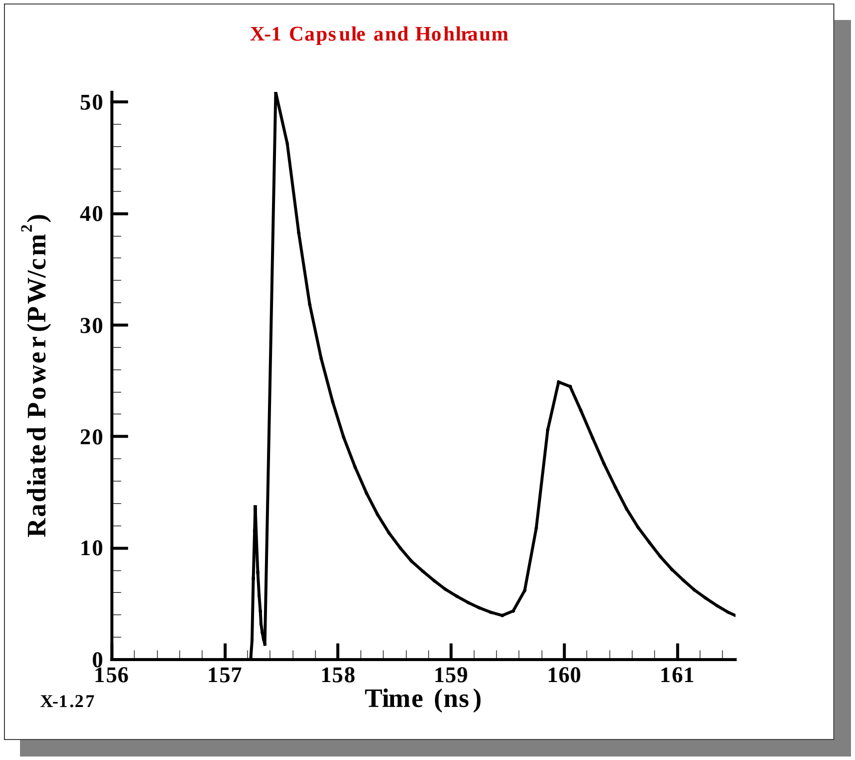
X-ray Emission from Indirect Drive (X-1) Targets Due to Collisions Between Expanding Shells

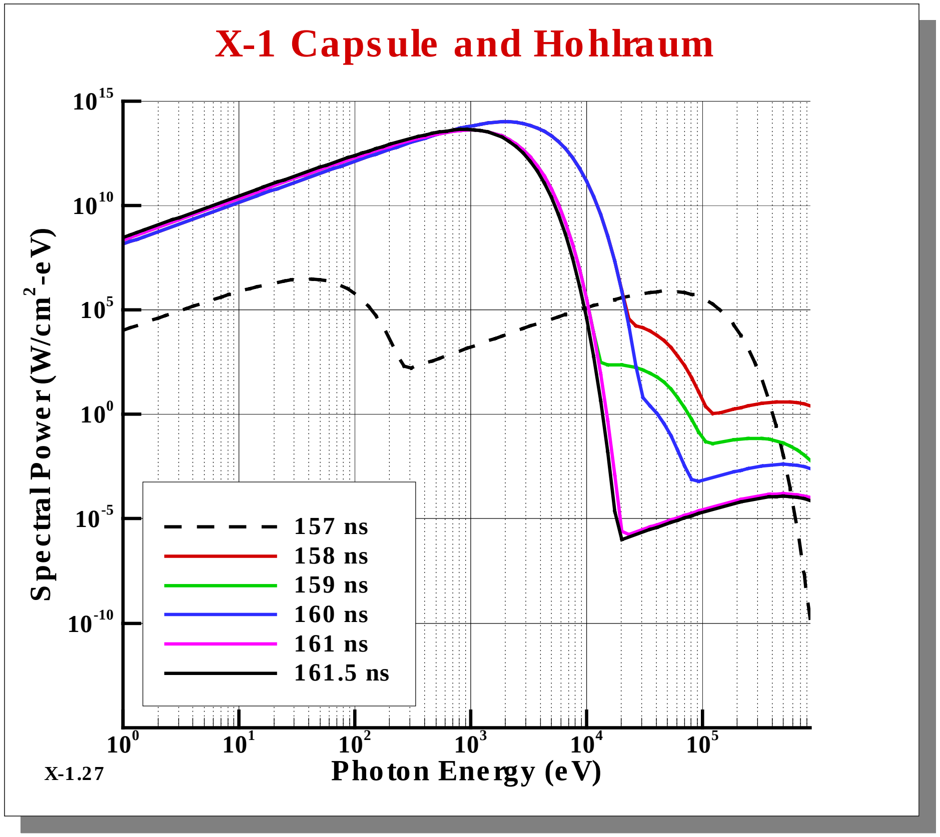
Fusion Technology Institute University of Wisconsin - Madison

Output X-rays are released in two pulses over about 5 ns.

Output X-ray Spectrum: Sum of 3 Blackbody spectra

157 ns: 14 eV, 177 keV
158 ns: 709 eV, 6 keV, 177 keV
159 ns: 354 eV, 6 keV, 100 keV
160 ns: 709 eV, 4 keV, 177 keV
161 ns: 354 eV, 6 keV, 177 keV
161.5 ns 325 eV 6 keV, 177 keV





Computer Simulations of Hole Closure in Z-Pinch Hohlraum Experiments on Z

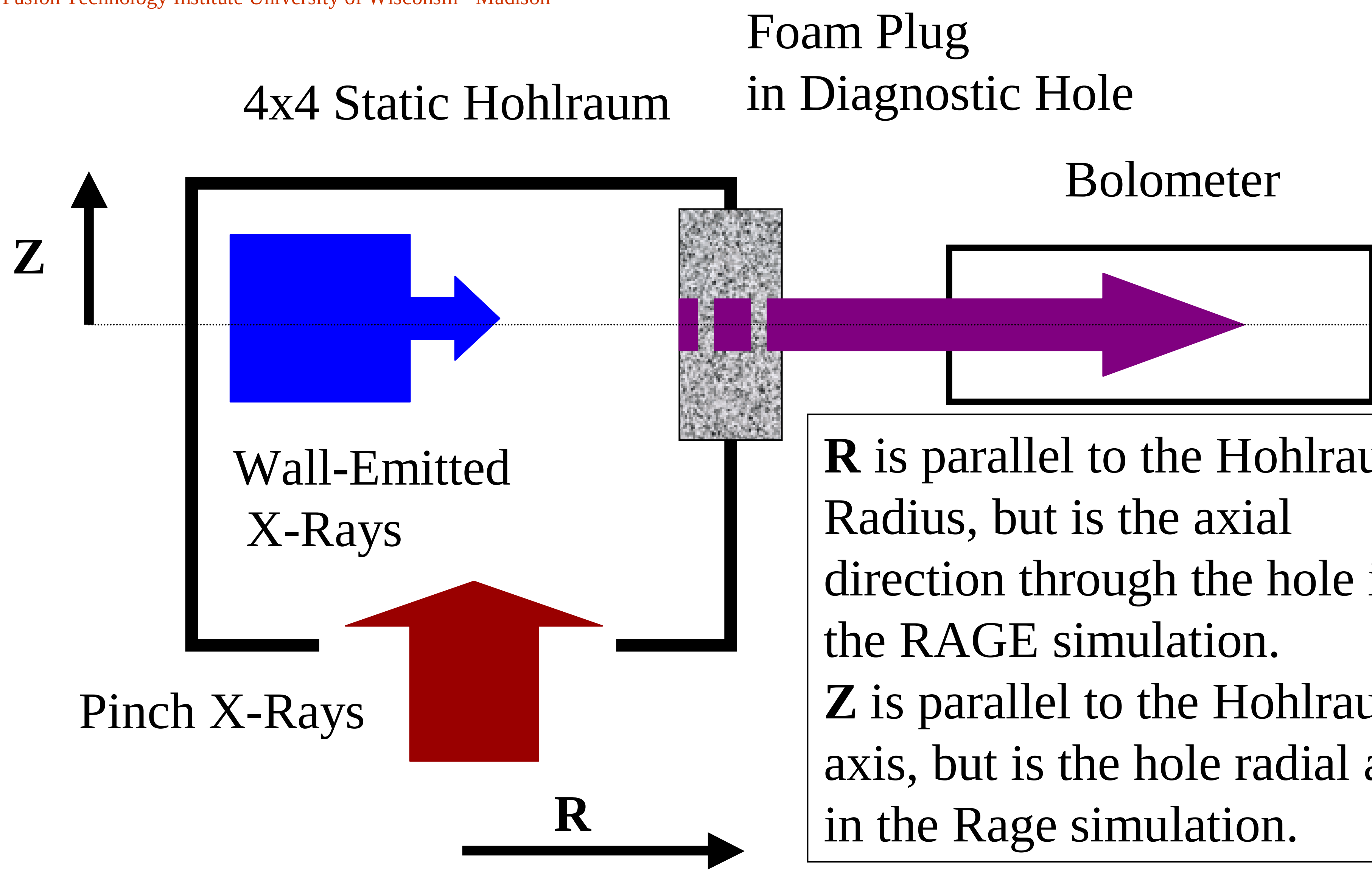
R.R. Peterson

University of Wisconsin-Madison

Sandia National Laboratories
November 6, 2000

RAGE Target Simulations of Z Hohlraums

Fusion Technology Institute University of Wisconsin - Madison



R is parallel to the Hohlraum Radius, but is the axial direction through the hole in the RAGE simulation.
Z is parallel to the Hohlraum axis, but is the hole radial axis in the Rage simulation.

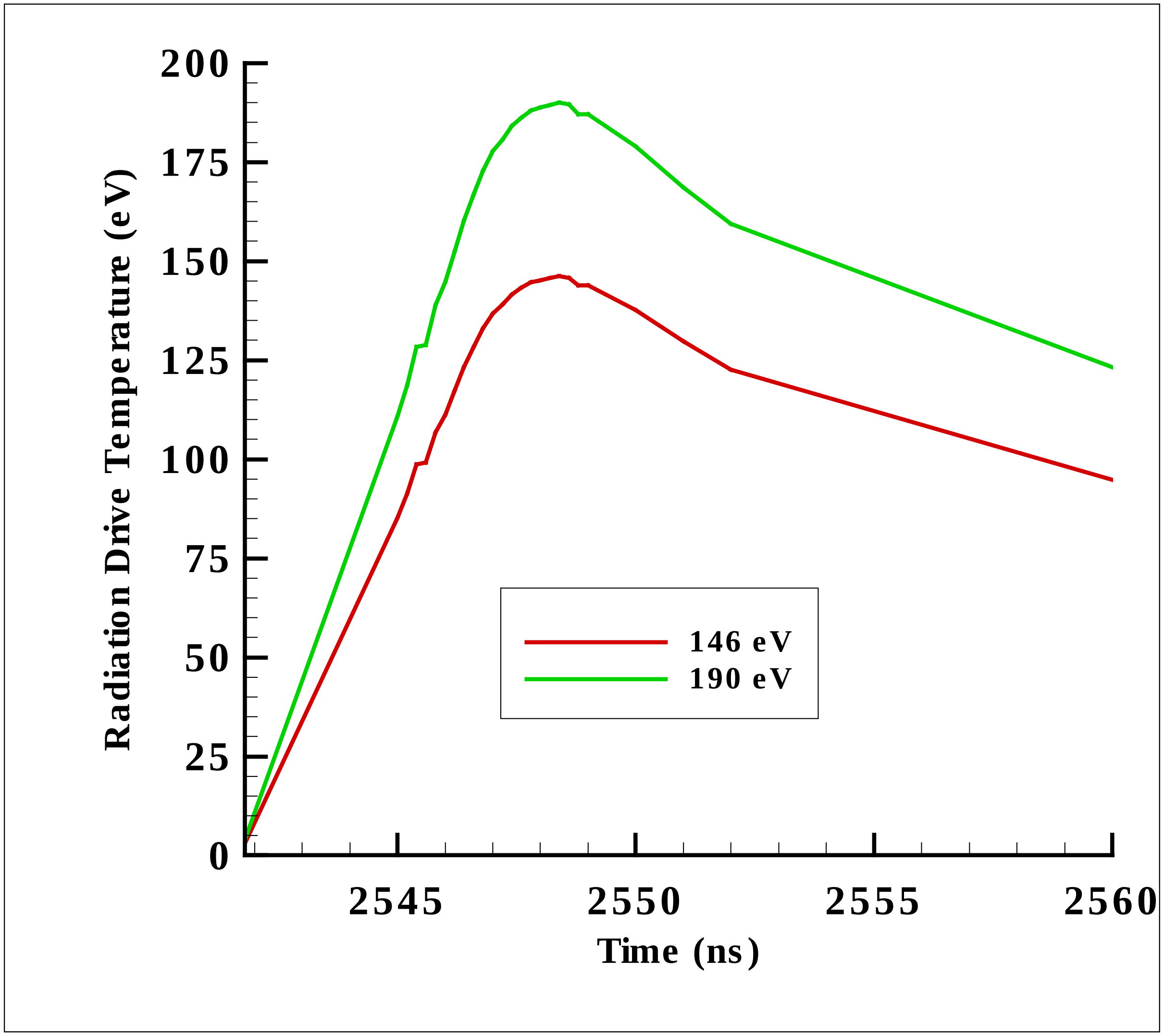
RAGE is a 1, 2, or 3-D AMR Radiation Hydrodynamics Computer Code

- Hydrodynamics with an Adaptive Mesh Refinement (AMR) method.
- Radiation Transport by Grey Diffusion
- Applied temperature and energy sources.
- Opacities and equations of state from SESAME or analytic models.
- Platforms: LANL Cray or ASCI.
- Post-Processing with POP

RAGE Target Simulations Performed for Two Drive Temperature Histories

Fusion Technology Institute University of Wisconsin - Madison

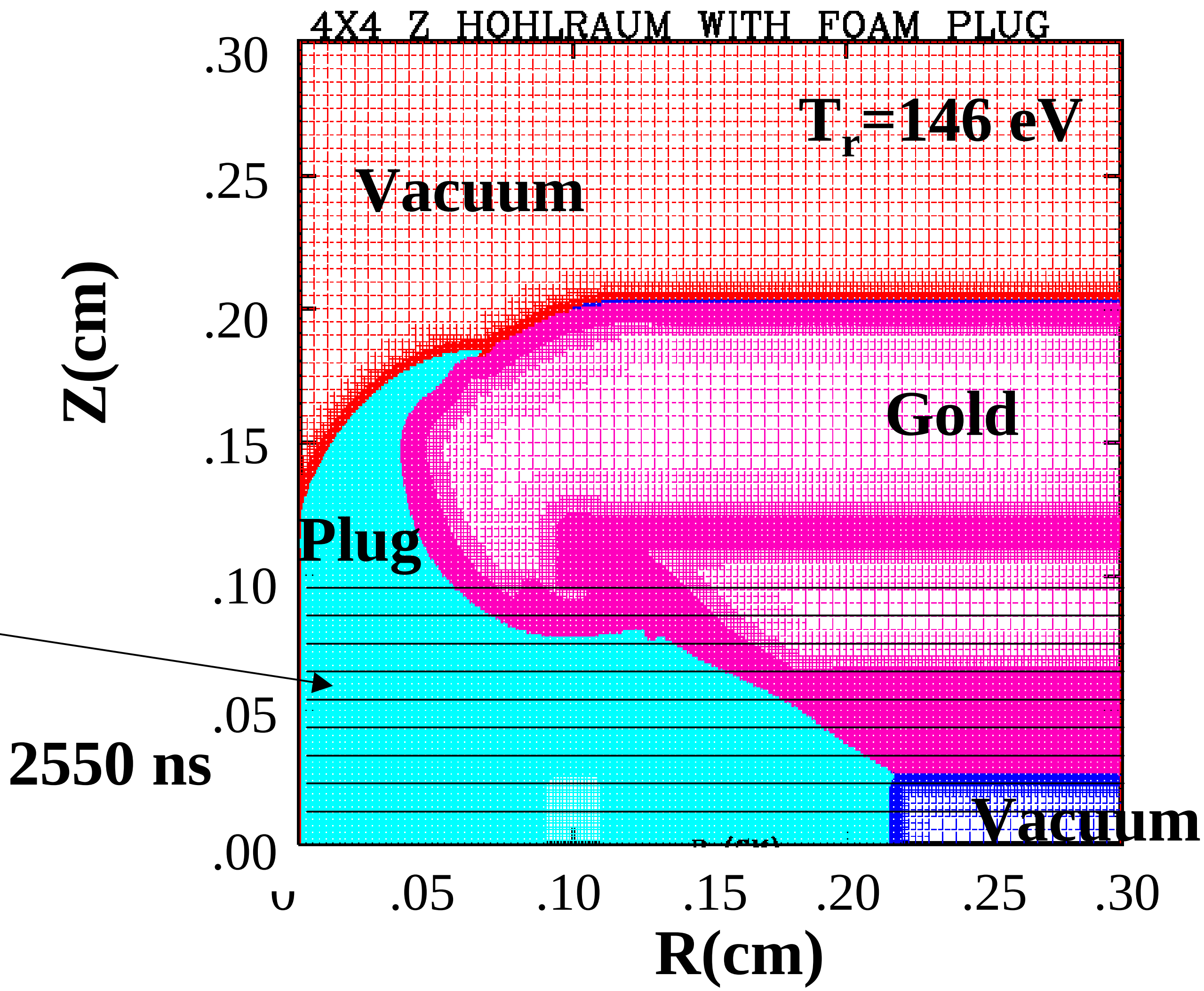
- •Radiation temperature was originally estimated from Bolometer measurements on shot Z442 by assume diagnostics hole radius of 1.4 mm.
- •Observed radiation is from Wall, so must divide by albedo to get drive temperature.
- •Original drive temperature peaks at 146 eV.
- •Other diagnostics (shock break-out) suggest a peak drive temperature of 190 eV.
- •Time is measured from Marx trigger.



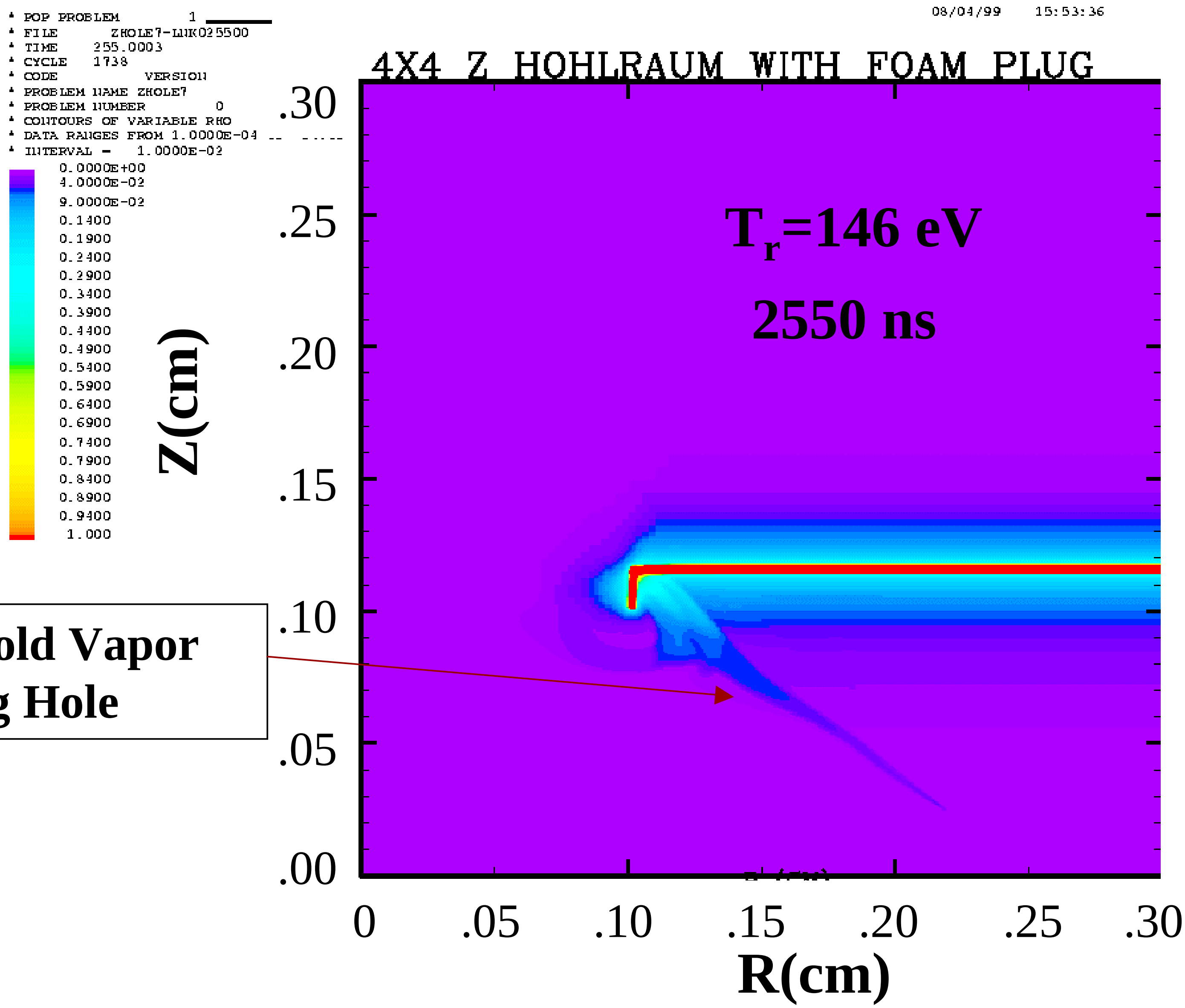
Geometry Used RAGE Target Simulations

- RAGE mesh
- Much finer at material interfaces and density gradients.

Optical Depth Integrals performed down hole axis



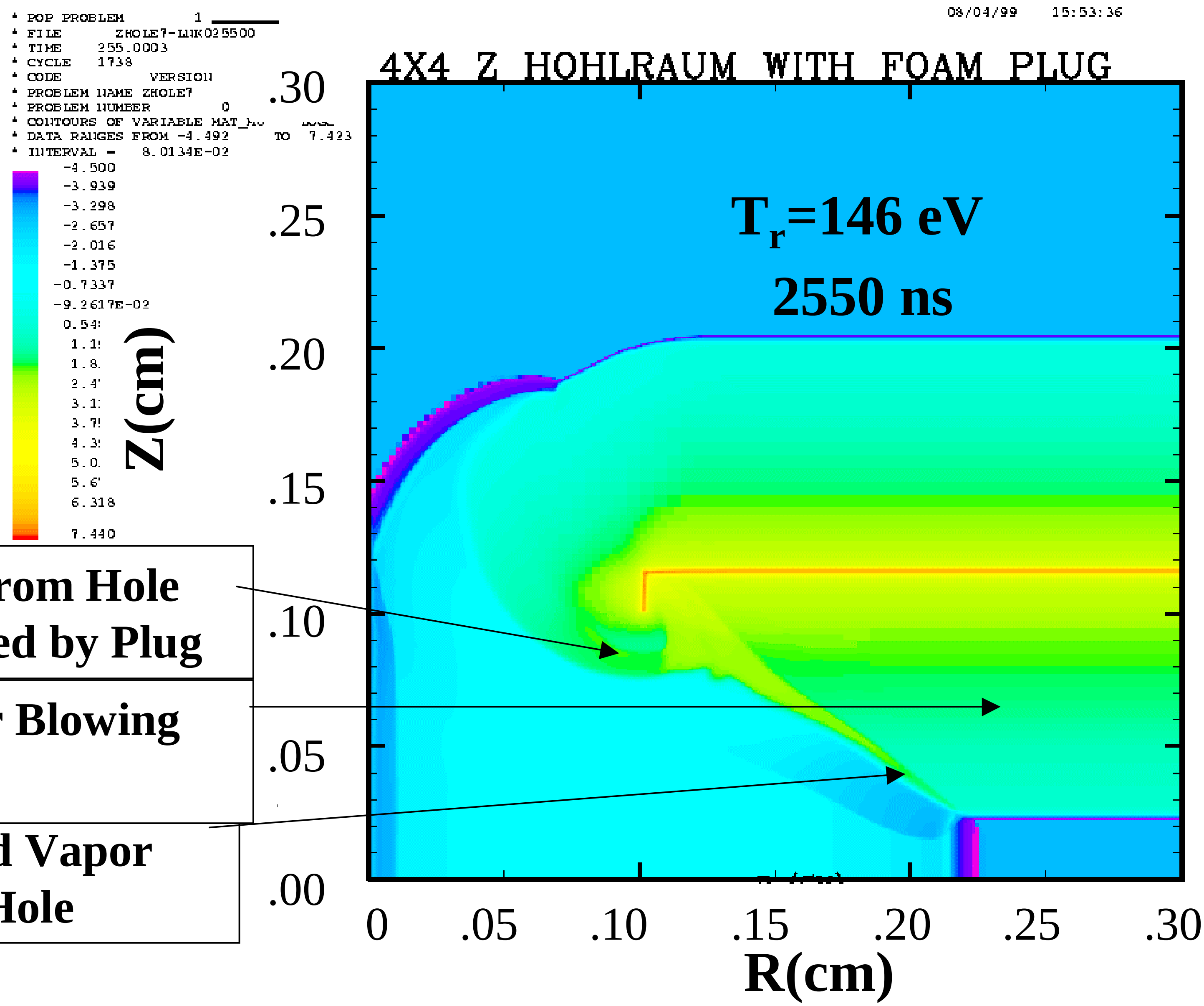
Mass Density Contours Show Jetting from Corner



Jet of Gold Vapor Blocking Hole

Opacity Contours Show Blockage of Hole Due Blow-off From Top and Jetting From Corner

Fusion Technology Institute University of Wisconsin - Madison



Blow-Off From Hole Edge Limited by Plug

Gold Vapor Blowing Off of Top

Jet of Gold Vapor Blocking Hole

Diagnostics Hole Closure is Due to Gold Blow-off from Edge of Hole and Top of Hohlraum

Fusion Technology Institute University of Wisconsin - Madison

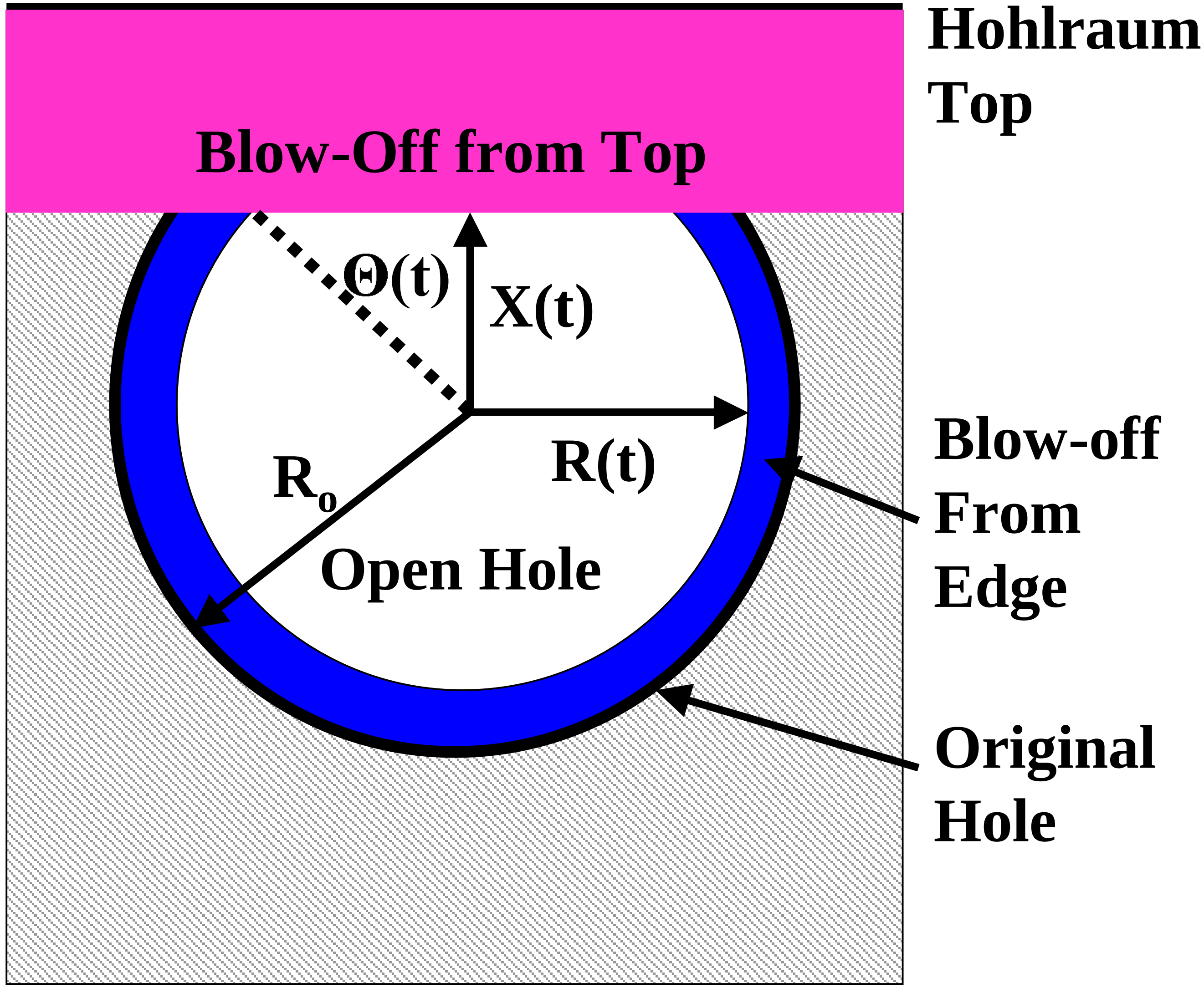
$$\Theta(t) = \cos^{-1}\left(\frac{X(t)}{R(t)}\right)$$

$$\text{Total Open Area} = A(t)$$

$$= \begin{bmatrix} (\pi - \Theta(t)) + \\ (\sin(\Theta(t))\cos(\Theta(t))) \end{bmatrix} R^2(t)$$

