LIFE

LIFE Laser Overview

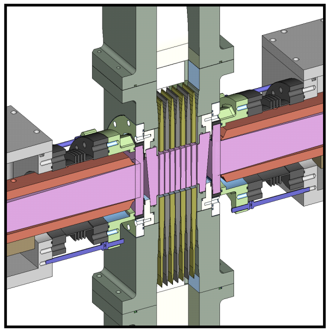
Presentation to
National Research Council's review on
"Prospects for Inertial Confinement Fusion Energy Systems"
January 29, 2011

Andy Bayramian, Bob Deri, et al

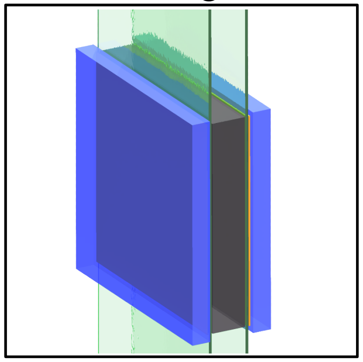
LLNL

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344

LIFE laser architecture attributes

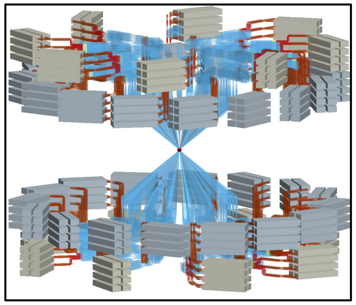


- **Provides ~18% efficiency at high repetition rate (16 Hz)**
  - — Diode pumped, Helium cooled amplifiers
  - — High efficiency harmonic conversion using pulse splitting



- **Will be built with existing materials**
  - — Glass slabs: thermal birefringence compensated by architecture
  - — DKDP Pockels cell: polarization switching minimizes heat load

- **Designed for high availability operation**
  - — Robustness: Low 3ω fluence operation, no plasma electrodes
  - — Headroom: beamline power to meet operational requirements
  - — Optics preparation to mitigate damage



- **Suitable for remote (off-site) manufacturing**
  - — Modular beamlines permit hot-swapping
  - — Separation of laser manufacturing & power generation operations

The LIFE laser builds from a long line of glass laser systems developed for the ICF program

