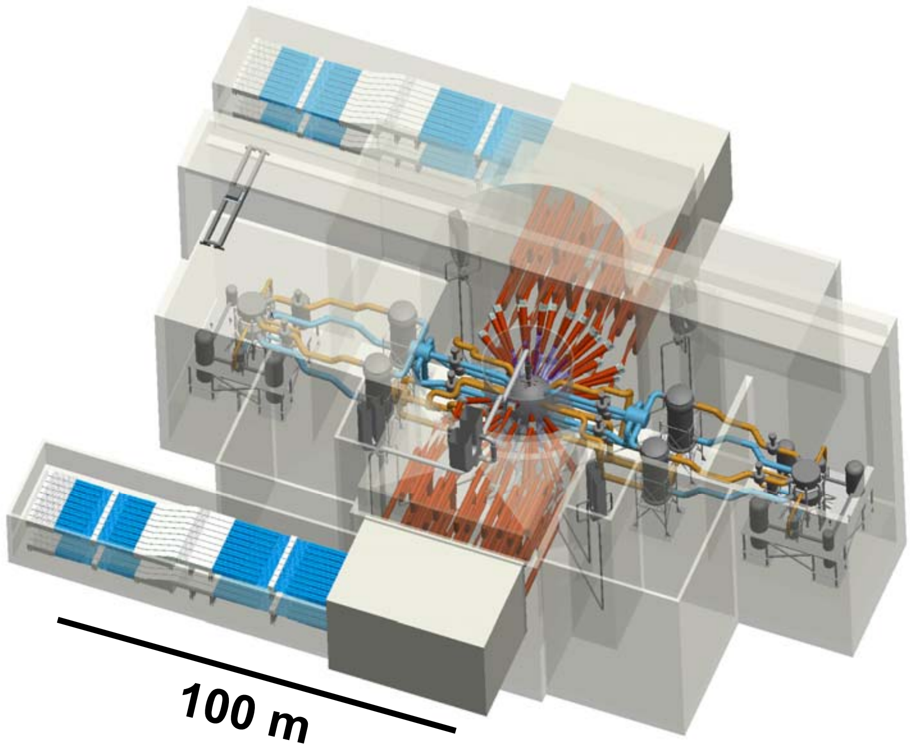
LIFE – Laser Inertial Fusion Energy based systems for electricity production and waste burning

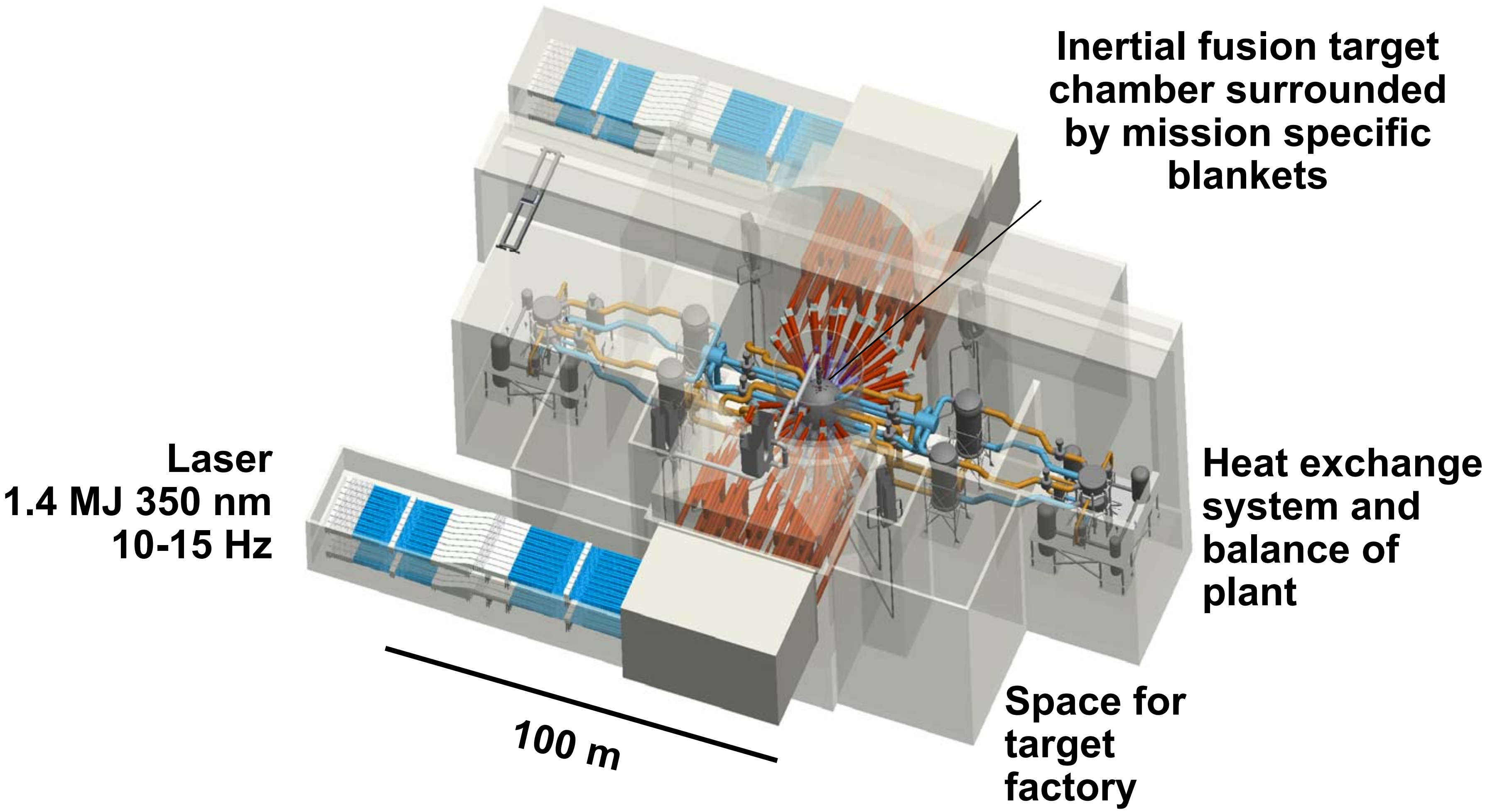


March 10, 2009

Erik Storm

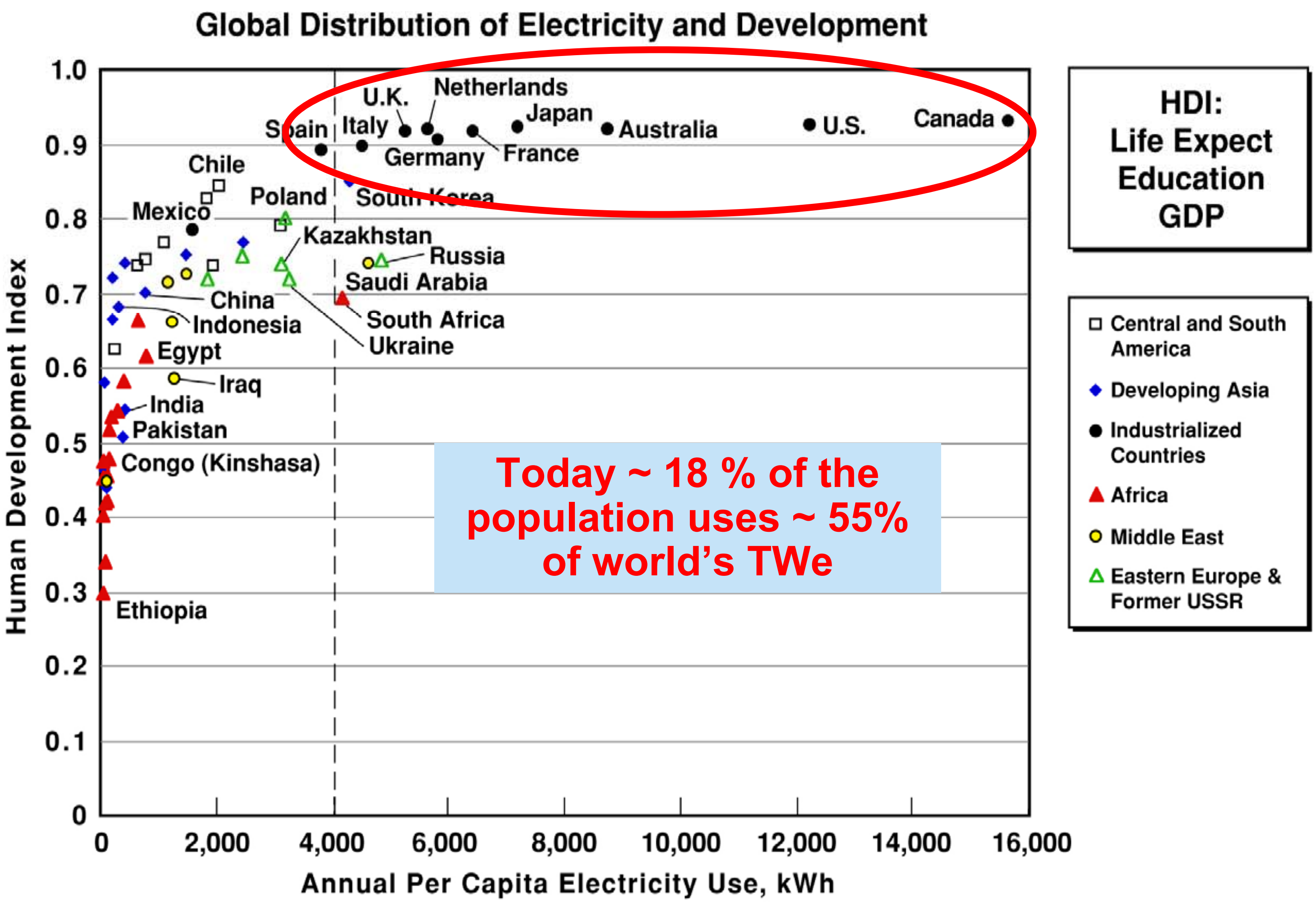
This work was performed under the auspices of the U.S. Department of Energy by
Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

One of LIFE’s goals is to provide an option for a once-through closed nuclear fuel cycle



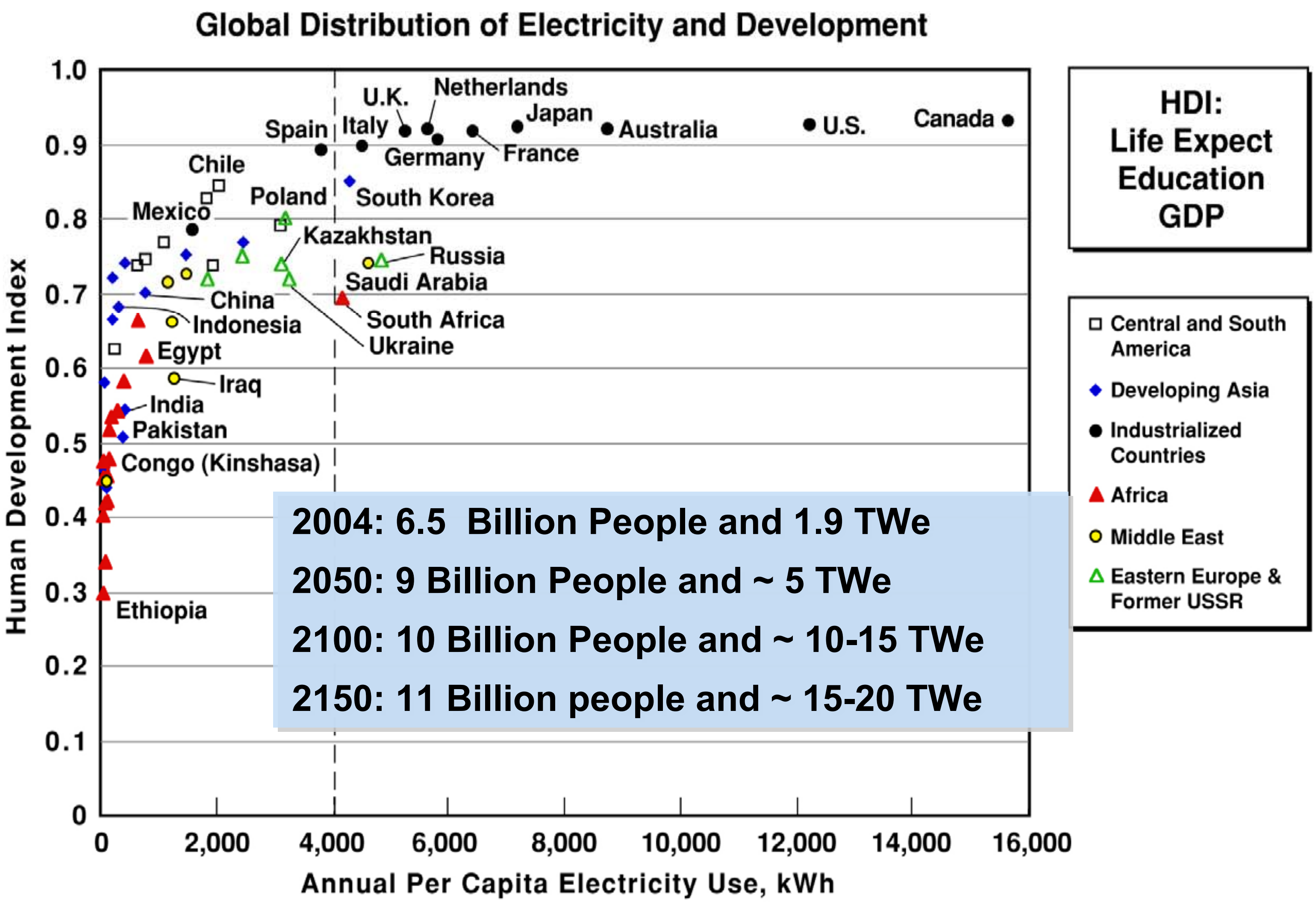
LIFE could provide the bridge from today’s nuclear power to a pure fusion option later in this century

The energy picture is not sustainable when we factor in future changes in global standard of living



Source: Pasternak, "Global Energy Futures and Human Development: A Framework for Analysis"

We will see significant increase in electricity demand as the rest of the world moves up the economic ladder



2004: 6.5 Billion People and 1.9 TWe

2050: 9 Billion People and ~ 5 TWe

2100: 10 Billion People and ~ 10-15 TWe

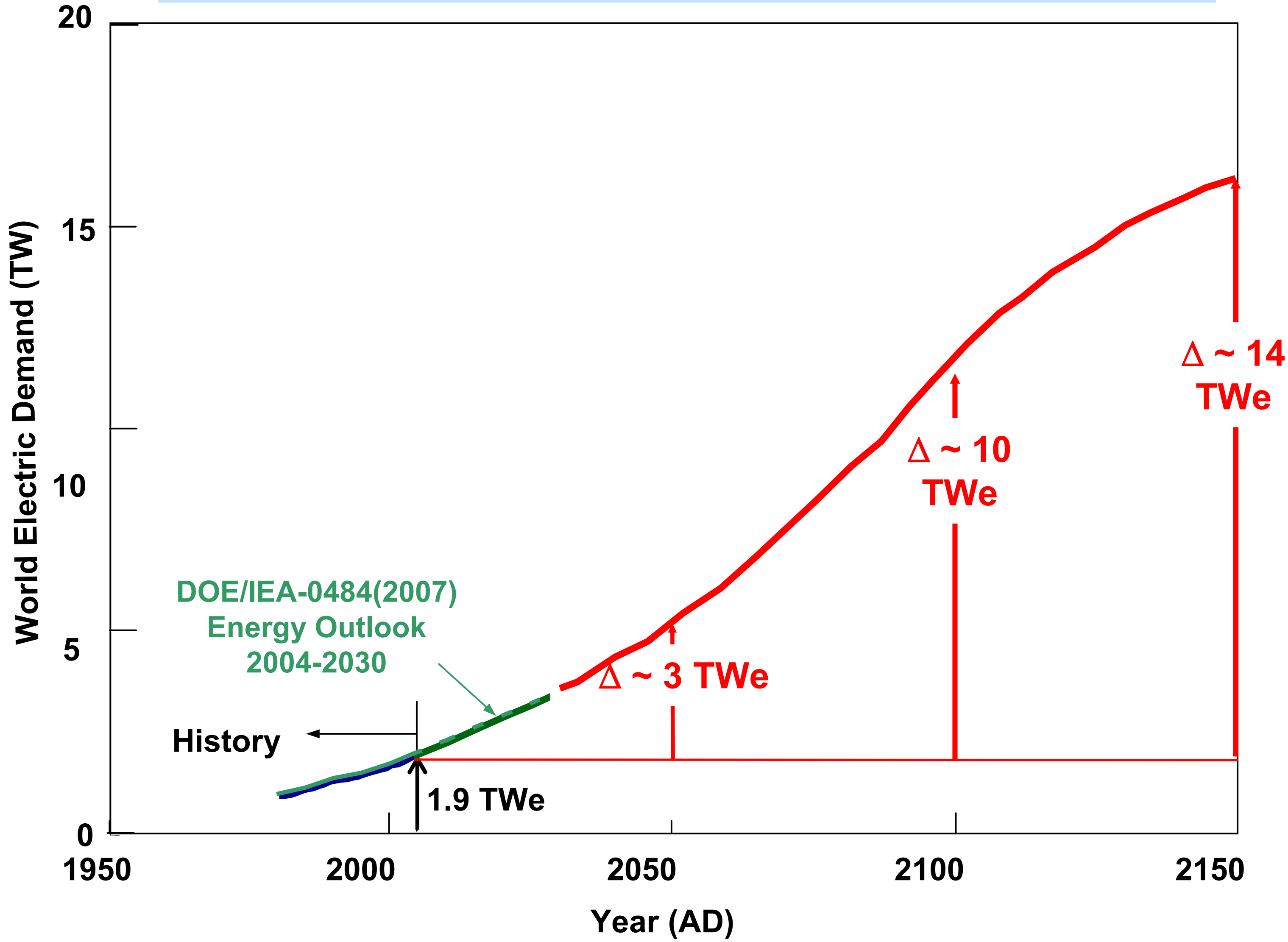
2150: 11 Billion people and ~ 15-20 TWe

Source: Pasternak, "Global Energy Futures and Human Development: A Framework for Analysis"

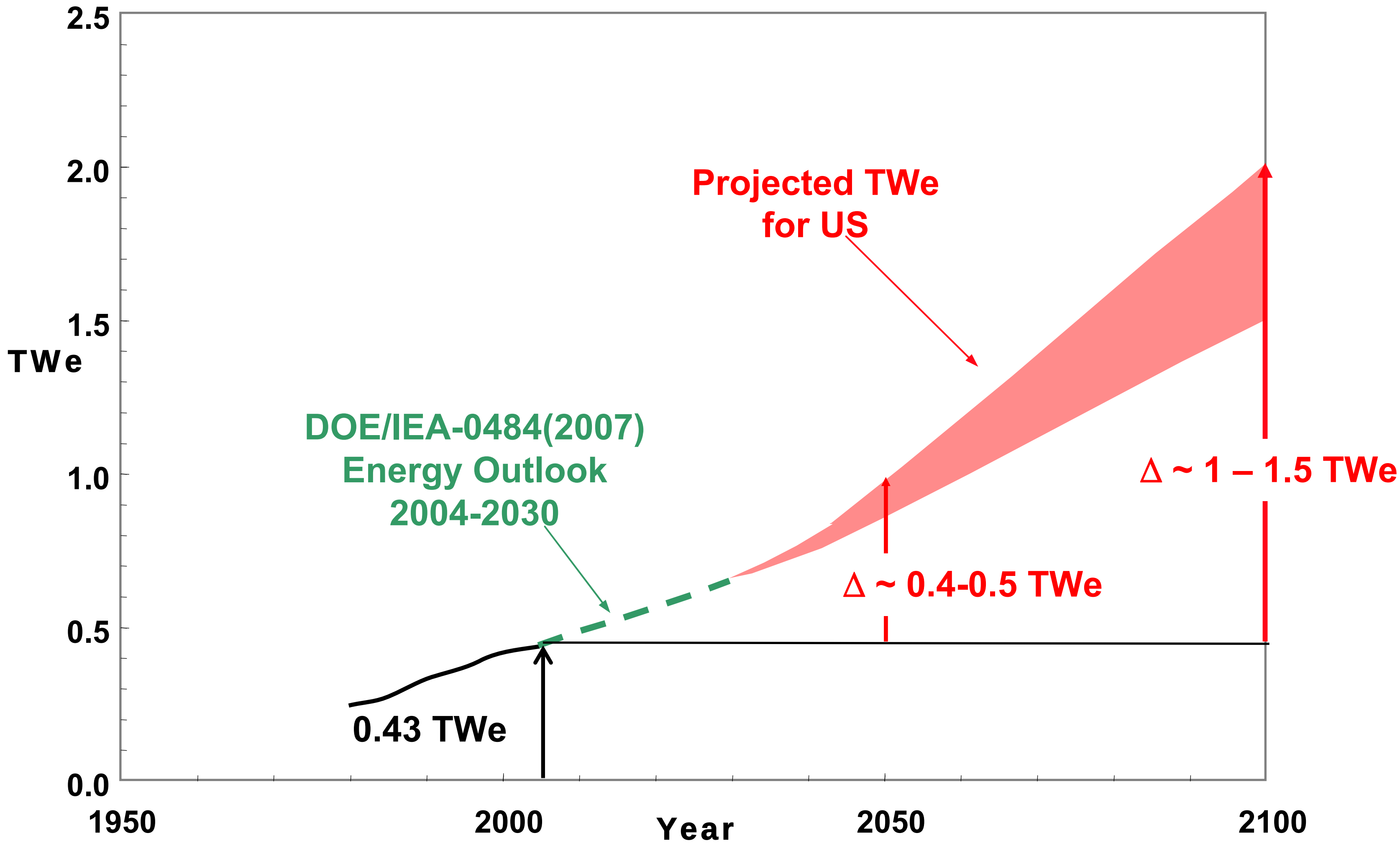
The implications are rather serious

Even by ~ 2050, NEW capacity would be ~ 1.5 X existing

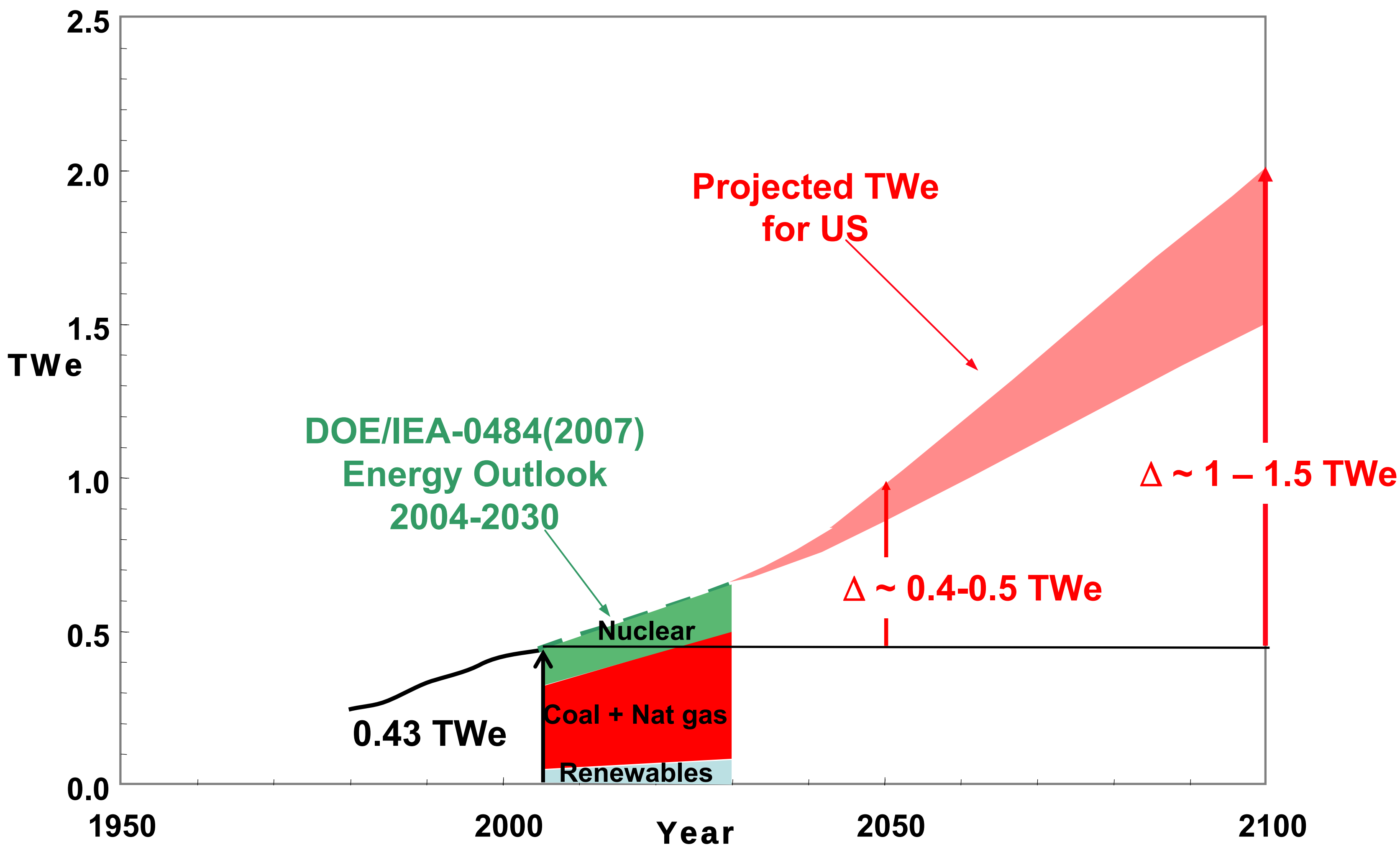
A Business as Usual approach is obviously not acceptable