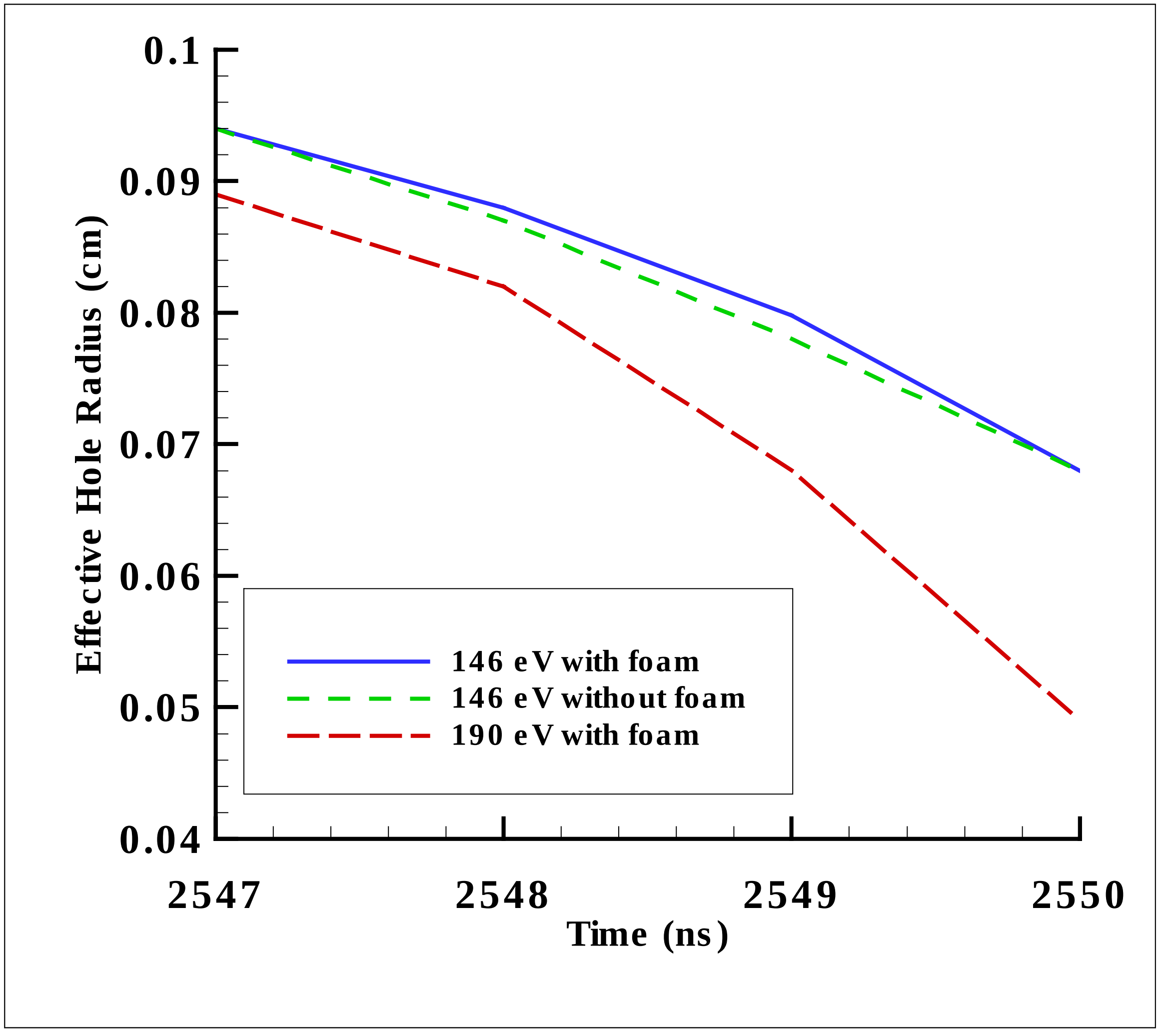
Effective Radius

$$R_{eff}(t) = \sqrt{A(t)/\pi}$$



Foam Plug has Little Effect on 146 eV Hohlraum Diagnostics Hole

- For a peak radiation drive temperature of 146 eV, the effective hole radius is the same with and without a foam plug.
- Hole closure is much more pronounced for a 190 eV drive temperature, with a foam plug



Calculations Indicate a Holhraum Temperature Greater than 146 eV, But Less than 190 eV

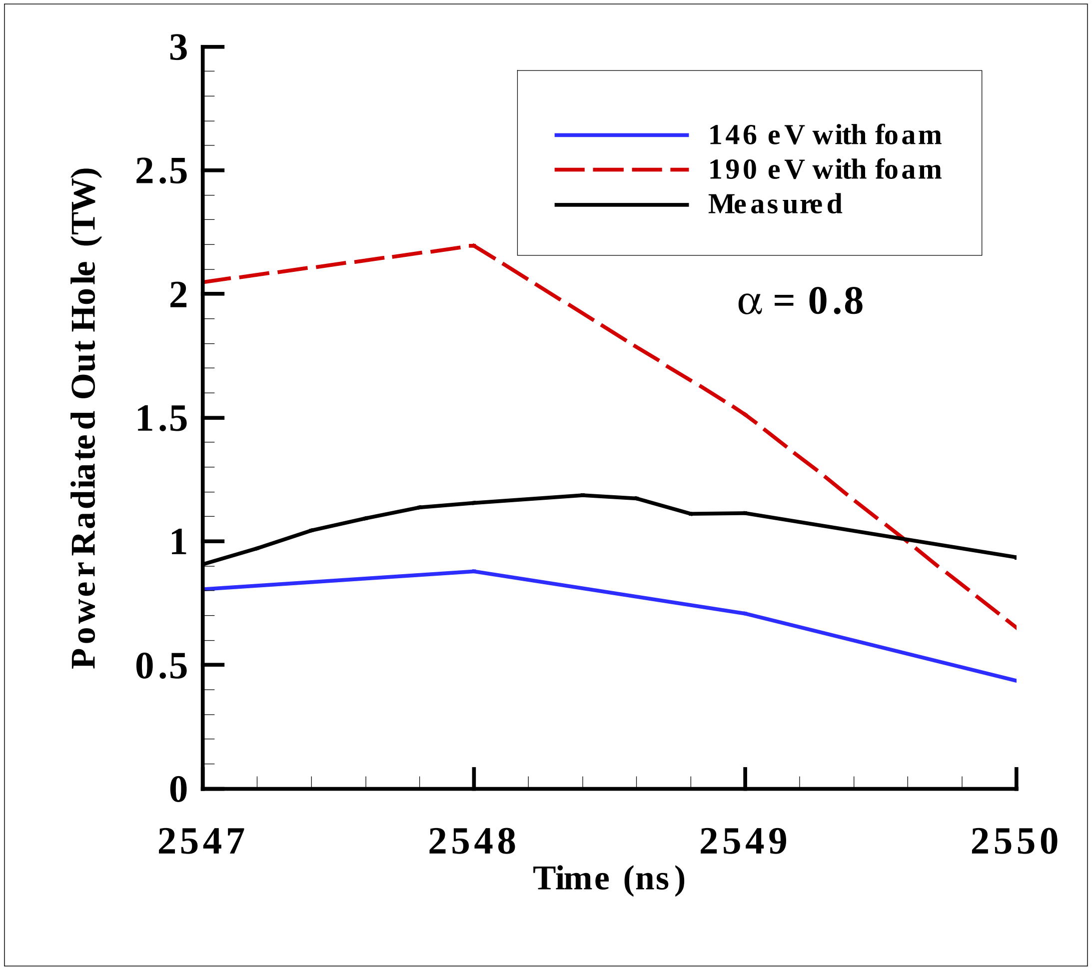
$$I = A(t)\alpha\sigma T_r^4$$

•RAGE calculations of hole area for 146 eV drive temperature predict a radiated power below the measured values.

•RAGE calculations at 190 eV over-predict radiated power, except late in time.

•Drive temperature must be somewhere in between 146 and 190 eV.

•Need to try more drive histories.



Additional Calculations are Needed and More Experiments Are Planned

- More RAGE calculations are needed:
  - —Calculations by Bowers predict a pre-pulse on the radiation pulse.
  - —Try more radiation histories between 148 and 190 eV.
  - —3-D simulations of hole closure.
  - —Other methods of measuring hole size.
  - —Study 7x6 hohlraums.
  - —Multi-group Radiation Transport will Soon be Working in RAGE
- Other Experiments:
  - —Spectrometer to measure temperature from spectrum.
  - —Rounded corners would reduce jetting and hole closure.
  - —Hohlraums driven by two zpinches.

Computer Simulations of Debris Production From Current Return Cans in Wire Array Implosions*

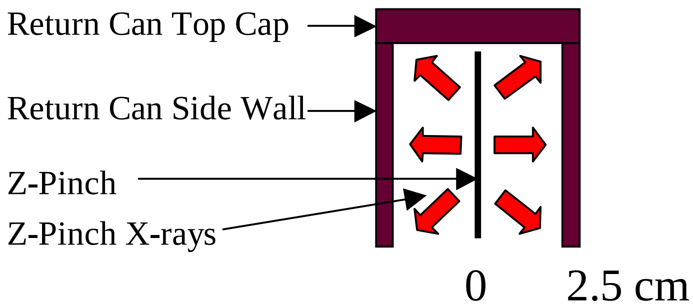
R.R. Peterson, D. Williamson, and J.P. Blanchard
University of Wisconsin-Madison

Sandia National Laboratories
November 6, 2000

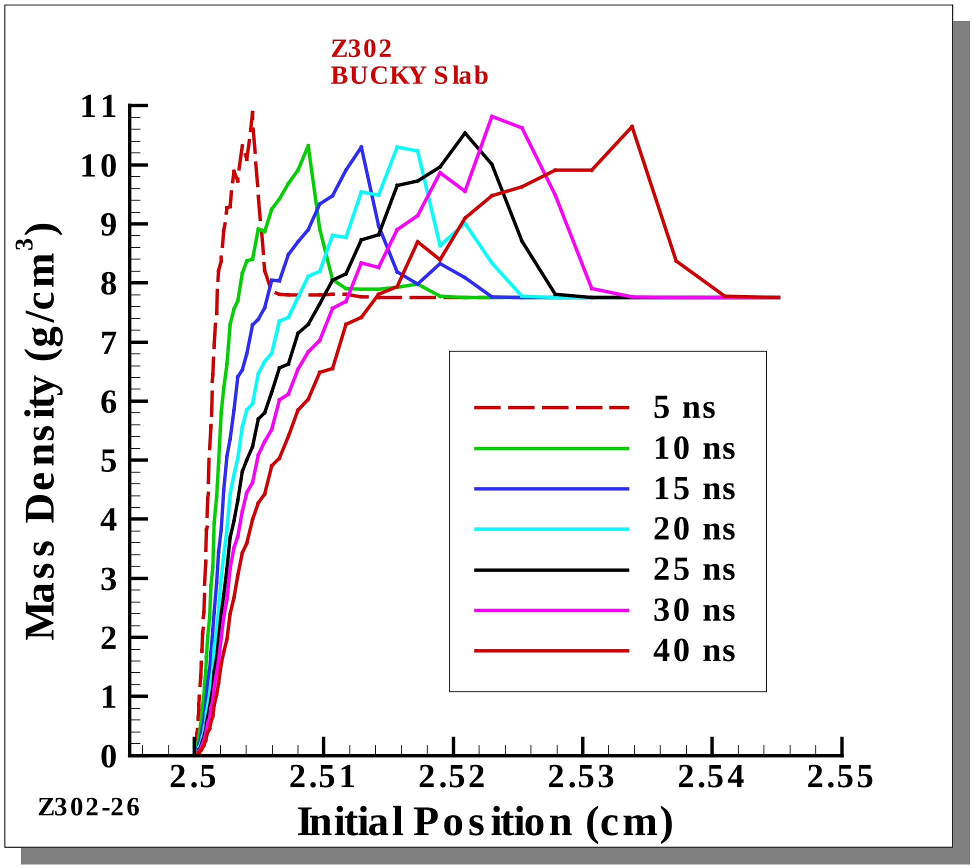
* Supported by SRI and DTRA

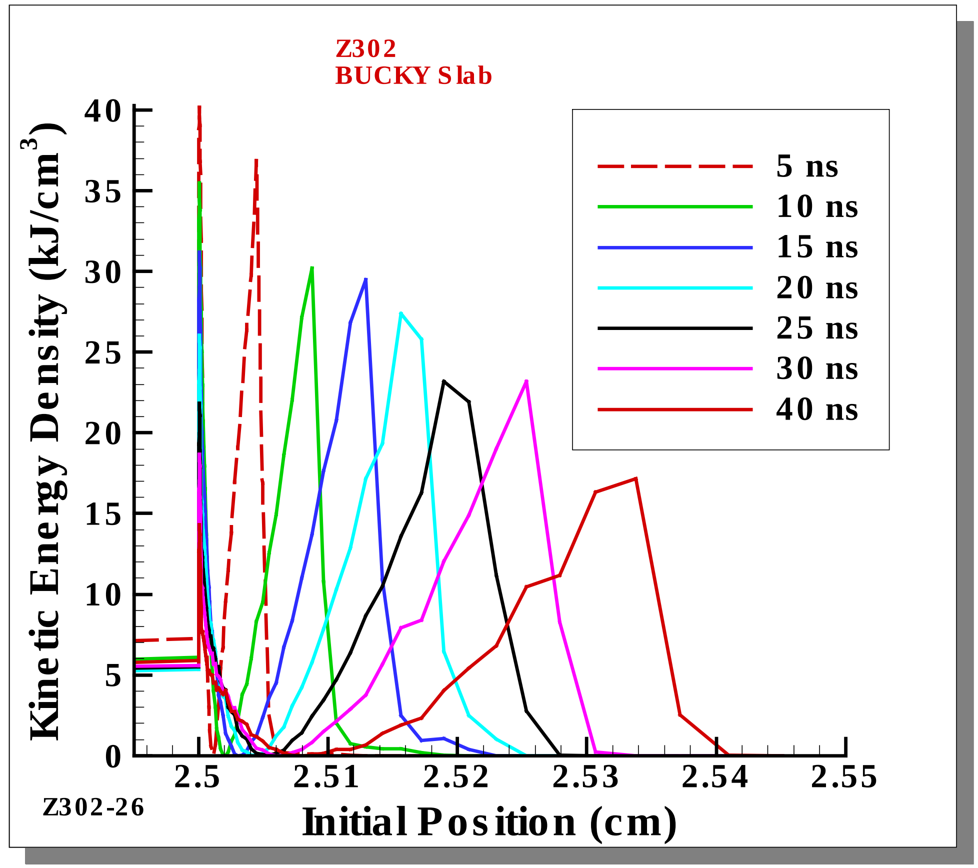
BUCKY Calculation of Response of Current Return Can to Ti Wire Array Z-Pinch-Produced X-rays on Shot Z302

Fusion Technology Institute University of Wisconsin - Madison



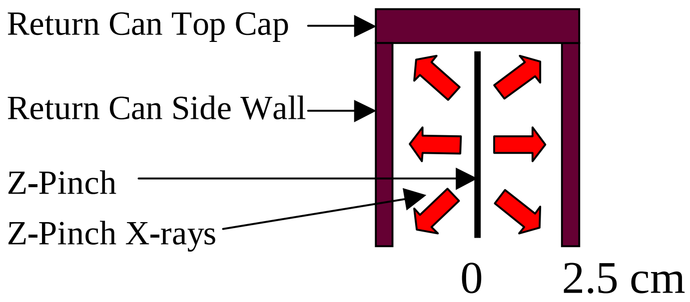
- Side Wall Calculations Shown Here; Top Cap Calculations have also been Performed.
- Steel in Can Compressed to 11g/cm^3.
- Shock Moves 0.3 mm in 40 ns (average speed = 7.5 km/s)



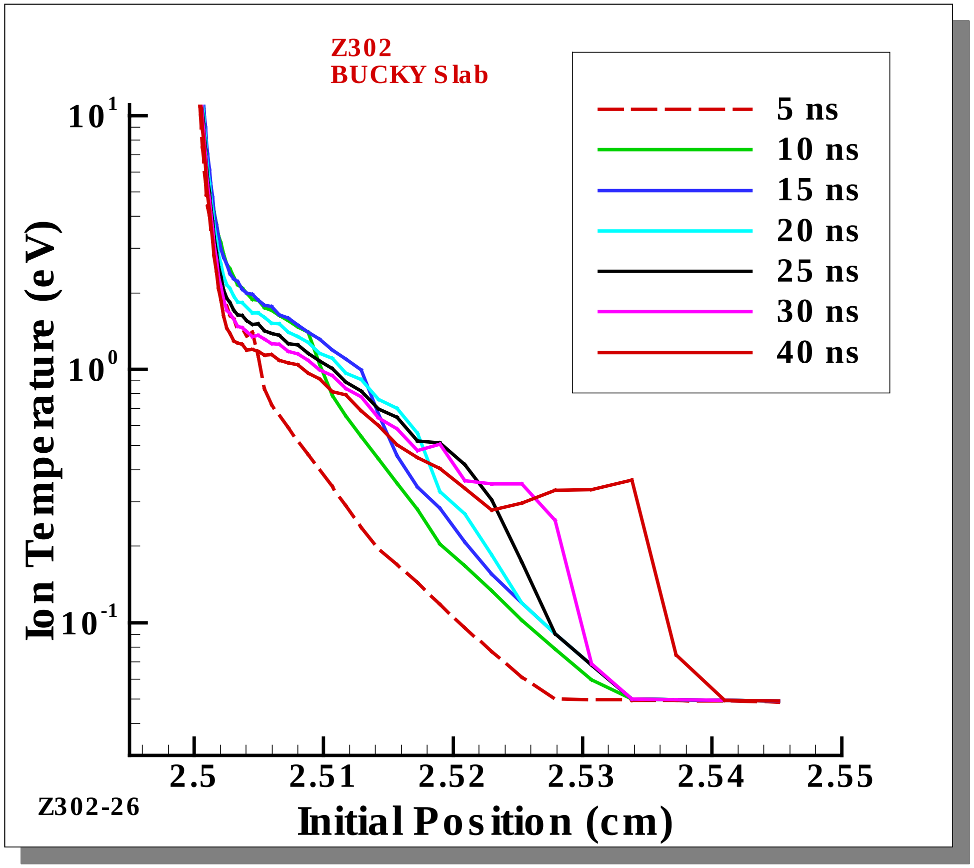


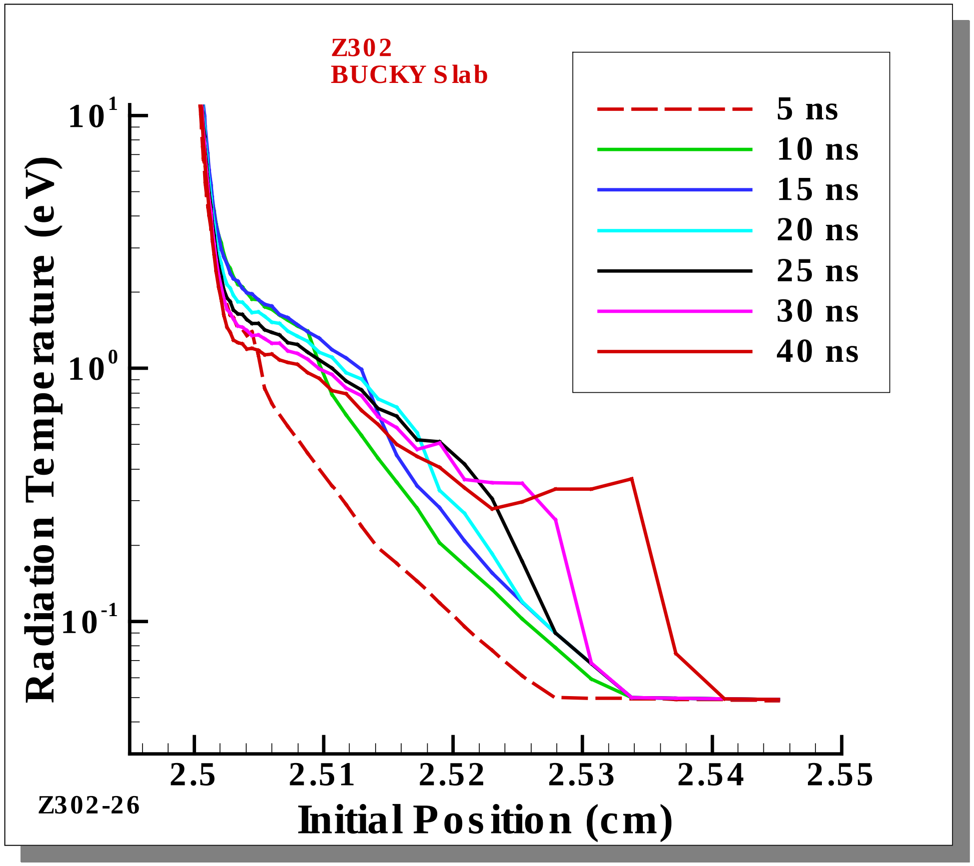
BUCKY Calculation of Response of Current Return Can to Ti Wire Array Z-Pinch-Produced X-rays on Shot Z302

Fusion Technology Institute University of Wisconsin - Madison



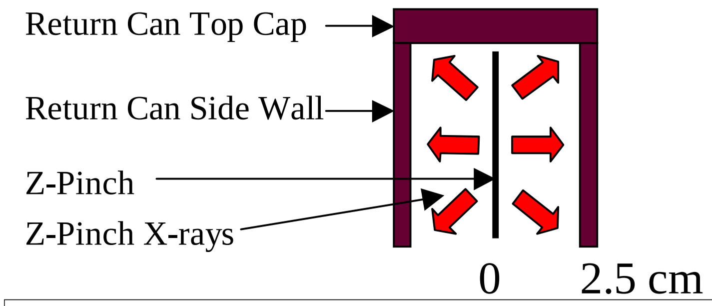
- Plasma Ion Temperatures in Can Are a Few eV on Surface and a Few Tenths of eV Behind Shock in Steel.
- Thermal Radiation from Steel is in Equilibrium with Plasma.



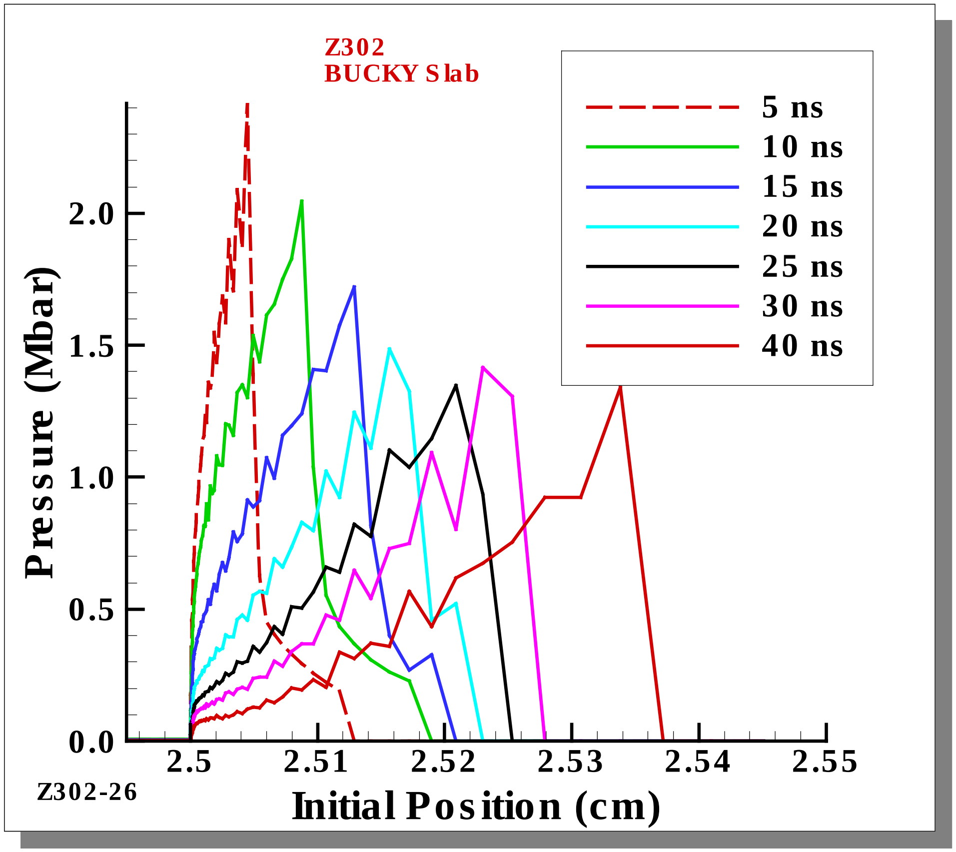


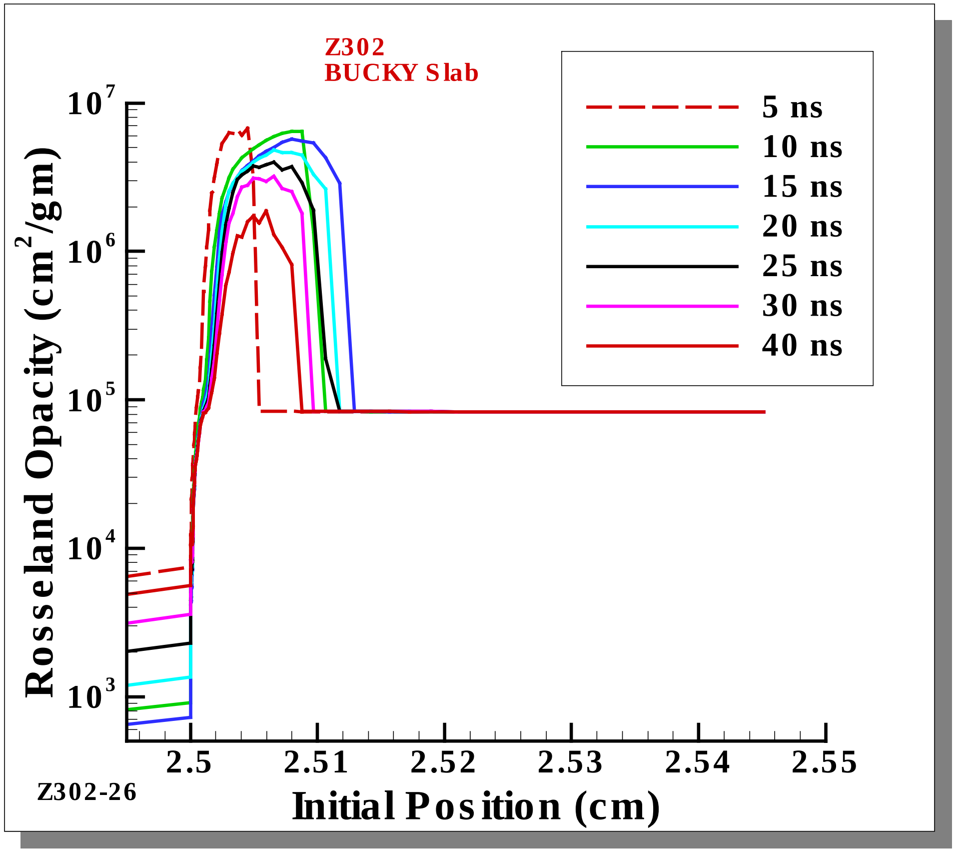
BUCKY Calculation of Response of Current Return Can to Ti Wire Array Z-Pinch-Produced X-rays on Shot Z302