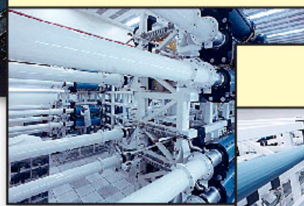
Janus, 1973

100J IR

Argus, 1976

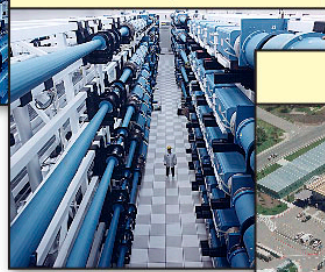
1kJ IR

Shiva, 1977



10kJ IR

Nova, 1984

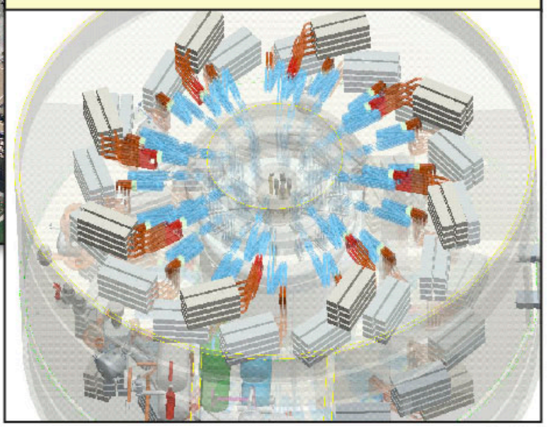


30kJ UV

NIF, 2009

4.1 MJ IR, 1.8 MJ UV

LIFE



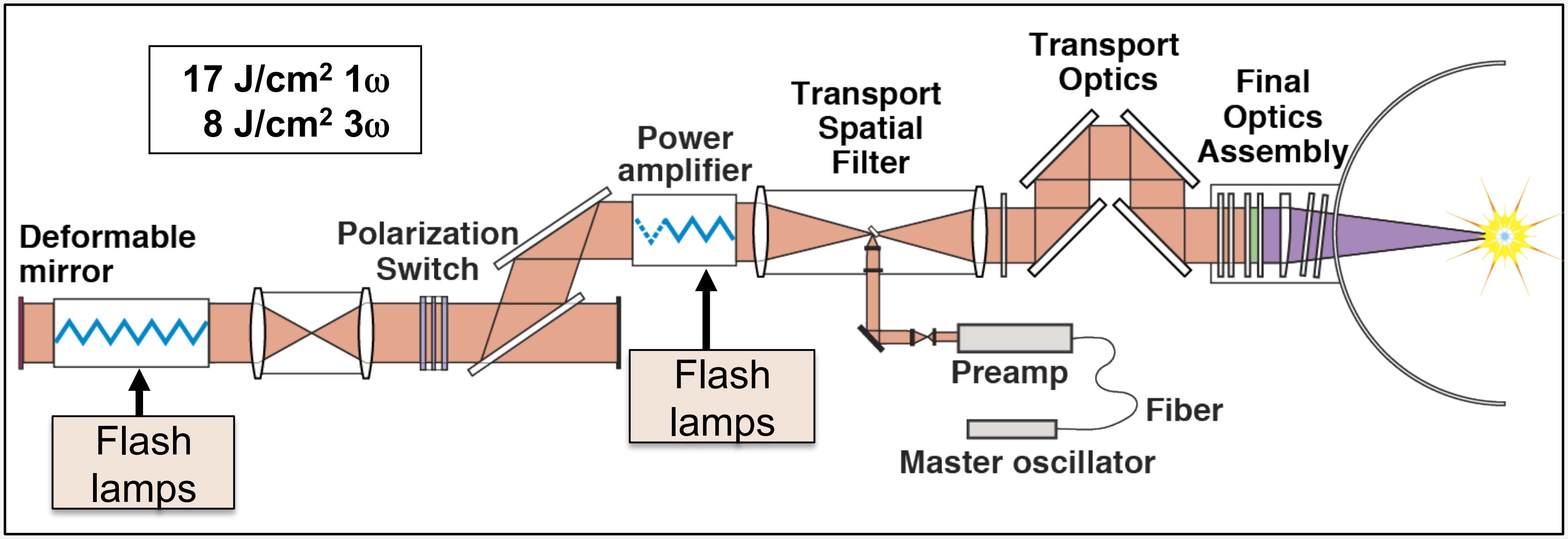
3.1 MJ IR, 2.2 MJ UV

Laser Bay

00ABC/abc • NIF-0508-14729s2

The NIF laser provides the single-shot baseline

NIF Beamline



Master oscillator / Preamplifier / Multi-pass architecture

Passive optical system performance

Line Replaceable Unit (LRU) methodology

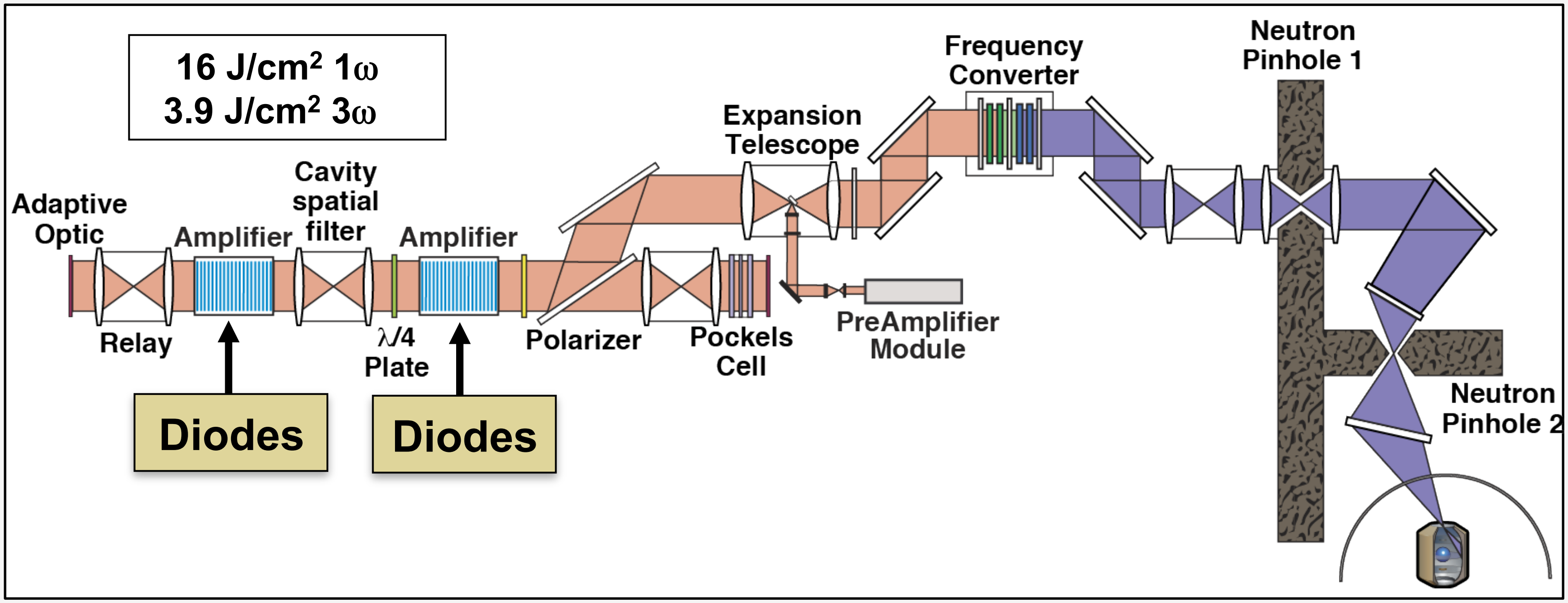
Whole-system design, construction, commissioning and operation

Optics production and performance experience base

Coupling demonstration to full-scale IFE target

LIFE combines the NIF architecture with high efficiency, high average power technology

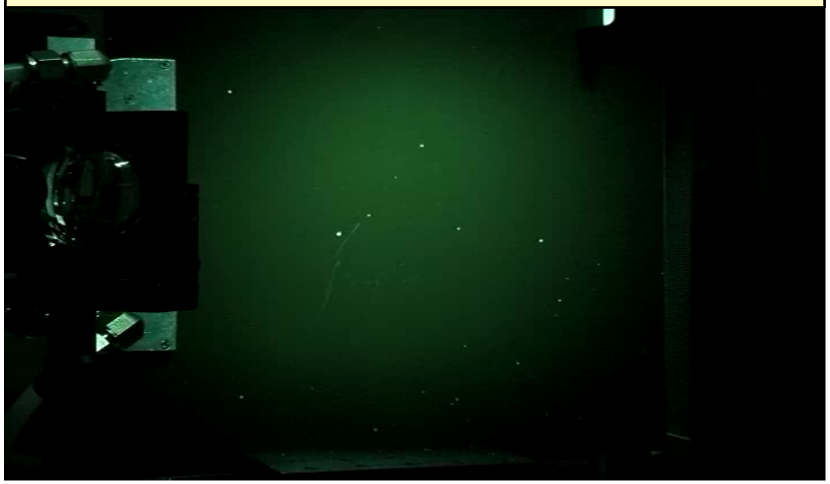
LIFE Laser 1ω Beamline Architecture



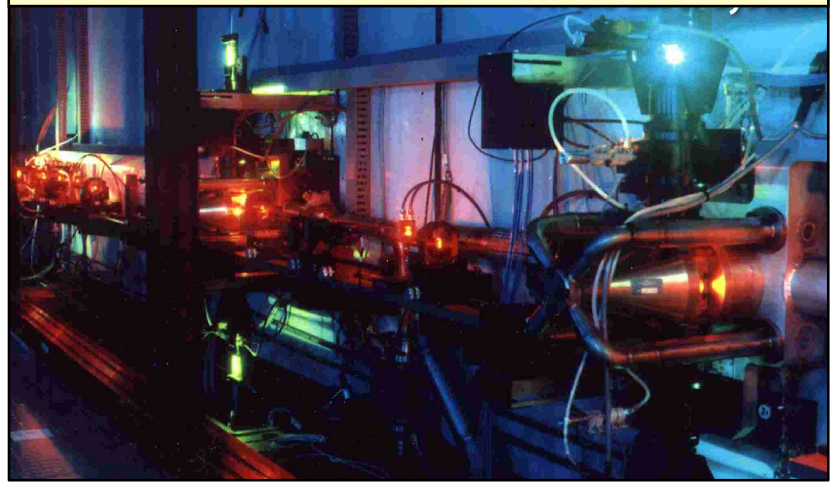
Diode pumps	→	high efficiency (18%)
Helium cooled amps	→	high repetition rate (16 Hz) with low stress
Normal amp slabs	→	compensated thermal birefringence, compact amp
Passive switching	→	performs at repetition rate
Lower output fluence	→	less susceptible to optical damage

LLNL average power lasers have been proving grounds for several key LIFE technologies