The situation in the US is equally serious: Demand could reach 1 TWe by 2050 and 2 TWe by 2100



A business as usual approach is not acceptable



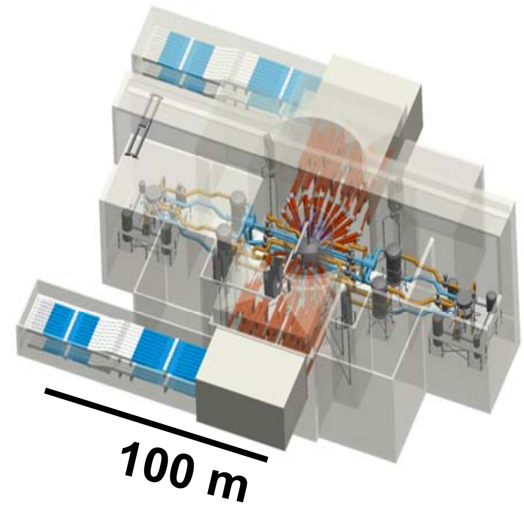
A significant increase in nuclear is a logical conclusion –

But at 1 TWe, this would require 1 Yucca Mountain ~ every 3-4 years

We need to close the nuclear fuel cycle

LIFE – one of our goals is to provide an option to close the nuclear fuel cycle

Requirements



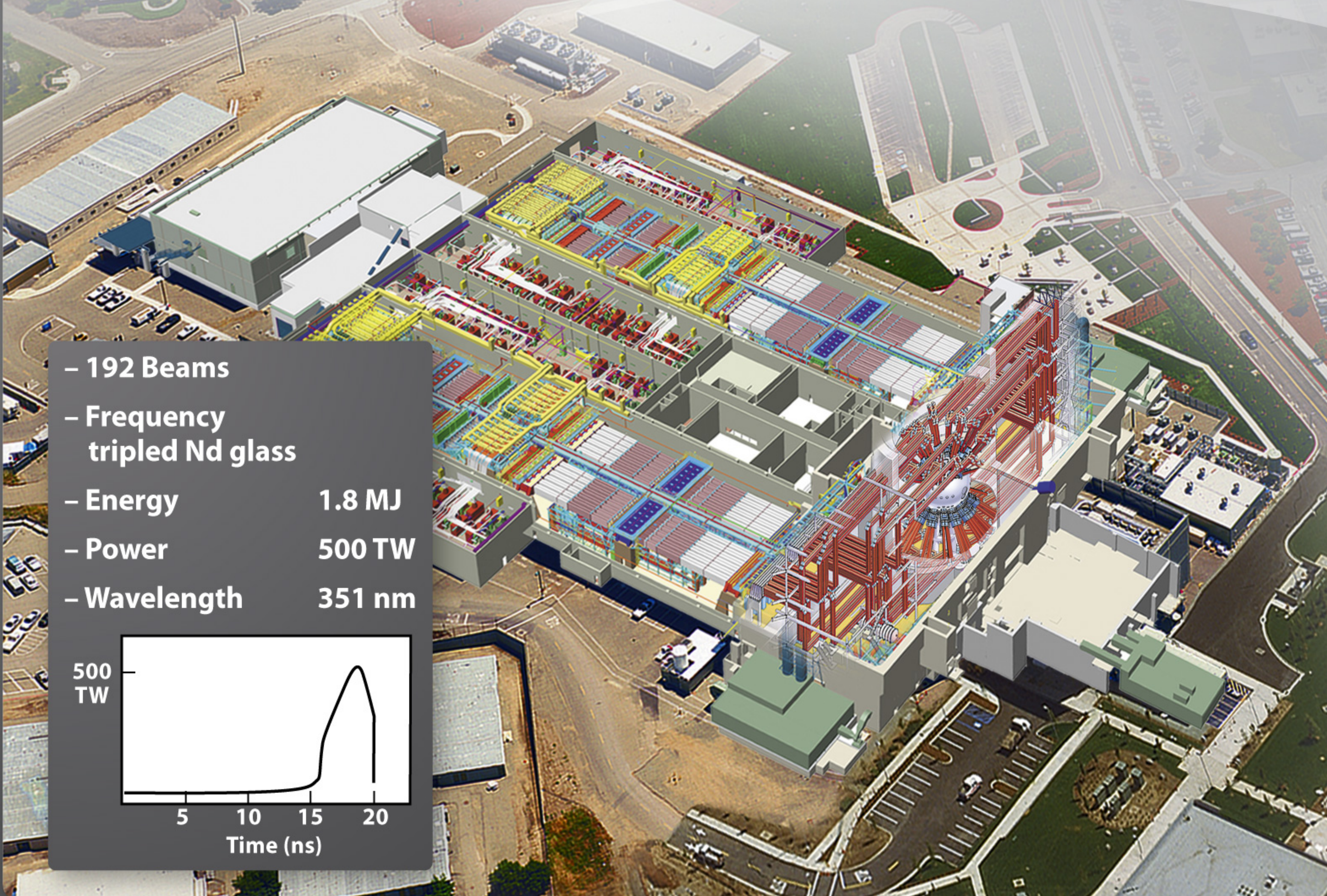
Front end
- No enrichment
- Sustainable fuel supply

Back end
- No reprocessing
- No weapons attractive quantities of actinides in the spent fuel
- Minimize requirements for geologic disposition

The system must also be safe and economically competitive

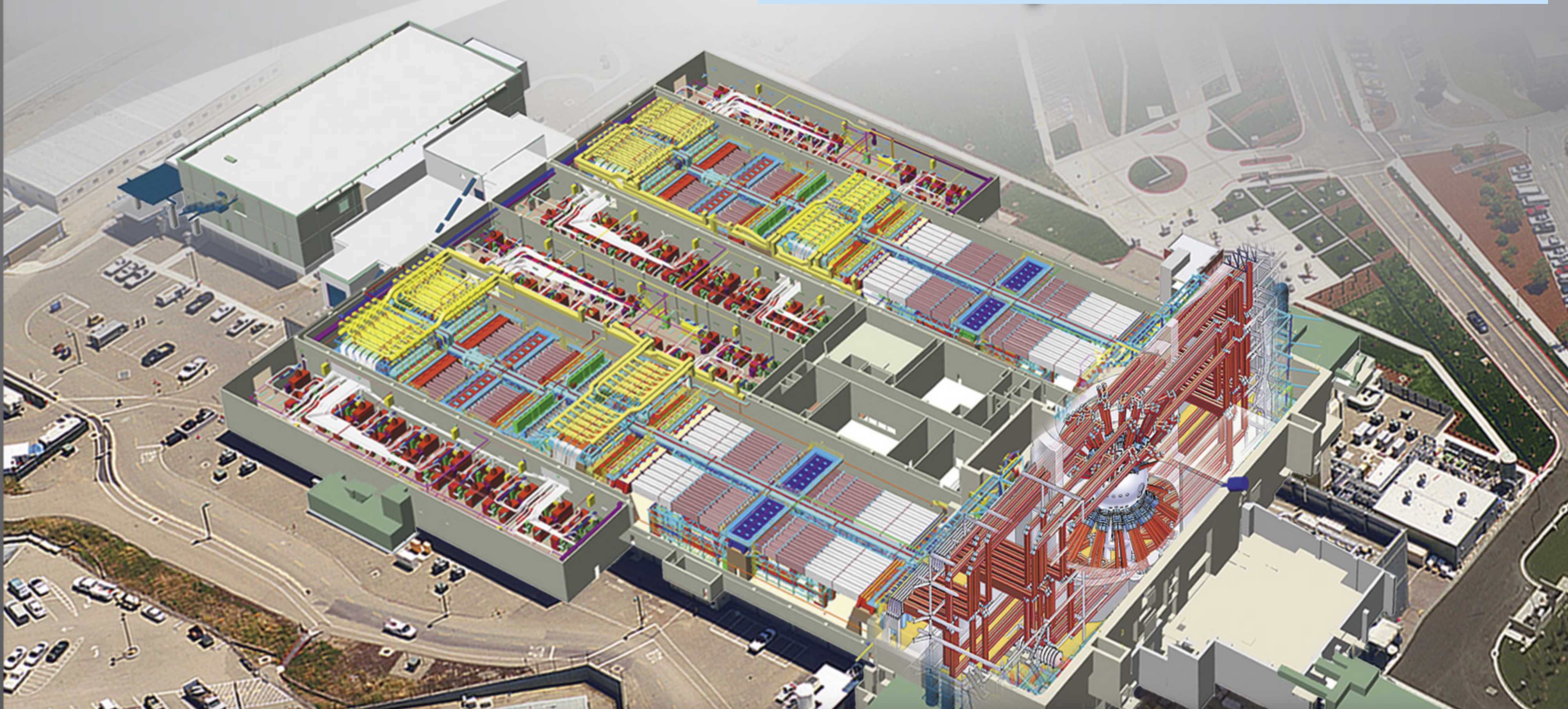
NIF Laser System

- 192 Beams
- Frequency tripled Nd glass
- Energy 1.8 MJ
- Power 500 TW
- Wavelength 351 nm



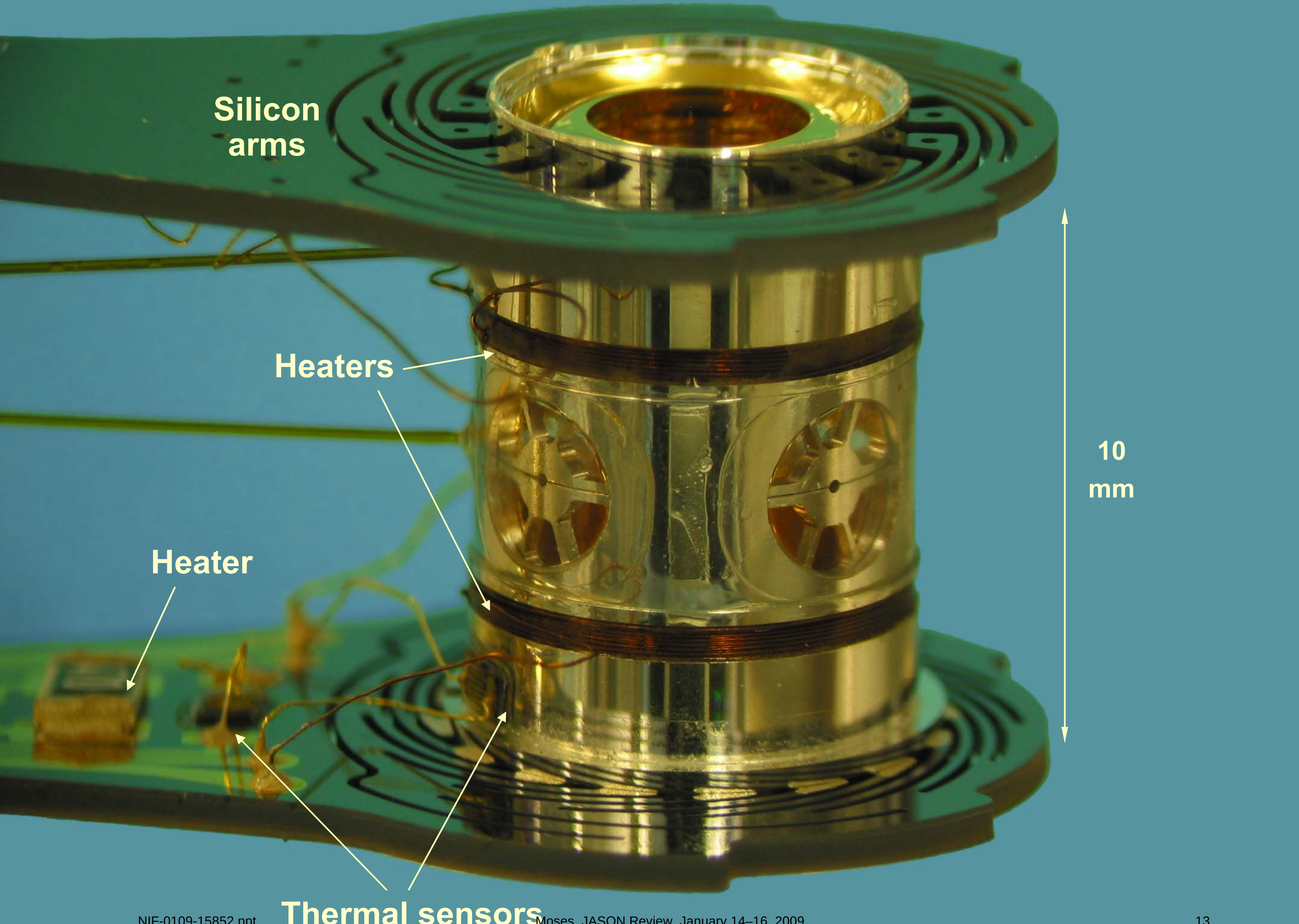

192 Main Laser Beams Operationally
Qualified September 24, 2008
ICCS DUTY ENGINEER
POWER CONDITIONING
World’s Highest Energy Laser – 4.2 MJ 1ω

NIF is not only complete NIF is operational

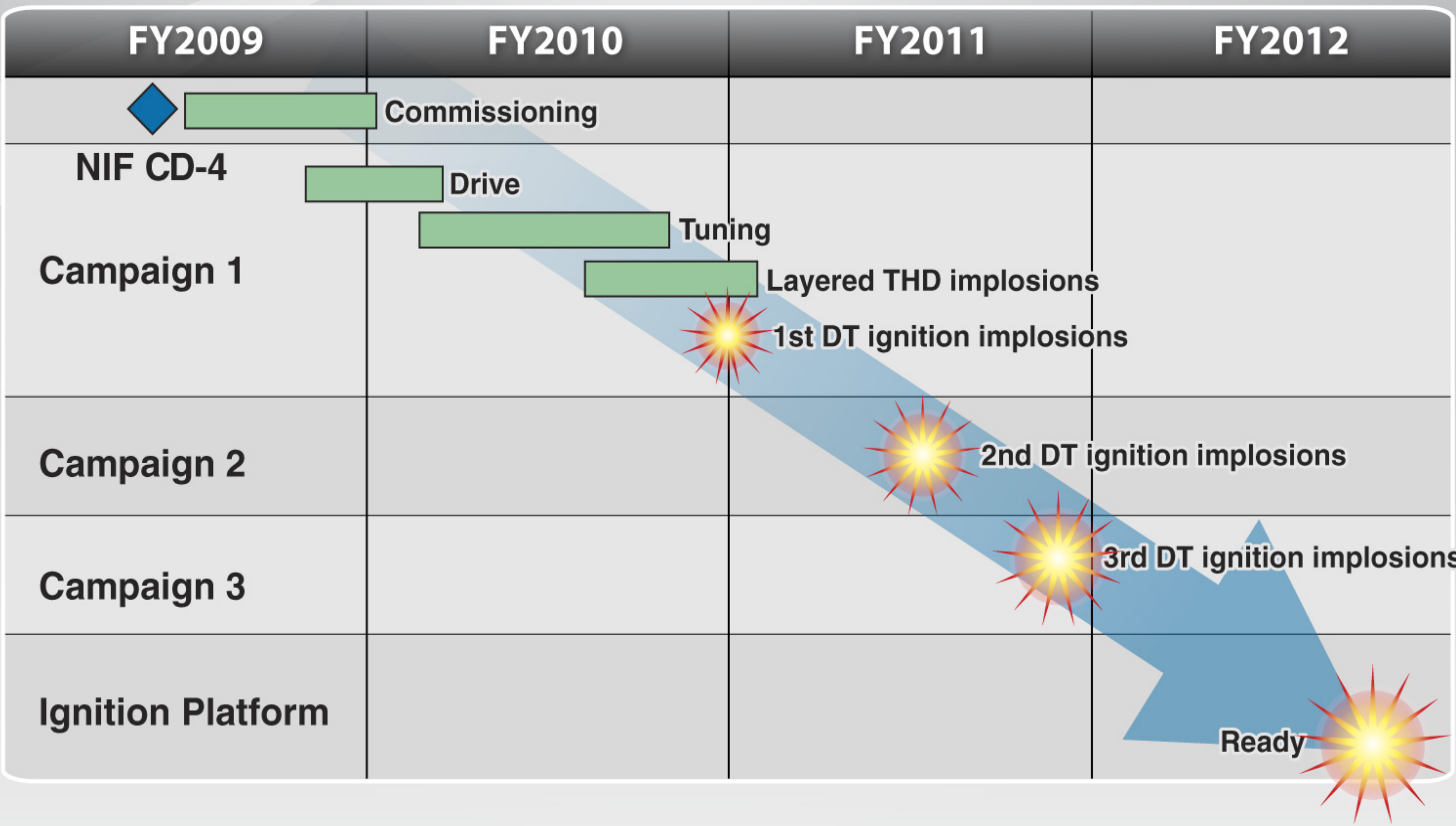


1.1 MJ/3w from 96 beams delivered to TTC 3:15 AM March 10, 2009

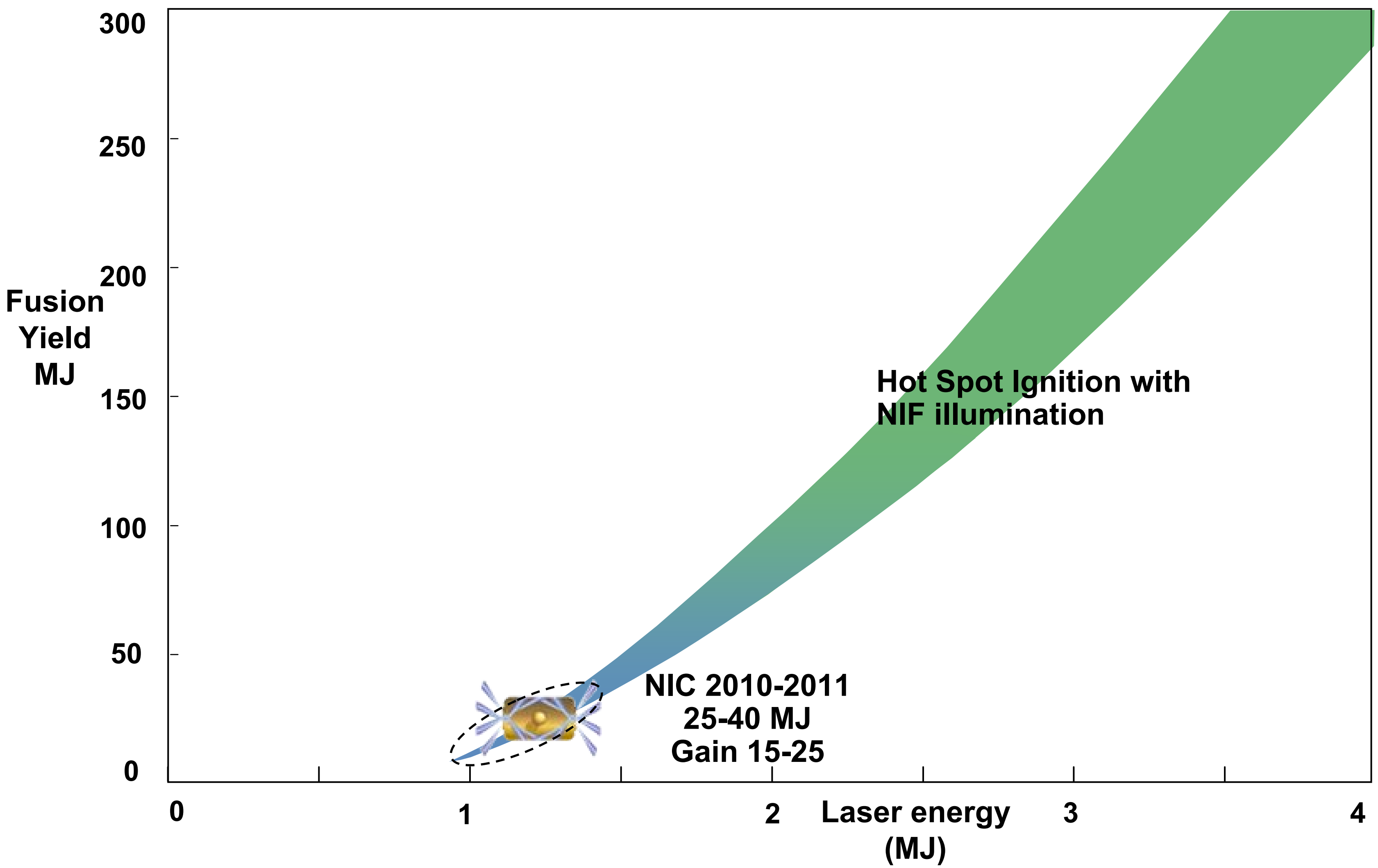
Target shots start in June, and the Ignition Campaign this fall


Silicon arms
Heaters
10 mm
Heater
Thermal sensors

NIF will execute four major ignition campaigns in the next four years

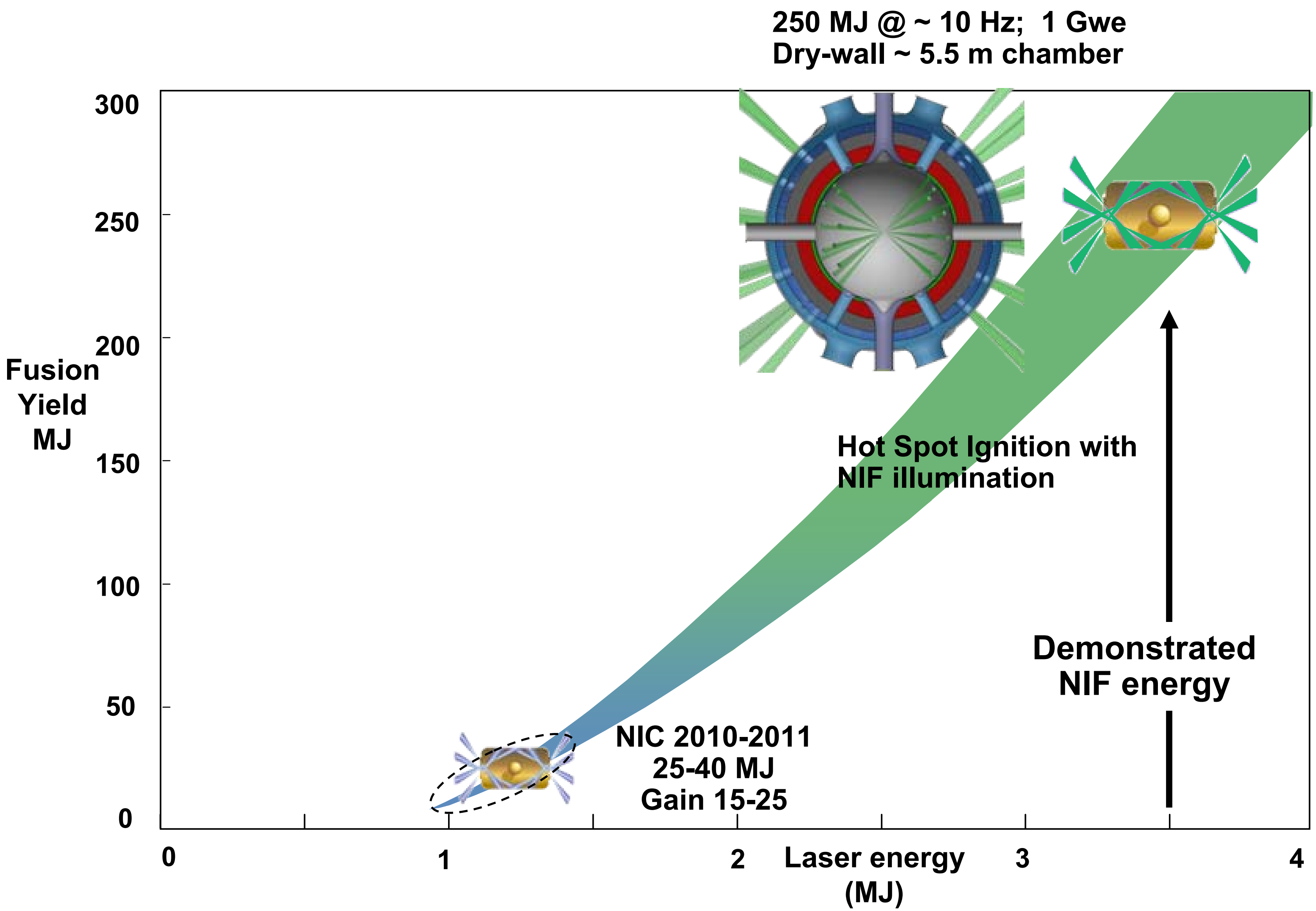


Ignition and gain on NIF will be a transforming event, and will focus the world's attention on the possibility of an inertial fusion energy option



