Lattice Energy LLC

Commercializing a next-generation source of safe CO_2-free nuclear energy

Scalability of LENR power generation systems

Do not involve fission or fusion or hard radiation emissions

Current laboratory devices produce only milliwatts to Watts thermal
Analogous to fission reactors: future scale-up to kilowatts and megawatts

Many-body collective effects enable safe electroweak nuclear catalysis at low temps via
***e* + *p* neutron-producing electroweak reaction that is triggered in condensed matter at STP**

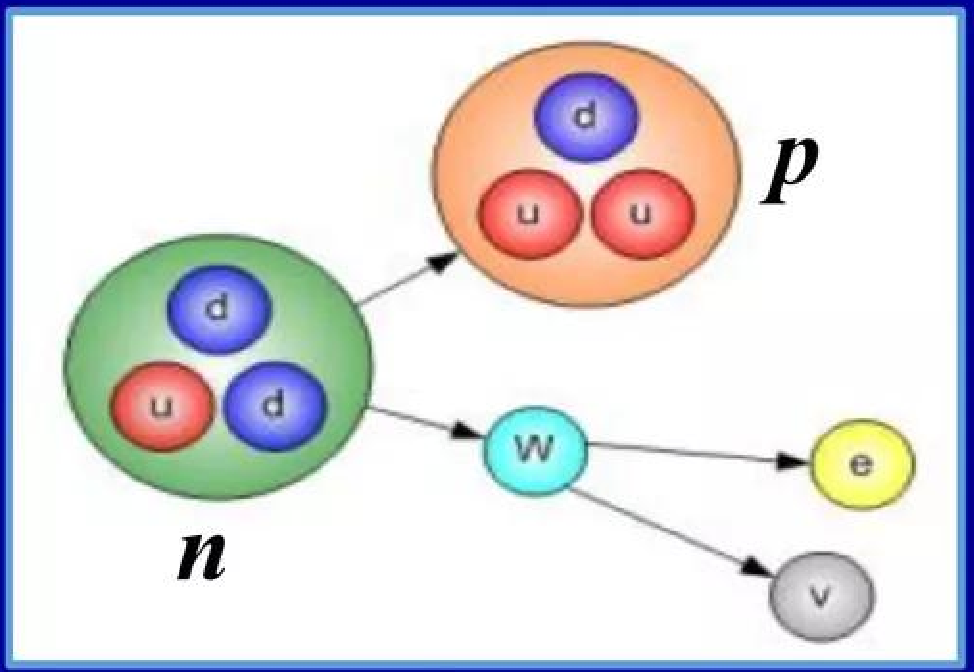

Image adapted from Physics Light

Lewis Larsen
President and CEO
November 29, 2015

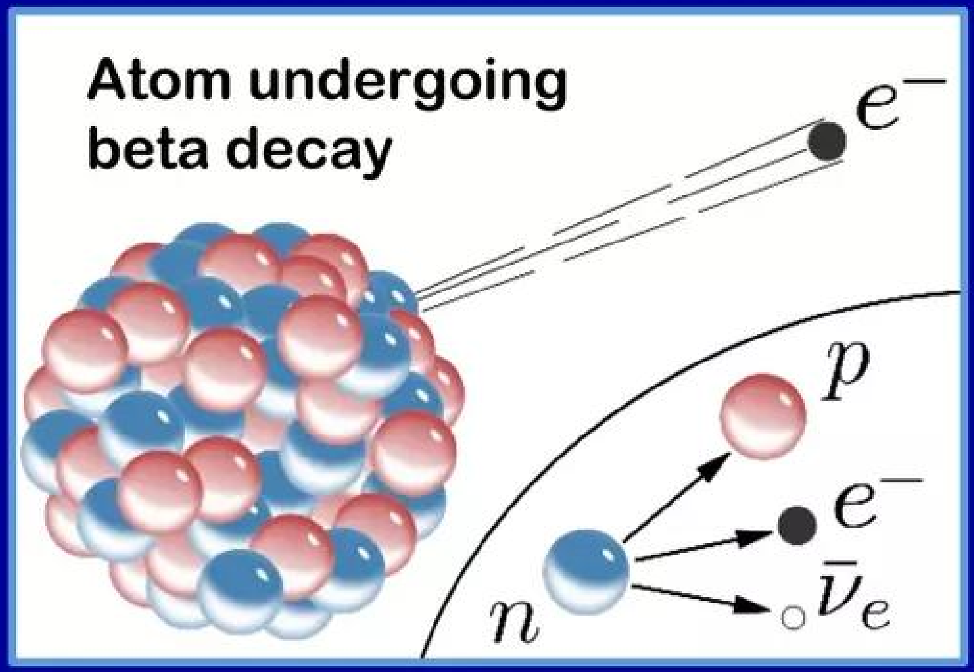

Image adapted from Wikipedia

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http://www.slideshare.net/lewisglarsen/presentations

Summary

Ultralow energy neutron reactions are truly 'green' nuclear processes

- ✓ Ultralow energy neutron reactions (LENRs) are 'green' nuclear processes that characteristically do not emit external fluxes of deadly MeV-energy neutron or gamma radiation. Neither do they produce biologically significant quantities of long-lived radioactive wastes. Importantly, LENRs can release copious amounts of clean heat that can potentially be used to do work and generate power
- ✓ For over 100 years, different LENR effects have been observed experimentally by scientists, recognized as being very anomalous, and then duly reported in respectable journals. However, causation of these results was not understood or attributed to nuclear processes because of a pronounced absence of MeV-energy neutron and/or gamma emissions. Since mechanisms producing such anomalous effects were unclear when they were reported, the data was either deemed to be inexplicable or simply the result of obscure experimental errors
- ✓ Thanks to new breakthrough technical insights provided by the Widom-Larsen theory of LENRs (first released as arXiv preprint in May 2005), much of this large, longstanding body of anomalous experimental results can finally be understood. It turns-out that --- unlike fission and fusion that mainly involve strong force interactions --- Widom-Larsen posits that crucial aspects of the physics of LENR processes depend on the electroweak force. This conceptual advance in W-L's physics, in conjunction with operation of collective many-body quantum effects (fission and fusion are few-body reactions) explains the rather unexpected suppression of hard radiation and long-lived radioactive isotopes

Summary

Collective many-body effects enable electroweak catalysis at low temps

- ✓ Radically different from few-body nuclear fusion reactions that require enormously high, star-like triggering temperatures to achieve commercially useful rates of reaction, collective many-body quantum effects in condensed matter enable LENRs to proceed at very substantial rates of reaction under rather surprisingly moderate macrophysical conditions and at relatively low triggering temperatures. In addition to being free of hard radiation, this amazing capability allows LENR experimentation to be conducted in tabletop apparatus without heavy shielding
- ✓ Uniquely 'green' characteristics of LENR processes would be extraordinarily attractive attributes in an advanced energy source for use in power generation applications. Since heavy, costly radiation shielding and containment systems would be unnecessary, power sources based on LENRs could take advantage of nuclear energy densities (at least 1 million times > chemical processes) and - since according to Widom-Larsen LENRs inherently occur in tiny nanometer-to-micron-sized active sites - commercial power sources could in principle scale-up from small battery-like devices to large many-megawatt central station power plants
- ✓ However, over the past 26 years essentially random Edisonian experimentation by most researchers has resulted in limited, hit-or-miss reproducibility with respect to macroscopic heat production by LENR devices. When devices have worked, total calorimetrically measured thermal output is generally on the order of milliwatts to several Watts for just several days. While a few notable experiments over that time have produced tens of Watts for months, they were erratic, irreproducible results

Summary

LENR power systems should eventually scale-up to kWh and megawatts

- ✓ Announcements by some parties working in the field who say their companies have built working LENR power systems with megawatt thermal outputs represent grossly exaggerated capabilities at best and possibly fraudulent claims at worst
- ✓ That said, with engineering guidance and proprietary insights from the Widom-Larsen theory's physics, an opportunity to commercialize LENRs as a truly 'green' nuclear energy source has recently been enabled by uniquely favorable, fortuitous juxtaposition of key parallel advances in certain vibrant new areas of nanotech (especially plasmonics), quantum entanglement, new innovations in nanoparticle fabrication techniques, as well as breakthroughs in advanced materials science
- ✓ Some may be skeptical that commercially competitive LENR power generation systems with power outputs on the order of kilowatts up to megawatts can ever be developed from presently primitive devices that can sometimes produce tens of milliwatts or Watt$^+$ for a day or two. Herein, Lattice will provide a high-level outline for a multidisciplinary engineering pathway leading to commercial prototypes and soon thereafter, system-level products suitable for many key market segments
- ✓ There is solid historical precedent for this optimism: herein we will show how today's 1,800 MW fission power reactors had similarly humble origins back in the 1940s. World's first fission reactor, CP-1 at the Univ. of Chicago, built for hugely expensive Manhattan atom bomb project only produced ½ Watt thermal, was 20' x 25', and weighed over 400 tons; LENRs already perform better than CP-1 reactor

Comparison of LENRs to fission and fusion

Fission, fusion, and LENRs all involve controlled release of nuclear binding energy (heat) for power generation: no CO_2 emissions; scale of energy release is MeVs (nuclear regime) > 1,000,000x energy density of chemical energy power sources

Heavy element fission: involves shattering heavy nuclei to release stored nuclear binding energy; requires massive shielding and containment structures to handle radiation; major radioactive waste clean-up issues and costs; limited sources of fuel: today, almost entirely Uranium; Thorium-based fuel cycles now under development; heavy element U-235 (fissile isotope fuel) + neutrons → complex array of lower-mass fission products (some are very long-lived radioisotopes) + energetic gamma radiation + energetic neutron radiation + heat

Fusion of light nuclei: involves smashing light nuclei together to release stored nuclear binding energy; present multi-billion $ development efforts (e.g., ITER, NIF, other Tokamaks) focusing mainly on D+T fusion reaction; requires massive shielding/containment structures to handle 14 MeV neutron radiation; minor radioactive waste clean-up $ costs vs. fission

Two key sources of fuel: Deuterium and Tritium (both are heavy isotopes of Hydrogen)

Most likely to be developed commercial fusion reaction involves:

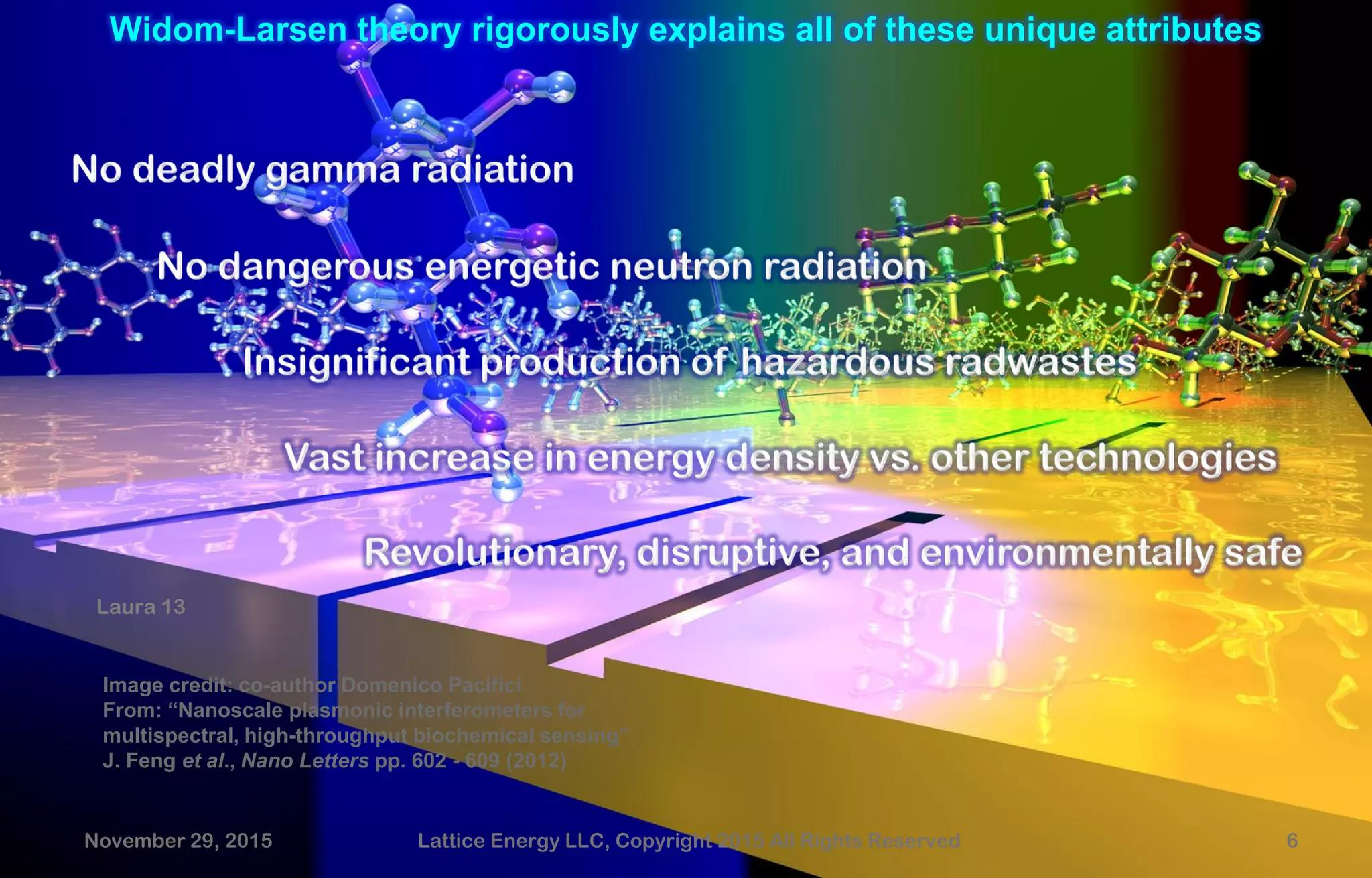
D + T → He-4 (helium) + neutron + heat (total energy yield 17.6 MeV; ~14.1 MeV in neutron)

Ultralow energy neutron reactions (LENRs): distinguishing feature is neutron production via electroweak reaction; neutron capture on fuel + gamma conversion to IR + decays [β , α] releases nuclear binding energy: early-stage technology; no emission of energetic neutron or gamma radiation and no long lived rad-waste products; LENR systems do not require massive and expensive radiation shielding and containment structures → much lower $$$ cost; many possible fuels: any element/isotope that can capture LENR neutrons; involves neutron-catalyzed transmutations of fuels into heavier stable elements that release heat

Revolutionary new type of safe nuclear energy technology

Unique advantages of ultralow energy neutron reactions (LENRs)

Widom-Larsen theory rigorously explains all of these unique attributes



No deadly gamma radiation

No dangerous energetic neutron radiation

Insignificant production of hazardous radwastes

Vast increase in energy density vs. other technologies

Revolutionary, disruptive, and environmentally safe

Laura 13

Image credit: co-author Domenico Pacifici
From: "Nanoscale plasmonic interferometers for multispectral, high-throughput biochemical sensing"
J. Feng *et al.*, *Nano Letters* pp. 602 - 609 (2012)

LENRs are green: no energetic radiation or radwastes

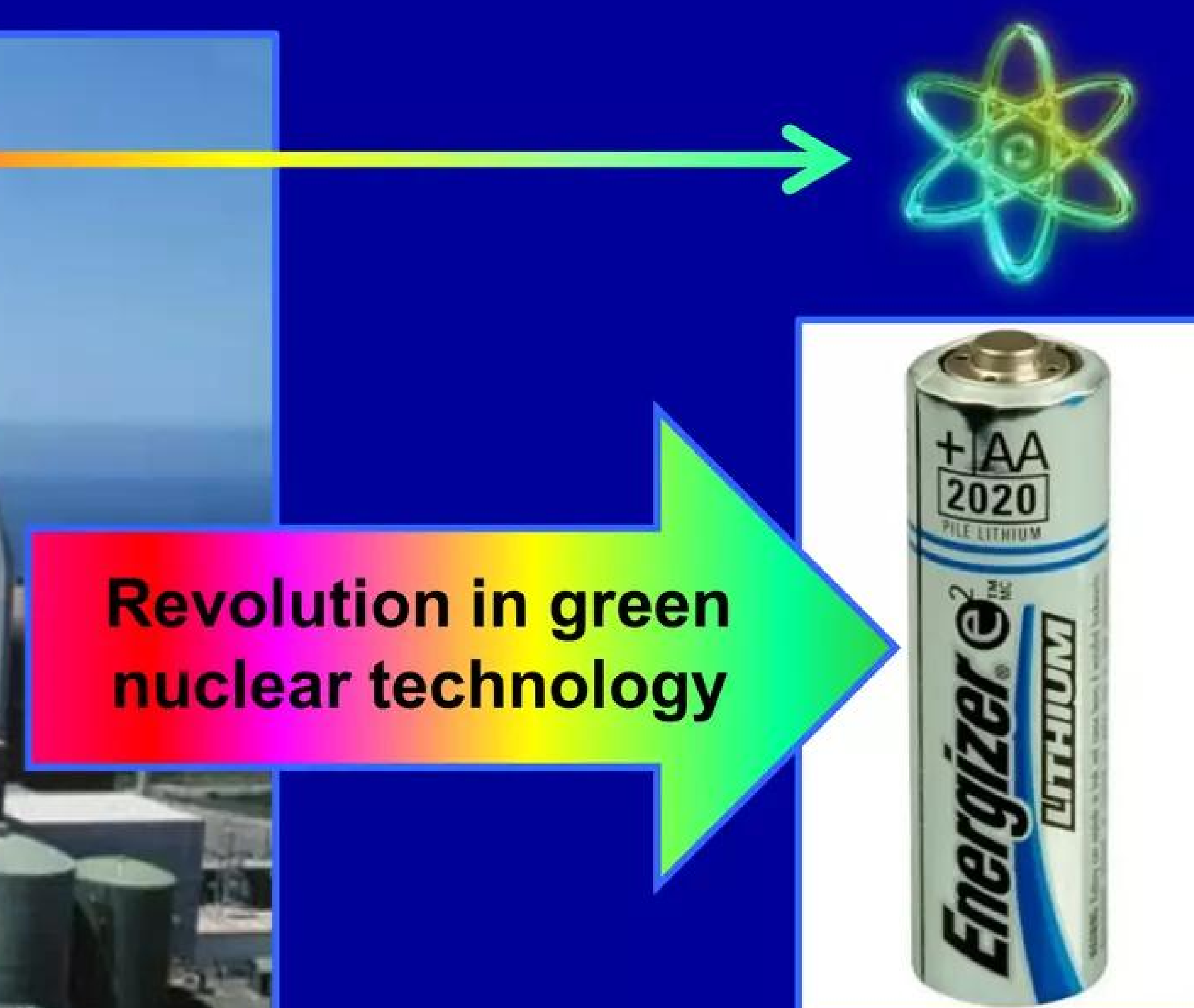
Lack of hard radiation obviates need for shielding and containment

Major opportunity to develop safe, battery-like portable LENR power sources

Fission and fusion processes both emit deadly MeV-energy neutron and gamma radiation

Fission reactors need 1 foot of steel and 3 feet of concrete to protect humans from hard radiation and wastes emitted by reactor; makes systems intrinsically large and heavy

LENRs enable devices something like this: small, portable battery-like power sources that are safe and disposable



Much larger LENR devices based on dusty plasma embodiments can potentially scale-up to megawatts; akin to today's power plants

Ultralow energy neutrons in LENRs are extremely safe

Fission and fusion neutrons are energetic, deadly and need shielding

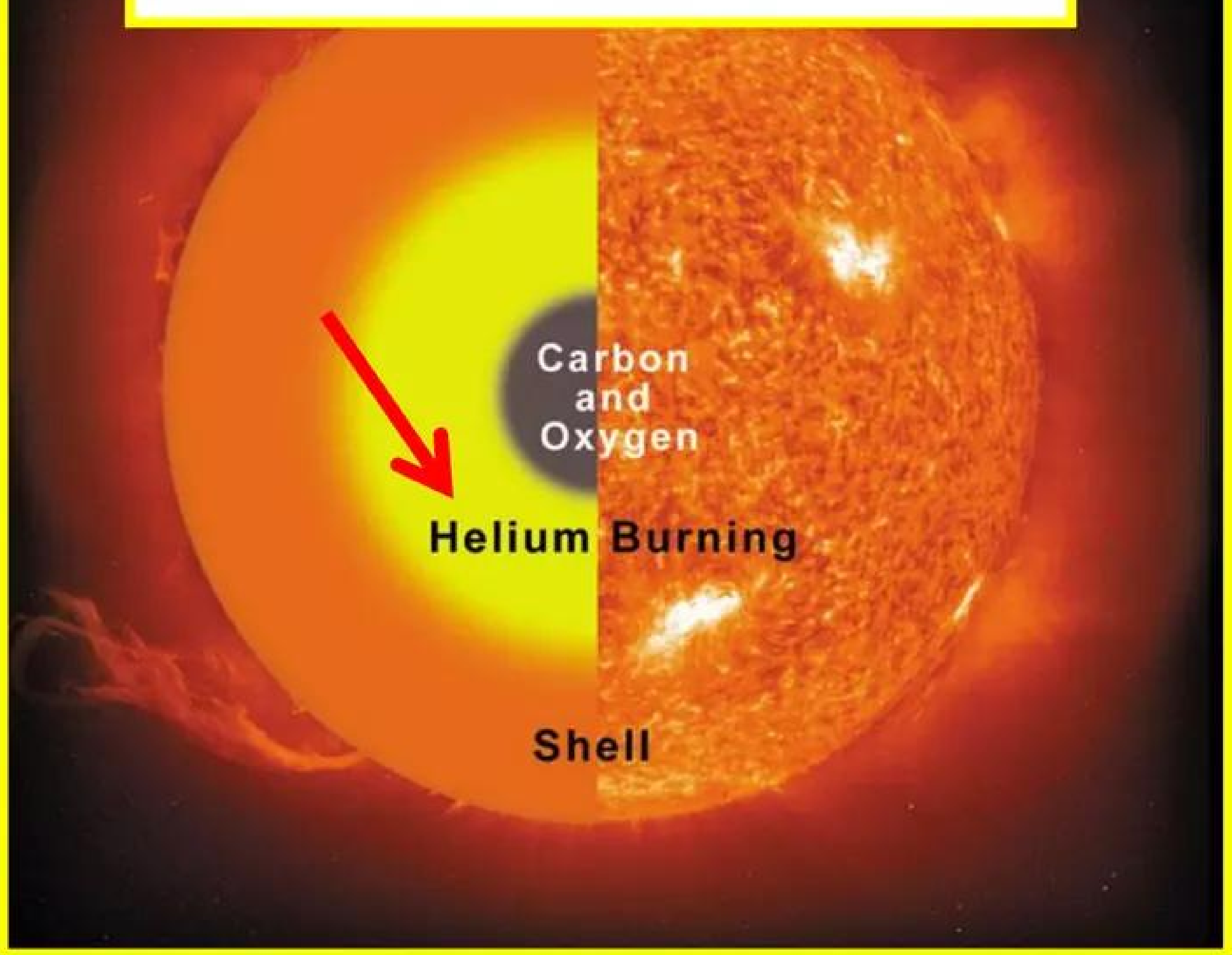
All of the nuclear reactions shown below create neutrons: only LENRs are safe