25 kW high average power laser



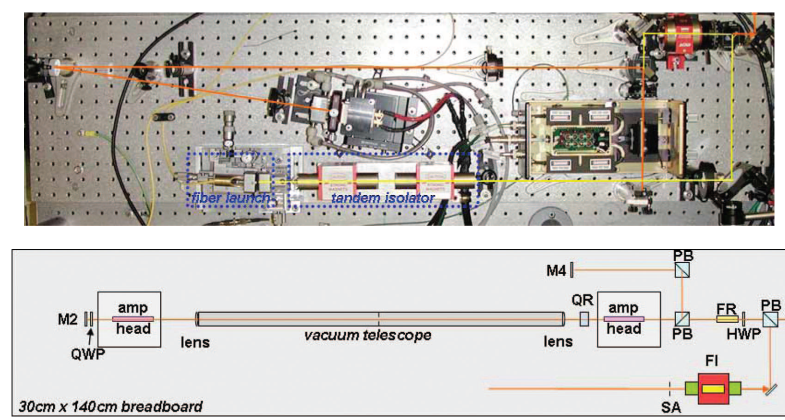
AVLIS 24/7 operational laser



600W, 10 Hz Mercury Laser

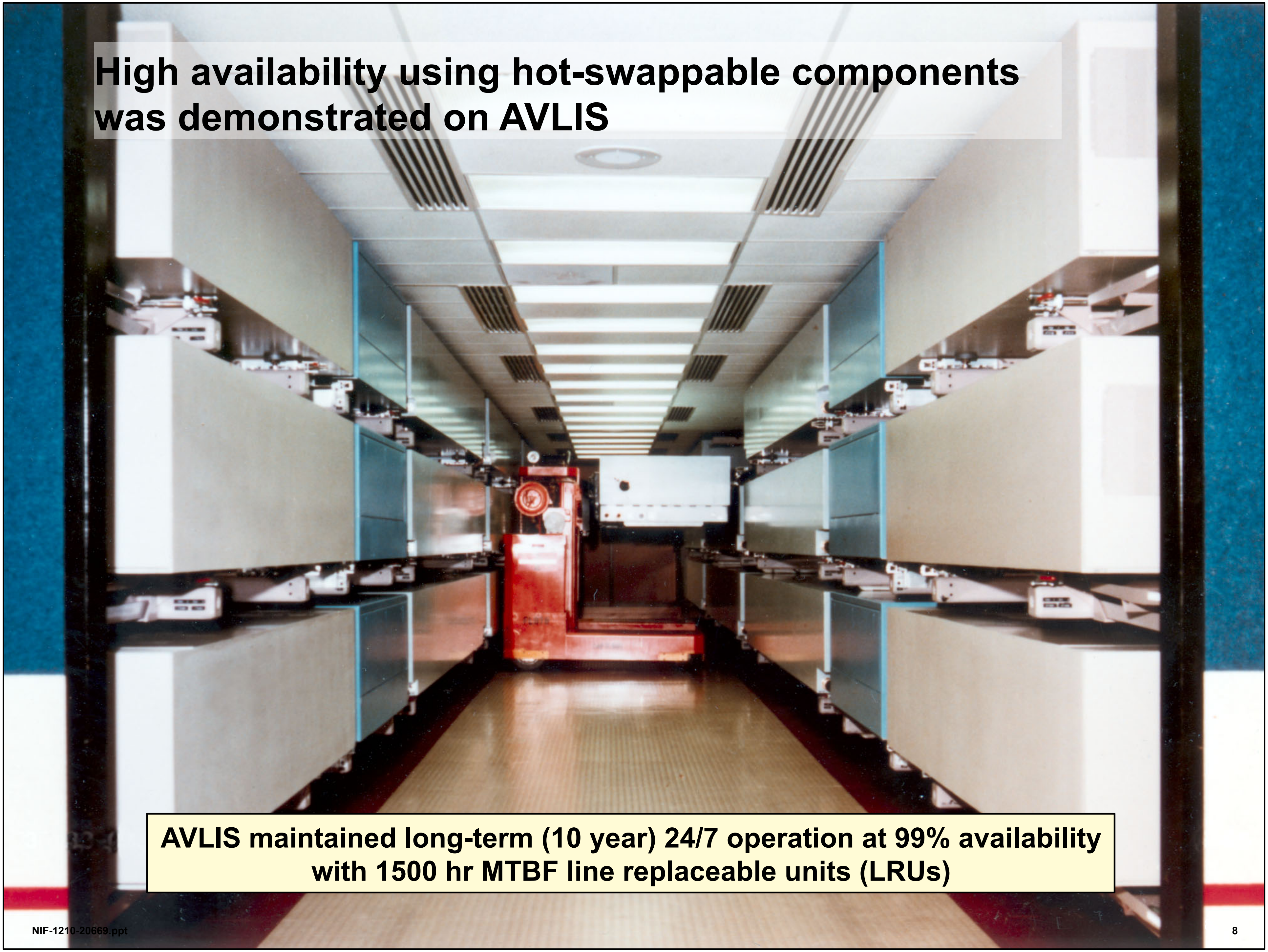
A.J. Bayramian et. al, *Fusion Sci. Tech.* 52, 383 (2007)

300 Hz, 38 W Pulse Amplifier



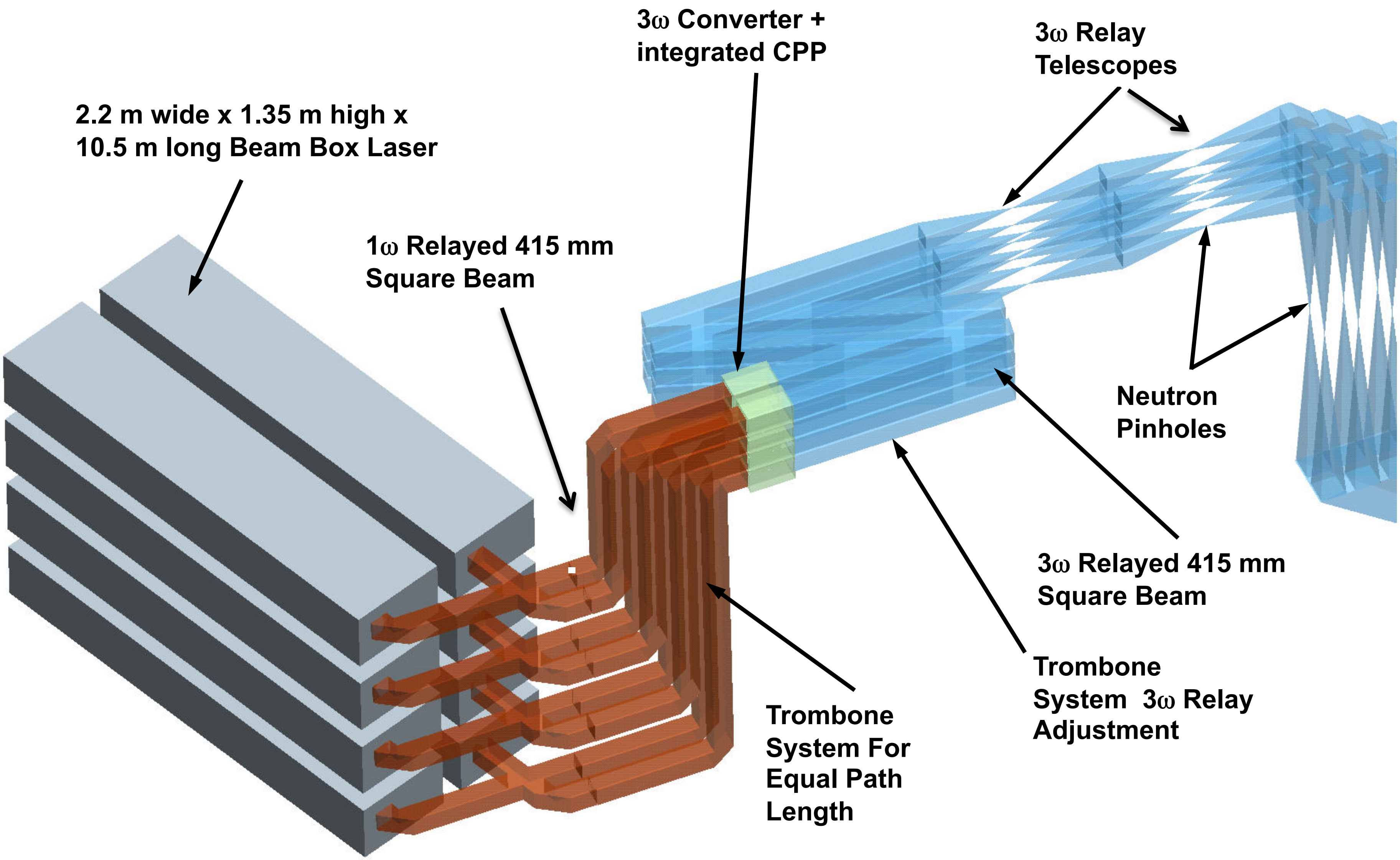
J. Honig, et. al, *Appl. Opt.* 46, 3269 (2007)