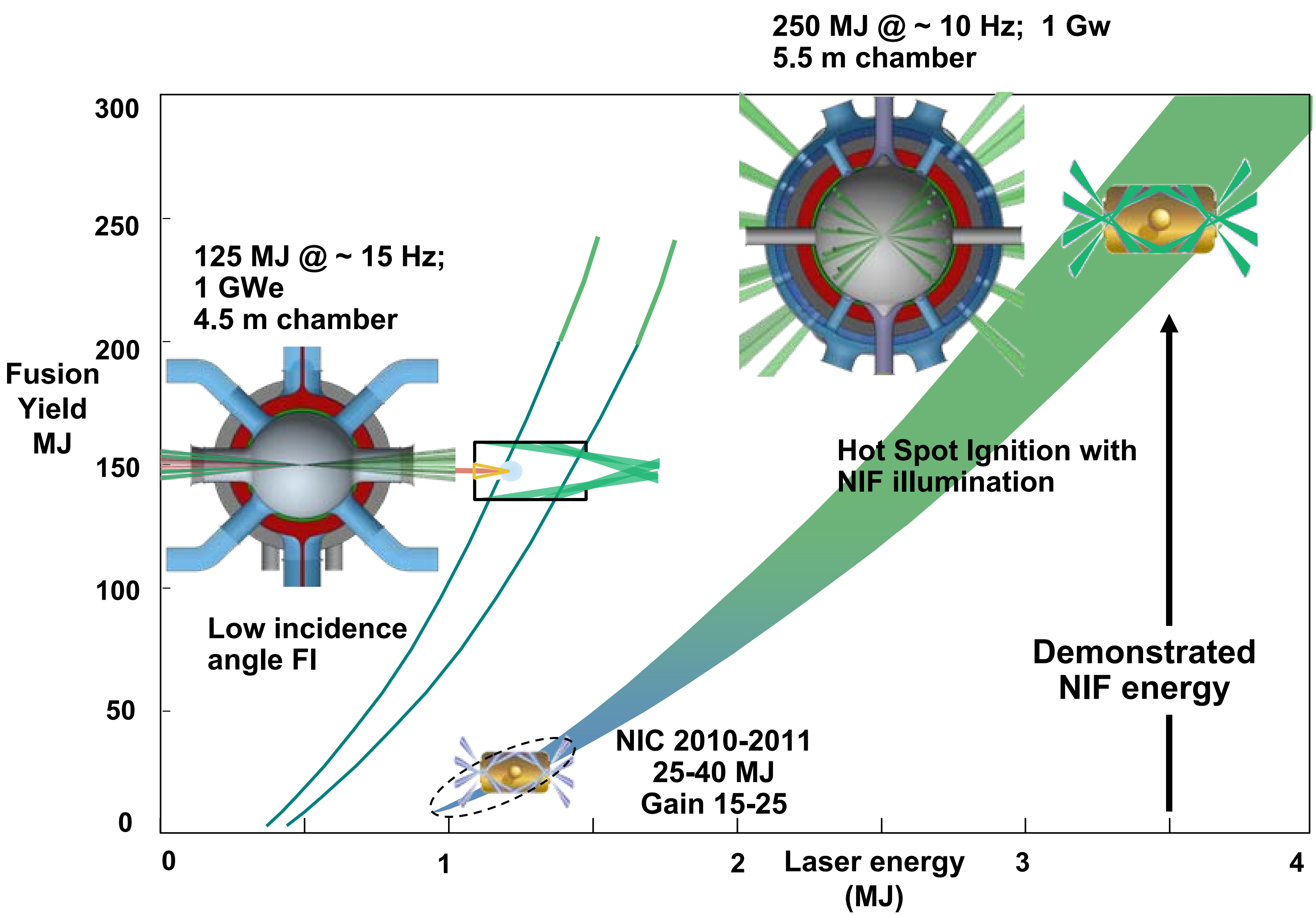
But NIF/NIC gains will not be adequate for an inertial fusion energy system

Pure IFE could be realized with NIF-like lasers, NIF-like targets and chambers ~ ½ the size of NIF



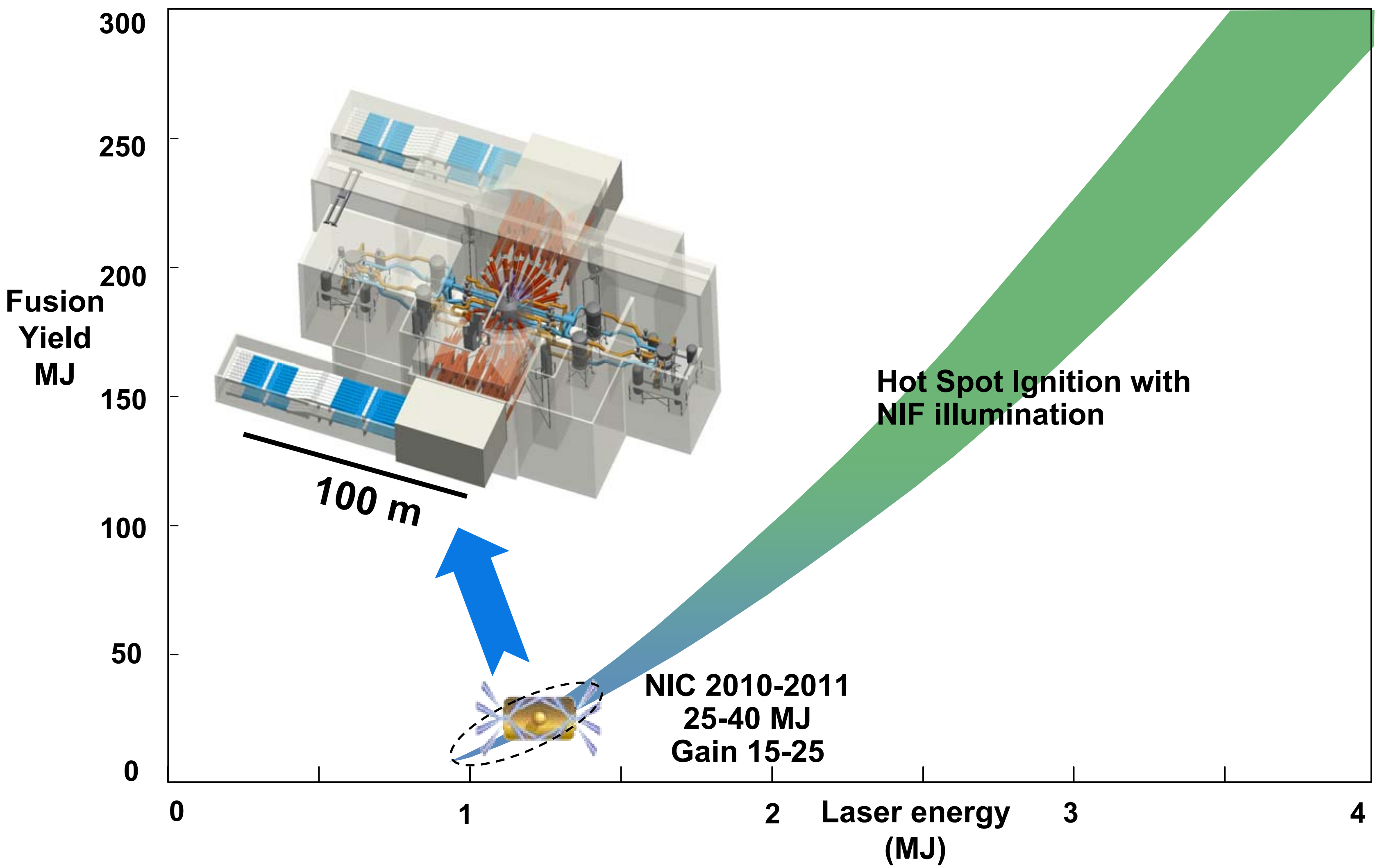
But IFE with 3-4 MJ lasers systems are unlikely to be economically attractive

With Fast Ignition, more attractive IFE systems are possible



We will resolve the physics issues of FI by early 2012/2013

The challenge is to find a fusion option that would work with NIF/NIC performance



We believe LIFE is such an option

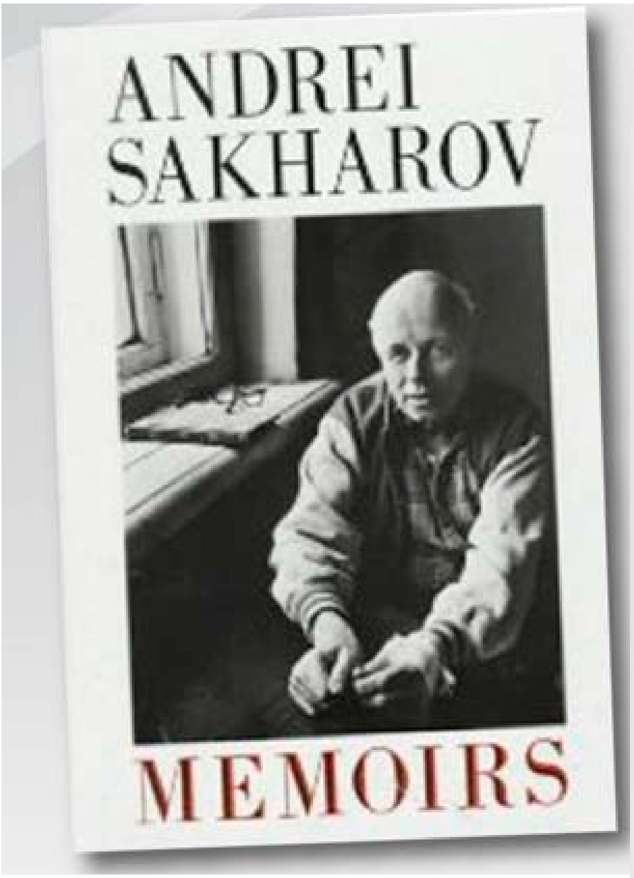
LIFE goal: Provide a sustainable, once-through closed nuclear fuel cycle energy option

- LIFE uses fusion neutrons to drive a subcritical fertile/fissile fuel blanket and provide a once-through closed nuclear fuel cycle

- The science and technology "building blocks" for a NIF-based LIFE system are logical and credible extensions of NIF, ignition on NIF and ongoing developments in the world nuclear power industry

- The inherent separability of LIFE, would allow a NIF-based LIFE system to be piloted by 2020-2025

The idea of a fusion-fission hybrid was first proposed more than 50 years ago




Proceedings

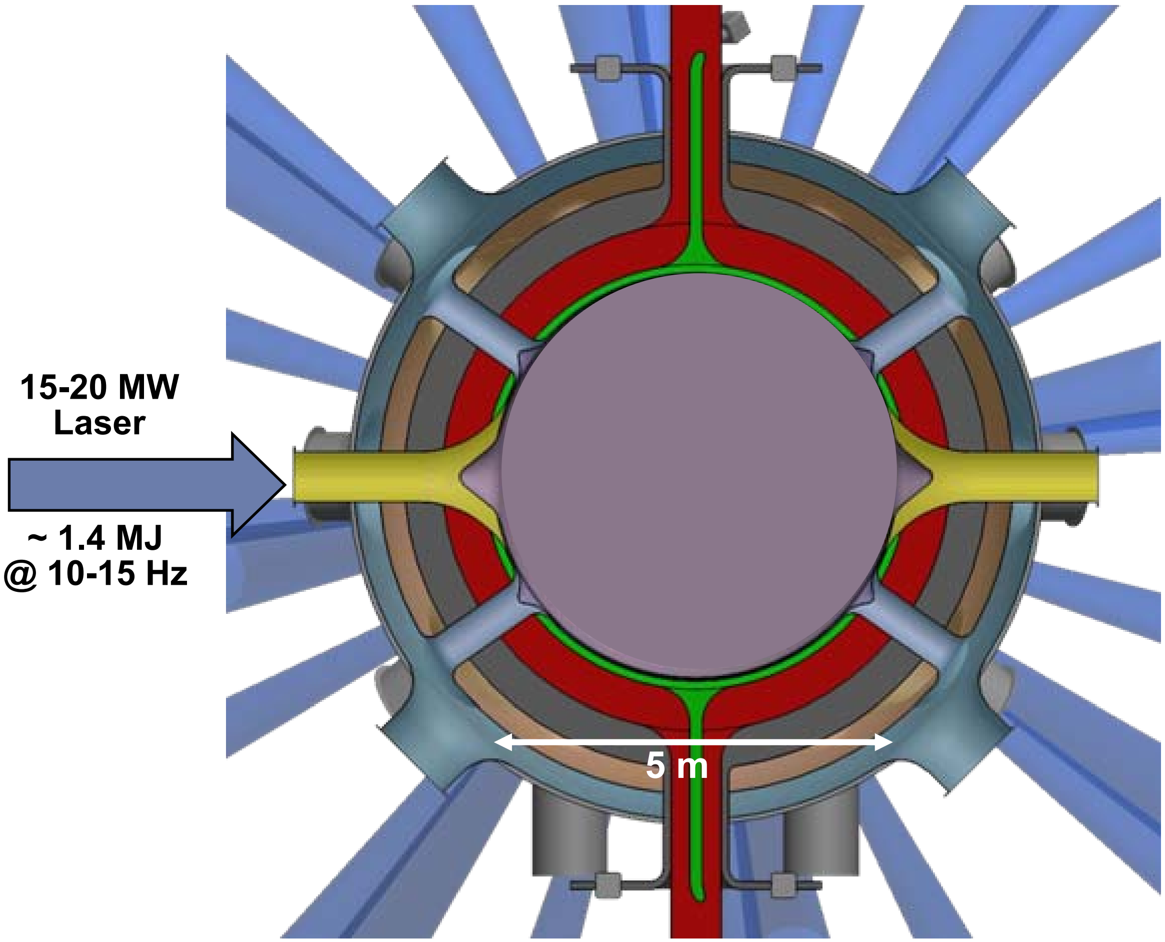
US—USSR SYMPOSIUM ON FUSION-FISSION REACTORS

July 13-16, 1976

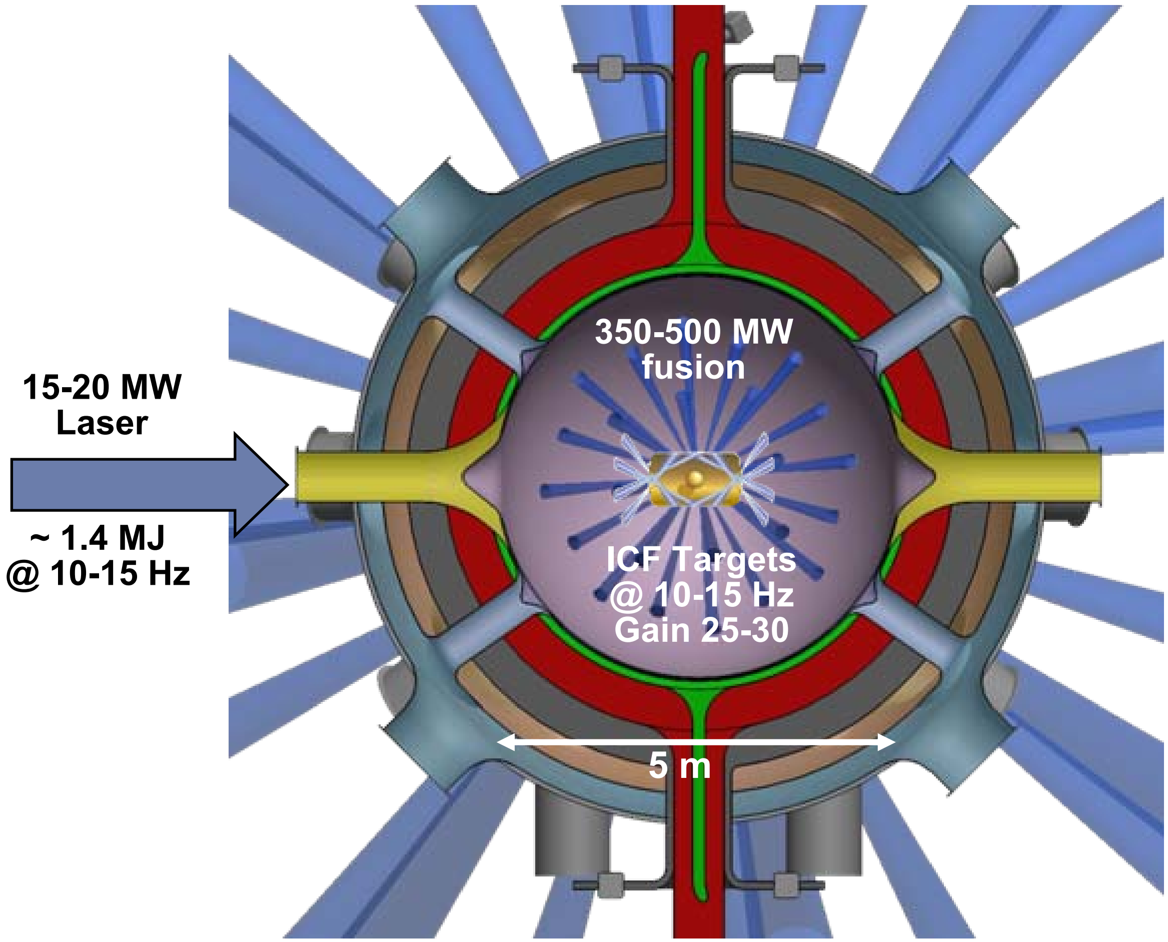
Hosted by
University of California,
Lawrence Livermore Laboratory
Livermore, California
Sponsored by LLL-ERDA

We believe LIFE is an idea whose time has come

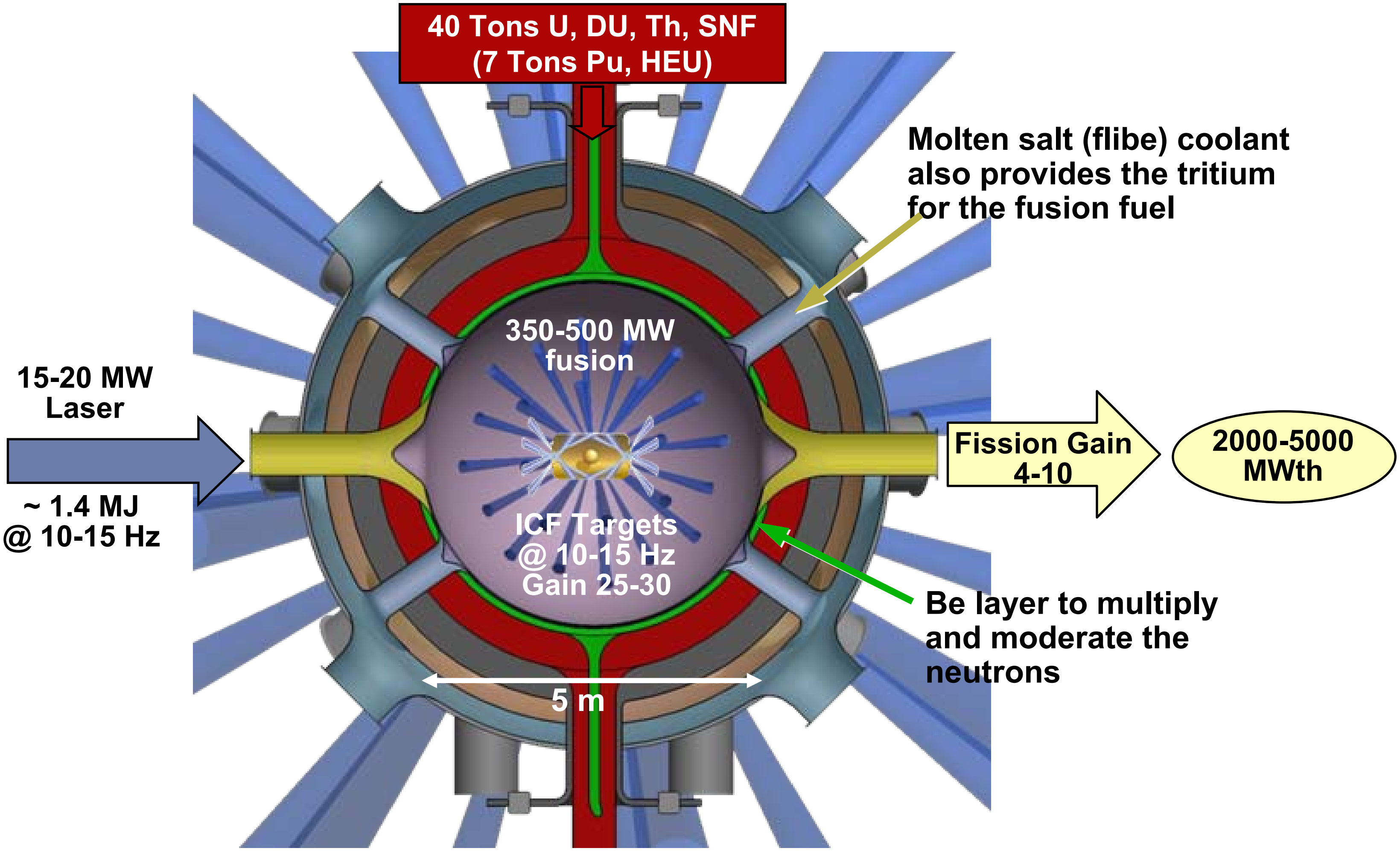
LIFE starts with a 15-20 MW laser (NIF-like 1.4 MJ @ 10 - 15 Hz)



NIF-like targets are injected at 10-15 Hz providing 350-500 MW of fusion

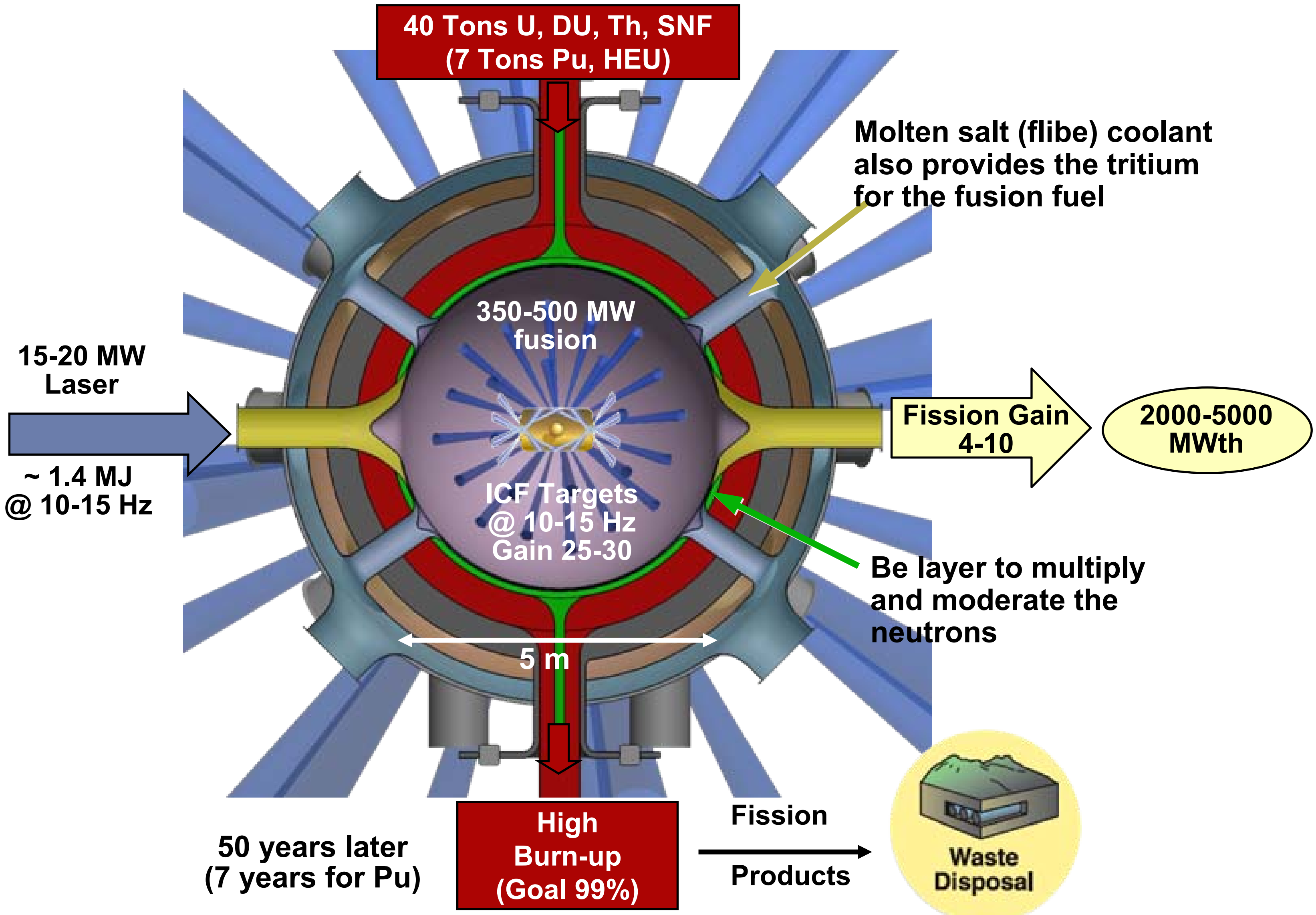


Fertile or fissile fuel, flibe coolant and a Be blanket provide the fission gain and tritium for the fusion targets

