Bigger is Better
NLO-Boosted Excimer Lasers for IFE

Canadian Workshop on Fusion Energy Science and Technology
Oct 24, 2023
Conner Galloway

XCIMER ENERGY CORPORATION

Our lasers will scale to **10s of MJs**
with flexible and reconfigurable illumination geometry
and fine-scale spatio-temporal pulse shaping

This enables
simpler and more **robust targets**

This simplifies
thick-liquid-wall chambers (HYLIFE)

Robust path to
inertial fusion energy

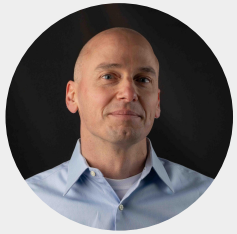
Our team

Conner Galloway
CEO, Founder

MIT Nuclear Engineering
Innoven, Alivecor

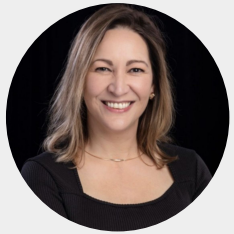
Alexander Valys
President, Founder

MIT EECS
Innoven, Alivecor, Meta



Benjamin Wheeler
VP Strategy, Founder

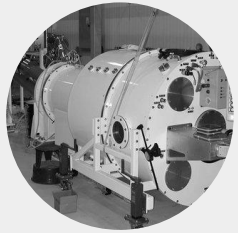
Dartmouth Physics, UoR Optics, Berkeley MBA
HP, In-Q-Tel



Dr. Susana Reyes
VP Chamber and Plant Design

Deputy Project Dir. at US ITER.

UNED Nuclear Engineering



Doug Weidenheimer
Director of Pulsed Power

40 years of experience in pulsed power engineering.

L3Harris

Dr. Cyrus Herring
Director of Laser Engineering

Laser and Optical Physics, Industrial Production Facilities for Optical Systems.

University of Illinois

Dr. J. Gary Eden
Laser & Optical Science

Prof. of Laser and Optical Physics at University of Illinois, 40 years experience in excimer physics.

We have experienced collaborators and advisors

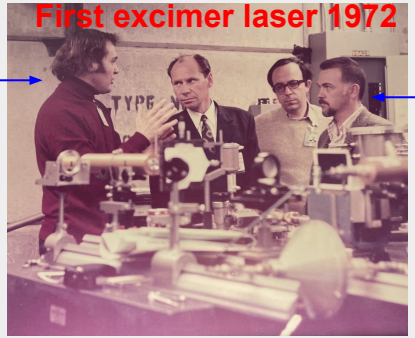
Dr. Bedros Afeyan
LPI, nonlinear optics, ML
Theory and Computation Lead

Dr. Robert Fedosejevs
Experimental nonlinear optics, LPI
Ultrashort laser physics
University of Alberta

Dr. Tom Mehlhorn
Plasma physics, KrF lasers
Technical Advisory Board

Dr. Cliff Thomas
Target Design
University of Rochester

Dr. Allan Offenberger
Nonlinear Optics
Technical Advisory Board



Dr. Paul Hoff
KrF Kinetics
Program Management
Technical Advisory Board

Dr. William Krupke
Technical Advisory Board

Dr. Joseph Mangano
KrF Laser Kinetics and Applications
Technical Advisory Board

Michael Tobin
Chamber and Neutronics
LLNL, MDA, JAPL, West Point

Dr. Wayne Meier
Chamber and Economics
40 years exp. at LLNL

Robert Lundy
VP, Defense
5-time startup CEO

A National Team of Institutions to Accelerate our Efforts

LABORATORY FOR LASER ENERGETICS
UNIVERSITY OF ROCHESTER

Dr. Cliff Thomas, Dr. Rick Spielman, Dr. Walter Shmayda

Fuel capsule design, tritium handling & pulsed power

Lawrence Livermore National Laboratory

Dr. Allison Christopherson, Dr. Omar Hurricane, Dr. Max Tabak.

Fuel capsule design and simulation, nonlinear optical modeling.

Los Alamos NATIONAL LABORATORY

Dr. John Kline, Dr. Mark Schmitt

Fuel capsule design and simulation.

Westinghouse

Cory Stansbury, Edward Lahoda

Thermal cycle, electrical generation and balance-of-plant.

NAVAL RESEARCH LABORATORY WASHINGTON, DC

Dr. Matthew Wolford, Dr. Dan Gordon, Dr. Frank Hegeler, Matthew Myers, Dr. Joe Schumer

Excimer laser design and engineering, nonlinear optical modeling.