High availability using hot-swappable components was demonstrated on AVLIS

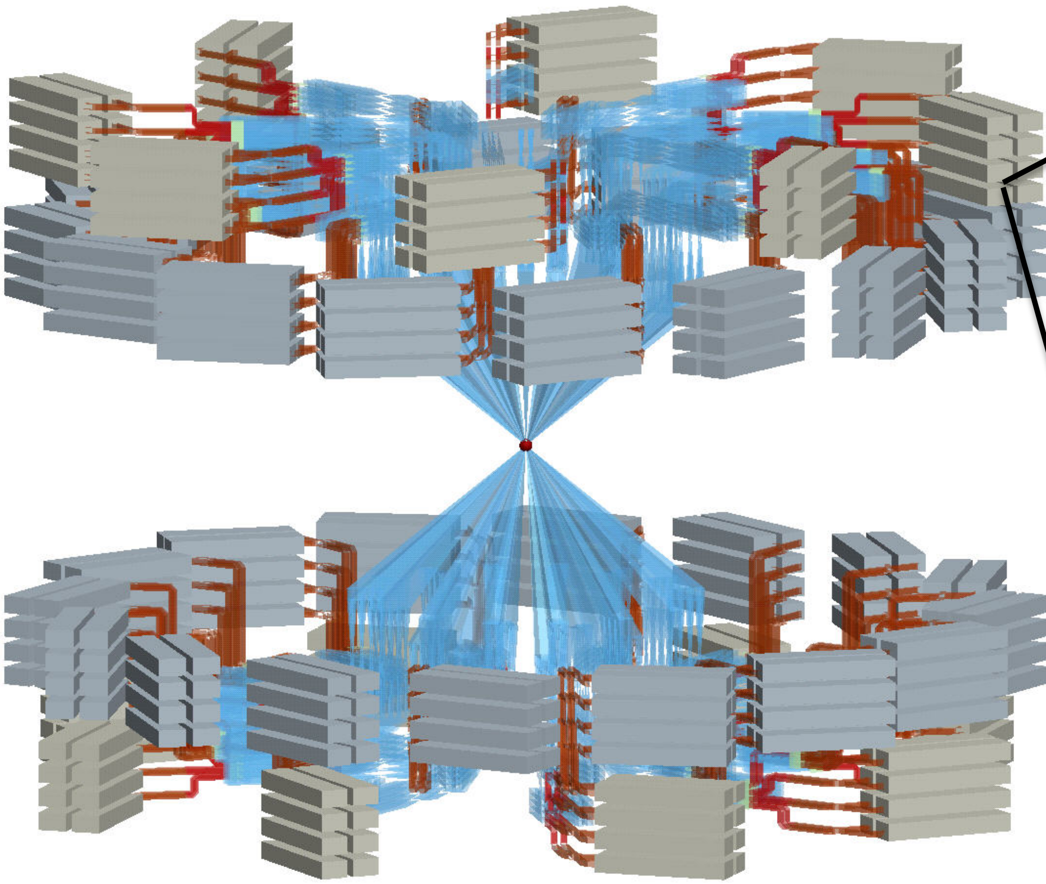


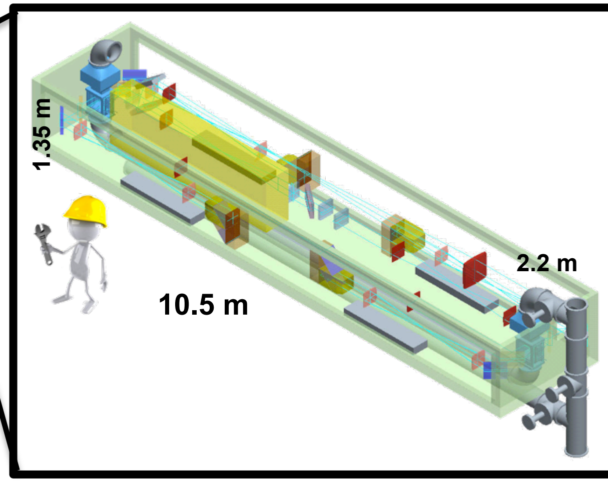
AVLIS maintained long-term (10 year) 24/7 operation at 99% availability with 1500 hr MTBF line replaceable units (LRUs)

End-to-end simulations follow the 1ω beam path to the harmonic converter and through the 3ω relays



The modular laser system allows realistic reliability specifications, affecting plant availability by <1%



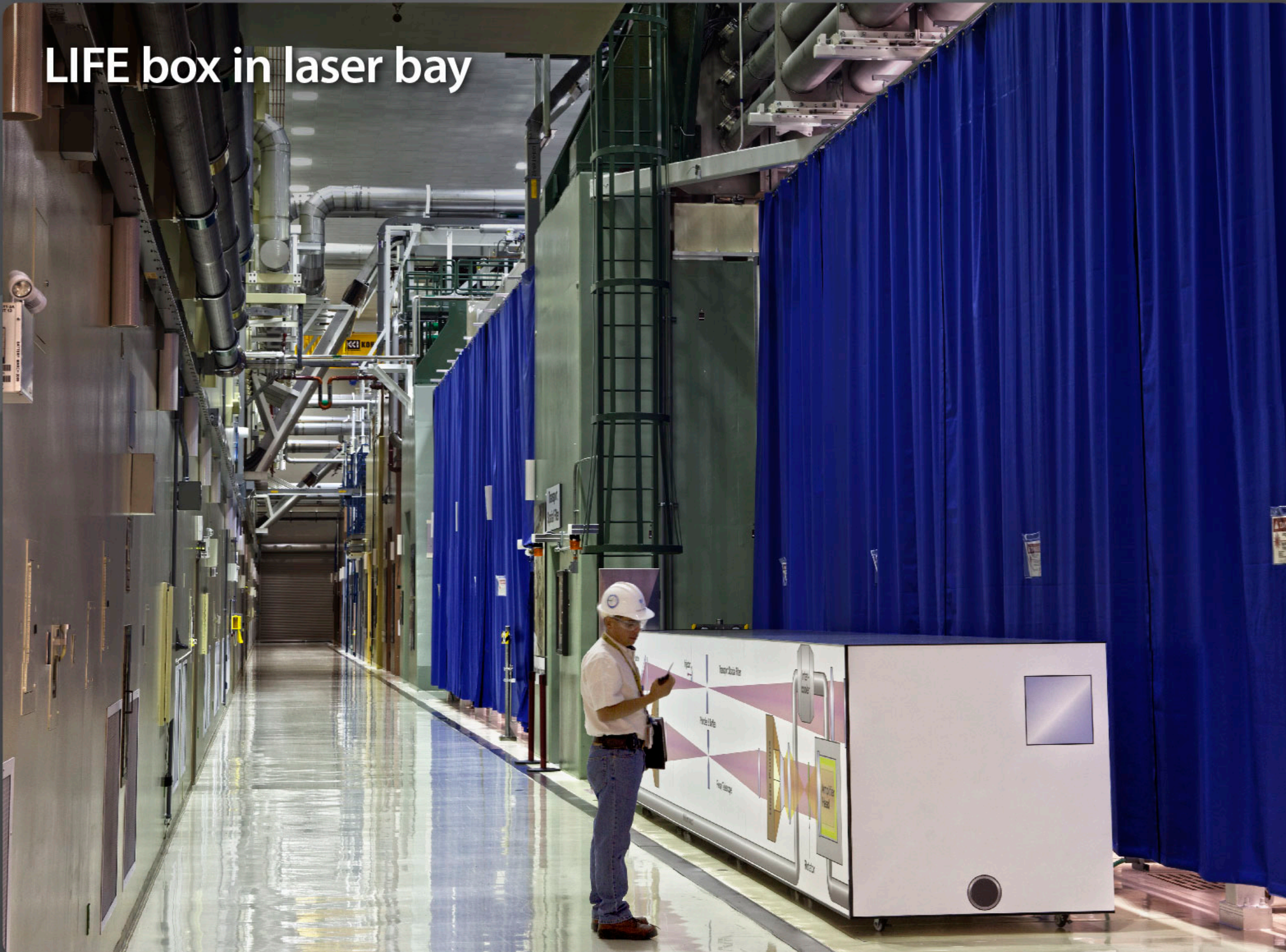


Dual neutron pinhole allows hands-on maintenance in laser bay

1ω beamline-in-a-box

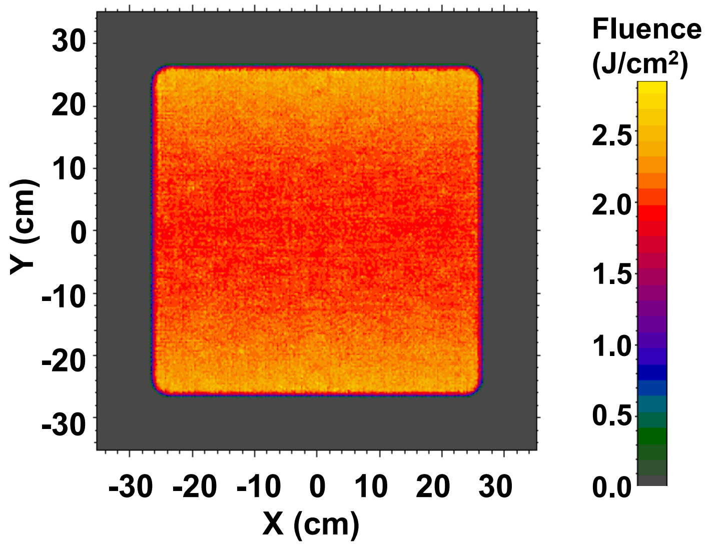
- Truck-shippable
- Efficient
- Damage resistant
- Affordable
- Reliable
- Target Shooter