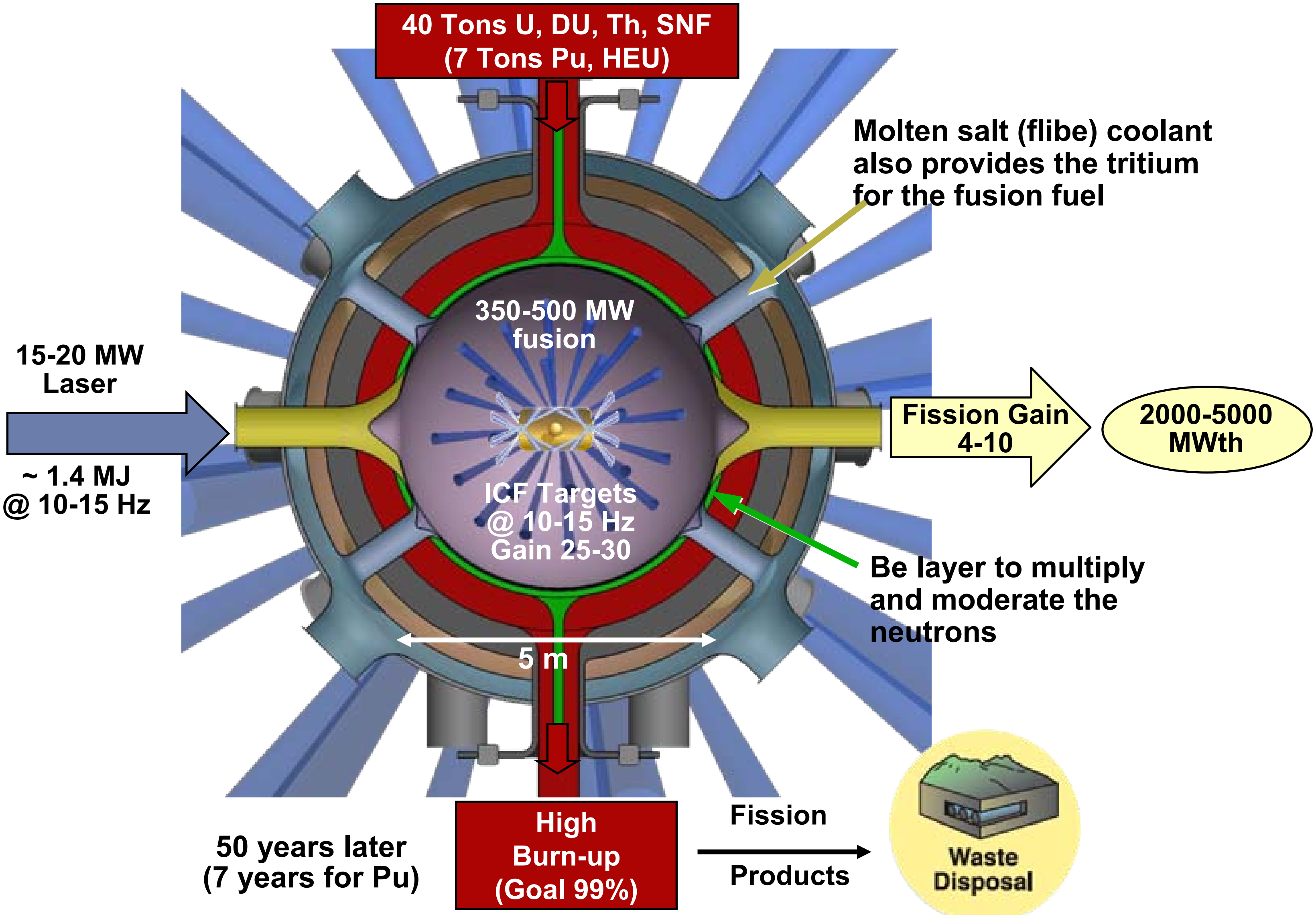


40 tons of fertile fuel could provide 2000-5000 MWth for 50 yrs (7 MT of fissile fuel for ~ 7 years)

The external neutrons allows us to burn the fuel to very high FIMA (goal > 99%) in one step



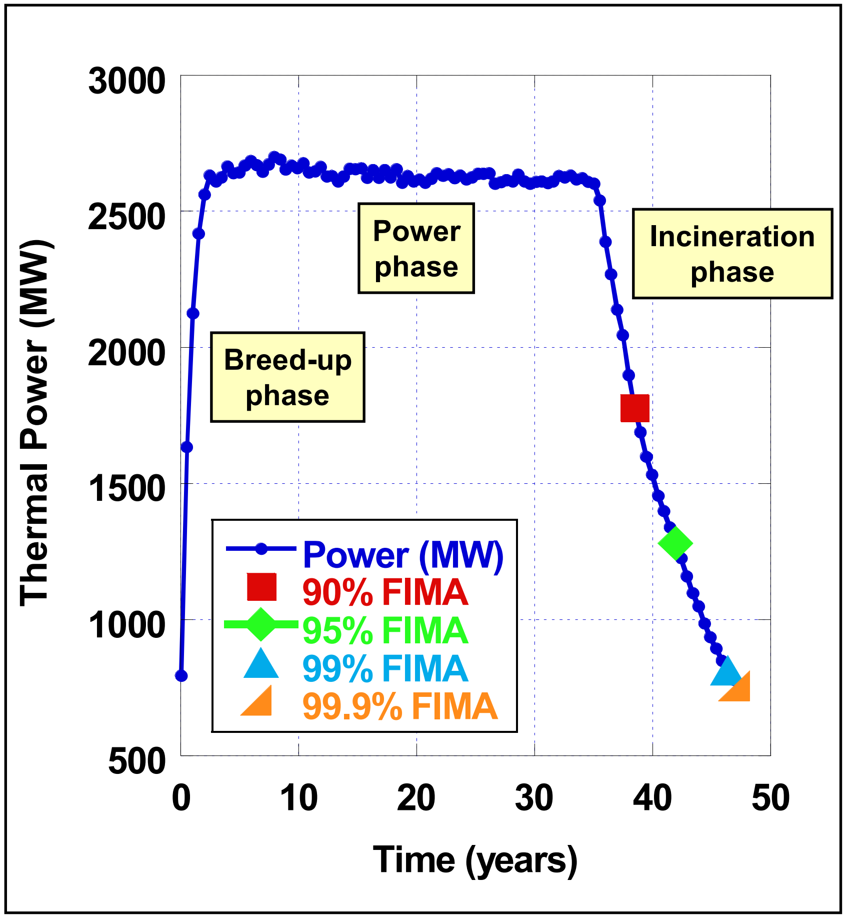
LIFE uses a point source of inertial fusion neutrons to drive a sub-critical fissile fuel blanket

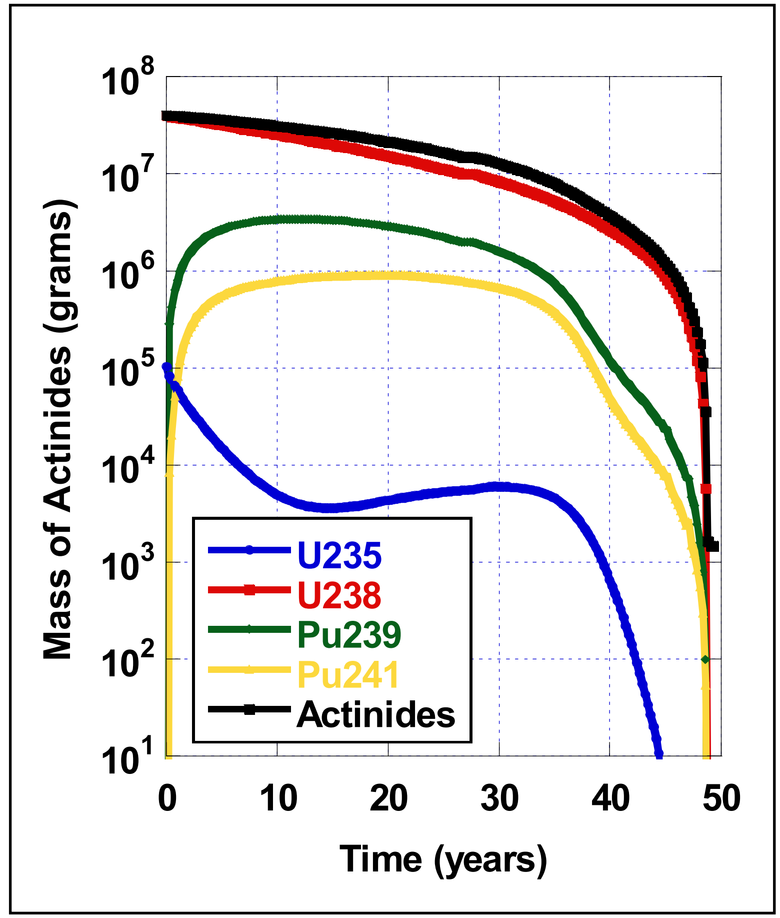


LIFE would provide a once-through, closed nuclear fuel cycle

LIFE provides decades of steady-power from a depleted uranium fuel loading

Thermal power and content of fertile and fissile material as a function of time for an optimized LIFE engine loaded with 40 tons of DU, driven by 500 MW of fusion





Level of LIFE fuel burn-up (FIMA) will be a trade-off between economic and proliferation constraints

LIFE fuel burn-up can be adjusted as desired

Remaining quantities of actinides for an initial load of 40 tons of DU as a fraction of burn-up (FIMA)

	Burn-up			
Isotope	**90%**	**95%**	**99%**	**99.9%**
^{235}U	1.6 kg	120 g	560 mg	36 mg
^{238}U	3300 kg	1800 kg	490 kg	150 kg
^{237}Np	5.4 kg	1.9 kg	290 g	69 g
^{239}Pu	210 kg	58 kg	11 kg	3.2 kg
^{241}Pu	10 kg	21 kg	3.6 kg	1.1 kg
^{241}Am	4.2 kg	270 g	13 g	1.9 g
^{246}Cm	150 kg	170 kg	120 kg	79 kg

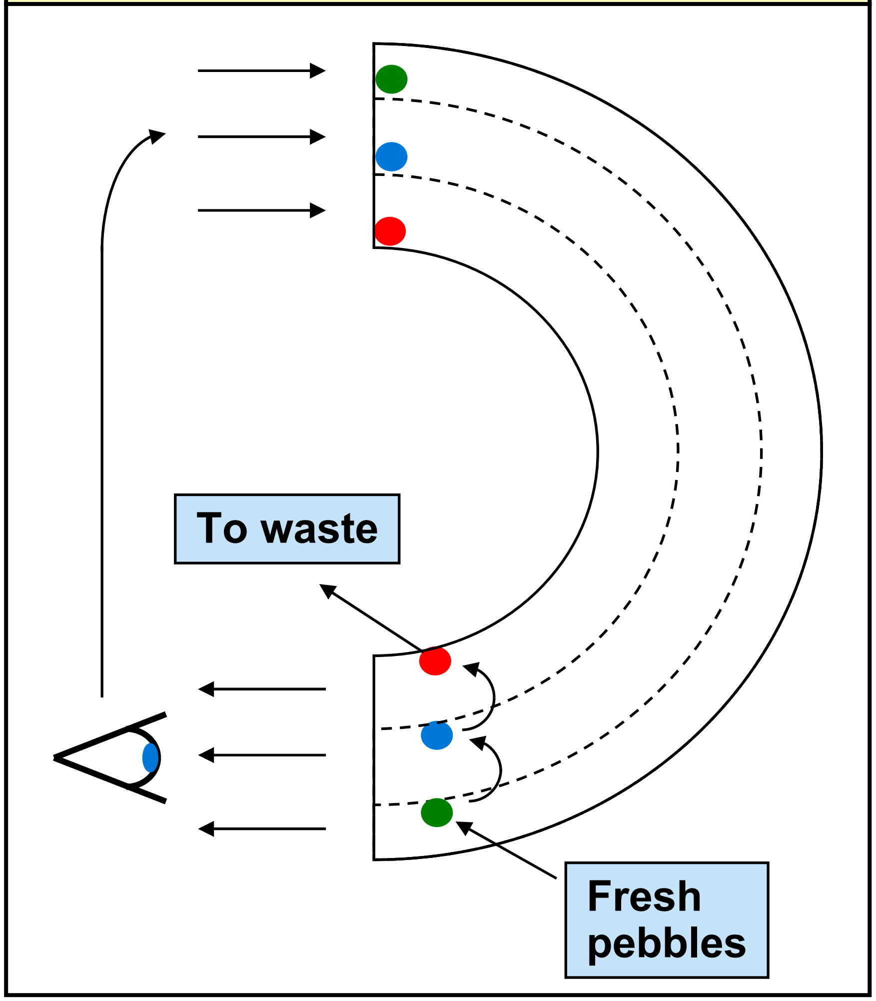
- **40 tons of depleted uranium can become nearly 40 tons of fission products**

With > 99% burn-up, LIFE produces up to 20 X less high level waste per GWe than once-through LWRs and has insignificant quantities of actinides at end of operation

Improved performance is realized by segmenting the blanket and extending the lifetime

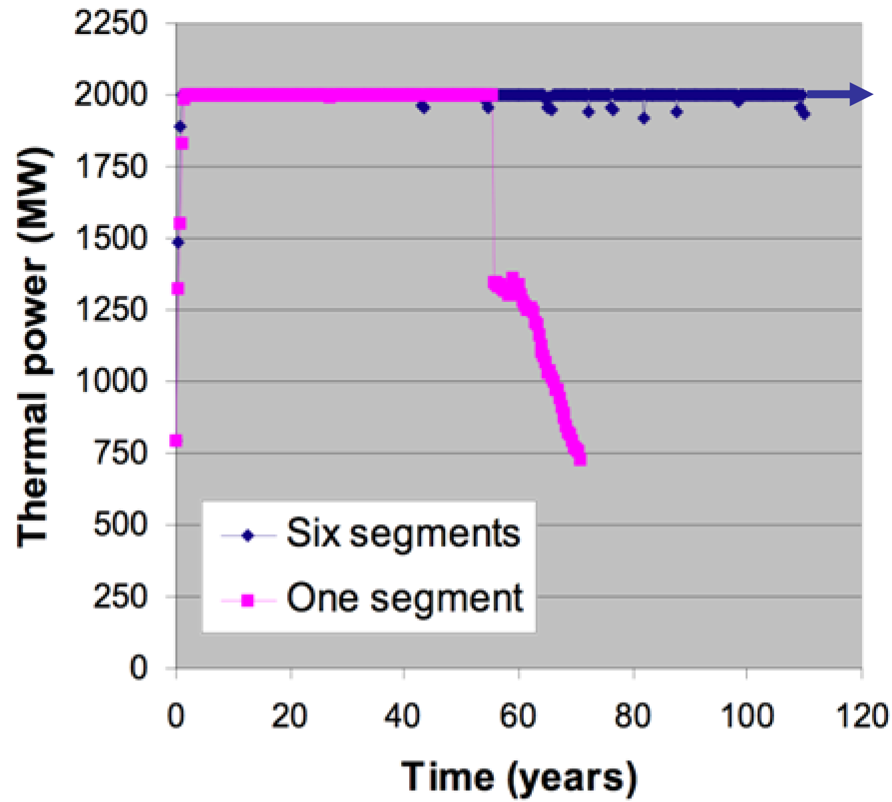
- **Different blanket regions (e.g., front, middle, back) experience different neutron fluxes**
- **When the front region is fully burned, successive layers are promoted, and new fuel is added to the back**

Segmented blankets would enable fuel burn-up to be tuned as desired



Segmented blankets can be operated as long as desired

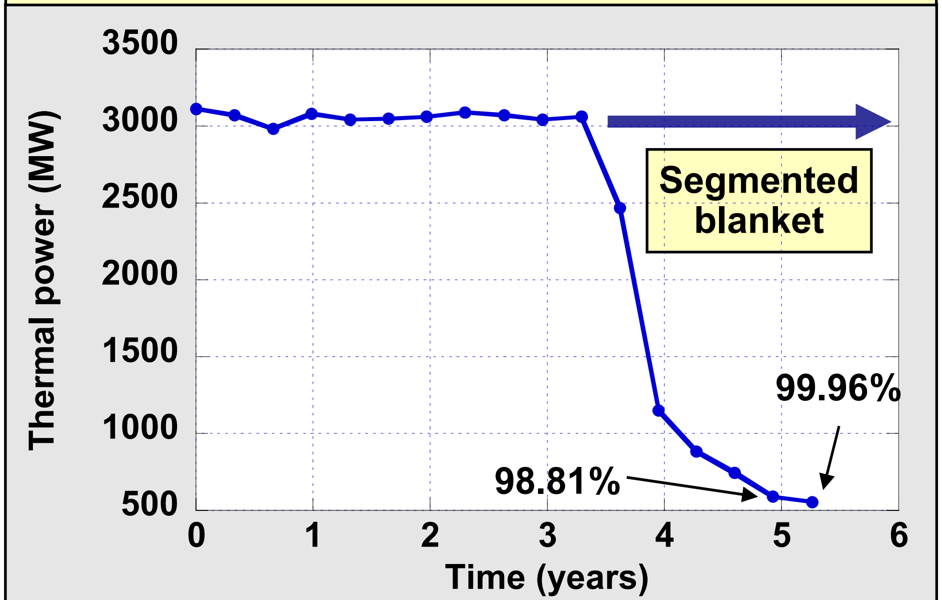
- Different blanket regions (e.g., front, middle, back) experience different neutron fluxes
- When the front region is fully burned, successive layers are promoted, and new fuel is added to the back
- Full power mode can be extended indefinitely



LIFE can burn excess plutonium in a high-gain blanket

- System fueld with 7 MT of weapons grade plutonium (WG-Pu)
  - Or 7 MT of PuMA from processed spent nuclear fuel
- Fuel (whether in "TRISO"-like loaded or Solid Hollow Core Pebbles) blended 80% ZrC + 20% Pu
  - Also loaded with 400 wppm boron as burnable poison
- Fusion power is 375 MW (25 MJ @ 15 Hz)Flat top thermal power is 3000 MW --- Blanket gain of 8

Pu blanket is driven by 375 MW of fusion



Isotope	Initial mass	Final mass
^{239}Pu	6.56 tons	1.3 mg
^{240}Pu	406 kg	<1 μg
^{241}Pu	9.1 kg	1.2 mg
^{242}Pu	1.4 kg	<1 μg
^{241}Am	15.4 kg	<1 μg
Total actinides	6.99 tons	2.83 kg (2.04 kg ^{246}Cm)

LIFE offers key benefits relative to other nuclear systems

- LIFE would be a unique fusion-fission system:
  - Operates with a variety of different fuels
    - Depleted or Natural uranium, SNF, Excess weapons material, Thorium
  - No enrichment and no reprocessing
  - No weapons attractive materials at start or end of operation minimizes proliferation concerns
  - Deeply sub-critical at all times and passive removal of decay heat makes it inherently safe

- Simple technological solutions
  - Low-yield
  - Dry wall
  - Fast development path
  - Makes its own fuel (fusion & fission)
  - Incinerates its own actinide waste

We believe the S&T for a NIF-based LIFE system are logical and credible extensions of NIF, NIC and ongoing developments in the world nuclear power industry

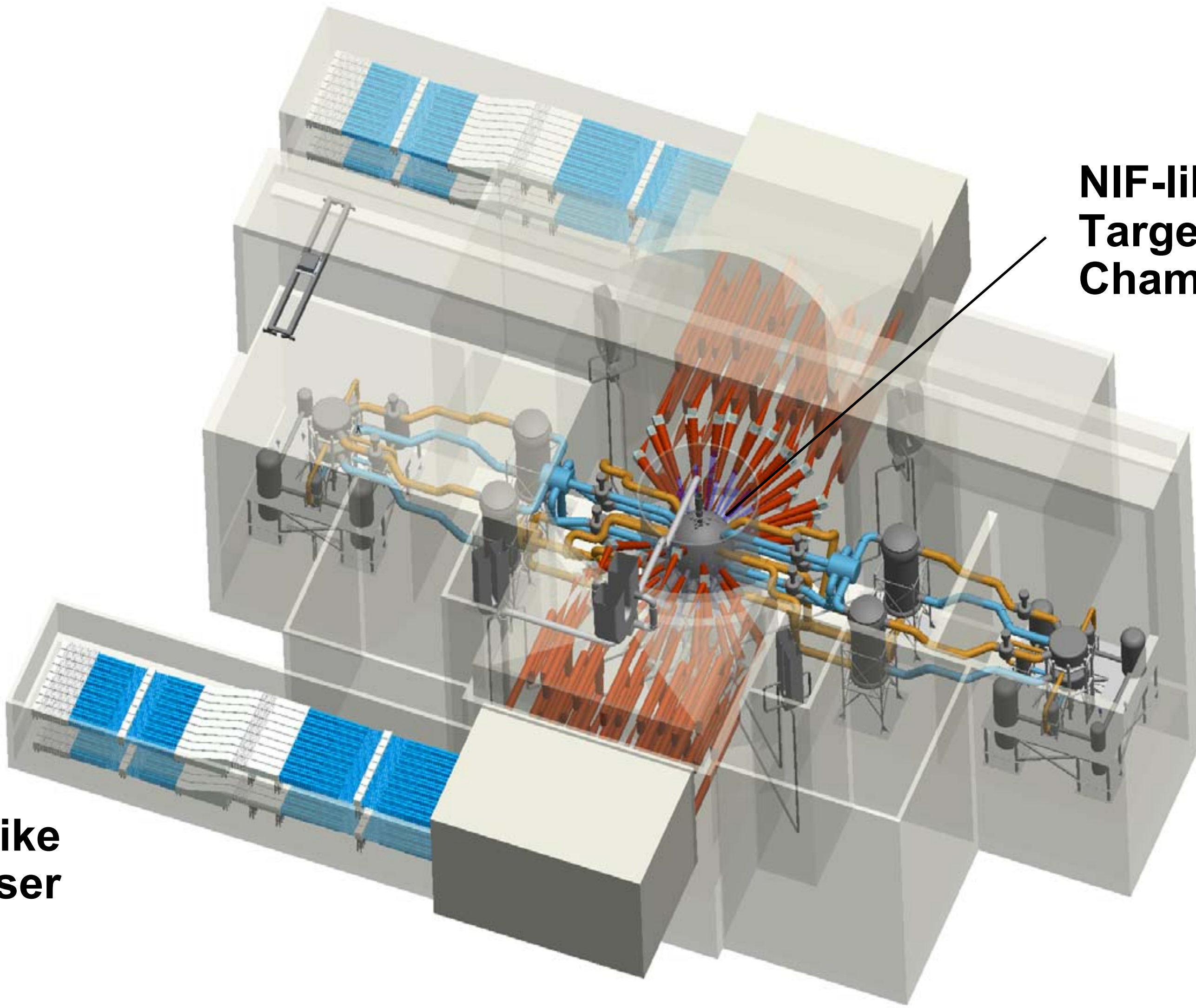
LIFE goal: Provide a sustainable, once-through closed nuclear fuel cycle energy option

- LIFE uses fusion neutrons to drive a subcritical fertile/fissile fuel blanket and provide a once-through closed nuclear fuel cycle

- The science and technology “building blocks” for a NIF-based LIFE system are logical and credible extensions of NIF, ignition on NIF and ongoing developments in the world nuclear power industry

- The inherent separability of LIFE, would allow a NIF-based LIFE system to be piloted by 2020-2025

A NIF-based LIFE engine comprises a NIF-like laser system, a NIF-level point source of neutrons and a subcritical fission blanket



and builds on ongoing developments in the world nuclear power industry

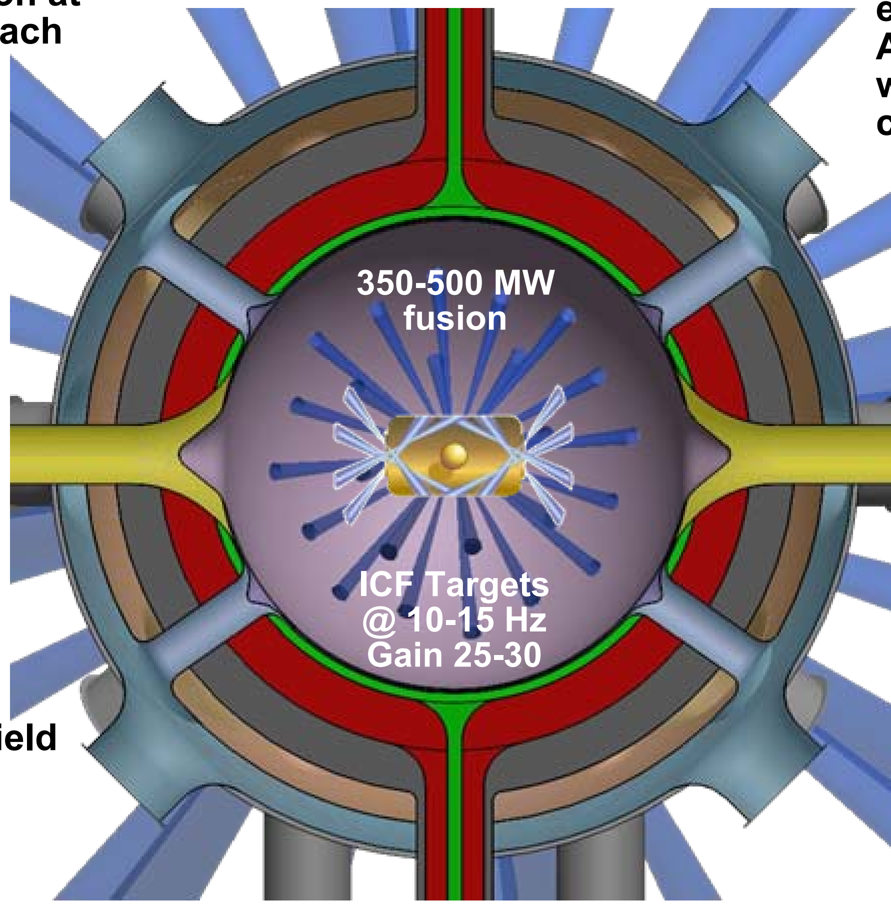
The Baseline, NIF-based LIFE faces technical and scientific challenges

