National Ignition Facility

A New Age for HED Science

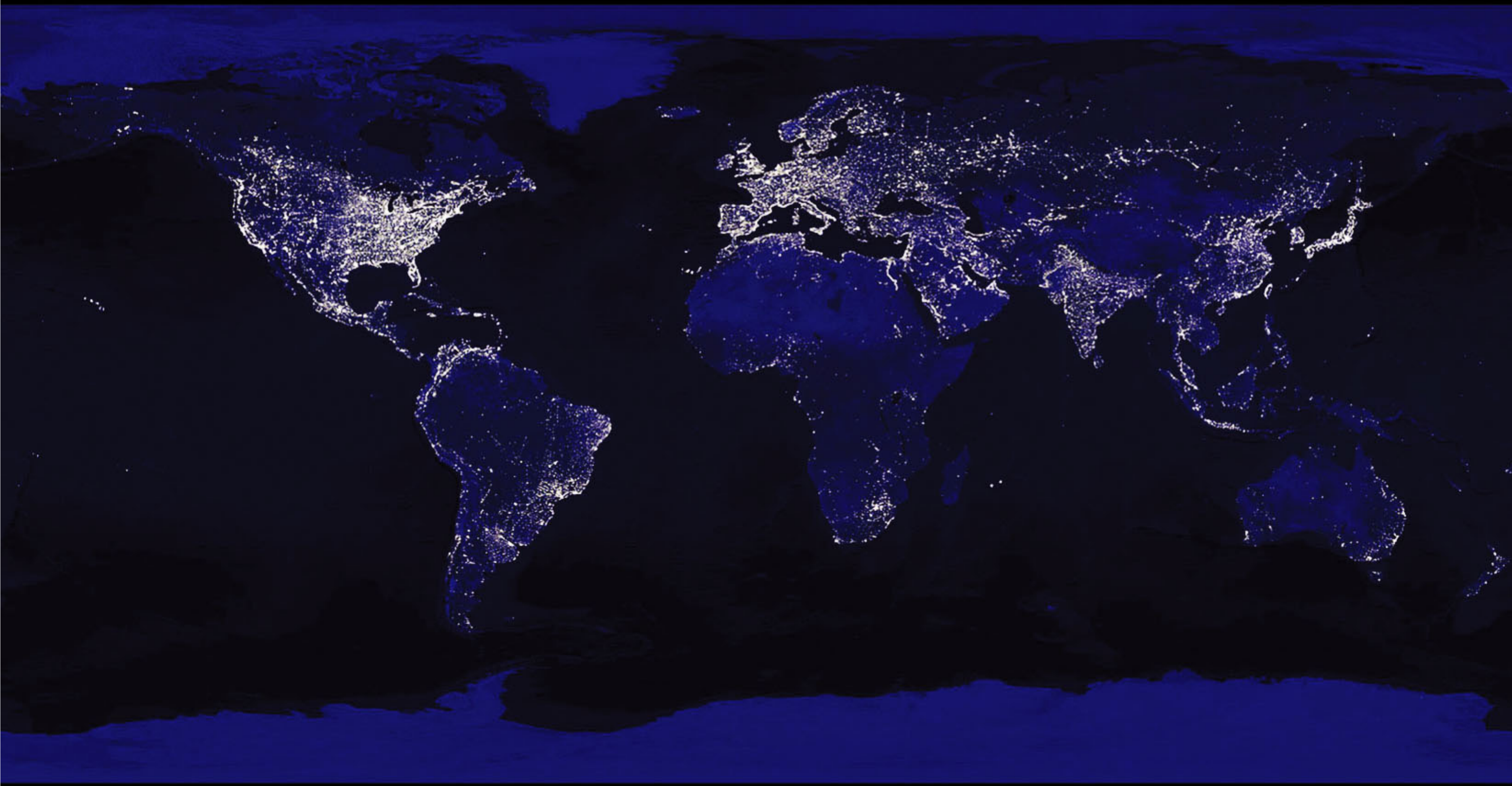
Fusion Power Associates
Oak Ridge, Tn, December 4, 2007,
Edward I. Moses, NIC Director

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

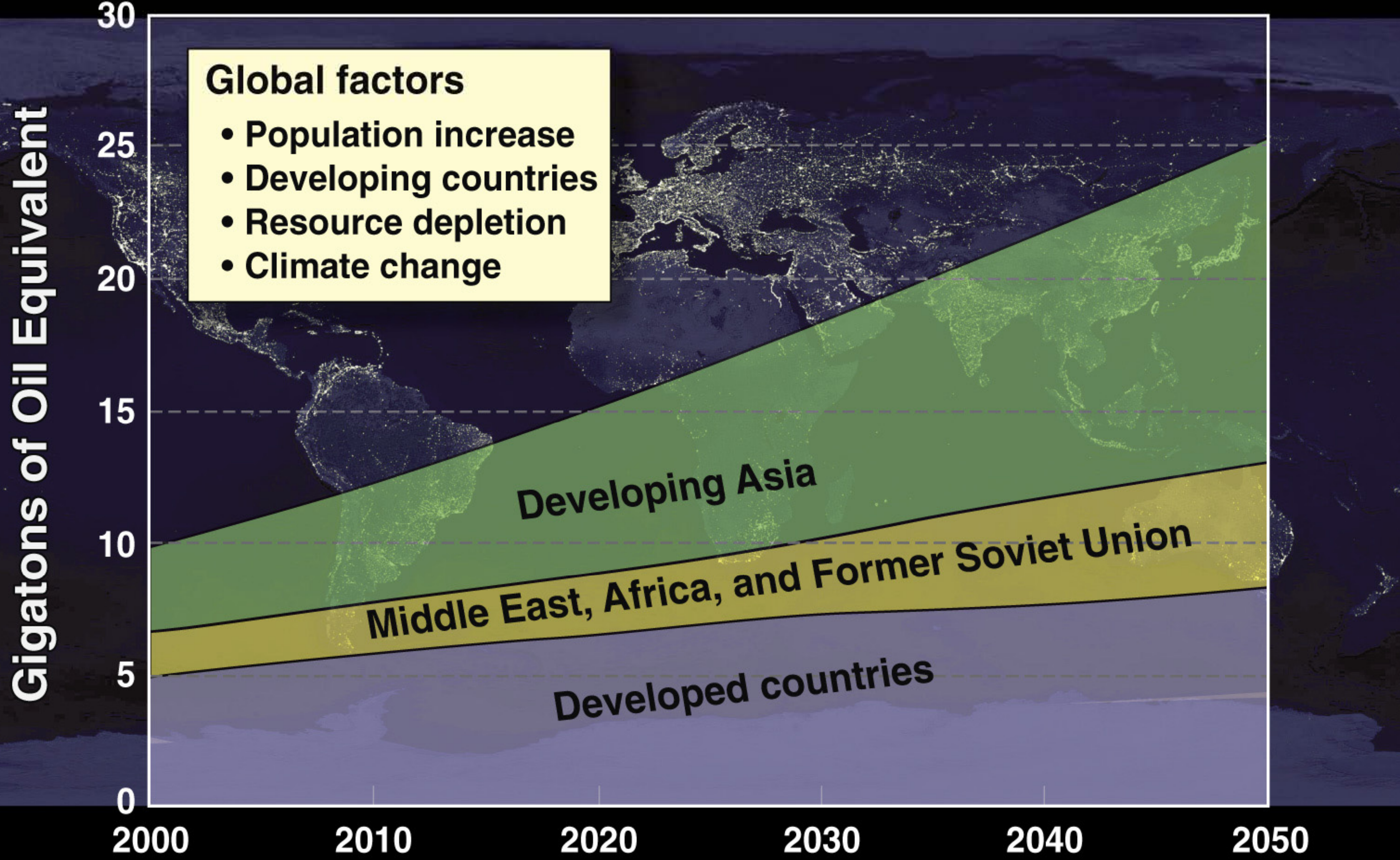
The National Ignition Facility

Limitless Clean Energy
Eye on the Cosmos

Clean Energy: Humankind's Challenge



Clean Energy: Humankind's Challenge

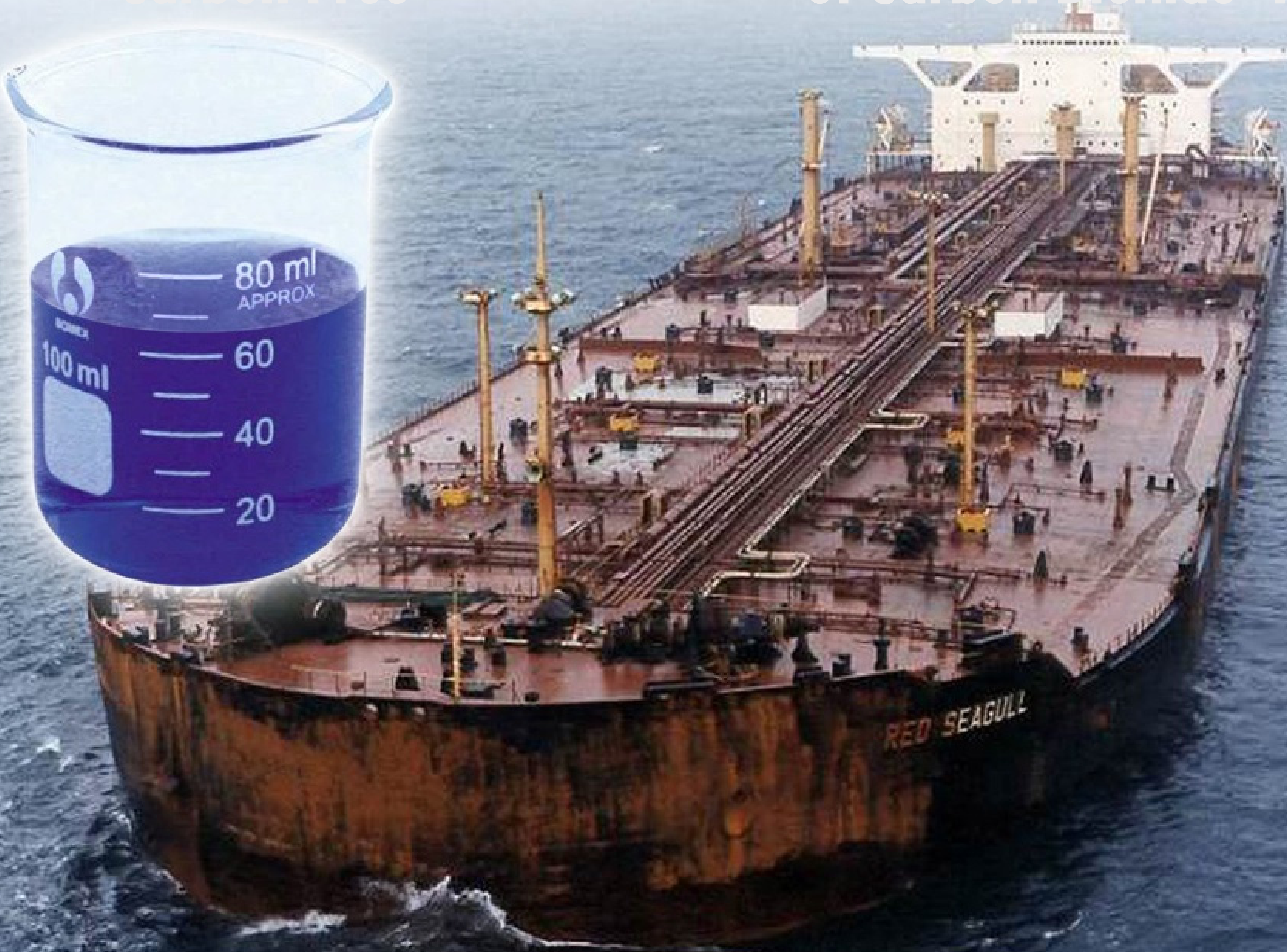


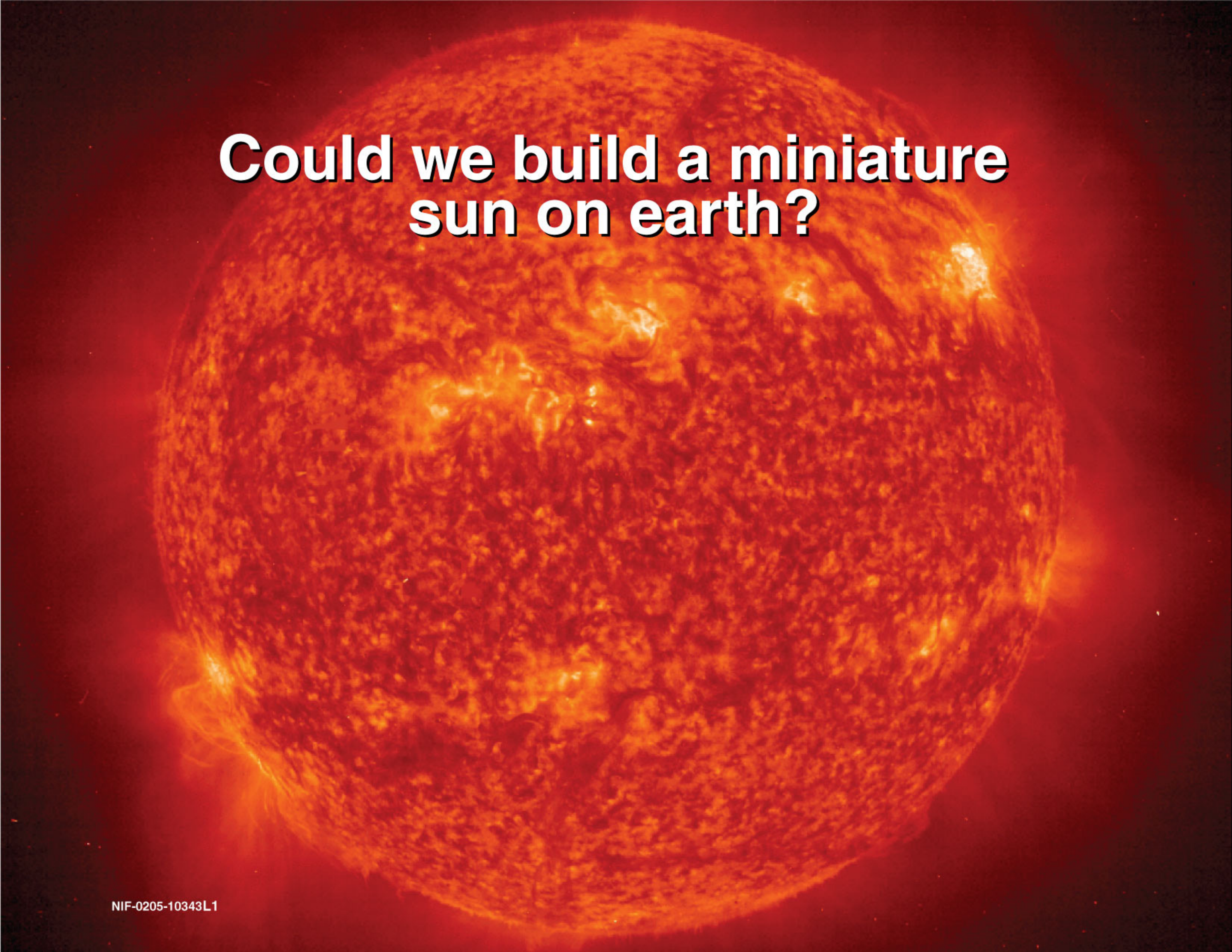

How Many More Power Plants
Do We Need?
10,000 Power Reactors Must Be
Built This Century
Two New Ones Each Week!

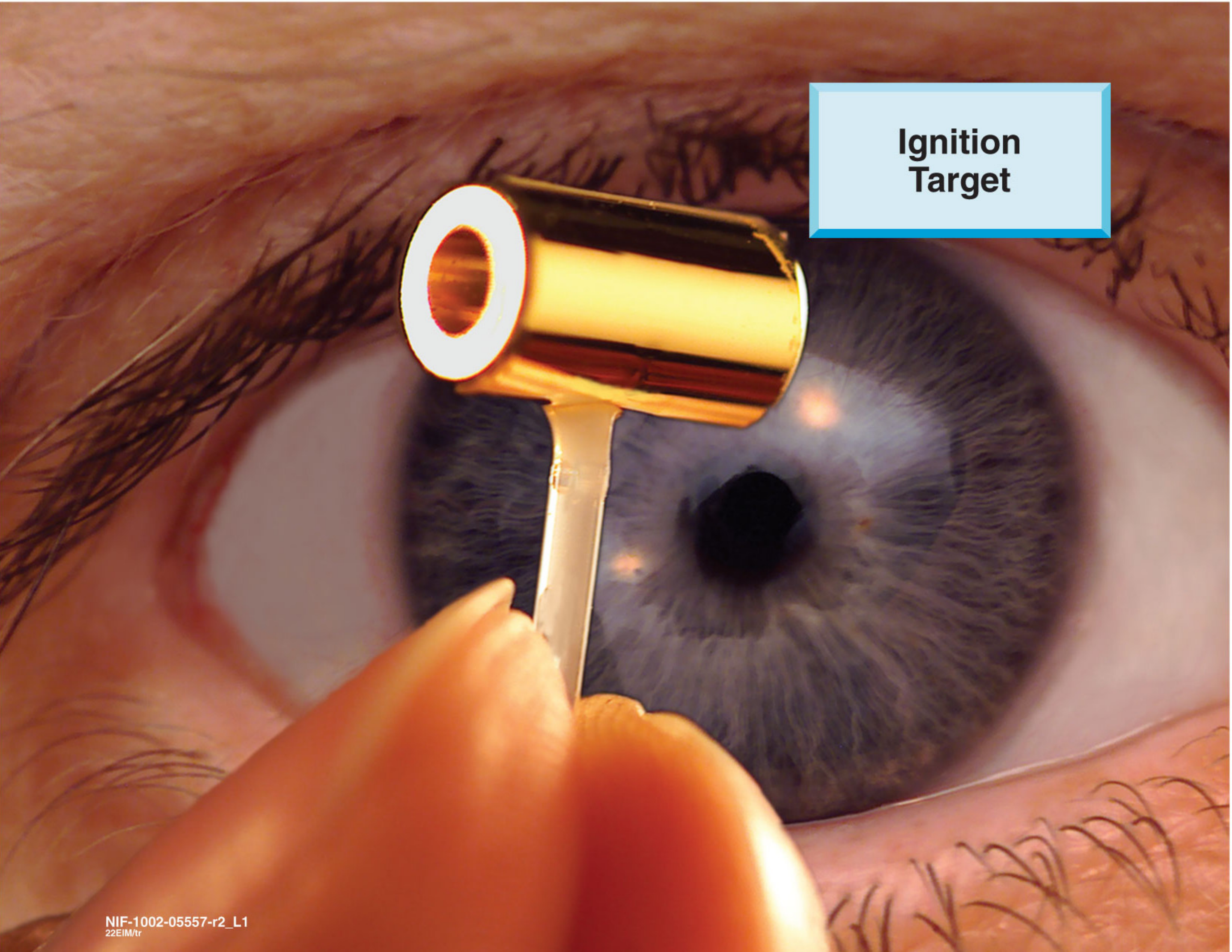
Fusion Energy:
70 g of Water
Carbon Free