Gigantic stars vastly larger than Earth

Stellar fusion reactions make MeV neutrons

$$^{13}_{6}C + ^{4}_{2}He \rightarrow ^{16}_{8}O + n$$

$$^{22}_{10}Ne + ^{4}_{2}He \rightarrow ^{25}_{12}Mg + n$$



Length-scale: millions of miles

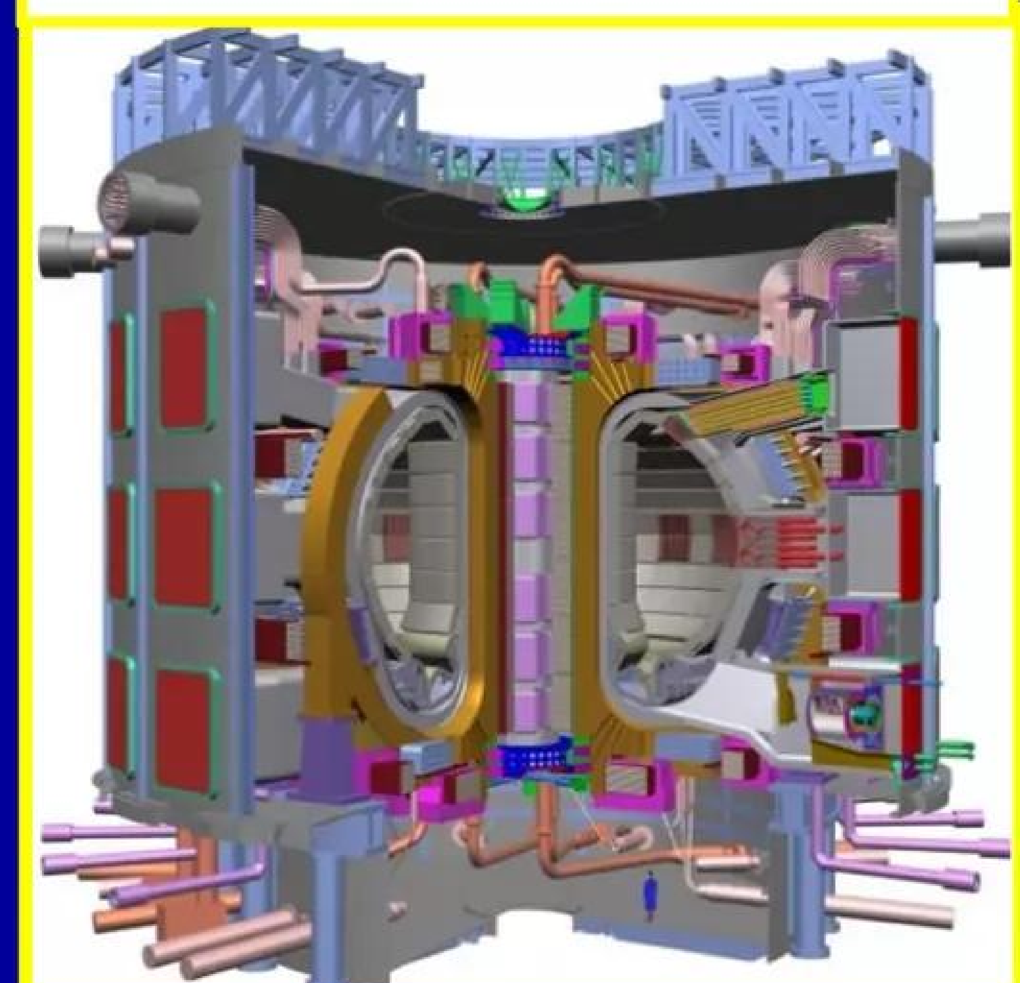
Temperatures: many millions of degrees

Huge 400,000 MT reactors

ITER: D+T fusion reactor

Dangerous 14.1 MeV neutrons

$$^{2}_{1}D + ^{3}_{1}T \rightarrow ^{4}_{2}He + ^{1}_{0}n$$



Length-scale: hundreds of feet

Temperatures: many millions of degrees

Compact devices

Hand-held devices

Safe ultralow energy neutrons do not escape apparatus

$$e + p \rightarrow \nu_e + n$$

Length-scale: inches

Temperatures: only thousands of degrees in microscopic regions

LENRs are green benign type of nuclear energy technology

Energy release greatly surpasses chemical but is less than fission

Some LENRs release > energy than D+T fusion without hard radiation

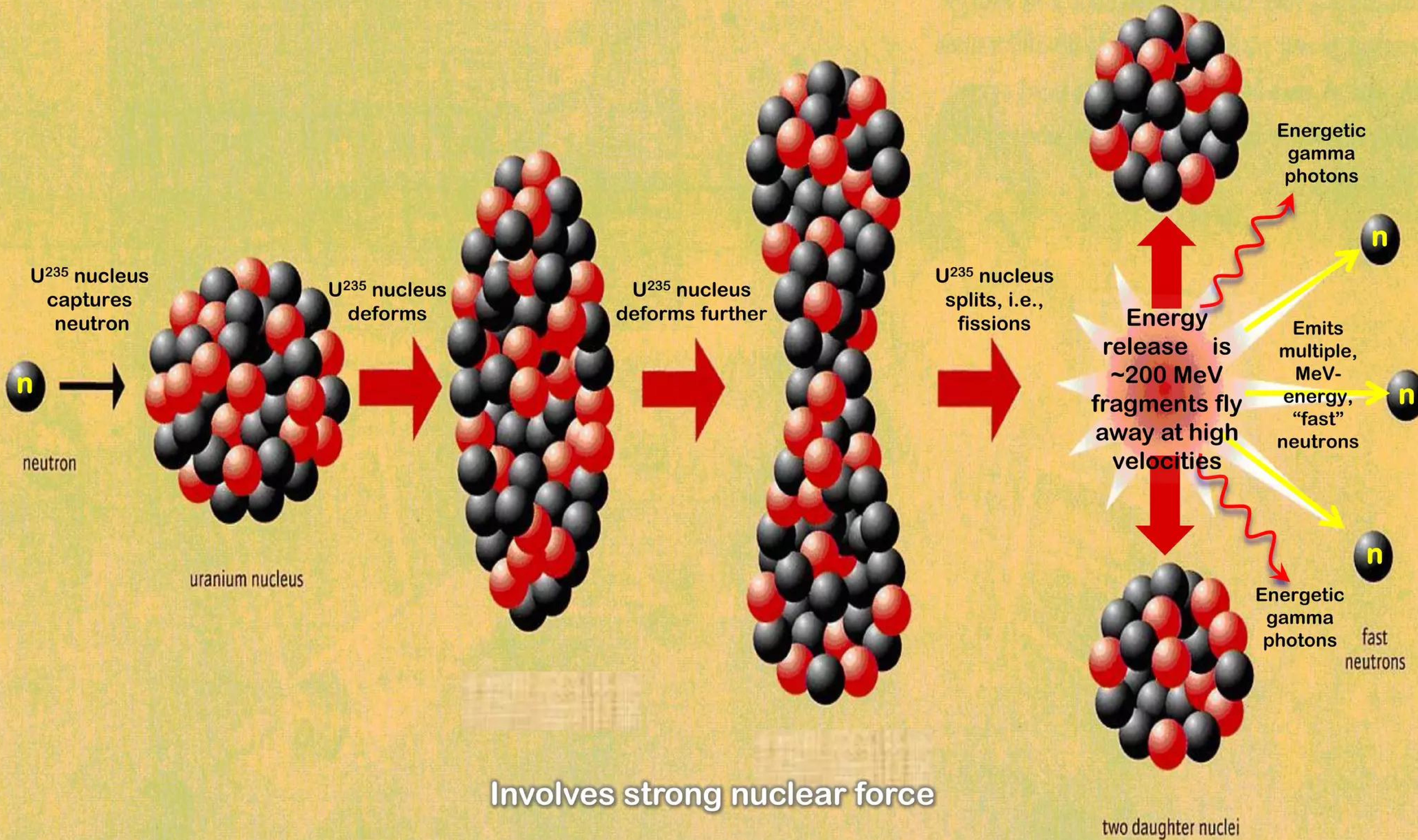
Less Energy Per Reaction

Nuclear revolution

Reaction Type	Typical "Average" Energy Release		Relative Index of Energy Release	
U-235 Conventional Fission (1938)	220 MeV	Nuclear: Strong Interaction	1000	Radiation
H+H Fusion in Stars (1939)	27 MeV		123	
D+T Fusion Reactors (1950s)	17. 6 MeV		80	
LENRs today	~ 22 MeV (high side)	Nuclear: Weak Interaction	91	Benign
	~ 0.1 MeV (low side)		0.45	
Blacklight Power's "Hydrinos" (1991)	max 0.02 MeV	?	0.09	Chemical
Hydrogen Fuel Cells (1838)	0.0002 MeV	Chemical	0.0001	
Combustion of Gasoline (1876)	0.0001 MeV		0.00005	

Neutron-induced nuclear fission of Uranium-235 nucleus

Capture of a neutron triggers fission and shatters heavy atomic nucleus

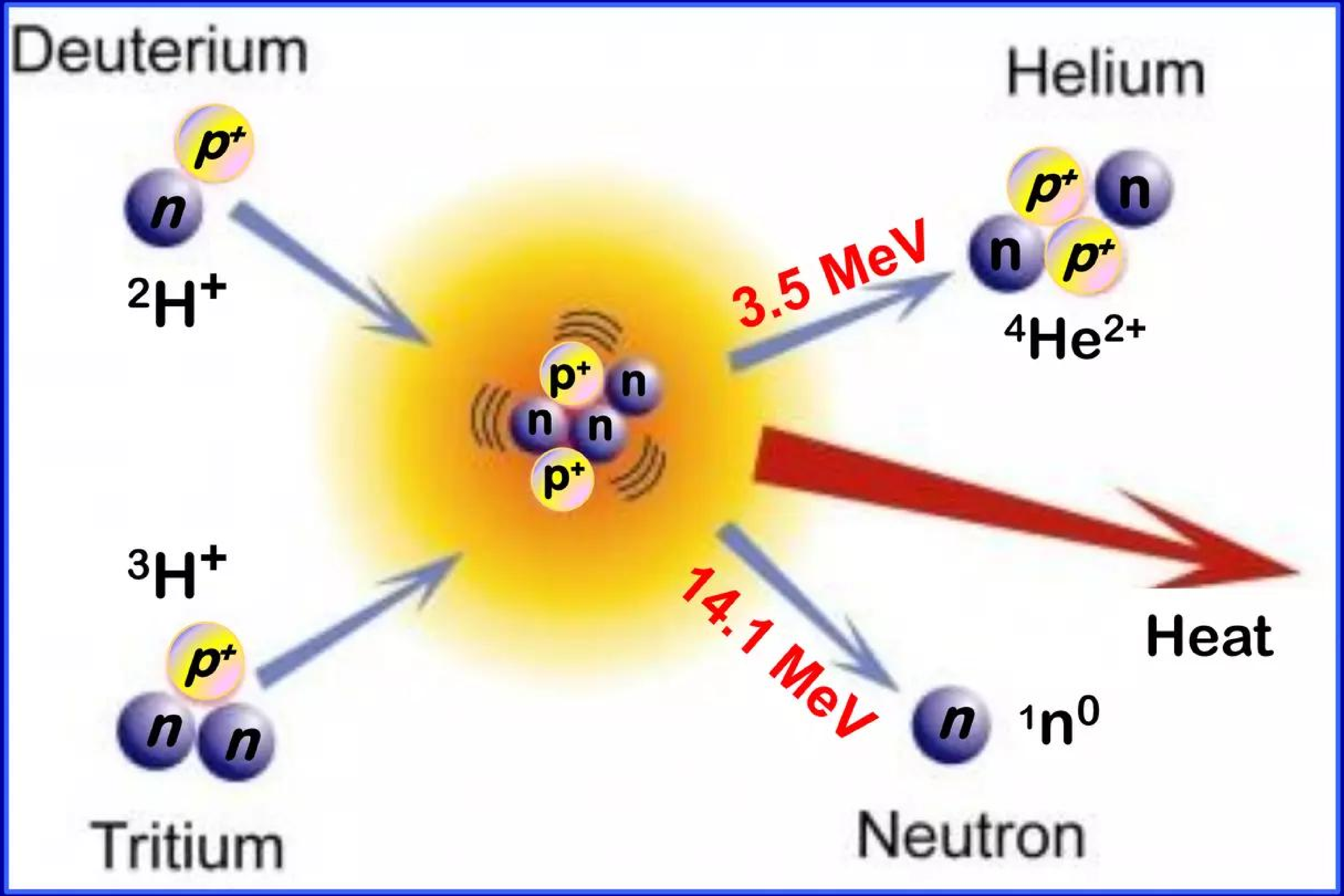


Nuclear fusion reaction between light Hydrogen nuclei

ITER and Tokamaks trigger Deuterium-Tritium Hydrogen fusion reactions

$$^{2}H^{+} + {}^{3}H^{+} \rightarrow {}^{4}He^{2+} + {}^{1}n + 17.6\ MeV$$

fusion — heat



Involves strong nuclear force

Weak force as explained by Frank Wilczek in his new book

Note on terminology: weak force = weak interaction = electroweak reaction

"Neither of these two great theories [QCD and QED], however, incorporates processes whereby protons transform into neutrons and vice-versa. How can we account for them? To explain these events, physicists had to define one more force in addition to those of gravity, electromagnetism, and the strong force.

This new addition, the fourth force, is called the weak force. The weak force completes our current picture of physics: the Core.

Life on Earth is powered by a tiny fraction of the energy released from the Sun, captured as sunlight. The Sun derives its power by burning protons into neutrons, releasing energy. The weak force, in this very specific sense, makes life possible."

• • •

"These [various weak force reactions] give rise to many forms of nuclear decay (radioactivities), destabilize other hadrons, and drive many transformations in cosmology and astrophysics (including the synthesis of all the chemical elements, starting from a primordial mix of protons and neutrons)."

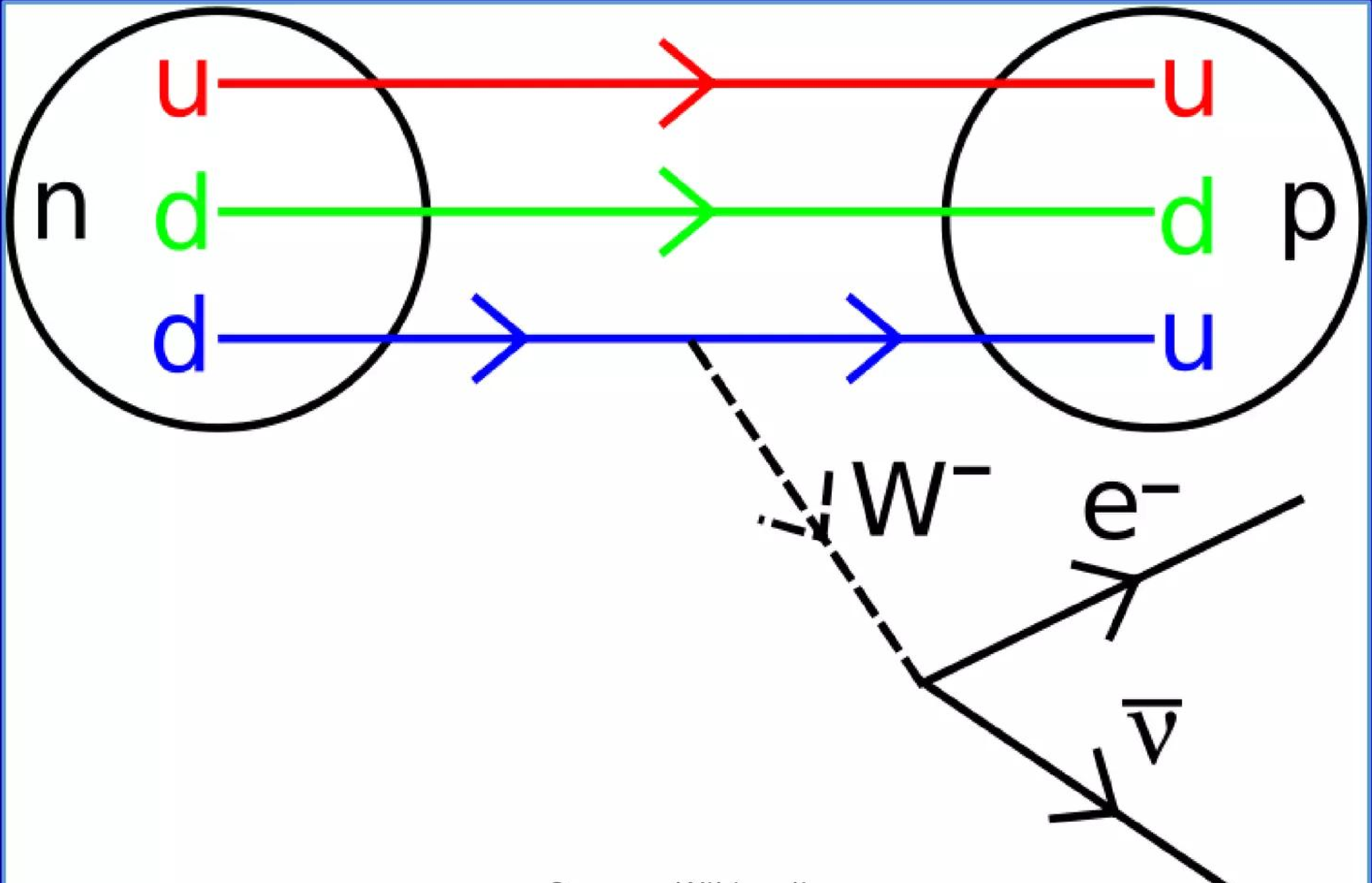
Quoted from "A beautiful question - finding Nature's deep design" by Frank Wilczek (2015)

Beta⁻ decay (β^-) involves neutron conversion: $n \rightarrow p + e + \overline{\nu}_e$

Neutron (n) inside an unstable atomic nucleus changes into proton (p)

Process transmutes one element to another along rows of the Periodic Table

Widom-Larsen theory: electroweak neutron production ~ reverse of β-minus decay



Source: Wikipedia

Electroweak reaction in Widom-Larsen theory is simple

Protons or deuterons react directly with electrons to make neutrons

Capture of produced neutrons by atoms induces green nuclear transmutations

electrons + protons (Hydrogen) → neutrons + neutrinos (benign photons, fly into space)

Require source(s) of input energy

Input energy creates electric fields > 2.5 x10^{11} V/m

Collective many-body quantum effects: many electrons each transfer little bits of energy to a much smaller number of electrons also bathed in the very same extremely high local electric field

Many-body collective electroweak neutron production

Heavy-mass e^{-*} electrons react directly with protons

Quantum electrodynamics (QED): smaller number of electrons that absorb energy directly from local electric field will increase their effective masses ($m = E/c^2$) above key thresholds β_0 where they can react directly with a proton (or deuteron) → neutron and neutrino

$$\text{Energy}_{\text{E-field}} + e^-_{sp} \rightarrow e^{-*}_{sp} + p^+ \rightarrow n^0 + \nu_e$$

ν_e neutrinos: ghostly unreactive photons that fly-off into space; n^0 neutrons capture on nearby atoms

Radiation-free LENR transmutation

Neutrons + fuel elements → heavier elements + decay products

Neutrons induce nuclear transmutations that release enormous amounts of clean, CO_2-free heat

Electroweak neutron production occurs in two regimes

Magnetic regime occurs in plasmas: earth lightning and stellar flux tubes

Production of neutrons from protons and electrons via electroweak catalysis:

Many-body collective quantum effects in condensed matter + input energy

$\text{Energy}_{\text{E-field}} + e^{-}_{sp} \rightarrow e^{-*}_{sp} + p^{+} \rightarrow n + \nu_e$ [high electric fields in condensed matter]

$\text{Energy}_{\text{B-field}} \rightarrow e^{-} + p^{+} \rightarrow lepton + X$ [organized magnetic fields in plasmas]

Collective electroweak production of neutrons on micron-scales in condensed matter and via direct acceleration of particles in large-scale magnetic fields

Transmutation of fuel elements into other heavier isotopes/elements:

Both types of processes release nuclear binding energy (heat)

$n + \text{fuel}\ (Z, A) \rightarrow (Z, A+1)$ [neutron capture on fuel atoms]

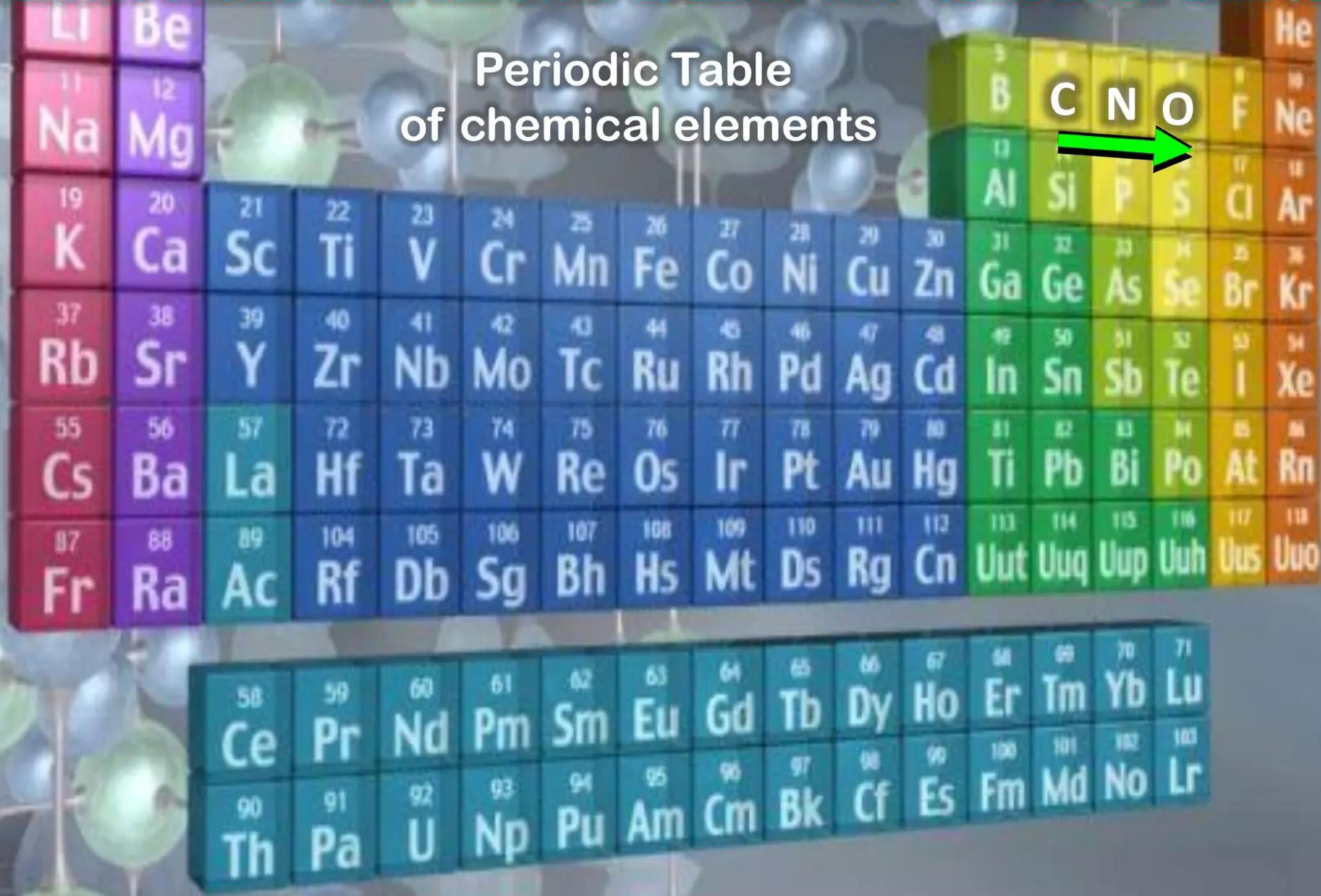
$(Z, A+1) \rightarrow (Z+1, A+1) + e_{\beta}^{-} + \bar{\nu}_e$ [unstable products beta^{-} decay]

Mainly rapid β^{-} decays of unstable neutron-rich isotopic products

LENR transmutations go left-to-right along rows of Table

Transmutation of Carbon to O_2 releases 5,000x > heat than combustion

Any element in Periodic Table can serve as LENR fuel - some better than others

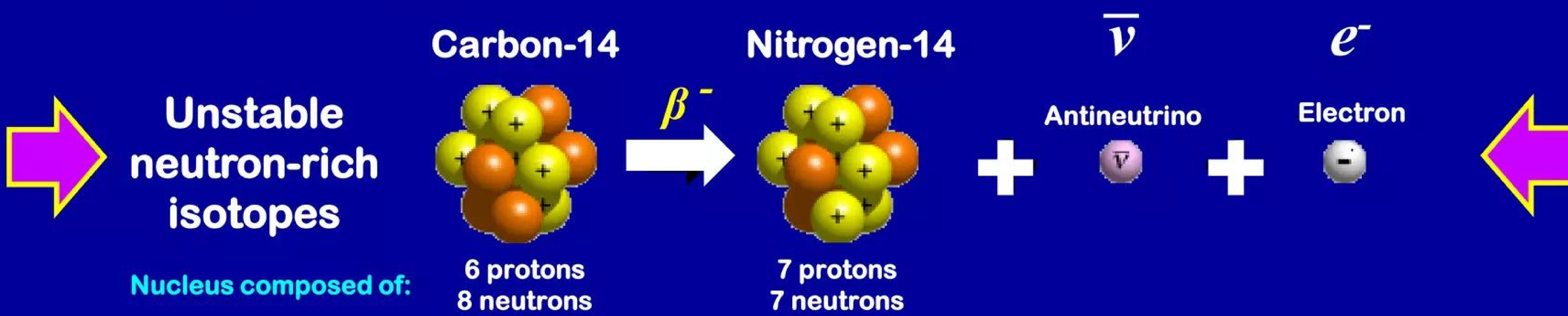


Examples of Beta-minus and Beta-plus decays

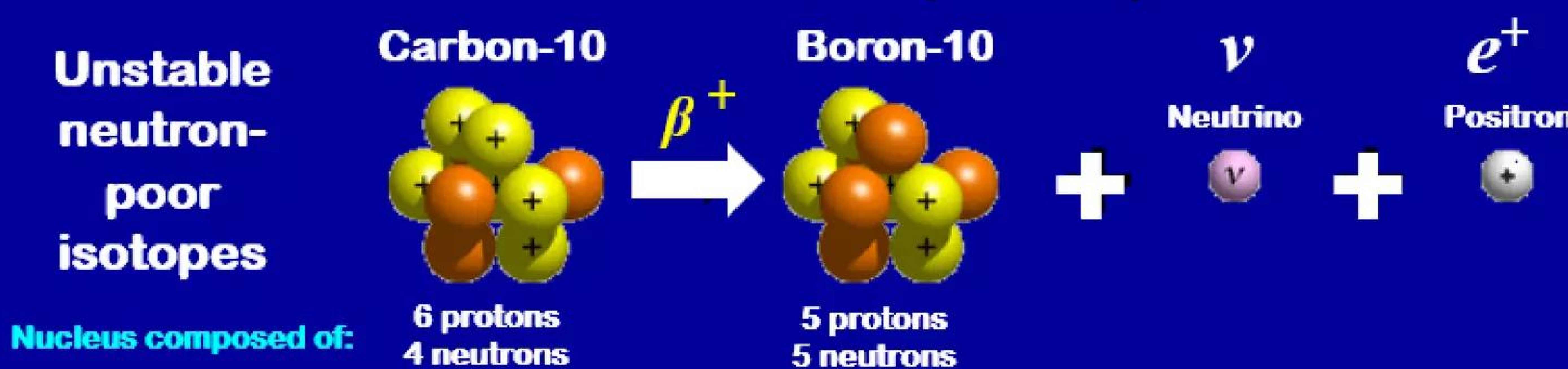
Carbon is transmuted into Nitrogen and into Boron respectively

Beta-minus is a very frequent decay mode for unstable neutron-rich atoms

Beta-minus decay (β^-): one neutron spontaneously converts into a proton



Beta-plus decay (β^+): one proton spontaneously converts into a neutron

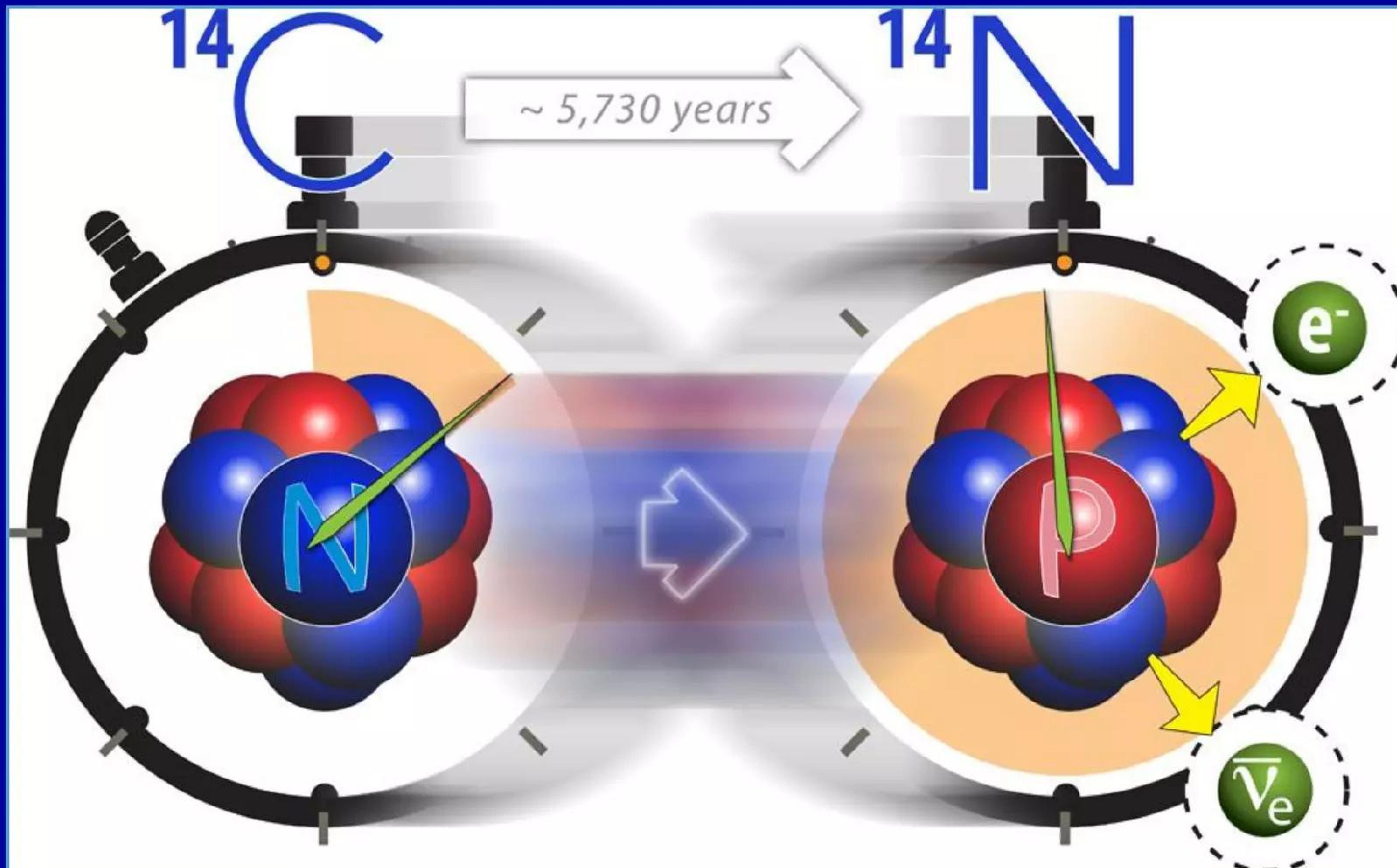


Details of Beta-minus decay of unstable isotope: Carbon-14

5,730 year half-life: Carbon is transmuted into Nitrogen during decay

In this decay unstable radioactive Carbon transformed into stable Nitrogen

^{14}C = unstable and mildly radioactive



^{14}N = very stable and non-radioactive

Image credit: Hai Ah Nam and Andrew Sproles (ORNL)

Leo Szilard filed patent on fission reactor back in 1934

While not actually built was based on idea of nuclear chain reactions

Cited "improvements in or relating to the transmutation of chemical elements"

PATENT SPECIFICATION

630,726

Application Date: June 28, 1934. No. 19157/34.