Target injection, survival of cryo fuel, tracking and laser intercept

Target production at 15 Hz @ ~ 30¢ each

Manage fusion environment:
A threat to final optics, 1st wall, beam propagation, chamber clearing, - -

Low cost NIF-energy level DPSSL @ 10-15 Hz 10-15% with high availability

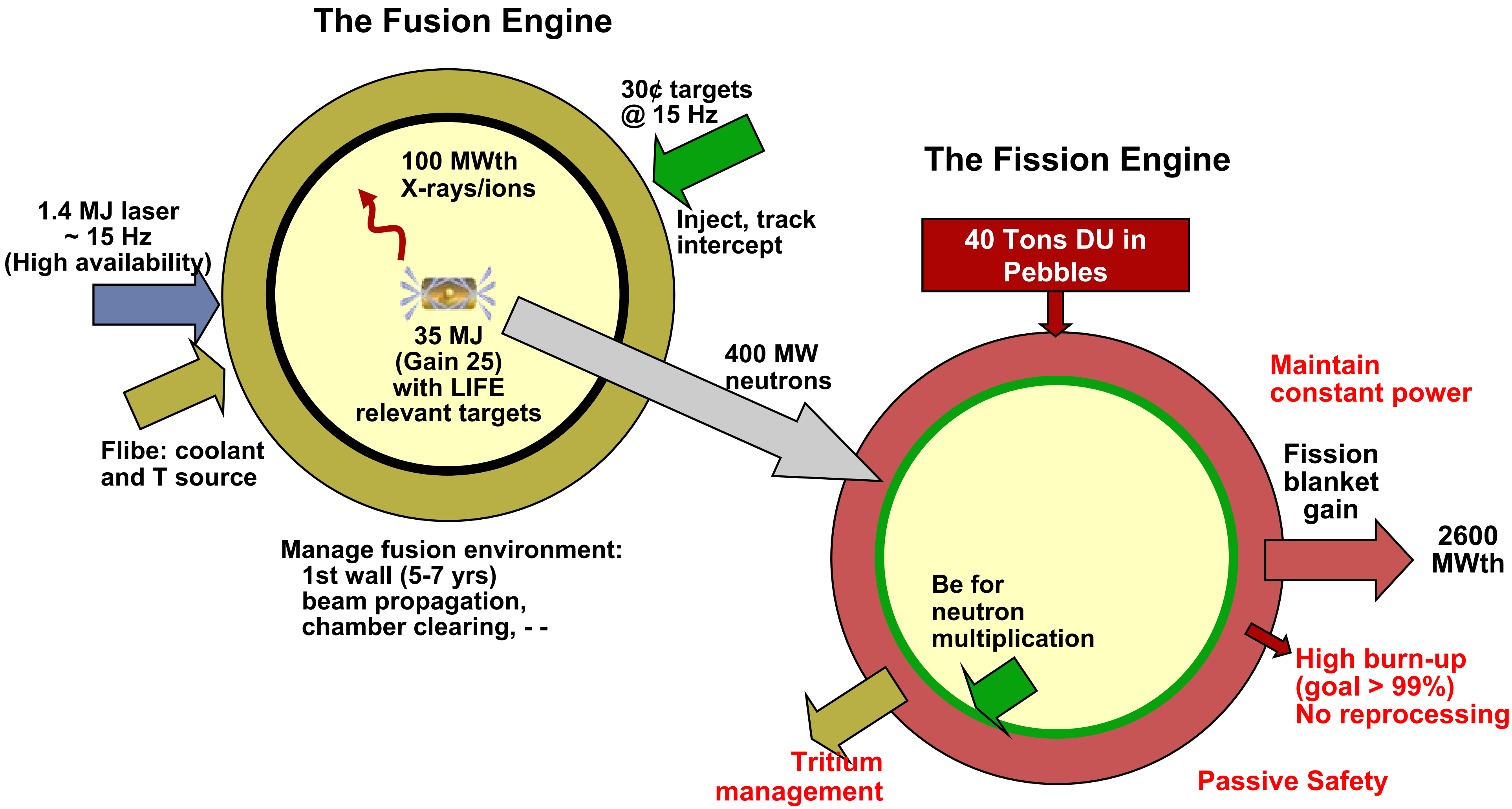


1st wall survive 5 to 7 years from fusion neutron, x-rays and ions

Robust Hot Spot yield w /LIFE-relevant targets

High burn-up of fuel (goal is > 99%) without reprocessing

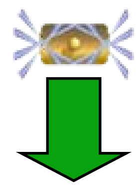
LIFE divides naturally into a Fusion and Fission engine with different and distinct challenges



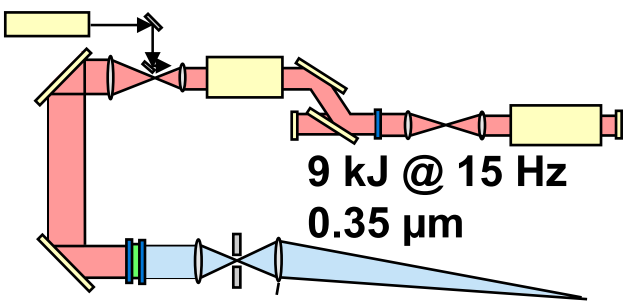
The fusion engine further divides into four separate and distinct subsystems

Target Factory

Targets @ ~15 Hz and ~ 30¢

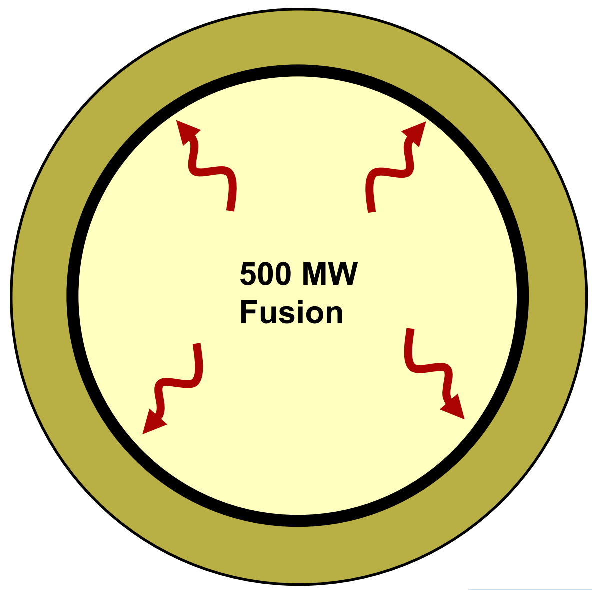


The 1.4 MJ laser which will consist of ~ 160 LIFElet "building blocks"



9 kJ @ 15 Hz
0.35 μm

13% efficiency, 15 Hz;
High availability demonstrated with LIFElet



The fusion target chamber

Manage fusion environment:
- 1st wall (5-7 yrs)
- beam propagation,
- chamber clearing, - -

ICF performance

35 MJ (Gain 25) with LIFE relevant targets will be done on NIF

We believe the S&T building blocks for NIF-based LIFE are credible extensions of NIF/NIC and ongoing developments in the world nuclear power industry

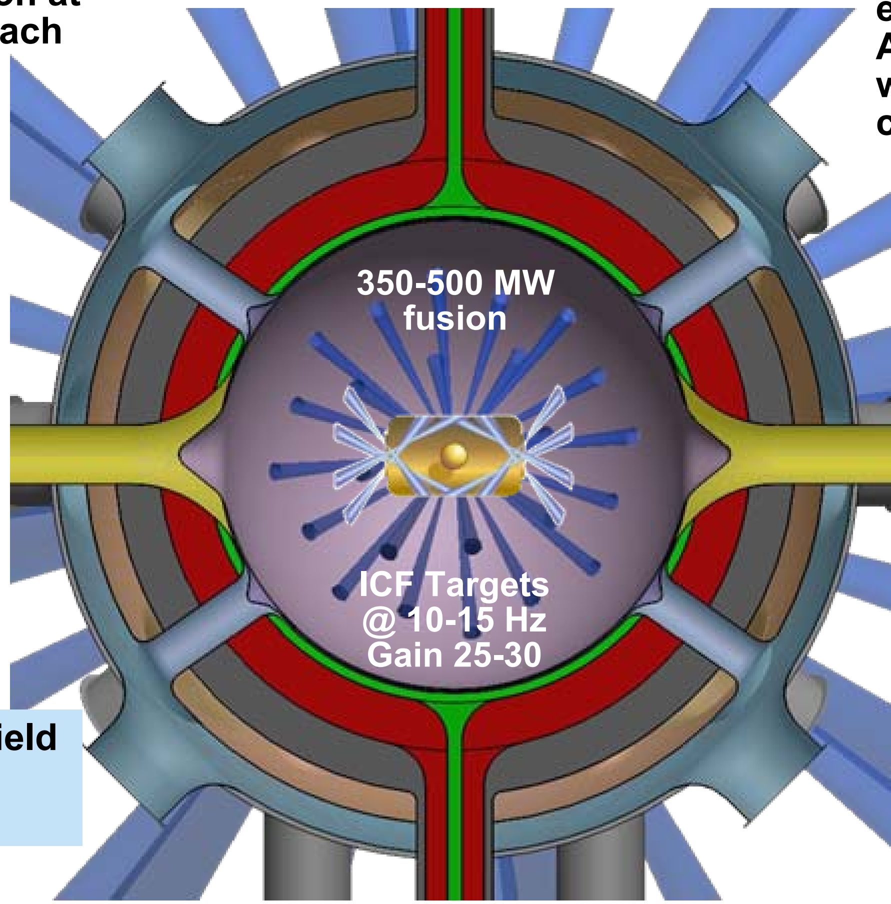
We have identified S&T development paths: Fusion yield

Target injection, survival of cryo fuel, tracking and laser intercept

Target production at 15 Hz @ ~ 30¢ each

Manage fusion environment:
A threat to final optics, 1st wall, beam propagation, chamber clearing, - -

Low cost NIF-energy level DPSSL @ 10-15 Hz 10-15% with high availability



1st wall survive 5 to 7 years from fusion neutron, x-rays and ions

Robust Hot Spot yield w /LIFE-relevant targets

High burn-up of fuel (goal is > 99%) without reprocessing

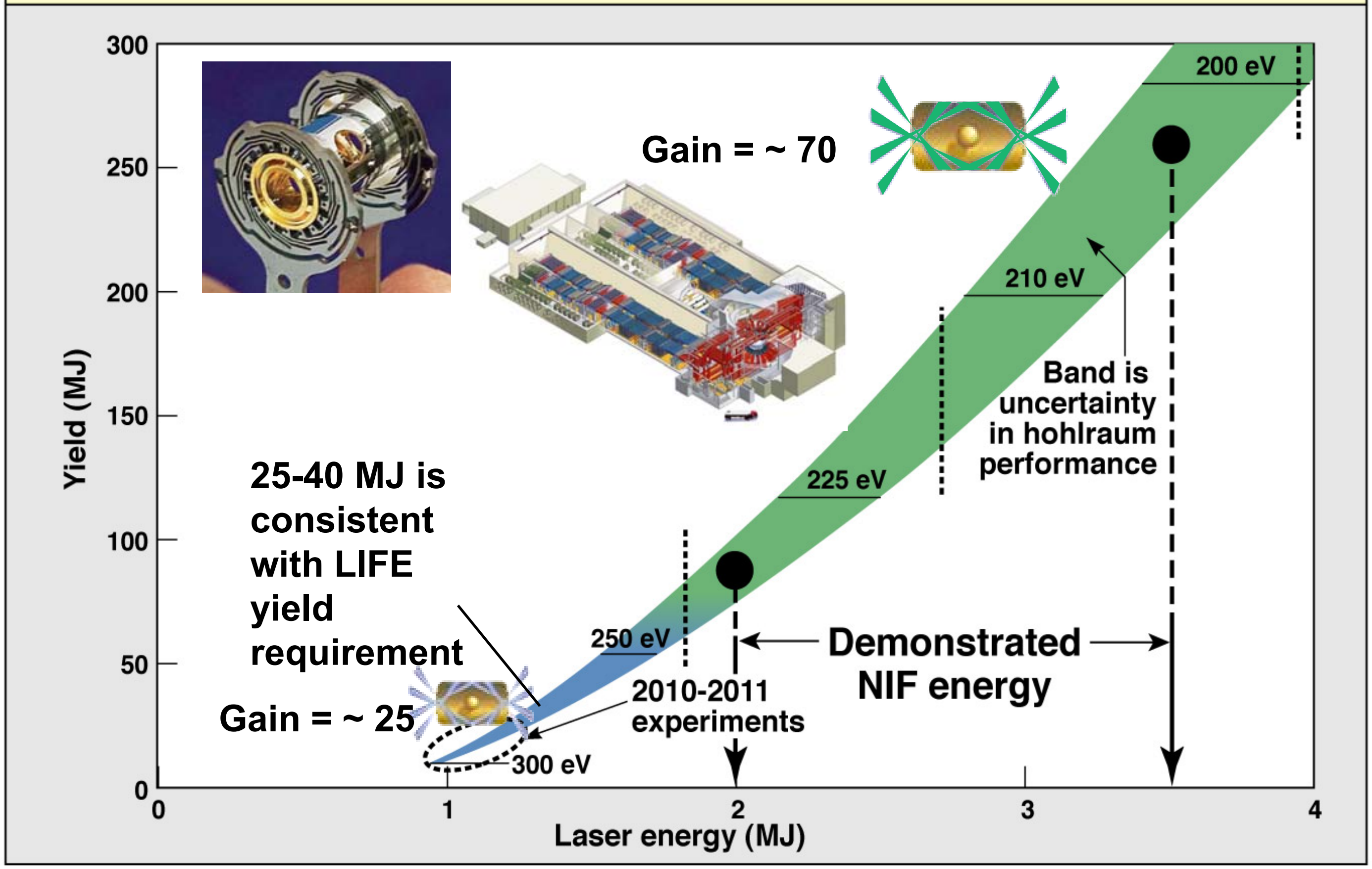
NIF target yields are enabling for LIFE and will be demonstrated with NIC

NIF Hot-spot Ignition Campaign will start in 2010

— Target, cryo technologies and diagnostics have been developed

— The scientific basis for HIS targets has been extensively developed

Yields versus laser energy for hot spot ignition in NIF geometry hohlraums



We anticipate LIFE-level yields by 2012 and with LIFE type targets by 2013

We have identified S&T development paths:
Fusion laser

Target injection,
survival of cryo fuel,
tracking and laser
intercept

Target production at
15 Hz @ ~ 30¢ each

Manage fusion
environment:
A threat to final optics, 1st
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Low cost
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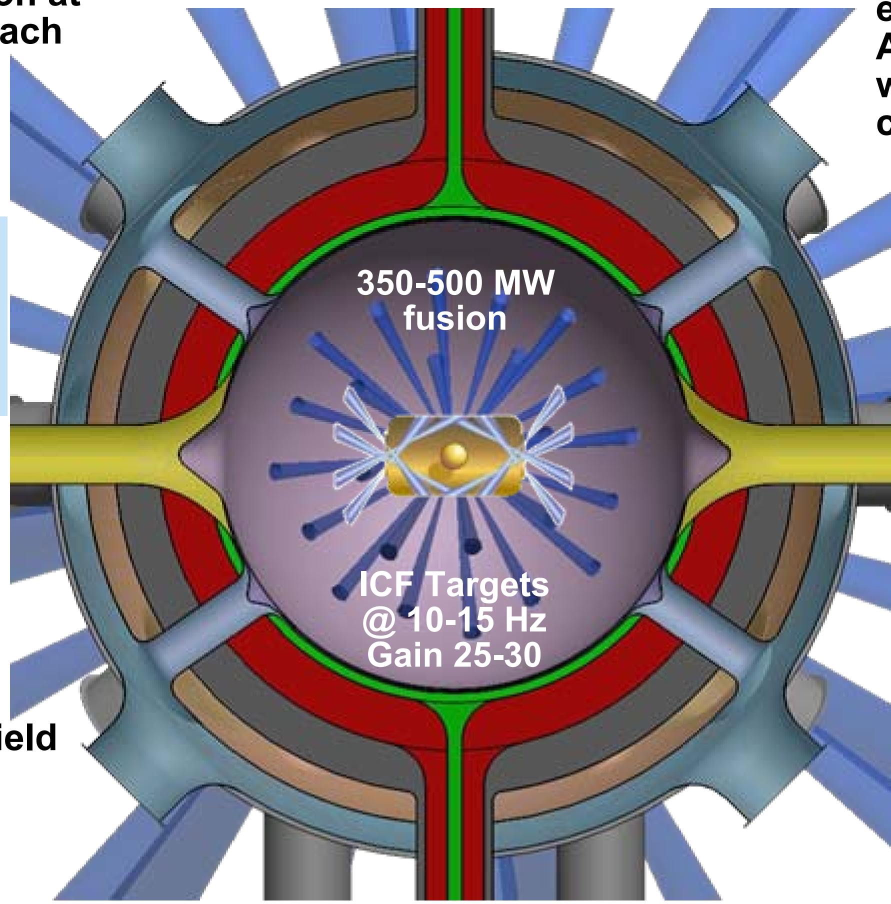


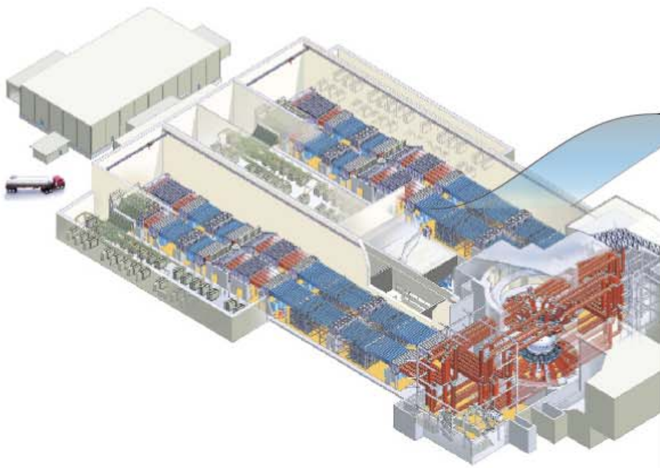
1st wall
survive 5 to 7
years from
fusion
neutron, x-
rays and ions

Robust Hot Spot yield
w /LIFE-relevant
targets

High burn-up of fuel
(goal is > 99%)
without
reprocessing

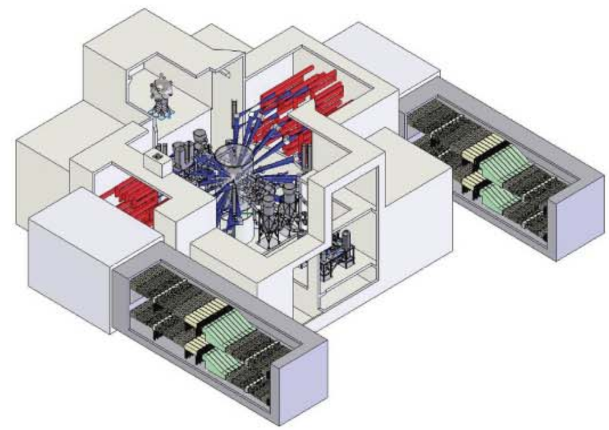
The LIFE laser is a logical extension of the NIF laser

NIF (2 MJ)



Repetition frequency 10^{-4} Hz
Electrical efficiency 1%

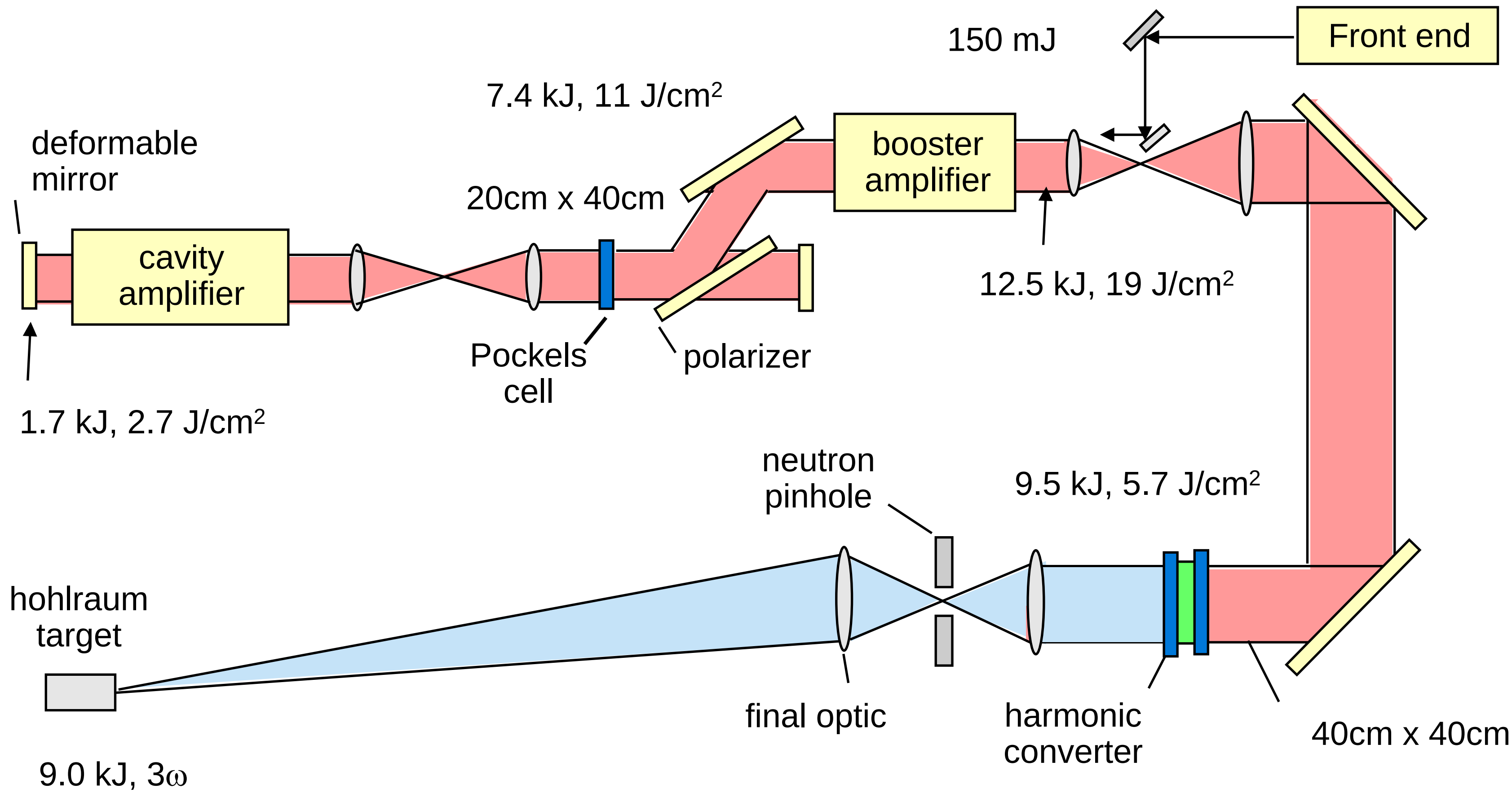
LIFE (17 MW)



Repetition frequency 13 Hz
Electrical efficiency >10%

- Fluence is identical
- He cooling enables average power
- Diode pumping enable efficiency

The LIFE laser 100 KW "building block" is a NIF-like beamline producing 7 kJ at ~ 15 Hz



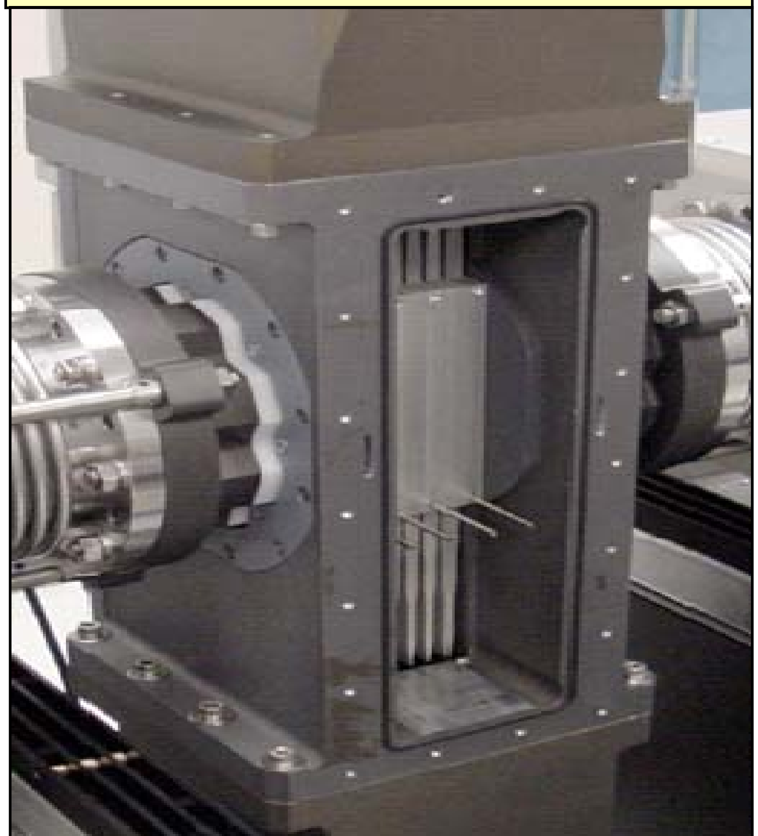
Efficient high power laser diodes and high flow rate He cooling allows this NIF-like beamlet to operate at 15 Hz