=

Chemical Energy:
Supertanker Full
of Carbon Dioxide-Rich Oil




Could we build a miniature sun on earth?
NIF-0205-10343L1

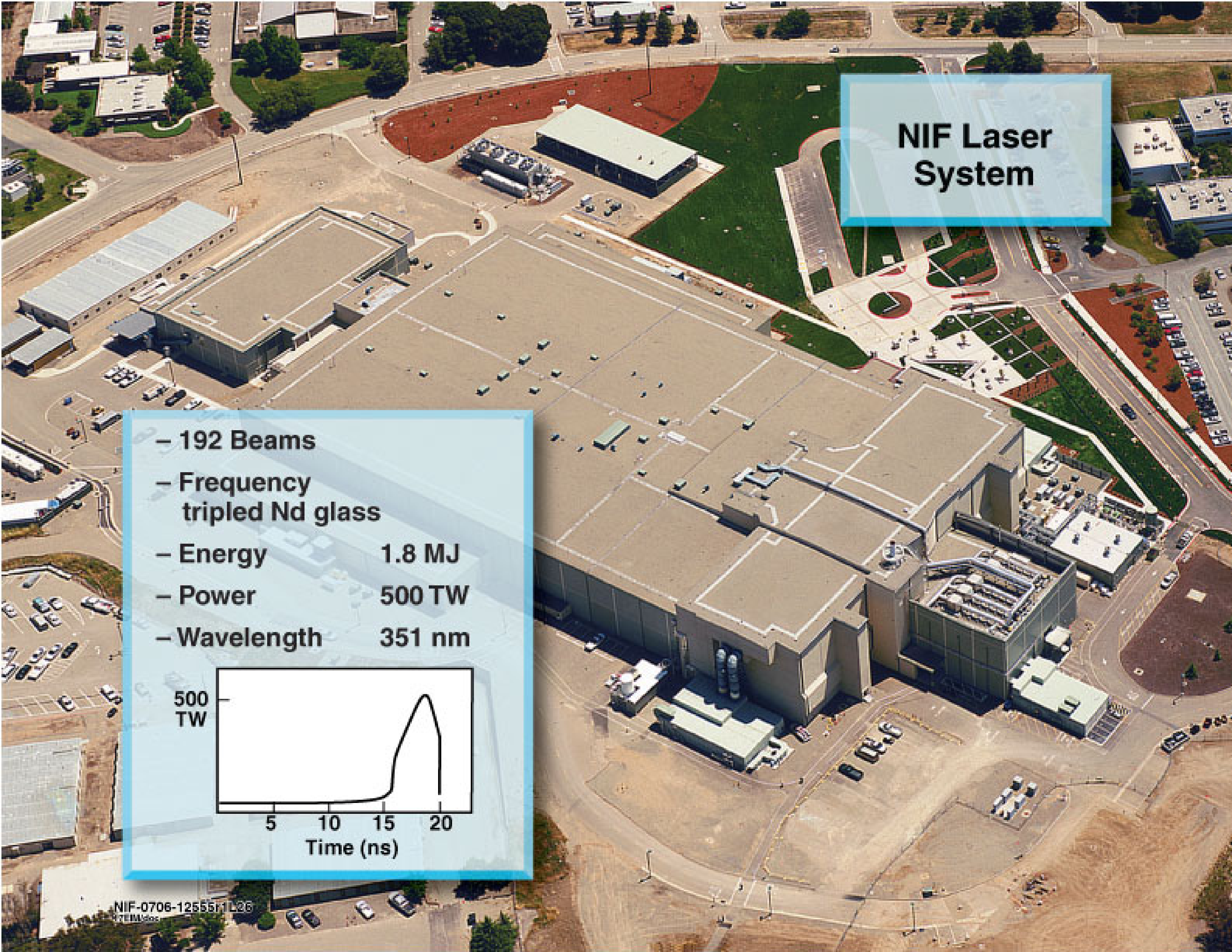

Ignition
Target
NIF-1002-05557-r2_L1
22EIM/tr

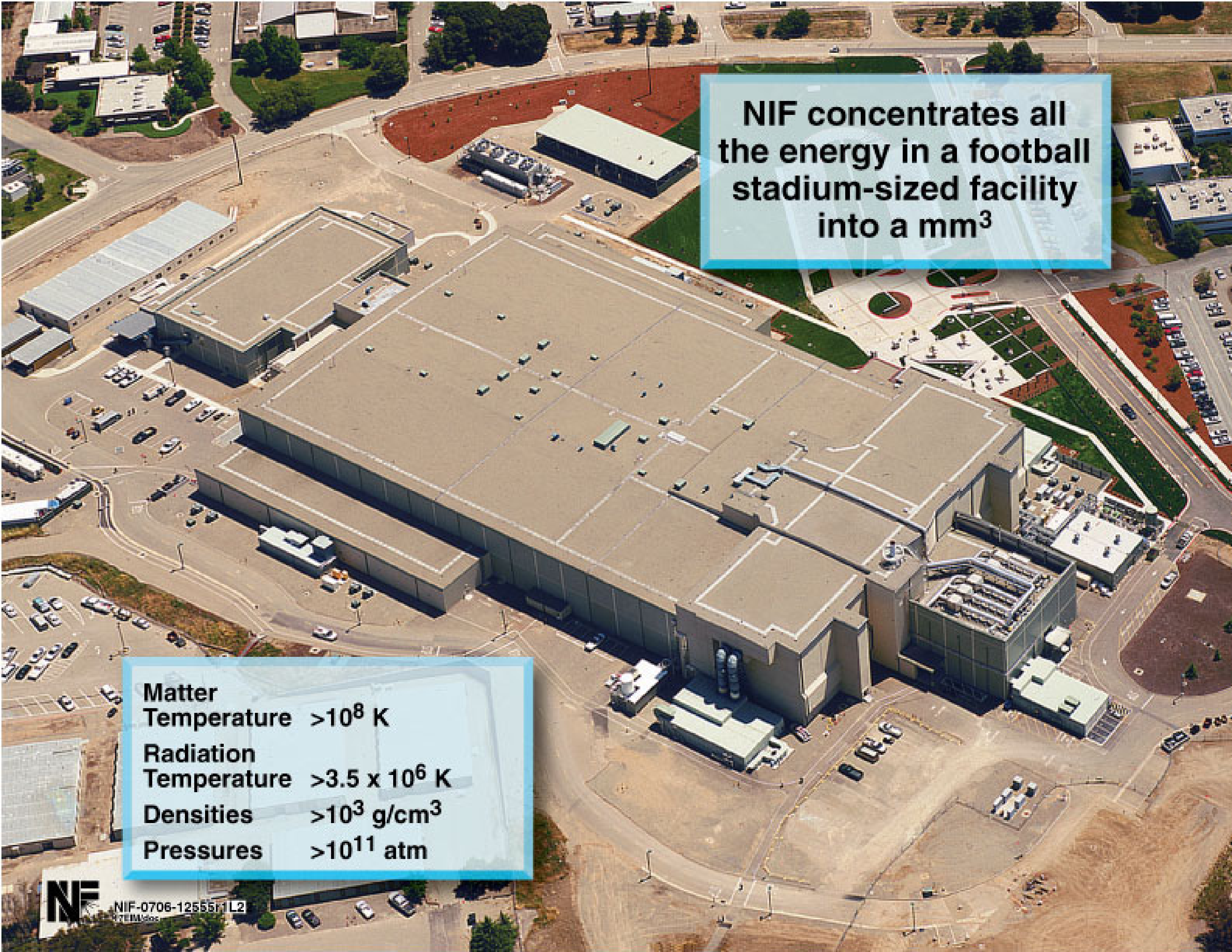
After 47 years, all of the pieces for ignition are nearly in place

- The NIF laser and the equipment needed for ignition experiments, including high quality targets, will be available in 24 months
- We have an ignition point design target near 1 MJ with a credible chance for ignition during early NIF operations
- We have an Early Opportunity Shots (EOS) system commissioning campaign with 96 beams planned to start in 12 months
- The initial ignition experiments will only scratch the surface of NIF's potential, which includes high yields with green light and greatly expanded opportunities for the uses of ignition by decoupling compression and ignition in Fast Ignition (FI)


San Francisco
(45 mi.)
Lawrence Livermore National Laboratory
National Ignition Facility
NIF-0605-10997-L47
27EIM/cld


NIF is
705,000
square feet
49ers
SAN FRANCISCO
REDSKINS
WASHINGTON
RAIDERS
OAKLAND
NIF-0706-12555 L4
17EIM/doc

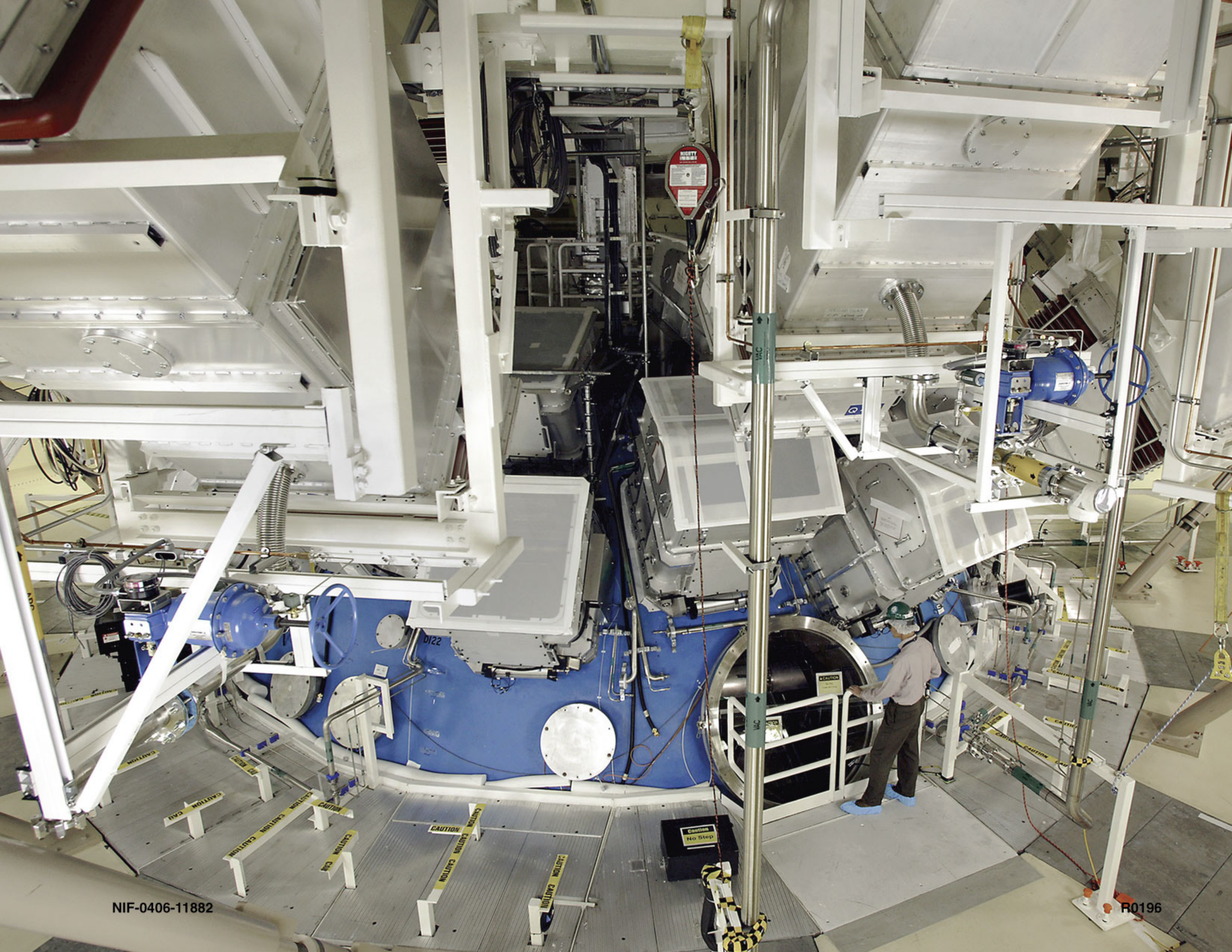

NIF Laser System
– 192 Beams
– Frequency tripled Nd glass
– Energy 1.8 MJ
– Power 500 TW
– Wavelength 351 nm
500 TW
5
10
15
20
Time (ns)
NIF-0706-12555r1L26



NIF concentrates all the energy in a football stadium-sized facility into a mm³
Matter Temperature >10⁸ K
Radiation Temperature >3.5 x 10⁶ K
Densities >10³ g/cm³
Pressures >10¹¹ atm
NIF
NIF-0706-12555r1L2


National Ignition Facility
• NIF Project is 95% complete
• NIF will be complete in 16 months
NIF-0706-12555r1L20


Laser Bay 2
25/2 T
40-60-0500-2429#13-r1_L1
P6294

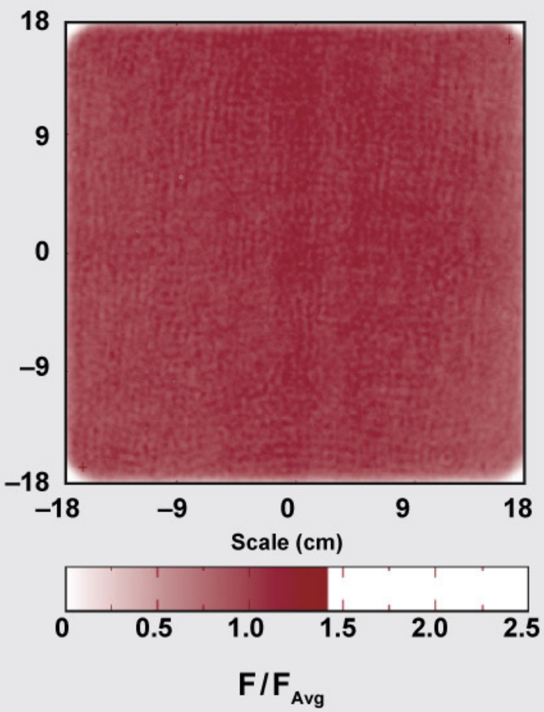

NIF-0406-11882
R0196
Caution
No Step
CAUTION
DI22
VAC


Target Chamber
NIF-0501-02172
X2235


15 Main Laser Bundles
Operationally
Qualified
October 31, 2007
World's Highest Energy
Laser – 2.5 MJ 1ω
NIF-0807-13919r4
31BVW/sb

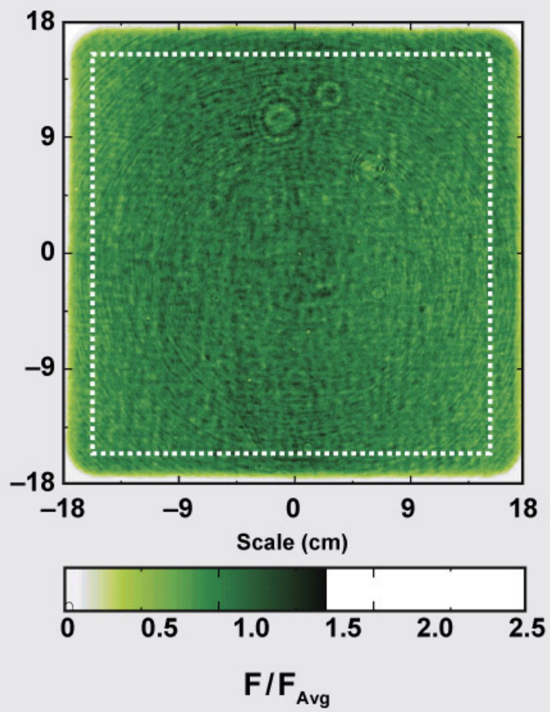
Beamline Performance

25 kJ



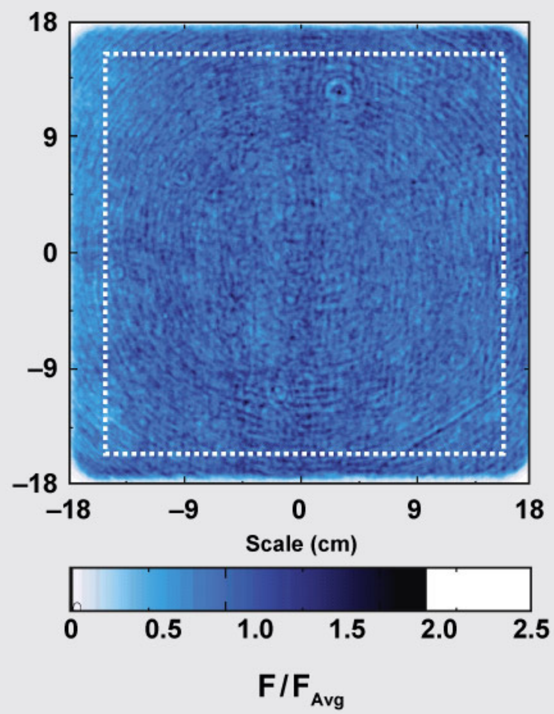
4 MJ

17 kJ



3.4 MJ

11 kJ



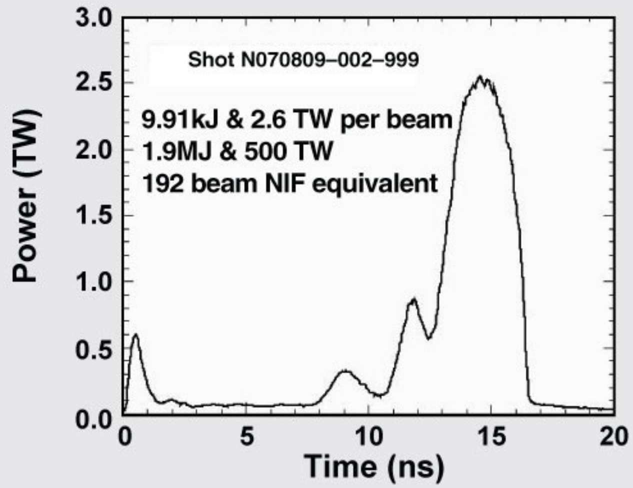
1.9 MJ

Each beam on NIF, is on its own, the World's most energetic laser

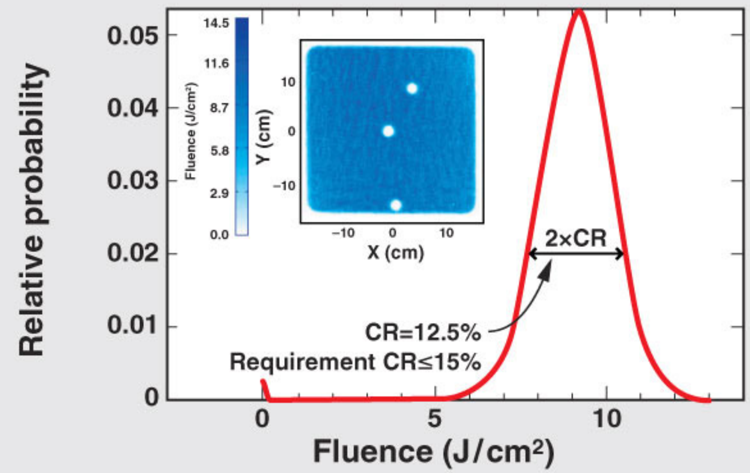
NIC 1.8 MJ ignition point design, energy, power, pulse shape & smoothing were achieved simultaneously