Fusion Technology Institute University of Wisconsin - Madison



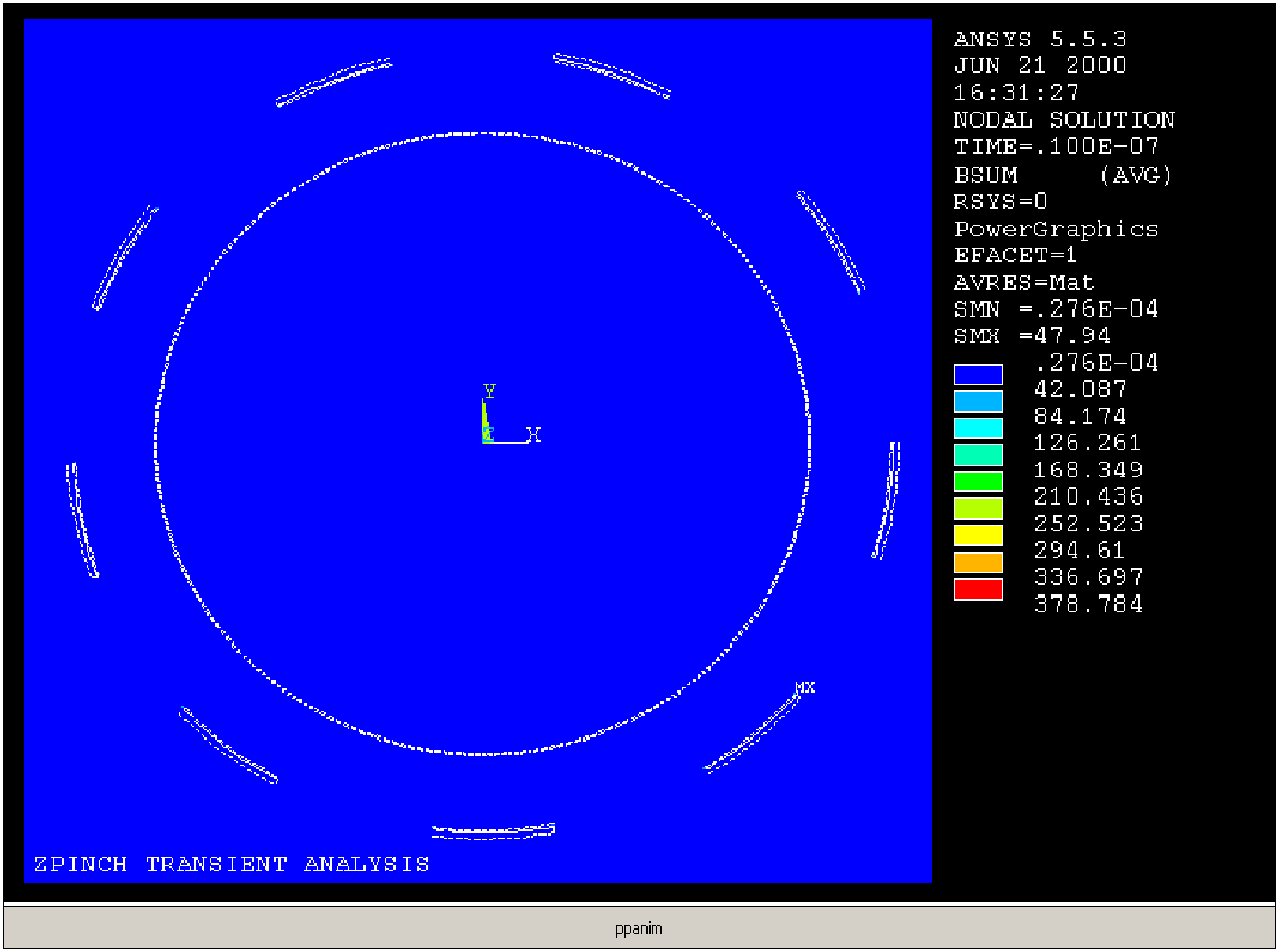
•Pressures of 1-2 Mbar Generated in Side Wall by X-rays.
•Low Temperature Opacity Model Critical to Understanding Propagation of Re-radiated Photons into Material.





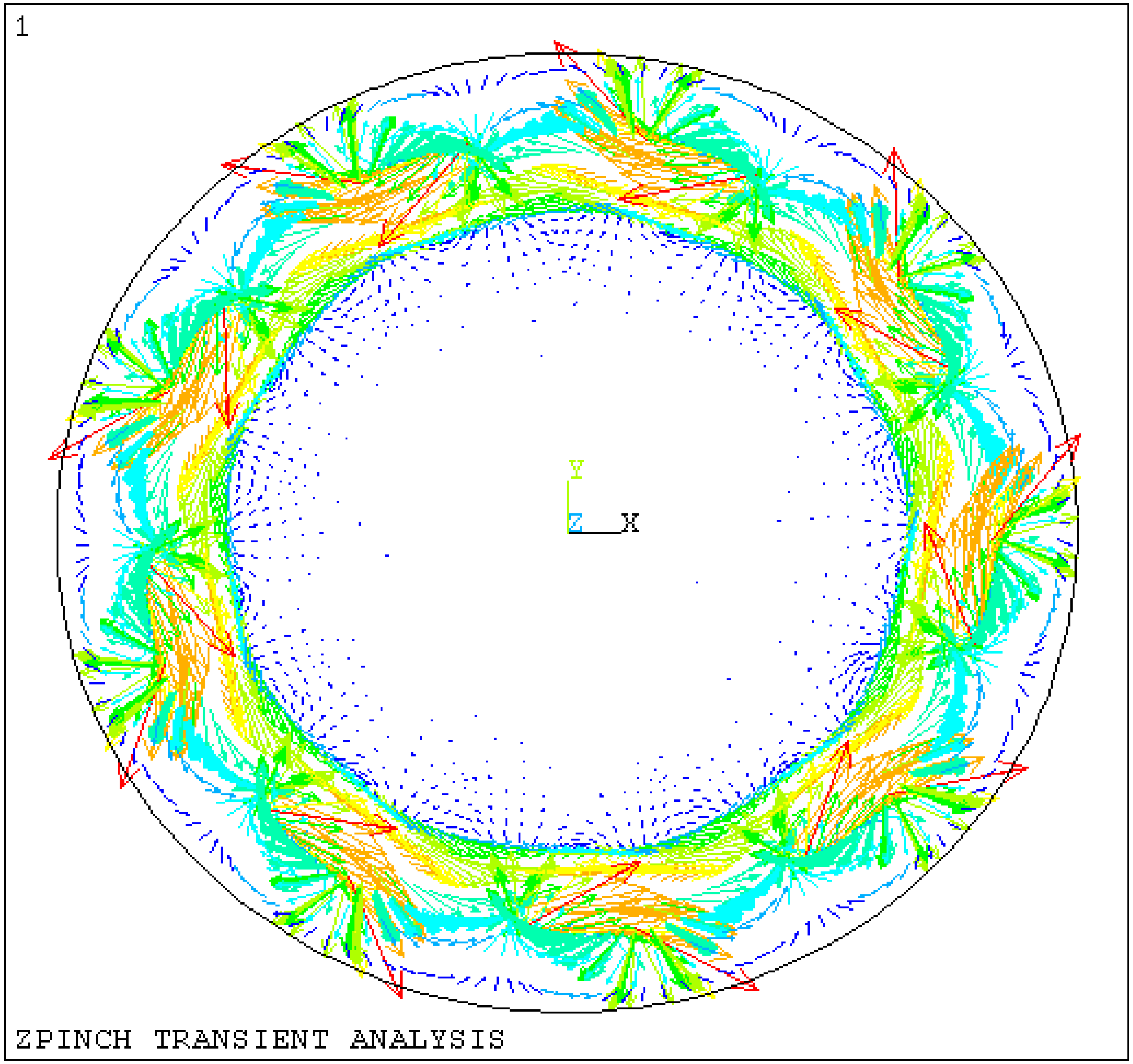
Current Density in 9 Slot Return Can

Fusion Technology Institute University of Wisconsin - Madison



Electro-Magnetic Modeling of Slotted Current Return Can Using ANSYS

Fusion Technology Institute University of Wisconsin - Madison



ANSYS 5.5.3

Magnetic Field when current is a maximum

Units below are in Tesla.

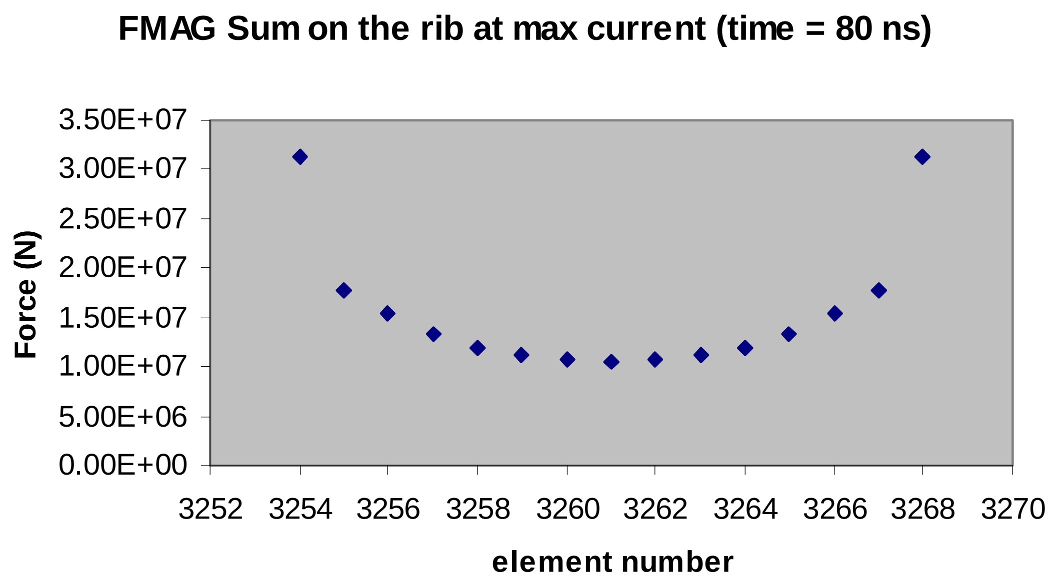
MIN=.621E-06
MAX=266.215

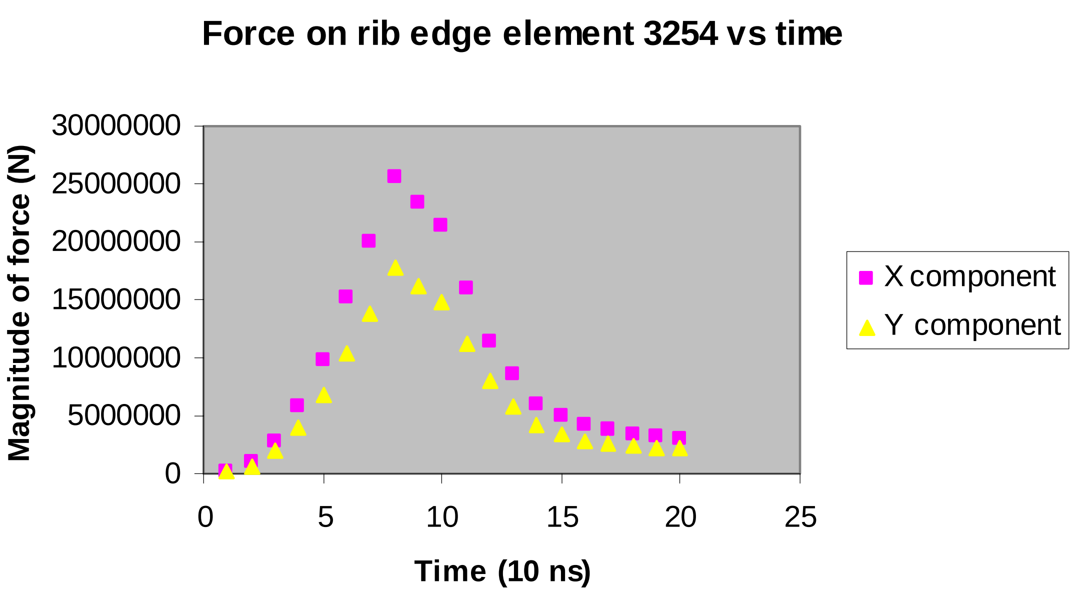
.621E-06
29.579
59.159
88.738
118.318
147.897
177.476
207.056
236.635
266.215

Calculations Performed by Don Williamson

Magnetic Force Per Element on a Rib As a Function of Position

Fusion Technology Institute University of Wisconsin - Madison





Computer Simulations of Aluminum Contained EOS Experiments

R.R. Peterson and D.A. Haynes
University of Wisconsin-Madison

Sandia National Laboratories
November 6, 2000

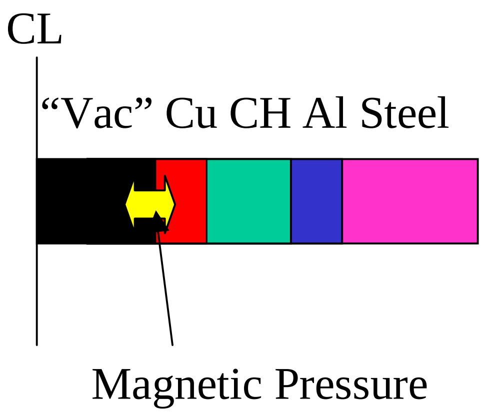
Calculation of Debris Plume in EOS Experiments Provides a Source Term for Debris Containment Analysis and Design

Fusion Technology Institute University of Wisconsin - Madison

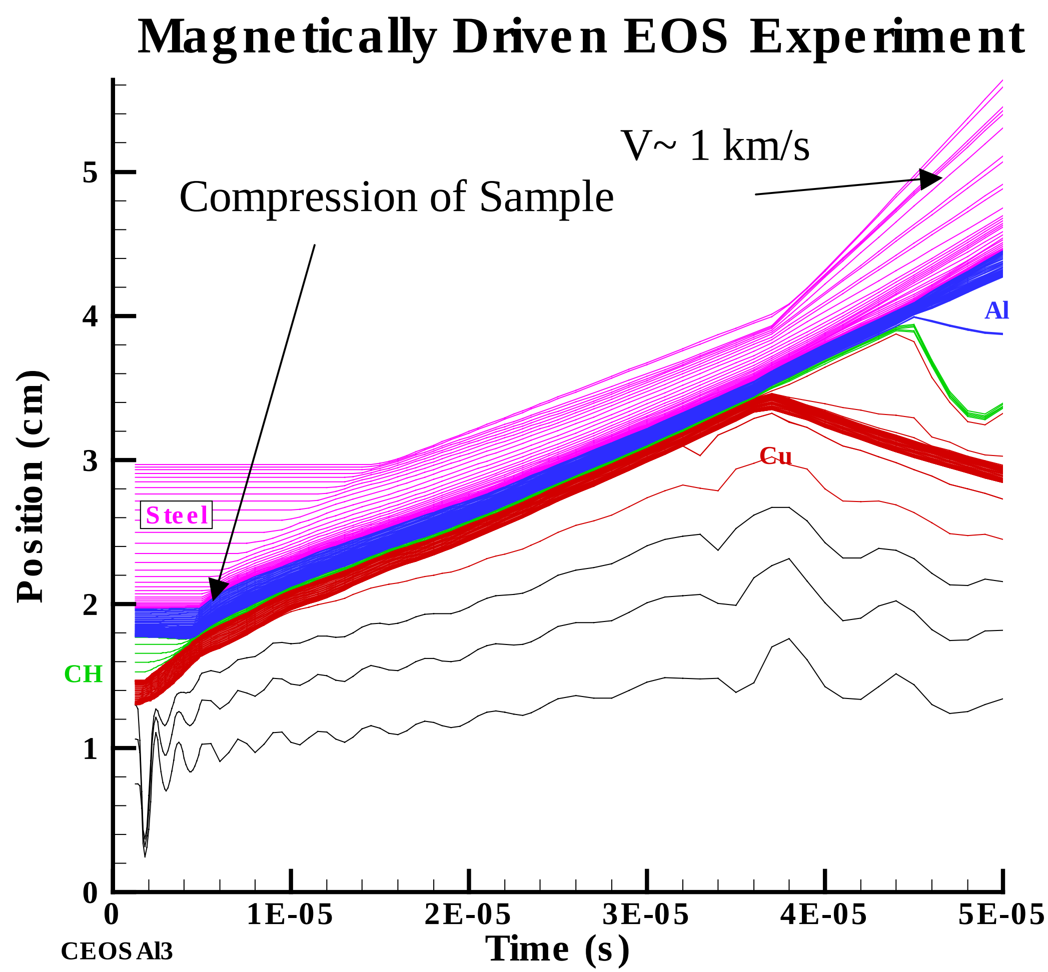
- 1-D BUCKY Simulations to Get Velocities and Strain-Rates.
- Drugan Model Estimates of particle sizes.
- First Calculation: Z599 Experiment for Aluminum.
- Assessment of this Approach.
- What About ALEGRA and/or CTH?

BUCKY Simulation of Magnetically Driven Aluminum EOS Experiment on Z # 1; 0.1 g/cc CH and 4.0 g/cc Steel

Fusion Technology Institute University of Wisconsin - Madison

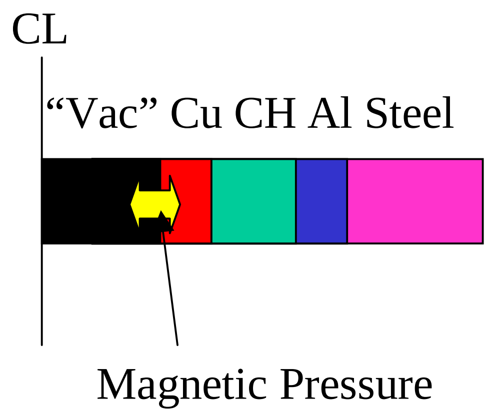


- 1-D Cylindrical Geometry.
- Magnetic Pressure Applied Over 10 zones of Cu Flyer Plate. This Region is Initially 67 µm Wide.
- Magnetic Field Diffusion Model in BUCKY <u>NOT</u> Used; BUCKY Was Designed for All Current Flowing in the Same Direction.
- SESAME EOS Used: Negative or Very Low Pressures May Lead to “Interesting” Results.



BUCKY Simulation of Magnetically Driven Aluminum EOS experiment on Z #2; Solid Density CH and Steel

Fusion Technology Institute University of Wisconsin - Madison

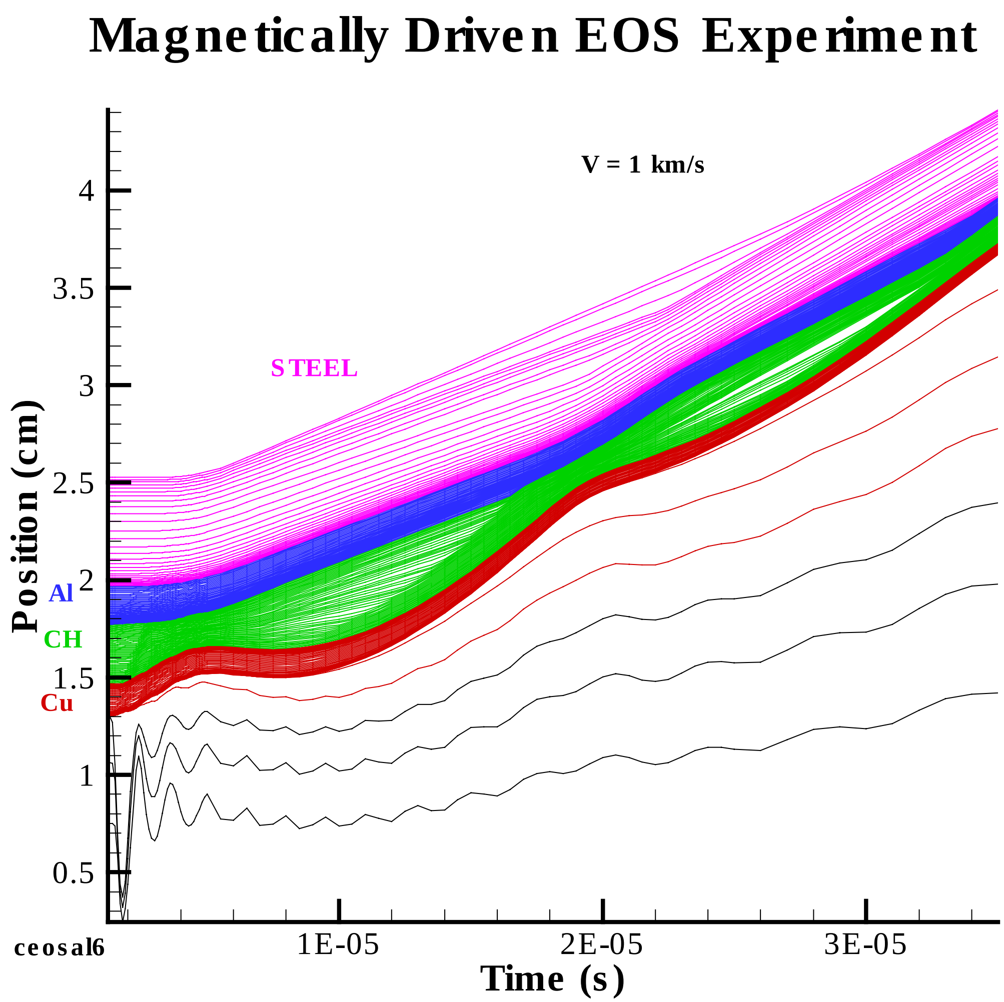


•1-D Cylindrical Geometry.

•Magnetic Pressure Applied Over 10 zones of Cu Flyer Plate. This Region is Initially 67 µm Wide.

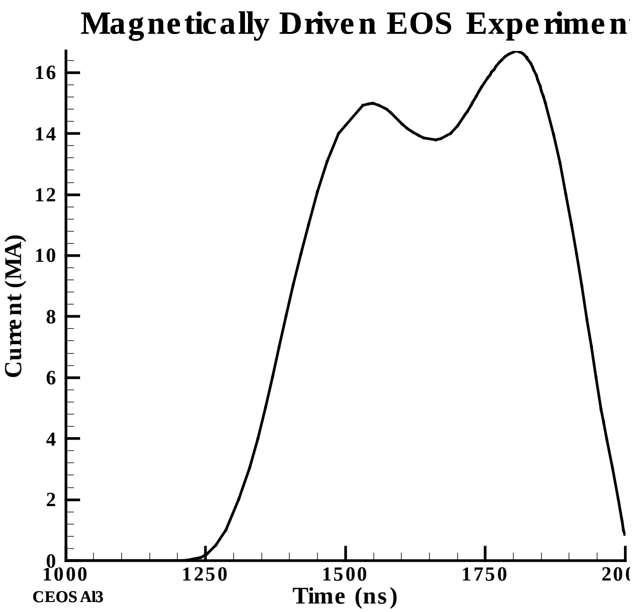
•Magnetic Field Diffusion Model in BUCKY <u>NOT</u> Used; BUCKY Was Designed for All Current Flowing in the Same Direction.

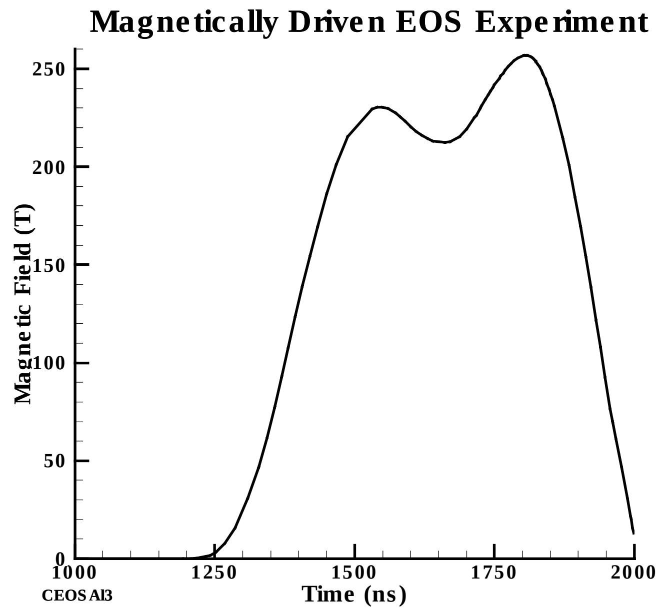
•SESAME EOS Used: Negative or Very Low Pressures May Lead to "Interesting" Results.

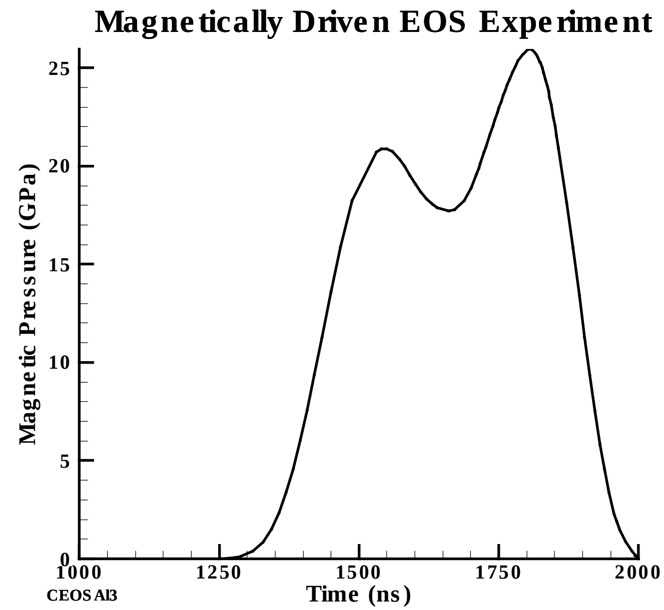


Magnetic Pressure Calculated from SCREAMER Current and Assumed Flow Geometry

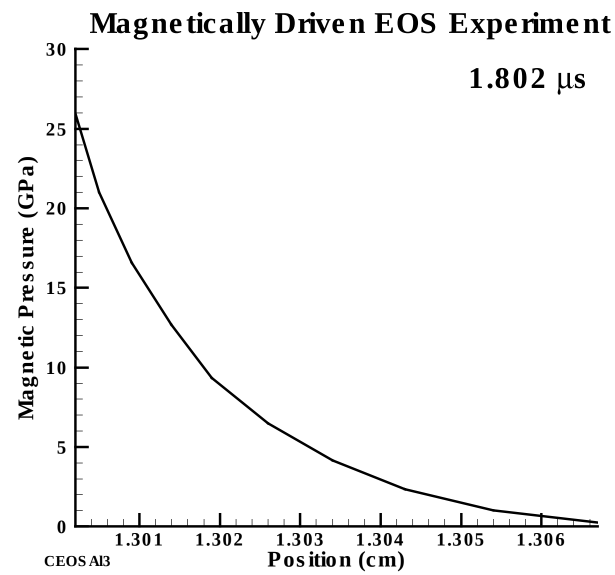
Fusion Technology Institute University of Wisconsin - Madison







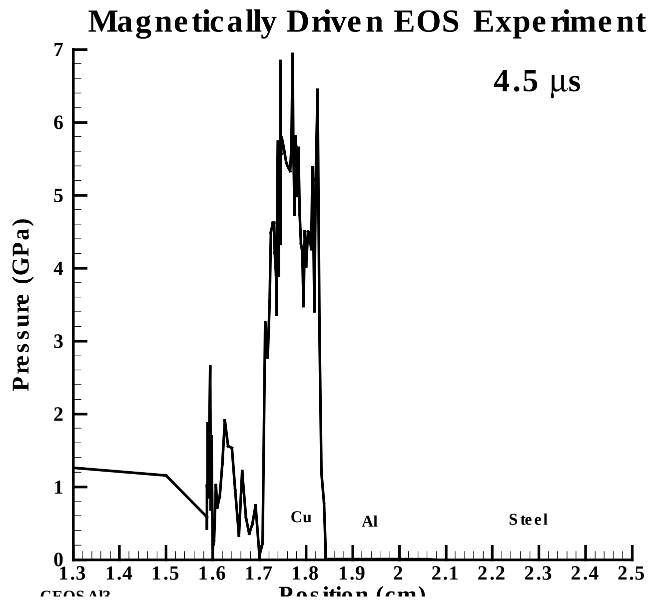
- Current is from a SCREAMER Calculation of Shot Z599 Supplied by Chris Jeffs.
- Equal and Opposite Currents Flow in the Inner and Outer Conductors.
- The Outer Conductor is the Cu Flyer Plate with an Inner Radius of 1.3 cm; Current Flows Uniformly in 67 μm thick layer.
- Magnetic Field is I/rc, where I is the enclosed net Current.
- Magnetic Pressure is $B^2/8\pi$.