LIFE box in laser bay



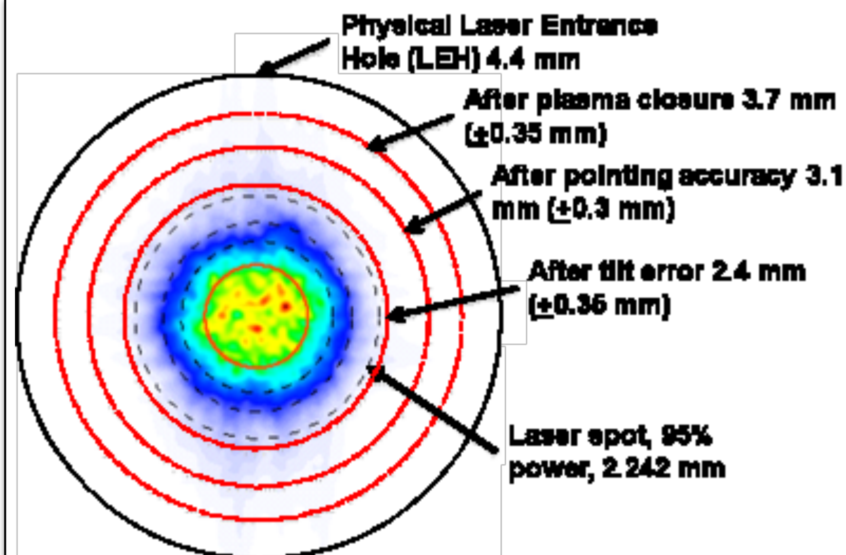
Detailed propagation simulation (based on measured NIF optics aberrations) shows excellent performance

Beam contrast at the final Fresnel optic is excellent.



Energy = 5462 J
Mean fluence = 1.55 J/cm^2
Contrast = 6.5%

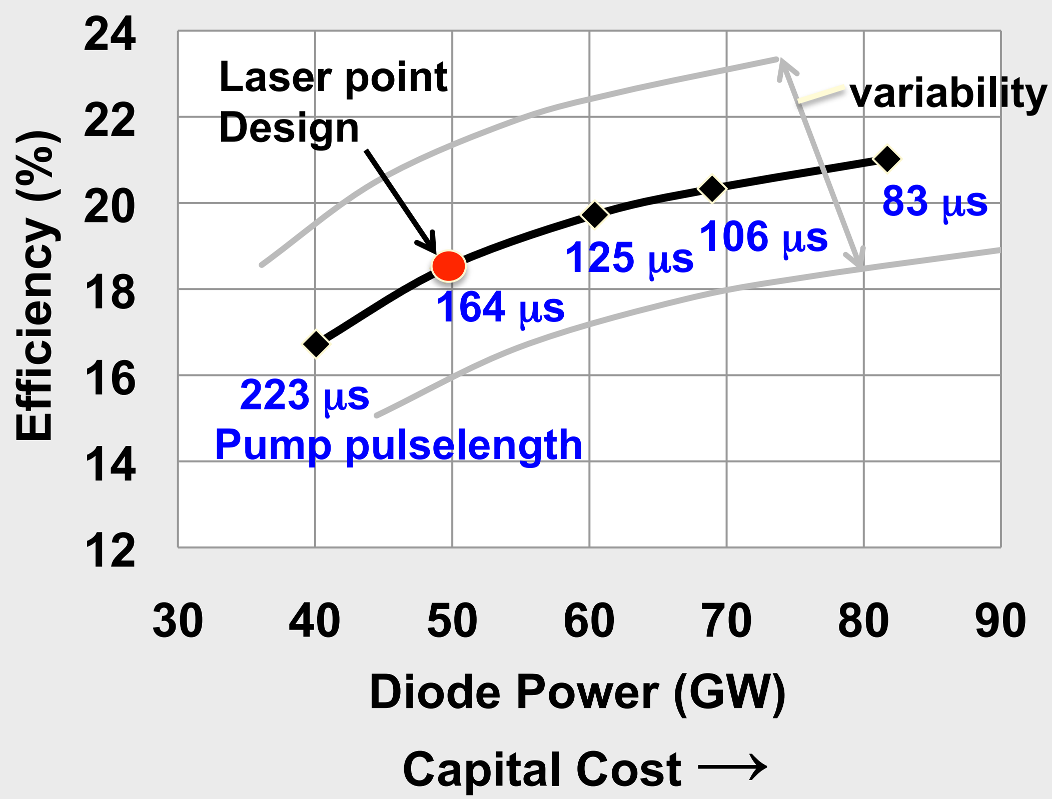
Focal spot at hohlraum clears the laser entrance hole



Outer illumination cone is shown, with allowances for pointing and plasma closure.

The LIFE laser will achieve high efficiency, optimized at ~18% to balance economic and performance terms

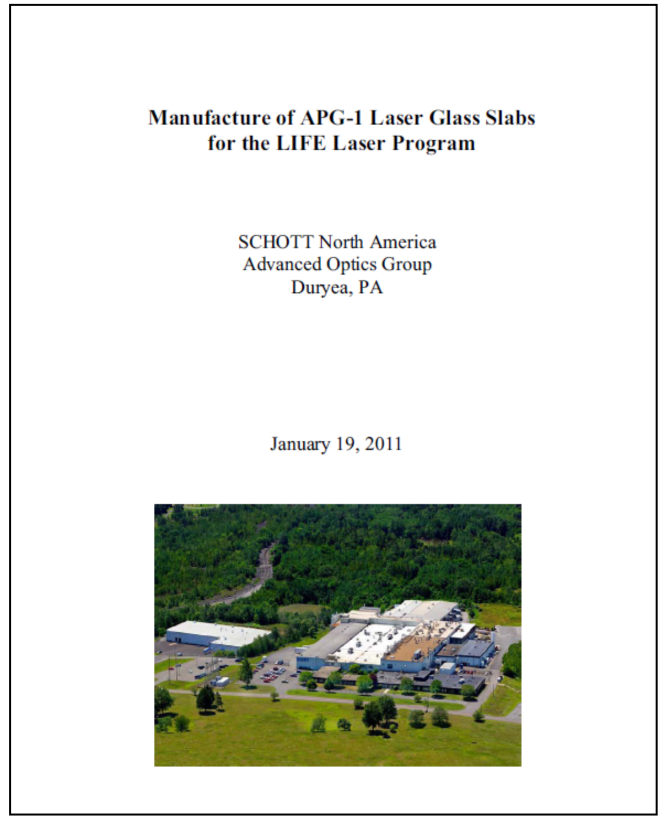
Electrical to 3ω Optical Efficiency



- APG-1 laser glass
- 5.7 kJ/beam @ 3ω
- 25-cm aperture @ 1ω
- 1-cm-thick slabs
- 384 beams (2.2 MJ @ 3ω)
- Cooling power not included (~16% including cooling)

Use of an existing glass (APG-1) as the gain media enables rapid LIFE driver development

	Nd:glass
Storage Lifetime (ms)	0.36
Absorption FWHM (nm)	12.5
Laser Wavelength (nm)	1053
Pump Wavelength (nm)	872
Quantum Defect (%)	17
Saturation Fluence (J/cm^2)	5
Thermal conductivity (W/m K)	1
Thermal fracture coeff. (W/cm)	1.3
Fabrication (cm^2)	40 x 70
Operating Temperature (°C)	25~80