" " July 4, 1934. No. 19721/34.

One Complete Specification left (under Section 16 of the Patents and Designs Acts, 1907 to 1946): April 9, 1935.

Specification Accepted: March 30, 1936 (but withheld from publication under Section 30 of the Patent and Designs Acts 1907 to 1932)

Date of Publication: Sept. 28, 1949.

Index at acceptance:—**Class 39(iv),** P(1:2:3x).

PROVISIONAL SPECIFICATION

No. 19157 A.D. 1934.

Improvements in or relating to the Transmutation of Chemical Elements

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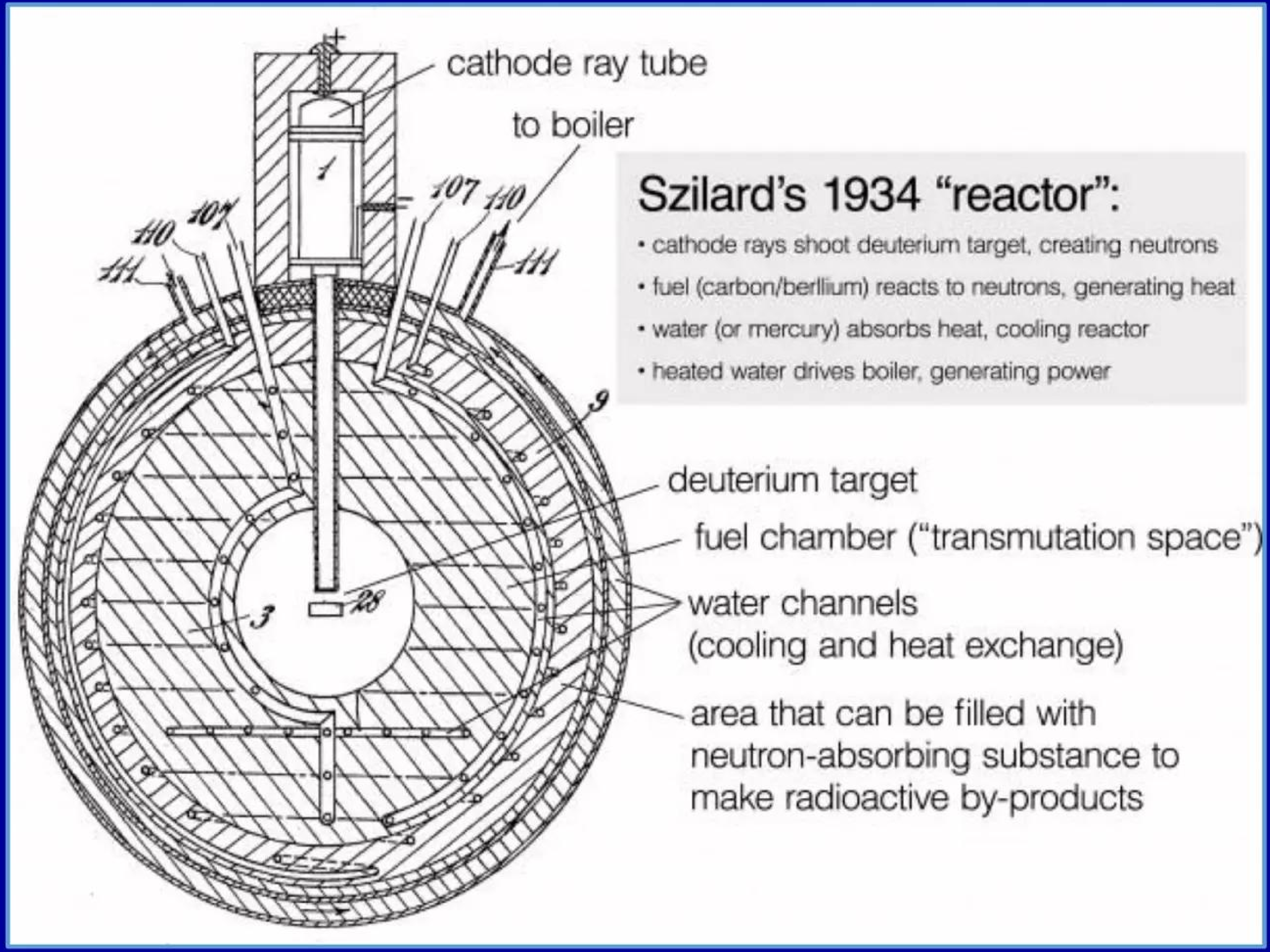
1934



1934

Graphic adapted from Figure in British patent application 630,726

First fission reactor produced only tiny amounts of heat

Fermi pile CP-1 at University of Chicago produced 0.50 Watts thermal

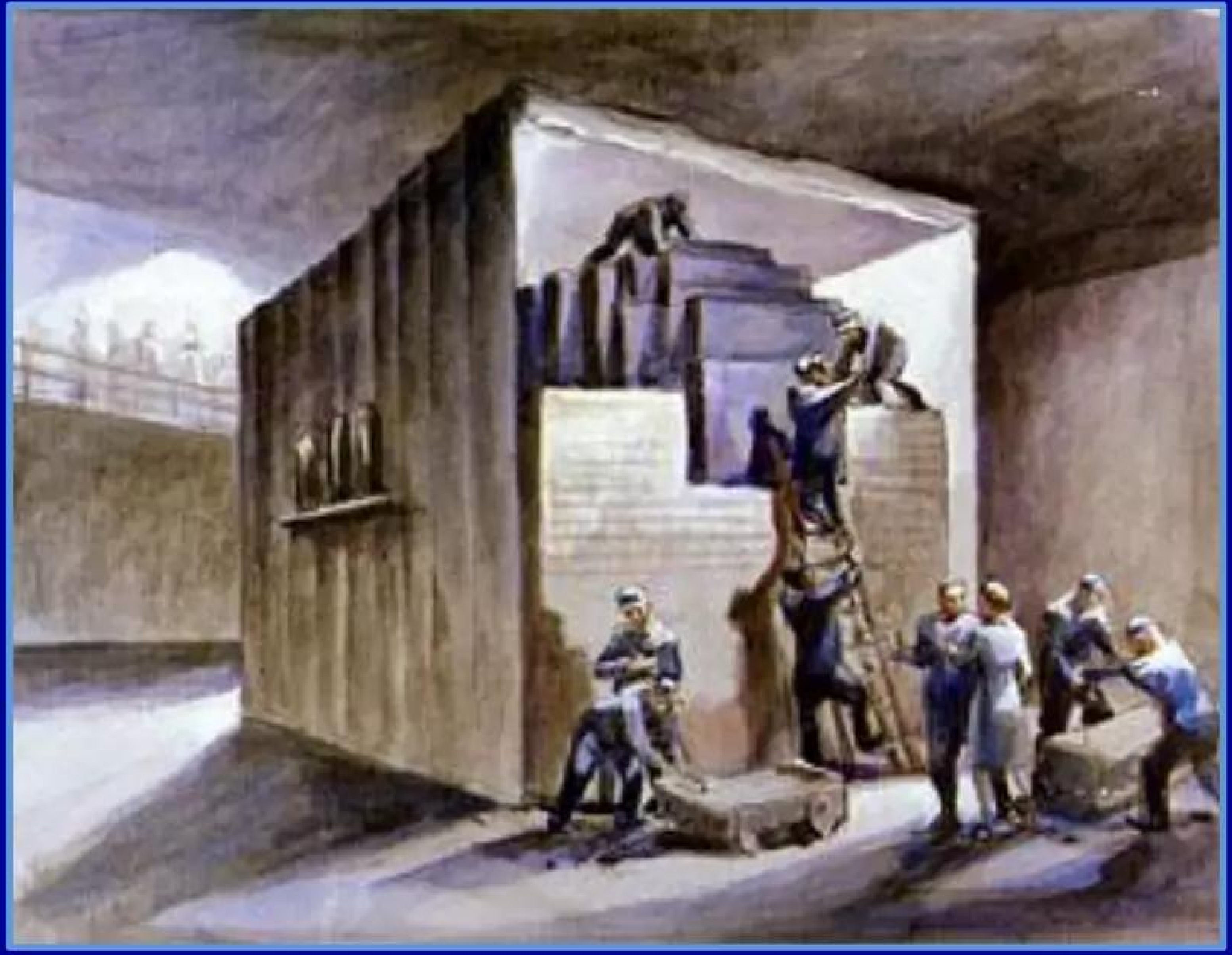
Self-sustaining nuclear fission chain reaction first occurred on December 2, 1942

Selected facts about reactor:

- ✓ Built for top secret Manhattan Project that aimed to create nuclear weapons
- ✓ Objective was to demonstrate that a nuclear chain reaction was achievable
- ✓ Shape of reactor was that of flattened ellipsoid ~25’ wide and 20’ high
- ✓ Contained: 771,000 lbs. of graphite; 80,590 lbs. of Uranium oxide; 12,400 lbs. of Uranium metal; and control rods
- ✓ Control of neutron fluxes in reactor was effected by cadmium metal control rods; these devices are strong neutron absorbers --- allow reactor’s internal U fission rate to increase when control rods are withdrawn from Uranium fuel

1942

Construction of CP-1 reactor at Chicago



Painting by John Cadel

First fission reactor produced only tiny amounts of heat

Fermi pile CP-1 at University of Chicago produced 0.50 Watts thermal

Self-sustaining nuclear fission chain reaction first occurred on December 2, 1942

Party of scientists present when CP-1 reactor at Chicago first achieved nuclear criticality

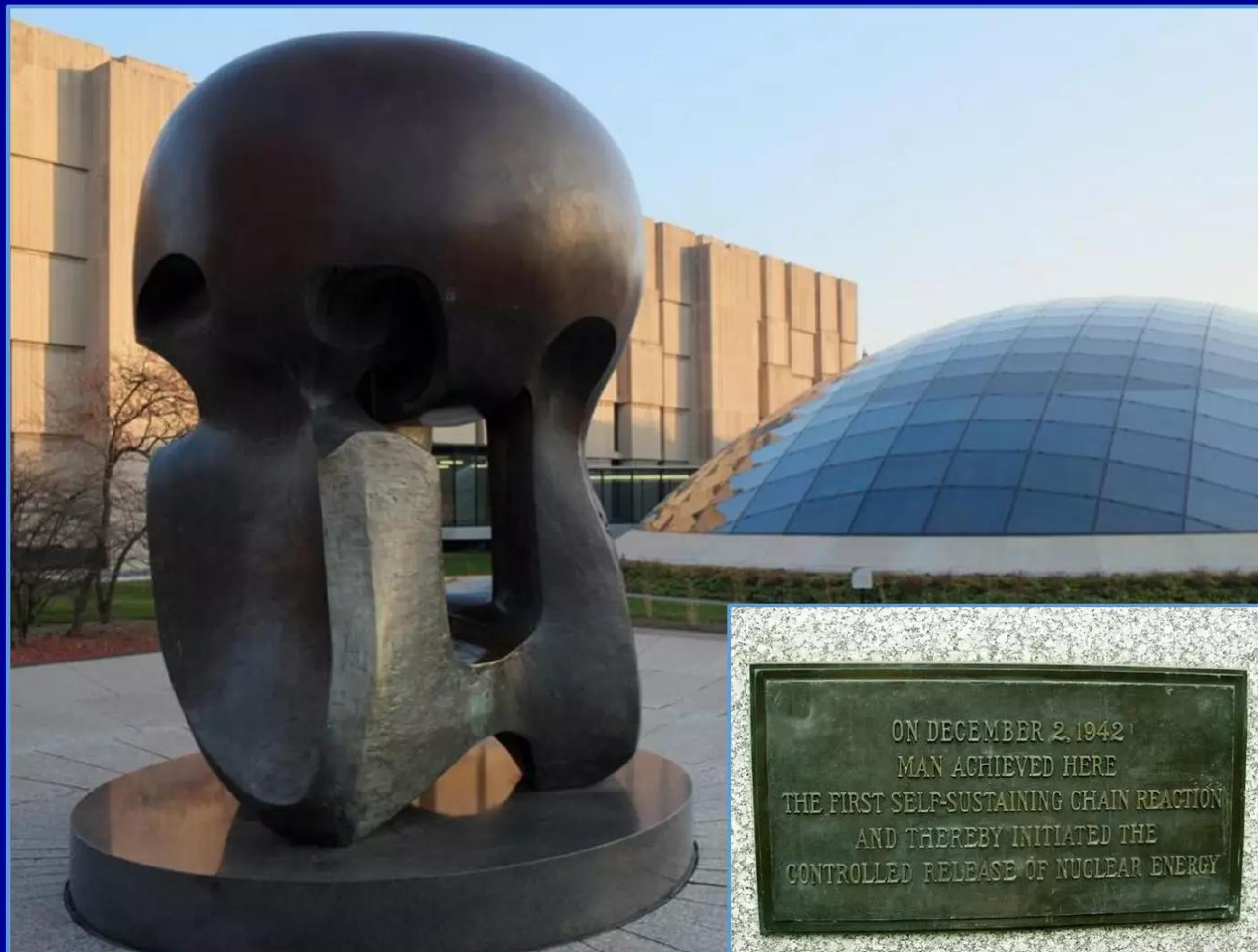
1942

1942

Painting by John Cadel

CP-1 reactor commemorated by Henry Moore sculpture

Located at the University of Chicago on the original site of this reactor

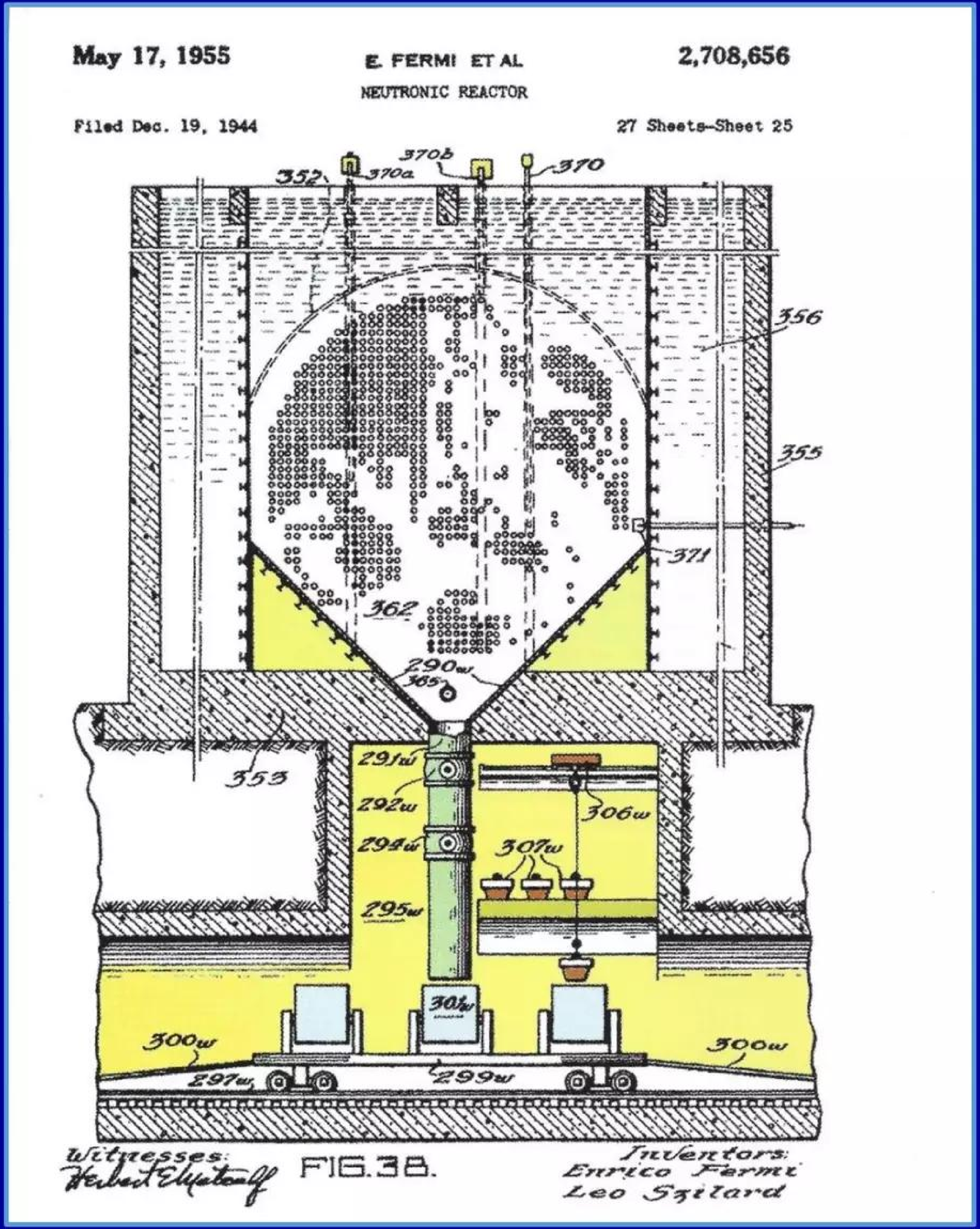


Sculpture titled "Nuclear Energy" was dedicated in 1967 with inset commemorative plaque

Fermi & Szilard's early design for neutronic fission reactor

Patent filed in 1944 but not published until 1955 after being declassified

1944



1944

EPR-1 was first-ever fission reactor to generate electricity

Generated ~800 Watts electrical power at Arco, Idaho on Dec. 20, 1951

Inefficient: thermal output of EPR-1 Uranium breeder reactor was 1.2 Megawatts

Selected facts about reactor:

- ✓ Main purpose of project was to show that fuel breeder concept could work, i.e. more fissile fuel could be produced than what was actually consumed in it
- ✓ Demonstration of illuminating four light bulbs was really more of a flashy stunt
- ✓ Shape of reactor was that of cylinder ~20' in diameter with integrated control and fuel rods, NaK coolant, and shielding
- ✓ Contained: ~112 lbs. of fully enriched Uranium-235; ~ size of an NFL football
- ✓ Shortly thereafter, electrical output was increased to 200 kWh, enough to self-power the entire EPR-1 reactor building

1951

Four light bulbs powered by reactor

December 20, 1951

EPR-1 was first-ever fission reactor to generate electricity

Generated ~800 Watts of electrical power at Arco, Idaho on Dec. 20, 1951

Proved that fuel breeder concept could work; still not commercialized as of 2015

Airborne view of site at present

1951

1951

First commercial fission power plant at Shippingport, PA

Central station facility provided 60 Megawatts of electricity to local grid

Unlike today's commercial nuclear reactors - it used highly enriched 93% U-235

Selected facts about reactor:

- ✓ First-ever commercial fission reactor used for civilian electrical power generation
- ✓ Demonstrated commercial possibilities for nuclear fission power generation industry
- ✓ Reactor vessel came from military nuclear aircraft carrier that had been cancelled; vessel shown to right itself weighed 921 tons
- ✓ Shape of reactor vessel was that of cylinder ~9' in diameter and 30' high
- ✓ Contained: ~14.2 tons of a natural Uranium 'blanket' + 165 lb. 'seed' of 93% enriched Uranium-235; seed made 50% of total power
- ✓ Began generating grid power Dec. 18, 1957

Reactor vessel during installation in 1956

Credit: photographer unknown

First commercial fission power plant at Shippingport, PA

Central station facility provided 60 Megawatts of electricity to local grid

New type of reactor core installed in 1977 increased output up to 236 megawatts

1957

1957

Credit: Duquesne Electric

Modern Uranium-fuel commercial nuclear fission reactors

Power output of today's power plants can range up to 1,800 megawatts

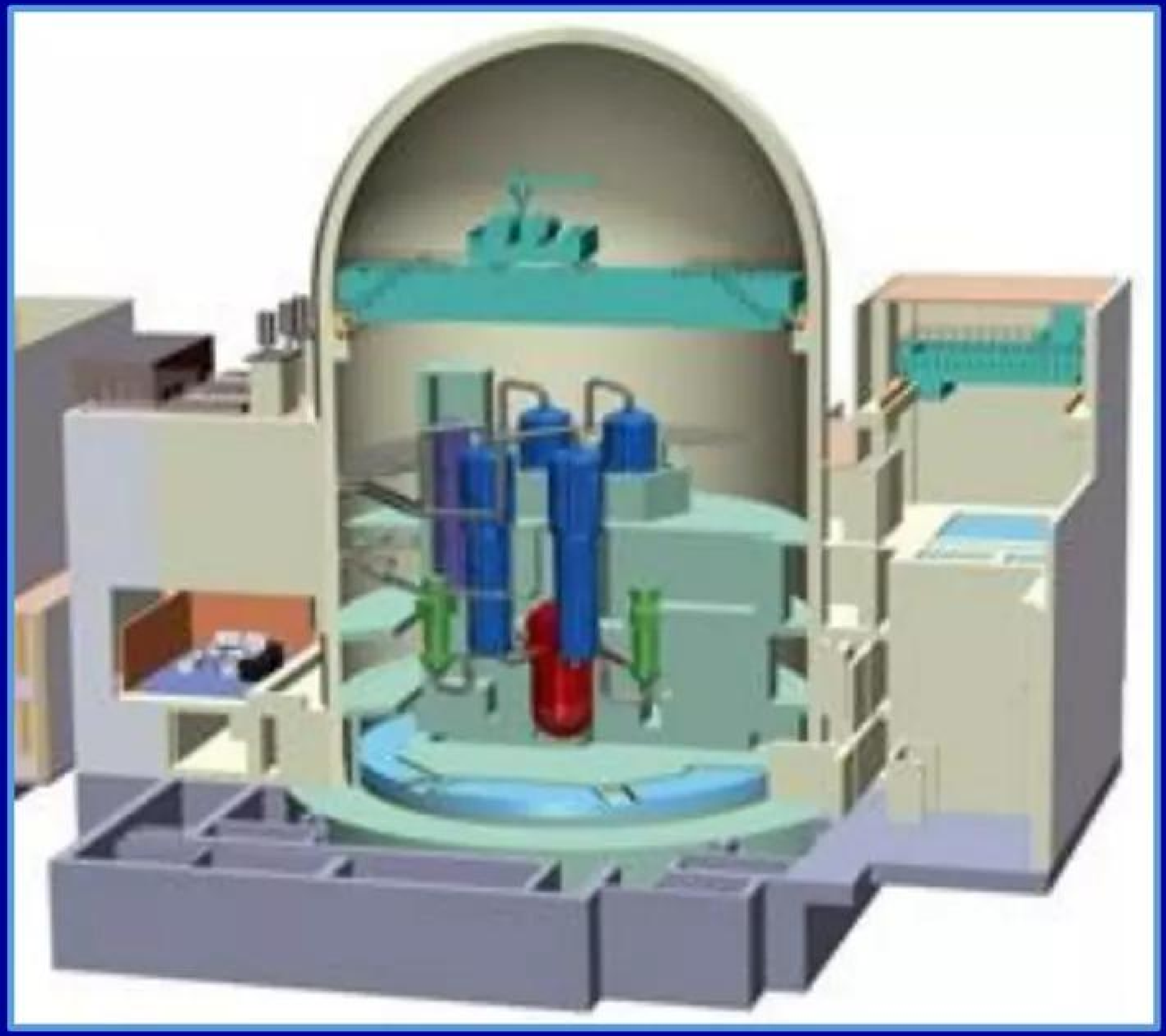
Mitsubishi Heavy Industries also presently conducting R&D programs in LENRs

Selected facts about today's reactors:

- ✓ Different competing reactor designs being built by manufacturers all around world
- ✓ All such reactors now fueled with Uranium
- ✓ June 1, 2015: total of 238 nuclear power plants were then operating worldwide
- ✓ Average power output is ~1,000 MW per reactor but ranges up to ~1,800 megawatts
- ✓ Tokyo Electric Power Co. (TEPCO) Kashiwazaki-Kariwa plant in Japan is presently world's largest nuclear power plant with net capacity of 7,965 MW; site comprises seven boiling water reactors with gross installed capacity of 8,212MW
- ✓ USA does not have waste disposal solution

Future - 20xx ?

MHI design for 4,451 MW APWR reactor



Credit: Mitsubishi Heavy Industries (MHI)

Modern commercial nuclear fission reactors

Image of present-day nuclear power plant with prominent cooling tower

2015

2015

Scale-up of fission power technology over past 73 years

Thermal output of first fission reactor CP-1 was similar to LENR devices

Difference is that 0.5 W LENR devices weigh < 5 lbs.; CP-1 weighed over 400 tons

Disparity in weight suggests LENR system power densities could be higher than fission

> The Atomic Age began at 3:25 p.m. on Dec. 2, 1942—quietly, in secrecy, on a squash court under the west stands of old Stagg Field at the University of Chicago.