Laser diodes and He gas cooling enable a NIF-like architecture to meet LIFE high rep rate high efficiency requirements

High Power Diode Arrays

100 kW peak power

High Speed Gas Cooling



3 W/cm^2 cooling (average)

These technologies have been developed as part of the Mercury Project

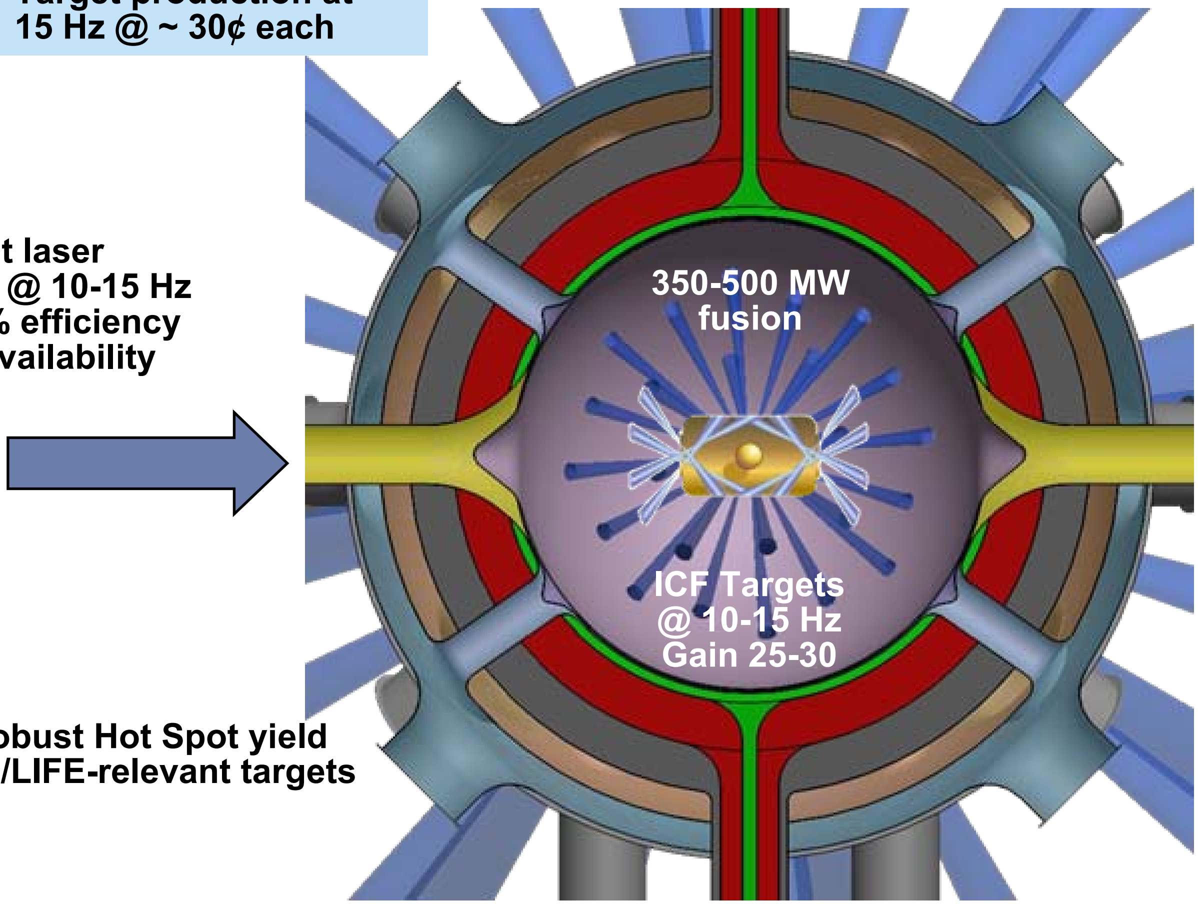
We have identified S&T development paths:
Fusion targets

Target injection
Tracking
Laser intercept

Target production at
15 Hz @ ~ 30¢ each

Manage fusion environment:
- 1st wall
- beam propagation,
- chamber clearing, - -

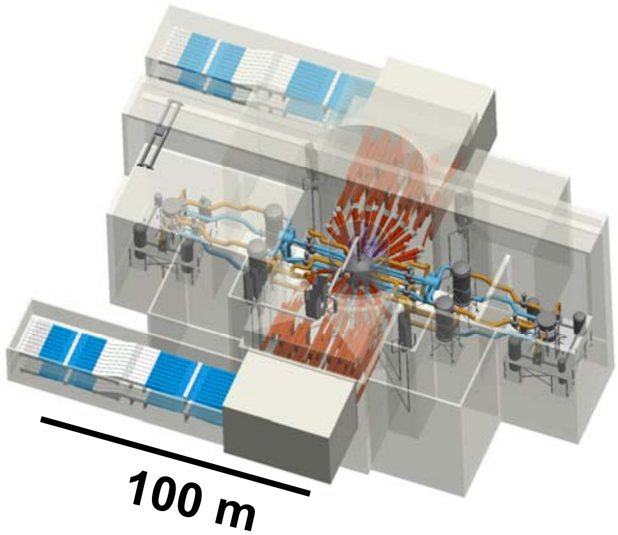
Low cost laser
- 1.4 MJ @ 10-15 Hz
- 10-15% efficiency
- High availability



1st wall 5 to 7 years life
- fusion neutron
- x-ray / ion thermal load

Robust Hot Spot yield
w /LIFE-relevant targets

System and economic criteria for LIFE targets are more stringent than NIF



	NIF	LIFE
Rep-rate	$<10^{-5}$ Hz	10 - 15 Hz
Cost	~$100,000	~$0.2 - $0.4
Waste stream	< 1 gm	10^{6} gm/year
Chamber placement	~10 μm^3,	~1 - 5 mm^3
Chamber impact- mass/ shot	gm	100 mg
Number/year	100	6x 10^{8}

The material costs are low

Item	Material	Cost ($)	Process
Hohlraum/cone	Pb	< $0.01	Deep-draw
Capsule			
Ablator	CH	$0.000003	Micro-encapsulation
Foam	CH	$0.00007	CO_2 extraction
DT		$0.00001 (D)	Permeation
Total costs		$0.01	

Total estimated target material cost = $0.01

Target cost will be in production processes

Costs are in mass-production at high precision

Estimated production costs based on typical factory

Item	Number	Cost/year ($M)
Operating personnel	69 people at $300K/yr	21
Capital depreciation	$200,000,000 typical factory/5 years	40
Maintenance	5% cost of equipment	10
Electricity	Factory typical	8
Total factory cost/yr		79
Production cost per target	631 million/year (20 Hz operation)	$0.13
Target material cost (Pb)		$0.01
Target material recycle costs		$0.10
Total target cost		$0.24

Together with GA we are developing a research plan for target fabrication to meet cost/precision objectives

There are examples of mass produced components that are comparable to LIFE requirements in volume, precision and cost

	LIFE	Mil Spec Bullet
Number/year	3.1-6.3 x 10^8	9 x 10^9
Dimensional tolerance	± 50 µm	± 40 µm
Cost	$0.20-0.30	$0.21

Bullets are an interesting comparison, as they are multi-component, multi materials, that tolerate high acceleration and high velocity

However

LIFE targets with ~ 2 mg/cc foam filled Pb hohlraums, Cryo-DT in ~2 mg/cc carbon foams CH shells and µm precision assembly will clearly require significant development

Injection demonstration at GA to simulate the full length of a LIFE fueling system have demonstrated many objectives

- **Injection at 6 Hz (burst mode) 400 m/sec to 200 μm demonstrated**
- **Additional R&D needed for Cryogenic targets and >10 Hz**

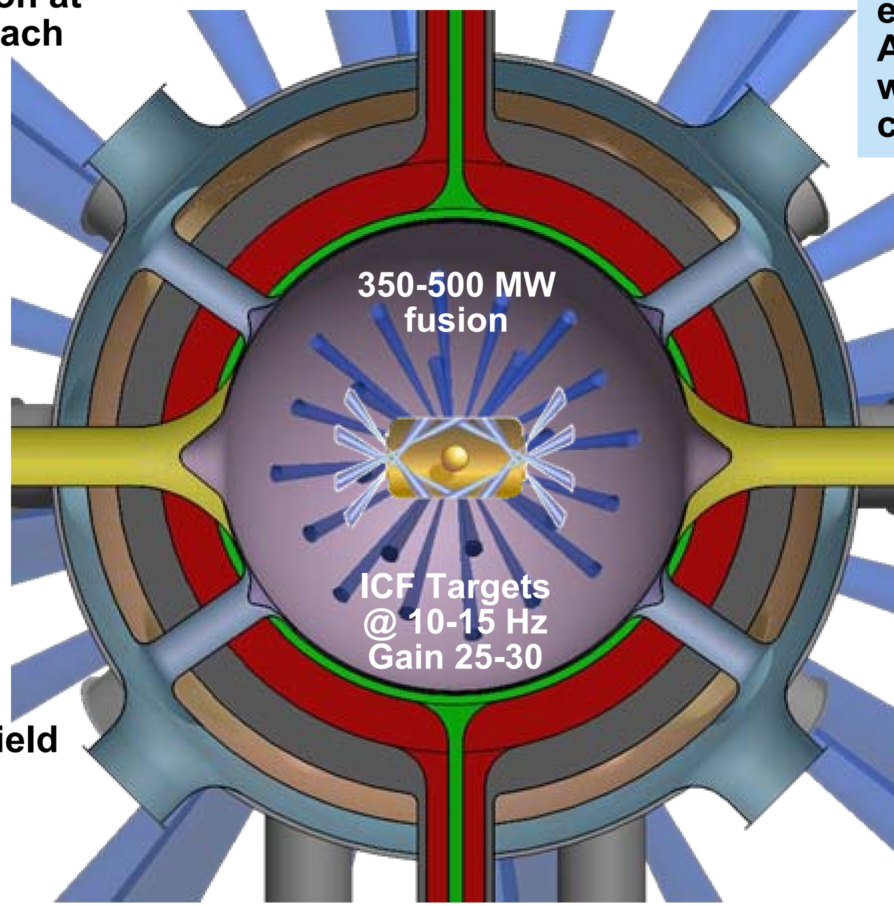
We have identified S&T development paths:
Managing fusion environment and 1st Wall

Target injection,
survival of cryo fuel,
tracking and laser
intercept

Target production at
15 Hz @ ~ 30¢ each

Manage fusion
environment:
A threat to final optics, 1st
wall, beam propagation,
chamber clearing, - -

Low cost
NIF-energy level
DPSSL
@ 10-15 Hz 10-15%
with high availability



1st wall
survive 5 to 7
years from
fusion
neutron, x-
rays and ions

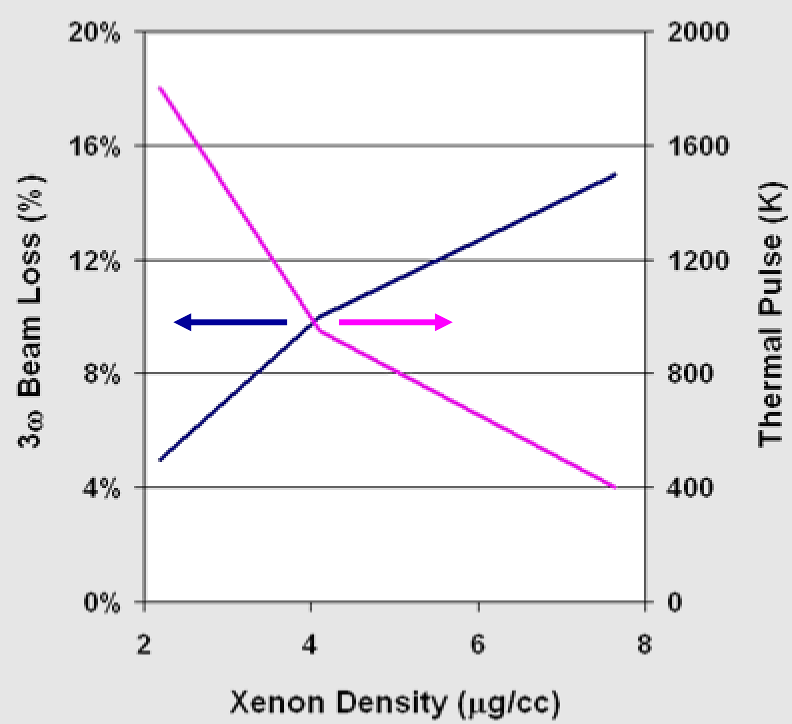
Robust Hot Spot yield
w /LIFE-relevant
targets

High burn-up of fuel
(goal is > 99%)
without
reprocessing

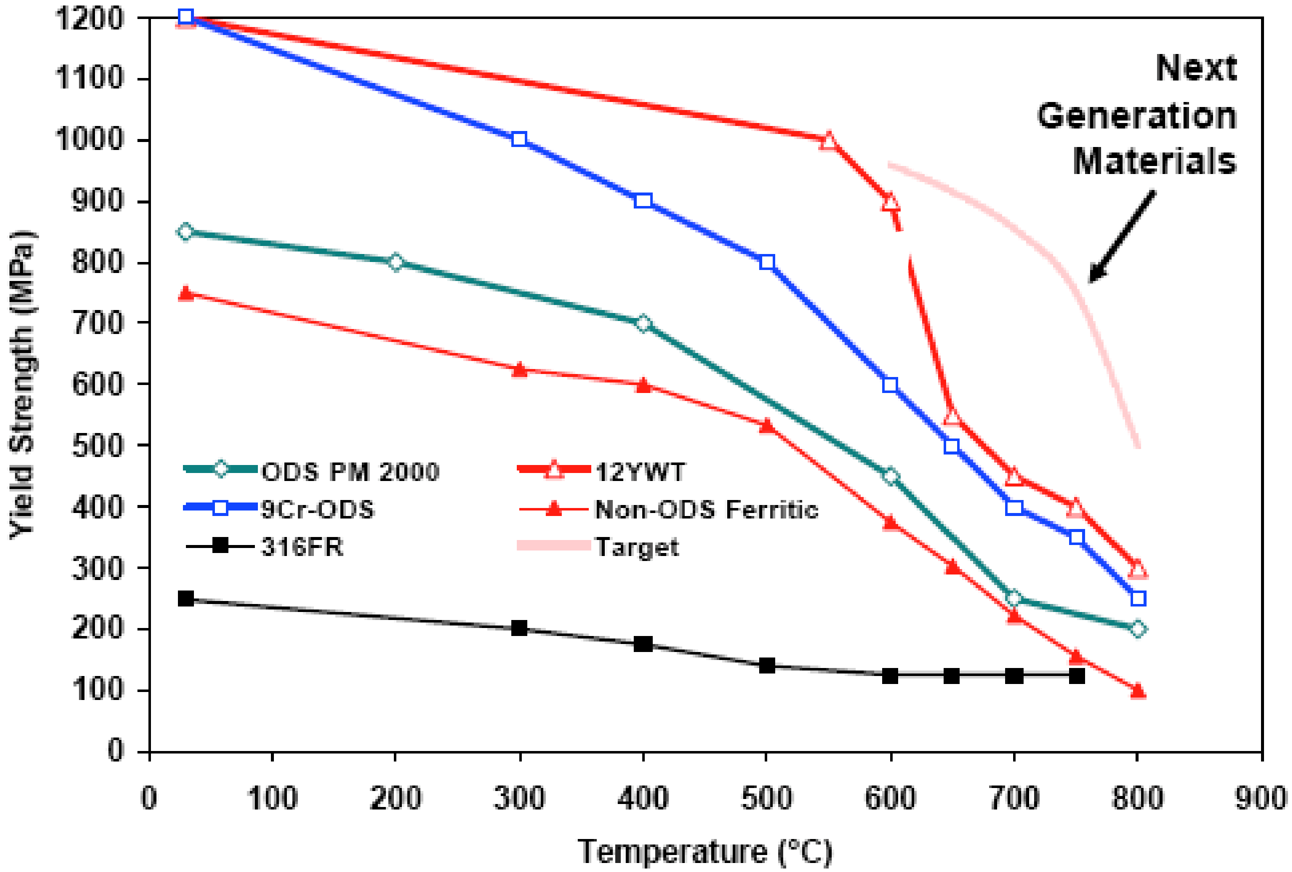
Thermal robustness of indirect-drive targets allow use of chamber fill gas and compact chambers

- First wall is oxide dispersion strengthened ferritic steel over-coated with 500 µm W
- X-rays from target pre-ionize gas near target and causes partial laser absorption by inverse bremsstrahlung
- Gas stops all ions (~ 4MJ) and ~ 90% of 4.5 MJ of x-rays
- Absorbed energy is re-radiated over 100's µsec
- Experiments and modeling at LLNL, UCSD and UW for ~ 1800 K pulses

Xenon densities of ~4 µg/cc reduce the thermal pulse to <1000 K



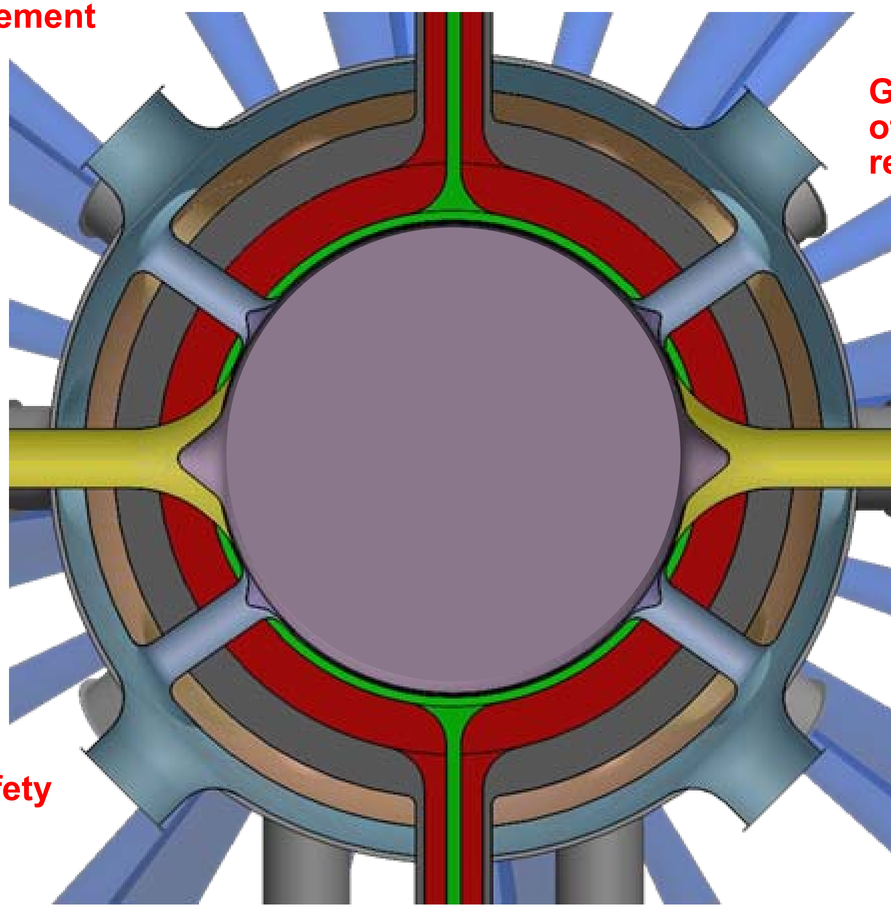
ODS-Ferritic Steel is a good baseline material for LIFE 1st wall



ODS steel tested in BOR-60 sodium-cooled fast flux reactor (> 85 dpa)

Ion beam irradiation at 500 °C project to 150 dpa, (1st wall lifetime of ~ 5 years)

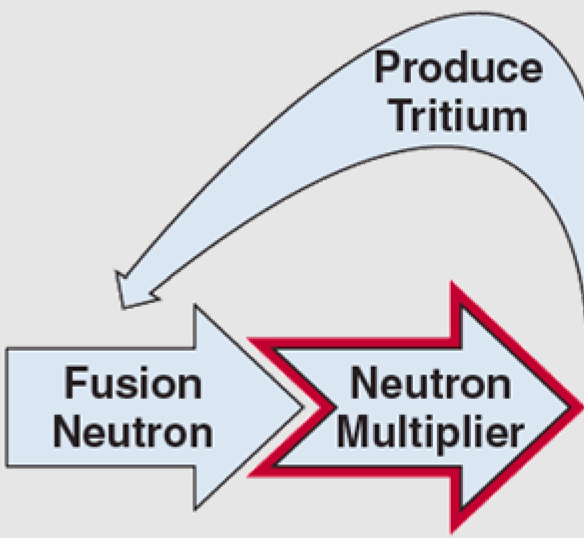
We have identified S&T development paths:
Fuels and fission engine systems optimization



Ongoing developments in the world nuclear power industry give us confidence that these challenges are tractable

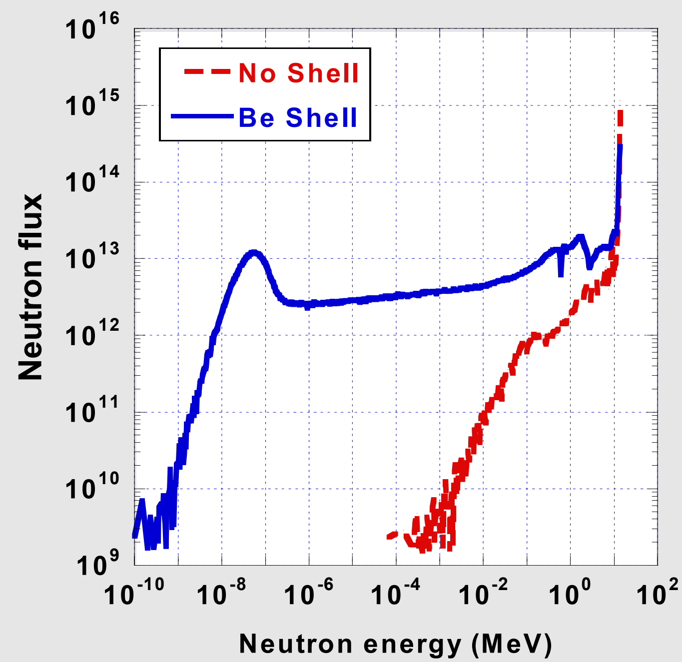
Beryllium multiplication and moderation enables rapid production of fissile material

Neutrons are multiplied via $^9Be(n,2n)$ reactions



Beryllium produces ~1.8 neutrons for every fusion neutron

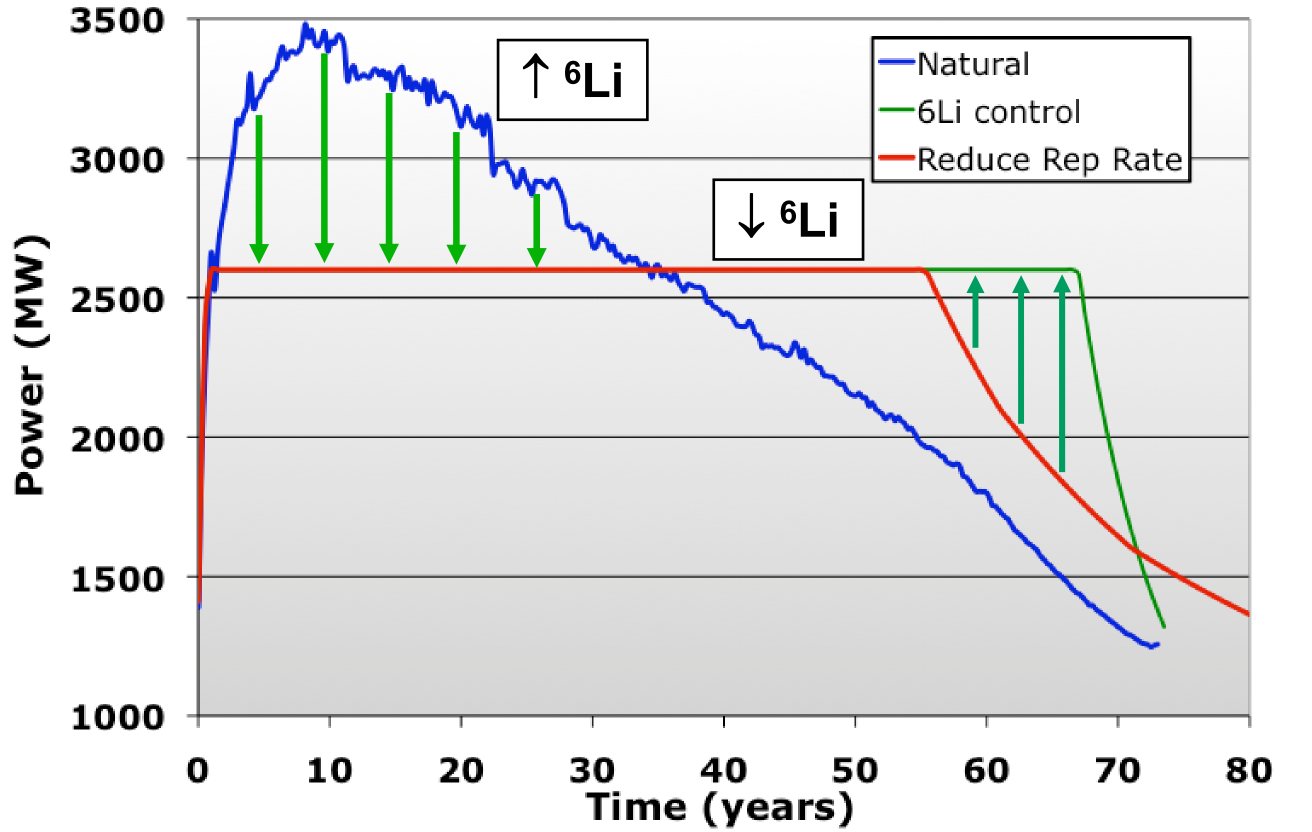
10 cm of Be considerably softens the neutron spectrum