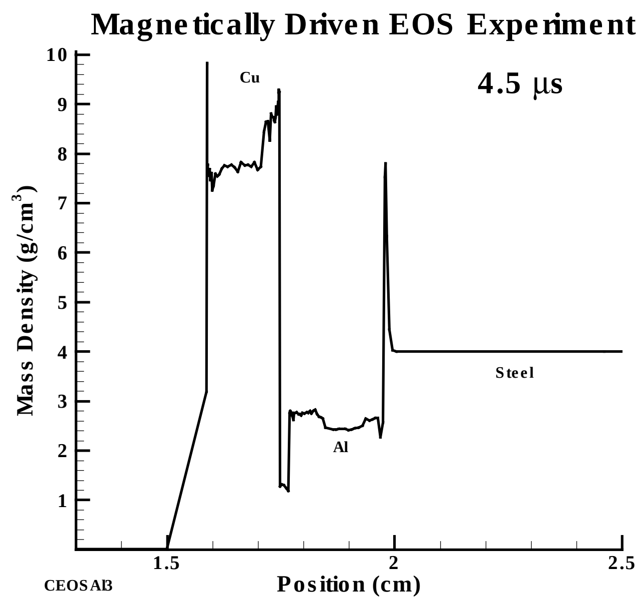


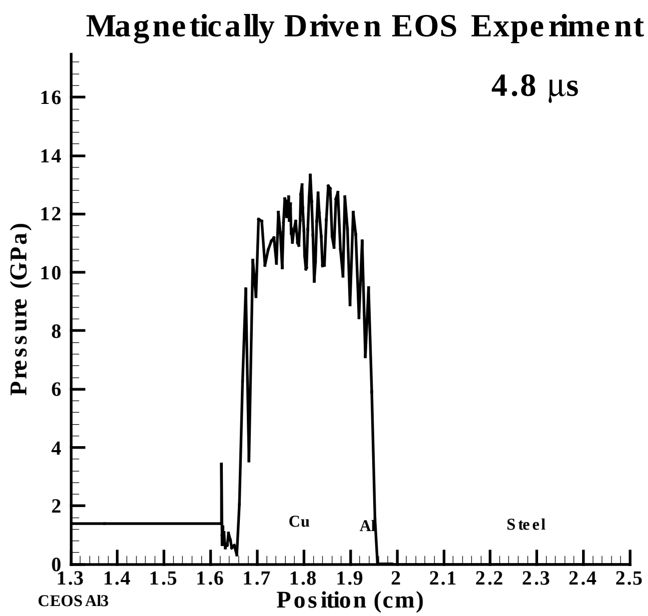
Pressure and Mass Density Profiles During Compression of Al Sample for Run #1

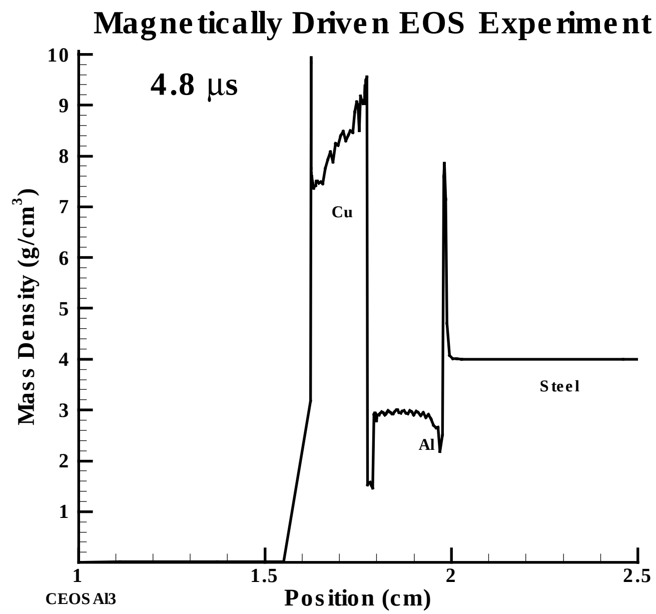
Fusion Technology Institute University of Wisconsin - Madison

- Noise in Pressure and Density Profiles May be Due to Choice of SESAME EOS.
- Analytic EOS model is available for BUCKY; Should be investigated.
- The Behavior of the Al sample is a good way to Test the Validity of BUCKY and Give Some Credence to Debris Prediction.

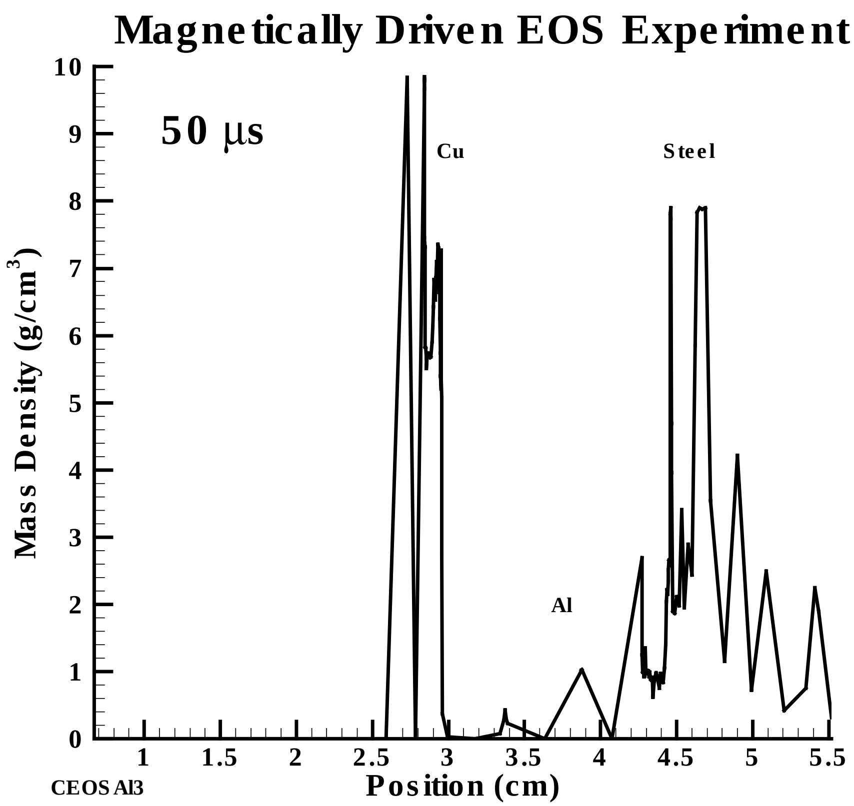


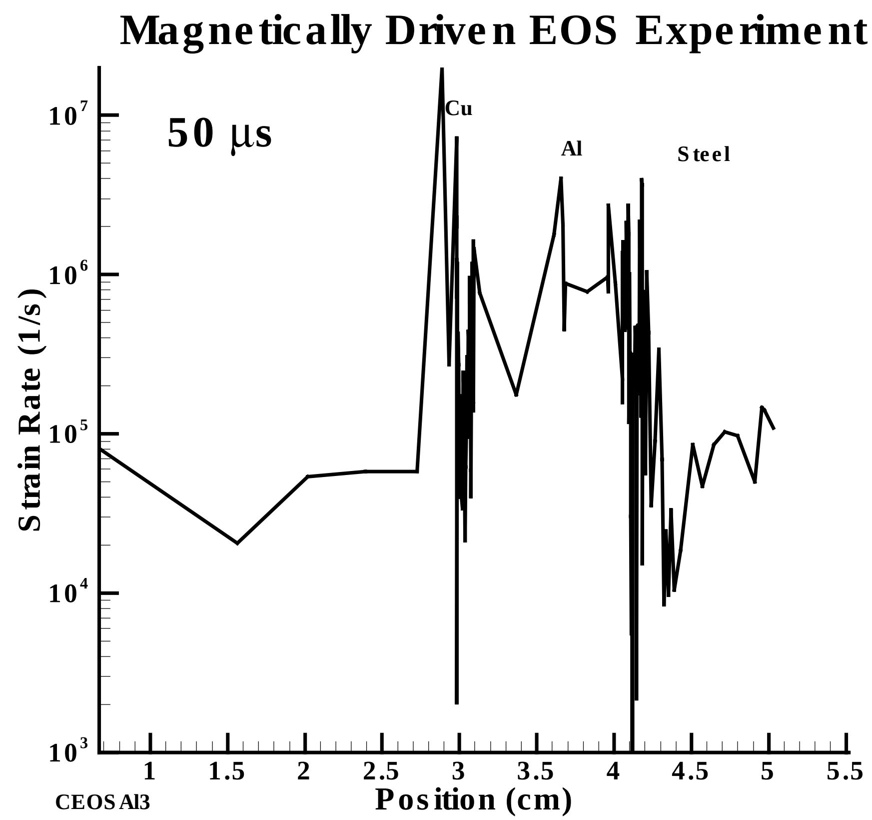






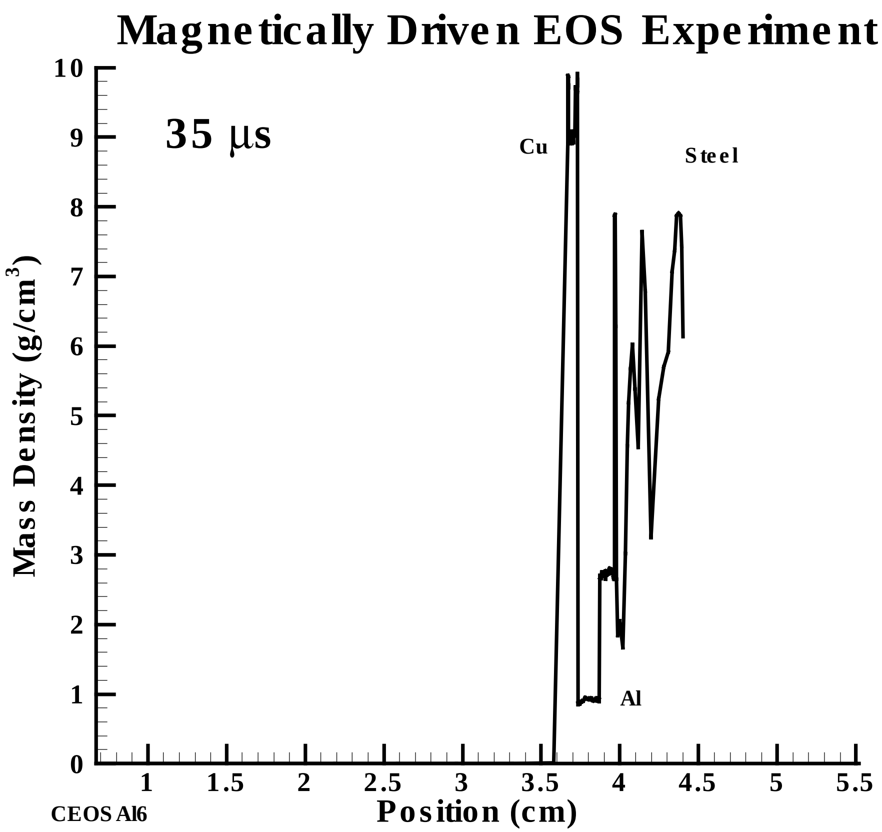
Mass Density and Strain Rate Profiles at End of BUCKY Run #1 (50 μs)

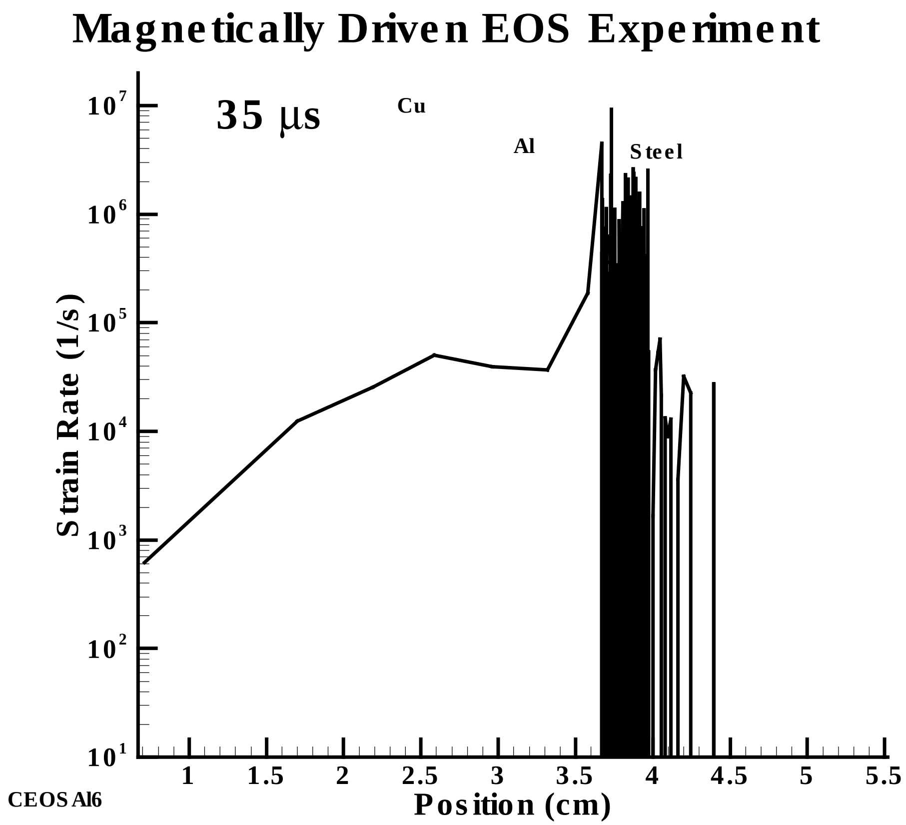




Mass Density and Strain Rate Profiles at End of BUCKY Run #2 (35 μs)

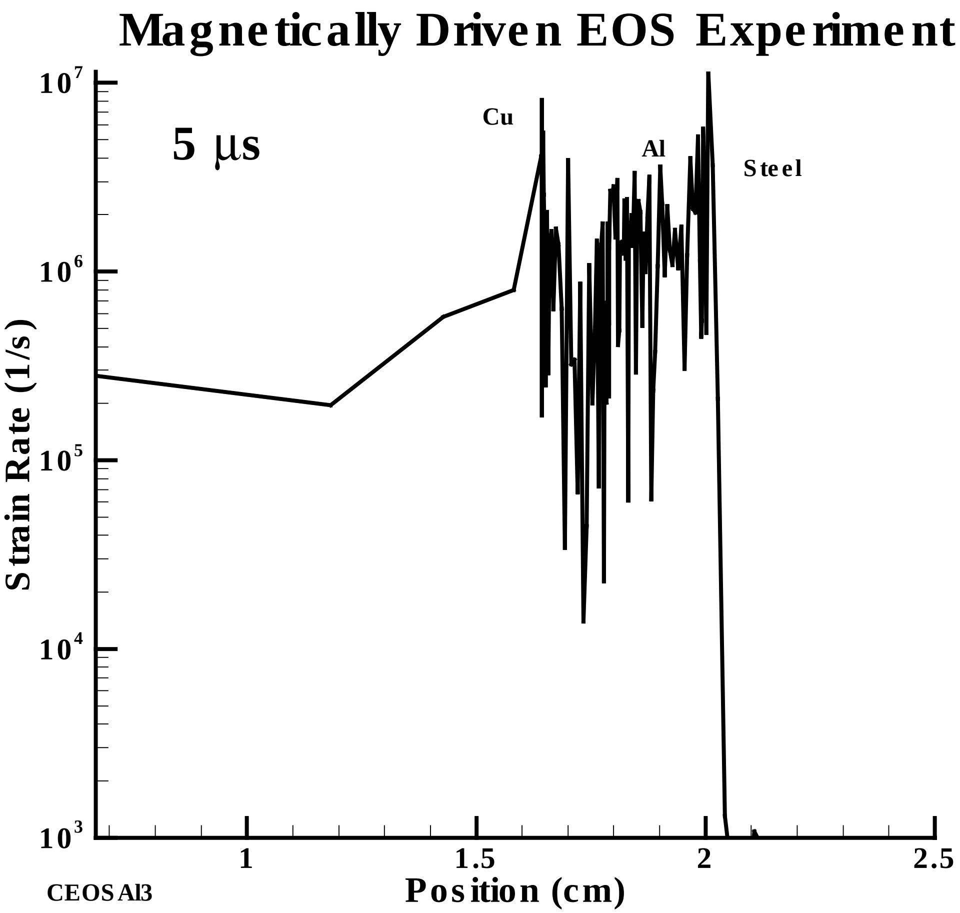
Fusion Technology Institute University of Wisconsin - Madison





Fracture of Experiment into Debris Fragments is Approximated with a Strain-Rate-Based Model

- Strain-Rate is 10^6 1/s in Aluminum.
- Strain-Rate in Steel is $10^5 - 10^6$ 1/s at 50 µs.
- From Drugan Model a range of Fragment Sizes can be Estimated.
- Aluminum size = 0.473 mm
- Steel size = 0.405 mm



Experiments on Z to Simulate IFE Target Chamber Phenomena*

R.R. Peterson
University of Wisconsin-Madison

Sandia National Laboratories
November 6, 2000

Energetic Ablator Ions Play a Dominant Role Direct-Drive Target Output : Z Experiments are Planned

Fusion Technology Institute University of Wisconsin - Madison

<u>Predicted Target Output</u>
(SOMBRERO)

<u>X-Rays</u>
22.41 MJ

<u>Debris Ions</u>

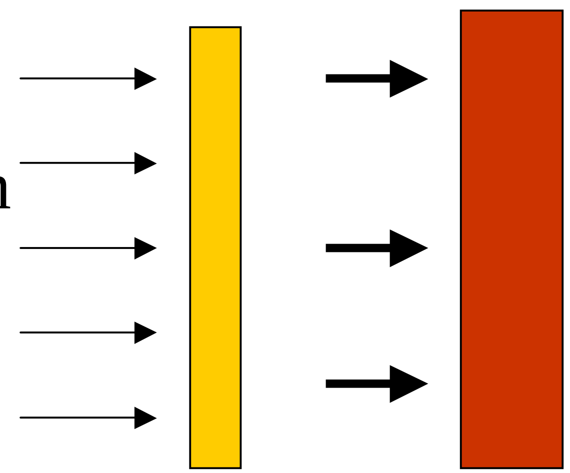
94 keV D -	5.81 MJ
141 keV T -	8.72 MJ
138 keV H -	9.24 MJ
188 keV He -	4.49 MJ
1600 keV C -	55.24 MJ
Total -	83.24 MJ

<u>Neutrons</u>
317 MJ

<u>Total Yield</u>
402 MJ

Ablator Material: CH, CH + Au, CH foam

X-rays from Z-pinch on Z



Detector: Time-Resolved Mass Spectrometer

Thermal X-rays Play a Dominant Role In-Direct-Drive Target Output : Z Experiments Could be Done

Predicted Target Output

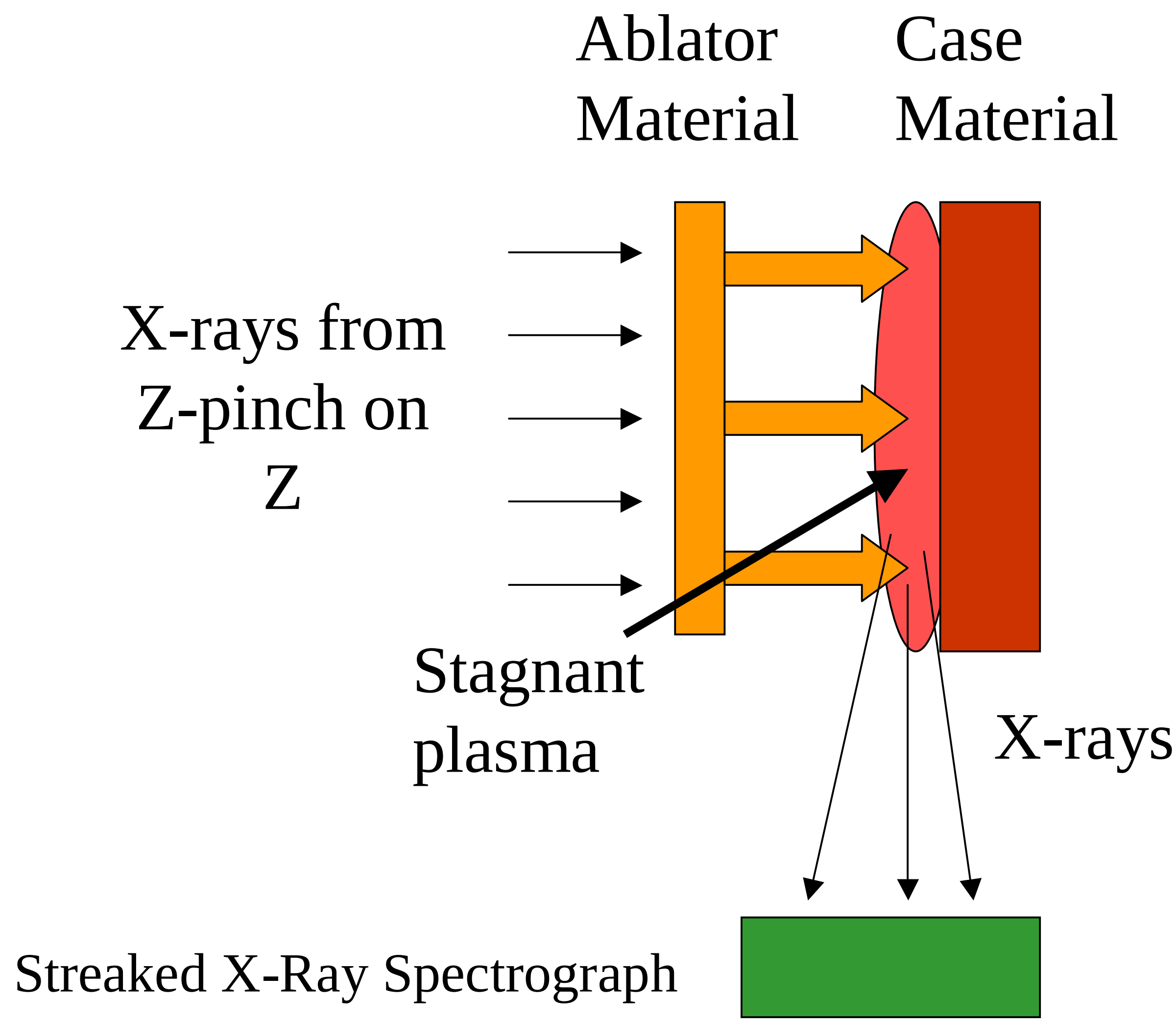
X-Rays
22.41 MJ

Debris Ions

94 keV D -	5.81 MJ
141 keV T -	8.72 MJ
138 keV H -	9.24 MJ
188 keV He -	4.49 MJ
1600 keV C -	55.24 MJ
Total -	83.24 MJ

Neutrons
317 MJ

Total Yield
402 MJ



X-ray Environment for Some IFE Target Chambers

Parameter	HIBALL	CASCADE	HYLIFE-II	LIBRA-SP	OSIRIS
X-ray Energy per shot (MJ)	89.5	75	56	168.1	71.9
Distance from X-ray Source (cm)	500	400	50	400	350
X-ray Fluence per shot (J/cm^2)	28.5	37.3	1800	83.6	46.7
T_{BB} (eV)	450	450	100-400	450	450
Material	$Pb_{83}Li_{17}$	Graphite	Flibe	$Pb_{83}Li_{17}$	Flibe

Both Z and NIF Can Produce X-ray Environment Relevant to IFE Target Chambers

X-ray Damage Parameters for Z

Parameter	Z (z-pinch only)			
X-ray Energy per shot (MJ)	2			
Distance from X-ray Source (cm)	399	72.8	39.9	7.28
X-ray Fluence per shot (J/cm^2)	1.0	30	100	3000
T_{BB} (eV)	200			

X-ray Damage Parameters for NIF

Parameter	NIF (20 MJ Target)				NIF (1.4 MJ laser only)			
X-ray Energy per shot (MJ)	4				1			
Distance from X-ray Source (cm)	564	103	56.4	10.3	282	51.5	28.2	5.15
X-ray Fluence per shot (J/cm^2)	1.0	30	100	3000	1.0	30	100	3000
T_{BB} (eV)	400				100-400			

X-Ray Response Experiments are Possible on Z

BUCKY code calculations for x-ray response experiments proposed for Z. Results show (Figures 1 and 2) that Z x-rays can produce shock in steel similar to what the target x-rays would in a power plant (LIBRA-SP).

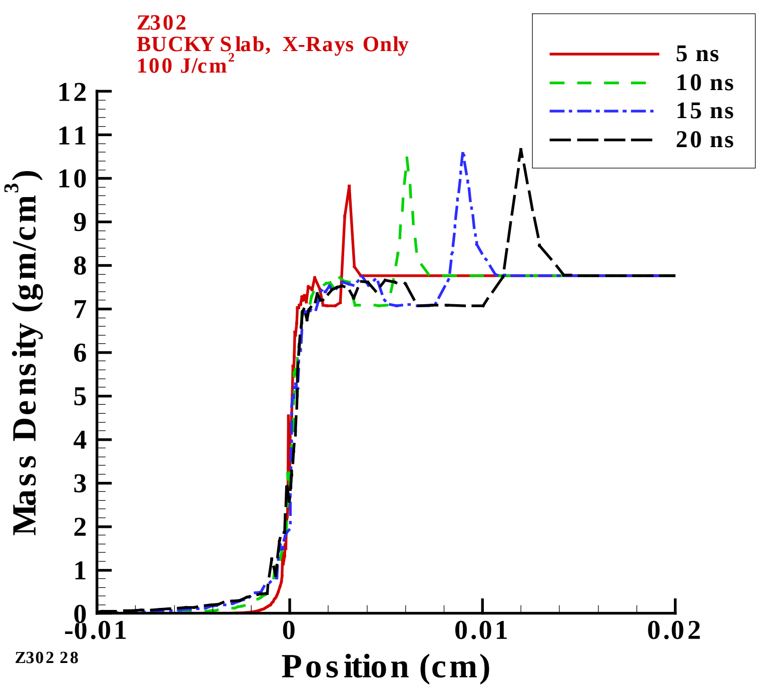


Figure 1. Mass density profiles at various times calculated in stainless steel with BUCKY. 100 J/cm^2 of x-rays with the spectrum and pulse width from Z shot 302.

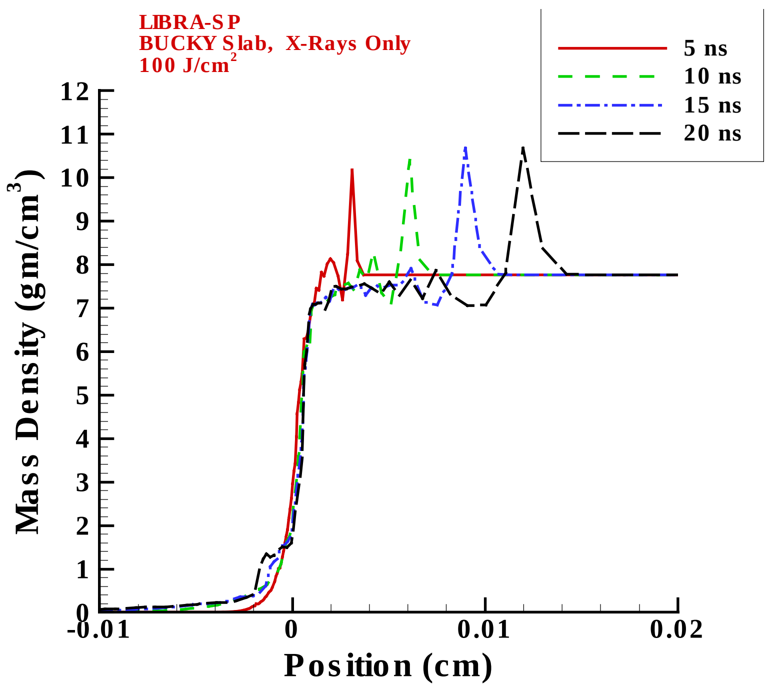


Figure 2. Mass density profiles at various times calculated in stainless steel with BUCKY. 100 J/cm^2 of x-rays with the spectrum and pulse width calculated for the LIBRA-SP target.