Manufacture of APG-1 Laser Glass Slabs for the LIFE Laser Program

SCHOTT North America
Advanced Optics Group
Duryea, PA

January 19, 2011

The LIFE baseline Schott APG-1 (commercially available)

- **Schott White Paper confirms readiness to supply**
- **Similar White Paper(s) from vendors in optics, coating & laser industries**

Diode suppliers state LIFE targets are achievable

LLNL-TR-465931

LAWRENCE LIVERMORE NATIONAL LABORATORY

Semiconductor Laser Diode Pumps for Inertial Fusion Energy Lasers

R. Deri, J. Geske, M. Kanskar, S. Patterson, G. Kim, Q. Hartmann, F. Leibreich, E. Deichsel, J. Ungar,P. Thiagarajan, R. Martinsen, P. Leisher,E. Stephens, J. Harrison, C. Ghosh, O. Rabot, A. Kohl

January 2011

Coauthored by 14 key laser diode vendors

Semiconductor Laser Diode Pumps for Inertial Fusion Energy Lasers

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Dr. Andreas Kohl, R&D Manager, Quantel, Les Ulis, France

Introduction and Overview

Solid-state lasers have been demonstrated as attractive drivers for inertial confinement fusion on the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory (LLNL) and at the Omega Facility at the Laboratory for Laser Energetics (LLE) in Rochester, NY. For power plant applications, these lasers must be pumped by semiconductor diode lasers to achieve the required laser system efficiency, repetition rate, and lifetime. Inertial fusion energy (IFE) power plants will require approximately 40-to-80 GW of peak pump power, and must operate efficiently and with high system availability for decades. These considerations lead to requirements on the efficiency, price, and production capacity of the semiconductor pump sources. This document provides a brief summary of these requirements, and how they can be met by a natural evolution of the current semiconductor laser industry.

The detailed technical requirements described in this document flow down from a laser amplifier design described elsewhere. [1] In brief, laser amplifiers comprising multiple Nd:glass gain slabs are face-pumped by two planar diode arrays, each delivering 30 to 40 MW of peak power at 872 nm during a ~200 μs quasi-CW (QCW) pulse with a repetition rate in the range of 10 to 20 Hz. The baseline design of the diode array employs a 2D mosaic of submodules to facilitate manufacturing. As a baseline, we envision that each submodule is an array of vertically stacked, 1 cm wide, edge-emitting diode bars, [e.g.; 2] an industry standard form factor. These stacks are mounted on a common backplane providing cooling and current drive. Stacks are conductively cooled to the backplane, to minimize both diode package cost and the number of fluid interconnects for improved reliability. While the baseline assessment in this document is based on edge-emitting devices, the amplifier design does not preclude future use of surface emitting diodes, [3,4] which may offer appreciable future cost reductions and increased reliability.

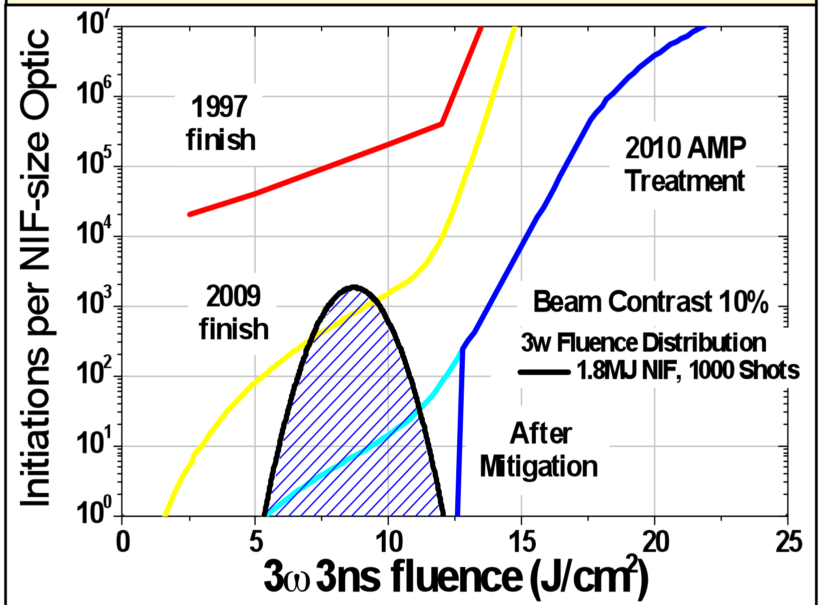
The high-level requirements on the semiconductor lasers involve reliability, price points on a price-per-Watt basis, and a set of technical requirements. The technical requirements for the amplifier design in Ref. [1] are discussed in detail below and are summarized in Table I. These values are still subject to changes as the overall laser system continues to be optimized. Since pump costs can be a significant

3

- **2009 Industry Consensus: 3¢/W @ 500 W/bar, with no new R&D**
- **Sustained production of LIFE plants reduces price to ~$0.007/W**

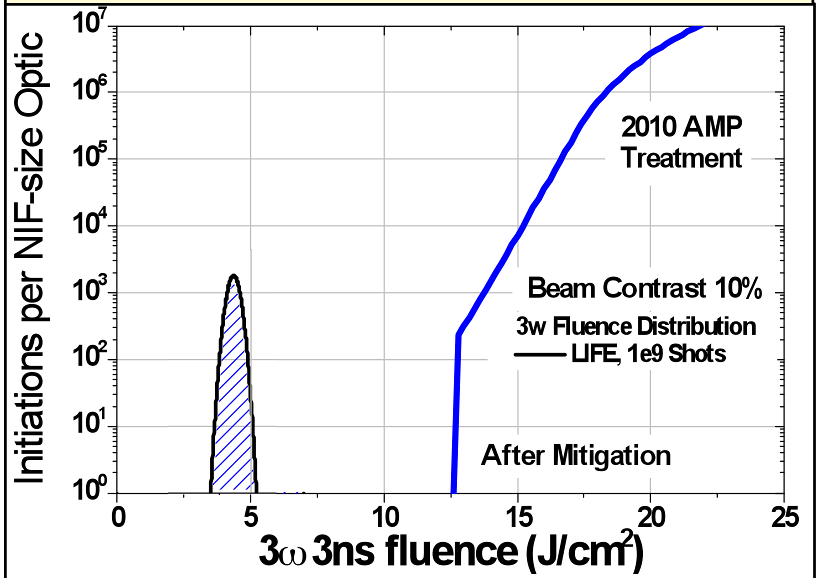
3ω optical damage can be eliminated using existing NIF technologies and through fluence scaling