More thermal neutrons are available to produce tritium and fissile material

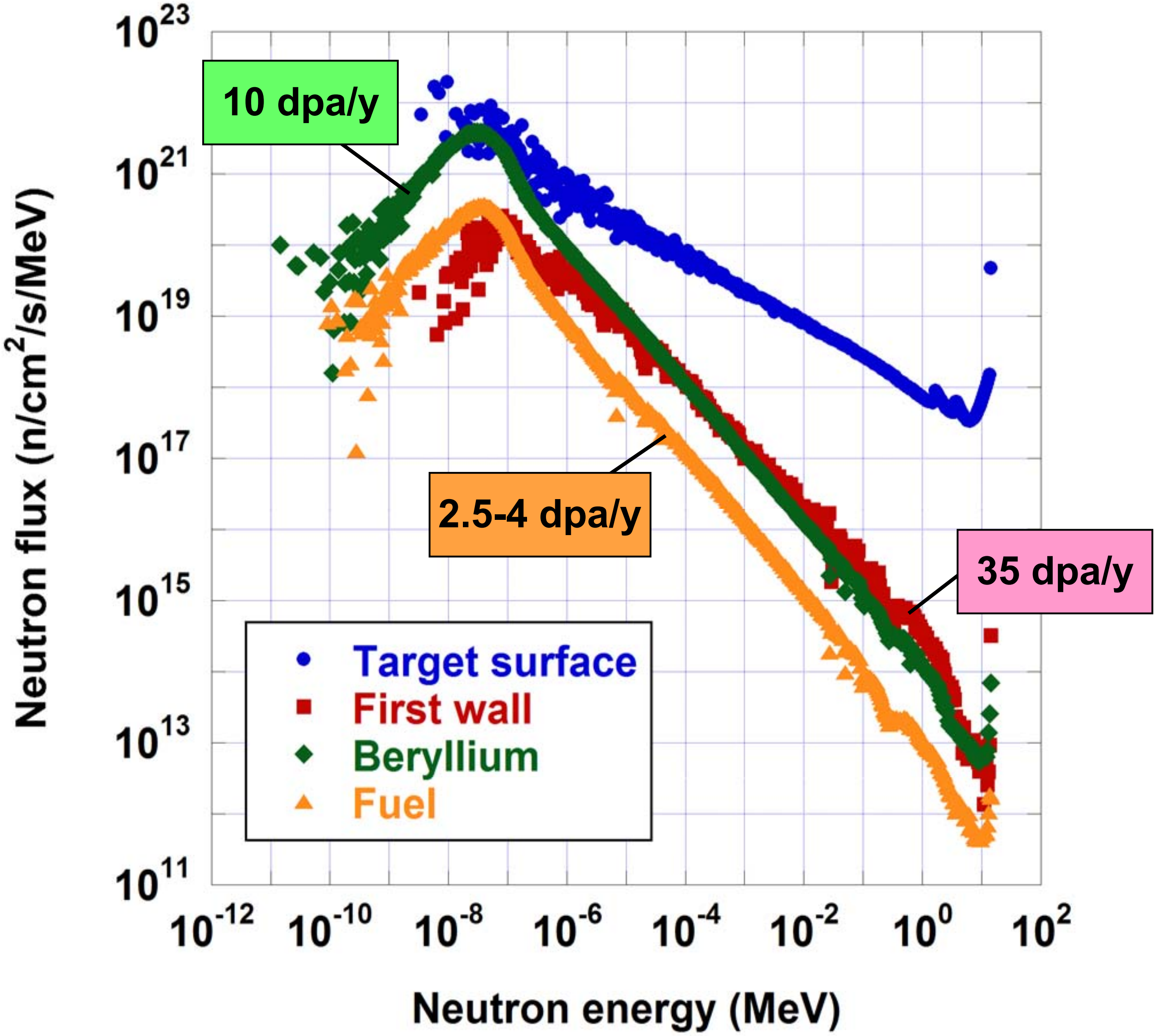
LIFE uses ^{6}Li as a burnable poison to control the thermal power and produce tritium

A flat power curve is desirable



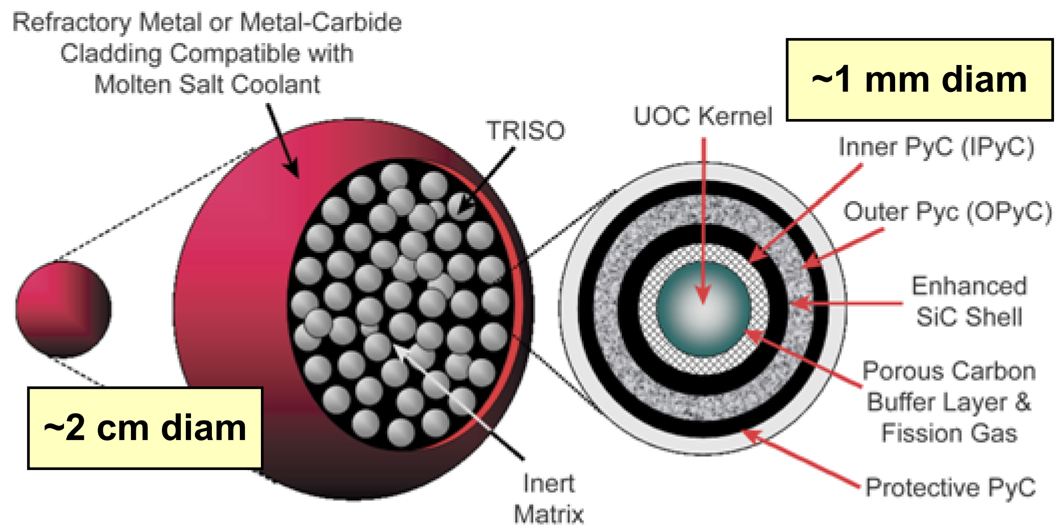
Systems achieving 90%+ balance of plant utilization may be possible through tritium management

The neutron spectrum varies considerably in the different regions of a LIFE engine

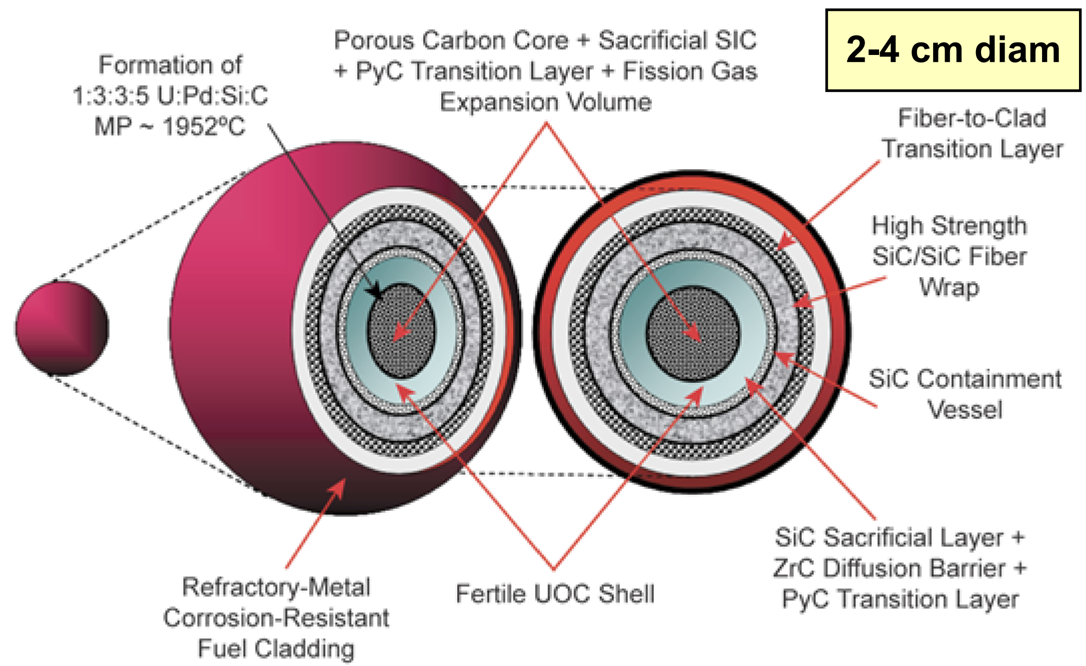


LIFE could potentially use a variety of fuels

- **Enhanced TRISO for WG-Pu and HEU**

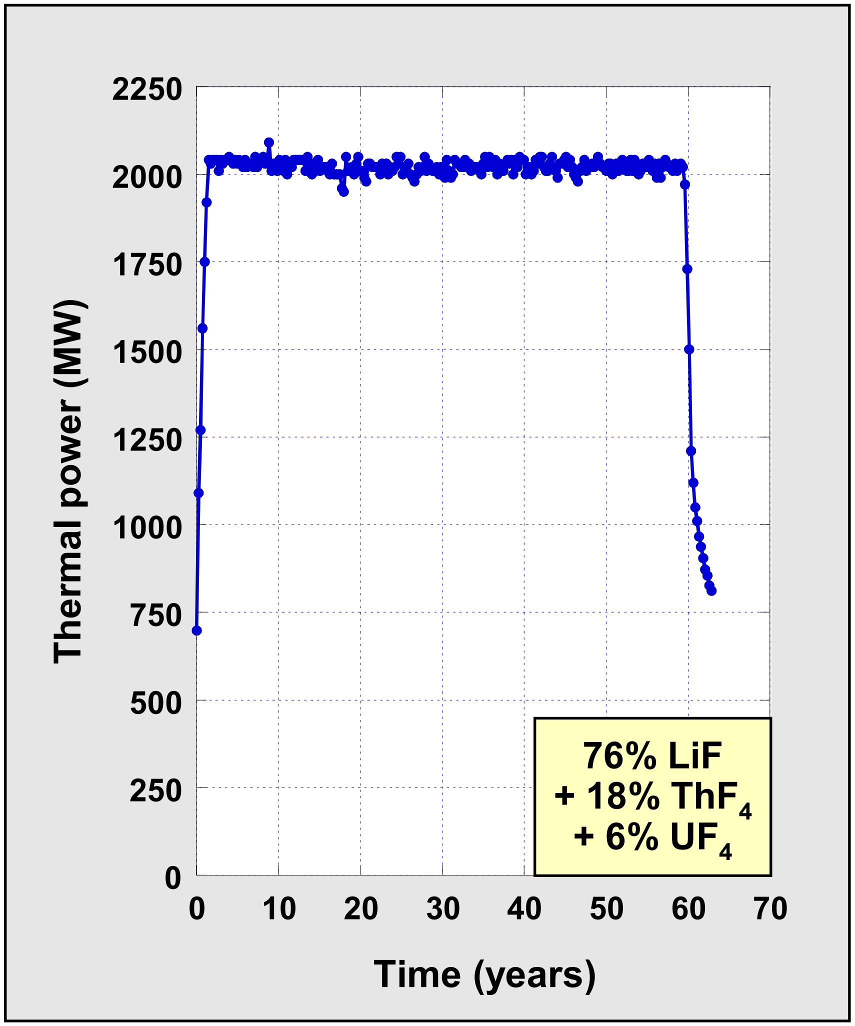


- **Solid hollow core and Encapsulated powder pebbles for fertile fuels (DU, Nat U, Th and SNF)**



Molten salt fuel is an attractive option for burning fertile fuels

- Radiation damage to fuel is a non-issue
- Rare earth elements removed to avoid precipitation (on-line processing)
- Plutonium maintained below solubility limit → can adjust Th/U ratio to control $[Pu]_{max}$
- Blanket gain of 6-10× possible with on-line refueling



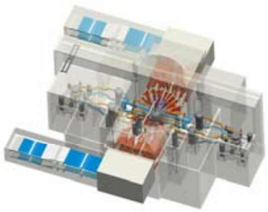
LIFE goal: Provide a sustainable, once-through closed nuclear fuel cycle energy option

- LIFE uses fusion neutrons to drive a subcritical fertile/fissile fuel blanket and provide a once-through closed nuclear fuel cycle

- The science and technology "building blocks" for a NIF-based LIFE system are logical and credible extensions of NIF, ignition on NIF and ongoing developments in the world nuclear power industry

- The inherent separability of LIFE, would allow a NIF-based LIFE system to be piloted by 2020-2025

There are three phases that lead to commercial power from the NIF-based LIFE



2030-2035 Commercial power on the grid

2022

LIFE Integrated Pilot and Prototype (IPP) --- Phase II

Full scale 500 MW fusion facility with partial fission blanket operating at plant performance specifications for a total of 350 MW of electric power
Full life test of structural and fuel materials for licensing of commercial plant

2018

LIFE Integrated Pilot and Prototype (IPP) --- Phase I

Full Scale Laser Plant, with subscale, Integrated Technology Demonstration of LIFE's fusion facilities operated in burst mode (15 Hz for minutes)
Demonstrate molten salt system and tritium recovery
Fuel blanket pebble injection (without fissile fuel), flow and extraction
Materials test facility at full neutron, ion and x-ray fluences

2014

LIFE Technology Development Program (TDP)

Demonstrate LIFE fusion performance on the National Ignition Facility (NIF)
Establish and validate LIFE-ITDF technologies
(Ignition will be demonstrated by the separately funded National Ignition Campaign)

2010

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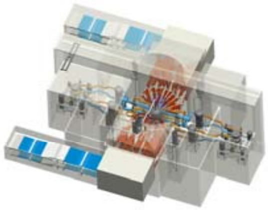

2030-2035 Commercial power on the grid

The separability of ICF and LIFE makes such a rapid demonstration path possible

2022

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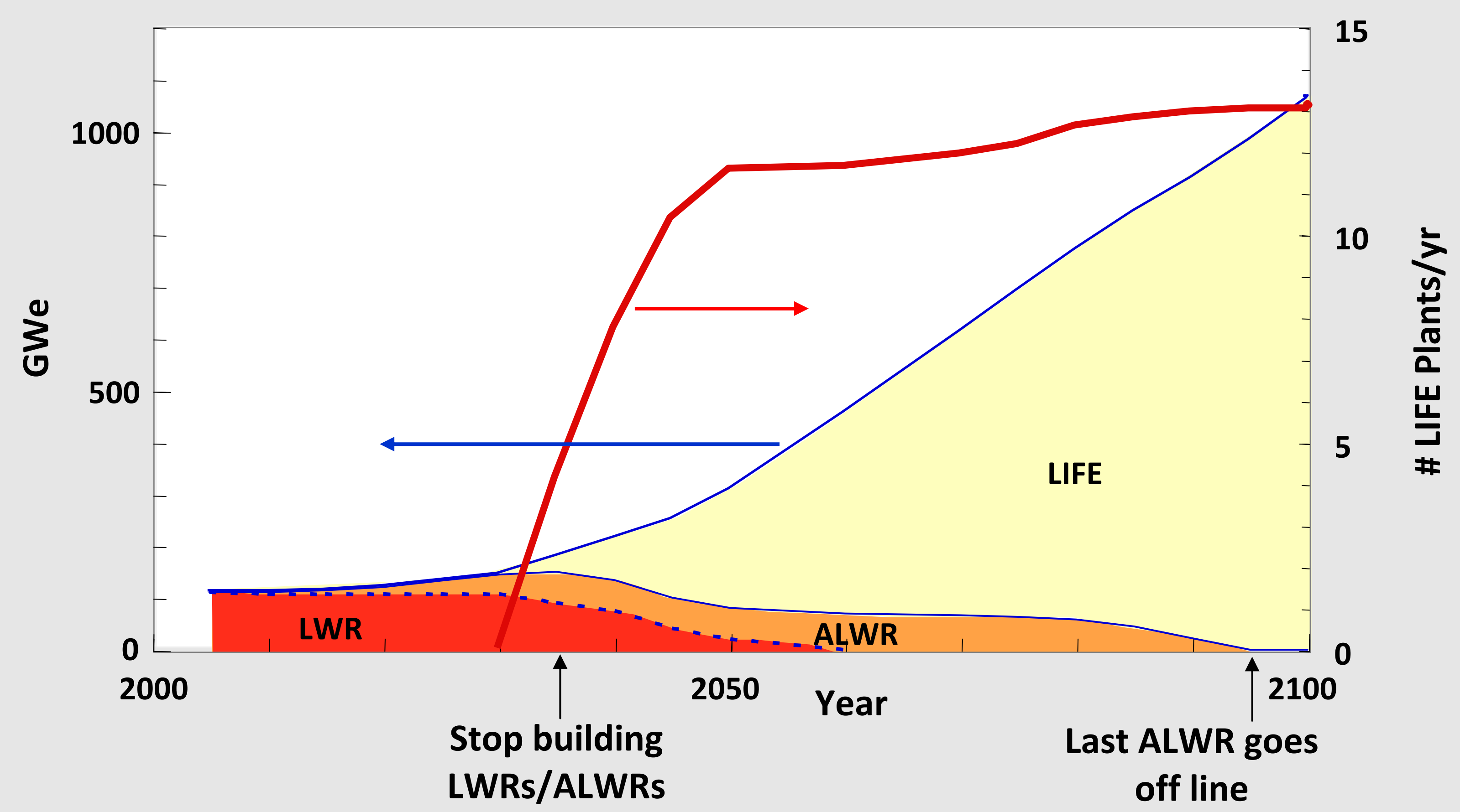
LIFE could begin to provide electricity by the mid 2030's and one-half of expected U.S. baseload demand by ~ 2100

Scenario for 1 Twe from LIFE engines burning DU and/or SNF (50% of projected U.S. electricity demand in 2100)



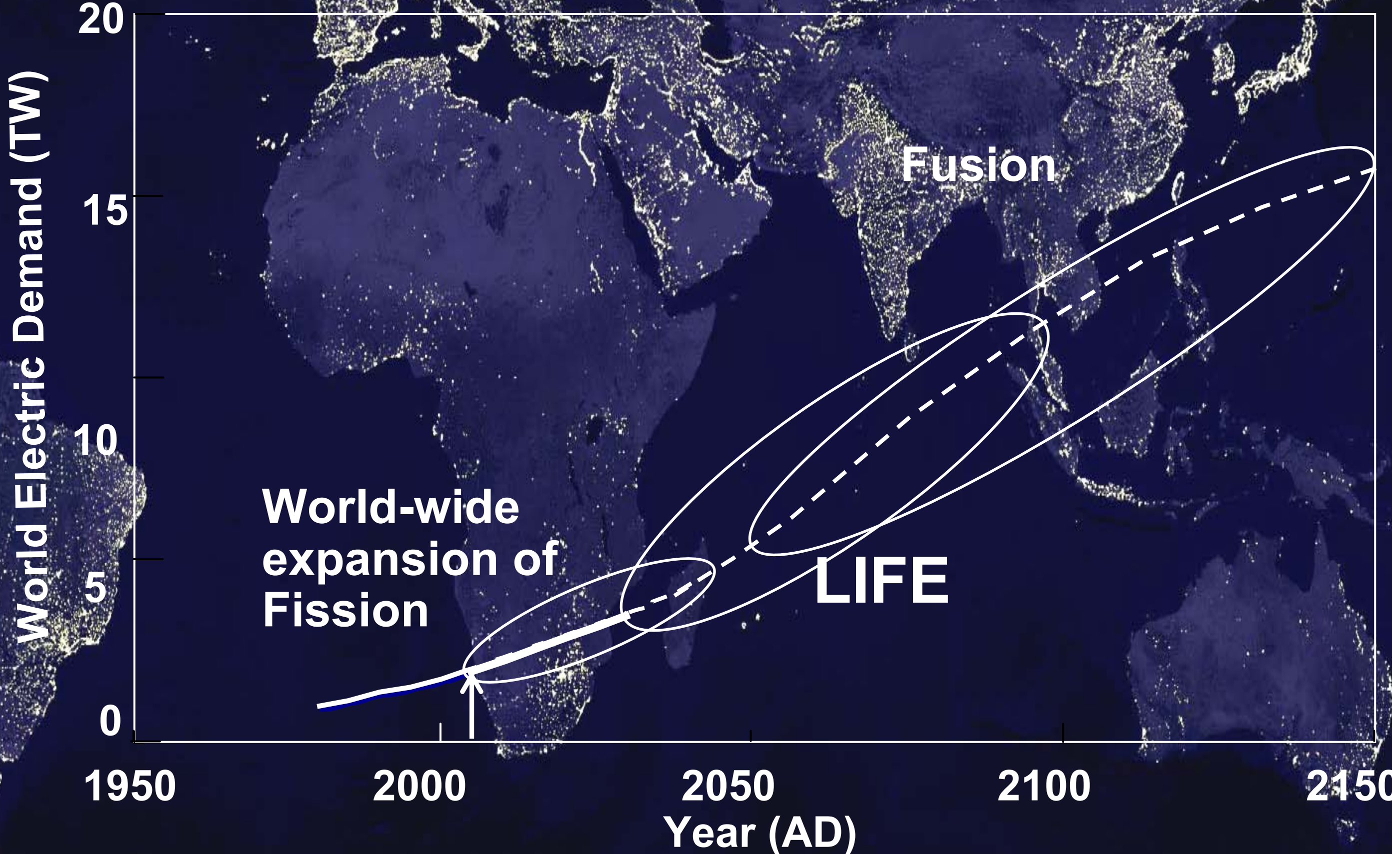
We believe that a NIF-based LIFE with "today's technology" is credible and meets LIFE goals

- NIF-like lasers
  - APG-1 glass; He cooling; high power edge emitting diodes
- NIC-like targets
  - Hot spot ignition; 25-40 MJ @ 1-1.4 MJ
- Target production, injection and engagement
  - Studies and scaled experiments at GA
- Fusion environment, 1st wall and final optics
  - Xe-filled, compact chambers; ODS-FS 1st wall
  - Thin Fresnel fused silica lens – self annealing color centers
- High burn-up Fuels
  - SHC pebbles provide options for high burn-up
  - Molten salt – radiation damage not an issue

And LIFE can only get better: By the time of a LIFE Pilot/Integrated Test Facility

- **Next generation NIF-like lasers**
  - — Y-SFAP; He cooling; VCSEL diodes
  - ➡ 3x fewer diodes; lower cost
- **Fast Ignition targets**
  - — Fast Ignition; 25-40 MJ @ 0.5-0.6 MJ and 0.53 μm
  - ➡ Lower cost lasers, lower operating costs
- **Target production, injection and engagement**
  - — Studies and scaled experiments at GA
- **Fusion environment, 1st wall with improved materials**
  - — Radiation resistant materials; Higher temp 800 vs 700 C
  - ➡ 1st wall last 10 yrs; Thermal to electric eff 43% - 52 %
- **High burn-up Fuels**
  - — Radiation resistant materials
  - ➡ Improved blanket gain and > 99.9% FIMA for all fuel forms in solid pebbles

We believe that LIFE could provide the bridge to the future

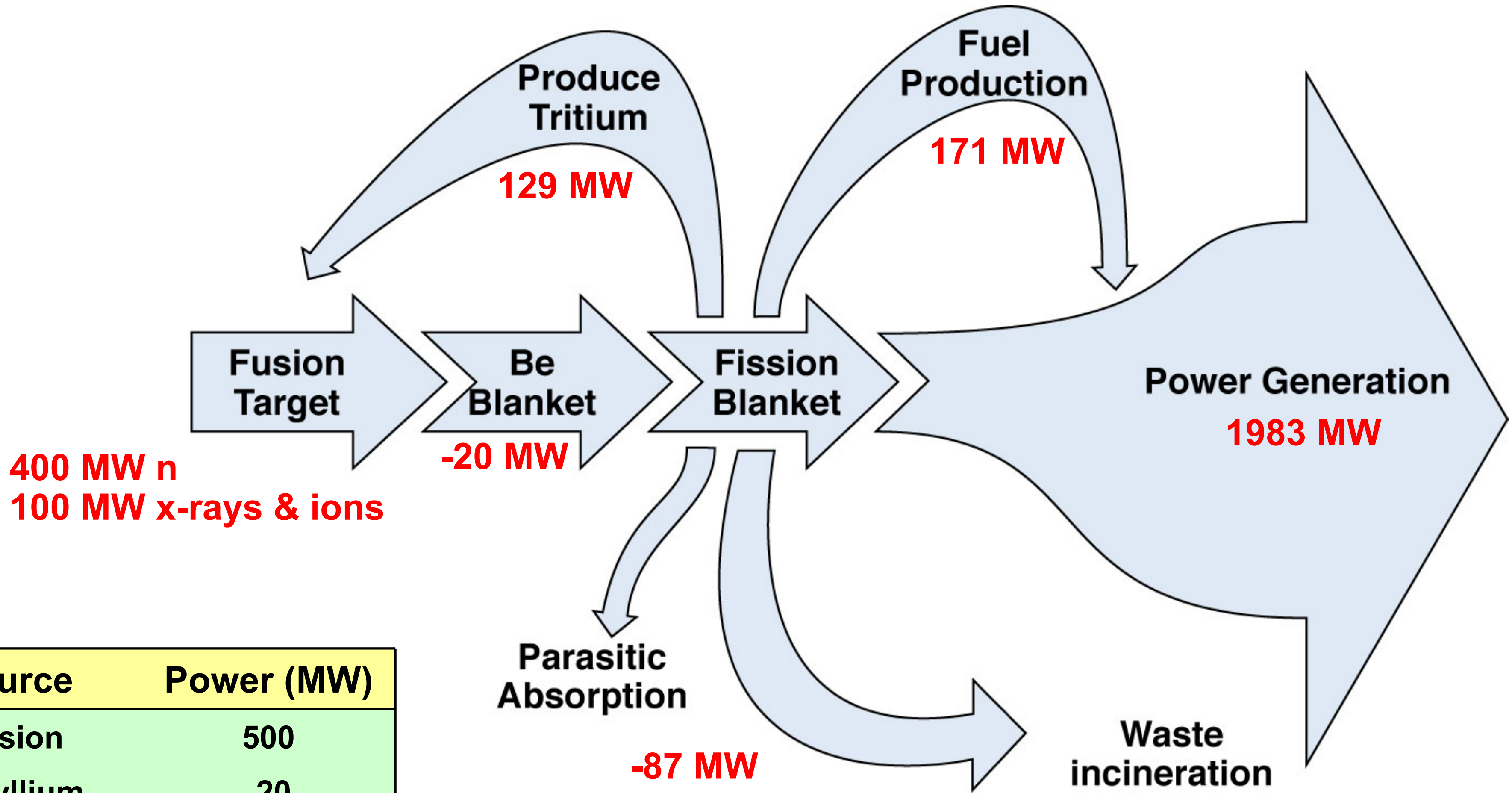


Global Factors

- Population increase
- Developing countries
- Resource depletion
- Climate change