The National Ignition Campaign

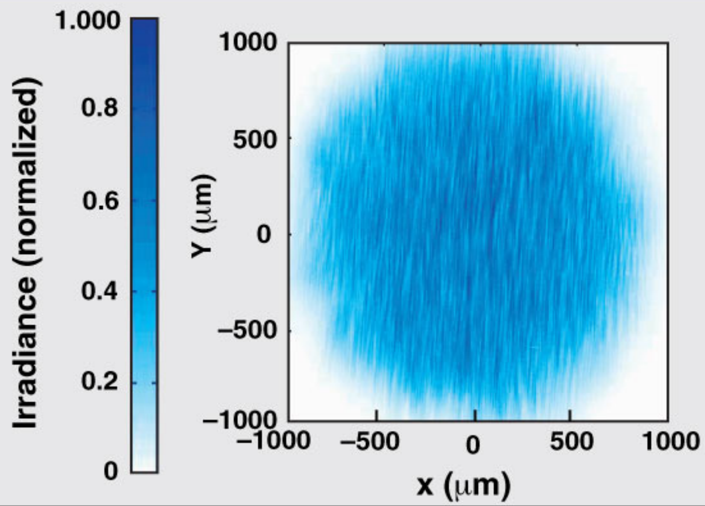
3ω Pulse Shape (500 TW)



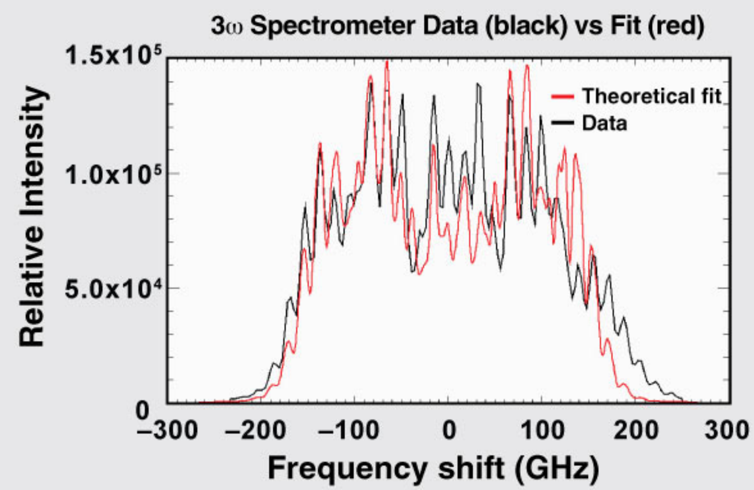
3ω Near Field Profile



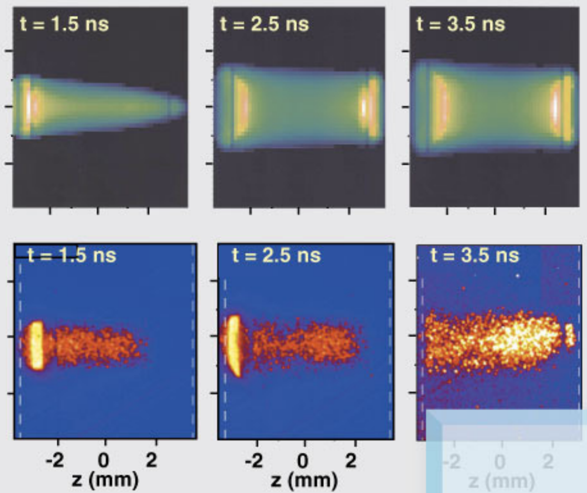
3ω Focal Spot (1.91 × 1.64 mm²)



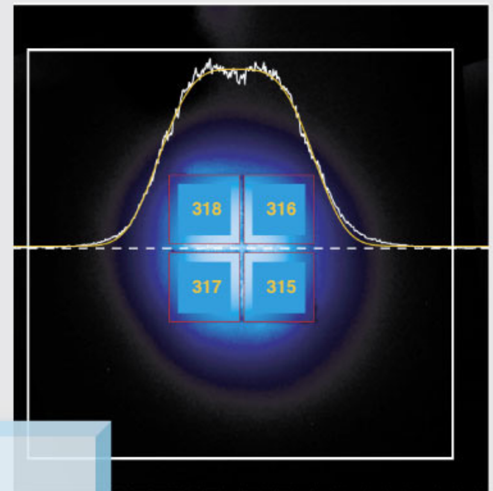
3ω SSD Bandwidth (270 GHz)



LPI

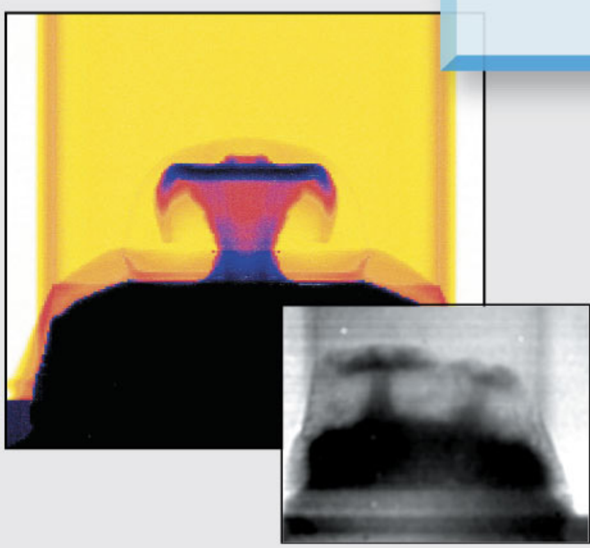


Hohlraums

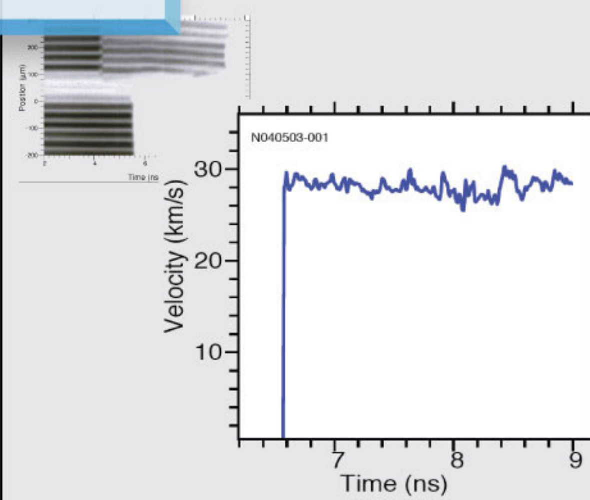


NIF is steadily developing a large range of experimental capabilities

Hydro



EOS



"External Users" participated in the 2004 NIF Early Light Experiments

Physical Review Letters

PRL 94, 095005 (2005) — week ending 11 MARCH 2005

Experimental Investigation of High-Mach-Number 3D Hydrodynamic Jets at the National Ignition Facility

B. E. Blue,[1] S. V. Weber,[1] S. G. Glendinning,[1] N. E. Lanier,[2] D. T. Woods,[1] M. J. Bono,[1] S. N. Dixit,[1] C. A. Haynam, J. P. Holder,[1] D. H. Kalantar,[1] B. J. MacGowan,[1] A. J. Nikitin,[1] V. V. Rekow,[1] B. M. Van Wonterghem,[1] E. I. Moses, P. E. Stry,[1] B. H. Wilde,[2] W. W. Hsing,[2] and H. F. Robey[1]

[1]Lawrence Livermore National Laboratory, Livermore, California 94550, USA
[2]Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA

(Received 11 October 2004; published 11 March 2005)

The first hydrodynamic experiments were performed on the National Ignition Facility. A supersonic jet was formed via the interaction of a laser driven shock (~40 Mbar) with 2D and 3D density perturbations. The temporal evolution of the jet's spatial scales and ejected mass were measured with point-projection x-ray radiography. Measurements of the large-scale features and mass are in good agreement with 2D and 3D numerical simulations. These experiments provide quantitative data on the evolution of 3D supersonic jets and provide insight into their 3D behavior.

DOI: 10.1103/PhysRevLett.94.095005 — PACS numbers: 52.35.Tc, 52.50.Jm, 52.57.–z

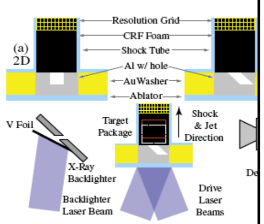


FIG. 1 (color). Schematic of a 2D target (a), a 3D target and the radiographic configuration used on NIF (c) (not to scale).

0031-9007/05/94(9)/095005(4)$23.00 — 095005-1 — © 2005 The American Physical Society

Los Alamos National Lab

Nuclear Fusion

Institute of Physics Publishing — Nuclear Fusion
Nucl. Fusion 44 (2004) S185–S190 — PII: S0029-5515(04)86276-8

Progress in long scale length laser–plasma interactions

S.H. Glenzer, P. Arnold, G. Bardsley, R.L. Berger, G. Bonanno, T. Borger, D.E. Bower, M. Bowers, R. Bryant, S. Buckman, S.C. Burkhart, K. Campbell, M.P. Chrisp, B.I. Cohen, C. Constantin, F. Cooper, J. Cox, E. Dewald, L. Divol, S. Dixit, J. Duncan, D. Eder, J. Edwards, G. Erbert, B. Felker, J. Fornes, G. Frieders, D.H. Froula, S.D. Gardner, C. Gates, M. Gonzalez, C. Haynam, G. Heestand, M. Henesian, G. Hermes, D. Hinkel, J. Holder, F. Holdner, G. Holtmeier, W. Hsing, S. Huber, T. James, S. Johnson, O.S. Jones, D. Kalantar, J.H. Kamperschroer, R. Kauffman, T. Kelleher, J. Knight, R.K. Kirkwood, W.L. Kruer, W. Labiak, O.L. Landen, A.B. Langdon, S. Langer, D. Latray, A. Lee, F.D. Lee, D. Lund, B. MacGowan, S. Marshall, J. McBride, T. McCarville, L. McGrew, A.J. Mackinnon, S. Mahavandi, K. Manes, C. Marshall, J. Menapace, E. Mertens, N. Meezan, G. Miller, S. Montelongo, J.D. Moody, E. Moses, D. Munro, J. Murray, J. Neumann, M. Newton, E. Ng, C. Niemann, A. Nikitin, P. Opsahl, E. Padilla, T. Parham, G. Parrish, C. Petty, M. Polk, C. Powell, I. Reinbachs, V. Rekow, R. Rinnert, B. Riordan, M. Rhodes, V. Roberts, H. Robey, G. Ross, S. Sailors, R. Saunders, M. Schmitt, M.B. Schneider, S. Shiromizu, M. Spaeth, A. Stephens, B. Still, L.J. Suter, G. Tietbohl, M. Tobin, J. Tuck, B.M. Van Wonterghem, R. Vidal, D. Voloshin, R. Wallace, P. Wegner, P. Whitman, E.A. Williams, K. Williams, K. Winward, K. Work, B. Young, P.E. Young, P. Zapata, R.E. Bahr[1], W. Seka[1], J. Fernandez[2], D. Montgomery[2] and H. Rose[2]

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Online at stacks.iop.org/NF/44/S185
doi:10.1088/0029-5515/44/12/S08

Abstract

The first experiments on the National Ignition Facility (NIF) have employed the first four beams to measure propagation and laser backscattering losses in large ignition-size plasmas. Gas-filled targets between 2 and 7 mm length have been heated from one side by overlapping the focal spots of the four beams from one quad operated at 351 nm (3ω) with a total intensity of 2×10^{15} W cm^{-2}. The targets were filled with 1 atm of CO_2 producing up to 7 mm long homogeneously heated plasmas with densities of $n_e = 6 \times 10^{20}$ cm^{-3} and temperatures of $T_e = 2$ keV. The high energy in an NIF quad of beams of 16 kJ, illuminating the target from one direction, creates unique conditions for the study of laser–plasma interactions at scale lengths not previously accessible. The propagation through the large-scale plasma was measured with a gated x-ray imager that was filtered for 3.5 keV x-rays. These data indicate that the beams interact with the full length of this ignition-scale plasma during the last ~1 ns of the experiment. During that time, the full aperture measurements of the stimulated Brillouin scattering and stimulated Raman scattering show scattering into the four focusing lenses of 3% for the smallest length (~2 mm), increasing to 10–12% for ~7 mm. These results demonstrate the NIF experimental capabilities and further provide a benchmark for three-dimensional modelling of the laser–plasma interactions at ignition-size scale lengths.

PACS numbers: 52.38.-r, 52.25.-b, 52.35.-g

0029-5515/04/120185+06$30.00 © 2004 IAEA, Vienna Printed in the UK — S185

University of Rochester, LLE

Physics of Plasmas

PHYSICS OF PLASMAS 13, 032703 (2006)

Hard x-ray and hot electron environment in vacuum hohlraums at the National Ignition Facility

J. W. McDonald, L. J. Suter, O. L. Landen, J. M. Foster,[a] J. R. Celeste, J. P. Holder, E. L. Dewald, M. B. Schneider, D. E. Hinkel, R. L. Kauffman, L. J. Atherton, R. E. Bonanno, S. N. Dixit, D. C. Eder, C. A. Haynam, D. H. Kalantar, A. E. Koniges, F. D. Lee, B. J. MacGowan, K. R. Manes, D. H. Munro, J. R. Murray, M. J. Shaw, R. M. Stevenson,[a] T. G. Parham, B. M. Van Wonterghem, R. J. Wallace, P. J. Wegner, P. K. Whitman, B. K. Young, B. A. Hammel, and E. I. Moses
Lawrence Livermore National Laboratory, P.O. Box 808, Livermore, California 94550

(Received 25 October 2005; accepted 23 February 2006; published online 31 March 2006)

Time resolved hard x-ray images ($h\nu > 9$ keV) and time integrated hard x-ray spectra ($h\nu = 18$–150 keV) from vacuum hohlraums irradiated with four 351 nm wavelength National Ignition Facility [J. A. Paisner, E. M. Campbell, and W. J. Hogan, Fusion Technol. 26, 755 (1994)] laser beams are presented as a function of hohlraum size, laser power, and duration. The hard x-ray images and spectra provide insight into the time evolution of the hohlraum plasma filling and the production of hot electrons. The fraction of laser energy detected as hot electrons (F_{hot}) shows a correlation with laser intensity and with an empirical hohlraum plasma filling model. In addition, the significance of Au K-alpha emission and Au K-shell reabsorption observed in some of the bremsstrahlung dominated spectra is discussed. © 2006 American Institute of Physics. [DOI: 10.1063/1.2186927]

[a]Atomic Weapons Establishment, Aldermaston, United Kingdom.

1070-664X/2006/13(3)/032703/7/$23.00 — 13, 032703-1 — © 2006 American Institute of Physics

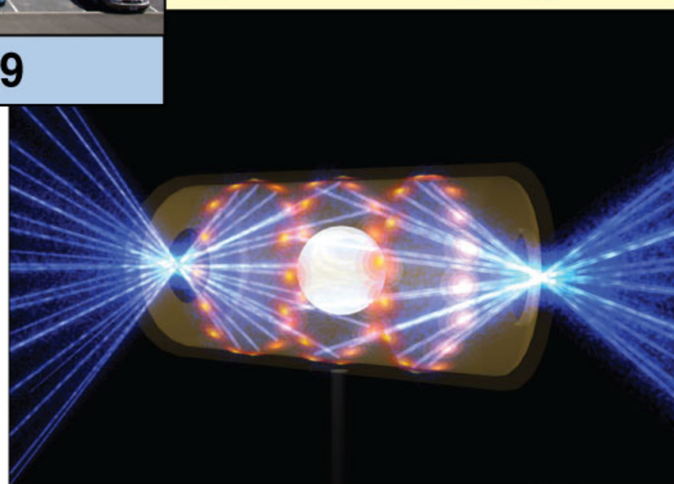
Atomic Weapons Establishment

The goal of NIC is thermonuclear burn in the laboratory with a credible campaign in 2010

NIF Project

Completion in 2009

National Ignition Campaign

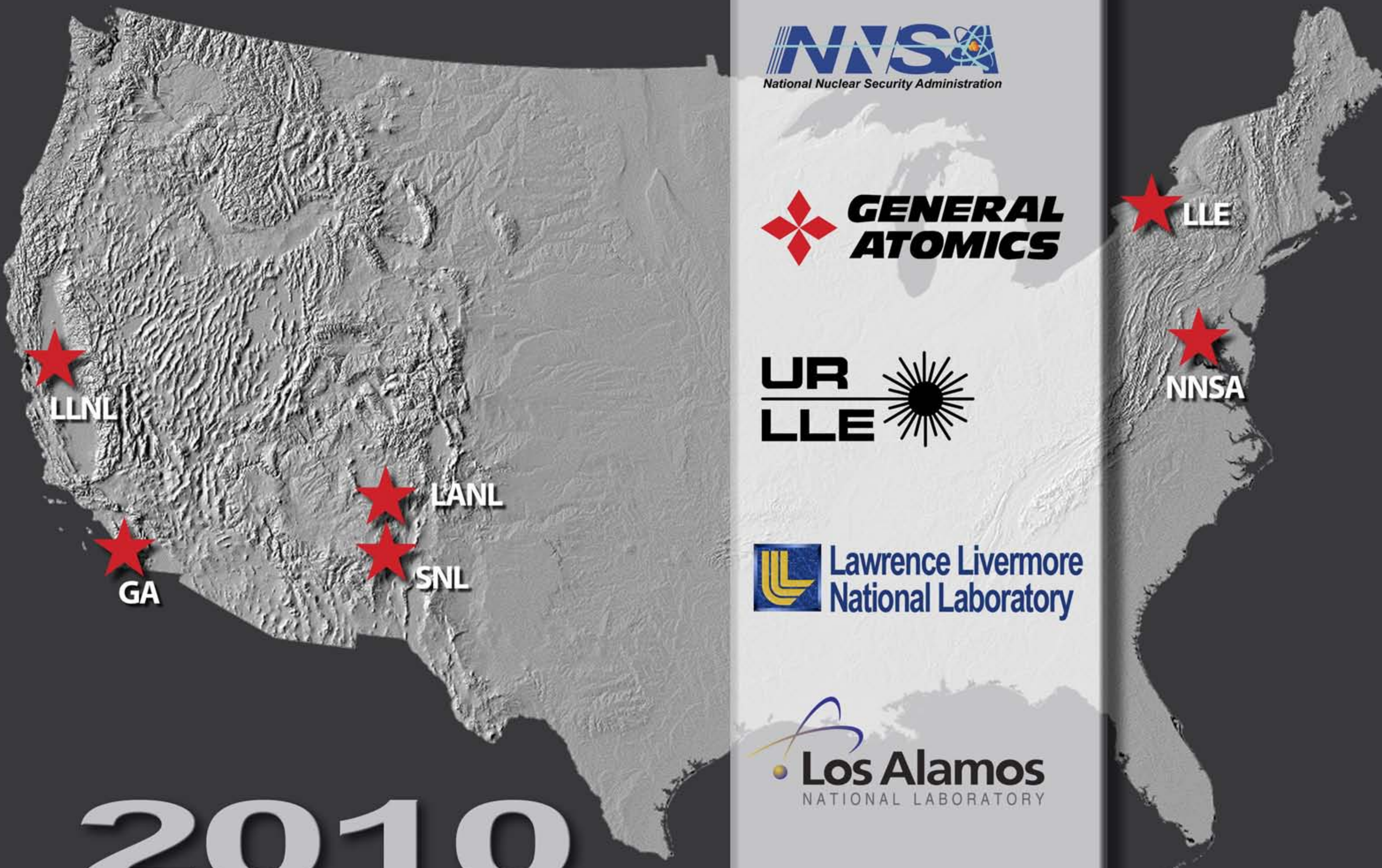


2006—2012

National User Facility

2009—2030

NIC is the bridge from NIF to routine operations of a highly flexible HED science facility