Savannah River National Laboratory®

Dr. Christopher Dandeneau, Dr. Brenda Garcia-Diaz

Tritium handling.

OAK RIDGE National Laboratory

Dr. Kevin Robb, Jeff Ullreich

Flibe chemistry and handling.

Massachusetts Institute of Technology

Prof. Akintunde Akinwande

Electron beam diode materials.

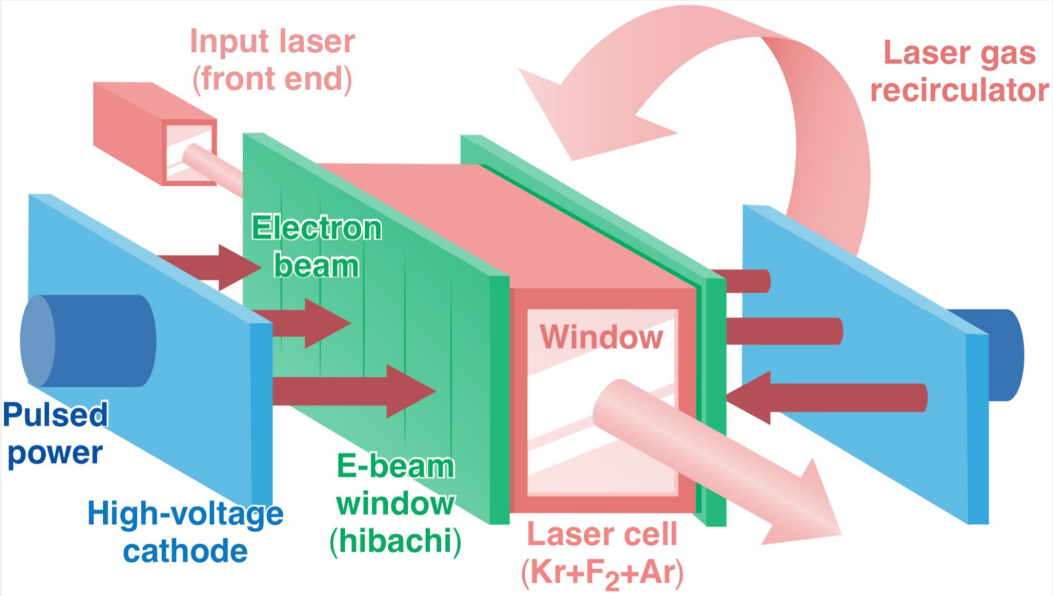
GENERAL ATOMICS

Dr. Neil Alexander

Capsule fabrication, fueling and injection.

Basic elements of a KrF laser

$$\text{Energy} + (Kr + F_2) \rightarrow (KrF)^* + F \rightarrow Kr + F_2 + h\nu \ (\lambda = 248\ \text{nm})$$



Short upper state lifetime	**~3 ns**
Low saturation fluence	**~2 mJ/cm^2**

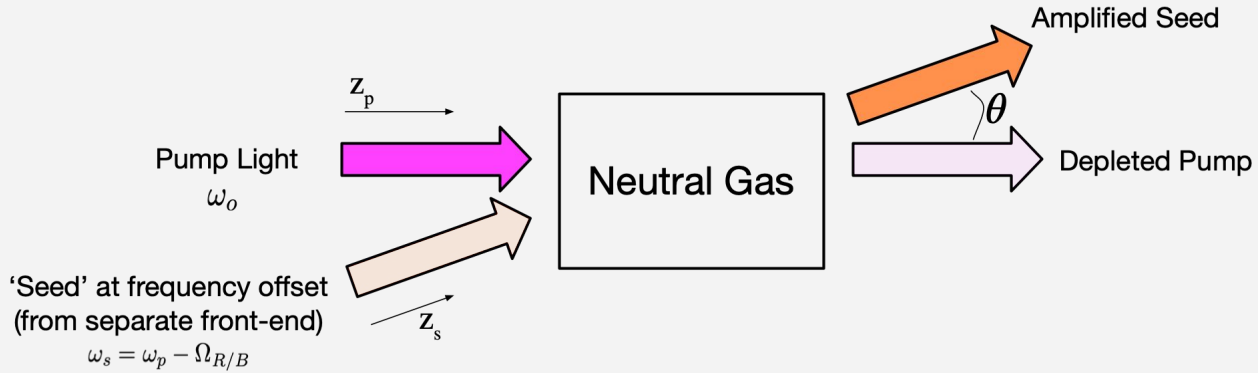
→ NOT a storage laser, must be continually pumped