R. R. Peterson, C. L. Olson, T. J. Renk, G. E. Rochau, and M. A. Sweeney, “Chamber Dynamic Research with Pulsed Power,” presented at the 13th International Symposium on Heavy Ion Fusion, March 13-17, 2000, San Diego, California.

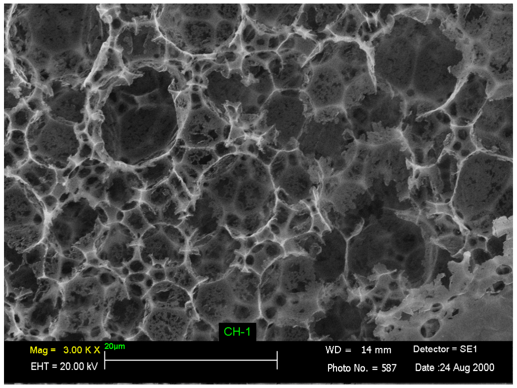
Experiments on Z to Study Radiation Transport Through Plastic Foams

G.A. Rochau
University of Wisconsin-Madison

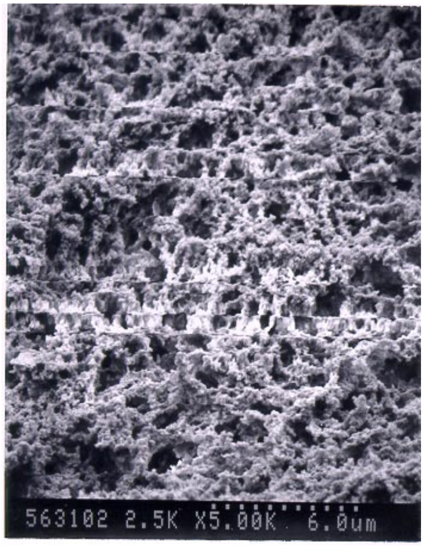
Sandia National Laboratories
November 6, 2000

The propagation of radiation in porous foams is a crucial issue for many types of z-pinch experiments.

Microscopic structure of 10 mg/cc foams

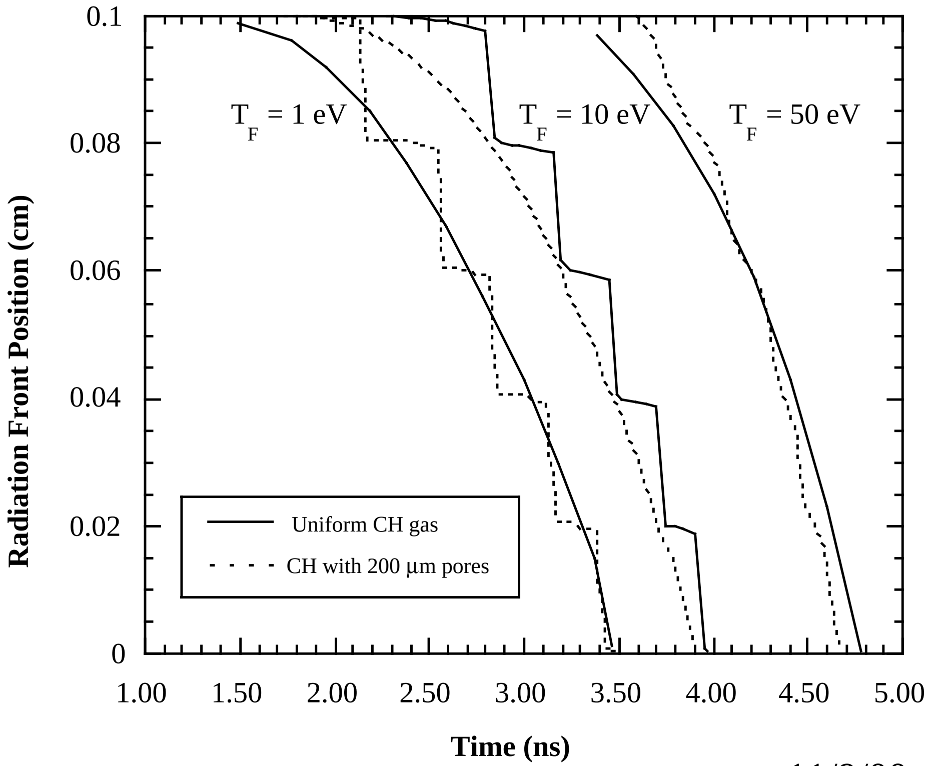


20 µm pore size



2 µm pore size

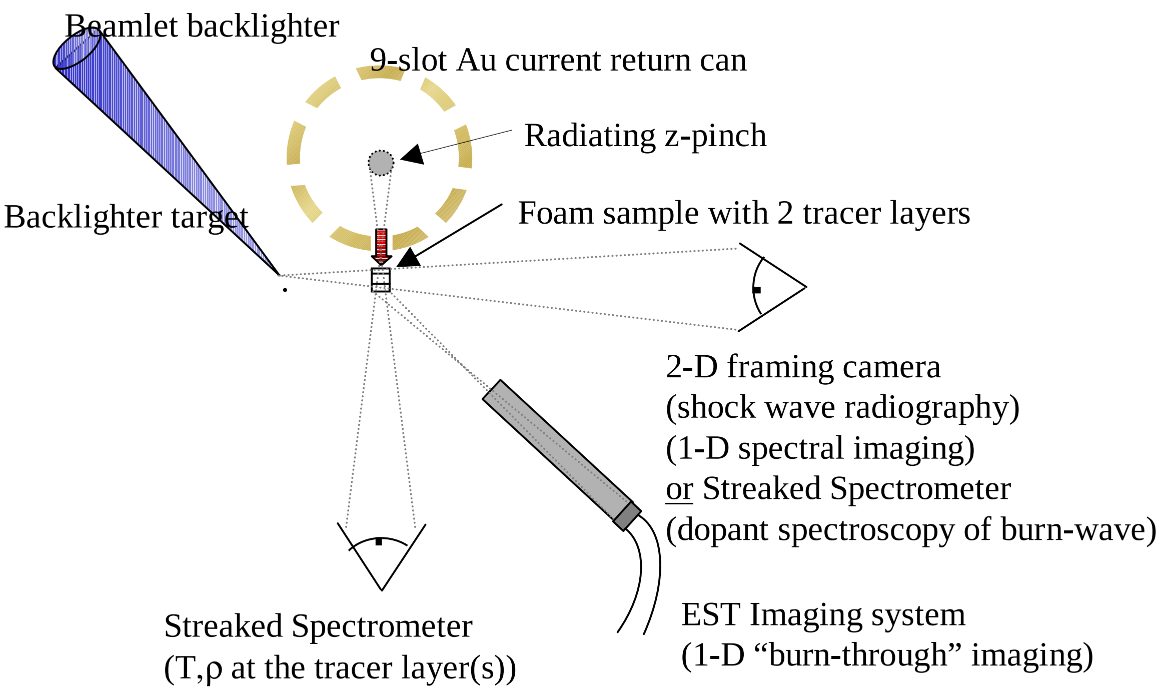
1-D BUCKY simulations may provide rough insight into the effect of porosity on radiation transport.



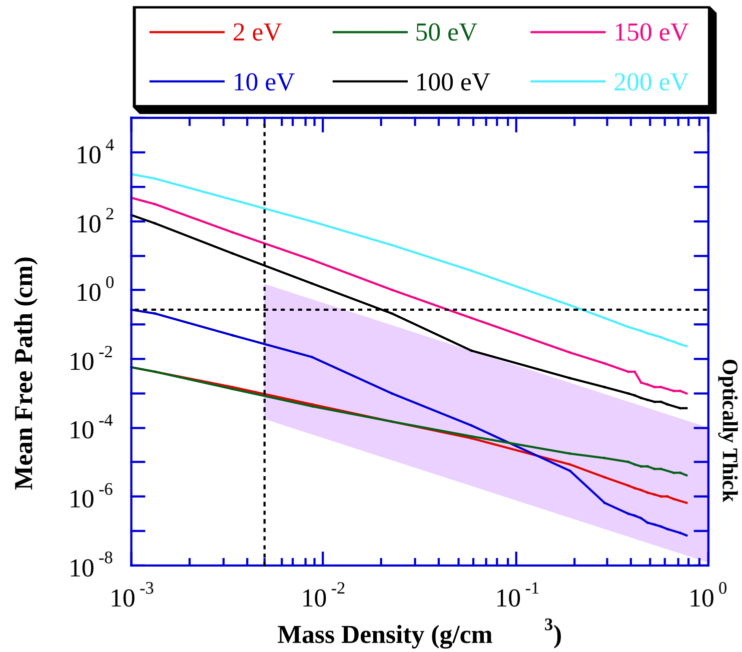
The Z machine is a good test-bed for radiation propagation studies in foams and other materials of general interest

Fusion Technology Institute University of Wisconsin - Madison

“Ride-Along” Experimental Arrangement



Attainable conditions in a CH_2 foam for “ride-along” type experiments



D.C. Kammer
University of Wisconsin-Madison

Sandia National Laboratories
November 6, 2000

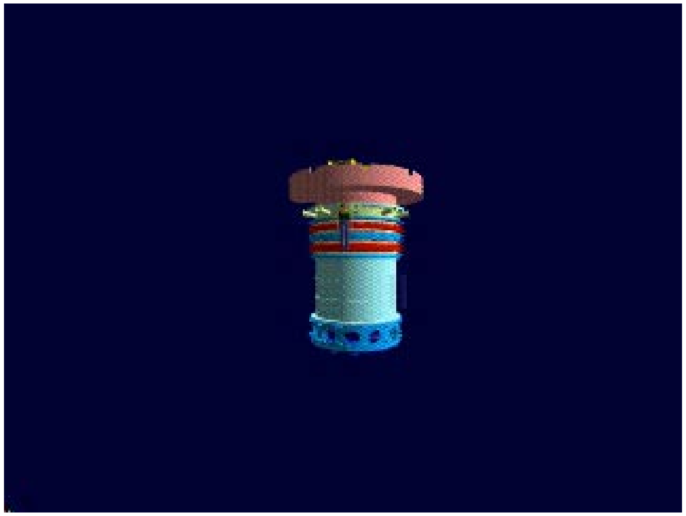
ICF Physics and Near Term Z-pinch Related Projects at The University of Wisconsin

1. **CAD Model for Z**
2. **Preliminary Finite Element Structural Modeling and Analysis of Z**
3. **Design of a System to Catch and Contain Debris from EOS Experiments**
4. **Shielding Analysis for the X-1 Target Chamber**
5. **Activation of X-1 Target Chamber**

Model of Z

G.A. Rochau, M. Redmond
University of Wisconsin-Madison

Sandia National Laboratories
November 6, 2000



Preliminary Finite Element Structural Modeling and Analysis of Z

Dan Kammer and Andrew Kostuch
University of Wisconsin-Madison

Sandia National Laboratories
November 6, 2000

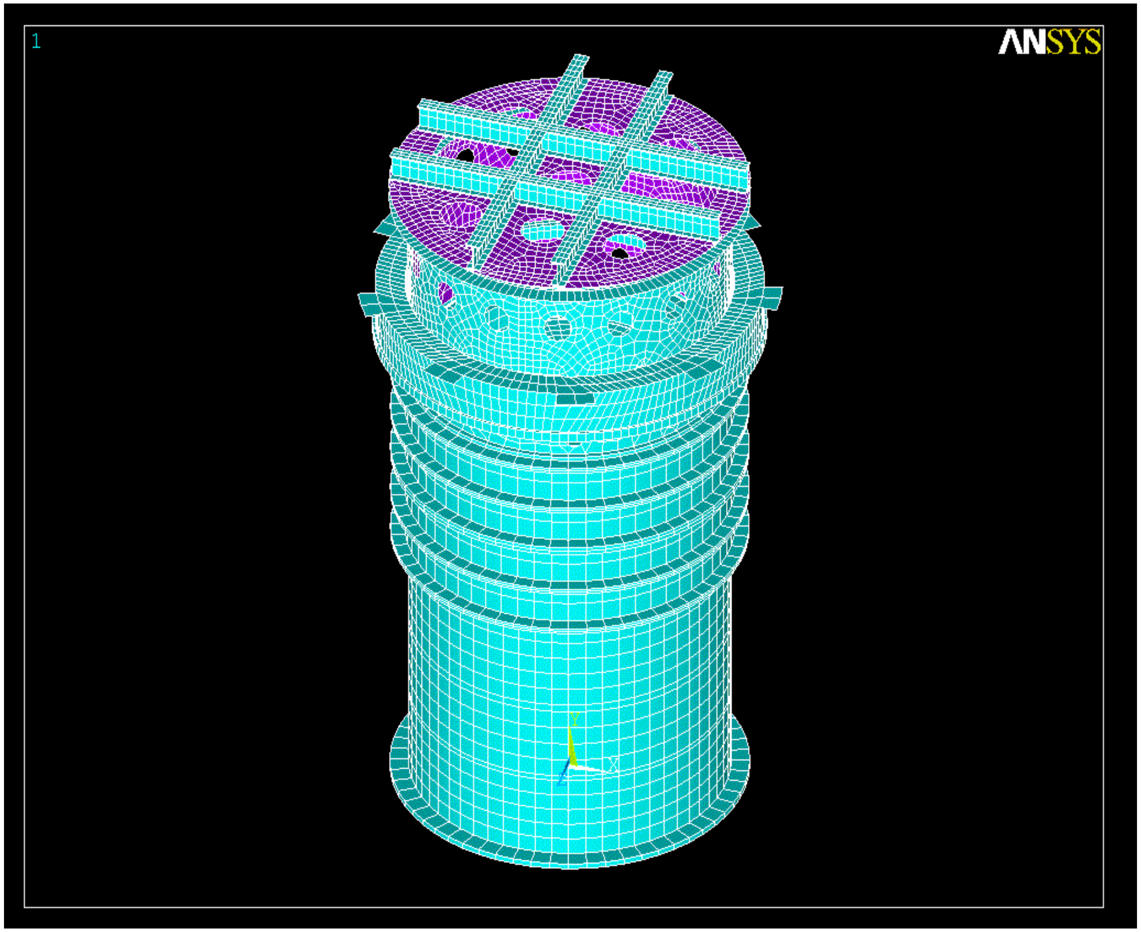
Z Finite Element Model

- ProENGINEER
- Cubit
- ANSYS 5.5

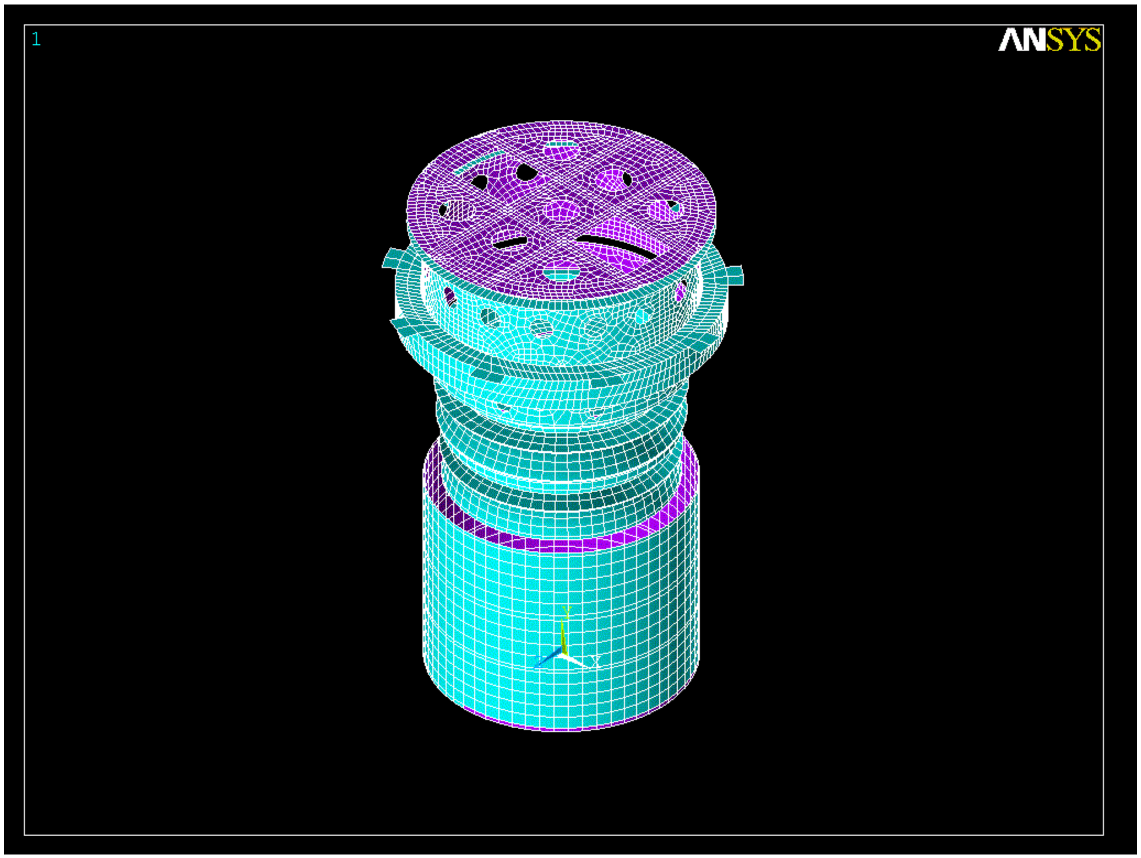
Model Statistics

Fusion Technology Institute University of Wisconsin - Madison

- 21329 Elements
- 25960 Nodes
- 152160 Degrees of Freedom
- Separated into 28 Components

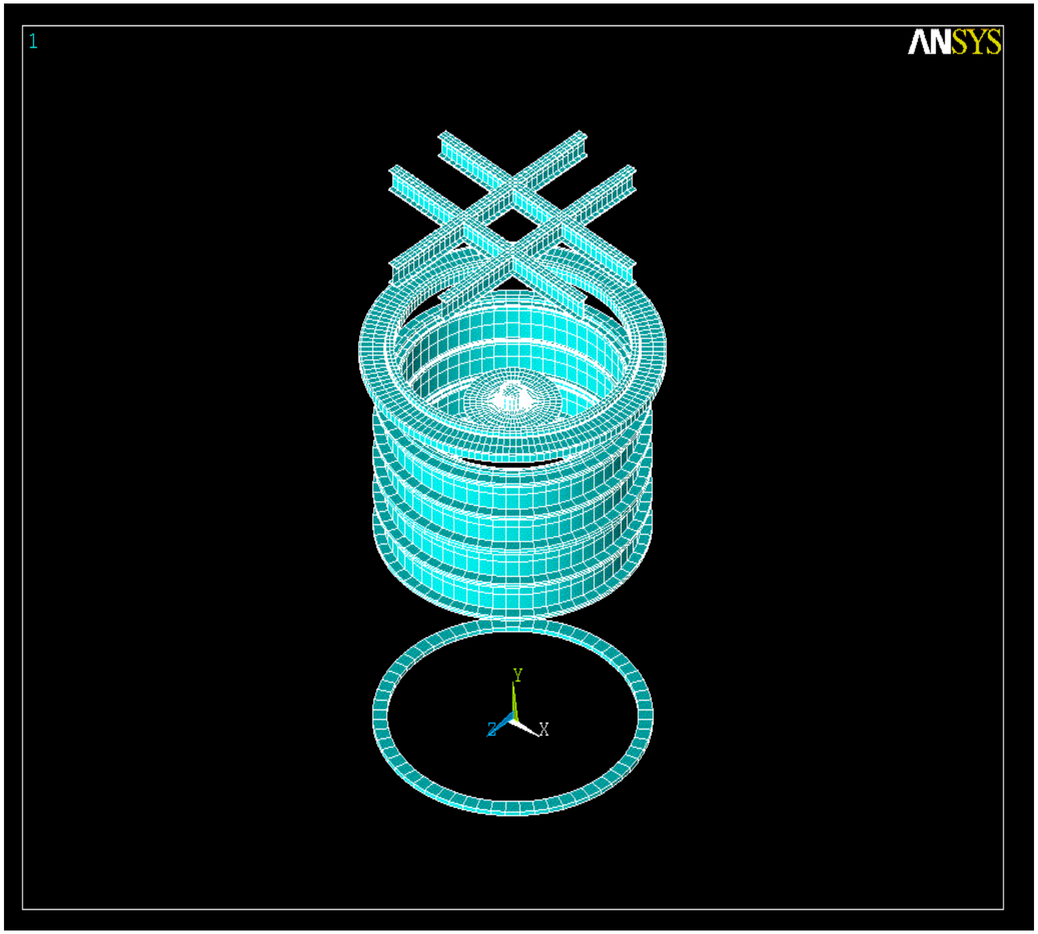


Shells



- 12 Components Modeled with Shells
- All Shells Shown Here

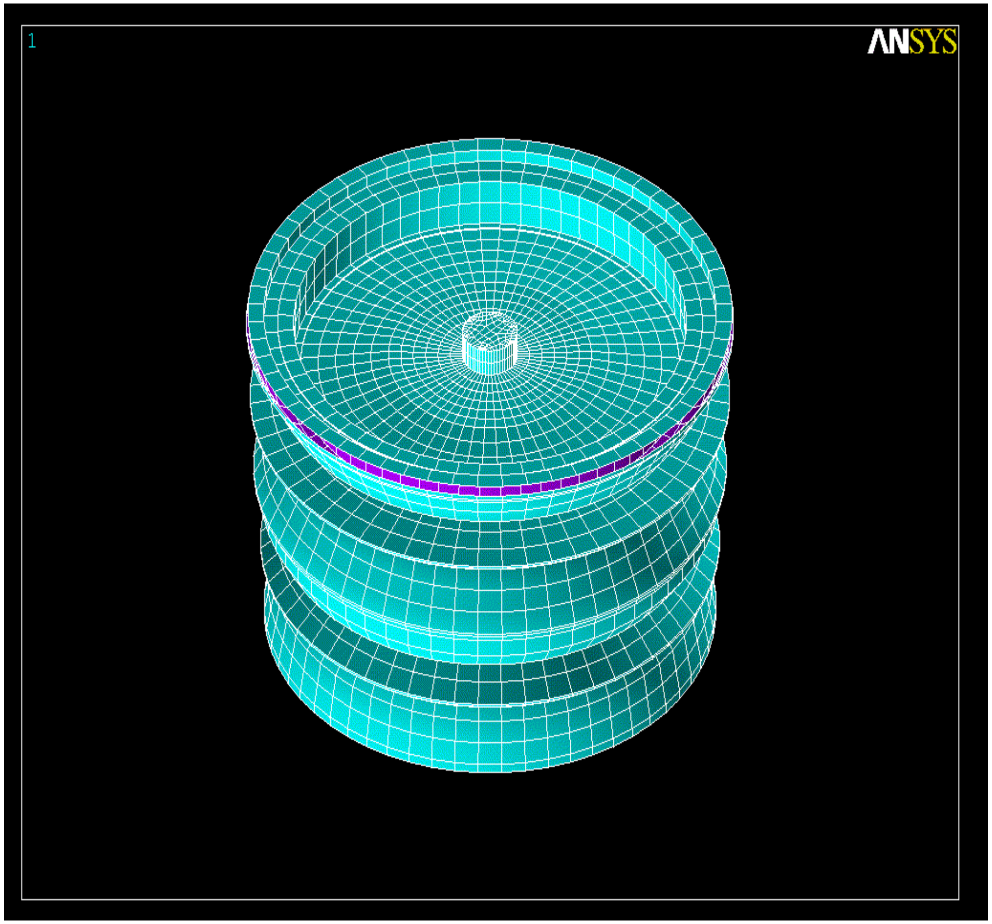
Solids



- 16 Components Modeled with Solids
- All Solids Shown Here

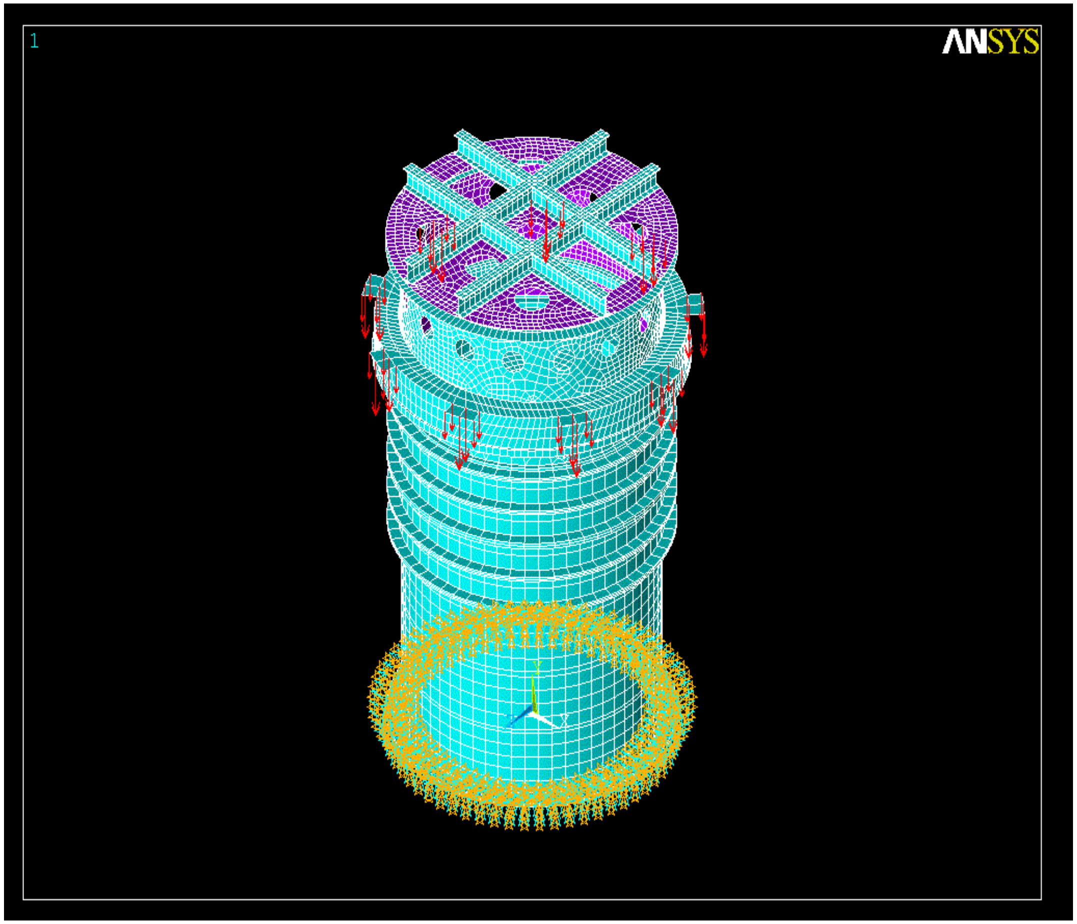
MITLS

- Mitls Modeled with Shells
- Attached to Idealized Center Can



Loads and Constraints

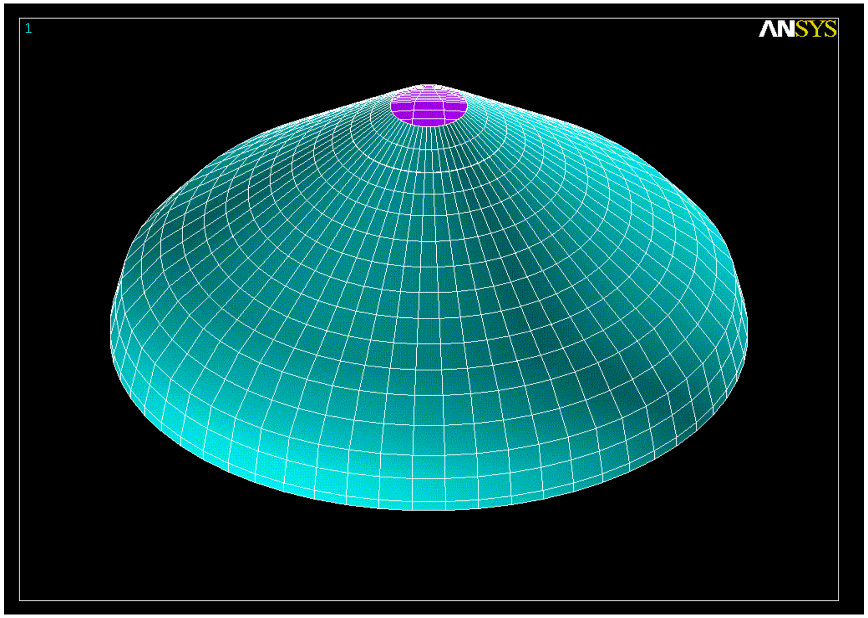
Fusion Technology Institute University of Wisconsin - Madison