Fused Silica Lenses



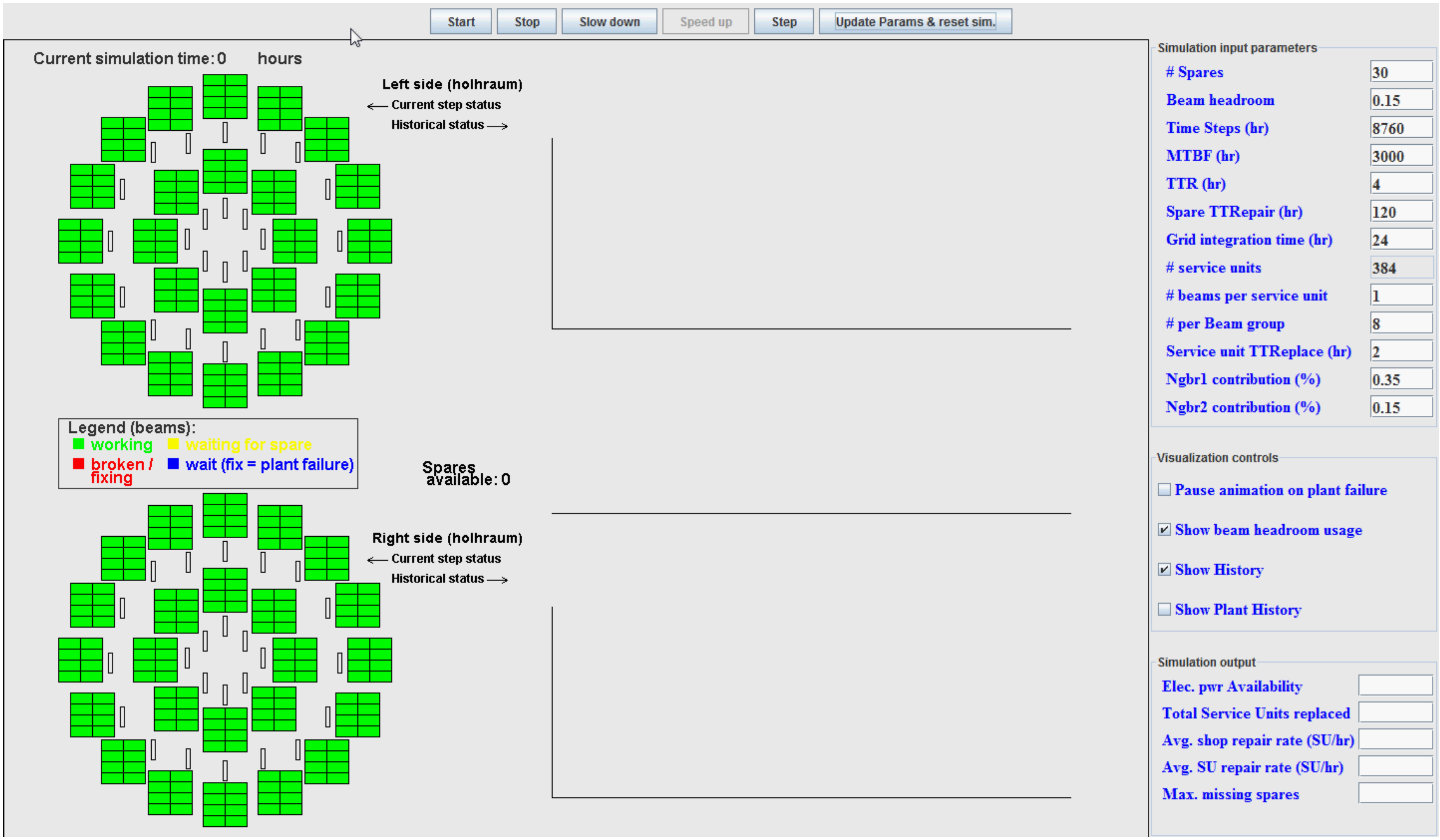
Tremendous progress has been made improving the damage resistance of optics for NIF

Fused Silica Lenses

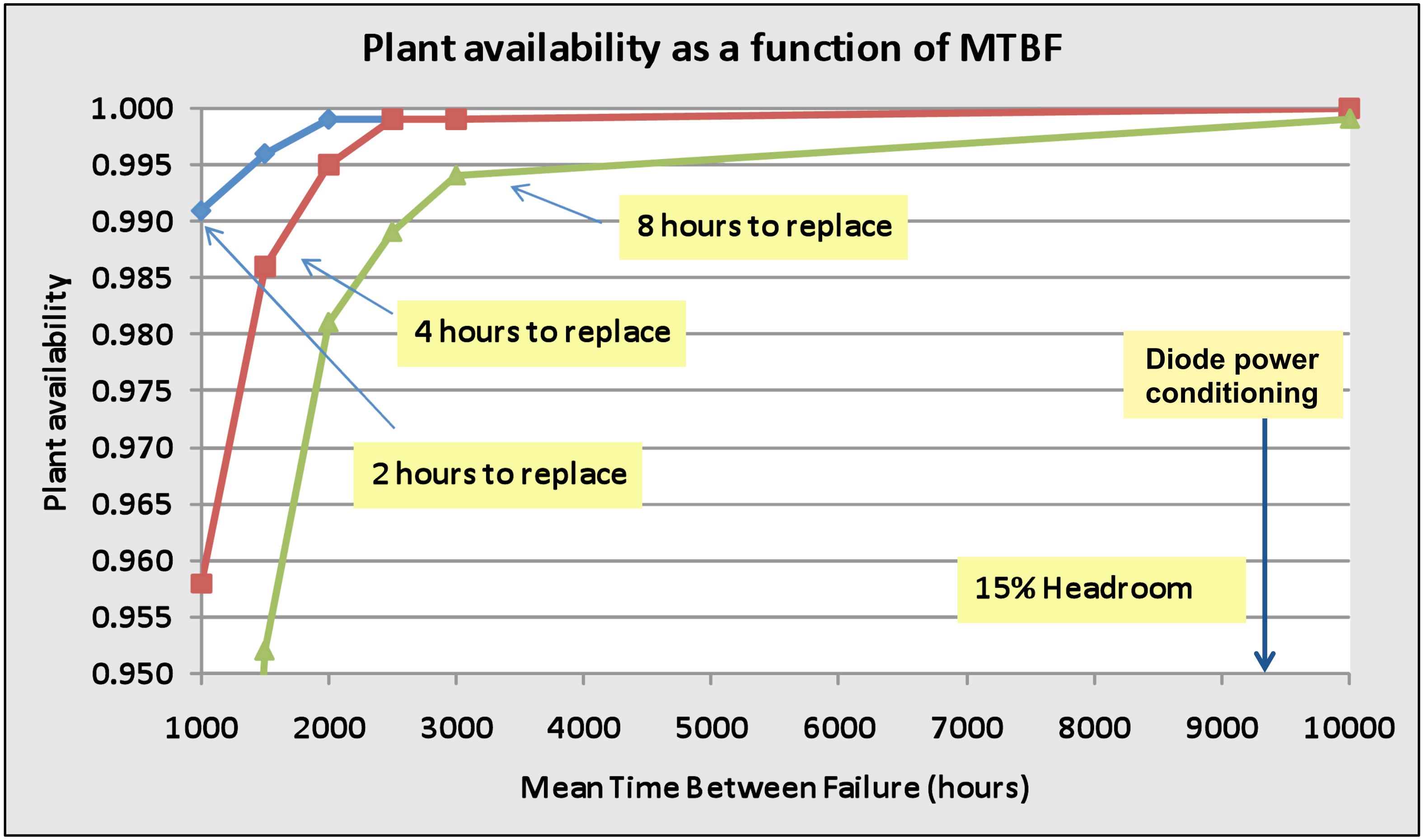


LIFE: average fluence reduced by 2X to add margin against modulation for high average power

High laser system availability achieved through modular architecture and on-line maintenance



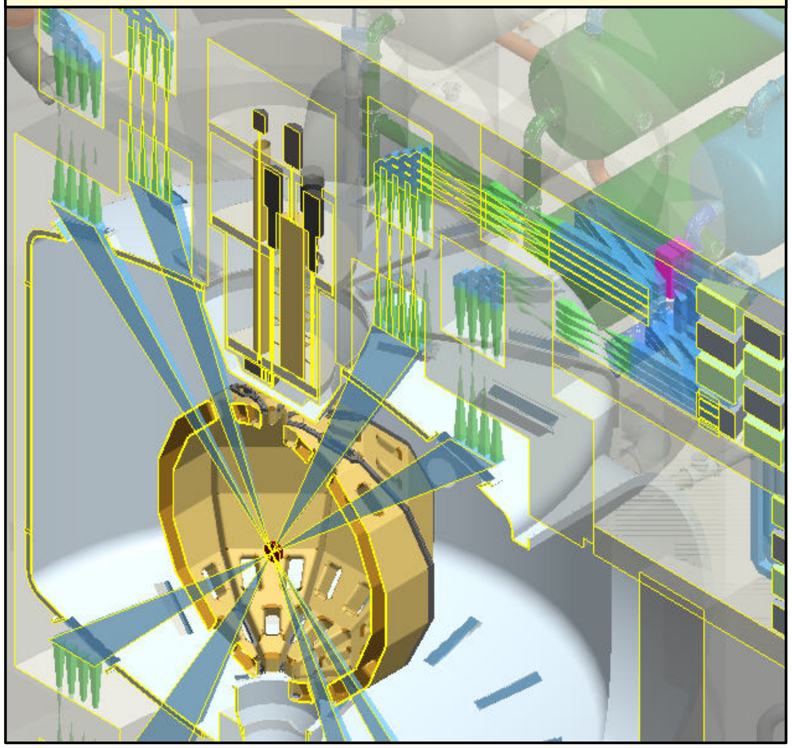
Laser architecture largely decouples system availability from beam box reliability