Reactor	Year	~Reactor vessel size in feet	~Total mass of U fuel in system	~Total reactor system weight (tons)	Total power output of system in Watts
CP-1	1942	25 x 20 x 20	46.5 tons	400 tons	0.5 Watts
EPR-1	1951	20 dia. x 20	<<< 1 ton	Hundreds	1.2 MW
Shippingport	1957	9 dia. x 30	14 tons	Thousands	60 MW
Modern plant today	2015	Tens in all dimensions	Tens of tons	Thousands	1,000 to 1,800 MW
Mitsubishi H.I. APWR design	Future 20xx ?	Tens in all dimensions	Tens of tons	Thousands	4,451 MW

ITER fusion reactor now being built in Cadarache, France

Designed to produce 500 MW thermal heat from 50 MW of input energy

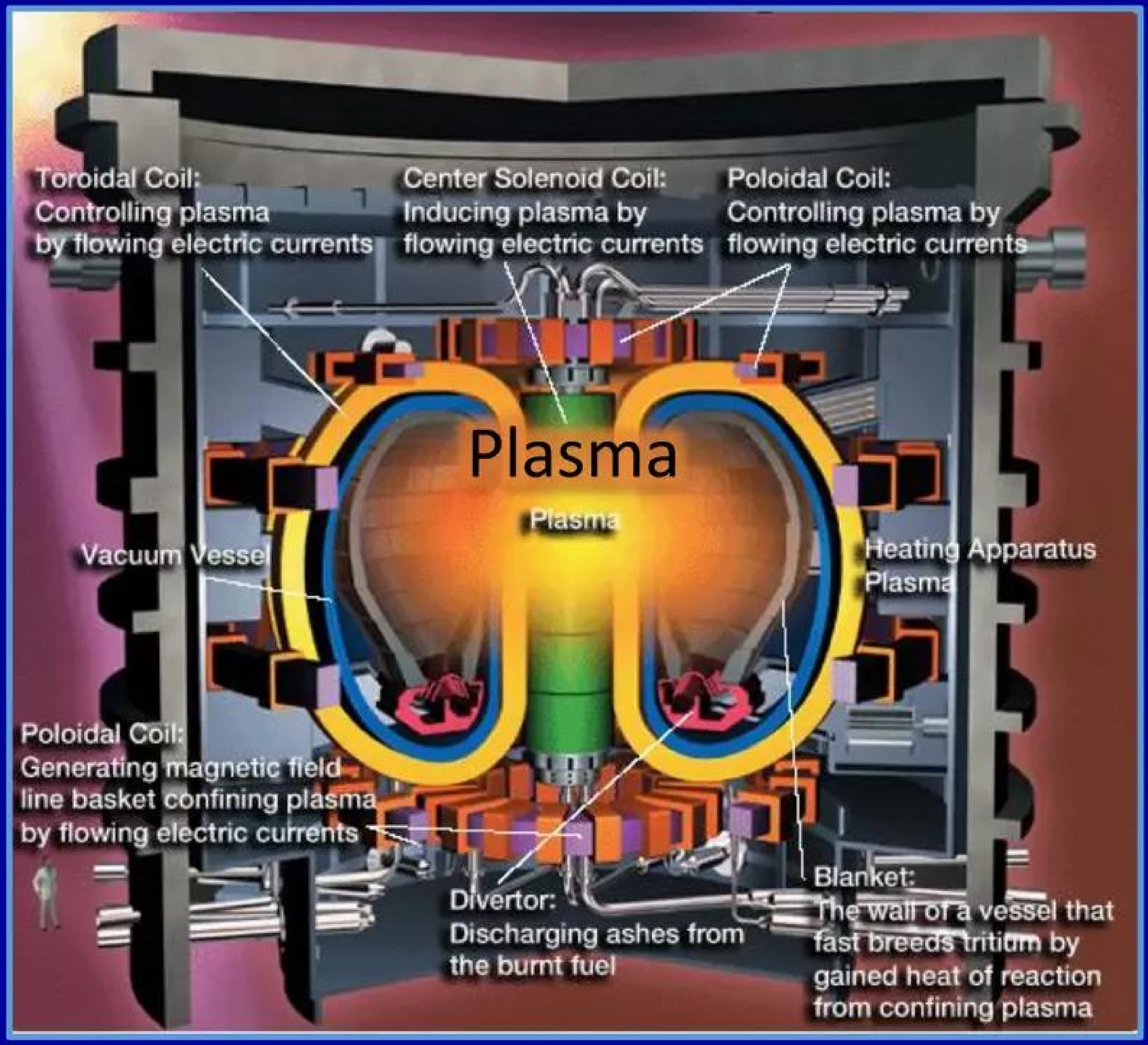
Not really a commercial power plant – that would be even further into the future

Selected facts about ITER reactor:

- ✓ Main purpose is to demonstrate proof-of-concept for a commercial fusion reactor
- ✓ Key goal: show self-sustaining, stable D-T fusion plasma for adequately long periods
- ✓ Designed to produce 500 MW thermal heating power from 50 MW of electrical input energy, i.e. gain Q = ~10 x input
- ✓ Reactor building will be ~180 feet tall
- ✓ Will not generate electricity; that task left to follow-on reactor if ITER is successful
- ✓ Estimated cost as of today: ~16 billion €
- ✓ Completion presently scheduled for 2023

2023 ?

ITER Tokamak schematic diagram



Source: ITER project team

ITER fusion reactor now being built in Cadarache, France

Designed to produce 500 MW thermal heat from 50 MW of input energy

B2 slab will support ~400,000 MT building + equipment incl. ~23,000 MT Tokamak

2015

2015

Source: ITER project team

"The energy produced by breaking down the atom is a very poor kind of thing. Anyone who expects a source of power from the transformations of these atoms is talking moonshine."

Ernest Rutherford (1933)

"I have learned to use the word 'impossible' with the greatest caution."

Wernher von Braun (ca. 1960s)


Nanotechnology and LENRs are mutually joined at the hip
Large length scales
What was formerly thought impossible becomes possible by utilizing Widom-Larsen and applying nanotechnology
Nuclear-strength electric fields in μ-sized LENR-active sites enable $e + p$ reaction
Huge array of new technological possibilities and opportunities open-up at micron to nanometer length-scales

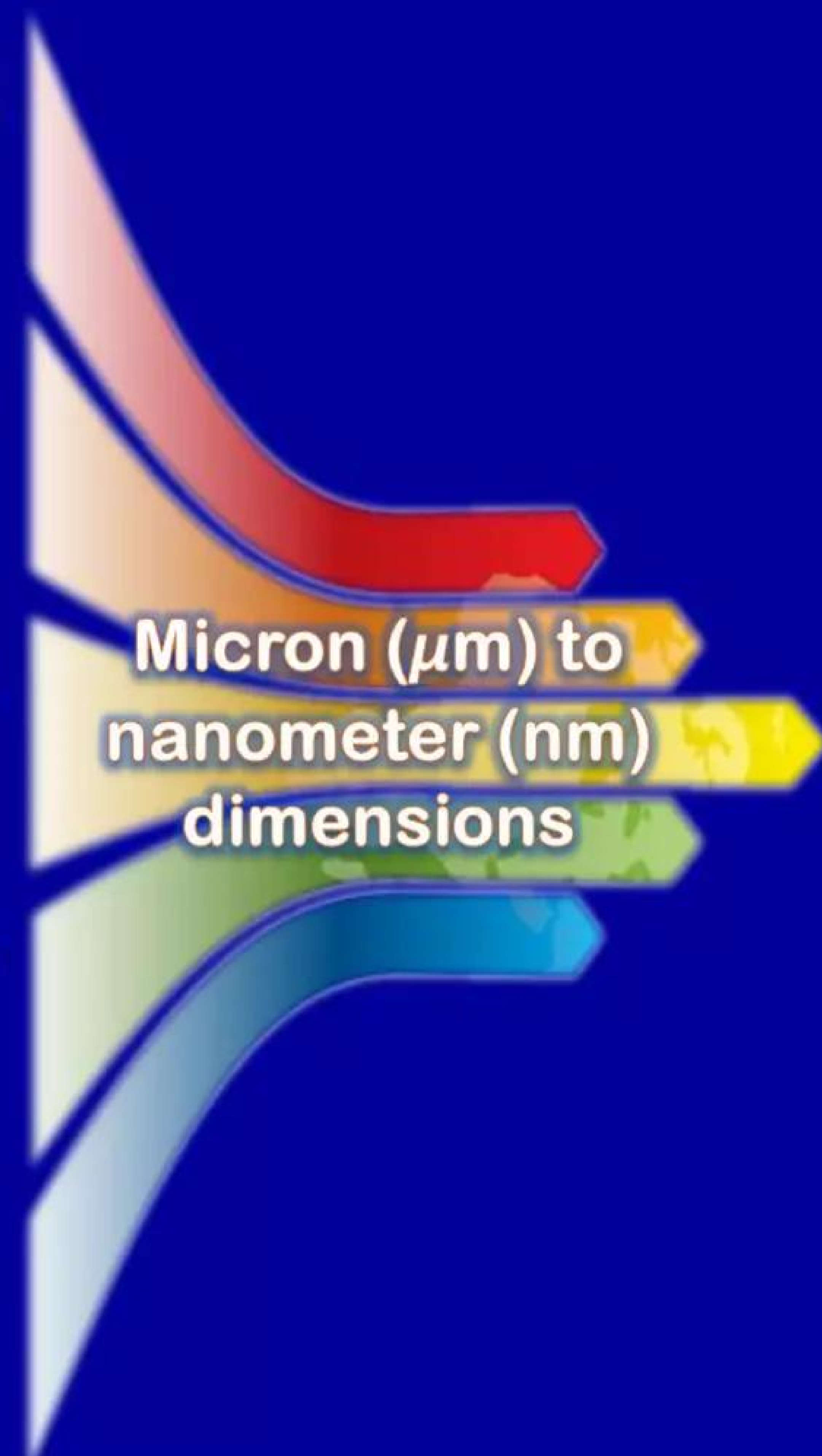
LENRs are an incredibly interdisciplinary area of science

Resisted understanding until Widom-Larsen able to put pieces together

Nanometer-to-micron scale many-body collective effects enable the 'impossible'

Scientists were observing LENRs for >100 years - didn't understand what they were seeing

Quantum electrodynamics (QED)
Collective many-body effects
Modern quantum mechanics
Condensed matter physics
Classical electrodynamics
Modern nuclear physics
Surface chemistry (H)
All nanotechnology
Surface physics
Plasma physics
Plasmonics



Widom-Larsen theory and Lattice's three-phase engineering plan for developing prototypes of LENR-based commercial power generation systems utilize broad base of selected technical knowledge derived from all of these many varied disciplines

Summary of steps in Widom-Larsen theory of LENRs

5-step green process in sites occurs in 300 - 400 nanoseconds or less

Collective many-body surface patches of protons can become LENR-active sites

1. Collectively oscillating, quantum mechanically entangled, many-body patches of Hydrogen (either +-charged protons or deuterons) will form spontaneously on metallic hydride surfaces or at certain types of interfaces, e.g. metal/oxide

2. Born-Oppenheimer approximation spontaneously breaks down, allows E-M coupling between local surface plasmon electrons and patch protons; application of input energy creates nuclear-strength local electric fields >2.5 x 10^{11} V/m - increases effective masses of surface plasmon electrons in patches

3. Heavy-mass surface plasmon electrons formed in many-body patches then react directly with electromagnetically interacting protons; process creates neutrons and neutrinos via many-body collective electroweak $e + p$ reaction

4. Neutrons collectively created in patch have ultralow kinetic energies and are all absorbed locally by nearby atoms - no dangerous energetic neutron fluxes escape apparatus; any locally produced or incident gammas are converted directly into safe infrared photons (heat) by unreacted heavy electrons (Lattice patent US# 7,893,414 B2) - no hard MeV-energy gamma emissions

5. Transmutation of elements and formation of craters at active sites begins

Appropriate input energy is required to produce neutrons

Electron or ion currents; E-M photon fluxes; organized magnetic fields

Input energy is required to trigger LENRs: to create non-equilibrium conditions that enable nuclear-strength local E-fields which produce populations of heavy-mass $e^{-}*$ electrons that react with many-body surface patches of p^{+}, d^{+}, or t^{+} to produce neutrons via $e^{-}* + p^{+} \rightarrow 1\,n$ or $e^{-}* + d^{+} \rightarrow 2\,n$, $e^{-}* + t^{+} \rightarrow 3\,n$ (energy cost = 0.78 MeV/neutron for H; 0.39 for D; 0.26 for T); includes (can combine sources):

- ✓ **Electrical currents** - i.e., an electron 'beam' of one sort or another can serve as a source of input energy for producing neutrons via $e + p$ electroweak reaction
- ✓ **Ion currents** - passing across a surface or an interface where SP electrons reside (i.e., an ion beam that can be comprised of protons, deuterons, tritons, and/or other types of charged ions); one method used for inputting energy is an ion flux caused by imposing a modest pressure gradient (Iwamura *et al.* 2002)
- ✓ **Incoherent and coherent electromagnetic (E-M) photon fluxes** - can be incoherent E-M radiation found in resonant electromagnetic cavities; with proper momentum coupling, SP electrons can also be directly energized with coherent laser beams emitting photons at appropriate resonant wavelengths
- ✓ **Organized magnetic fields with cylindrical geometries** - many-body collective magnetic LENR regime with direct acceleration of particles operates at very high electron/proton currents; includes organized and so-called dusty plasmas; scales-up to stellar flux tubes on stars with dimensions measured in kilometers

Widom-Larsen enables commercialization of LENRs

Applied nanotechnology and LENRs are mutually joined at the hip

Development risks can be reasonable thanks to Widom-Larsen and nanotech

Guided by physics of the Widom-Larsen theory, an opportunity to commercialize LENRs as truly green CO_2-free nuclear energy source has been enabled by a unique juxtaposition of very recent parallel advances in certain very vibrant areas of nanotechnology (esp. plasmonics), quantum entanglement, new innovations in nanoparticle fabrication techniques, as well as an array of new discoveries in advanced materials science.

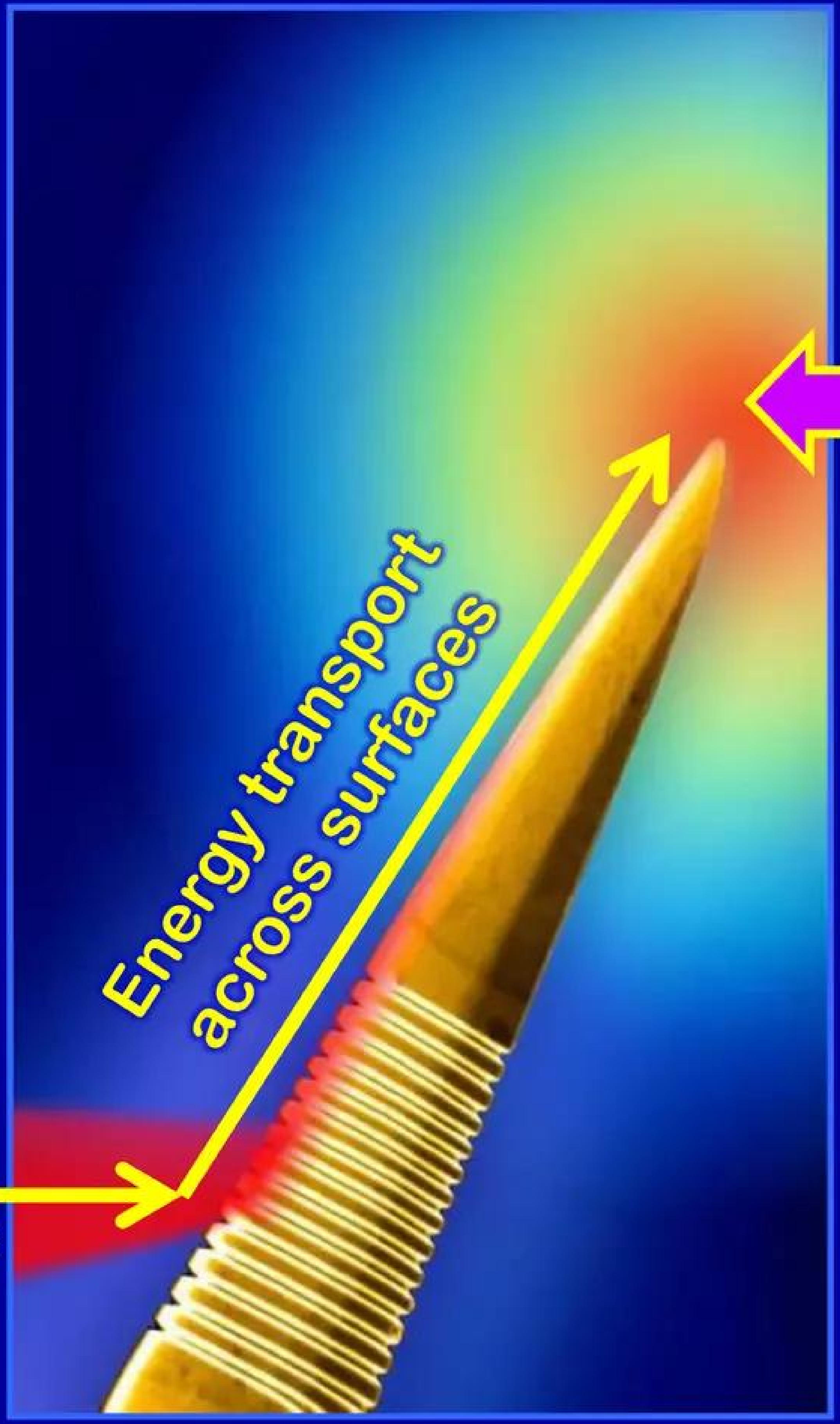
Visualization of plasmon electric fields on surface

Surface plasmons readily mediate input energy to LENRs

SP electrons can absorb, transport, concentrate, and store input energy

Properly engineered LENR target fuel nanoparticles can capture E-M input energy

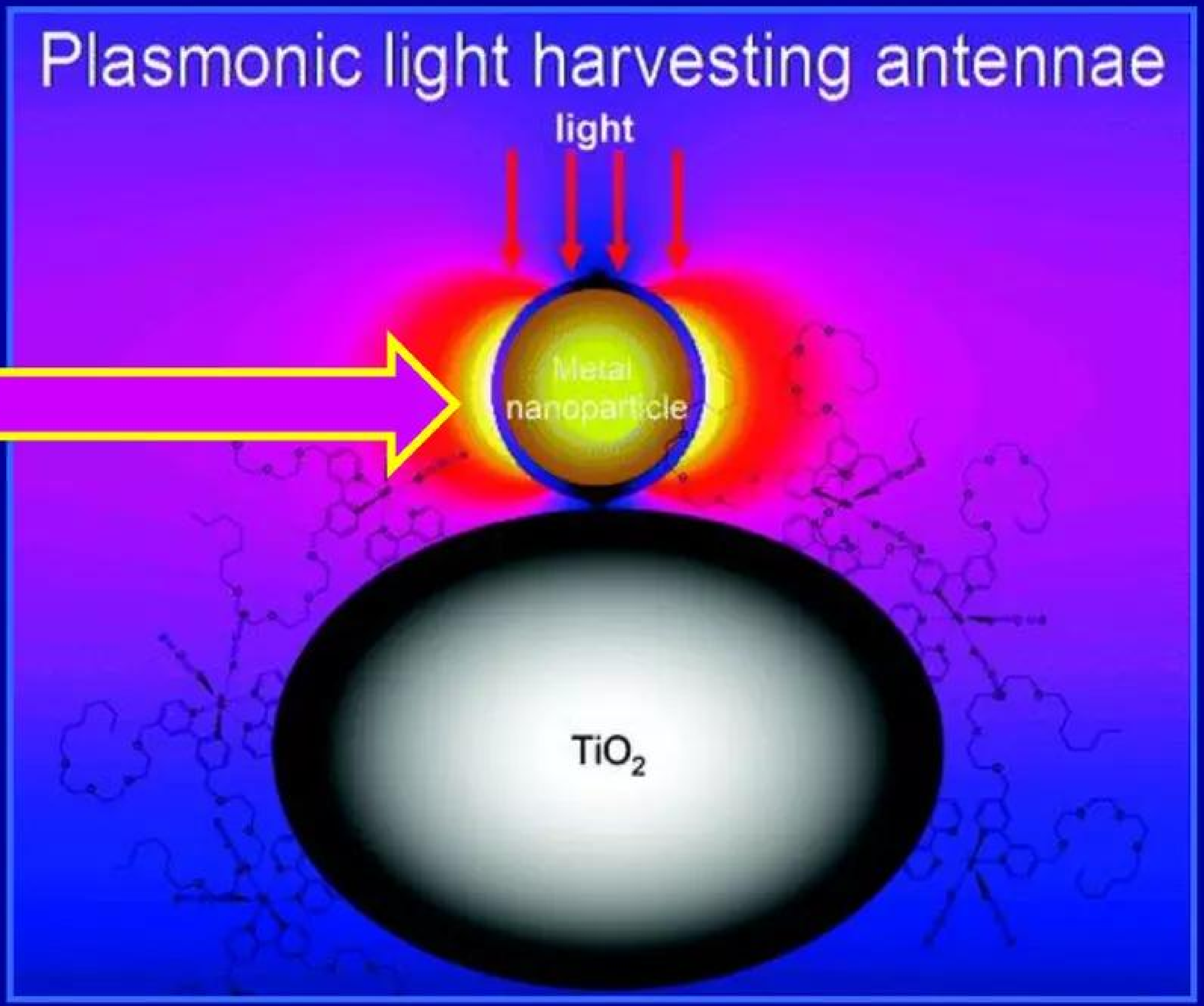
Sharp tips can exhibit "lightning rod effect" with very large increases in local electric fields



E-M photons

Regions of very high E-M fields

Source of image just below is the Wiesner Group at Cornell University; shows target nanoparticle on TiO_2



http://people.ccmr.cornell.edu/~uli/res_optics.htm

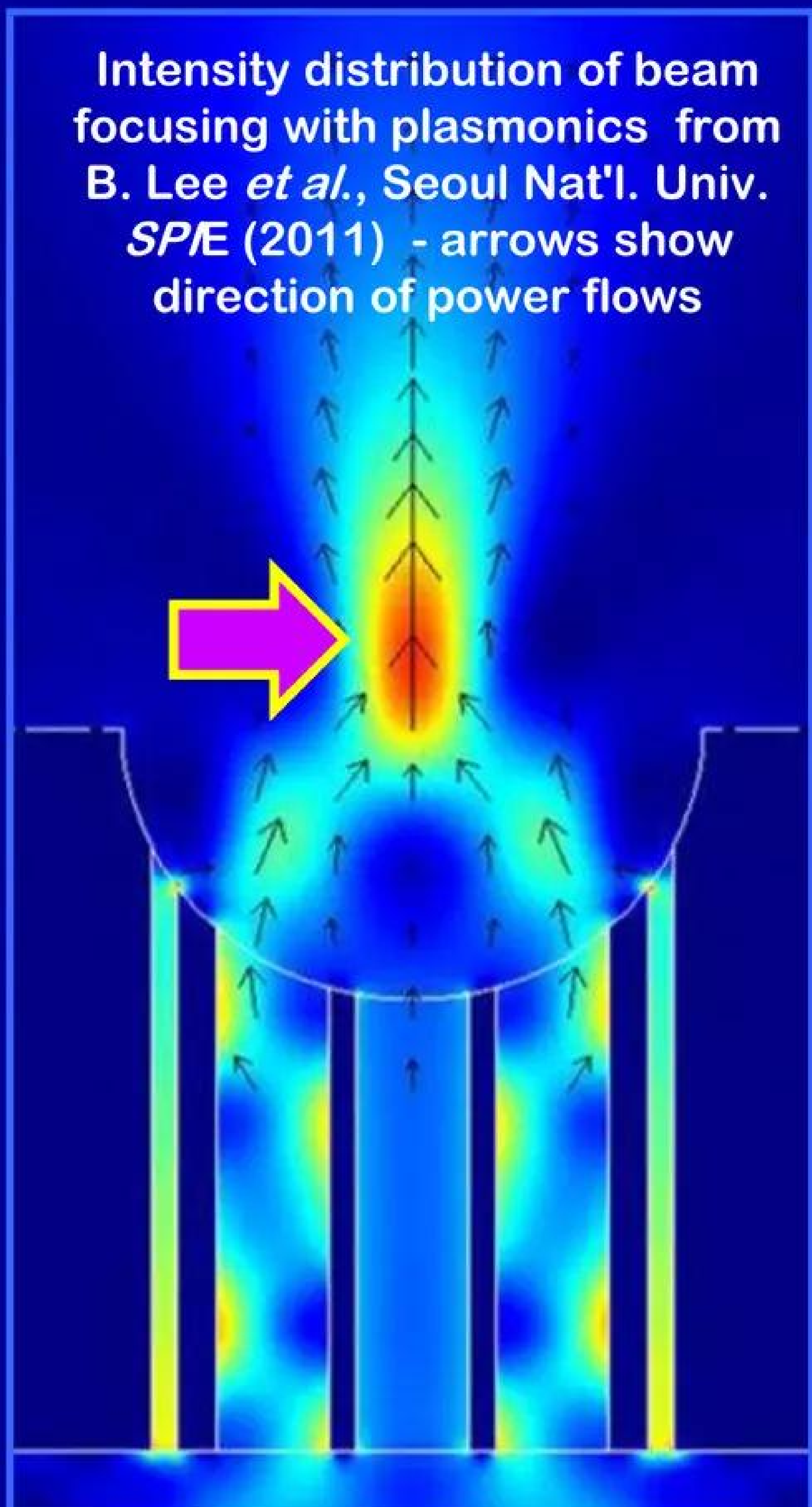
See: "Plasmonic dye-sensitized solar cells using core-shell metal-insulator nanoparticles," M. Brown *et al.*, *Nano Letters* 11 (2) pp. 438 - 445 (2011)

http://pubs.acs.org/doi/abs/10.1021/nl1031106

Input energy concentrated and stored by surface plasmons

SP electrons can absorb, transport, concentrate, and store input energy

B. Lee et al. show concentration of E-M energy in resonant electromagnetic cavity



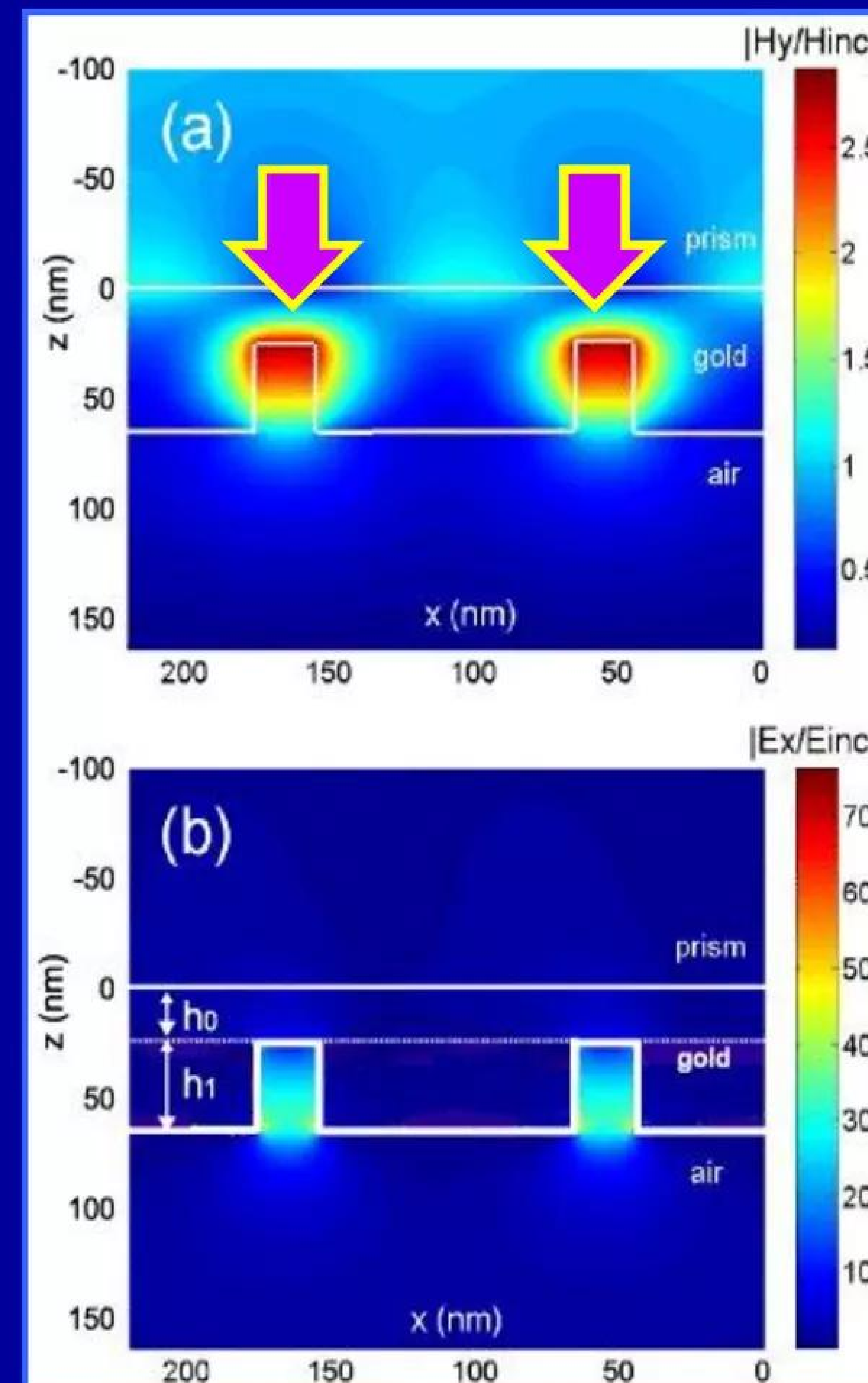
http://spie.org/documents/Newsroom/Imported/003435/003435_10.pdf

Reference:

"Enhancing reactive energy through dark cavity plasmon modes" J. Le Perchec *Europhysics Letters* 92 DOI: 10.1209/0295-5075/92/67006 (2010)

Abstract:

"We present an opto-geometrical configuration in which a metallic surface having nanometer-scale grooves can be forced to efficiently resonate without emitting radiation. The structure is excited from the backside, by an evanescent wave, which allows to inhibit light re-emission and to drastically modify the quality factor of the resonance mode. The energy balance of the system, especially the imaginary part of the complex Poynting vector flux, is theoretically analysed thanks to a modal method. It is shown how the generated hot spots (coherent cavity modes of electro-static type) can store a great amount of unused reactive energy. This behaviour might thus inspire a novel use of such highly sensitive surfaces for chemical sensing."