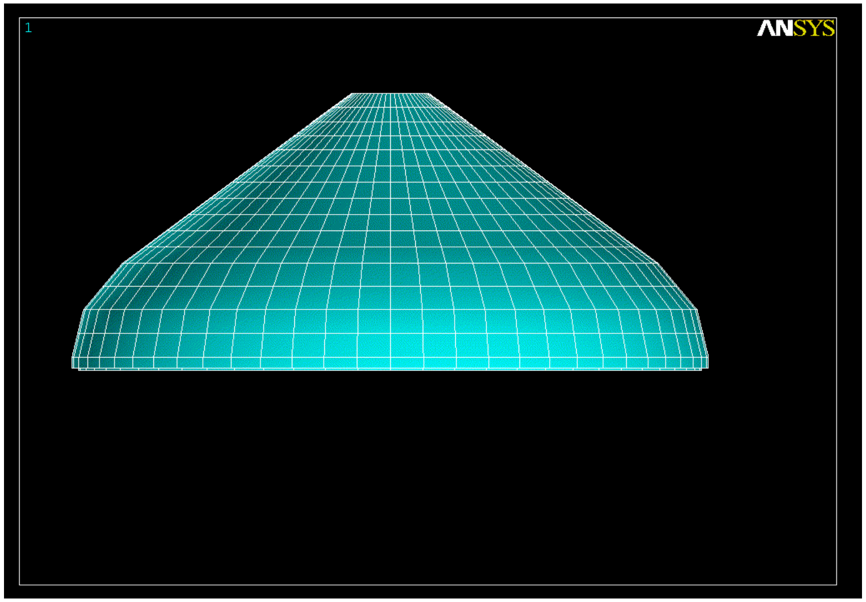


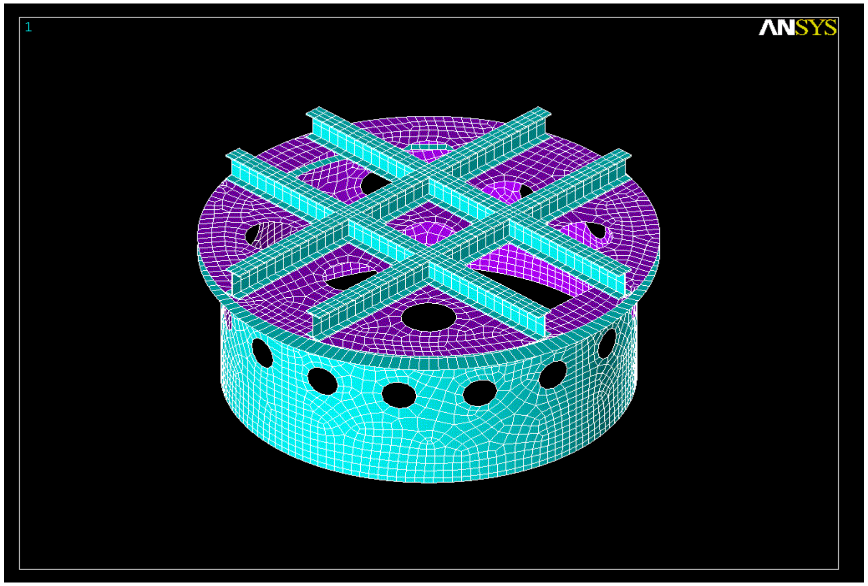
- Fully Constrained at the Base (shown in yellow)
- Applied Compressive Load for Pre-stress Effects (shown in red)
- Vacuum and Water Pressure Forces yet to be Applied

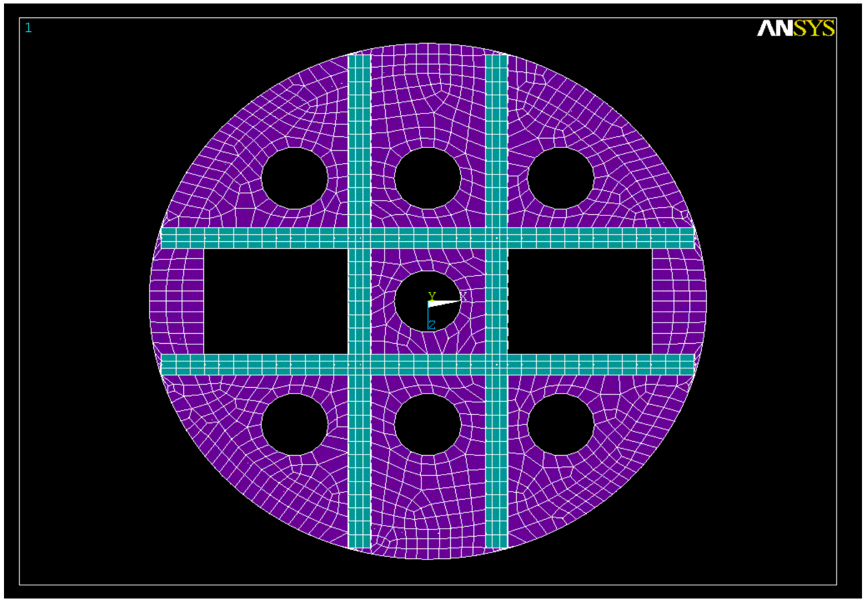
Selected Component Sets

Fusion Technology Institute University of Wisconsin - Madison



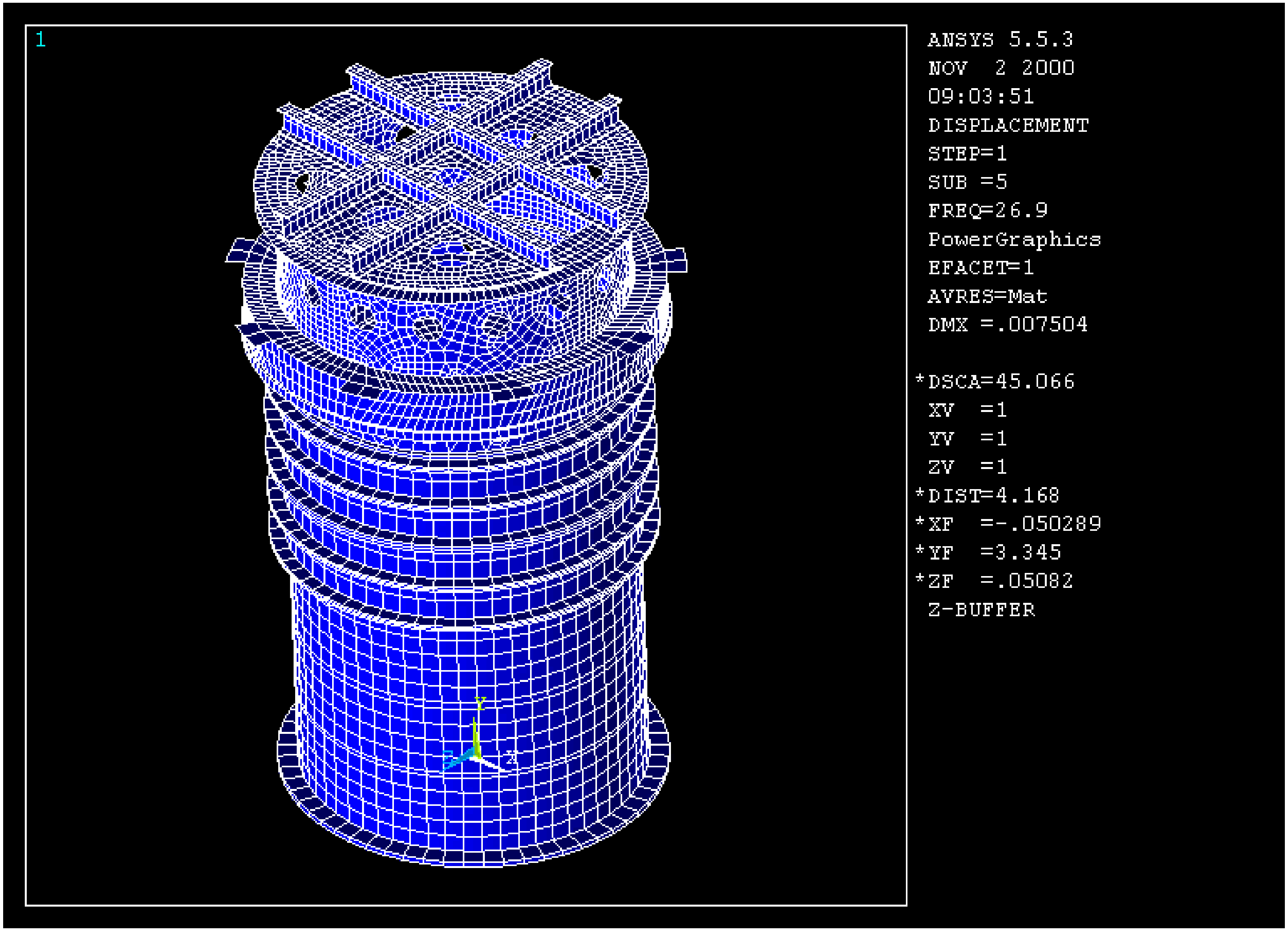






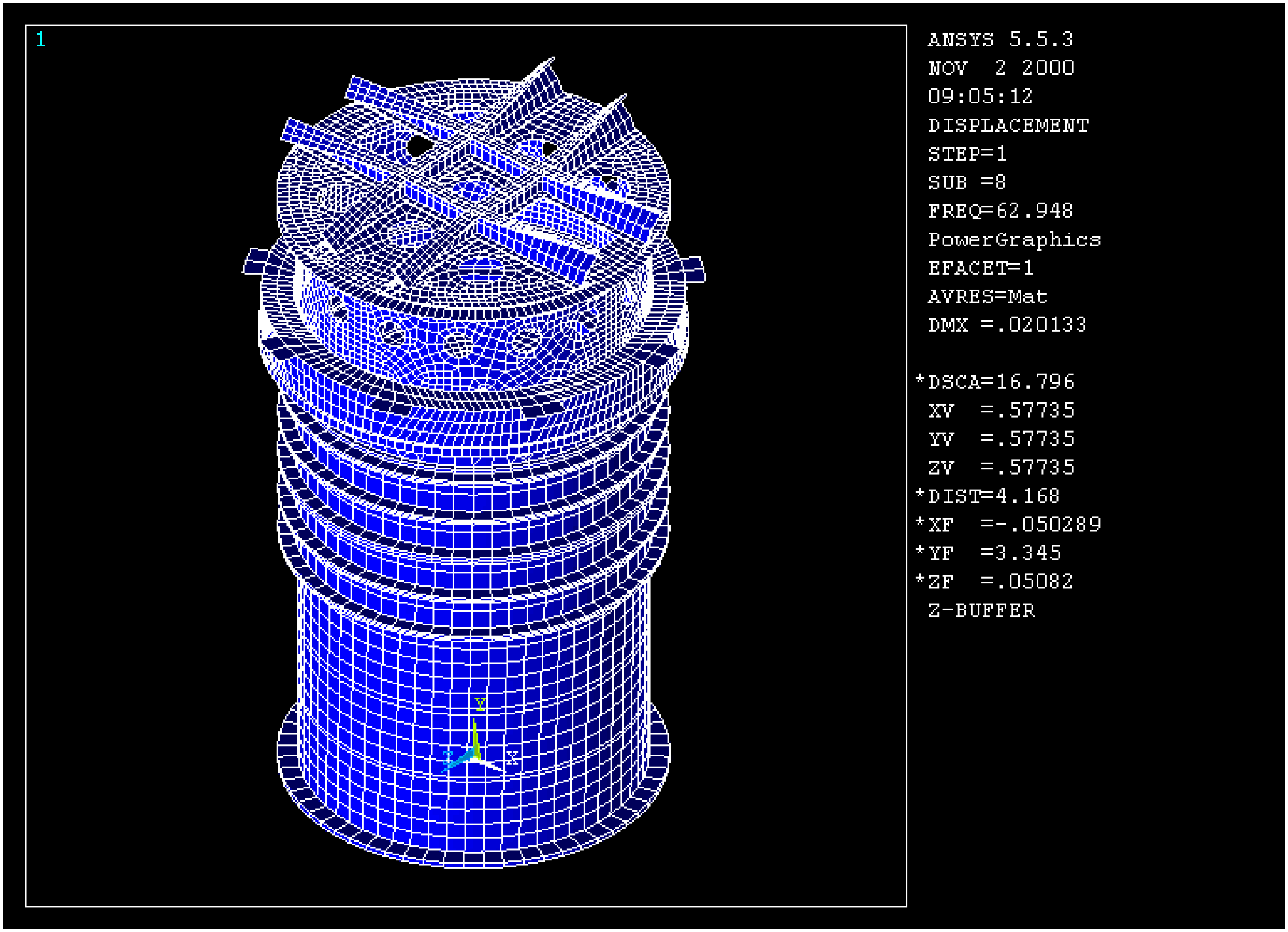
Mode 5 (26.9 Hz)

Fusion Technology Institute University of Wisconsin - Madison

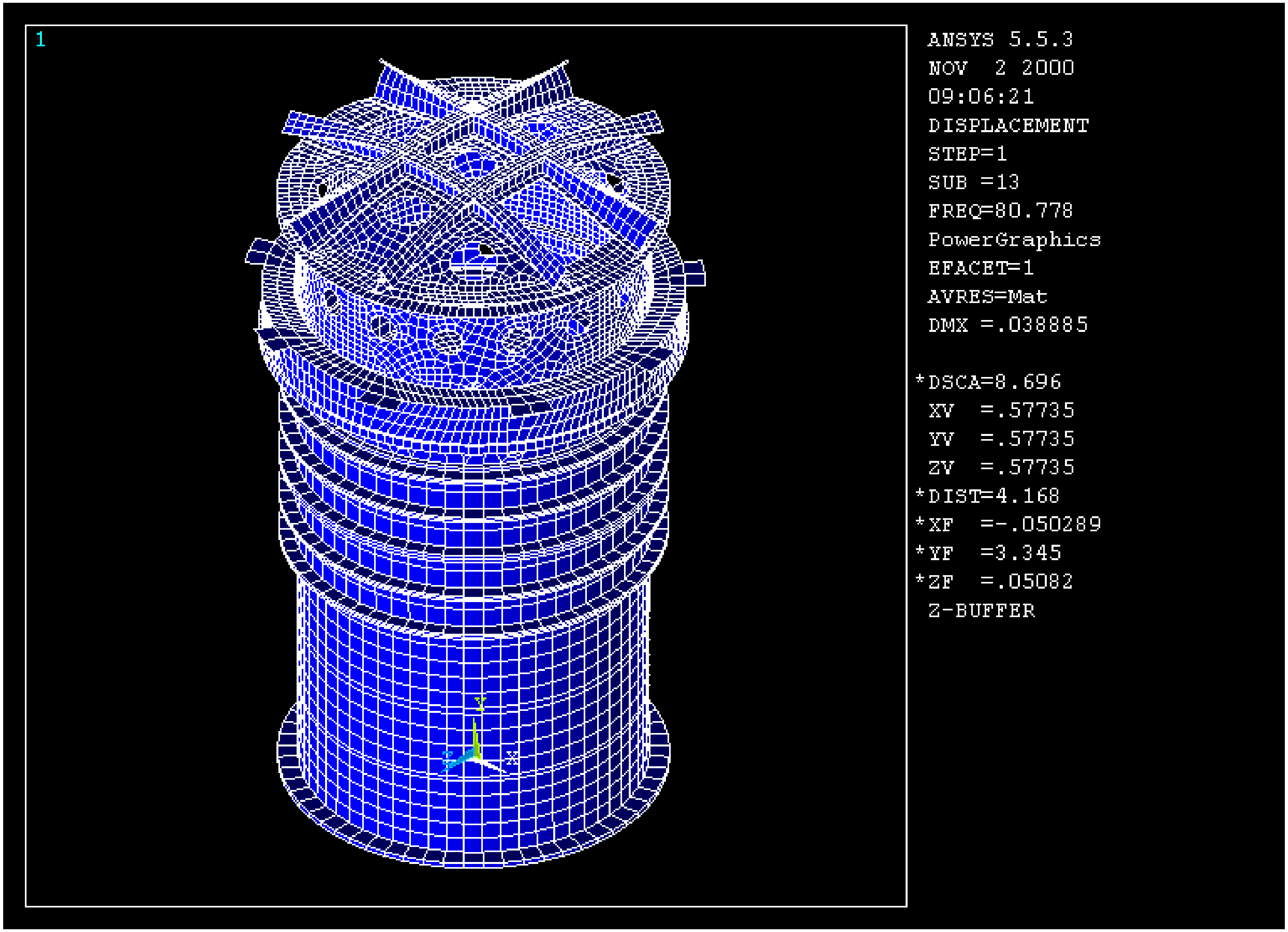


Mode 8 (62.9 Hz)

Fusion Technology Institute University of Wisconsin - Madison



Mode 13 (80.8 Hz)

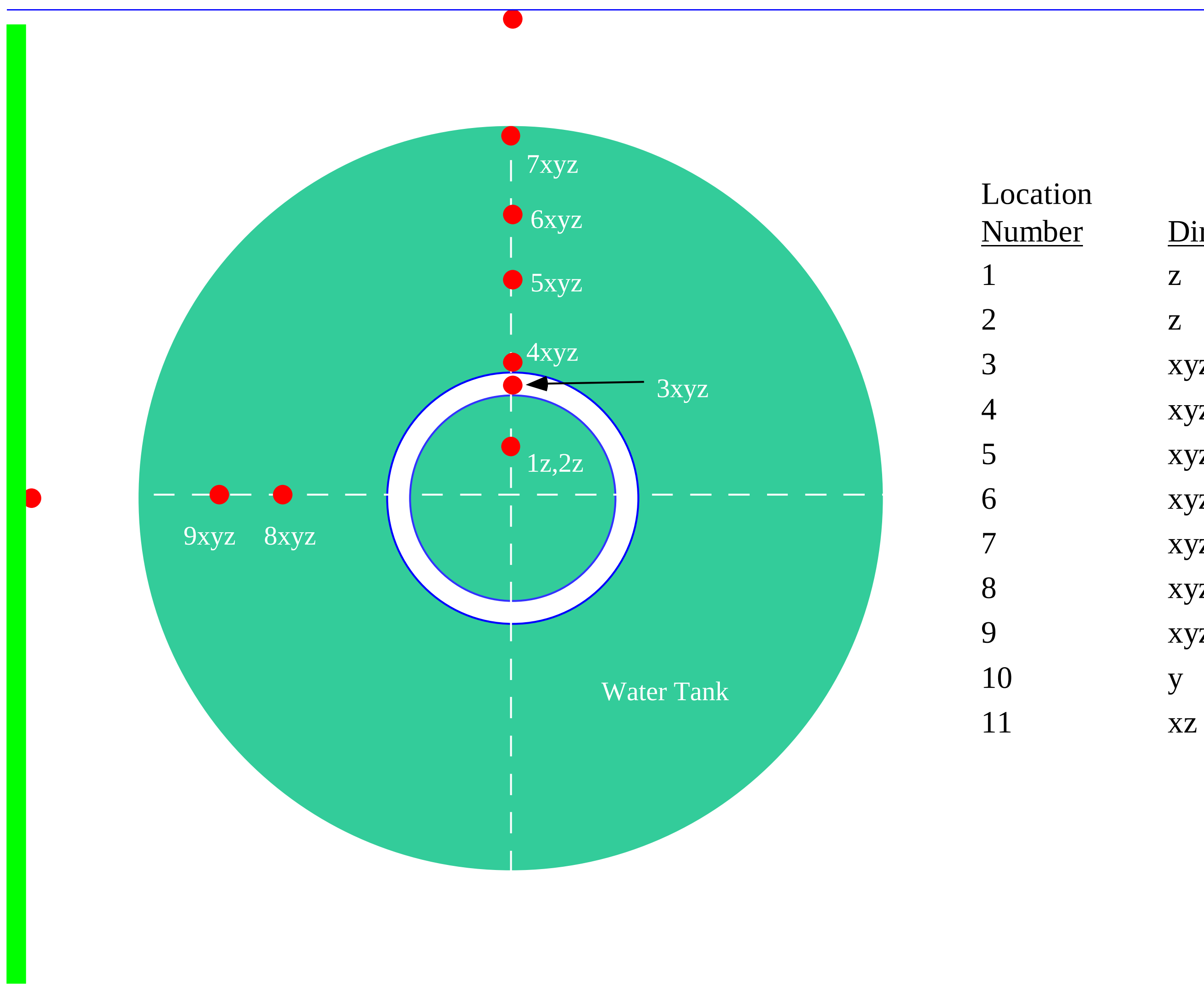


Near Term Work

- Generate Hydrostatic Loads
- Generate Vacuum Loads
- Compute Prestressed Mode Shapes and Frequencies
- Perform Trade Studies to Determine Number of Modes to be Retained for Transient Analysis
- Perform Structural Loads Analysis
- Apply Mode Acceleration Technique to Predicted Results

Proposed Accelerometer Placement for *Z* Shock Vibration Experiments

Fusion Technology Institute University of Wisconsin - Madison



Location Number	Directions	Description
1	z	Top MITL
2	z	Bottom MITL.
3	xyz	Bottom of circular beam.
4	xyz	Inside wall of vacuum chamber.
5	xyz	Bottom of water tank.
6	xyz	Housing surrounding water switch.
7	xyz	Outer wall of water tank.
8	xyz	Bottom of water tank.
9	xyz	Housing surrounding water switch.
10	y	North wall by crane track.
11	xz	Face of crane.

Design of a System to Catch and Contain Debris from EOS Experiments

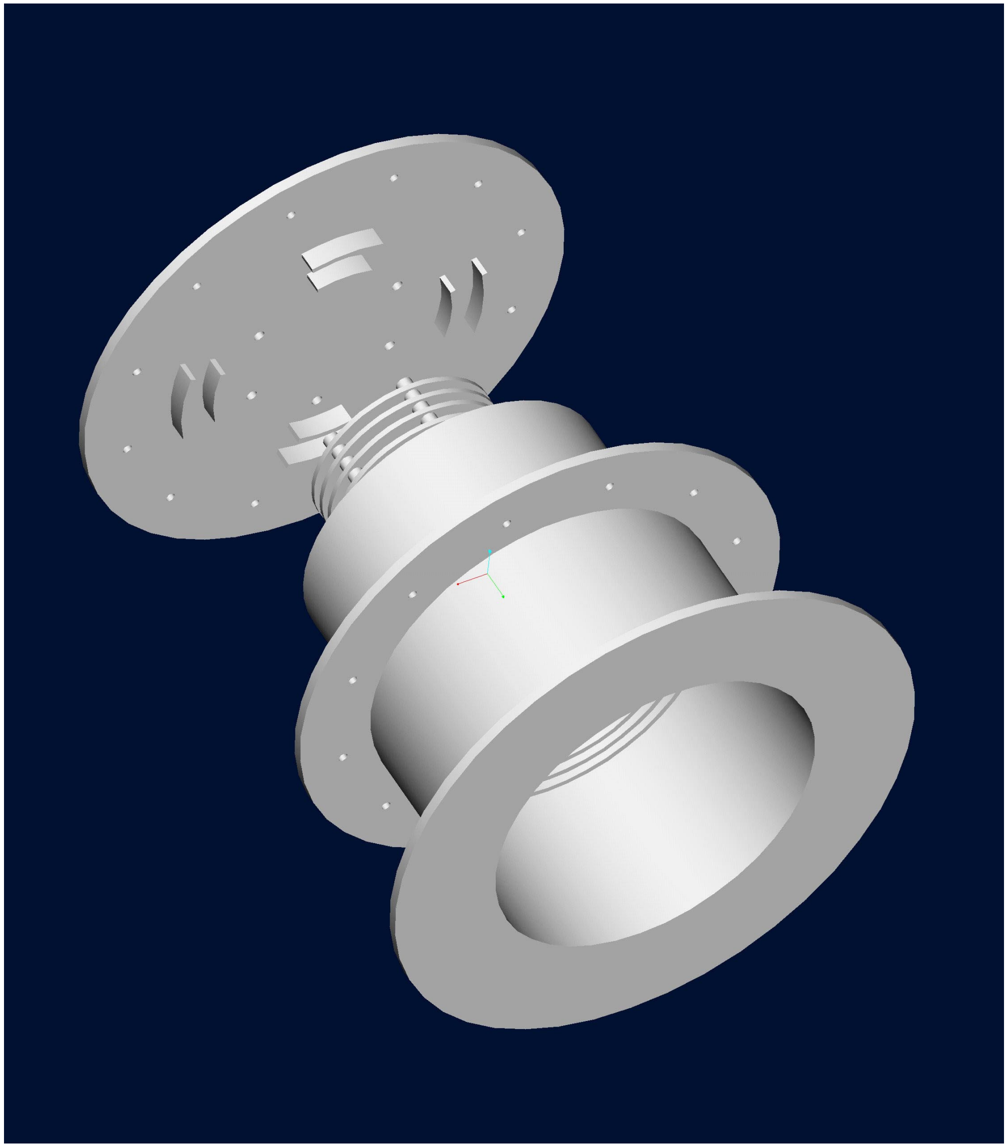
I.N. Sviatoslavsky and G. Shanmugasundar
University of Wisconsin-Madison

Sandia National Laboratories
November 6, 2000

ProE Model of Debris Catcher Can be Processed with CUBIT to Make a Mesh for ANSYS

Fusion Technology Institute University of Wisconsin - Madison

- ProEngineer Model Developed
  - Modification of SNL Catcher
  - Additional Cylindrical Absorbers in Back of Samples
- Mesh will be Created with CUBIT
- Mechanical Load from BUCKY Simulations
- ANSYS model of Structural Response



Neutron and Gamma Shielding Analysis and Design for the X-1 Target Chamber

M.E. Sawan
University of Wisconsin-Madison

Sandia National Laboratories
November 6, 2000

Neutronics Analysis for X-1: Overall Damage is Low But Damage to Insulators Needs Consideration

•Several 1-D calculations performed to determine neutron and gamma flux distribution and nuclear parameters for the chamber components.

•Cumulative fluence and damage in chamber components are very low allowing for re-welding. For 500 shots, the peak damage in chamber wall will be $2x10^{-4}$ dpa and $5x10^{-3}$ He appm

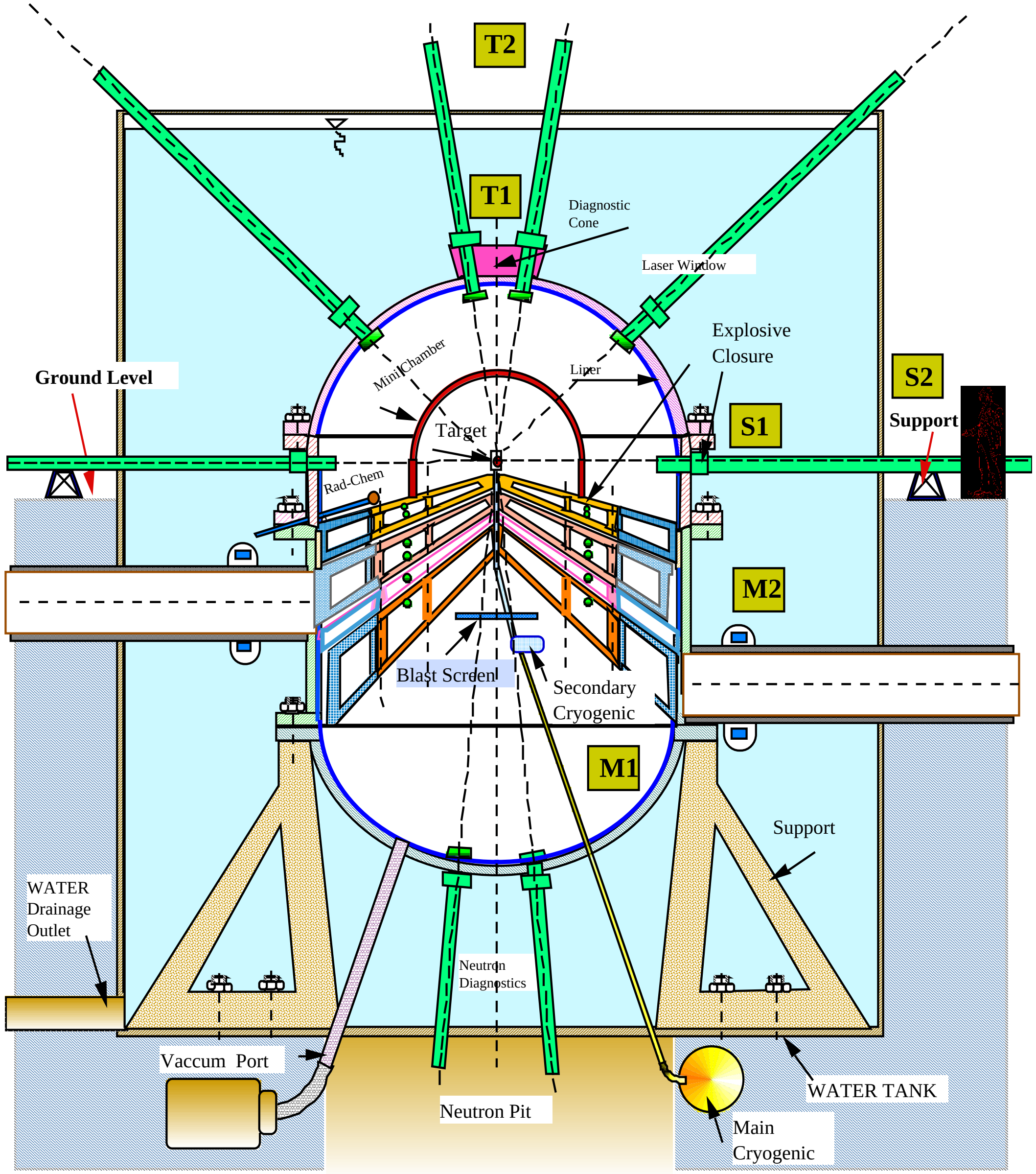
•Nuclear heating is very small and no additional cooling is needed

•Peak leakage fluence from shield tank is very small ($1.6x10^{4}$ n/cm^2 and $4.9x10^{9}$ γ/cm^2)

•Cumulative insulator fluence and dose are very small but high insulator dose rates result in significant degradation in resistivity @ 40 ns after shot. Based on data for ceramic insulators irradiated in HFIR, resistivity is expected to get back to unirradiated value before next shot.