High saturation intensity	**~1 MW/cm^2**
Output fluence	**~10 J/cm^2**
Pulse length	**~2 μs**

→ Optical energy must be **"pulse compressed"** for laser fusion

Beam fluence amplification and temporal compression achieved using nonlinear optics (NLO)

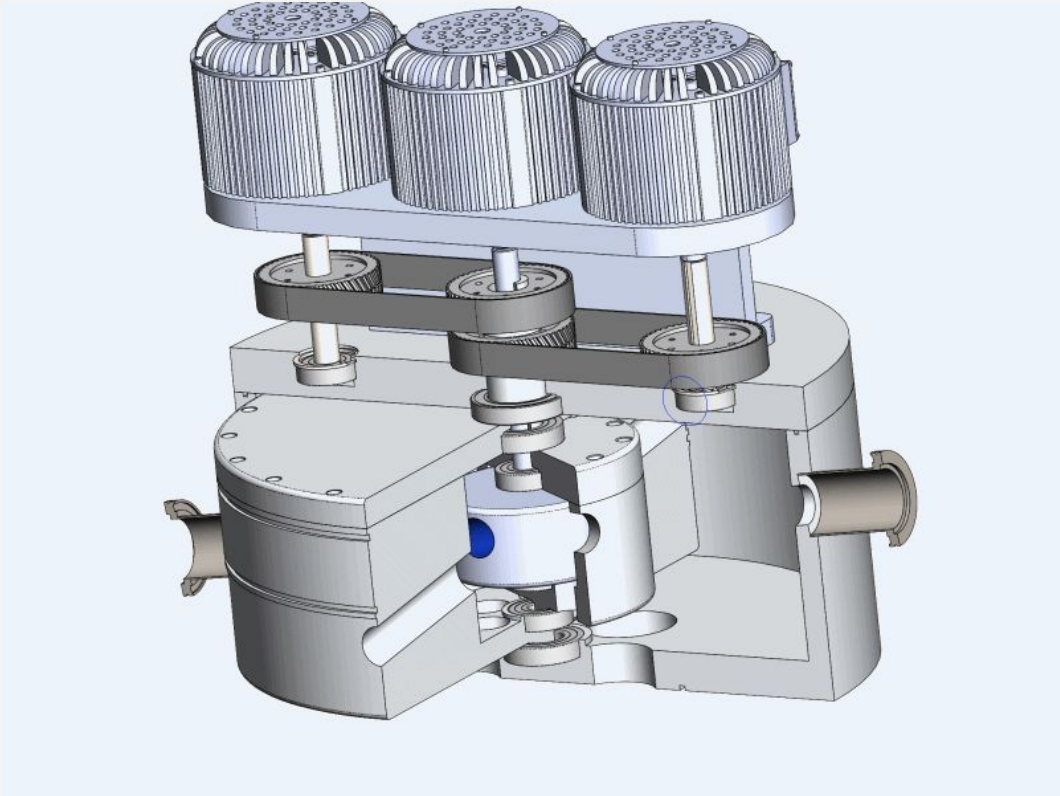
⇒ Stimulated Raman and Brillouin Scattering



Two light waves at slight frequency offset interact with excitation of gaseous medium:
Brillouin - acoustic phonon
Raman - molecular vibration / rotation

Result: seed pulse is amplified, pump pulse depletes: **energy transfer from pump to seed**

We propagate very-high-fluence laser pulses from gas to vacuum *without a window*