National Nuclear Security Administration

General Atomics

UR LLE

Lawrence Livermore National Laboratory

Los Alamos National Laboratory

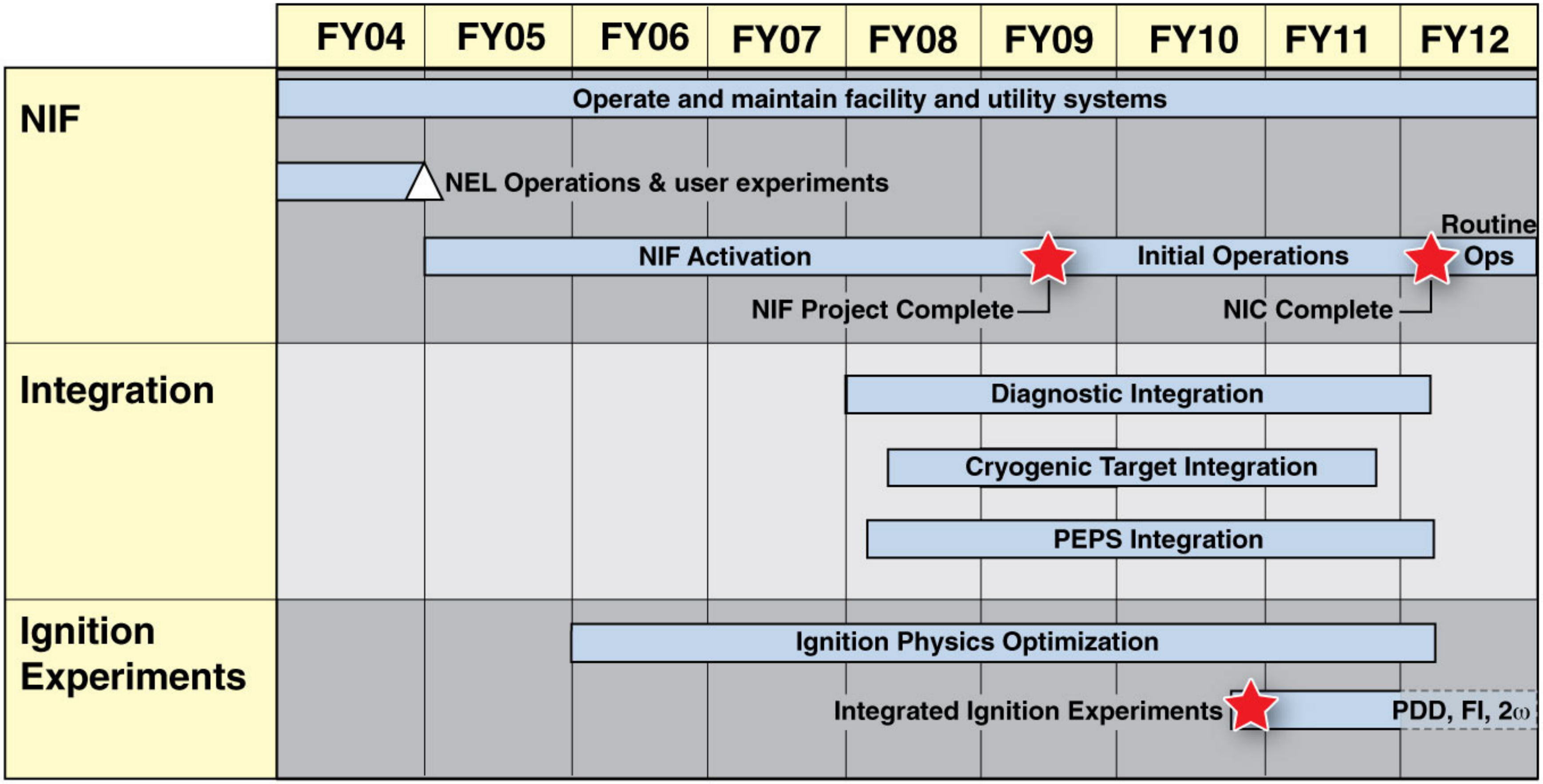
Sandia National Laboratories

2010

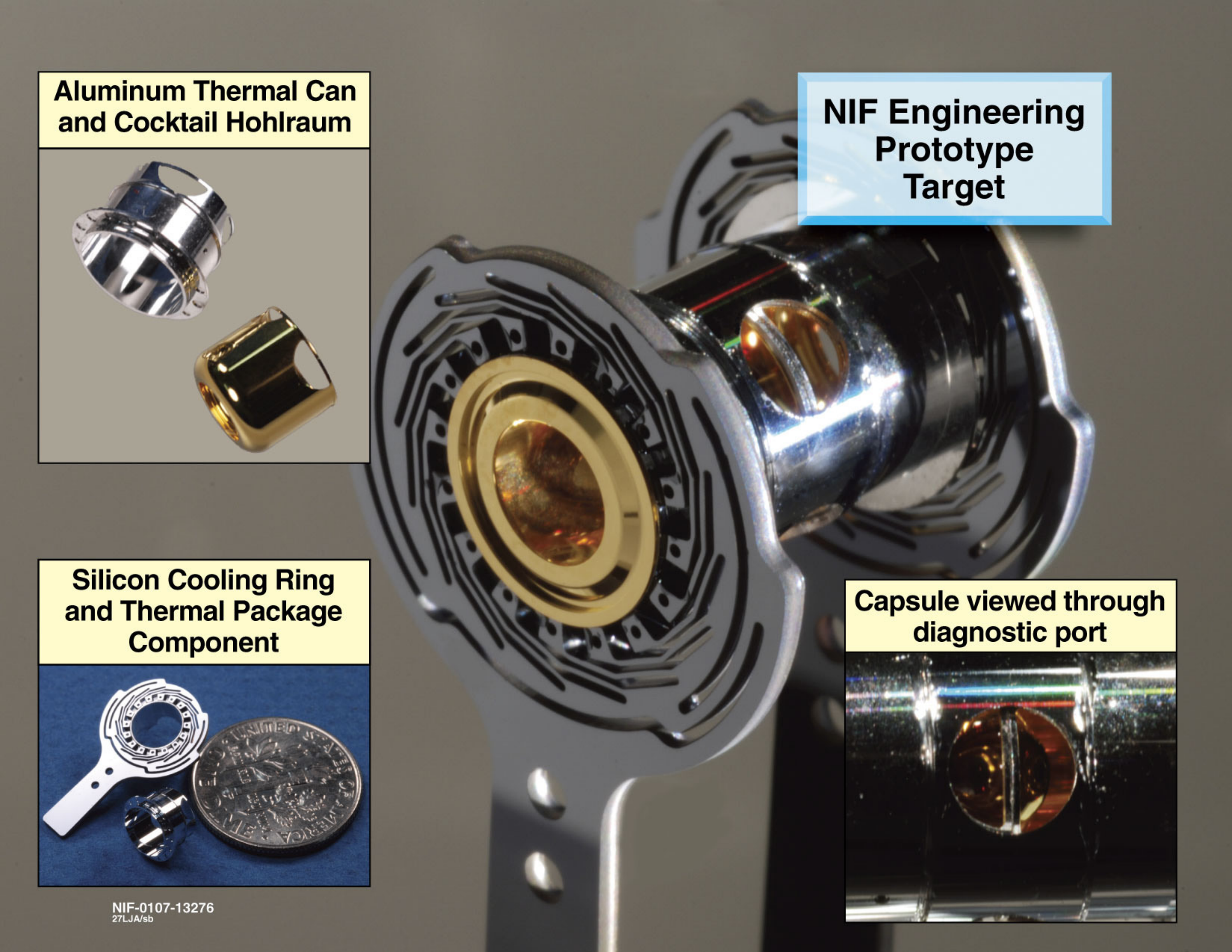
National Ignition Campaign

NIF/NIC Schedule

The National Ignition Campaign

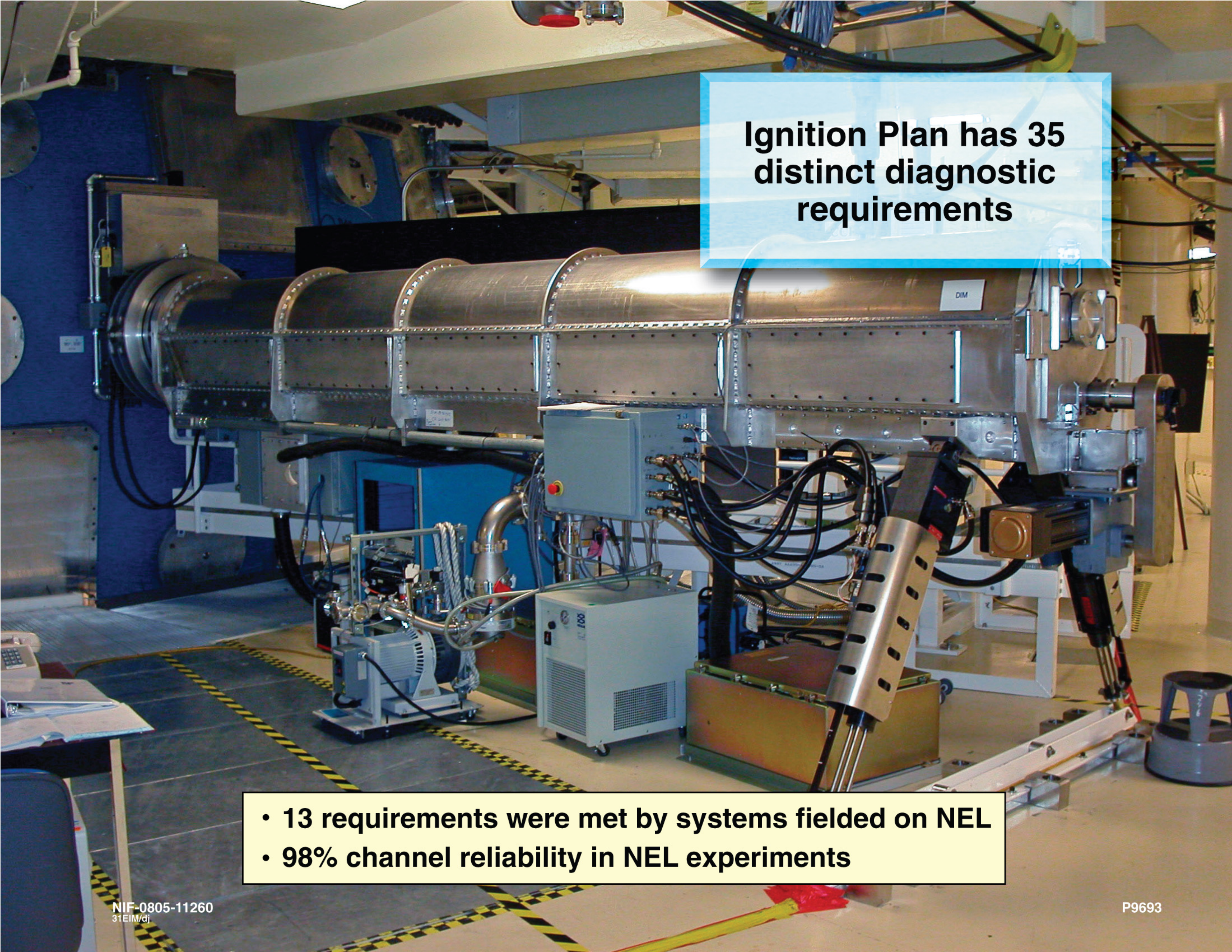


NIF-0805-11232r11
16EIM/dj

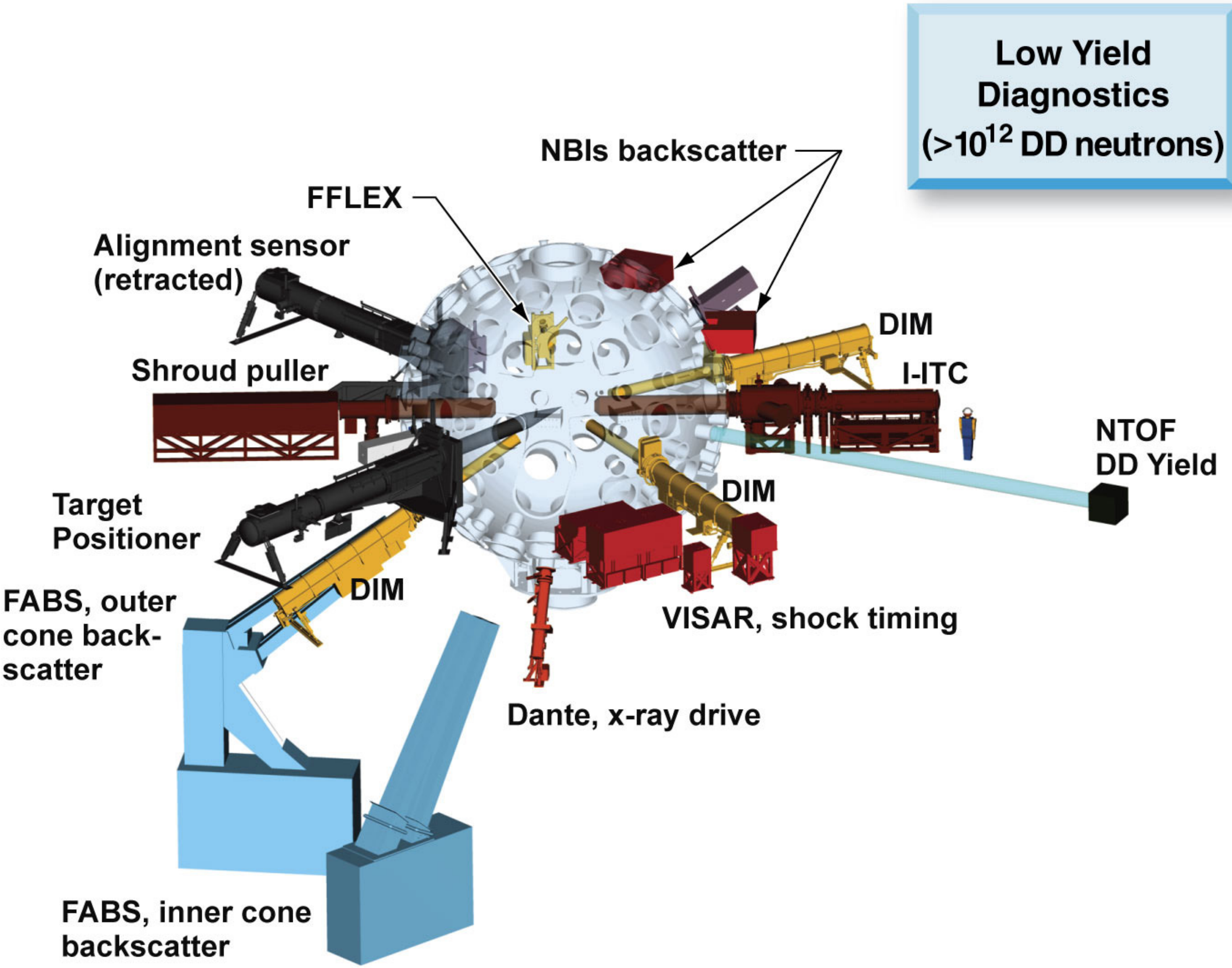


NIF-0107-13276
27LJA/sb

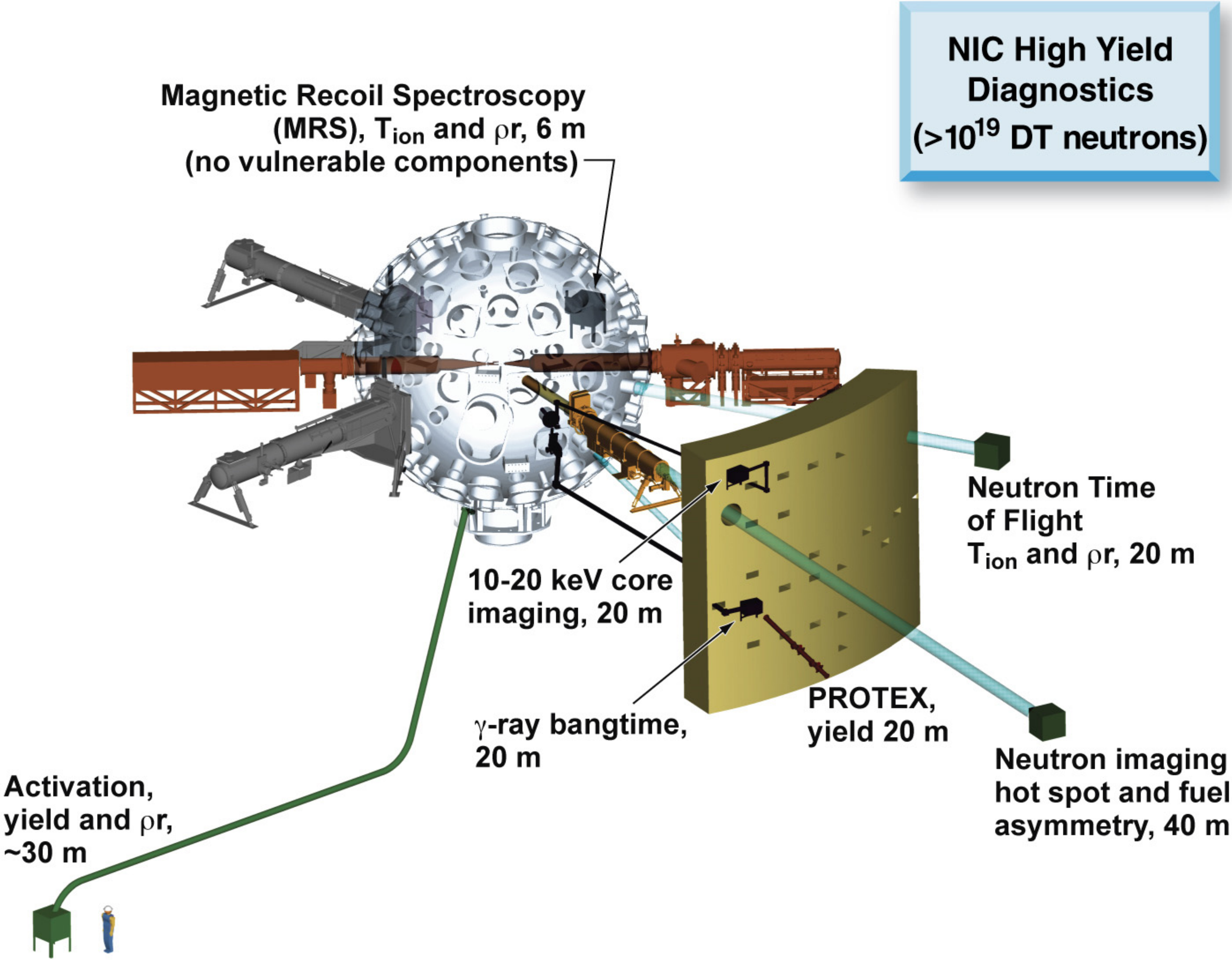
Ignition Plan has 35 distinct diagnostic requirements