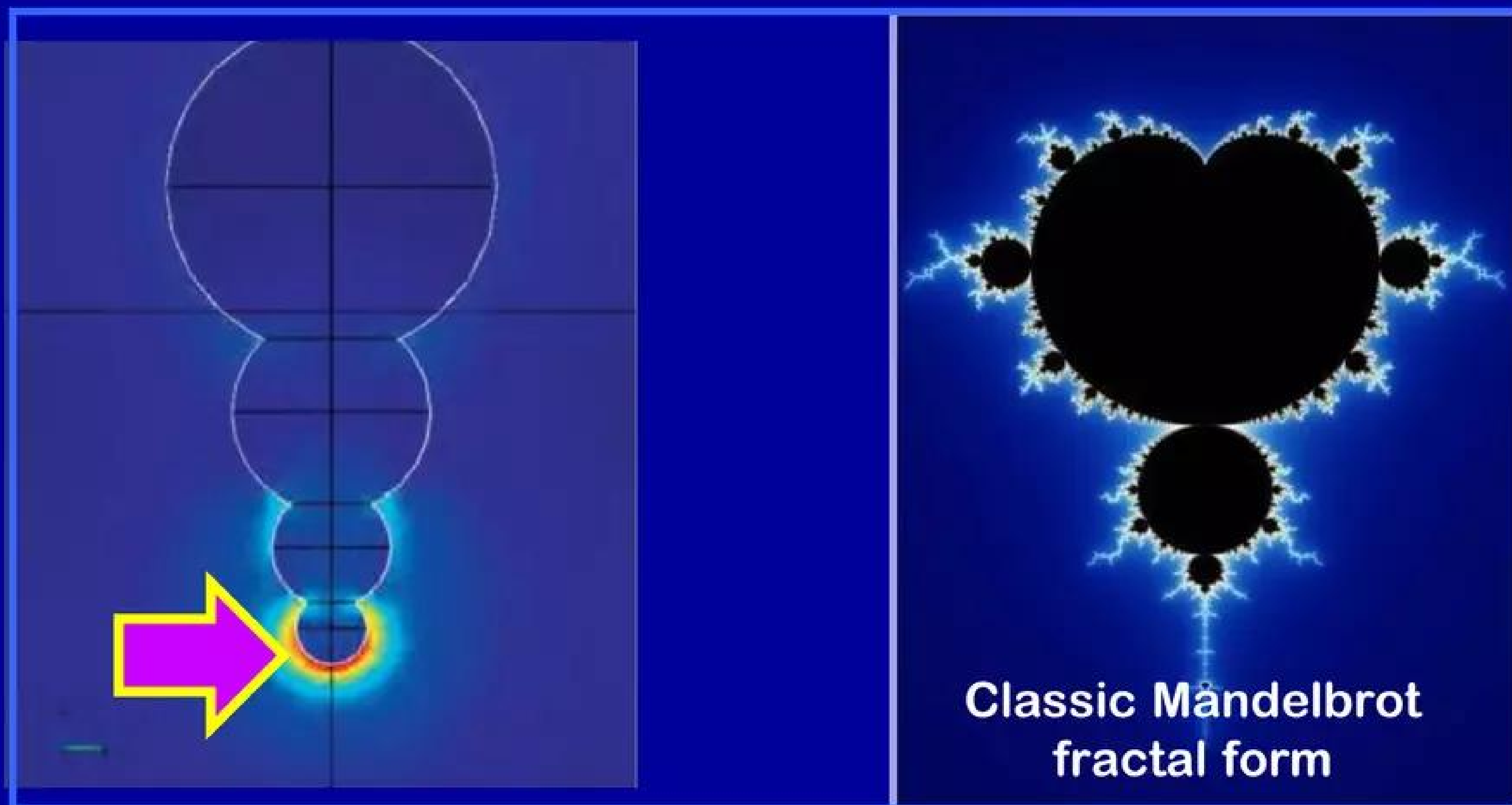


Credit: J. Le Perchec

Nanoparticle shape/proximity can boost local electric fields

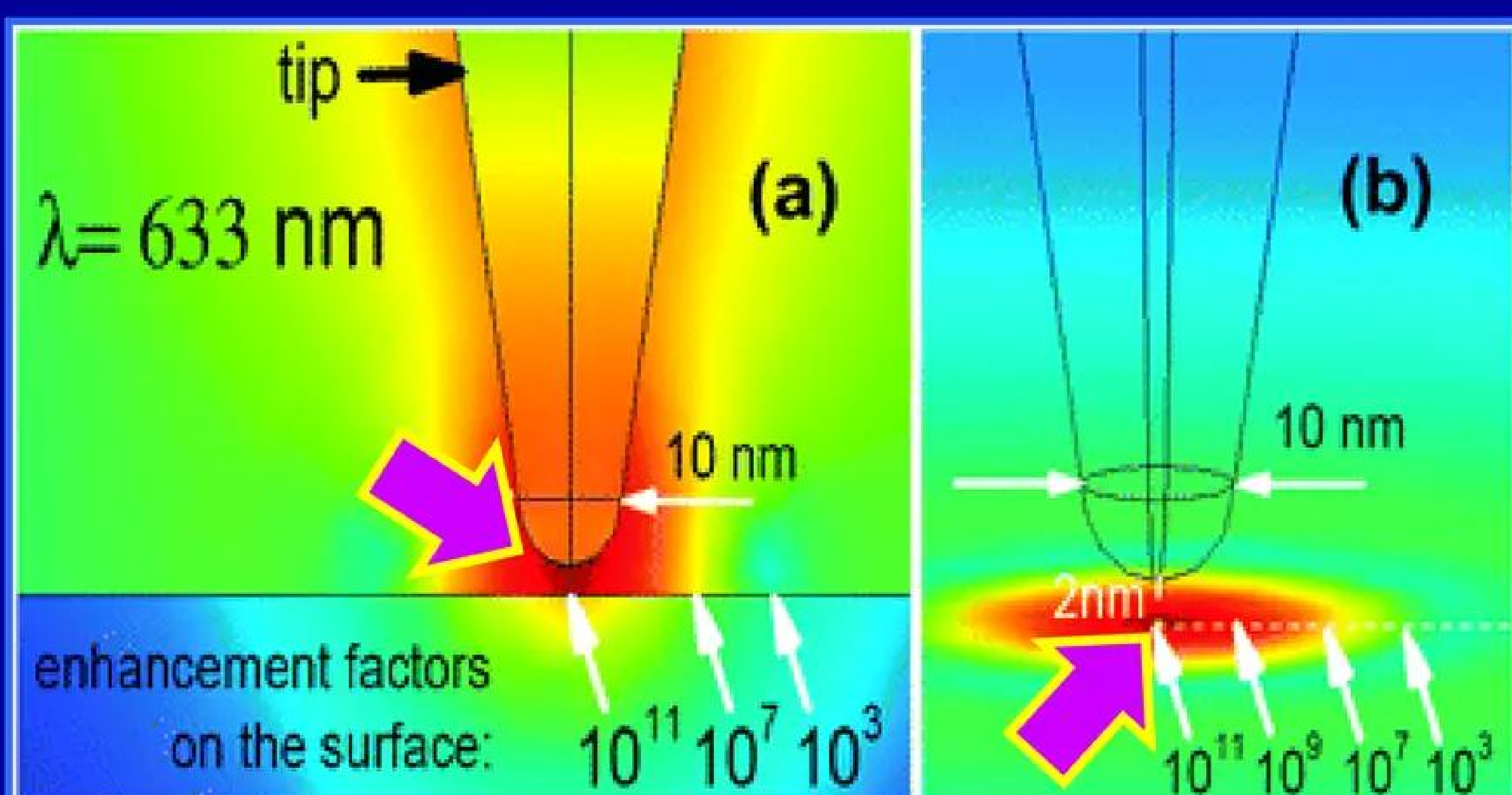
SP electrons can absorb, transport, concentrate, and store input energy

Nanoscale electric fields can be increased by multiples that may reach 10^{11} times

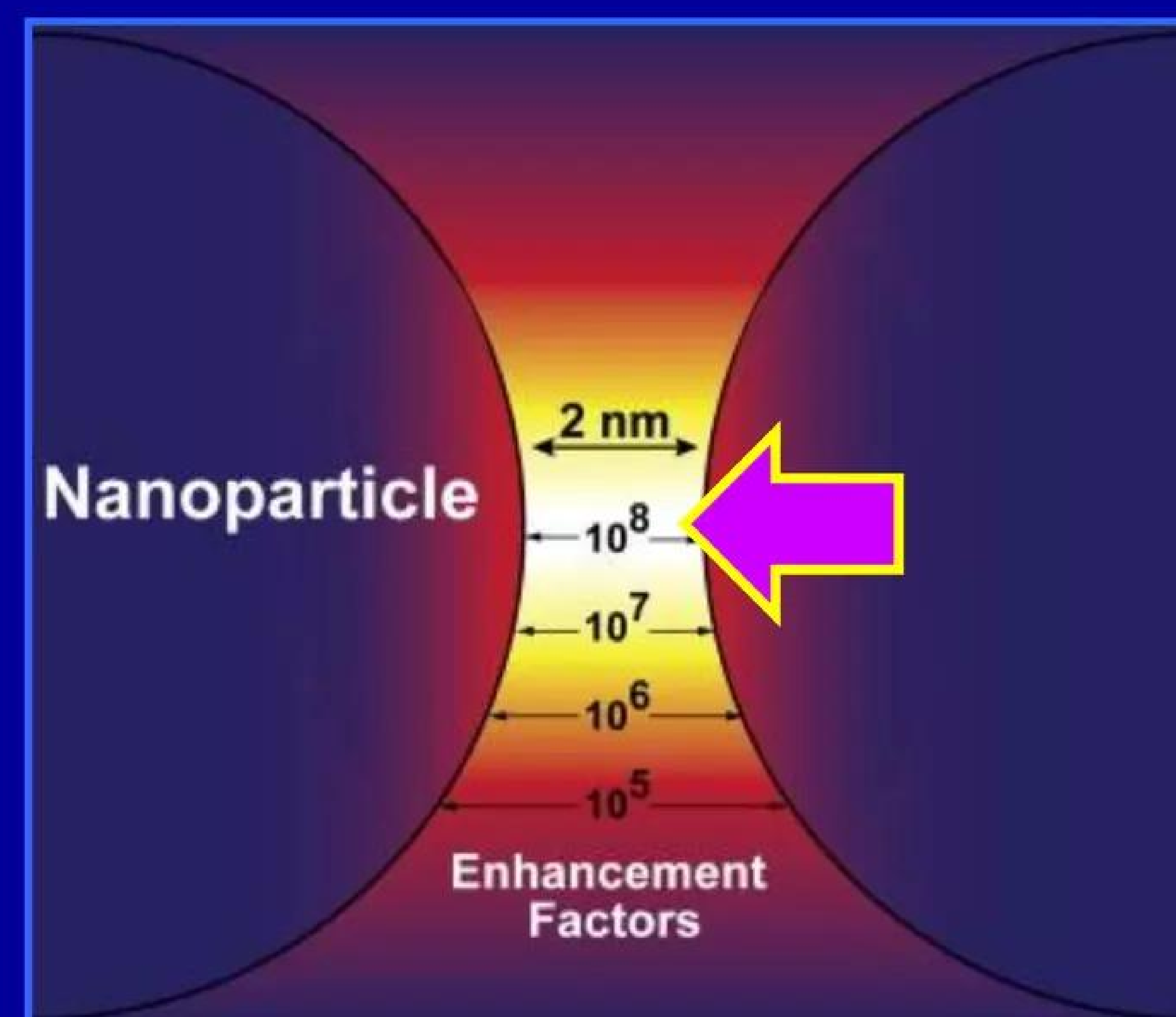


Sharp tips can exhibit the so-called “lightning rod effect” in terms of huge local enhancement of electric field strengths

Electric field enhancement at nano-antenna tip from R. Kappeler *et al.* (2007)



E-M field strength enhancement as a function of interparticle spacing



Nanoparticle shapes/positioning can vastly increase E-fields

Fang & Huang's Figs. 1 and 3 show how electric fields are redistributed

Nonuniformity can be predicted, modeled, used to design LENR-active sites

Figure 1.

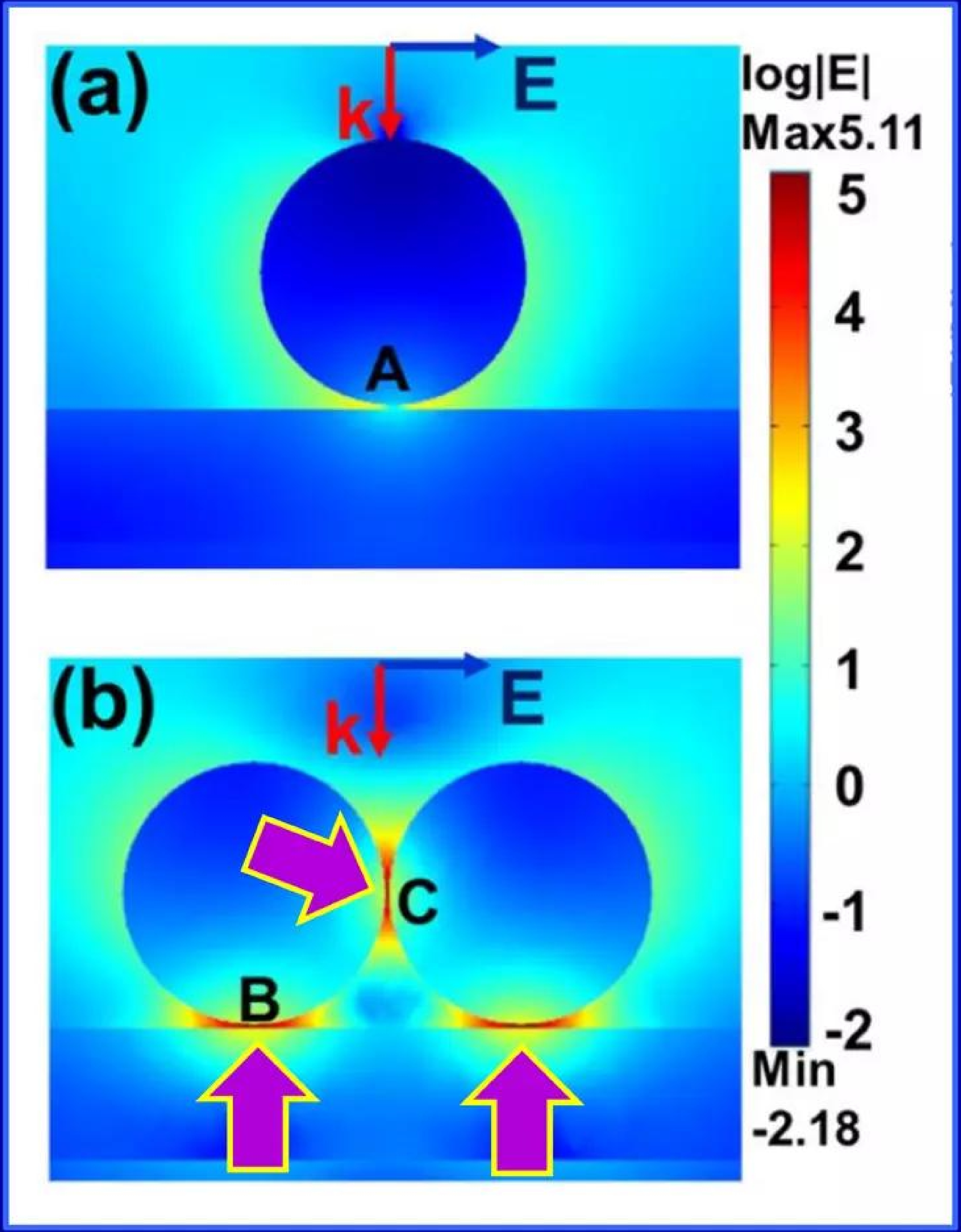
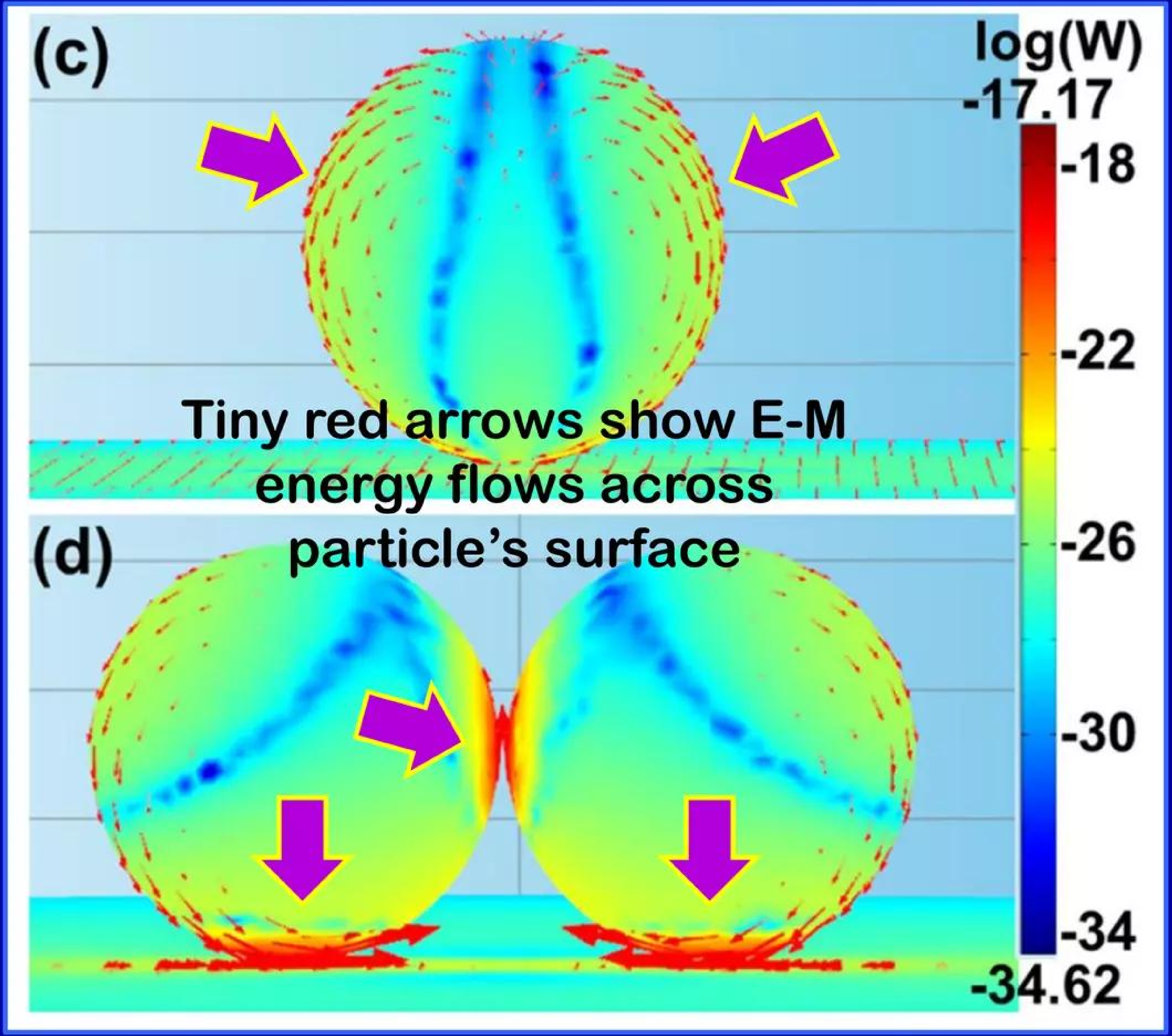


Figure 3.



http://publications.lib.chalmers.se/records/fulltext/178593/local_178593.pdf

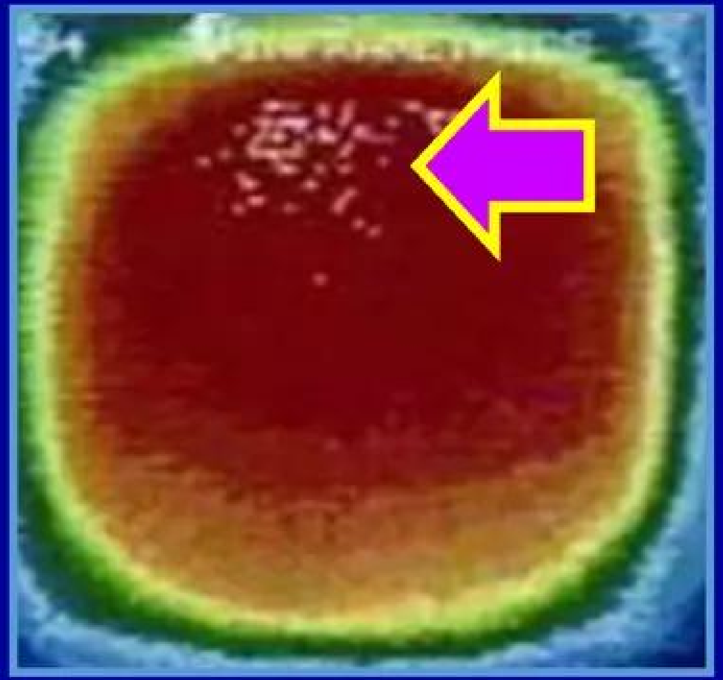
Widom-Larsen provides explanation for LENR-active sites

Size of these active sites ranges from 2 nanometers up to ~100+ microns

Active sites have limited lifetimes before being destroyed by fast nuclear heating

- ✓ Per Widom-Larsen theory, LENRs occur in localized micron-scale LENR-active sites on ~planar surfaces, at certain types of interfaces, or on curved surfaces of fabricated nanoparticles
- ✓ Tiny LENR-active sites live for less than ~300 - 400 nanoseconds before being destroyed by intense heat; local peak temps range from 4,000 - 6,000º C; LENR-active sites spontaneously reform under right conditions in well-engineered LENR thermal devices
- ✓ Microscopic 100-micron LENR hotspot can release as much as several Watts of heat in < 400 nanoseconds; create crater-like features on surfaces that are visible in SEM images and show evidence for flash-boiling of both precious & refractory metals
- ✓ Peak local LENR power density in microscopic LENR-active sites can hit > 1.0×10^{21} Joules/sec·m^3 during brief lifetimes
- ✓ Control macroscopic-scale temperatures in LENR systems by tightly regulating total input energy and/or total area/volumetric densities of LENR-active sites present in the reaction chambers

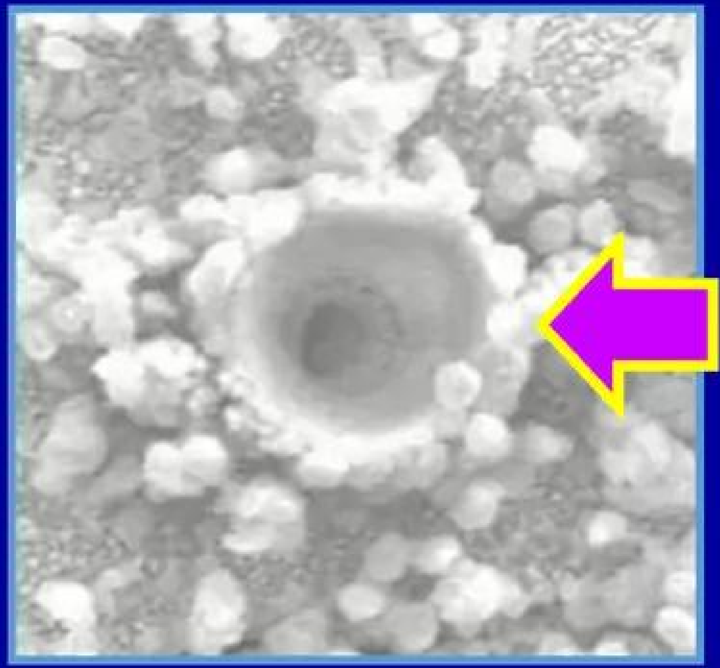
LENR hotspots on Palladium
Infrared video of LENR hotspots