Phoenix laser testbed facility - Q4 2025

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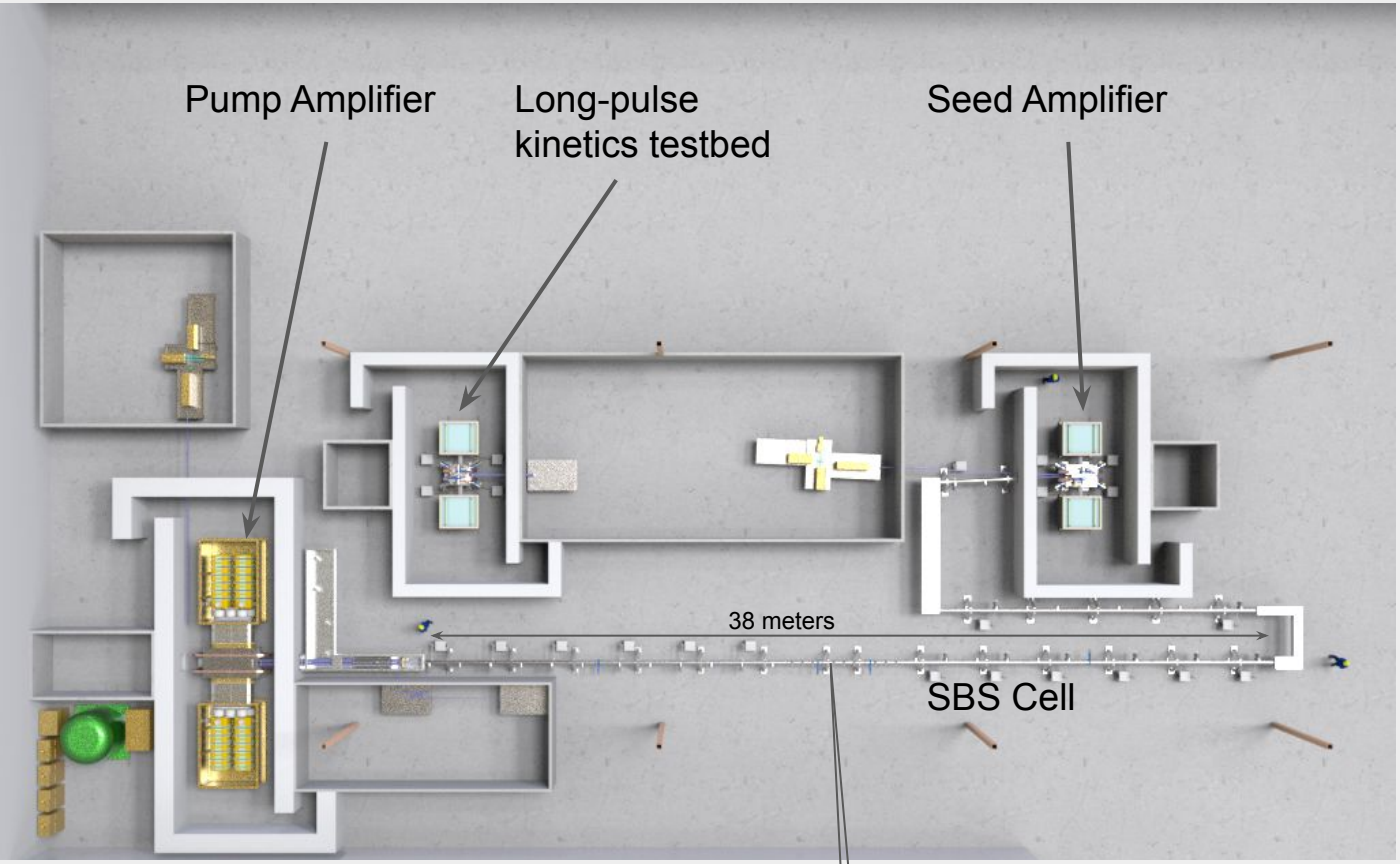
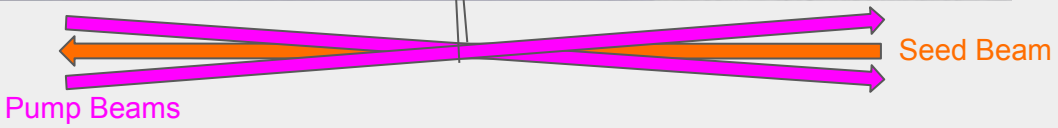




Demonstrate SBS compression in IFE-relevant parameter regime (SBS gain, saturation, beam size, nonlinear thresholds)

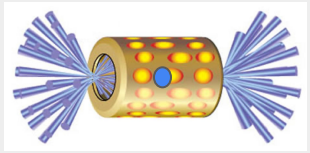
Imaging and AO through SBS, form target illumination pattern

Vacuum shutter

STUD pulses with arbitrary waveform generation through SBS

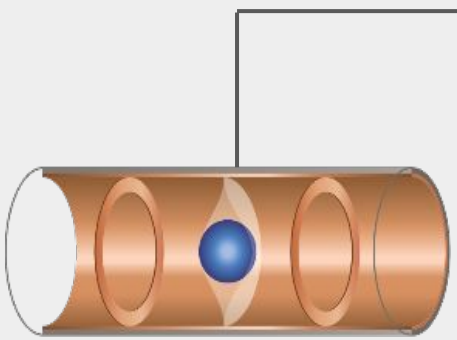
Utilizing only two beams, we will directly illuminate a larger target and couple over 30x more energy than NIF