- 13 requirements were met by systems fielded on NEL
- 98% channel reliability in NEL experiments



NIF-0506-12000
14EIM/dj



NIF-0506-12001
14EIM/dj

Multiple ARC radiographs at intervals ~20 – 80 ps with ~10 ps exposure times would produce valuable time-history data (Phys. Rev. Lett. worthy)

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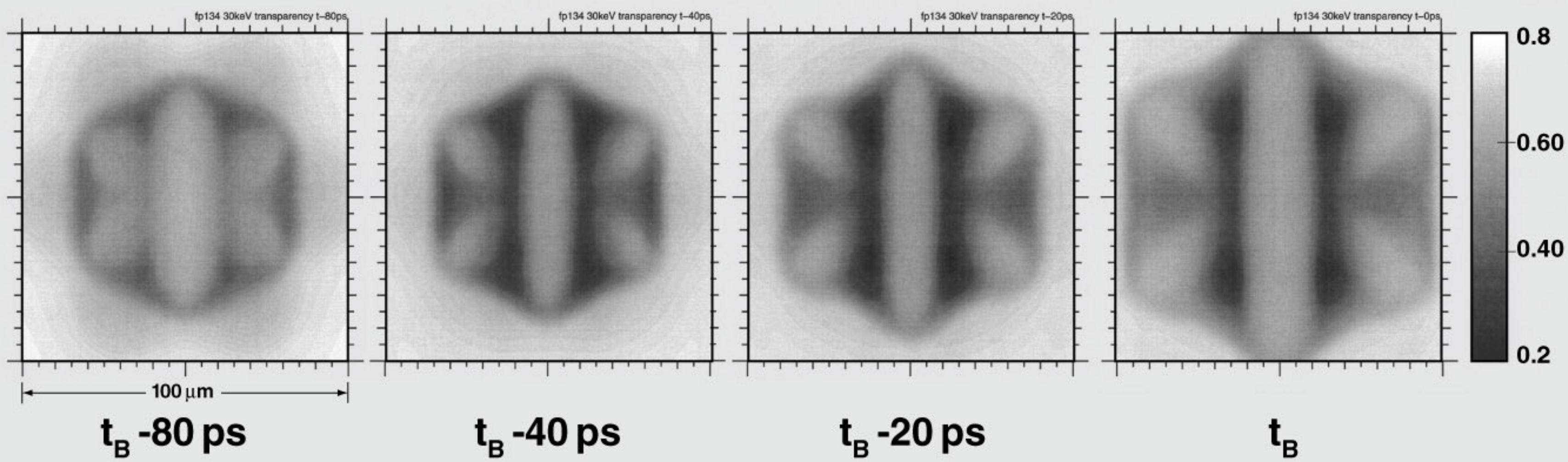
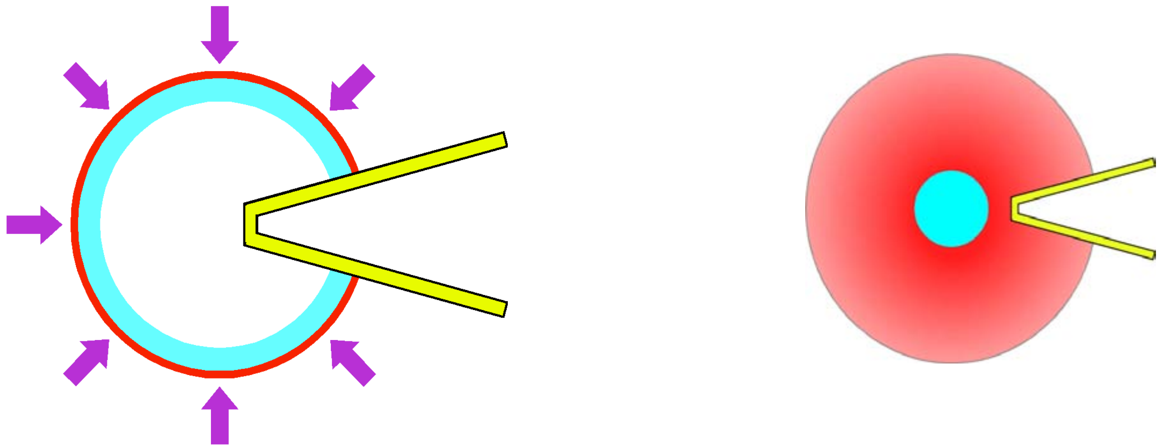
ARC Radiographs (same gray scale at all times)



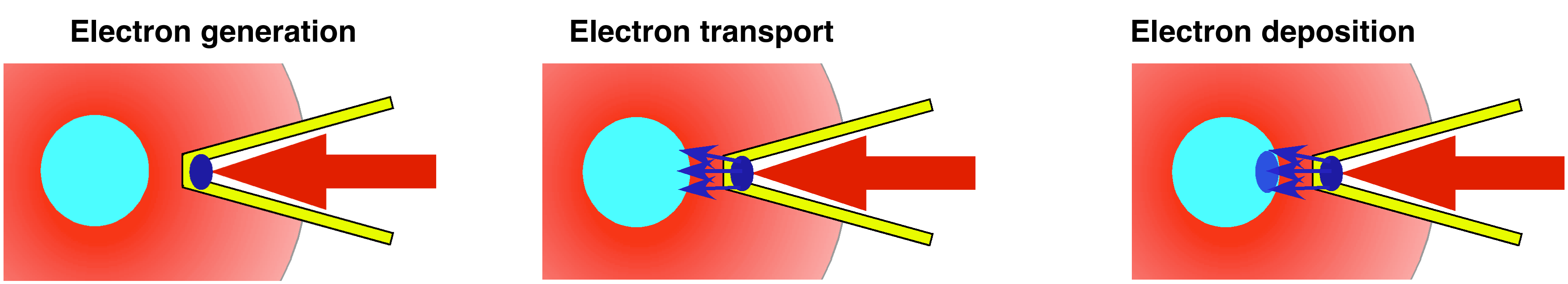
Multiple ARC images combined with reaction history and primary neutron imaging provide detailed core diagnostics

Fast ignition, which separates the fuel compression and ignition, will be tested on NIF

- **The compression laser assembles the fuel to uniform, high density:**



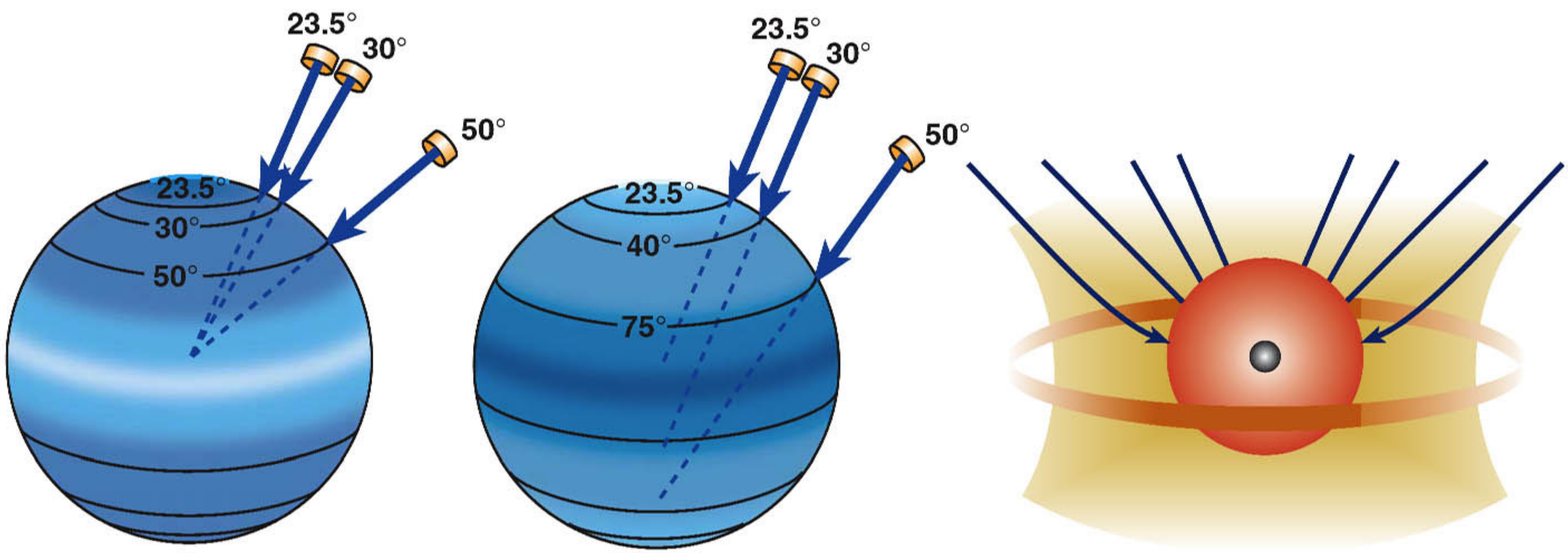
- **The ignition laser generates hot electrons that propagate through to the dense fuel and deposit their energy initiating a burn wave:**



Direct drive can achieve ignition conditions while NIF is in the x-ray-drive configuration

UR LLE

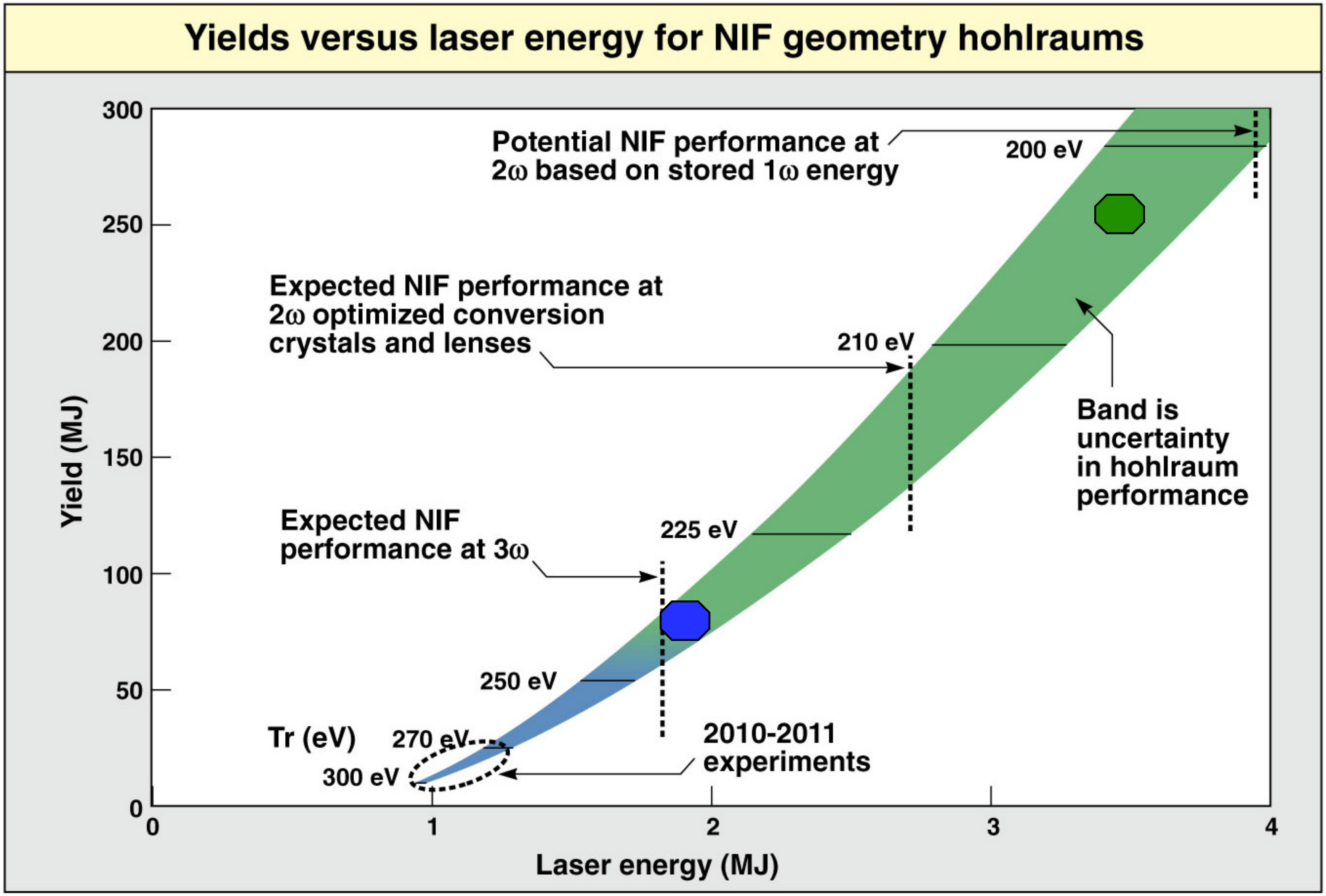
Standard pointing with x-ray-drive configuration	Repointing for polar direct drive (PDD)	Saturn concept



Experimental and theoretical progress gives increasing confidence in achieving PDD ignition.

F. J. Marshall FO26.2, S. Skupsky poster

Ultimately, yields well in excess of 100 MJ may be possible on NIF



NIF-0107-13186
26JL/cld

Is NIF a precursor to an Inertial Fusion Energy plant?

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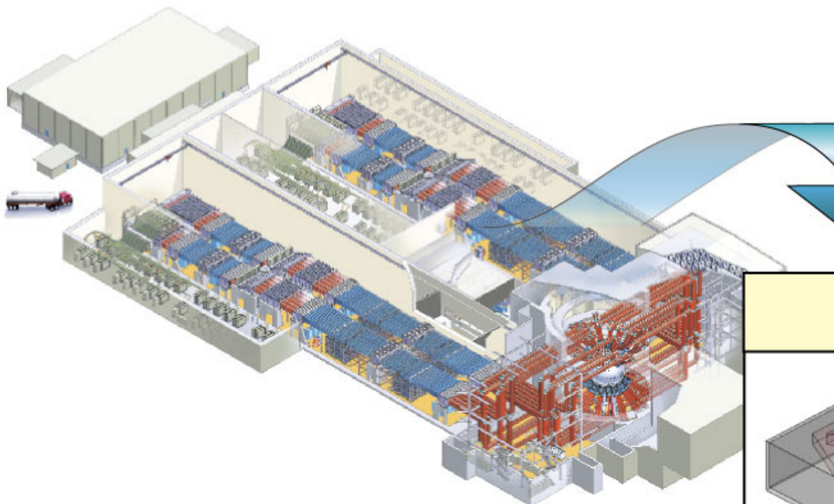
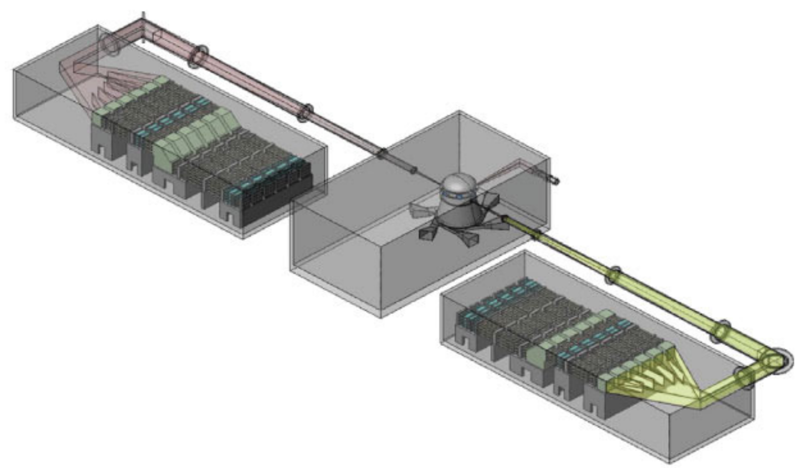
NIF (2 MJ)