Credit: P. Boss, U.S. Navy

http://www.youtube.com/watch?v=OUVmOQXBS68

100 μ LENR crater in Palladium
Boiling point 2,963°C



Credit: P. Boss, U.S. Navy

Release of nuclear binding energy produces usable heat

Several different mechanisms produce clean heat in LENR-active sites

Widom-Larsen explains what generates calorimetrically measured excess heat

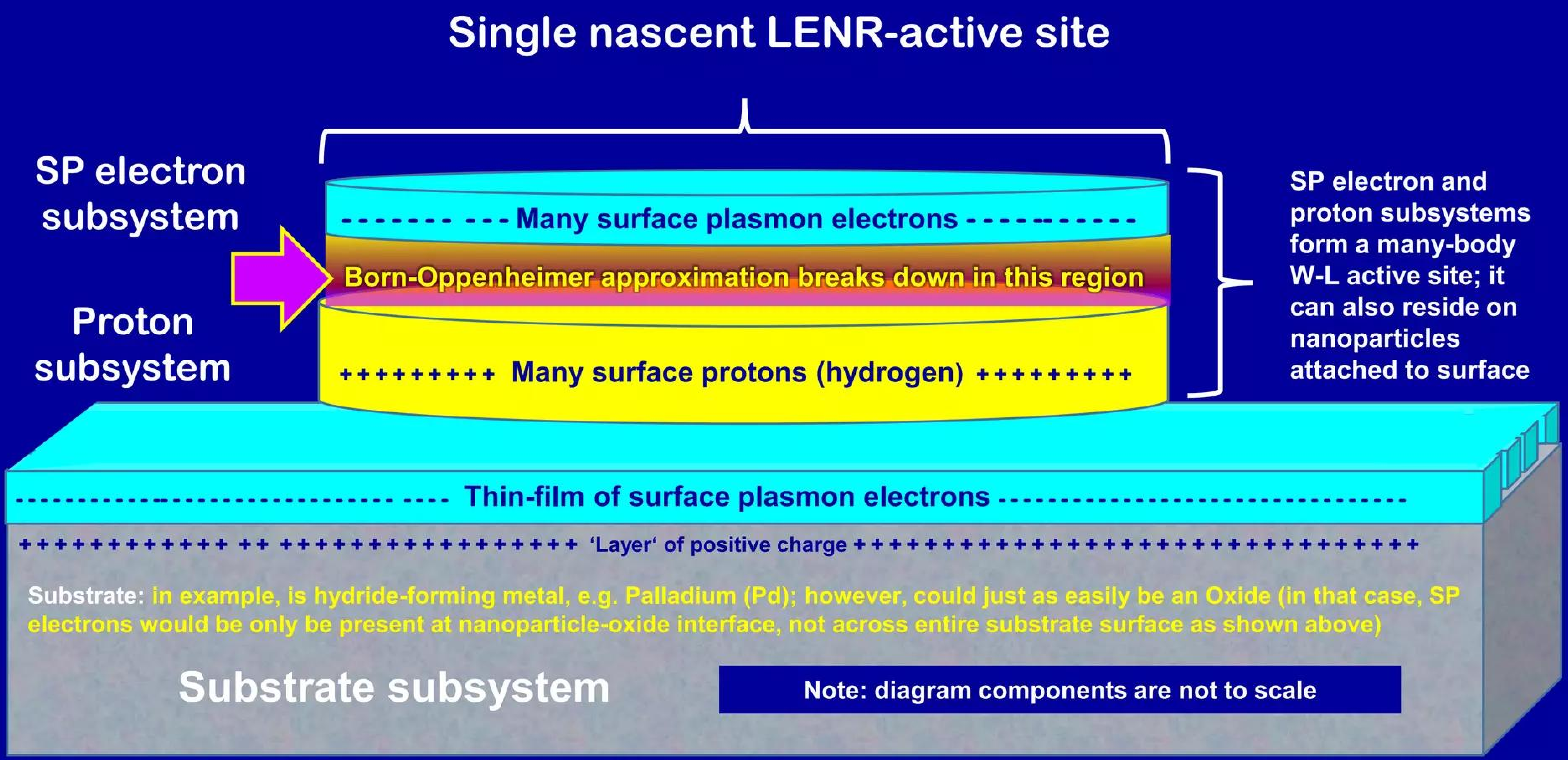
- ✓ Conceptually, LENR neutrons act like catalytic 'matches' that are used to 'light the logs' of target fuel nuclei. A neutron-catalyzed LENR transmutation network operates to release nuclear binding energy that has been stored and locked away in nuclei 'fuel logs' since they were originally produced at multi-million degrees in fiery nucleosynthetic processes of long-dead stars, many billions of years ago
- ✓ LENR transmutation networks can produce copious heat that comes mainly from:
  - Direct conversion of gamma photons (γ) into infrared photons (IR) by heavy electrons; e.g., γ from neutron captures or β and other types of decays. IR is then scattered and absorbed by local matter, increasing its temperature (heat)
  - Nuclear decays of unstable neutron-rich isotopes that emit energetic particles (e.g., betas, alphas, protons, etc.); these particles then transfer their kinetic energy by scattering on local matter, which increases its temperature (heat)
- ✓ Neutrino photons from weak interactions do not contribute to any production of excess heat; they will essentially bleed-off a small portion of released nuclear binding energy outward into space; unavoidable neutrino emissions are part of the energetic cost of obtaining energy releases in LENR networks from β^- decays

W-L concept of a microscopic LENR-active surface site

Comprised of many-body patches of protons and electrons on surface

SP electrons and protons oscillate collectively and are mutually Q-M entangled

Diameters of many-body active sites randomly range from several *nm* up to ~ 100^{+} microns



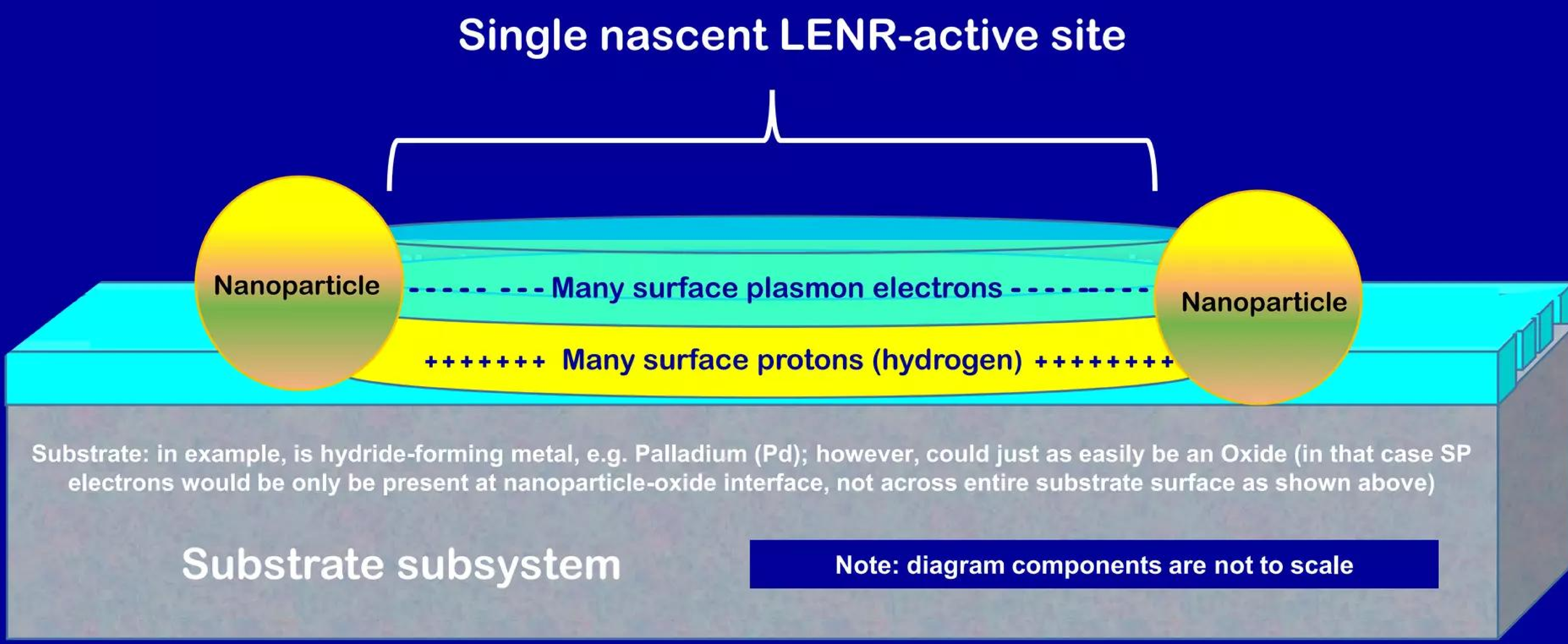
Input energy creates high electric fields in LENR active sites

Born-Oppenheimer breakdown enables nuclear-strength local E-field

Huge electric field increase effective masses of some patch SP electrons

Correct input energies create huge local E-fields > 2.5 x 10^{11} V/m between adjacent nanoparticles

Input energy$_{\text{E-field}} + e^{-}_{sp} \rightarrow e^{-*}_{sp} + p^{+} \rightarrow n + \nu_e$ **[condensed matter surfaces]**



LENRs occur in microscopic active sites found on surfaces

Many-body collections of protons and electrons form spontaneously

Ultralow energy neutrons produced & captured close to LENR-active sites

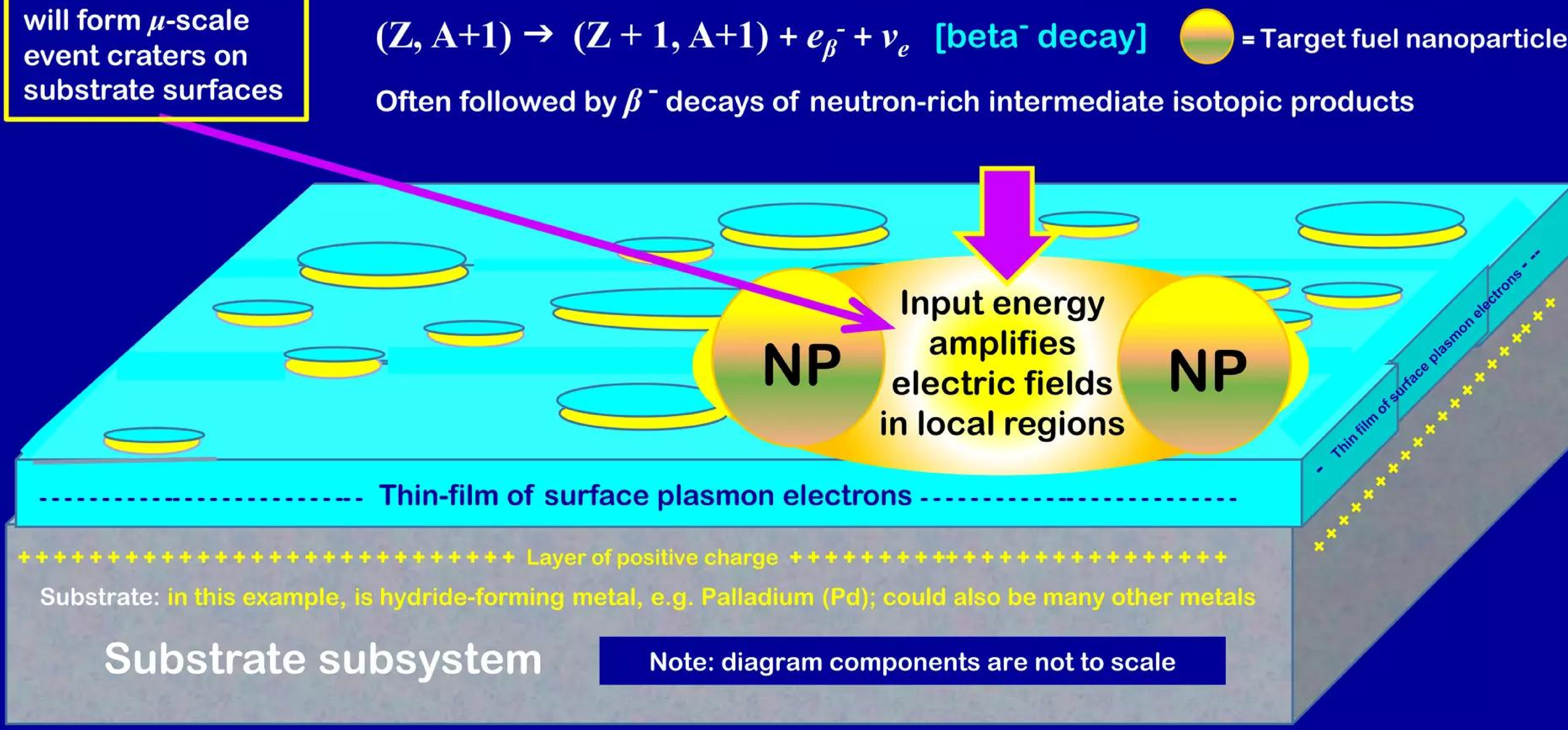
After being produced, neutrons capture on targets in/around active sites:

n + (Z, A) → (Z, A+1) [neutrons capture on nearby fuel targets]

(Z, A+1) → (Z + 1, A+1) + e_β^- + ν_e [beta$^-$ decay]

Often followed by β^- decays of neutron-rich intermediate isotopic products

Intense heating in LENR-active sites will form μ-scale event craters on substrate surfaces



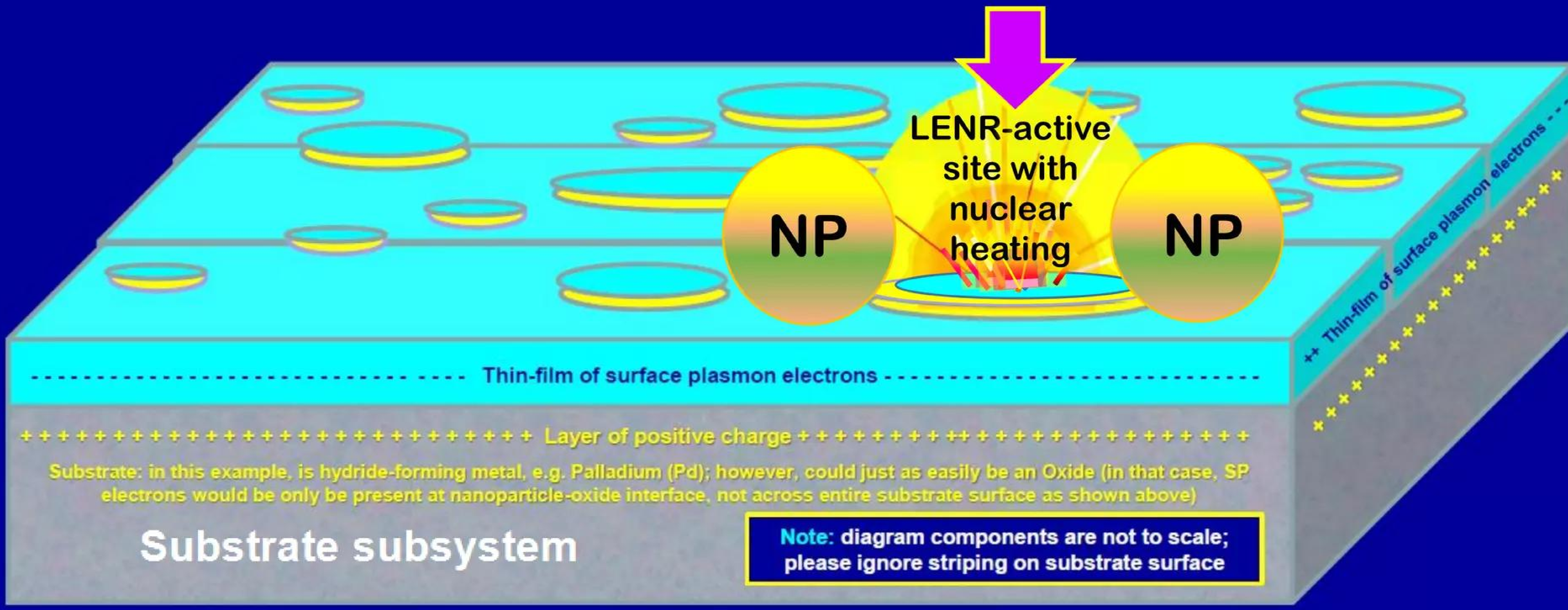
LENR-active sites will only exist for ~200 - 400 nanoseconds

Local heating will destroy needed quantum coherence and site dies

Produced neutrons captured locally → transmutation of fuel elements

Neutron capture process by itself extremely fast: occurs in just picoseconds

Heating in LENR-active sites often creates surface craters ~100 or so microns in diameter. These features can be observed on LENR-active surfaces post-experiment with scanning electron microscopes (SEM); wide variety of LENR transmutation products have been observed in exactly the same areas with SIMS

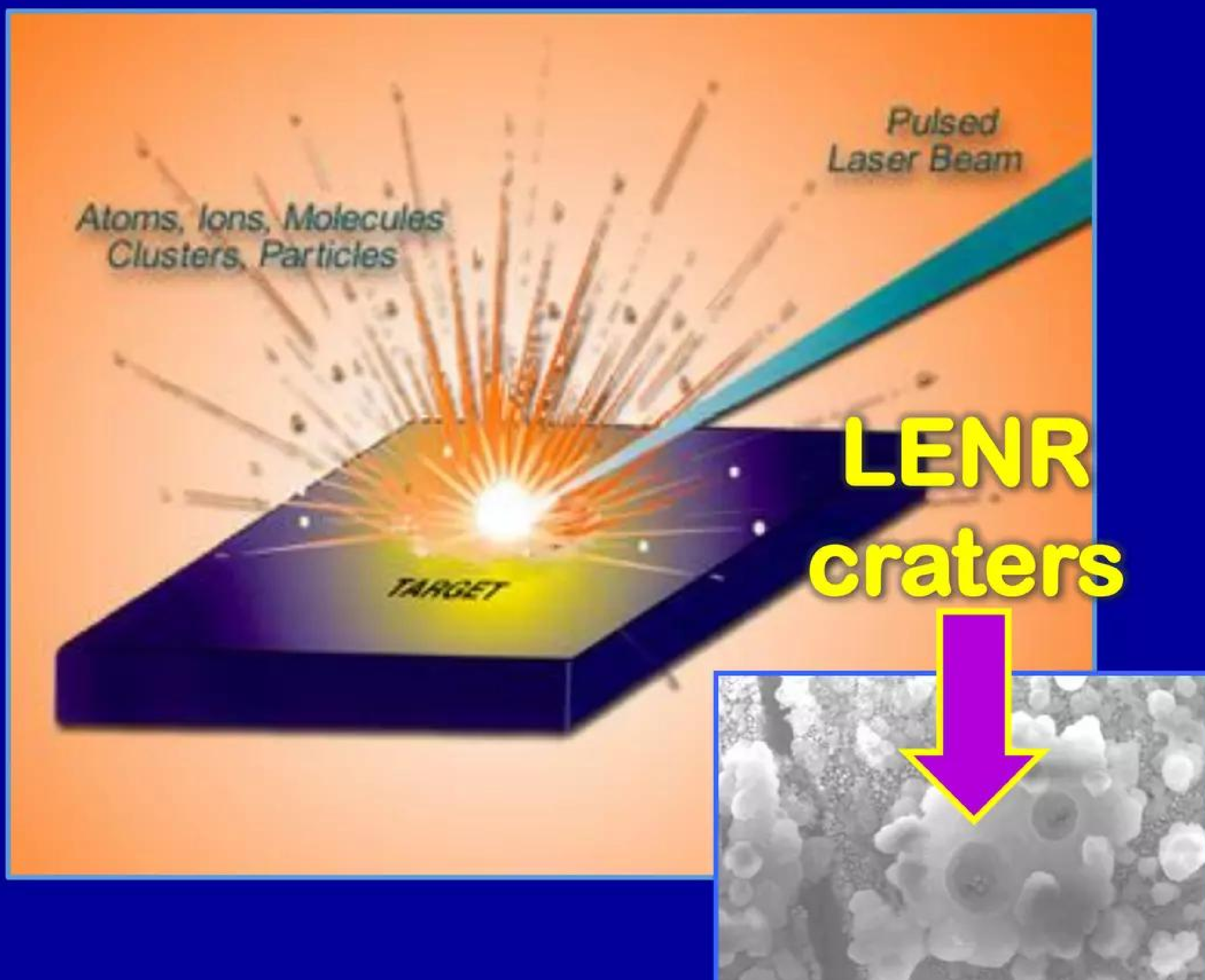


LENR-produced and laser ablation craters very similar

Produce micron-scale craters having similar sizes and morphologies

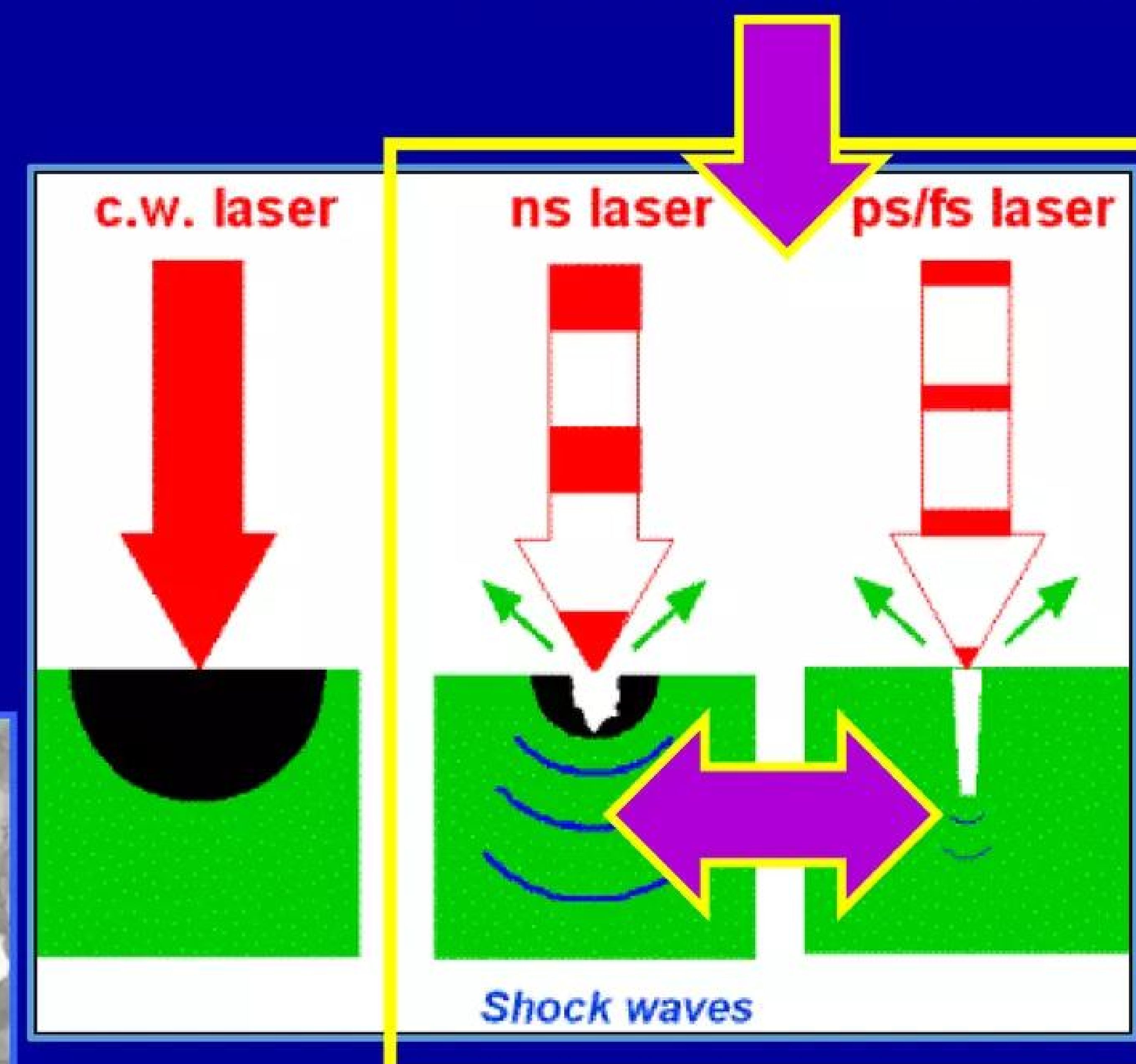
Some LENR craters exhibit steep walls that suggest very rapid energy releases

Direct gamma conversion in LENR-active sites creates intense infrared radiation sources



Pd - P. Boss, U.S. Navy

Shorter-duration laser pulses produce craters with steeper, sharply defined vertical walls



Enormous local power densities create surface craters

U.S. Navy SEM images of LENR-active Pd surfaces show μ-scale craters

Crater produced by laser ablation of Ba/Al surface

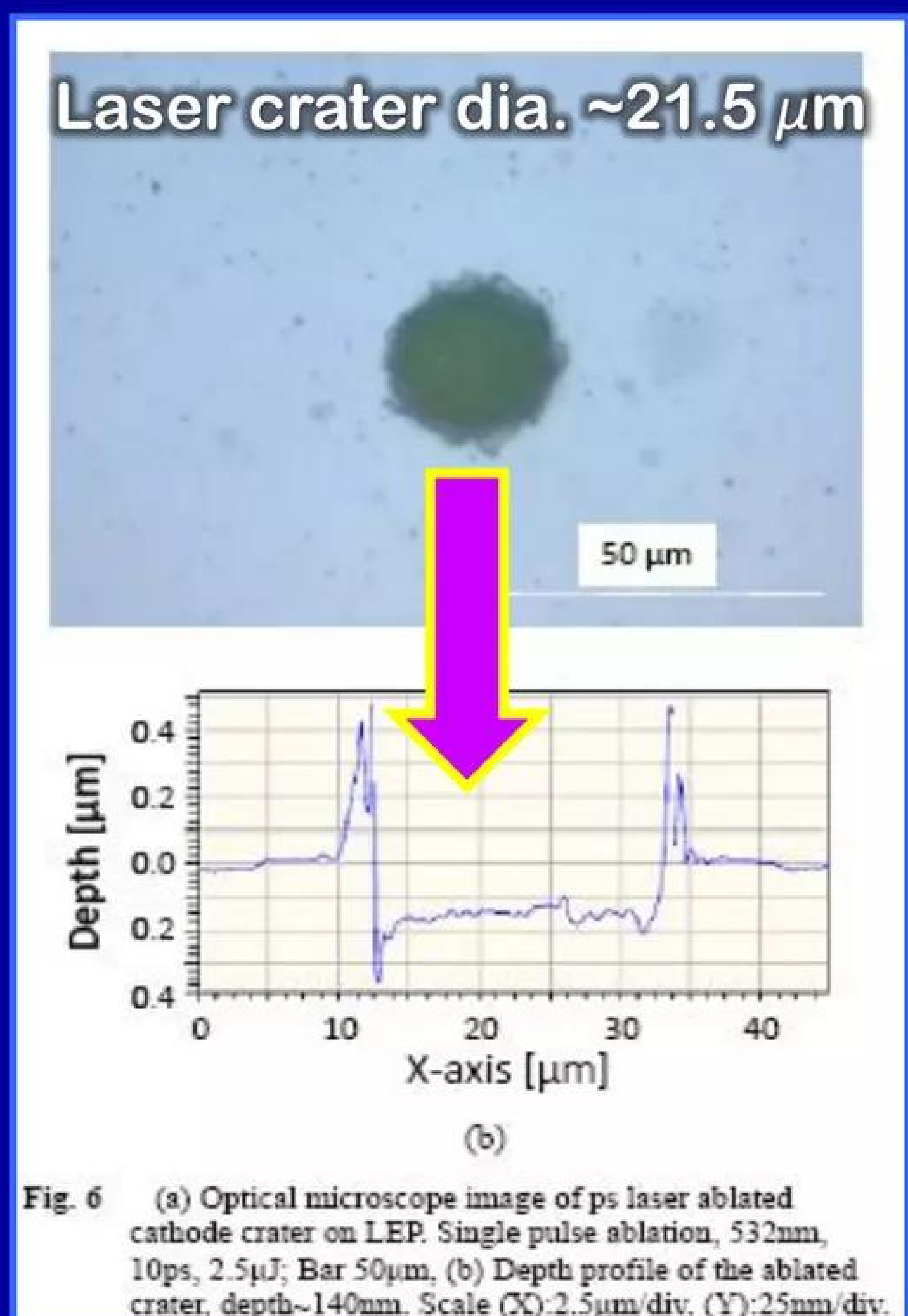


Fig. 6 (a) Optical microscope image of ps laser ablated cathode crater on LEP. Single pulse ablation, 532nm, 10ps, 2.5μJ; Bar 50μm, (b) Depth profile of the ablated crater, depth~140nm. Scale (X):2.5μm/div, (Y):25nm/div.