XCIMER



1 cm

NIF Target
~0.22 mg of DT
~250 kJ coupled



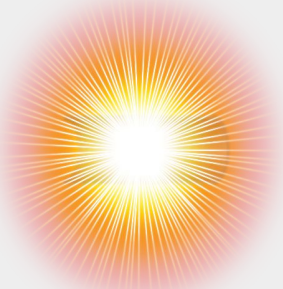
3.2 cm

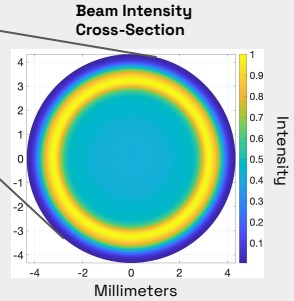
Xcimer Target
>20 mg of DT
>8 MJ coupled

1. First pulse, *indirect drive* illumination

2. Subsequent pulses, *direct drive* illumination (>90% of laser energy)

3. Ignition and burn





Ring-peaked laser intensity allows **spherical implosion** from **two-sided illumination**

4. **fusion burst yields >200x laser energy**
fuel burnup ~30%

It takes a village to innovate in IFE target design

Dr. Cliff Thomas ***(LLE)*** *has already initiated work with Xcimer under an INFUSE award in spring 2022. Dr. Thomas was a target designer at NIF for 10 years and initiated the bigfoot campaign which was a key step along the path to the August 2021 ignition and prior burning plasma shots on NIF. He is a designer at LLE on the direct drive implosion optimization campaign.*

Dr. Max Tabak ***(LLNL)*** *has broad experience in inertial fusion and was on the HALITE team that put to rest fundamental questions about the basic feasibility of achieving high gain in laboratory experiments. He was the co-inventor of the Fast Ignition concept and continues to contribute to its theoretical development. He will investigate both direct and indirect-drive targets utilizing two-sided illumination.*

Dr. Omar Hurricane *is Chief Scientist for the* ***LLNL*** *ICF Program and recipient of the Edward Teller Award. He led the team that developed the "basecamp" strategy leading to improved ignition performance. He will pursue gas-shell and hybrid-indirect-direct and pure direct-drive targets utilizing two-sided illumination.*

Dr. Alison Christopherson *is a Staff Scientist at* ***LLNL*** *and recipient of the Marshall N. Rosenbluth Outstanding Doctoral Thesis Award from the American Physical Society. She will contribute to exploration of the high-energy target design space enabled by the ASPEN architecture.*

Dr. Mark Schmitt *of* ***LANL****'s Plasma Theory and Applications group has successfully led many HED programs including recent experiments on NIF and will analyze the Hybrid design and alternatives.*

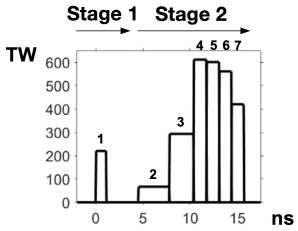
Dr. John Kline*,* ***LANL****'s Fusion Energy Science Program manager, will also contribute to target design investigation using LANL tools.*

Dr. Neil Alexander *is a Senior Scientist at* ***General Atomics*** *with extensive experience around ICF target fabrication for experiments and volume production concepts. He will lead development of a target fabrication process for the Xcimer experimental campaigns, FPP and commercial deployment.*

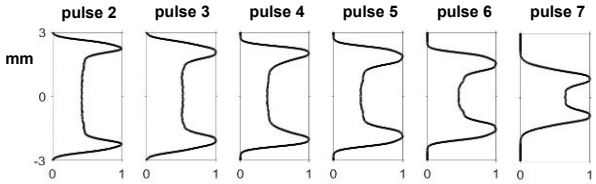
No substitute for peer review and competition, access to existing tools, prior experience

Hybrid targets have adequate implosion symmetry in simulation, and show scale is *highly* beneficial to margin*