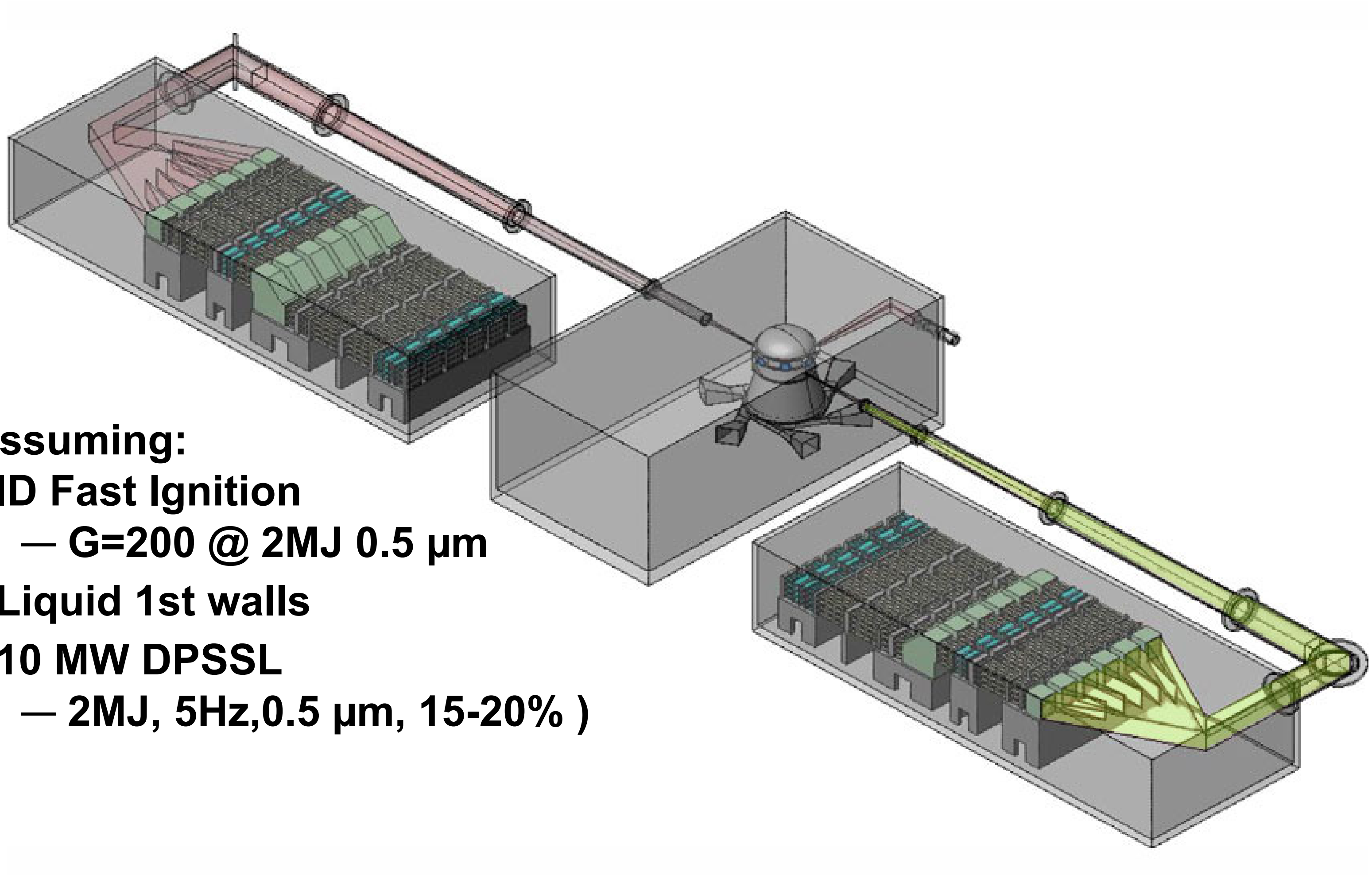
Repetition frequency 10-4 Hz
Electrical efficiency 0.5%

LIFE (20 MW)

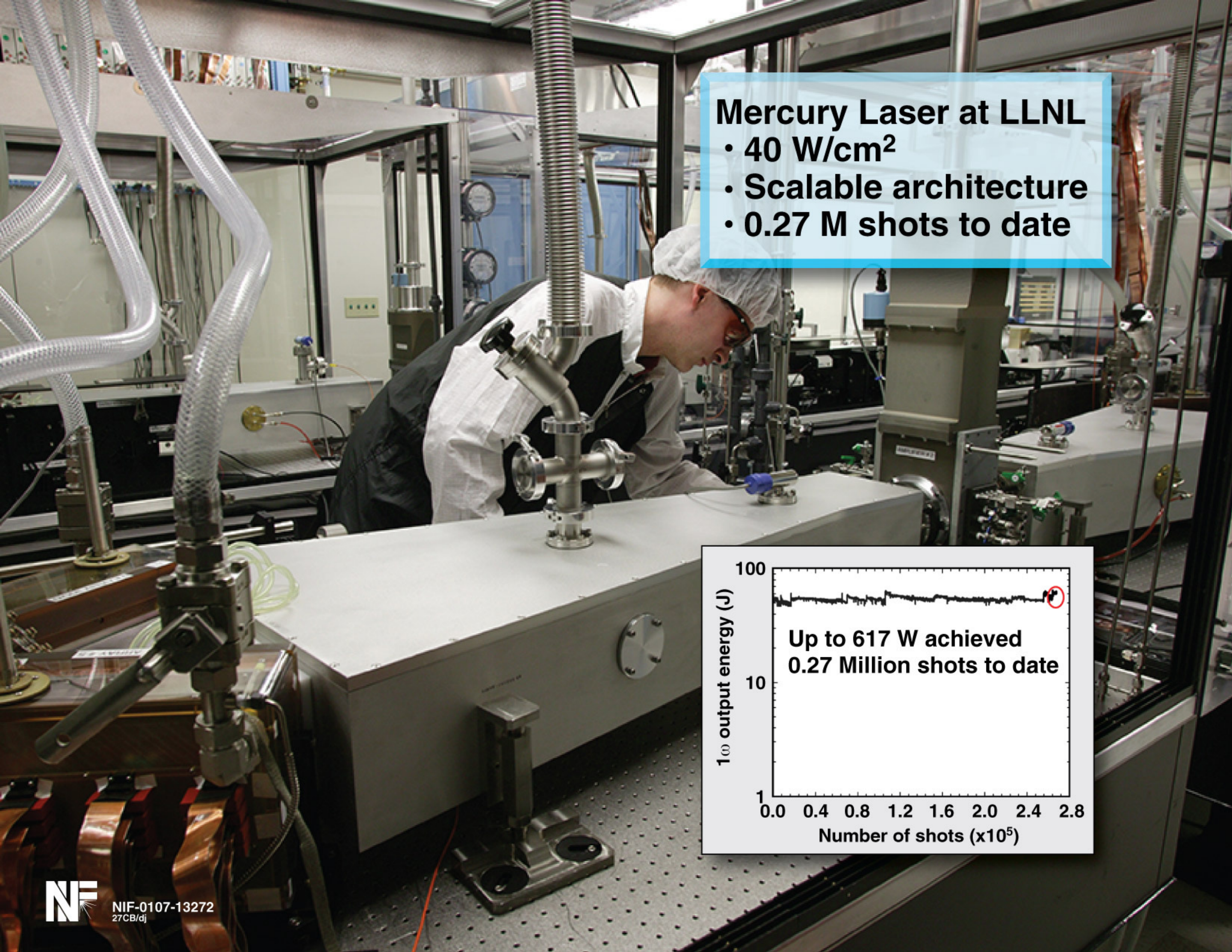


Repetition frequency 5 Hz
Electrical efficiency 20%

We have performed a systems study of a 1 GWe IFE power plant

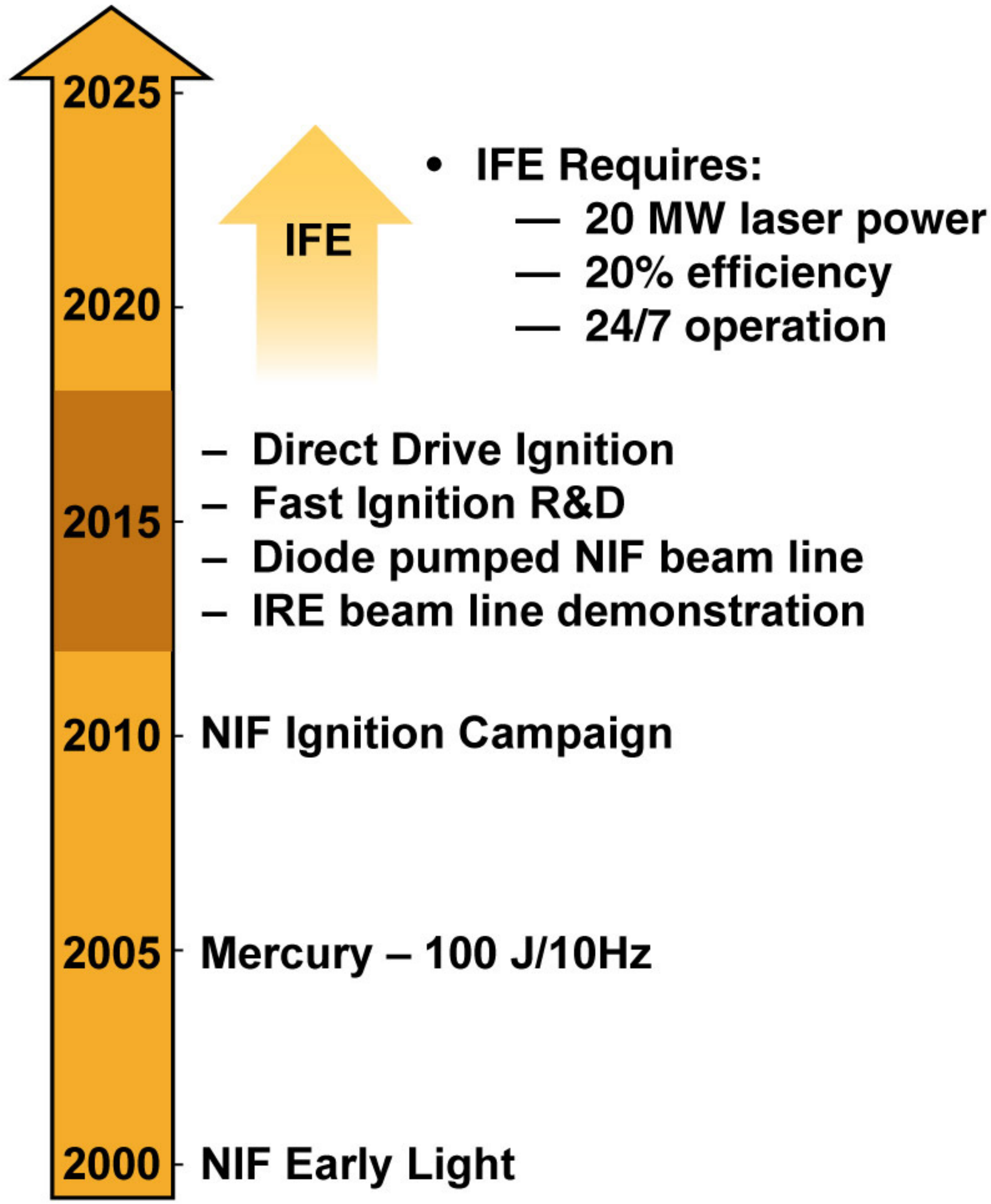


Assuming:
- **ID Fast Ignition**
  - **— G=200 @ 2MJ 0.5 µm**
- **Liquid 1st walls**
- **10 MW DPSSL**
  - **— 2MJ, 5Hz,0.5 µm, 15-20%)**


Mercury Laser at LLNL
• 40 W/cm²
• Scalable architecture
• 0.27 M shots to date
1ω output energy (J)
100
10
1
0.0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
Number of shots (x10⁵)
Up to 617 W achieved
0.27 Million shots to date
NIF-0107-13272
27CB/dj

Leveraging the NIF provides a near-term pathway for fusion energy

The National Ignition Facility

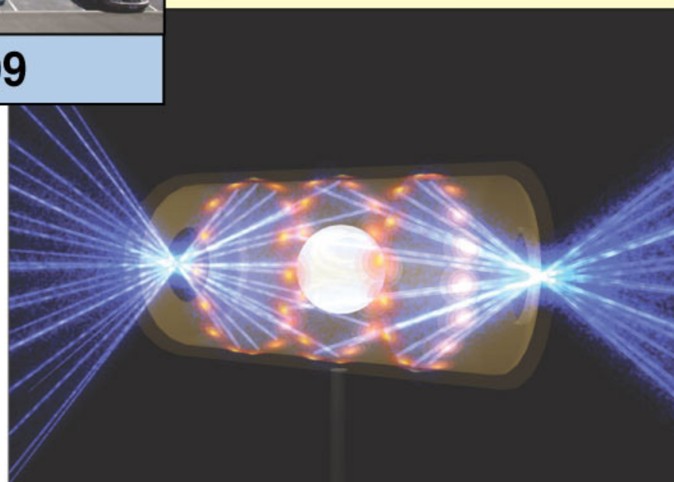


NIF Master Strategy

NIF Project

Completion in 2009

National Ignition Campaign



2006—2012

National User Facility

2009—2030

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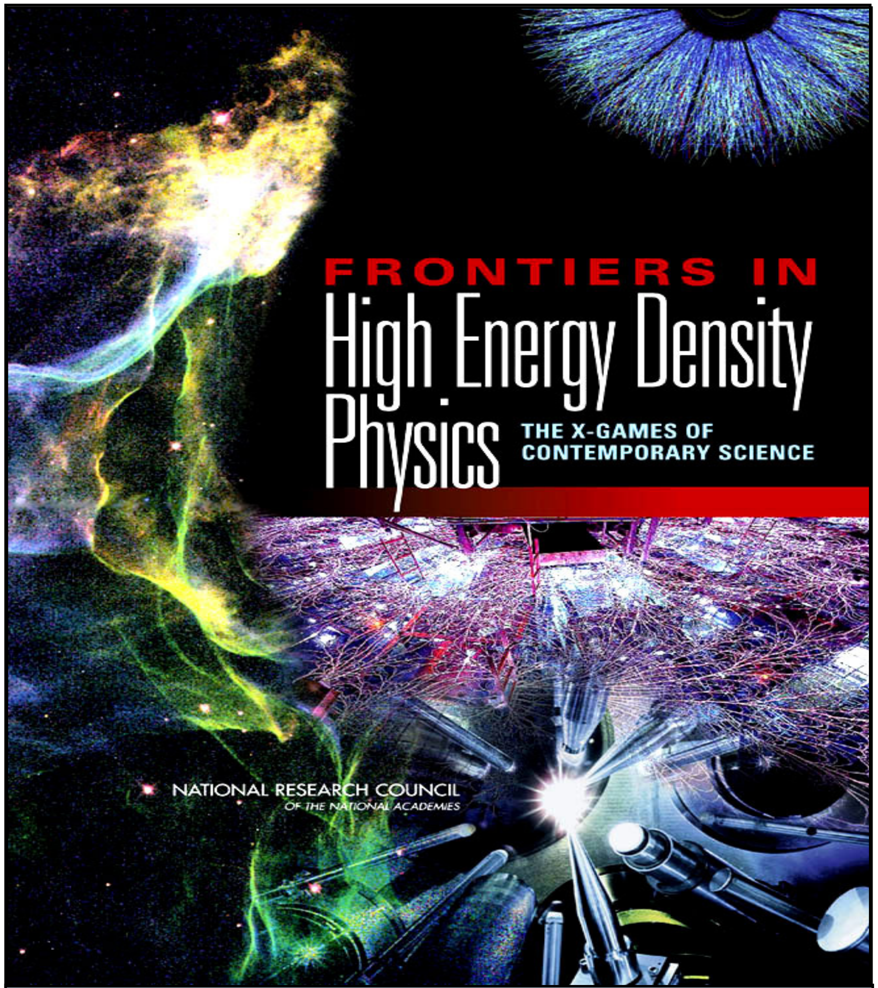
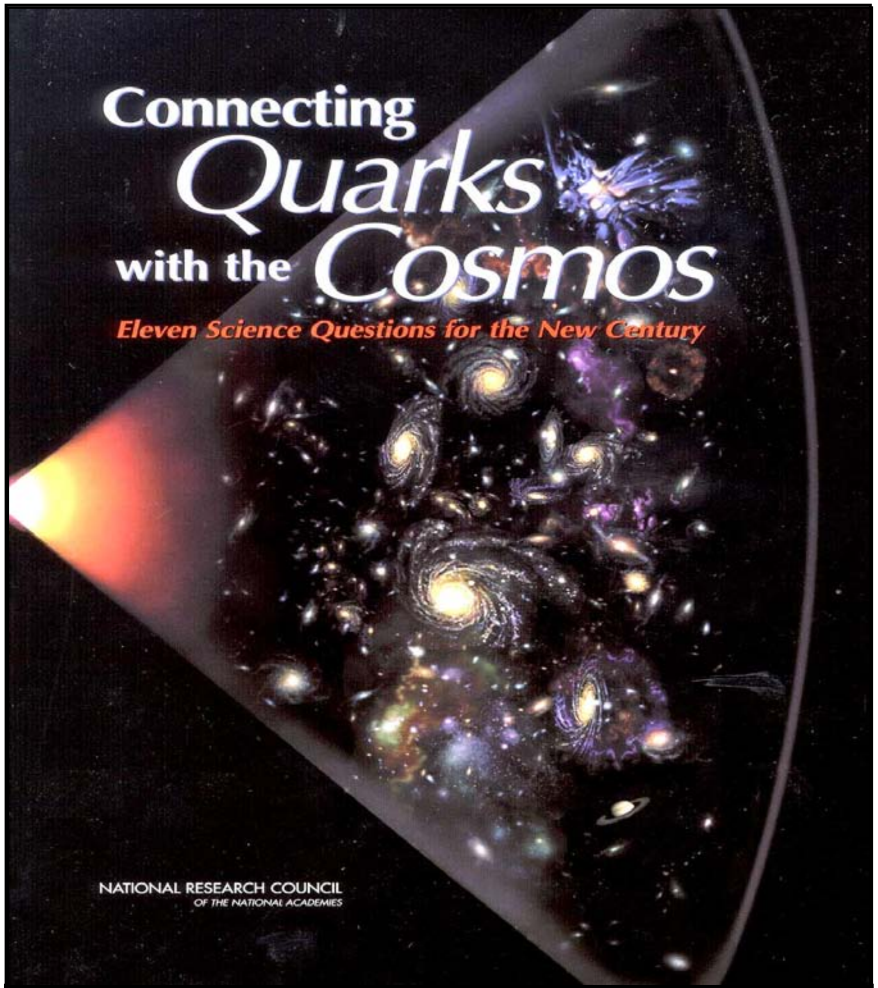
NIF can play a key role in international science vision



NRC committee on HEDP: X-Games of Contemporary Science

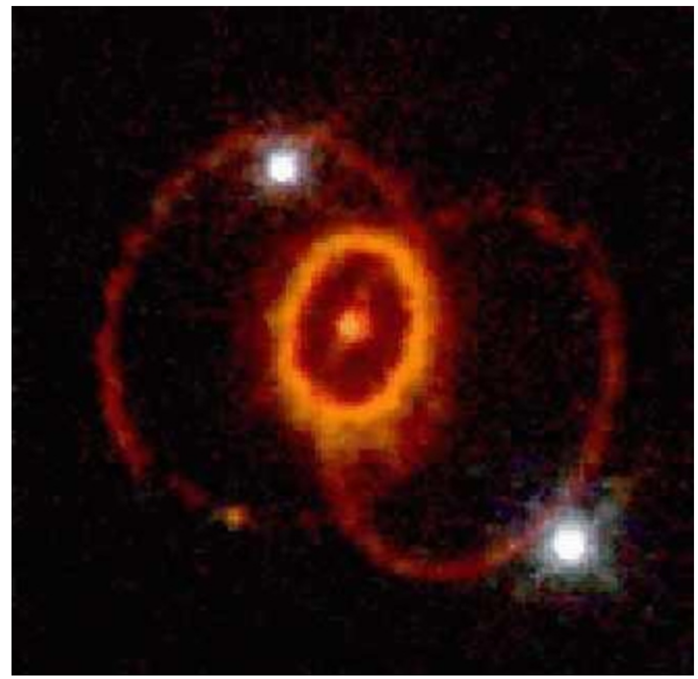


NRC committee on the Physics of the Universe

NIF's Scientific Environments

The National Ignition Facility

- These are the conditions of Extreme Laboratory Astrophysics
  - $T > 10^8$ K matter temperature
  - $\rho > 10^3$ g/cc density
  - Those are both 7x what the Sun does! Helium burning, stage 2 in stellar evolution, occurs at 2×10^8 K!
- Core-collapse Supernovae, colliding neutron stars, operate at $\sim 10^{20}$ n's/cc
  - NIF: $\rho_n = 10^{26}$ neutrons/cc
- These apply to Type Ia Supernovae!
  - Electron Degenerate conditions
  - Rayleigh-Taylor instabilities for (continued) laboratory study.
- Only need ~Mbar in shocked hydrogen to study the EOS in Jupiter & Saturn
  - Pressure $> 10^{11}$ bar

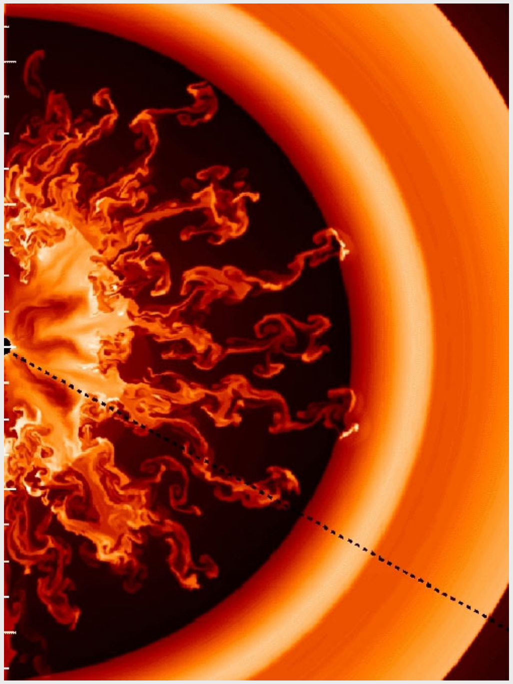


These certainly qualify as "unprecedented."