X-1 Experimental Chamber Design Concept

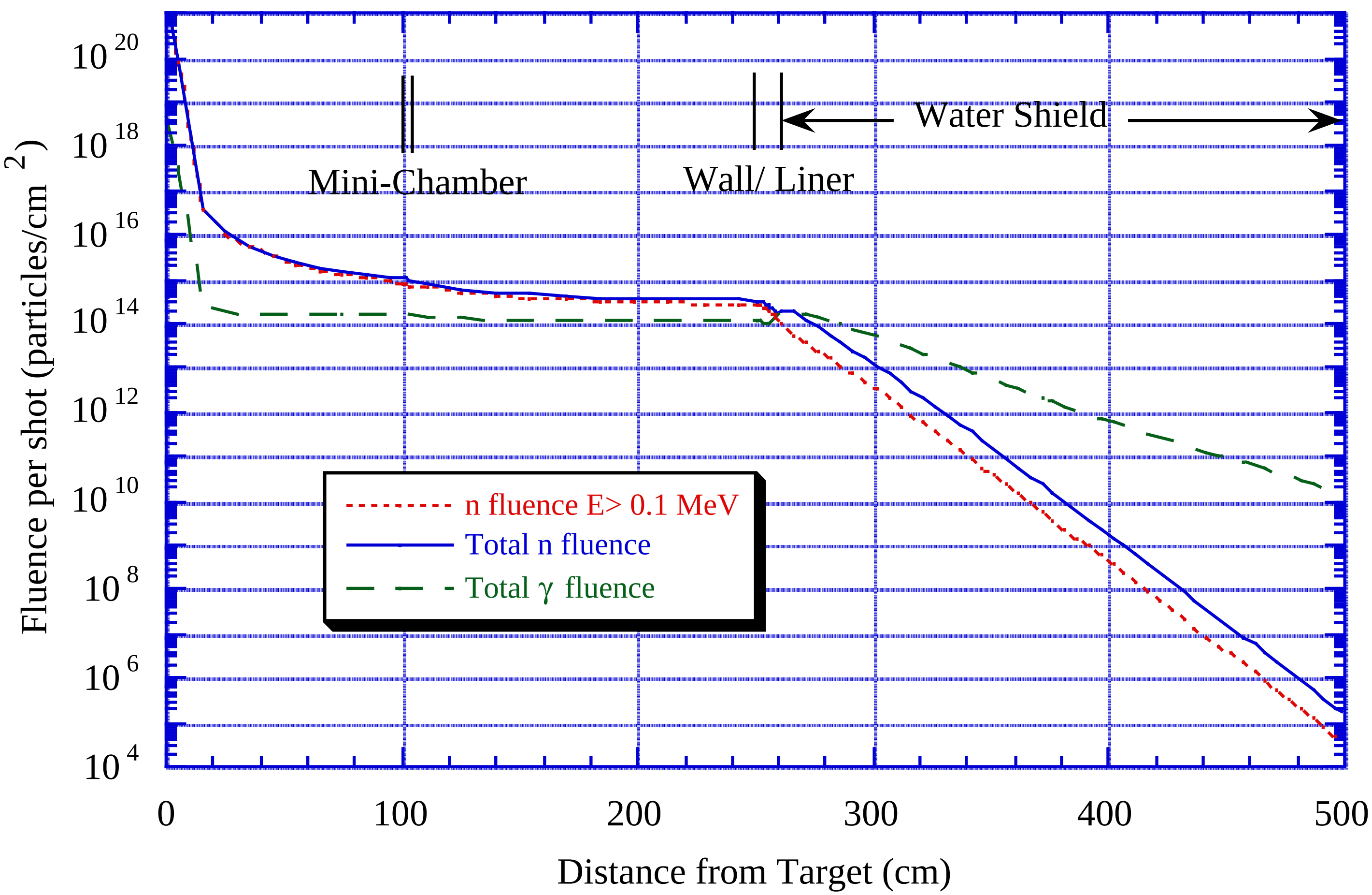
Fusion Technology Institute University of Wisconsin - Madison



Neutronics and Shielding Analysis for the X-1 Chamber

Fusion Technology Institute University of Wisconsin - Madison

Neutron and Gamma Fluence Variation in X-1 Chamber for 200 MJ Yield Shot



Neutron Damage to Insulator Stack in X-1 Target Chamber

Fusion Technology Institute University of Wisconsin - Madison

Assumptions:

- 200 MJ yield. 500 shots
- No material between target and insulator
- Insulator at 2.5 m from target
- Spinel representing ceramic insulator. Epoxy representing organic insulator

Ceramic Insulator:

Peak fast n fluence	3.9e14 n/cm^2/ shot
	2e17 n/cm^2/500 shots
Peak heating	13.6 J/cm^3 per shot
	4e5 Rads/shot
	2e8 Rads/500 shots
Peak dose rate	1.9e13 Rads/s
	@40 ns following shot

Organic Insulator:

Peak fast n fluence	2e14 n/cm^2/shot
	1e17 n/cm^2/500 shots
Peak heating	9.2 J/cm^3 per shot
	4.9e5 Rads/shot
	2.4e8 Rads/500 shots
Peak dose rate	2.3e13 Rads/s
	@40 ns following shot

•Significant instantaneous degradation in resistivity between shots. Is this a concern?

Activation of X-1 Target Chamber

H.Y. Khater
University of Wisconsin-Madison

Sandia National Laboratories
November 6, 2000

Assessment of Personnel Accessibility in the X-1 Pulsed Power Facility

Fusion Technology Institute University of Wisconsin - Madison

- Different types of yield as well as non-yield shots are proposed for X
- Ignition of ICF capsules may produce fusion yield of up to a 1000 MJ
- The blast resulting from the explosion of the capsule is confined insic an aluminum target chamber, submerged in a shielding water tank
- Fusion neutrons from yield shots and, to a lesser degree, photoneutron and ions will activate the experimental chamber
- Large pieces of magnetic debris, and most of the X-rays and debris io emitted from the target are stopped by a hemispherical mini-chambe made of Kevlar with a graphite inner coating
- The X-rays and debris ions that pass through the holes in the mini-chamber will be absorbed by an aluminum liner attached to the inne surface of the target chamber

Three Different Types of Shots are Assumed in This Analysis

- Radiation shots:
  - Only photoneutrons are produced during these shots
  - The photoneutrons are produced as a result of interaction between the Bremsstrahlung radiation and the MITLs
- Moderate yield shots:
  - These shots produce a fusion yield of 200 MJ
- High yield shots:
  - These shots produce a fusion yield of 1000 MJ

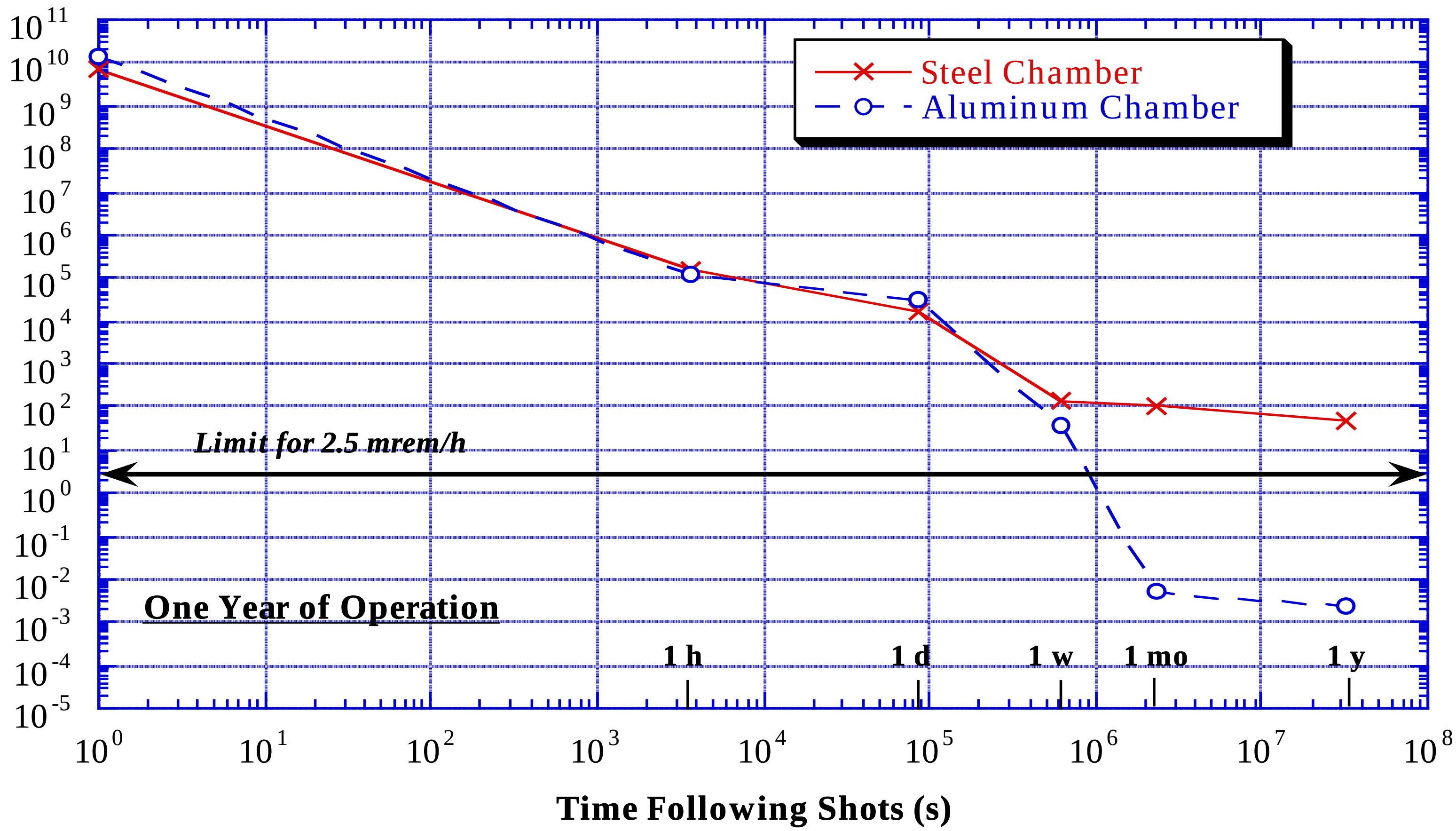
Shots schedule

- Radiation shots have a pulsing schedule of 1 shot per day for a total of 240 shots per year
- Moderate and high yield shots assume a pulsing schedule of 2 shots per month for a total of 24 shots per year

Aluminum 5083 is found to be an Acceptable Material for the X-1 Target Chamber from an Activation Point of View

Fusion Technology Institute University of Wisconsin - Madison

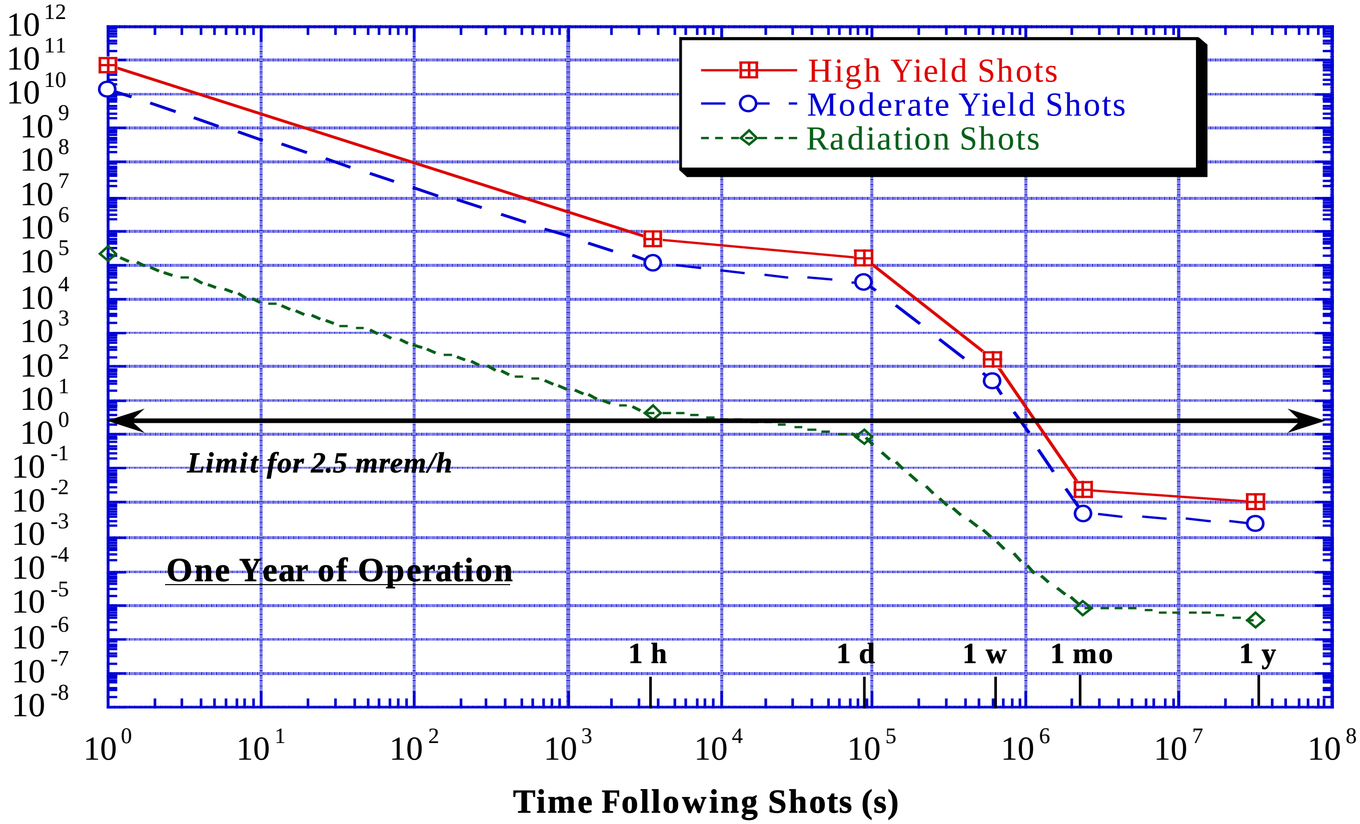
- The two alloys Al-5083 and 2 1/4 Cr-1 Mo steel are considered as chamber material candidates
- Using the aluminum chamber allows for hands-on maintenance, 10 days following moderate yield shots
- Using the steel chamber would not allow for hands-on maintenance at all times following shots.
- Based on these results, the Al-5083 alloy is selected as the preferred chamber material



Dose Rates at T1

Biological Dose Rates Following Radiation Shots (No Fusion Neutrons) are Lower, But Still Significant

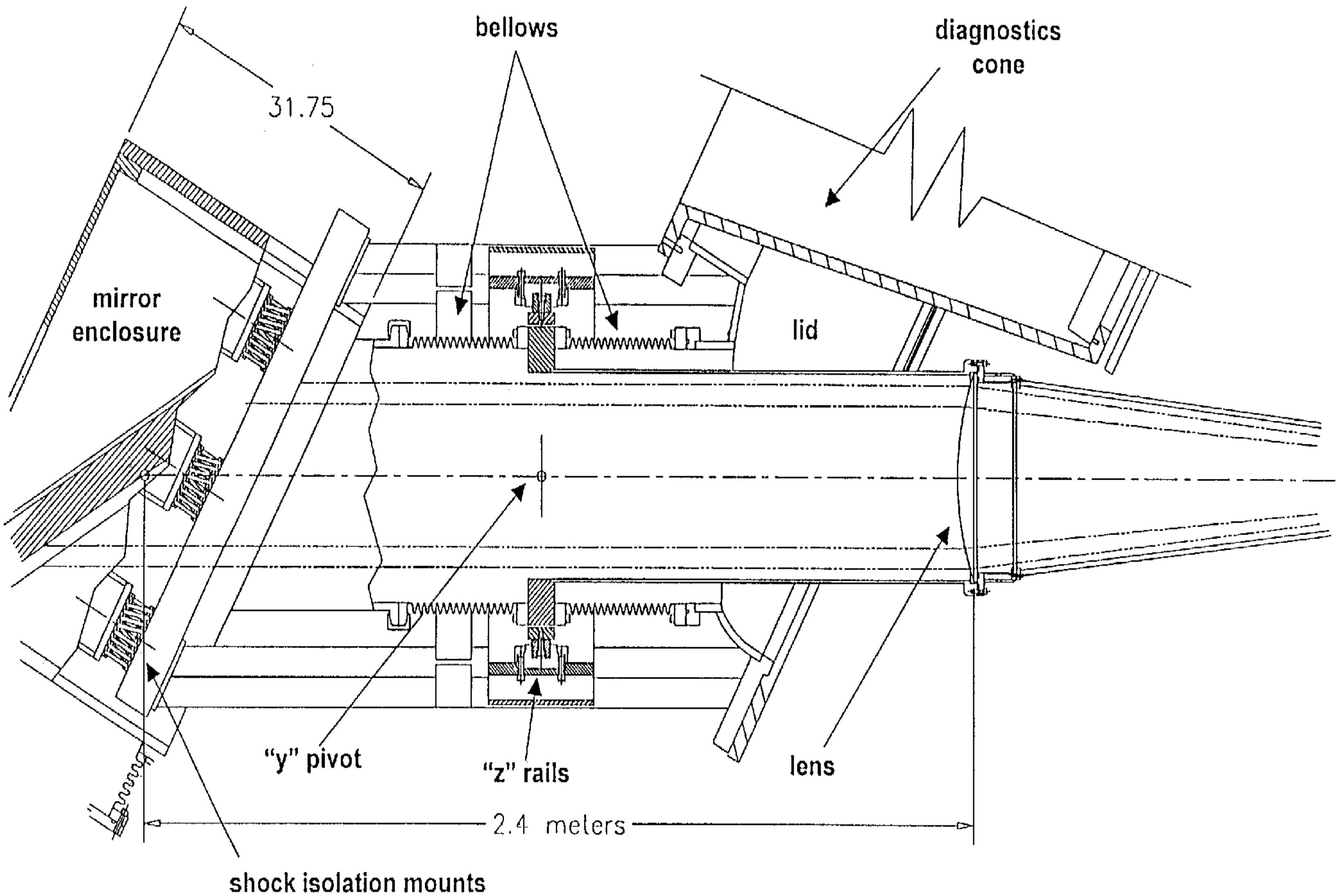
- Dose rates behind the chamber following radiation shots are 4 orders of magnitude lower than dose rates following moderate yield shots
- Hands-on maintenance activities outside the chamber may be allowed within a few hours following radiation shots
- A waiting period of about a day is needed before accessing the inside of the chamber following radiation shots



Dose Rates at T1

Neutronics and Activation Analysis of the Laser Backlighter on Z

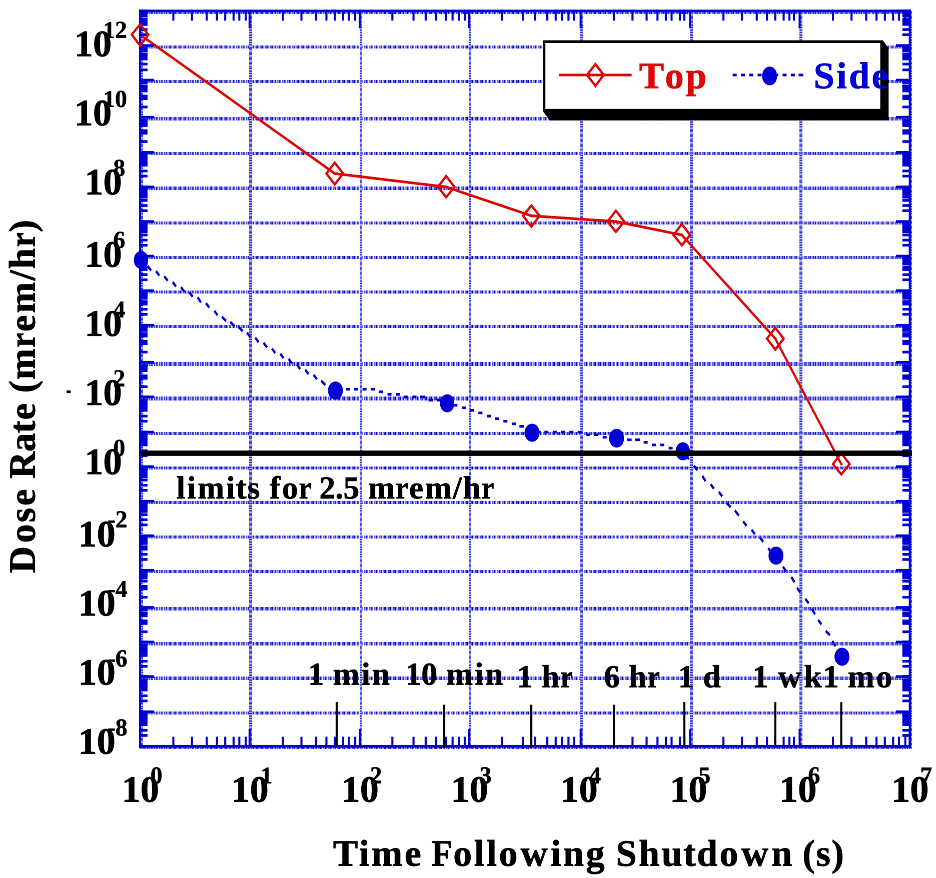
Fusion Technology Institute University of Wisconsin - Madison



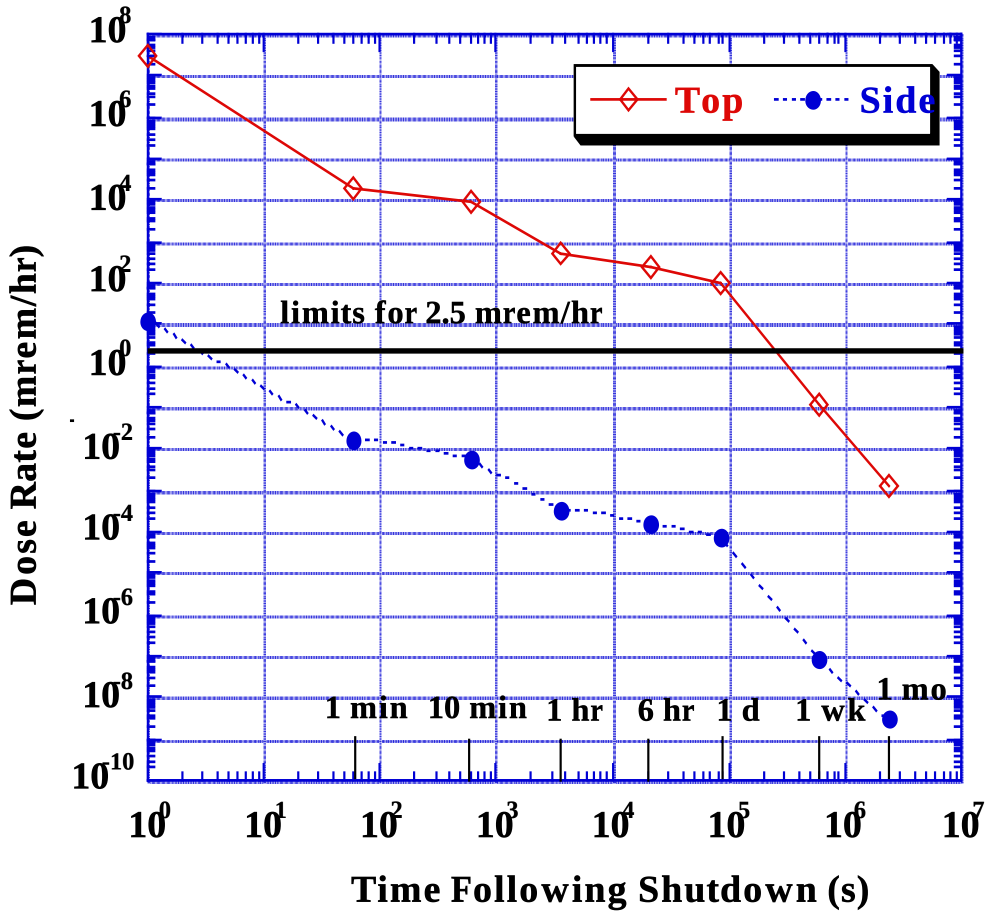
Biological Dose Rates Around the Final Focus Mirror Assembly on X-1

Fusion Technology Institute University of Wisconsin - Madison

Moderate Yield Shots
200 MJ
2 shots/month
1 year of operation



Radiation Shots
1 shot/day
1 year of operation



Number of mg of Pu Producing 1 rem off-site dose at the 1 km Site Boundary

The off-site dose calculations are performed using the following (worst release) conditions: ground release, atmospheric stability Class F, and 1 m/s wind speed

Isotope	Early Dose	Latent Dose
Pu-236 ($T_{1/2}$ = 2.87 y)	0.35	0.25
Pu-237 ($T_{1/2}$ = 45.2 d)	389	180
Pu-238 ($T_{1/2}$ = 87.7 y)	4.78	3.27
Pu-239 ($T_{1/2}$ = 2.41e4 y)	1224	821
Pu-240 ($T_{1/2}$ = 6.56e3 y)	334	224
Pu-241 ($T_{1/2}$ = 14.4 y)	43.9	28.2
Pu-242 ($T_{1/2}$ = 3.75e5 y)	20547	13698
Pu-243 ($T_{1/2}$ = 4.956 h)	79.1	67.7
Pu-244 ($T_{1/2}$ = 8e7 y)	4.64e6	3.06e6
Pu-245 ($T_{1/2}$ = 10.5 h)	5.3	5.26
Pu-246 ($T_{1/2}$ = 10.85 d)	6.37	5.02

Inertial Fusion Chamber Design Using an Electrically-Coupled (Z-pinch) Driver Concept

M.S. Derzon, C. Olson, G.E. Rochau, S. Slutz, A. Zamora,

Sandia National Laboratories

G.A. Rochau, R.R. Peterson, Fusion Technology Institute,

University of Wisconsin

J. DeGroot, *University of California, Davis, CA*

P. Peterson, *University of California, Berkeley, CA*

Z-Pinch Driven IFE Might Best Operate at Higher Target Yield and Lower Rep-Rate Than Traditional IFE

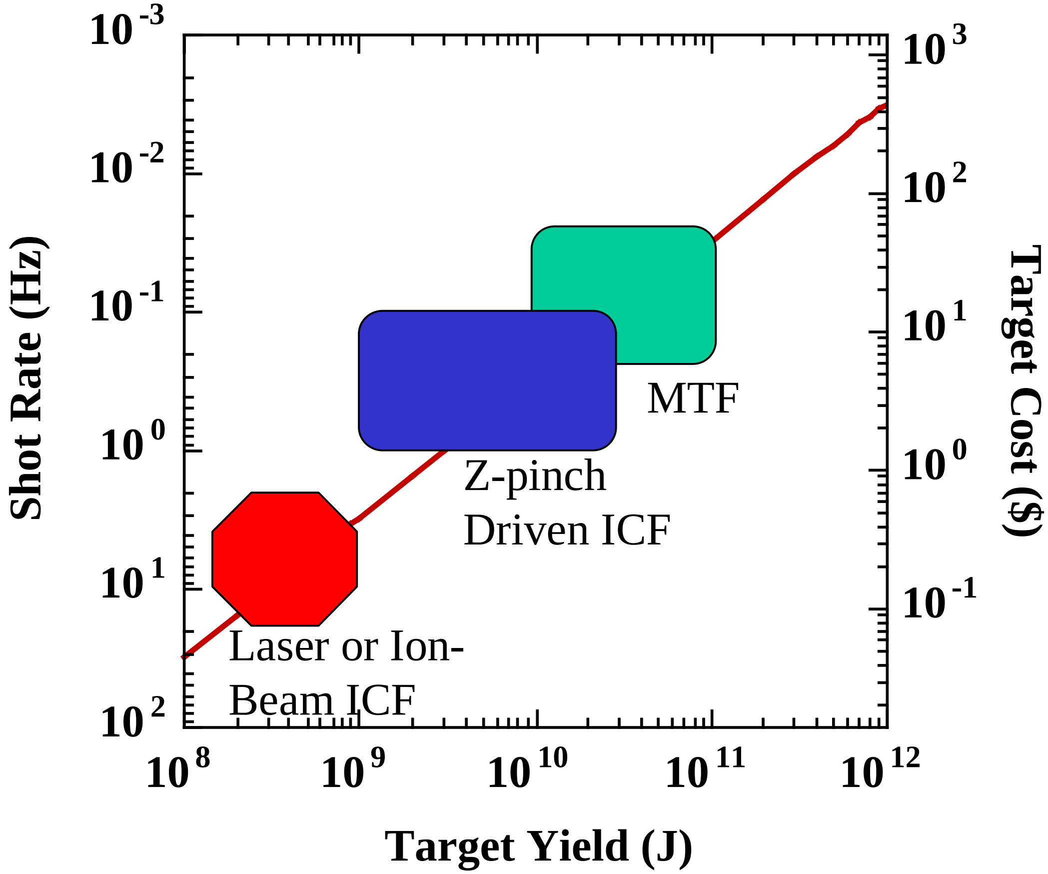


Fig. 3: Shot rate and target cost for a 1 GW_e pulsed fusion reactor. The shot rate is based on a 33% thermal to electrical energy conversion. The target cost is based on a $0.05/kWh energy cost and the assumption that target expenditures make up 10% of the overall cost of electricity.