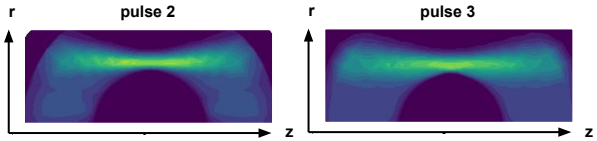
Tuned pulse sequence



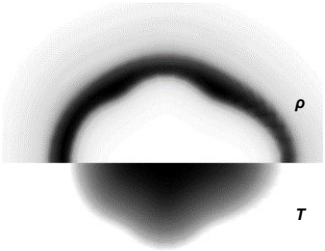
Optimized laser profiles



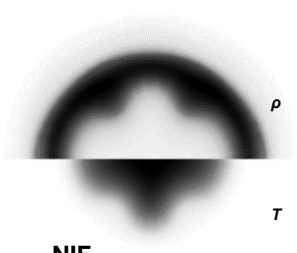
Local Total Intensity versus position

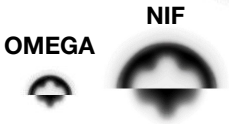


Hybrid with alphas ON
peak CR at 15.74 ns



Hybrid with alphas OFF
peak BR at 15.86 ns

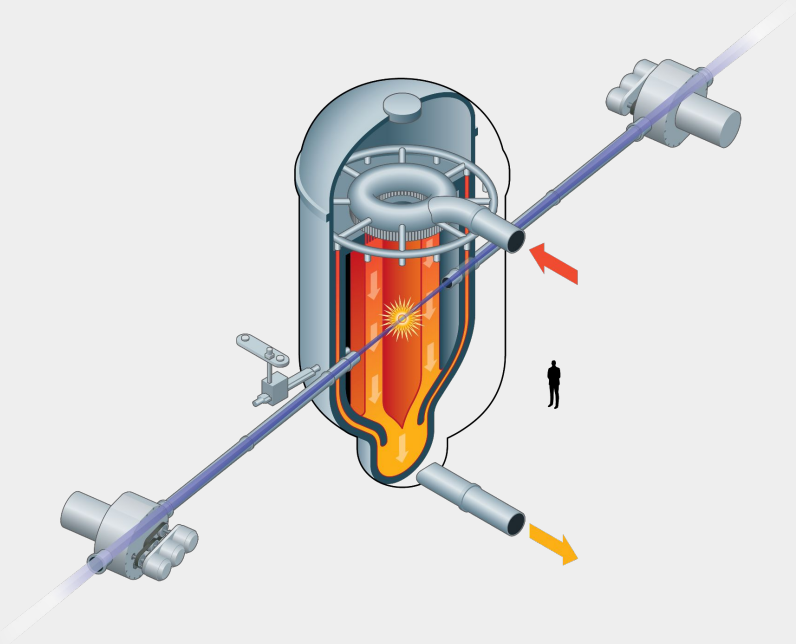




- ***4 MJ KrF reference design relative to NIF HyE:***
  - ***Stagnation pressure reproduced at adiabat 5-6***
  - ***Imploded mass (and areal density) exceeded by 12x (3x)***
  - ***Maximum gain exceeded by factor of 30-36***
  - ***Physical scale larger by 2.3x***
  - ***Lawson and alpha-heating metric χ ~ 2x larger***
- ***Target ignites if no-alpha yield > 1/10 of 1-D ($\chi \sim Y^{0.3}$)***
- ***Hotspot ρR > 0.3 g/cm^2 even if 9/10 of mass is dudded***
- ***Velocity (laser power) exceed threshold to ignite by 1.3x (1.5x)***
- ***Target goes off going in at modest CR ~ 19***

**Hybrid direct drive with a two-sided ultraviolet laser, paper submitted to PRL*

HYLIFE chamber advantages mitigate fusion challenges



Waterfall of FLiBe: coolant, x-ray/debris absorber, neutron moderator, and tritium breeding material all-in-one

Liquid FLiBe directly protects first wall from x-ray/debris and 14 MeV neutrons
➢ *Key advantage over other fusion approaches*

No “first wall problem” - structural wall can last entire 40-year-design lifetime of the plant.

Lower activation and waste production compared to conventional DT fusion approaches

Mitigating challenges of prior HYLIFE designs (LLNL):

- Only 0.25 - 1 Hz rep rate
- Large 50 m stand-off
- Only two beam ports ~10 cm across
- No jet oscillation required
- 30 m of 1 atm gas protects final optics

Fusion energy will ignite an era of prosperity and abundance.

JOIN US
info@xcimer.energy

We are building a team and technology to commercialize inertial fusion energy.