Three university teams are starting to prepare for NIF shots in unique regimes of HED physics

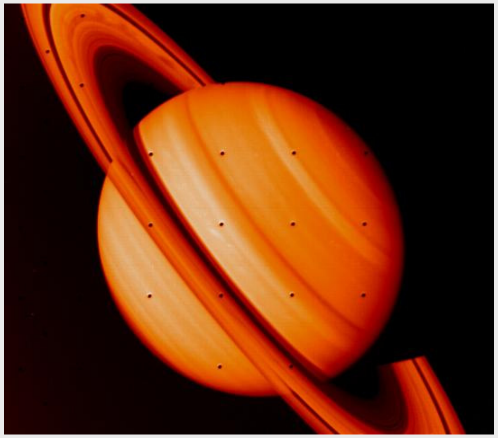
The National Ignition Facility

Astrophysics - hydrodynamics



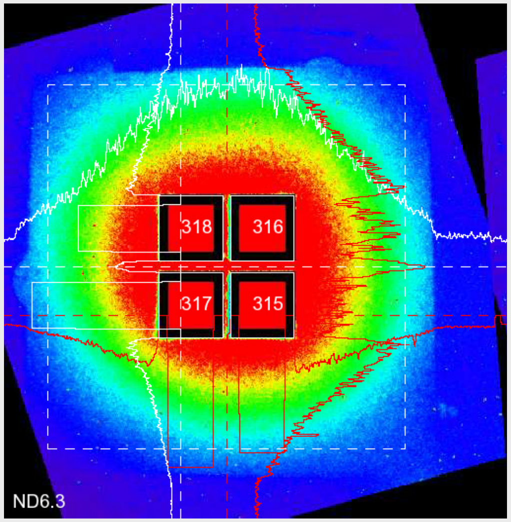
Paul Drake, PI, U. of Mich.
David Arnett, U. of Arizona,
Adam Frank, U. of Rochester,
Tomek Plewa, U. of Chicago,
Todd Ditmire, U. Texas-Austin
LLNL hydrodynamics team

Planetary physics - EOS



Raymond Jeanloz, PI, UC Berkeley
Thomas Duffy, Princeton U.
Russell Hemley, Carnegie Inst.
Yogendra Gupta, Wash. State U.
Paul Loubeyre, U. Pierre & Marie Curie, and CEA
LLNL EOS team

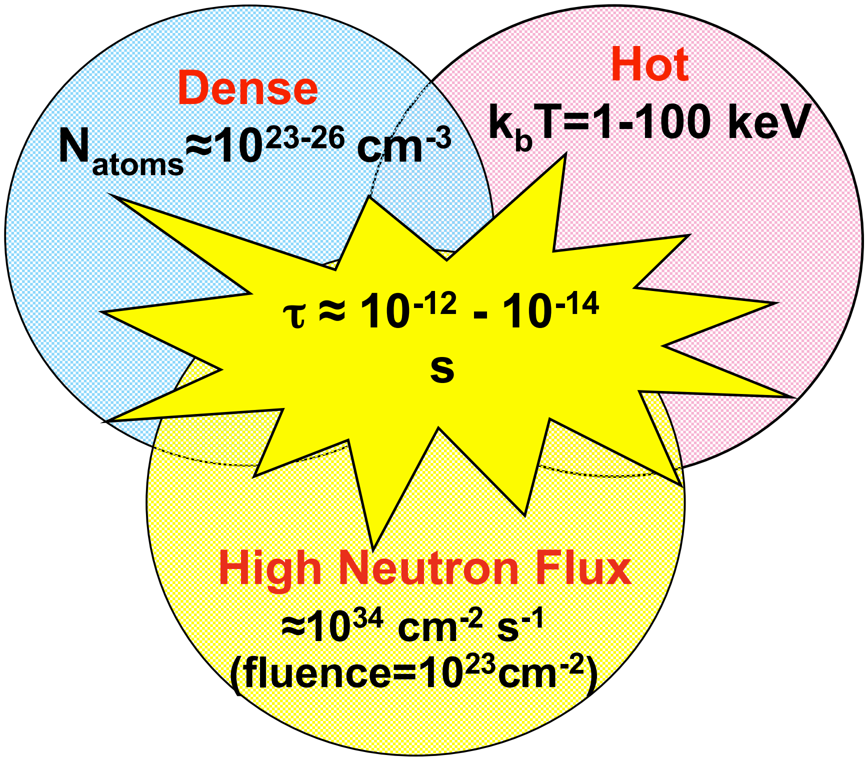
Nonlinear optical physics - LPI



Christoph Niemann, PI, UCLA NIF Professor
Chan Joshi, UCLA
Warren Mori, UCLA
Bedros Afeyan, Polymath
David Montgomery, LANL
Andrew Schmitt, NRL
LLNL LPI team

Nuclear science on NIF

- **Unique conditions on NIF will enable studying:**
  - **Dynamics of nuclei in excited states**
  - **Charged particle reactions relevant to nucleosynthesis**
  - **Solar neutrino physics**



A working group has been formed including: LLNL (Schneider), LBNL (Phair), UCB (Moretto), Univ. Notre Dame (Wischer), Colorado School of Mines (Greife), GSI, University of Oslo

NIF's planning supports DOE's goals for "civilian research" and NNSA-SC partnering

Orbach knows that change doesn't come easily for areas, such as nuclear weapons development, that have traditionally been walled off from civilian research. In initial meetings with applied-research managers, he admits, "people don't quite know what to make of us." But Edward Moses, director of the National Ignition Facility, a superlaser at Lawrence Livermore National Laboratory in California, says Orbach is helping him grow a civilian research community to utilize an instrument designed to maintain the nation's nuclear arsenal.

Science Sept 29 Issue, p1874

Ray Orbach Asks Science to Serve Society

For a decade, chemist Radoslav Adzic has explored the basic structure of metal-electrolyte interfaces at Brookhaven National Laboratory in Upton, New York. His employer, the U.S. Department of Energy (DOE), has long sponsored fundamental science on catalysis in such systems in hopes of making hydrogen fuel cells efficient enough to one day replace fossil fuels as an energy source. But it wasn't until 2004 that Adzic decided to tackle a research question with more direct applications: how to use monolayers of platinum to build cheaper fuel cells, focusing on hydrogen.

It wasn't a random decision. The year before, President George W. Bush had proposed an 8-year, $1.2 billion hydrogen fuels program that would begin with applied engineering studies. After attending a DOE-sponsored workshop to discuss the basic research needed to turn hydrogen into a commercially viable fuel, Adzic won a $700,000 grant to study [illegible]

[illegible] search could better fulfill energy needs. A 1997 report by the President's Council of Advisors on Science and Technology, for example, called for "better coordination" between basic and applied energy research. "Everyone knows it's a problem, but nothing's happened," says physicist George Crabtree, a manager at DOE's Argonne National Laboratory in Illinois.

One obstacle is the current rewards system in academia. Take the science behind superconductivity, which holds the promise of low-resistance power lines or incredibly efficient transformers. The kind of discovery that earns a scientist a paper in a top journal—learning why a material changes phase at a certain temperature—is too theoretical to help a company trying to make superconducting materials. But a commercially valuable yet incremental improvement in that technology wouldn't interest those top-tier journals. So a scientist might not even bother to record such an advance. "If the currency is just *PRL* [*Physics Review Letters*], *Nature*, and *Science*, you'll just move on," says materials scientist John Sarrao of Los Alamos National Laboratory in New Mexico.

Another barrier to developing new technologies, says Bodman, is DOE's current compartmentalized bureaucracy. In July, he sent out a memo giving Orbach "detailed access" to DOE's vast empire, hoping that regular meetings among disparate programs will break through that mentality. It's not a new concept, Orbach says, but "what's new is the intensity and importance" of those meetings.

Money greases the wheels of cooperation. In addition to the hydrogen initiative and a similar effort in solar energy, Orbach has called for $250 million for biofuel start-ups involving industrial scientists, technologists, and genomicists (*Science*, 11 August, p. 746). Sharlene Weatherwax, a DOE program manager, says a previous partnership with DOE's technology program might have consisted of a single grant.

Orbach knows that change doesn't come easily for areas, such as nuclear weapons development, that have traditionally been walled off from civilian research. In initial meetings with applied-research managers, he admits, "people don't quite know what to make of us." But Edward Moses, director of the National Ignition Facility, a superlaser at Lawrence Livermore National Laboratory in California, says Orbach is helping him grow a civilian research community to utilize an instrument designed to maintain the nation's nuclear arsenal.

Some fear that such cross-fertilizing could weaken basic science at DOE. "There is a danger of letting the basic program become a technical-

Teammates. Ray Orbach (*left*) hopes researchers can help his boss, Energy Secretary Samuel Bodman, (*right*) do his job, too.

support enterprise for the applied programs," says energy expert Robert Fri, a former Environmental Protection Agency official who believes unfettered basic work can "cook up" whole new energy ideas. Materials scientist Ward Plummer of the University of Tennessee, Knoxville, decries a 20% decline in funding core, unsolicited research within DOE's Office of Basic Energy Sciences in the last 3 years at the same time that solar energy, nanotechnology, and hydrogen programs have grown.

Plummer and others hope that DOE's new effort to define so-called grand challenges will stop that erosion. And although Orbach says he has no plans to "fuzz the boundaries" between basic and applied work, he is looking for greater cooperation between the two camps. A recent discussion with managers studying how fluids flow in dry soil at DOE's planned nuclear waste fuel repository at Yucca Mountain, Nevada, proves its value, he says. "When we met with Fossil Energy and learned more about carbon dioxide sequestration," Orbach recalls, "it suddenly popped out that that's the same problem."

Whatever happens, Orbach says DOE is determined to squeeze more impact out of its science. That's good news for Adzic, who relishes taking on challenges "directly important to society." It's also a good deal for academics. "If you publish something relevant" to a problem, says Adzic, "your paper is more [often] cited."

–ELI KINTISCH

CREDIT: DOE

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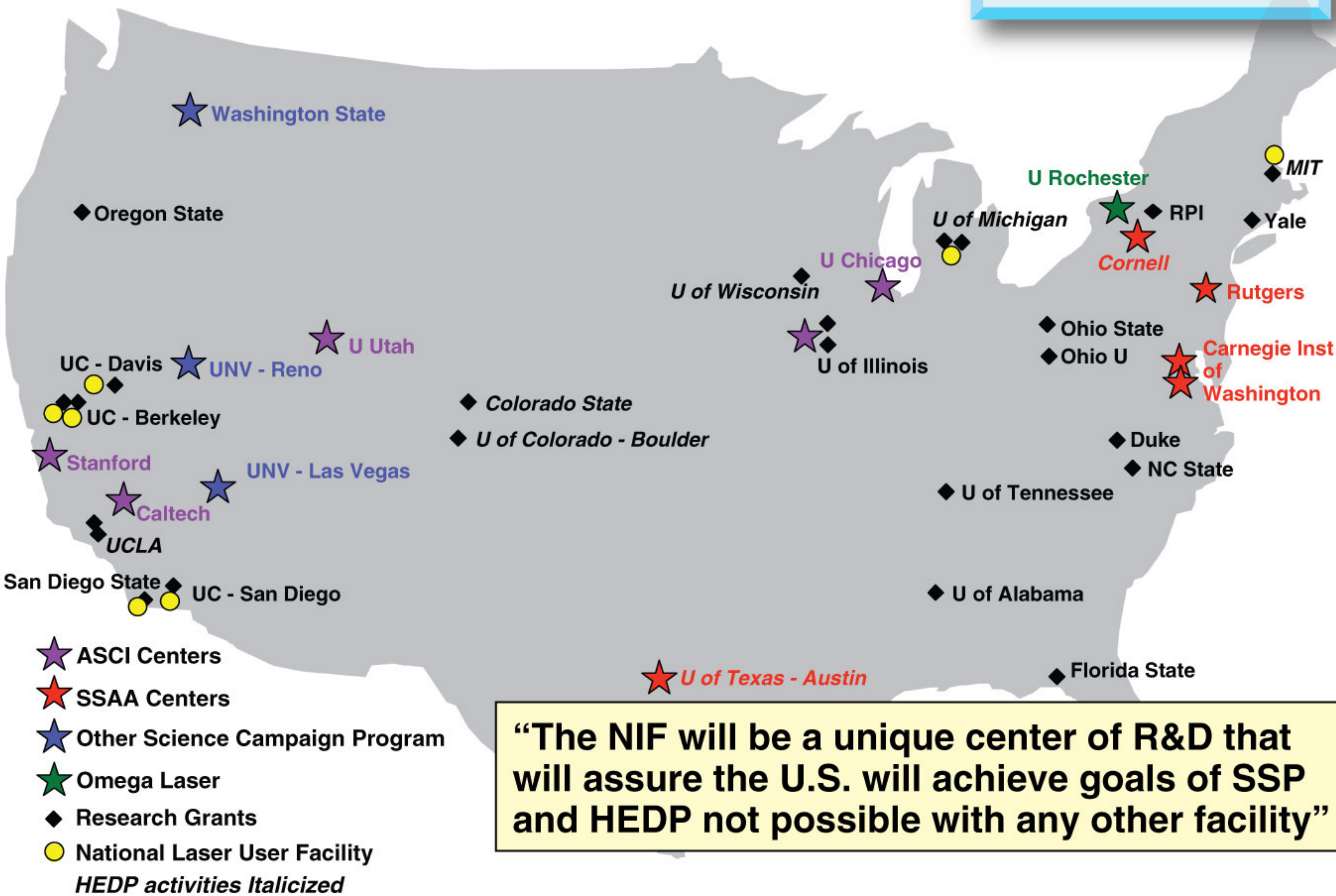
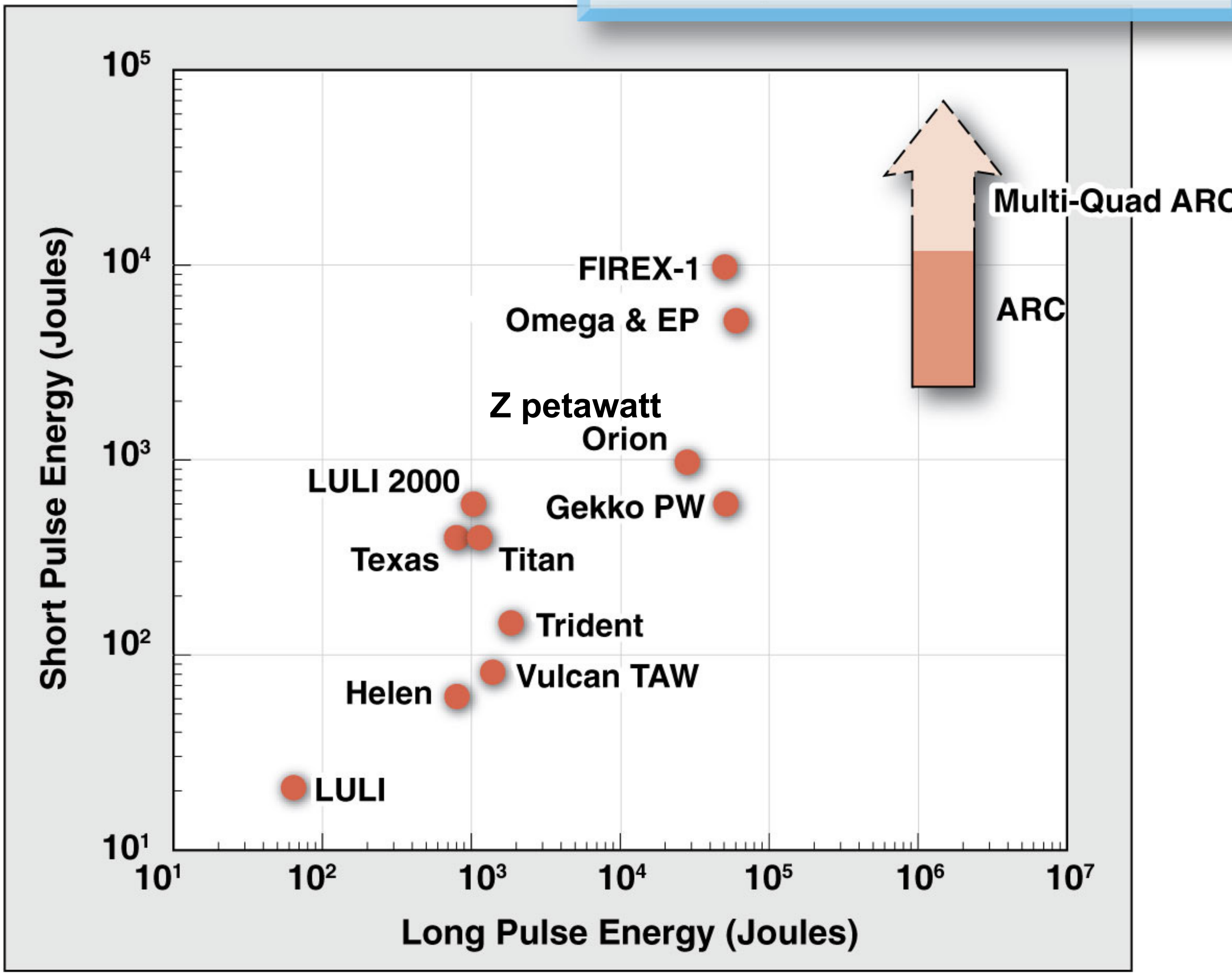