Quoting from Karnakis *et al.*:

"Laser irradiation at fluences between 137-360 mJ/cm^2 removed the cathode layer only, resulting in a uniform flat floor and an intact LEP surface, allowing a relatively wide process window for cathode removal.

A typical example of such laser patterned Ba/Al cathode layer on the OLED stack is shown in Figure 6.

The average fluence was 230 mJ/cm^2 irradiated with an estimated spot diameter at 1/e^2 of 35 μm.

This resulted in a crater diameter of 21.5 μm."

Fig. 6 Excerpted and quoted directly from:

"Ultrafast laser patterning of OLEDs on flexible substrate for solid-state lighting", D. Karnakis, A. Kearsley, and M. Knowles *Journal of Laser Micro/Nanoengineering* 4 pp. 218 - 223 (2009)

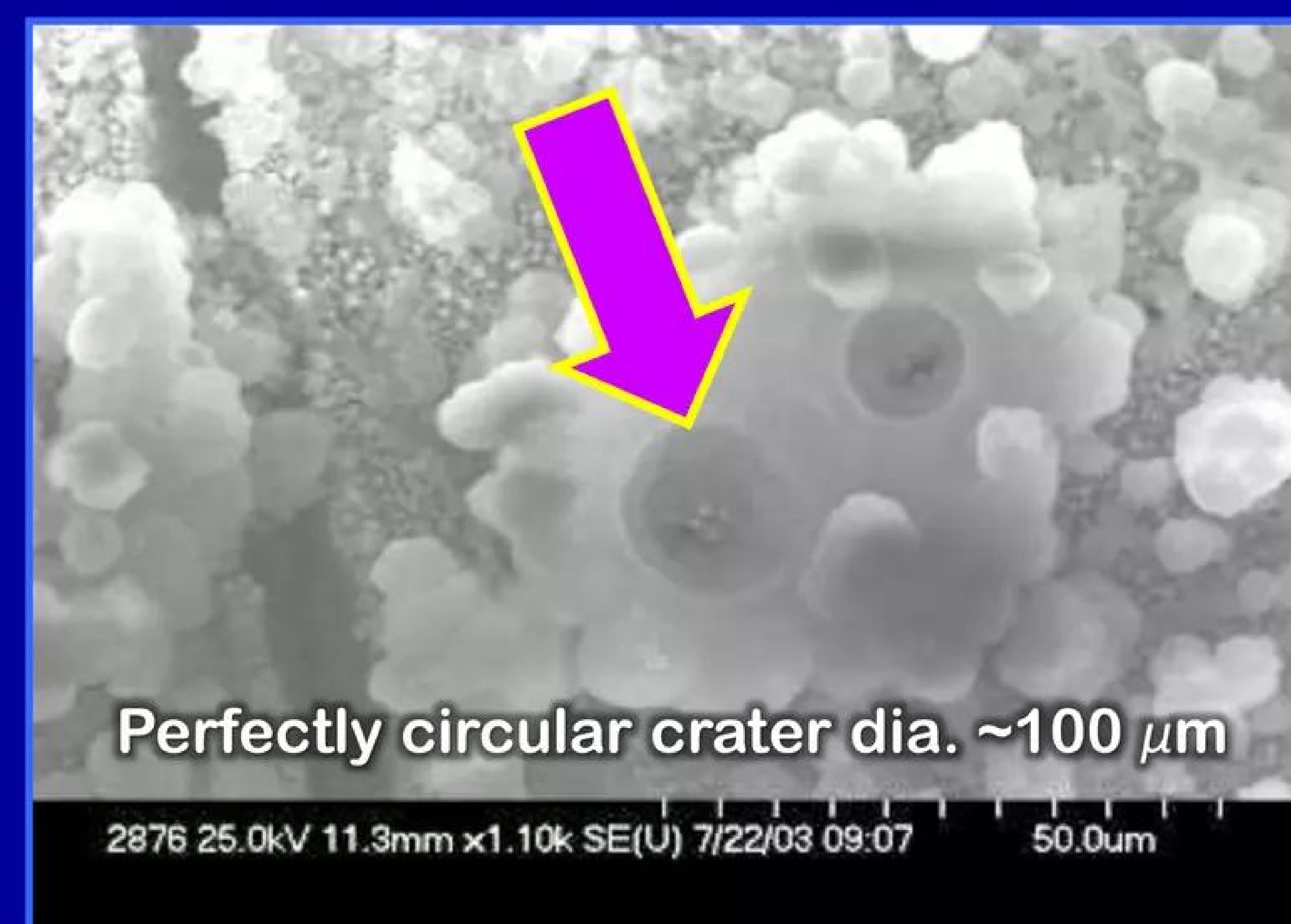
http://www.jlps.gr.jp/jlmn/upload/25e2c628adb23db70b26356271d20180.pdf

Craters produced on Palladium surface in an LENR device

Shows evidence for very explosive boiling of metals; morphology of LENR craters similar to ablative effects of energetic laser irradiation

LENR craters have sharp relief and high aspect-ratios like laser ablation

LENR Pd surface post-experiment
P. Boss *et al.*, U.S. Navy - SPAWAR



Note microspheres formed at lips of craters

Enormous power densities occur in LENR-active sites

LENRs can be triggered at very modest macroscopic temperatures

Peak power densities inside LENR-active sites maybe ~3.6 x 10^{19} x solar core's

Huge power densities in LENR-active sites enables large heat production in small devices

Simply calculated comparison of LENR patch power densities versus those thought to occur in the Sun's core; LENRs are amazingly high:

- ✓ Stromgrew (1965) calculated peak fusion power density in Sun's core at $E_{(J)}$ = 276.5 Joules/sec·m^3 (2.765 x 10^2)
- ✓ Seidman & Norem (2005) stated they believed that power densities in small sites on surfaces where collective electron field emission and electrical breakdown are occurring = 1.0 x 10^{21} Watts/sec·m^3
- ✓ While we might safely presume that peak power density in an LENR-active patch could likely be higher than that Seidman & Norem's number, let's conservatively assume it's just the very same value for total LENR energy releases that occur during a given surface site's brief effective working lifetime before it dies and then cools-off
- ✓ Thus, according to formula shown above to the upper right, these assumptions would suggest that peak local power density from an LENR-active patch might be as high as $E_{(J)}$ = 1.0 x 10^{21} Joules/sec·m^3
- ✓ Dividing 1.0 x 10^{21} (LENRs) by 2.765 x 10^2 (Sun's core) we calculate LENRs' relative power density = ~3.6 x 10^{19} times the solar core's

Energy E in joules (J) is equal to the power P in Watts (W), times the time period t in seconds (s):

$$E_{(J)} = P_{(W)} \times t_{(s)}$$

Comments:

One could quibble with details in these simplistic estimates; however, conclusion of this calculation is that LENR-active sites briefly have energy power densities that can be substantially higher than the Sun's inner core

This comparison suggests that LENRs could well have excellent potential as a new green energy source, provided that methods are found to fabricate high area-densities of LENR-active sites and that they can be reliably triggered and their rates fully-controlled

Widom-Larsen theory guides LENR device engineering

Parameters controlling neutron fluxes and heat production are known

- ✓ Term $(\beta - \beta_0)^2$ in our published rate equation reflects the degree to which heavy-mass (renormalized) $e^{-}*$ electrons in a given active site exceed the minimum threshold ratio for neutron production β_0. Details of this are explained in our first principles ULE neutron production rates calculation preprint found on the Cornell physics arXiv: http://arxiv.org/PS_cache/nucl-th/pdf/0608/0608059v2.pdf

- ✓ All other things being equal, the higher the density of $e^{-}*p^{+}$ reactants and the greater the rate and quantity of appropriate forms of nonequilibrium energy inputs, the higher the rate of ULE neutron production in nm- to μm-scale LENR-active sites in properly engineered LENR power generation systems

- ✓ LENR transmutation network pathways comprising series of picosecond neutron captures interspersed with serial beta-decay cascades can release substantial amounts of nuclear binding energy, much of it in the form of usable heat; e.g., there is a multi-step Carbon-fuel LENR transmutation network pathway that can release ~386 MeV over an average period of ~3.4 hours. **This total energy release over several hours is comparable to fission (U-235 is ~190 MeV) but without any high-energy neutron or gamma emission or production of long-lived radioactive isotopes; see Slide #55 at URL:**

http://www.slideshare.net/lewisglarsen/lattice-energy-llctechnical-overviewcarbon-seed-lenr-networkssept-3-2009

Fuel atoms emplaced in close proximity to active sites

Lithium LENR target fuel cycle releases more energy than D+T fusion

No dangerous radiation emitted by Li fuel cycle; has been demonstrated in lab

Widom & Larsen's 2006 *European Physical Journal C* paper shows the following Lithium-seed LENR network cycle:

Lithium-6 + 2 ULE neutrons → 2 Helium-4 + beta particle + 2 neutrinos + Q-value = 26.9 MeV

This particular cyclical LENR pathway can release about the same amount of energy as the D-T fusion reaction without creating any MeV-energy energetic neutrons, hard gamma radiation, or radioactive isotopes. Although a portion of the 26.9 MeV in excess nuclear binding energy released is lost (haircut) with emitted neutrinos, much of it still remains in the kinetic energy of the two helium atoms (which are low-energy alpha particles), and much more energetic beta particle.

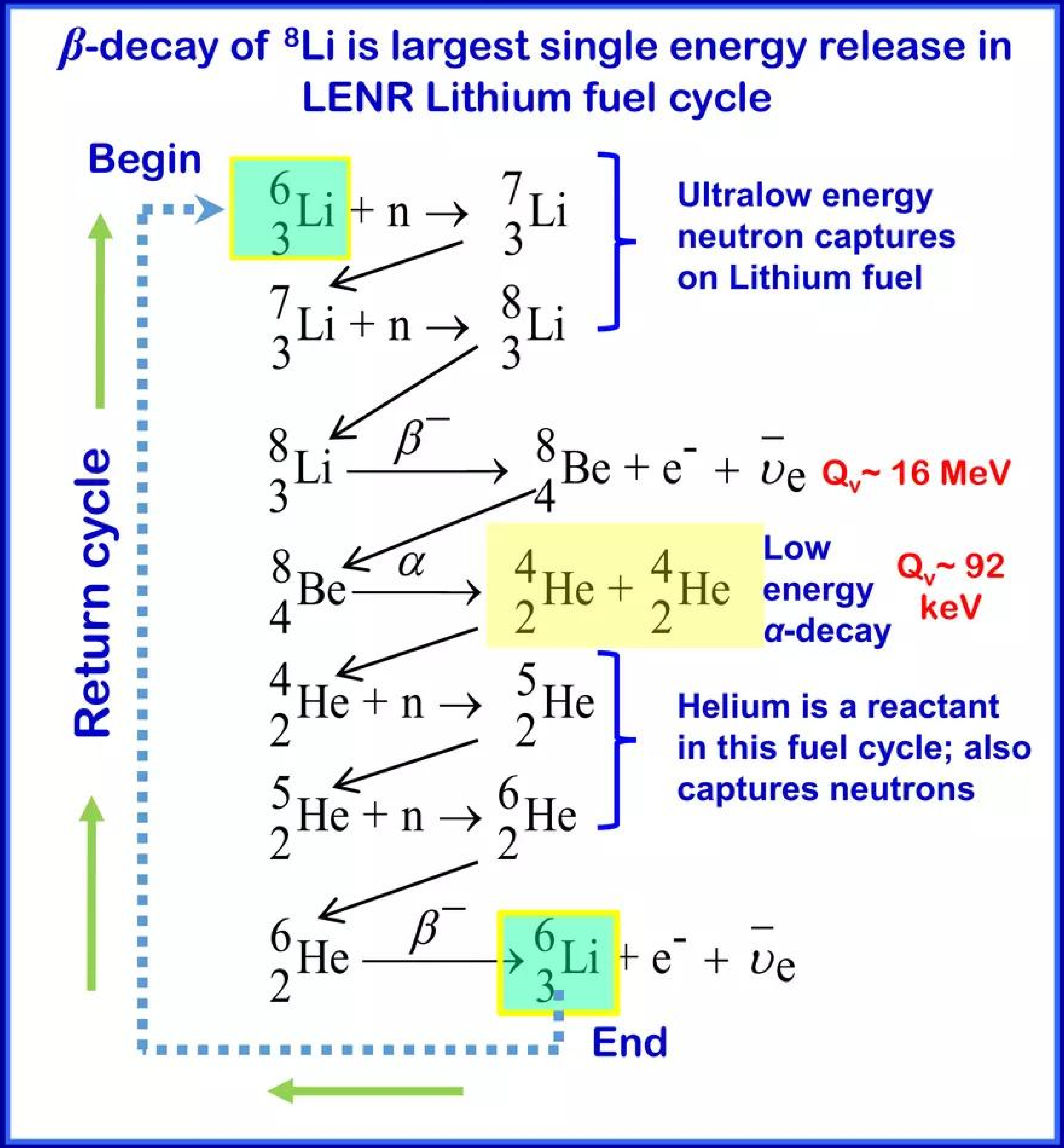
In this particular case, local solid matter is heated-up by the scattering of low-energy alpha and much-higher-energy beta particles; heavy-mass electrons also present in LENR-active patches convert any locally produced hard gammas or X-rays (from whatever process) directly into infrared heat.

See: "Ultra low momentum neutron catalyzed nuclear reactions on metallic hydride surfaces"
A. Widom and L. Larsen *European Physical Journal C - Particles and Fields* 46 pp. 107-111 (2006)

ULEN-catalyzed LENR Lithium network cycle is from Eqs. 30 - 32

http://www.slideshare.net/lewisglarsen/widom-and-larsen-ulm-neutron-catalyzed-lenrs-on-metallic-hydride-surfacesepjc-march-2006

LENR neutron-catalyzed Lithium fuel cycle



Lithium-fuel LENR reactors have energetic gains Q >10x

Calculations illustrate its potential for use in compact power sources

LENR system thermal output can be up to 34x input energy using Lithium fuel

- ✓ To simplify calculations, we will assume that utilization of input energy (in this case, an electric current) into energy needed to produce LENR ultralow energy (ULE) neutrons is 100 percent efficient in order to estimate a theoretical upper bound on potential heat production from a compact LENR heat source. Will also assume that ~100 percent of the ULE neutrons produced in our hypothetical device are absorbed locally (safe bet supported by 20^{+} years of experiments) and that they are only absorbed by a target fuel comprising isotopically pure Lithium-6. This results in a series of nuclear reactions beginning with Lithium-6 and ending with Helium-4. Lastly, we will assume that the Hydrogen isotope used to produce LENR ULE neutrons in our hypothetical device is Deuterium and that the device has an effective internal LENR-active working surface area of 1.0 cm^2
- ✓ Input energy required to produce 1 neutron/cm^2/sec from Deuterium to react with the Lithium-6 target fuel is 0.39 MeV per neutron. However, we need two ULE neutrons to complete the entire series of reactions, so required total input energy to the device is 0.78 MeV/cm^2/sec. The net energy release from that particular series of LENR reactions starting with Lithium-6 is 26.9 MeV/cm^2/sec = 4.28×10^{-12} J/cm^2/sec (1 eV = 1.602×10^{-19} J); value of 26.9 MeV translates into theoretical maximum upper bound of Q = ~34x total input energy for Lithium fuel

Lithium-fueled LENR heat sources scale to megawatts

Scale-up system power output simply by increasing total surface area

Neutron flux of ~1 x 10^{12} cm^2/sec creates heat output seen in some lab devices

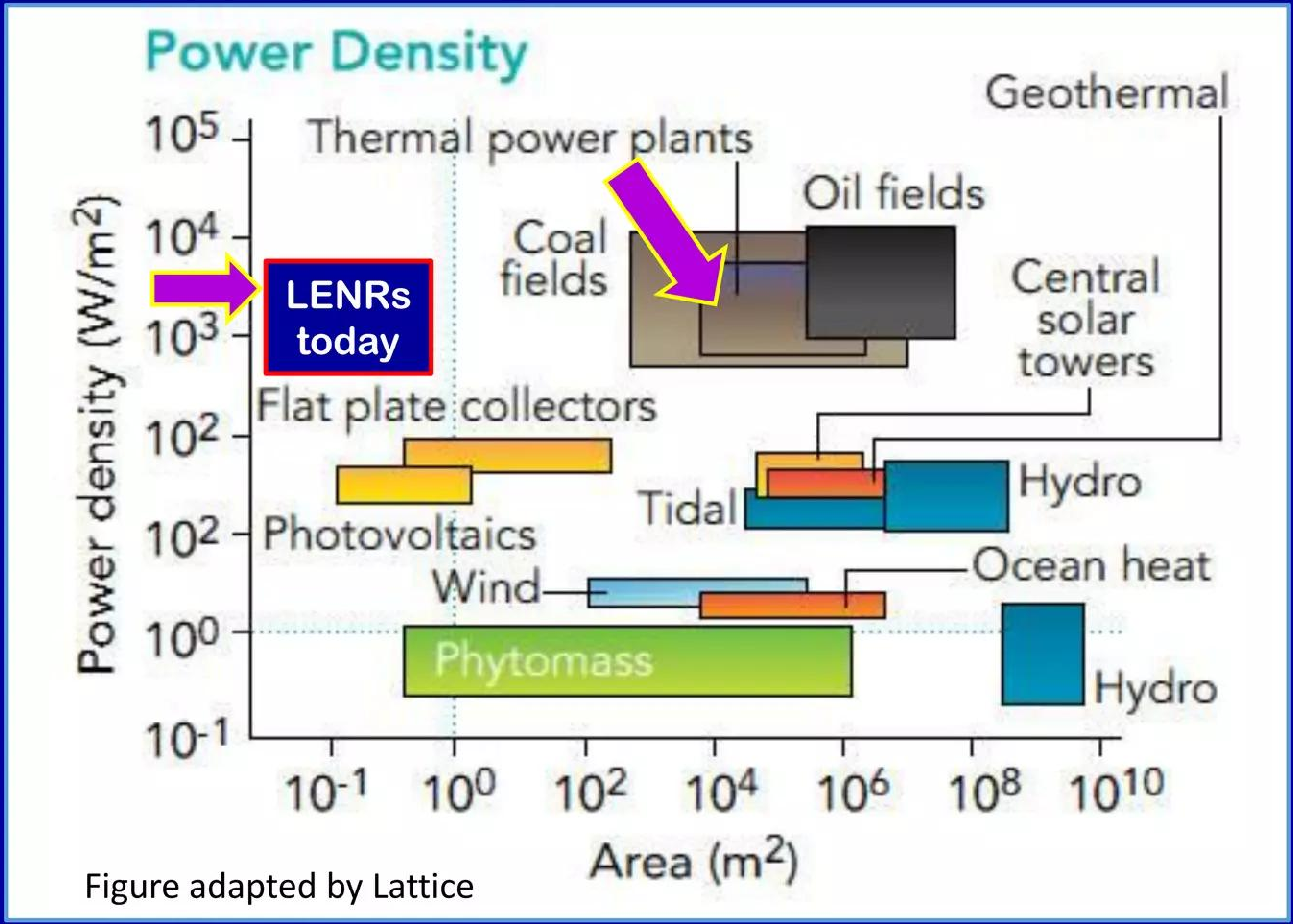
- ✓ As there are ~ 10^{14} of these 26.9 MeV energy releases taking place per second on the 1.0 cm^2 LENR device, the total energy release is 4.28 x 10^{-12} J/cm^2/sec x 10^{14} = 428 J/cm^2/sec. This represents 428 W/cm^2, a large device-level power density. At a lesser ULE neutron production rate of 1 x 10^{12} cm^2/sec, overall energy production rate would drop down to 4.28 J/cm^2/sec or 4.28 W/cm^2. At ULE neutron production rate of 1 x 10^{11} cm^2/sec, rate of heat production would drop down to 0.428 J/cm^2/sec or 0.428 W/cm^2 (4.28 x 10^3 W/m^2): value ~same as excess heat outputs observed in a somewhat limited subset of electrolytic LENR experiments researchers have deemed successful at making excess heat

- ✓ In this particular example, a heat generating rate of 428 W/cm^2 means 0.428 kWh/cm^2 produced in an hour for a Lithium-6-fueled 1 cm^2 LENR device, without releasing any CO_2. In comparison to minuscule nanogram (10^{-9} g) quantities of LENR reactants consumed, the complete combustion of 1 US gallon of gasoline (weighing 2.7 kg) with O_2 generates ~33.56 kWh of heat energy and releases ~8.8 kg of CO_2 into the atmosphere. Scaling-up surface area of the idealized LENR device 1,000 fold could generate 428 kWh, while a 1 m^2 device would create a 4.28 Megawatt eco-green nuclear power source

Power densities of primitive experimental LENR devices

Device power densities of 4.28×10^3 W/m^2 same as thermal power plants

LENR system areas small: no shielding and fuel energy density > 5,000x gasoline



Source: "Do We Have the Energy for the Next Transition?" R. A. Kerr in *Science* 329, pp. 781 (2010)

Resonant E-M cavities transfer energy into LENR sites

E-M, chemical & nuclear processes interoperate on substrate surfaces

Central role of surface plasmon electrons makes E-M resonances very important

- ✓ On LENR-active substrate surfaces, there are a multitude of different complex nanometer-to micron-scale electromagnetic, chemical, as well as nuclear processes operating simultaneously. LENRs involve complex interactions between surface plasmon electrons, electromagnetic (E-M) fields, and many different types of nanostructures with varied geometries, surface locations relative to each other, different-strength local E-M fields, and varied chemical or isotopic compositions; both chemical and nuclear energy realms coexist and interoperate at small length-scales on surfaces
- ✓ To varying degrees, a great many of these complex, time-varying surface interactions are electromagnetically coupled on many different physical length-scales: thus, mutual E-M resonances can be very important in such systems. In addition to optical frequencies, SP and π electrons found in condensed matter LENR systems often also have some absorption and emission bands in the infrared (IR) and/or UV regions of the E-M spectrum
- ✓ Metallic reactor vessels that utilize gas-loading of Hydrogen isotopes into nascent LENR-active sites emplaced on substrates located inside voids of gas-filled vessels can readily function as resonant electromagnetic cavities

Mitsubishi's gas-loading method has resonant E-M cavities

Measure LENR transmutation products with various techniques - not heat

Primarily employs pressure gradient + some E-M cavity heating to trigger LENRs

Experimental apparatus used by Toyota to confirm Mitsubishi's transmutation of Cs → Pr

Figs. 1 and 3 are reproduced from 2013 *Japanese Journal of Applied Physics* paper by T. Hioki *et al.*

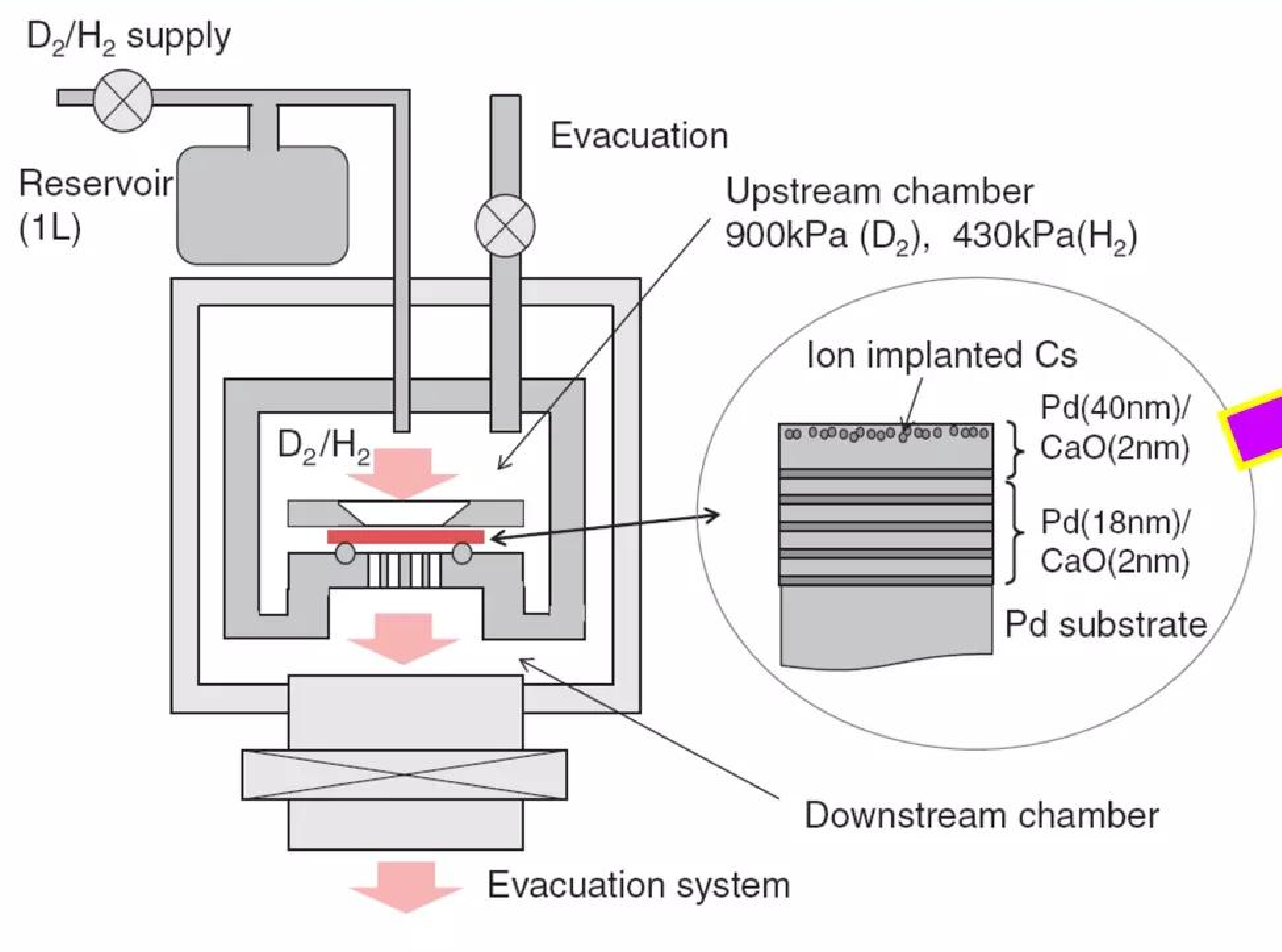


Fig. 1. (Color) Schematics of deuterium (/hydrogen) permeation system and Cs-ion-implanted Pd/CaO multilayer complex.