Schematic of a X-Pinch IFE Power Plant

Fusion Technology Institute University of Wisconsin - Madison

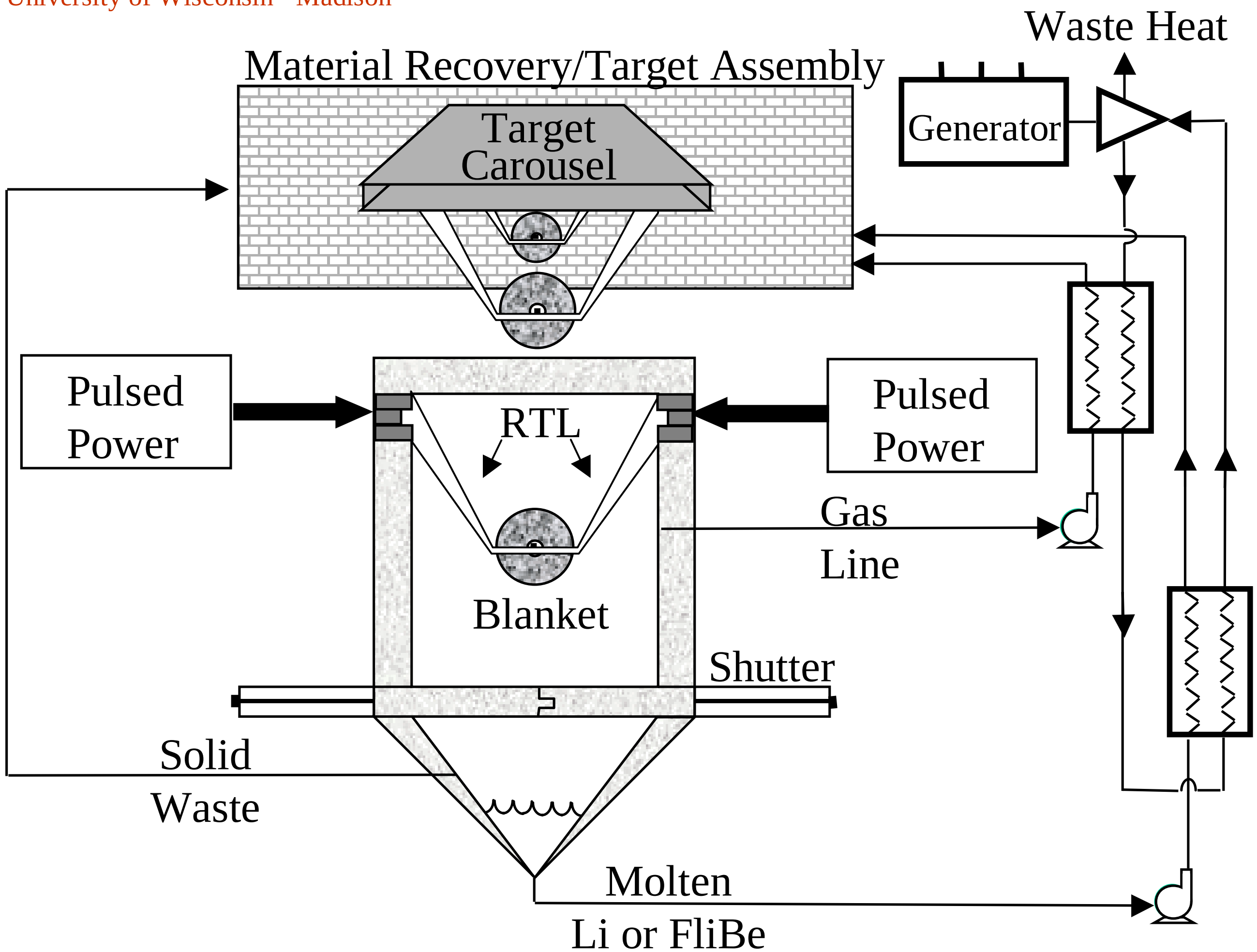


Fig. 4: Schematic of a single ZP-3 module. The pre-pumped, pre-aligned RTL and integrated target hardware is lowered into the chamber before each shot along with the blanket structure. The target energy yield vaporizes or liquefies part of the RTL and blanket which is pumped out of the chamber and circulated through a water or gas heat exchanger. After heat exchange, the material is sent through a tritium extractor and material separator and then recast into a blanket or RTL for a future shot.

Schematic of a X-Pinch IFE Power Plant

Fig. 5: An artist's rendition of the Z-Pinch Power Plant (ZP-3). In this version, the complex contains 12 modules which all share a single material collection and re-manufacturing center. Cartridges (blanket, RTL, and target assemblies) are cast from recycled material and distributed to each module while the post-shot material is pumped back to the manufacturing center for recycling.

Cross-sectional view of the spherical blanket models used in COG.

Fusion Technology Institute University of Wisconsin - Madison

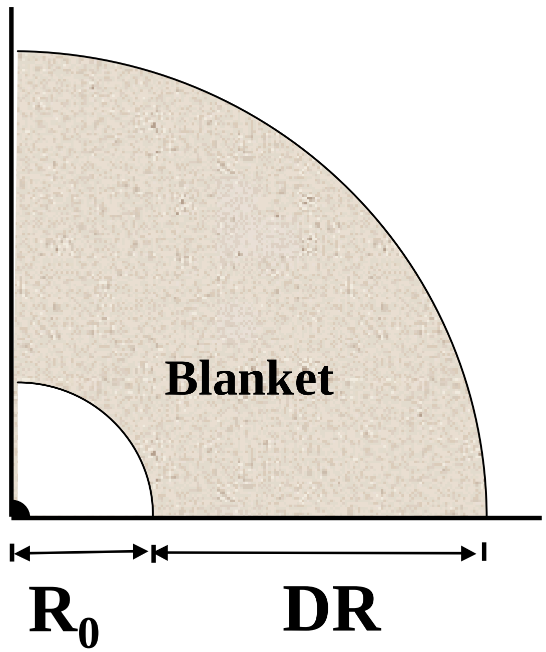


Fig. 7: Cross-sectional view of the spherical blanket models used in COG. Blanket materials which were modeled include natural Li, Pb-17Li, and FliBe.

COG Results for TBR, Energy Conversion and Neutron Shielding of a Z-Pinch IFE Target Chamber

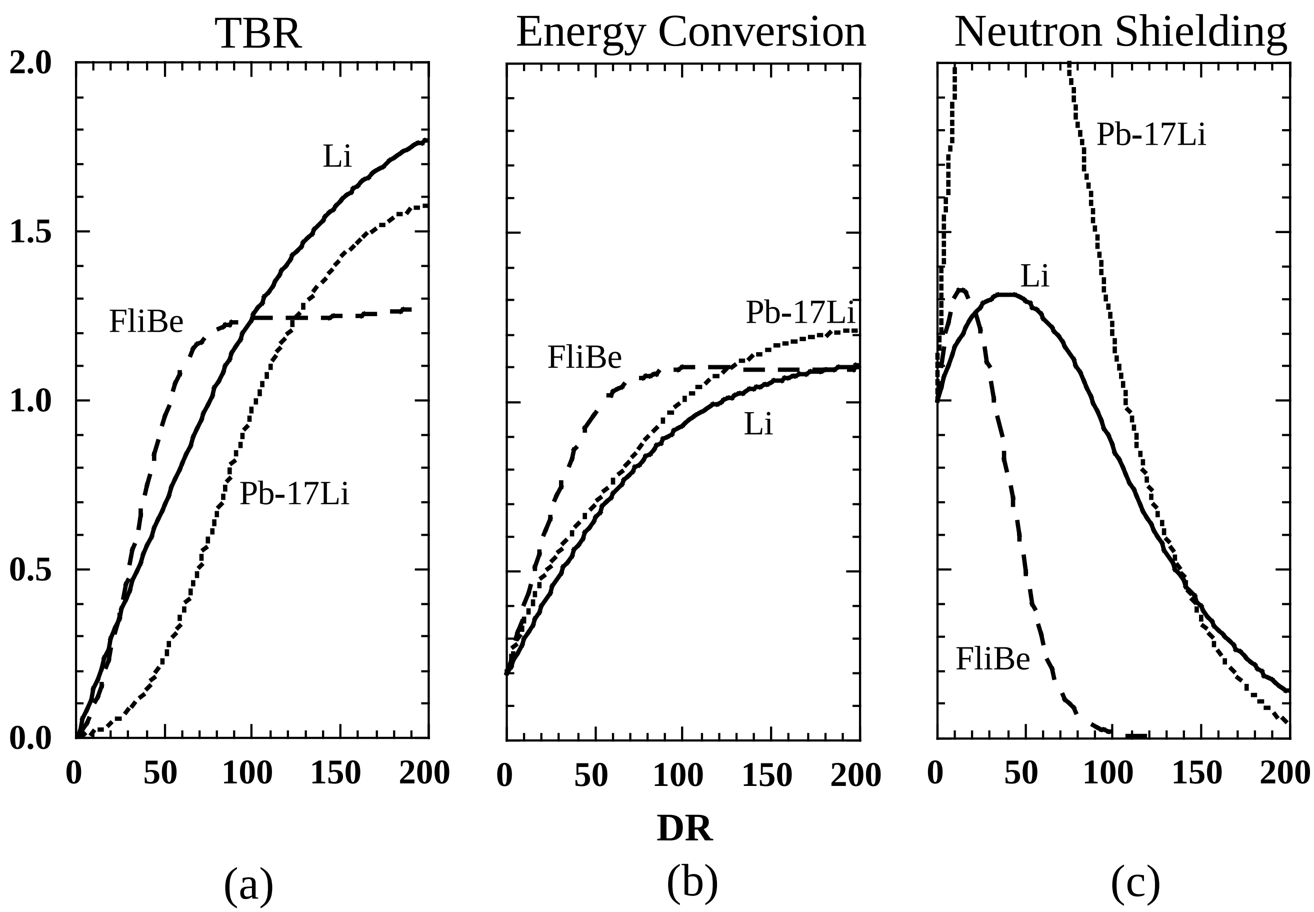


Fig. 8: COG calculations of the (a) tritium breeding ratio, (b) energy conversion ratio, and (c) neutron shielding effectiveness for natural lithium (solid), FliBe (dashed), and Pb-17Li (dotted). The energy conversion ratio is calculated by taking the ratio of the energy deposited in the blanket to the total released fusion energy while the shielding effectiveness is determined by taking the ratio of the COG calculated fluence at the blanket edge to the fluence assuming no blanket structure

Chamber geometry in COG and ALARA models for determining the chamber wall activation

Fusion Technology Institute University of Wisconsin - Madison

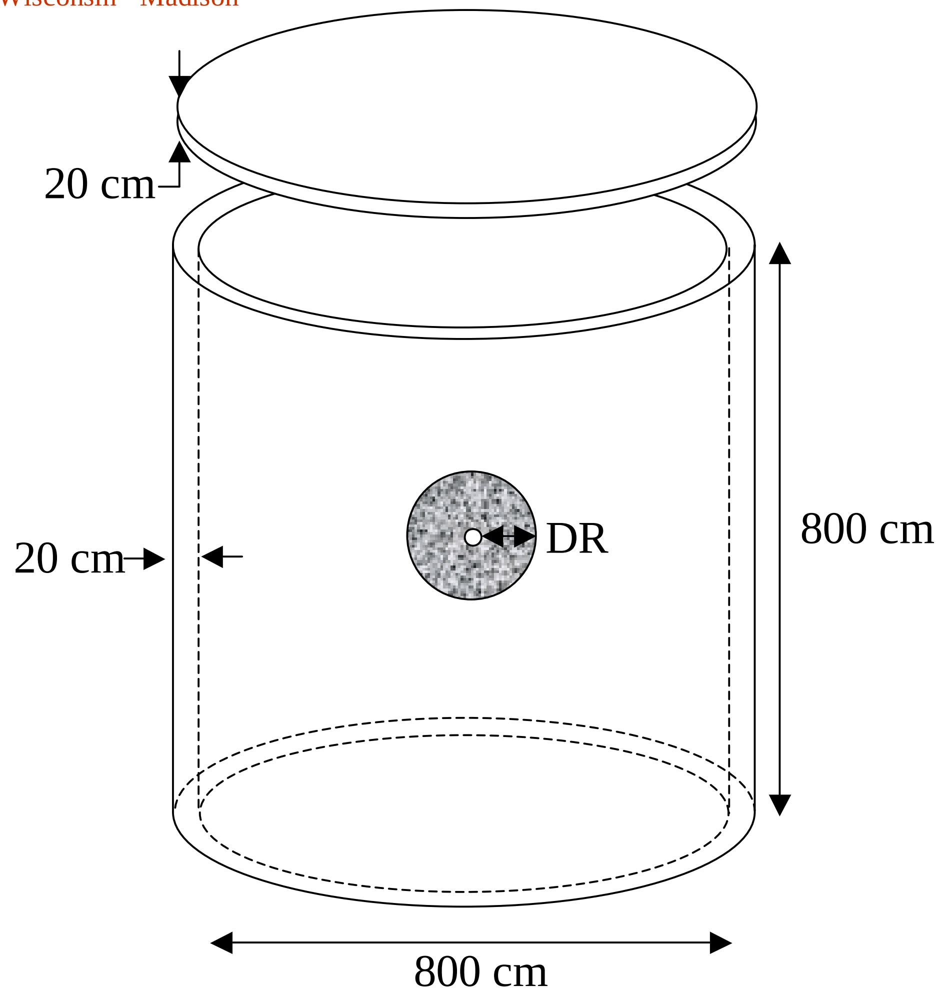


Fig. 10: Chamber geometry in COG and ALARA models for determining the chamber wall activation. SS316, 6061-T6 Al, and 2.25Cr-1Mo steel were considered as wall materials.

ALARA Calculated Chamber Wall Activation

Fusion Technology Institute University of Wisconsin - Madison

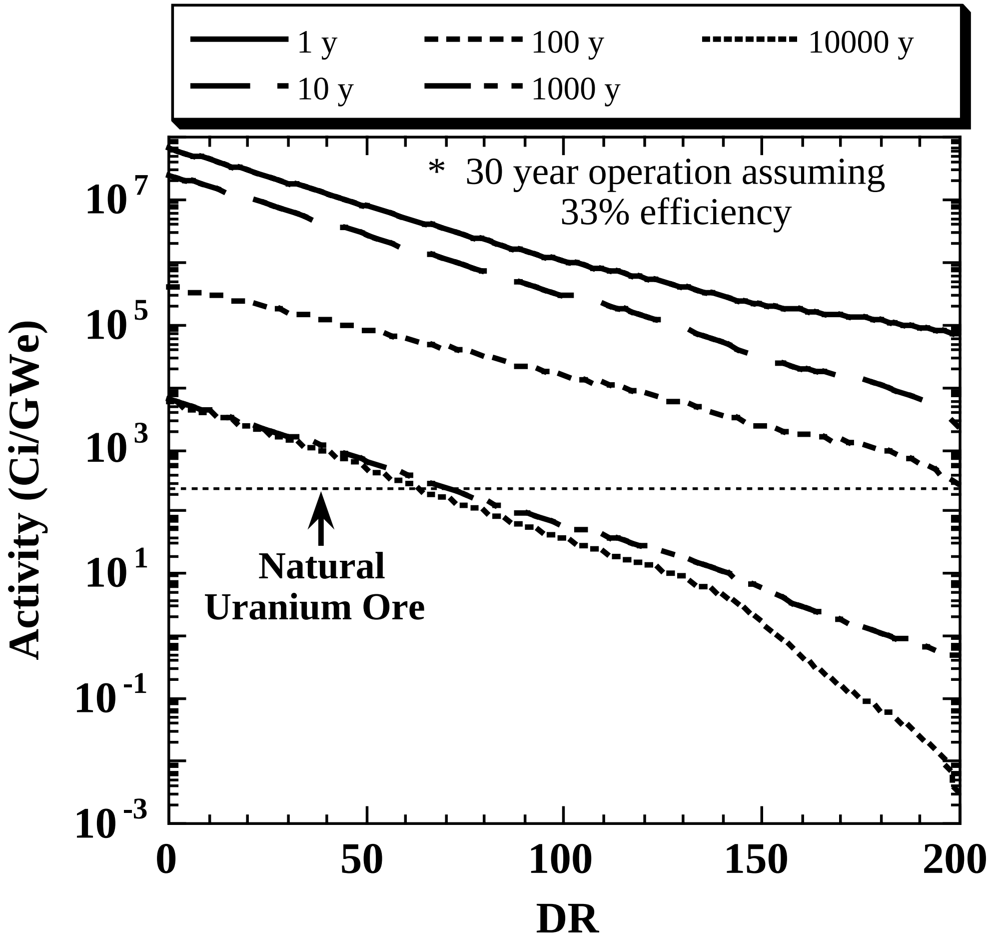
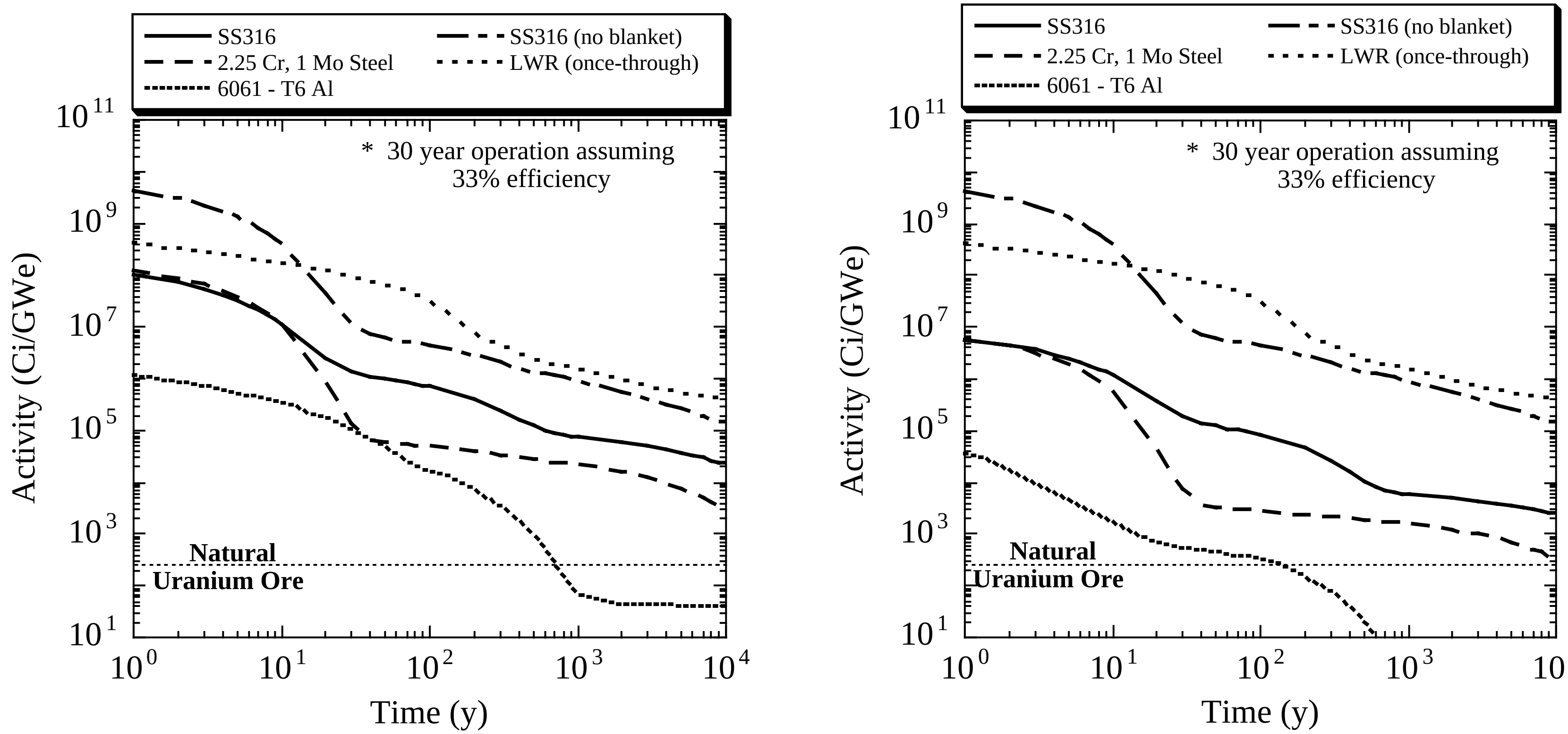


Fig. 11: ALARA calculated chamber wall activation as a function of blanket thickness assuming a cylindrical 6061-T6 Al chamber with a 20 cm wall thickness, a radius of 400 cm, a total height of 800 cm, and 20 cm thick Al end caps. The chamber activity is shown for cool-down periods of 1 year (solid), 10 years (large dashed), 100 years (small dashed), 1000 years (dot dashed), and 10000 years (dotted). These calculations do not include the shielding effect of the RTL structure.

Chamber Wall Activation As Function of Time After Shutdown

Fusion Technology Institute University of Wisconsin - Madison



(a) (b)

Fig. 12: Chamber wall activation as function of time after shutdown following a 30 year ZP-3 lifetime assuming a 30 GJ target yield and a 0.1 Hz shot rate for an (a) 95 cm thick Li blanket and a (b) 80 cm thick FliBe blanket. Chamber wall materials which were studied include SS316 (solid), 2.25 Cr -1 Mo Steel (dashed), and 6061 - T6 Al (small dotted). Also plotted are the activity of an SS316 chamber with no blanket (dot-dashed), and a once-through LWR (large dotted). These calculations were conducted with the ALARA activation code assuming continuous operation with no downtime for maintenance.

Temperature As a Function of Radius From Machine Center for Both Natural Lithium and Flibe

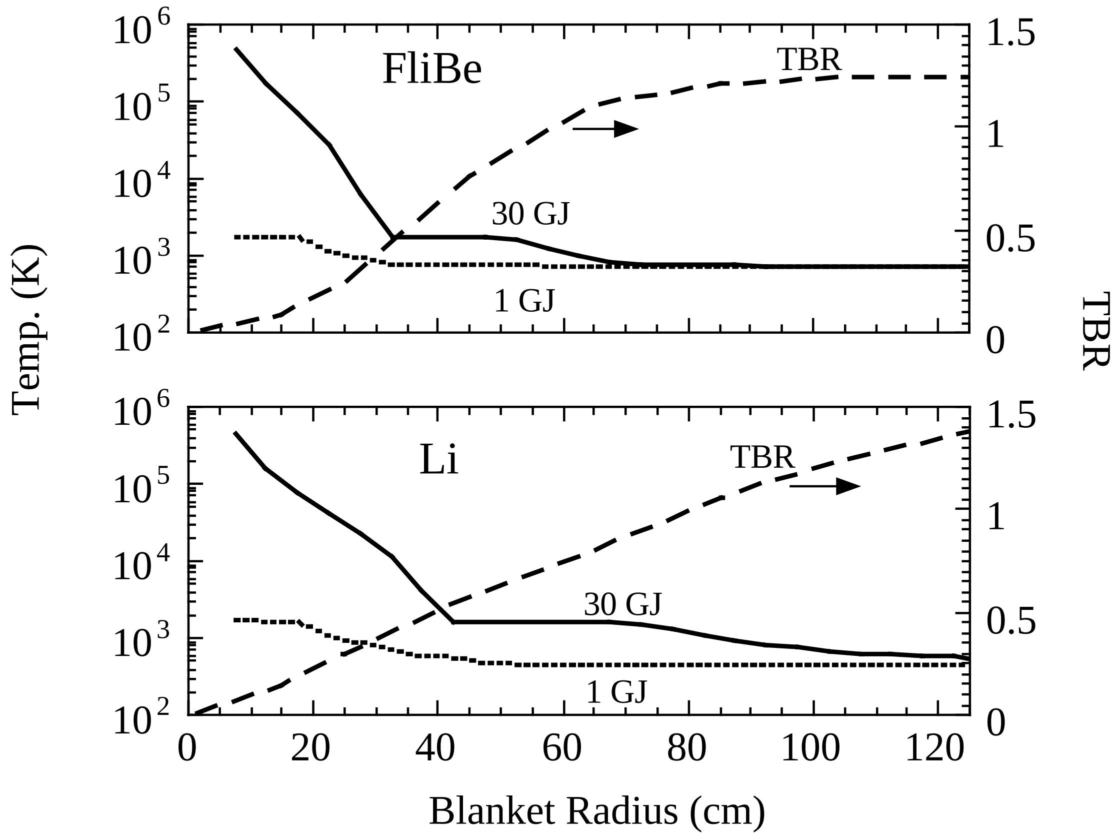


Fig. 13: Temperature as a function of radius from machine center for both natural lithium and FliBe breeder blankets for a 30 GJ target yield (solid) and a 1 GJ target yield (dotted). Both blankets were assumed to have an initial temperature 50 K below their respective melting points (350 K for Li and 742 K for FliBe). The tritium breeding ratios are also plotted as a function of radius (dashed) for reference.

University of Wisconsin Capabilities Related to ICF, IFE, and Pulsed Power

- Chamber and Power Plant Design
- Atomic Physics and Opacity Modeling (EOSOPA)
- Radiation-Hydrodynamics (BUCKY, DRACO, RAGE)
- Structural Mechanics (ANSYS)
- Fragmentation
- Mesh Generation (CUBIT)
- CAD
- Visualization
- Neutronics and Photonics (DANTSYS, MCNP)
- Radiation Effects to Solids
- Activation (DKR-ICF, ALERA)
- Shock Tube Experiments

University of Wisconsin Suggestions for Areas of Work with Sandia National Laboratories

- RAGE support for Hohlraum Experiments
- ALEGRA: debris generation, code validation
- CUBIT grid generation for ALEGRA
- BUCKY target calculations: capsules for z-pinch hohlraums
- Neutronics and Photonics:
- Radiation Effects:
- Safety:
- Z-pinch IFE Power plant design and analysis
- IFE relevant chamber experiments on Z
- Foam Radiation transport experiments and Z
- Structural analysis for Z and Z-upgrade
- BUCKY, ALEGRA and/or RAGE analysis of EOS experimental debris.