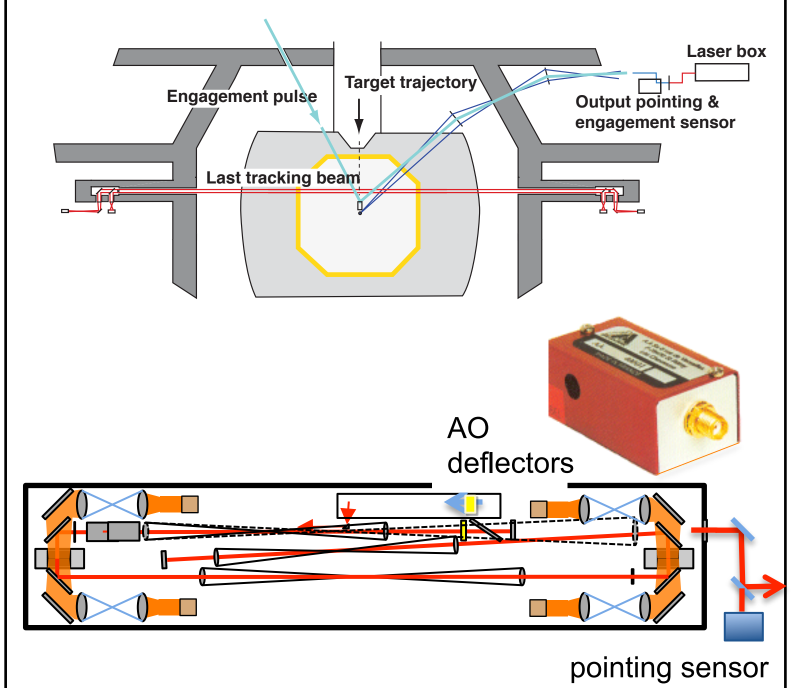
Laser system availability > 99%

Injection and tracking accuracy are readily obtainable using conventional technology

Conventional gas gun to inject at 500g, 250m/s, ±500μm (3.3σ). FEA models show that the target is mechanically robust



Target tracking and individual beam-line sensors feed back to the laser front-end for engagement. Calculated error of ±75μm



Integrated experiments underway this year

LIFE laser architecture attributes

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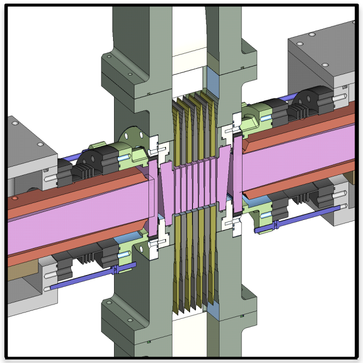

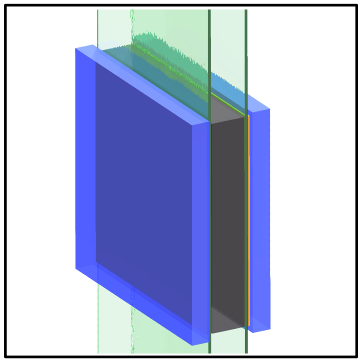

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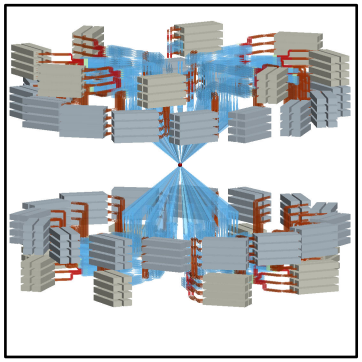

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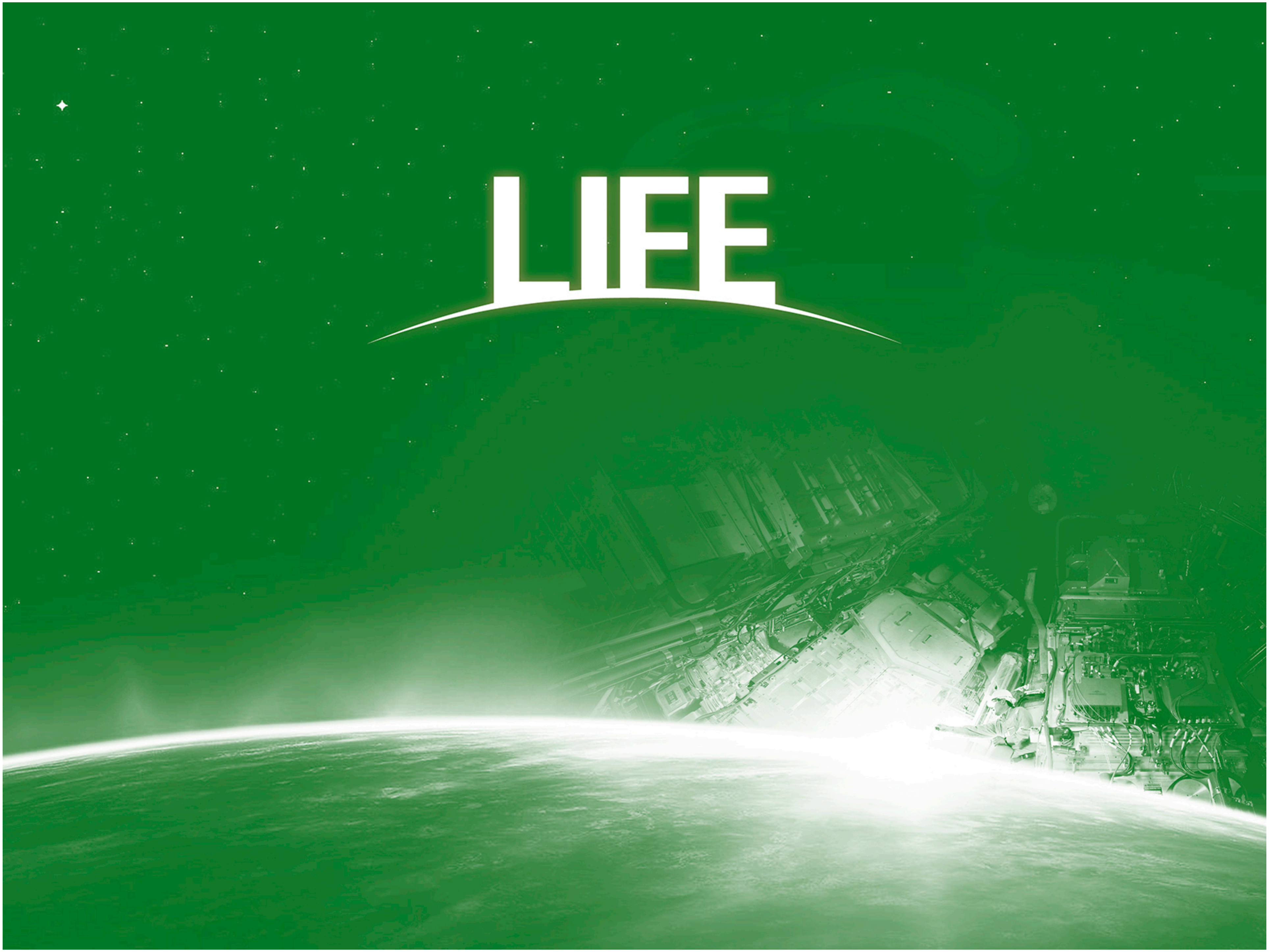
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