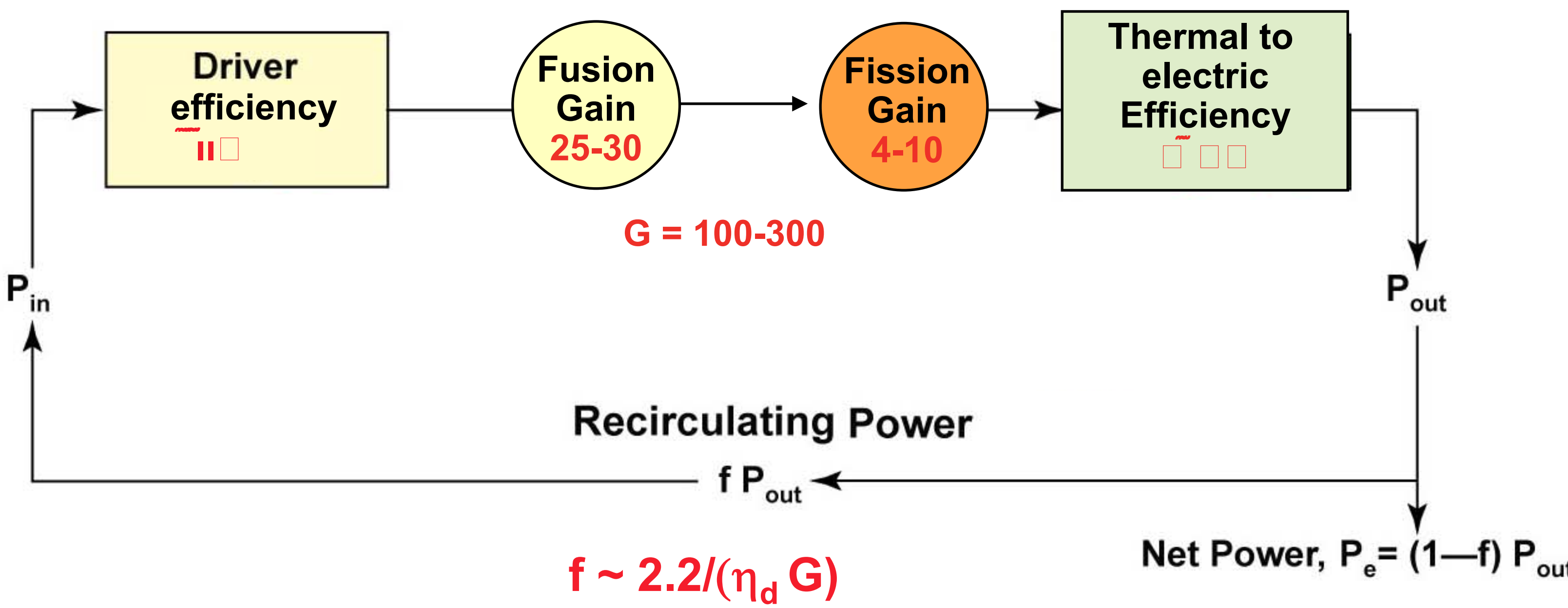
This challenge must be met and solved in the next 10-15 years …
Not 50 years from now

Neutron power flow for DU case at time of peak ^{239}Pu (~10 years); TBR = 1.09



Source	Power (MW)
Fusion	500
Beryllium	-20
Tritium prod.	129
Fuel prod.	171
Fission	1983
Incineration	-87
Total	2676

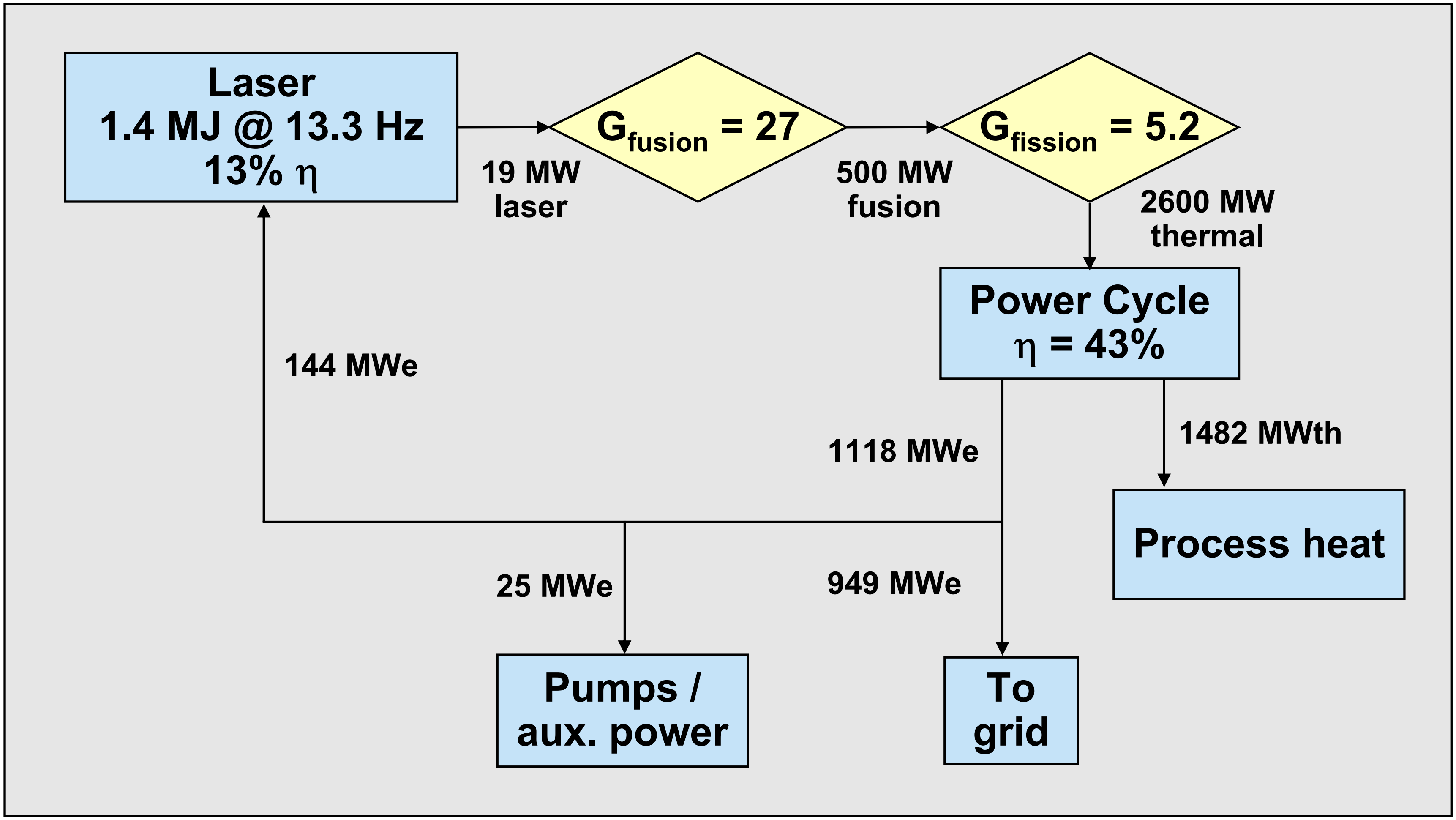
LIFE Engine basics – The extra fission gain makes low fusion gains viable



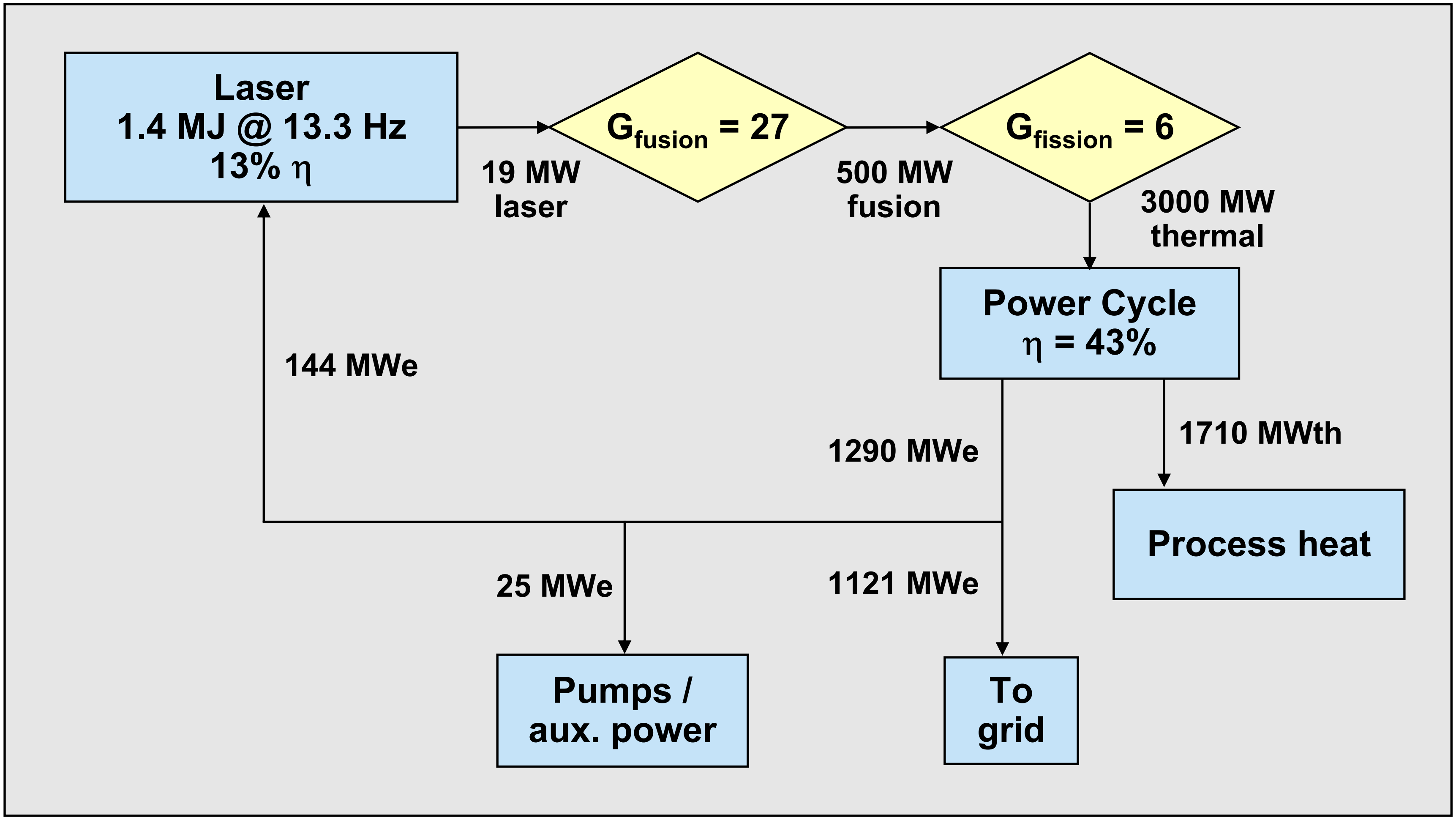
Recirculating fraction < 0.15 even for modest fusion gains of 25

NIF fusion gains alone would require recirculating fractions ~ 60 %

LIFE power flow for DU blanket



LIFE power flow for Pu blanket



The separability of ICF and LIFE makes a rapid demonstration path possible

- Demonstration of LIFE fusion yield with targets produced with low-cost fabrication technologies that scale to LIFE production quantities will be demonstrated on NIF

- Mass production technologies for the fusion targets at required precision will be done off line

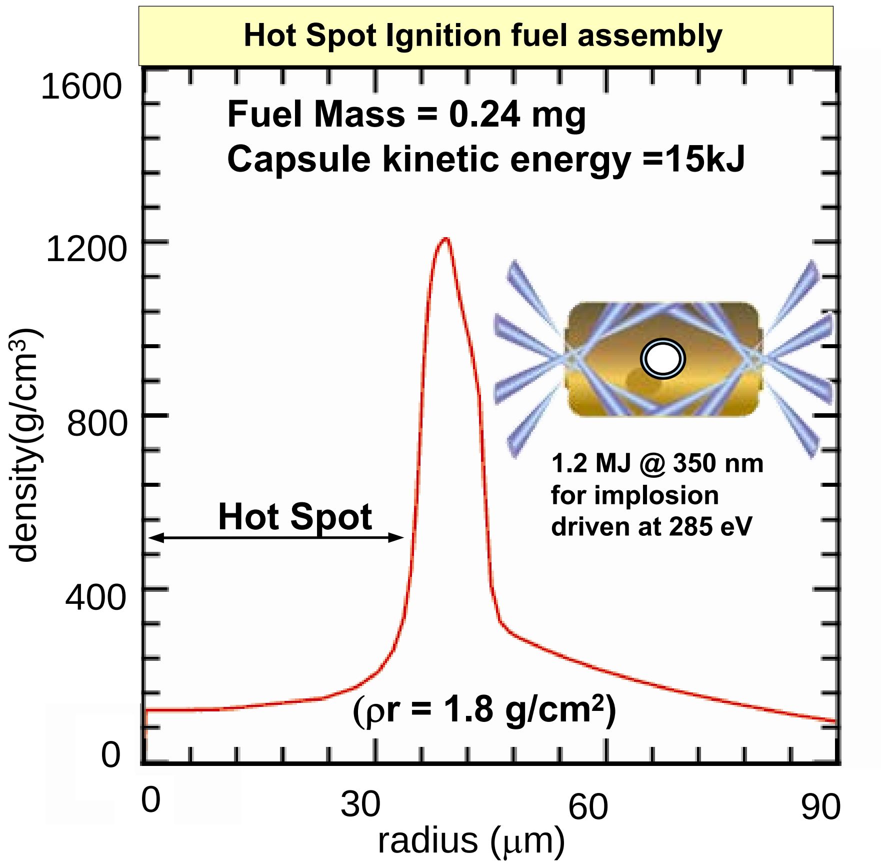
- Target delivery, tracking and engagement and chamber clearing will be demonstrated with surrogate targets and low power lasers in a separate facility

- The technology for the 15-20 MW LIFE diode pumped solid state laser (DPSSL) will be prototyped at the modular level.
  - One LIFE-let ~100 kW is the "building block"

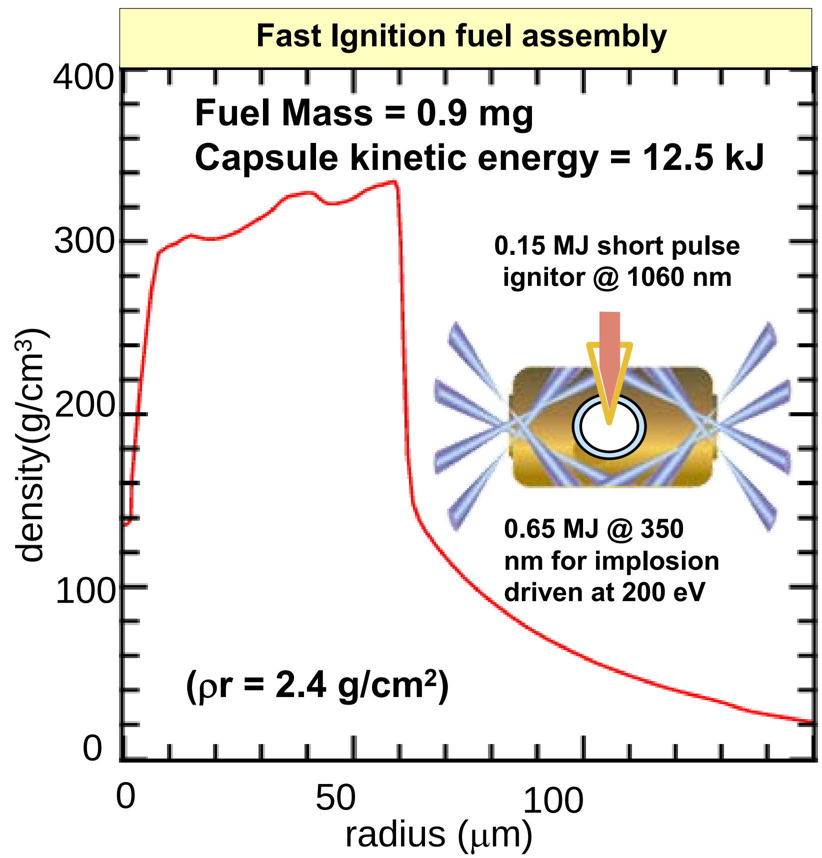
- Management of the fusion environment to demonstrate laser beam propagation, full life-cycle testing of thermal pulsing of 1st wall, and adequate lifetime of final optics will be performed in scaled experiments

- Ion beam-based accelerated testing coupled with multi-scaled modeling will be used to design and validate fuels and structural materials

We are also exploring advanced LIFE concepts
The most promising is Fast Ignition



20 MJ of fusion yield for a Gain of 17

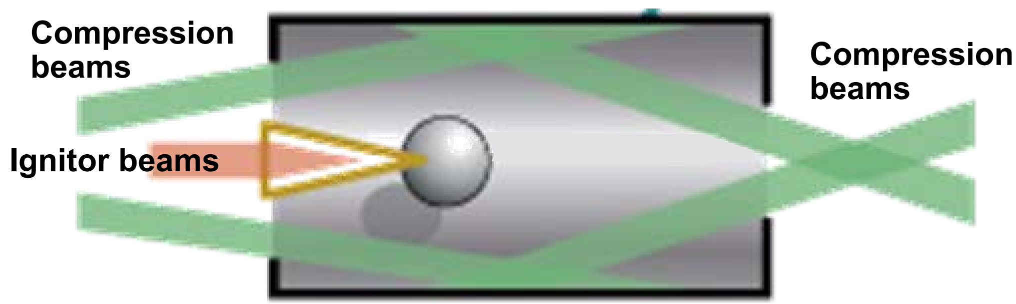


90 MJ of fusion yield for a Gain of 112

Fast ignition targets compress more fuel to ignition conditions with less laser energy, providing higher gain

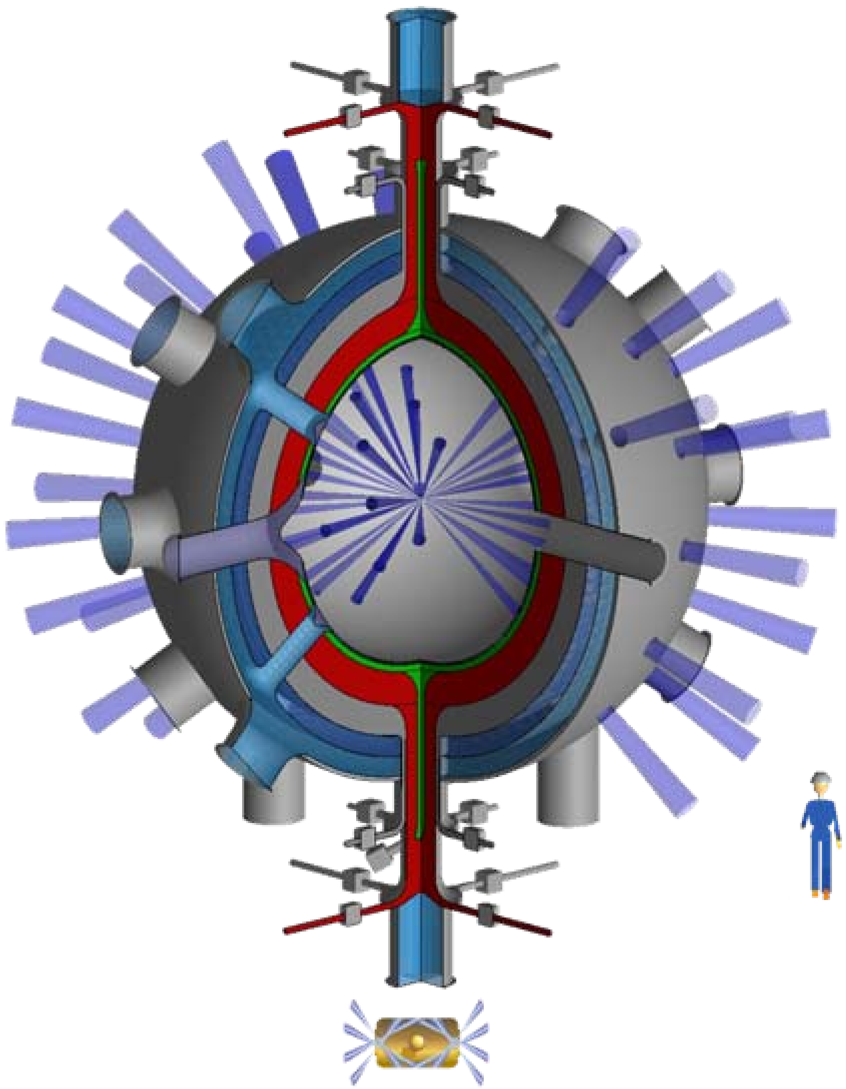
Indirect drive Fast Ignition has the potential of being compatible with low incidence angle illumination

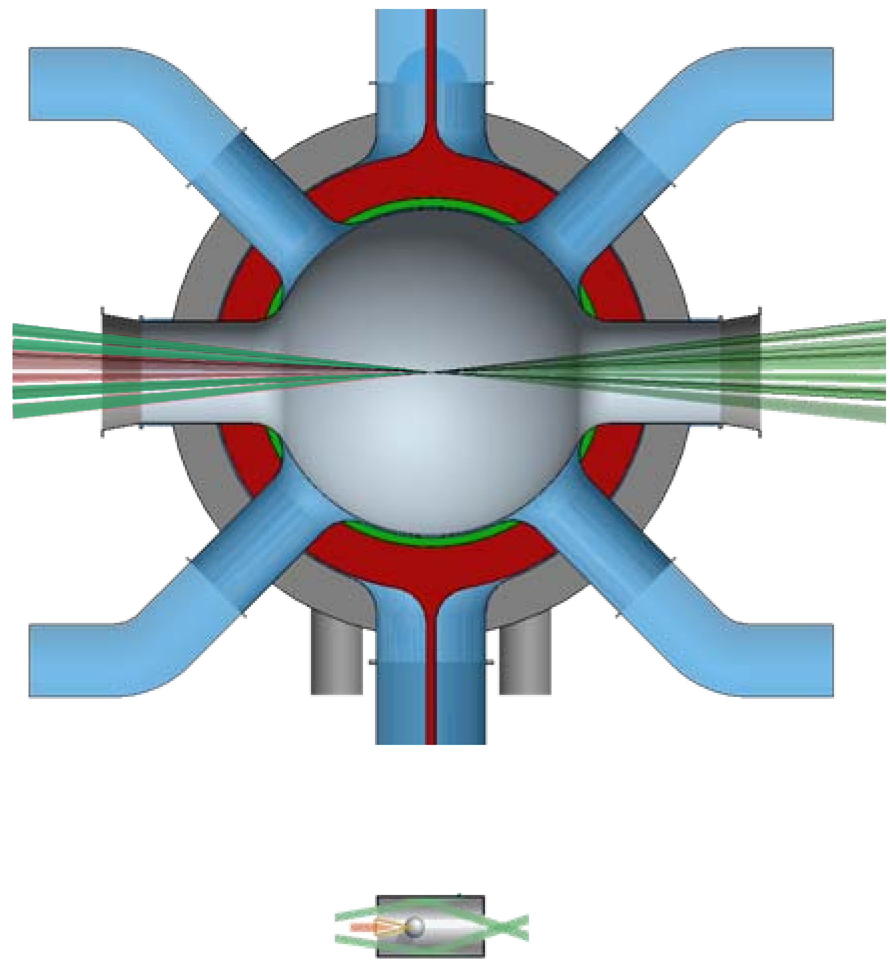
Possible Low Incidence Angle Indirect Drive Fast Ignition Target



- Symmetry requirements relaxed, allows low incidence angle illumination
- Lower drive pressures/Tr, i.e. LPI issues relaxed, allows longer wavelength driver (2ω)

Fast ignition thus offers the possibility of more attractive chamber options and 530 nm compression lasers





Different targets result in different chamber sizes and plant electric output