"The NIF will be a unique center of R&D that will assure the U.S. will achieve goals of SSP and HEDP not possible with any other facility"

NIF will be an integral member of the HED community



Our goal: turn NIF into the premier international center for HED experimental science

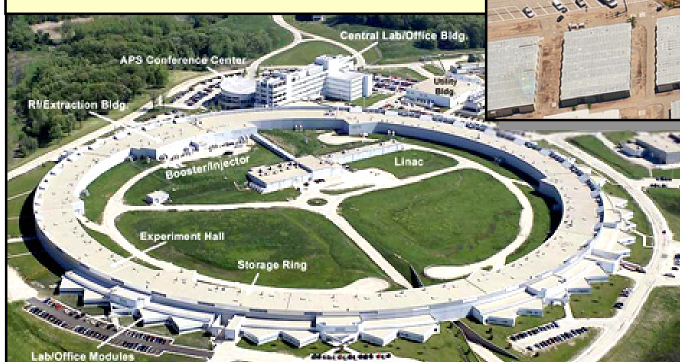
The National Ignition Facility

CERN

Chandra X-ray Observatory

NIF

APS



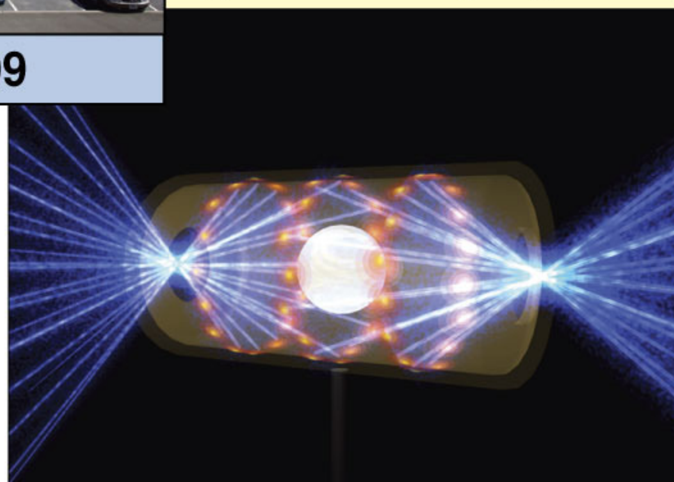
SLAC

NIF is a National User Facility

NIF Project

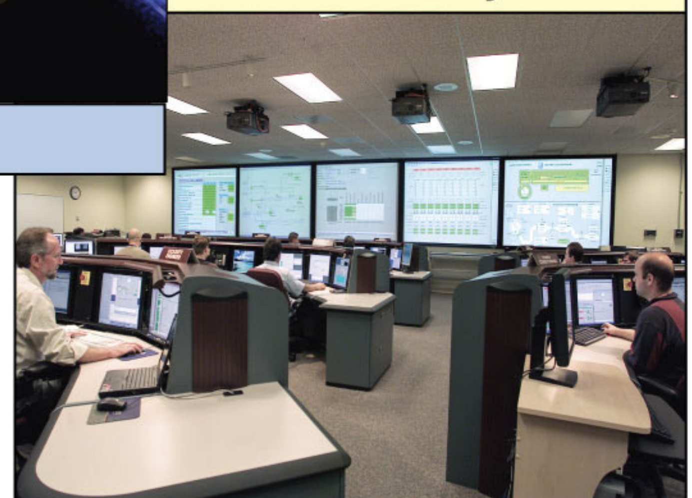
Completion in 2009

National Ignition Campaign



2006—2012

National User Facility



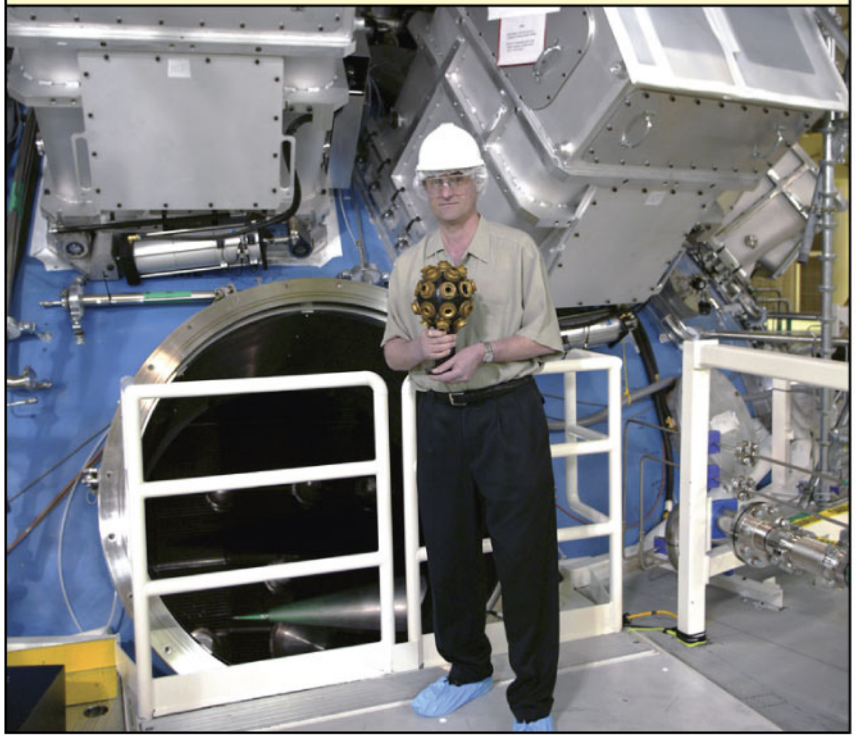
2009—2030

- A “Governance Model” is under development
- User friendly environment is being designed

NIF: Visions of yesterday become reality of today

The National Ignition Facility

1960's – Invention of Laser



2010 – Goal of Ignition

Ignition by 2010
Golden Anniversary of the Invention of the Laser and the ICF Concept

The National Ignition Facility

Limitless Clean Energy
Eye on the Cosmos

NATIONAL IGNITION FACILITY


Oct ’03
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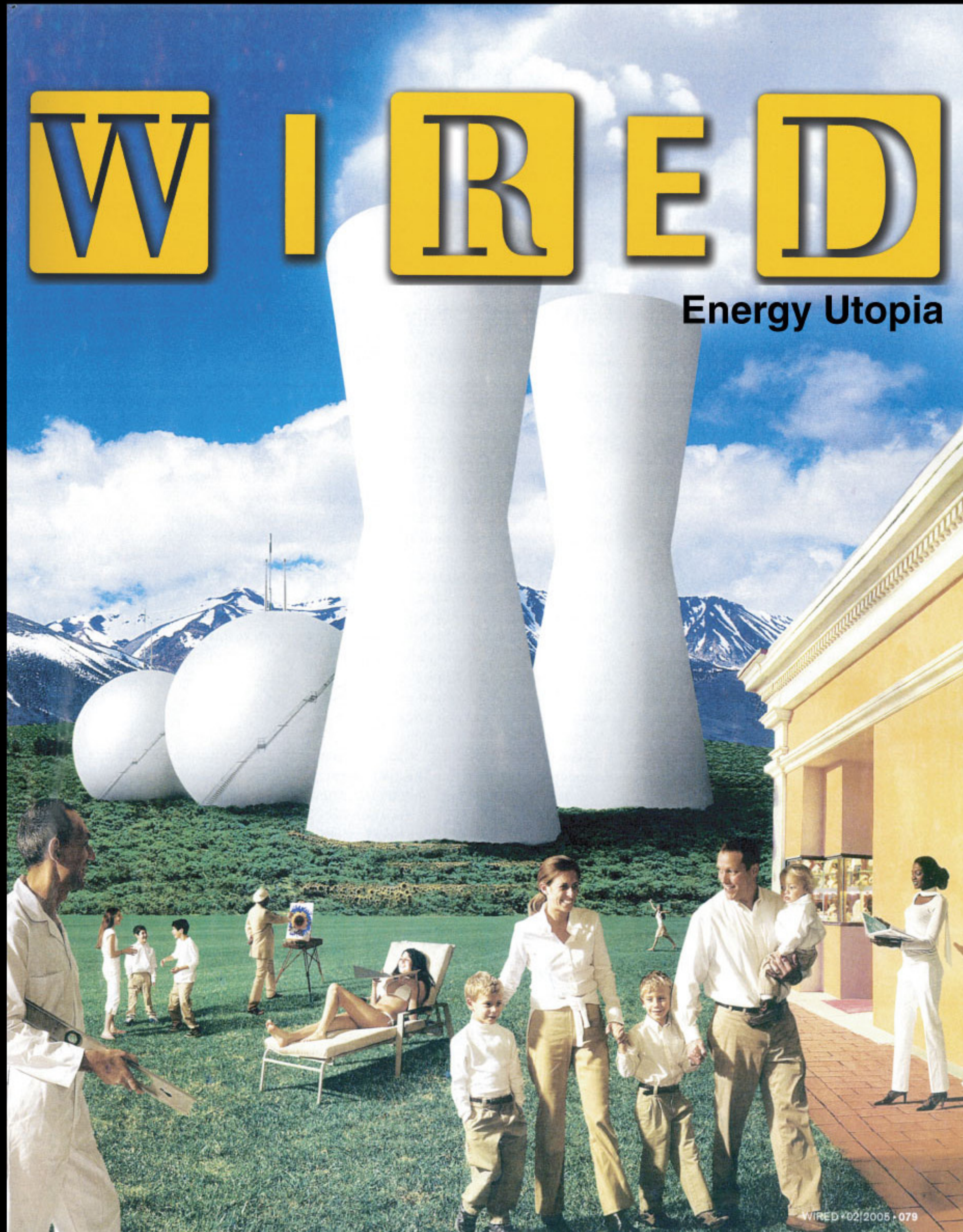
NIF-1106-12924
01EIM/mfm


Fossil Fuels Can't Keep Up and their Climatic Effects Could be Devastating



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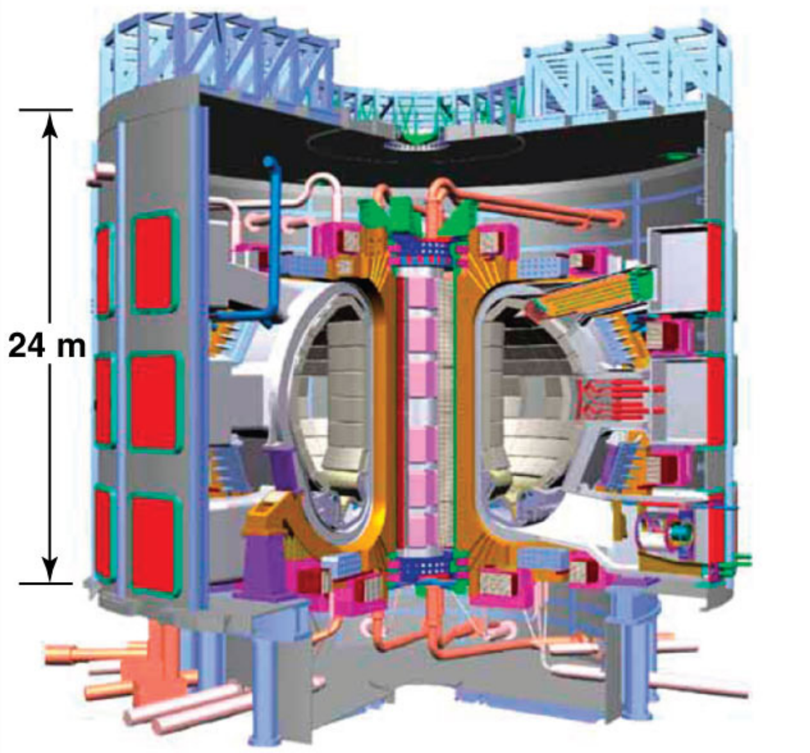
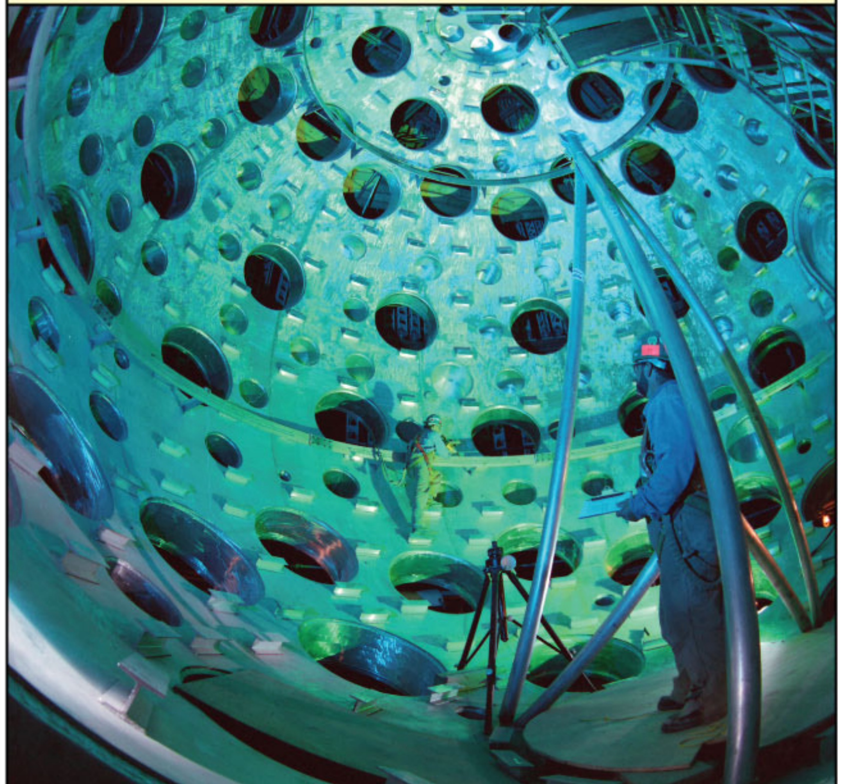
There are two major possibilities for fusion energy

The National Ignition Facility

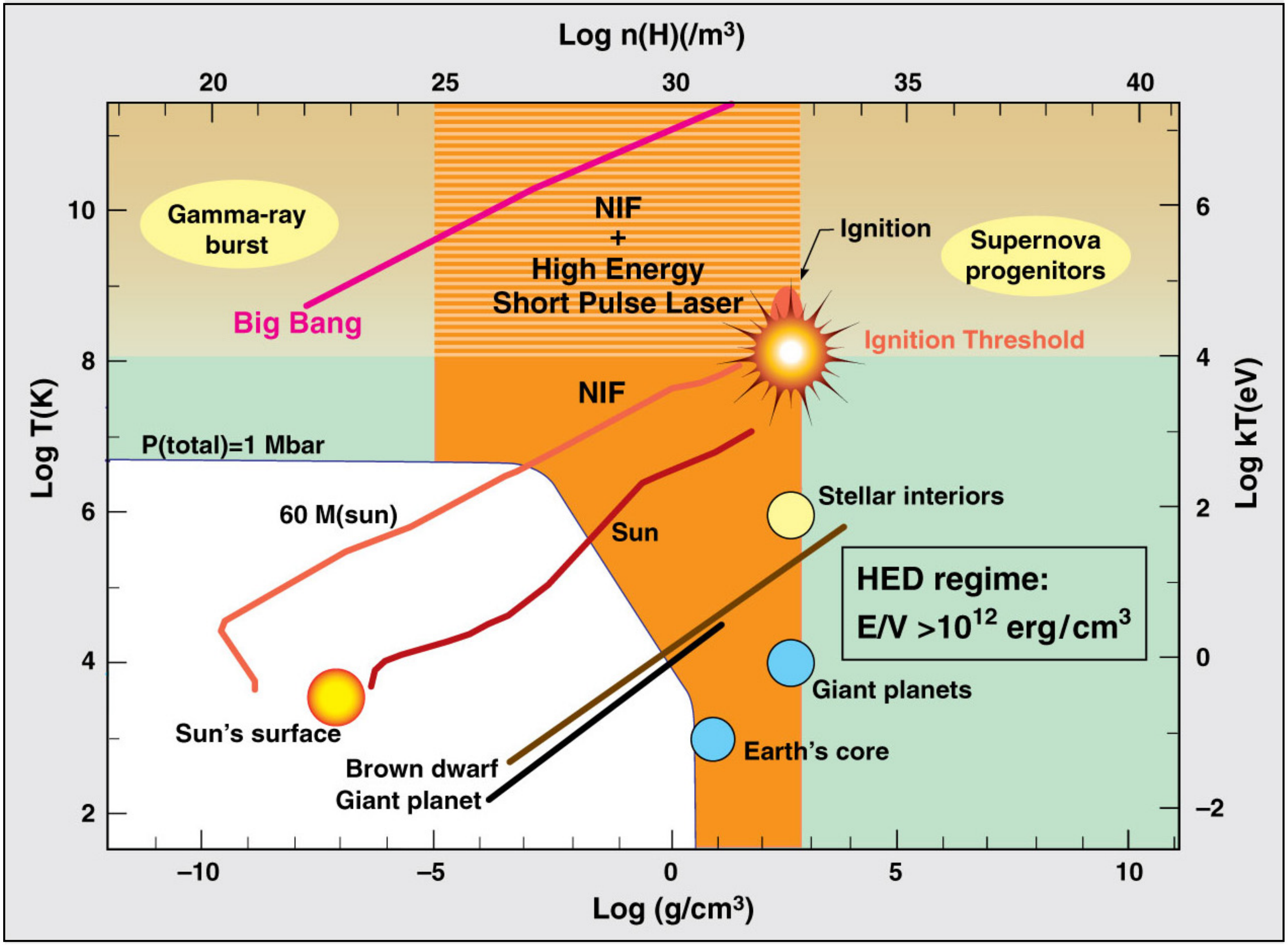
Magnetic Fusion Energy (1951)	Inertial Fusion Energy (1960)
	
DOE Office of Science	DOE NNSA

Challenges include making it safe, reliable, and cost effective


National Ignition Facility
Three Years to a New Age for Science

NIF provides unique environment for science

The National Ignition Facility



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