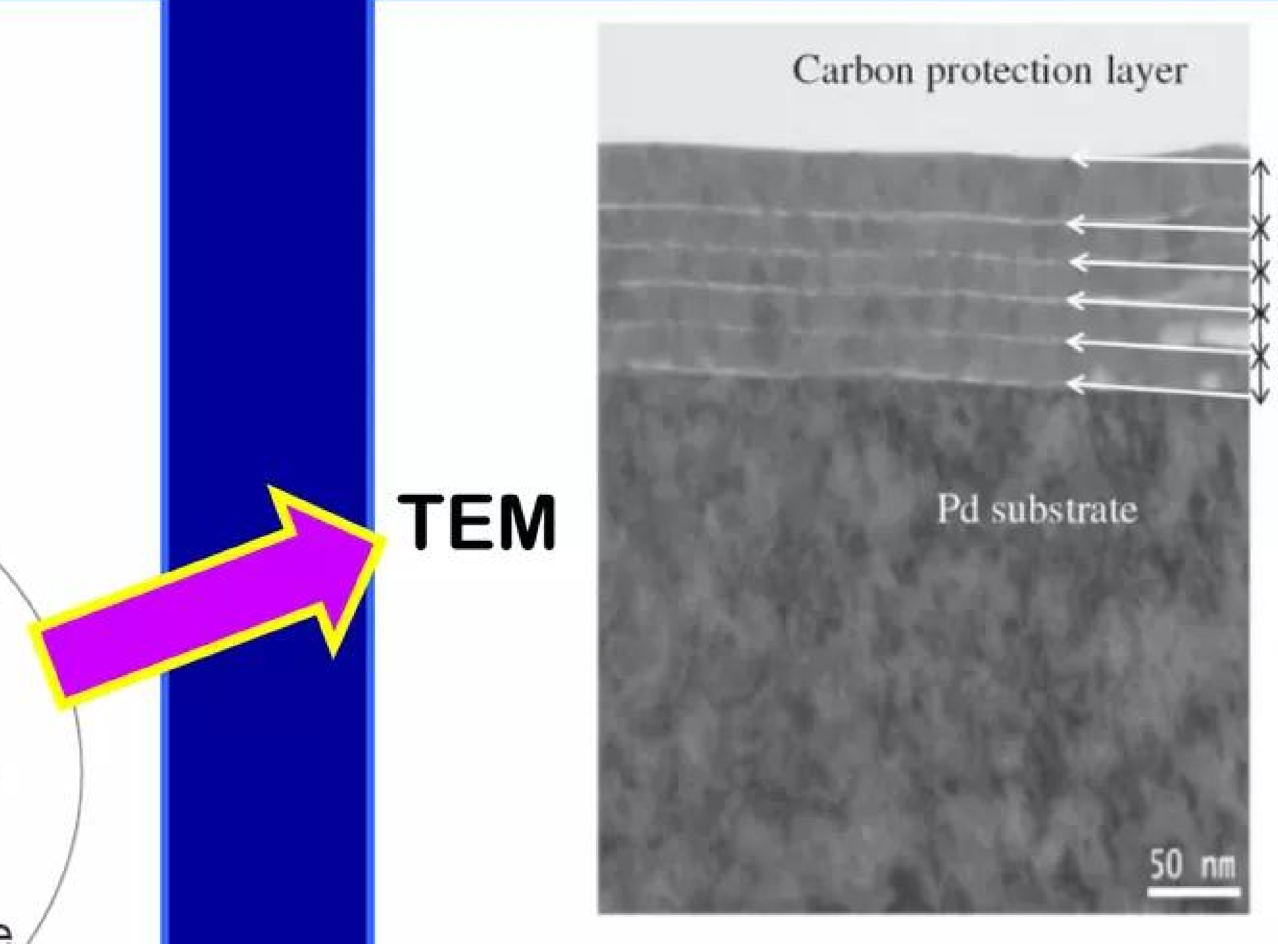


Fig. 3. Cross-sectional TEM view of the Pd/CaO multilayer complex.

"Inductively coupled plasma mass spectrometry study on the increase in the amount of Pr atoms for Cs-ion-implanted Pd/CaO multilayer complex with Deuterium permeation"

T. Hioki *et al. Japanese Journal of Applied Physics* 52 pp. 107301-1 to 107301-8 (2013)

http://iopscience.iop.org/1347-4065/52/10R/107301/

https://mospace.umsystem.edu/xmlui/bitstream/handle/10355/36792/RecentAdvancesDeuteriumPermeationPresentation.pdf?sequence=1

Resonant E-M cavities transfer energy into LENR sites

Metallic reaction vessels can be resonant electromagnetic cavities

In 1990s Italians triggered LENRs with gas-loading in metallic reaction vessels

- ✓ Walls of gas-phase metallic or glass LENR reaction vessels can emit various wavelengths of electromagnetic (E-M) photon energy into the interior space; in addition, glass tubes with inside surfaces that are coated with complex excitable phosphors can also effectively function as resonant E-M cavities
- ✓ Nanostructures, nanoparticles, and/or molecules associated with LENR-active sites and fuels found anywhere inside vessel cavities can actively absorb IR, UV, or other photons radiating from vessel walls if their absorption bands happen (or are engineered) to fall in same resonant spectral range as the E-M cavity wall radiation emissions. Absorption of incident E-M input energy from cavity walls can be used to help drive neutron production in LENR-active sites
- ✓ Complex two-way E-M interactions can occur between interior LENR-active sites and cavity walls; imagine reaction vessel's walls containing arrays of E-M nanoantennas that have two-way send/receive channels with LENR-active sites
- ✓ Back in 1990s, series of Italian LENR experiments utilized heated stainless steel reaction vessels that functioned as resonant E-M cavities; see Slides #23 - 25 and 35 - 49 in Lattice technical document in which this work is discussed:

http://www.slideshare.net/lewisglarsen/lattice-energy-llcnickelseed-lenr-networksapril-20-2011

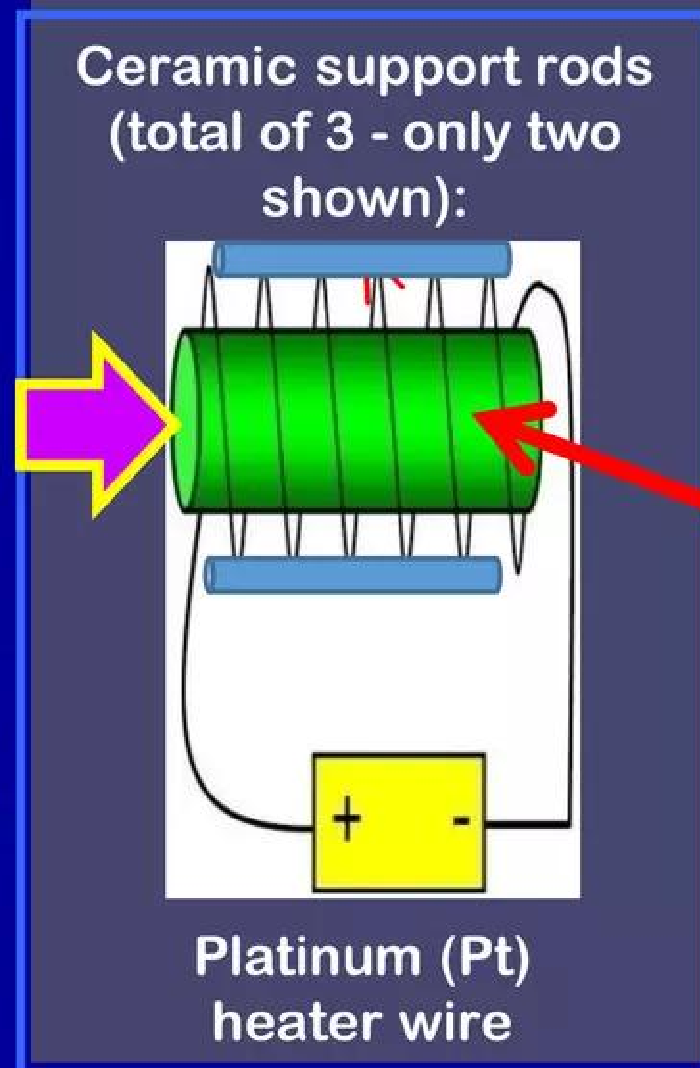
Italian gas-loading experiments used resonant E-M cavities

Several runs in 1990s produced 100s of megajoules of heat over months

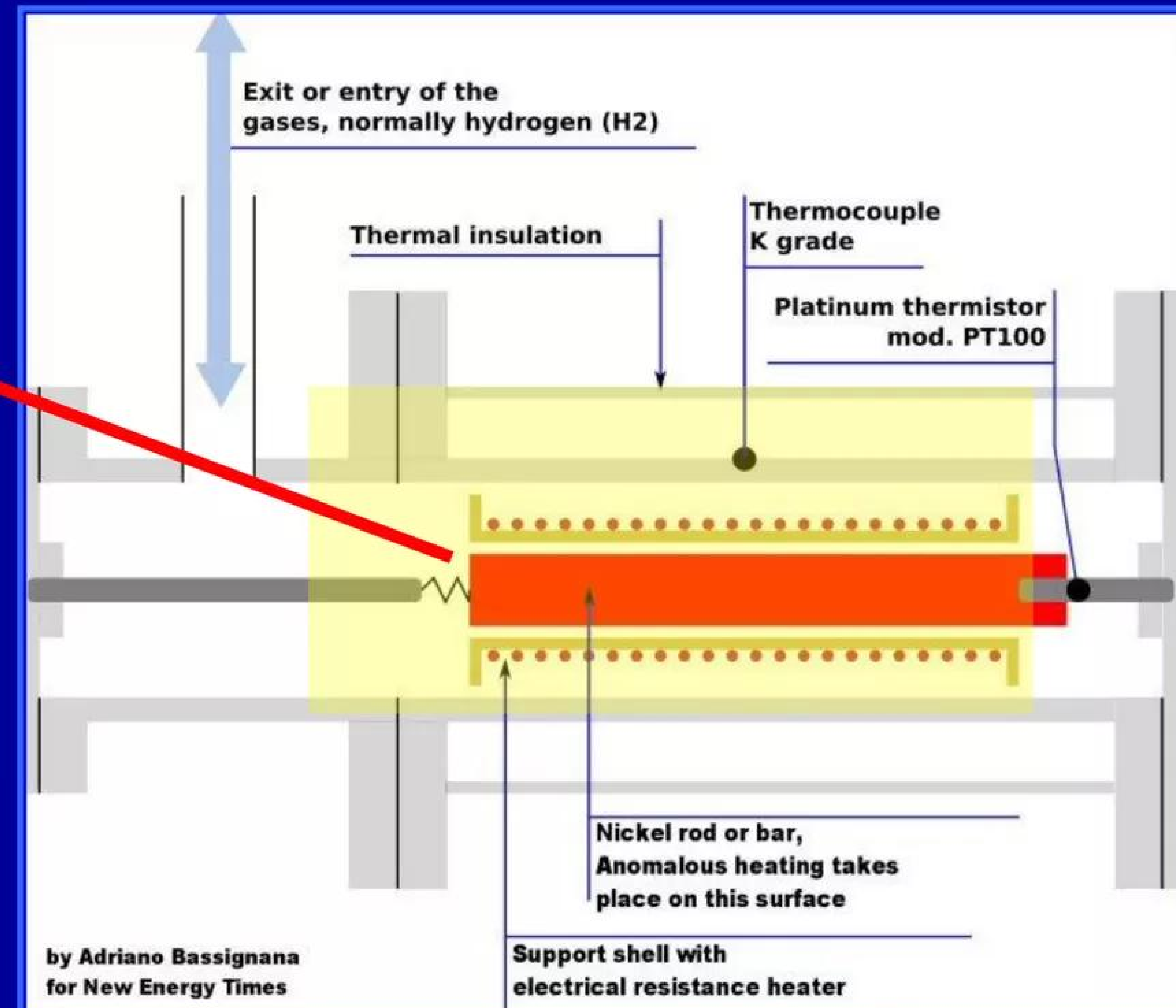
Piantelli-Focardi Ni-H reactor (*ca.* 1992)

Schematic of electrical resistance heater used

Nickel (Ni) rod or planar sample



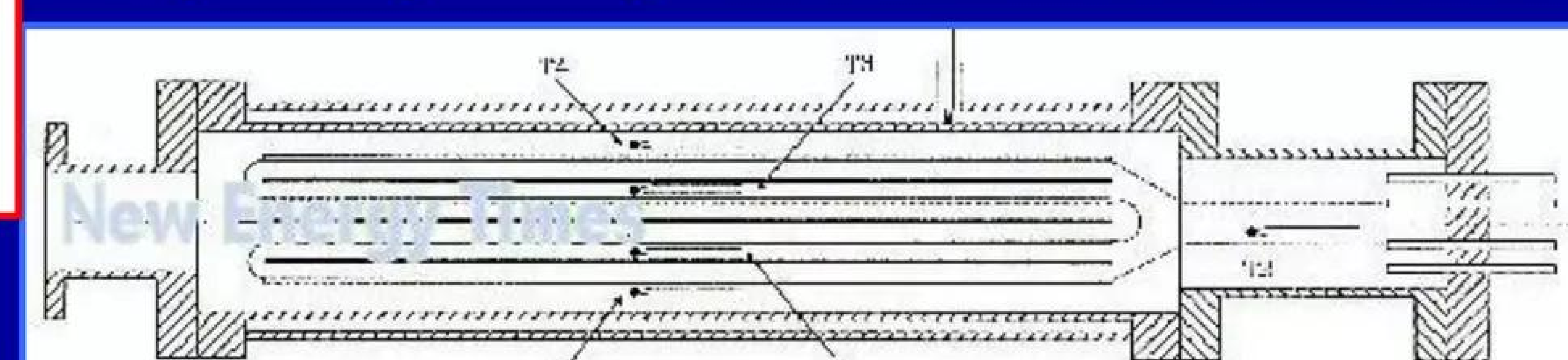
Conceptual diagram of Piantelli-Focardi Ni-H reactor



Another variant of Piantelli-Focardi Ni-H reactor (*ca.* 1992)

Note: there will be inductive E-M coupling between current flowing in Pt heater wire and E-M fields in ferromagnetic Ni fuel rod

Engineering drawing of Piantelli-Focardi Ni-H reactor



In 1990s Italians triggered LENRS in resonant E-M cavities

W-L's conversion of gammas to IR explains positive thermal feedback

Positive feedback loop in resonant E-M cavities enables large long-lived heat

- ✓ Unlike extremely penetrating MeV-energy gammas, reaction vessels' metallic stainless steel cavity walls are mostly opaque to incident infrared (IR) radiation; moreover, with thermal conductivity of only 12 - 45 W/(m·K) stainless steel LENR reactor walls will retain IR heat inside much better than Copper at 401 W/(m·K)
- ✓ When direct gamma conversion to IR occurs, nuclear binding energy released as infrared (IR) photons remains inside the cavity and is thus available to heat it up
- ✓ Heat retention within a resonant E-M cavity allows IR photon radiation (energy) to be reabsorbed by surface plasmons (found on LENR-active substrate surfaces located inside the cavity) that can further concentrate such incident energy and transport it to nascent active sites comprised of collectively oscillating protons or deuterons which can in turn can produce more ULE neutrons via $e + p$ reaction. 1990s Italian Nickel fuel devices created much heat for very long time because their energetic gain Q was ~ 8.83 (see Lattice document listed on previous slide)
- ✓ Gamma conversion + high fuel gain creates exploitable positive thermal feedback loop between local releases of nuclear binding energy, conversion of γ radiation to benign IR, local energy retention, reabsorption of cavity IR by SP electrons on nanostructures, followed by additional ULE neutron production in potentially self-sustaining virtuous circle until reactor effectively exhausts all of its e , p reactants

Progress in commercializing LENRs can be accelerated

Widom-Larsen theory of LENRs can guide device engineering efforts

- ✓ Since 1989, most researchers working in LENR R&D have pursued just random unguided Edisonian exploration of field's complex physics and vast materials parameter spaces; this impeded progress toward commercial heat sources
- ✓ During that time, majority of LENR researchers have pursued unrealistic goal of creating large macroscopic LENR devices capable of producing substantial fluxes of calorimetrically measured excess heat; inexplicably, most made no effort to measure emissions of energetic particles or transmutation products
- ✓ Even when substantial amounts of macroscopic excess heat were sometimes produced in 1 cm^2 LENR devices, designating heat as sole metric of success provided no insight into underlying mechanisms of heat production or what one might do to increase the quantity and duration of heat output in much-improved devices. By contrast, using mass spectroscopy to detect and identify nuclear reaction products created during experiments provides crucial technical data
- ✓ Absent having a Widom-Larsen theory of LENRs, a detailed understanding of nanoscale device physics, and knowing how to apply key nanotechnology and plasmonics, achieving success with blind Edisonian experimentation in LENRs will be a random hit-or-miss proposition; is akin to trying to fabricate computer chips with sub-micron feature sizes on silicon dies using machinists' T-squares, rulers, and scribes rather than the latest lithography and process technologies

Widom-Larsen theory enables LENR device engineering

Microscopic reproducibility of active sites is key to commercialization

- ✓ In successfully fabricated primitive laboratory devices typical of today, LENRs can presently reach temperatures of 4,000 - 6,000° K in relatively small numbers of microscopic LENR-active sites located on device surfaces. Evidence for the existence of such extremely hot localized sites is provided in post-experiment SEM images of working surfaces wherein distinctive crater-like structures are visible; these features are produced by rapid heat releases in LENR-active sites that briefly create local high temperature flash-boiling of metals like Palladium
- ✓ At present stage of LENR technology (TRL-2), trying to fabricate cm-scale and larger devices that can reliably and controllably produce macroscopically large fluxes of excess heat - “boiling a cup of tea” - is putting the cart before the horse
- ✓ Unlike its competitors, Lattice plans to use its unique proprietary knowledge of LENR devices and key operating parameters (e.g., achieving and maintaining very high local surface electric fields) to first get key LENR effects --- such as excess heat, transmutations --- working well microscopically. That is, to be able to reproducibly create purpose-designed nanoparticulate structures with their dimensions ranging from nanometers to microns that are fabricated using certain existing, off-the-shelf nanotechnology techniques/methods and then emplaced, along with suitable target fuel nuclei (e.g., Lithium) in close proximity, at what will become LENR-active sites situated on the surfaces of appropriate substrates

Lattice's engineering plan has three key phases:

(1) Reproducible fabrication of well-performing LENR-active sites

(2) Scale-up heat output by increasing # of active sites per unit area/volume

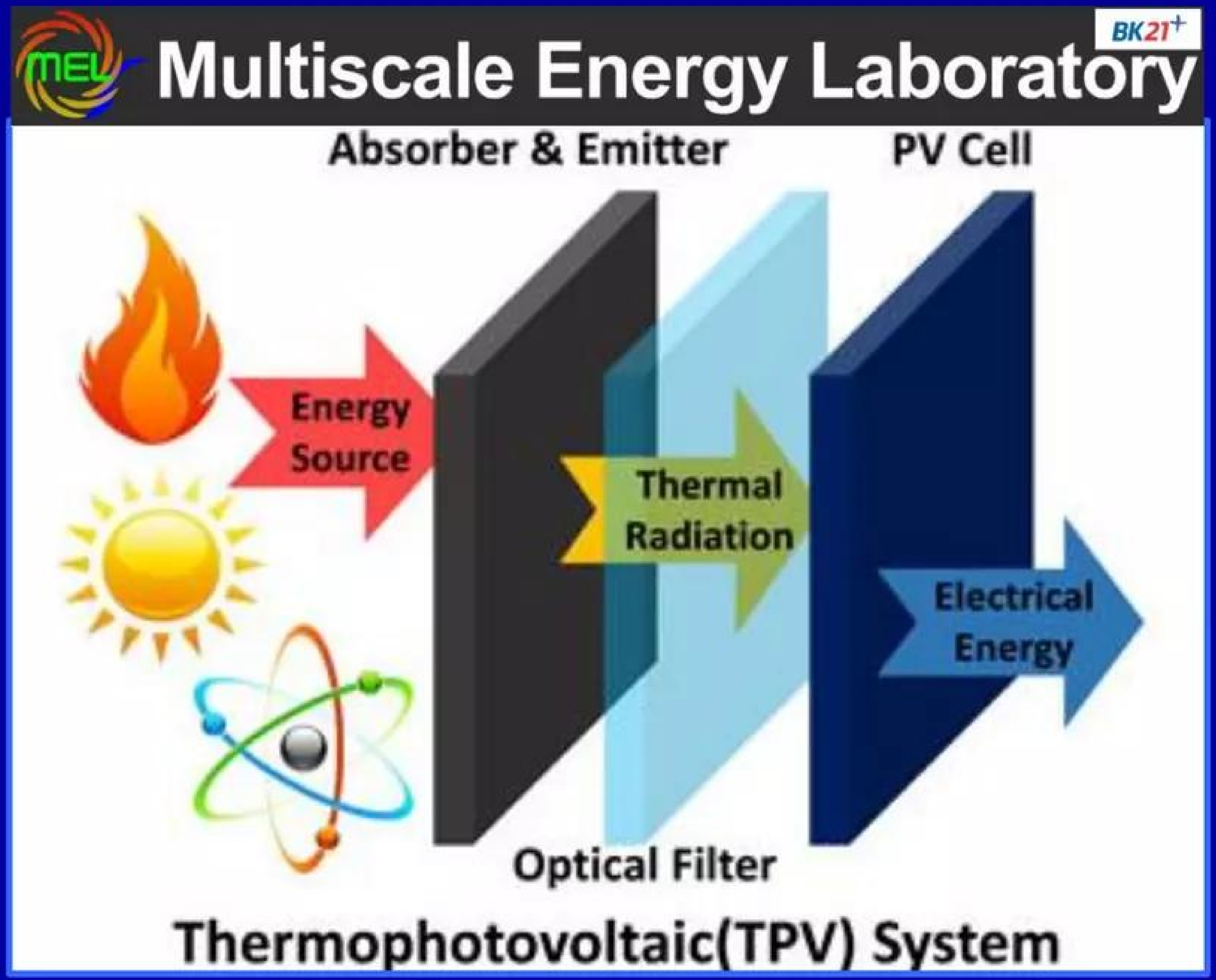
(3) Select and integrate energy conversion subsystems suitable for specific applications

- ✓ Once microscopic reproducibility of active sites is achieved, output of LENR heat sources could be readily scaled-up, either by (1) fabricating larger area-densities of affixed nanostructures that facilitate formation of LENR-active hot spot sites on device surfaces, or by (2) injecting larger quantities of specially designed target fuel host nanoparticles into volumetrically larger reaction chambers containing turbulent dusty plasmas, with or without spatially organized magnetic fields present
- ✓ Variety of off-the-shelf energy conversion subsystems could potentially be integrated with commercial versions of LENR-based heat sources. These include: thermophotovoltaic; thermoelectric; steam engines; Rankine cycle steam turbines; Brayton cycle gas turbines, simple boilers, etc. Other more speculative possibilities involve new types of direct energy conversion technologies that are still in very early stages of development
- ✓ Lattice's nanocentric approach to R&D is unique by being interdisciplinary and directly guided by various proprietary insights enabled by Widom-Larsen theory of LENRs and related relevant knowledge borrowed from advanced materials science, plasmonics, nanotechnology, and chemistry

Thermophotovoltaic conversion of IR heat into electricity

Integration of TPV with LENR IR heat sources good for smaller systems

- Development of revolutionary ultra long lived, battery-like, high performance portable power sources could be accomplished via chip-scale fabrication and integration of future efficient advanced thermophotovoltaic devices with gas-loaded resonant cavity LENR IR heat sources
- To envision what small portable LENR-based systems might initially resemble, please see referenced 2013 *PNAS* paper by Chan *et al.*; especially note Fig. 5 and then conceptually replace the catalytic propane combustor with much more powerful LENR infrared source
- Possible early portable LENR-based power products could be very compact, ultra-high performance Qi wireless battery chargers capable of simultaneously charging multiple smartphones and other mobile devices. Such Über high performance LENR chargers for conventional chemical batteries could be used safely inside buildings and vehicles (no noxious gaseous emissions), or in remote locations as uninterruptible DC or AC power sources



Source: Y. Nam, MEL, Kyung Hee University, Korea

"Toward high-energy-density, high-efficiency, and moderate-temperature chip-scale thermophotovoltaics" W. Chan *et al.* *PNAS* 110 pp. 5309 - 5314 (2013) http://www.pnas.org/content/110/14/5309

Lattice's market penetration strategy like semiconductors

Maximize total unit volumes and ride cost curve to attack target markets

- ✓ Over time, plan to ride down manufacturing experience cost curve; similar to build-cost reduction and market penetration strategies used by electronics manufacturers; e.g., microprocessors, memory chips, PCs, and smartphones
- ✓ As product manufacturing experience accumulates and internal build costs are progressively reduced, leverage enormous energy density/longevity advantages of LENRs (>million times larger than chemical); price LENR-based systems to drastically undercut price/performance provided by competing thermal sources and chemically-based power generation systems --- this strategy can be applied to portable, distributed stationary, mobile, and central station power markets
- ✓ Small-scale LENR systems might seem to be light years away from being able to compete with huge 500 - 1,500 MW coal-fired and Uranium-fission power plant behemoths; however, please recall history of personal computers versus mainframes. When PCs were first introduced 35 years ago, mainframe computer manufacturers regarded them as just toys, information processing jokes of no consequence. Less than 10 years later, mainframe companies weren't laughing any more. Today, except for just a handful of survivors like IBM, mainframe and minicomputer dinosaurs have disappeared, replaced by microprocessor arrays

Conclusions

Scale-up of LENR power generation systems is feasible in near-future

LENR reactors smaller and less expensive than equivalent fission counterparts

- ✓ Rates of LENRs could be vastly increased in ultra high performance commercial thermal power systems by utilizing unique technological insights provided by key Lattice-proprietary aspects of Widom-Larsen theory. Operating performance of well-engineered commercial versions of LENR systems could be dramatically enhanced to vastly increase neutron fluxes and duration of consequent heat production way above what would be attainable by LENR processes occurring in Nature or in any LENR laboratory experiments that have been conducted to date
- ✓ Average power densities in the cores of todays pressurized and boiling water (H_2O) Uranium fission reactors are on the order of 50 - 70 MW_{th}/m^3
- ✓ In theory, a planar LENR device could be scaled-up to produce thermal output of 4.28 MW/m^2 from a slab of appropriate substrate having a total thickness of less than 1 cm (LENR-active sites only go < 100 microns into substrate). With clever stacking and separation of such heating plates along with ultra high performance thermal management to transport heat away, one could potentially construct an LENR-based power generation reactor system producing ~64 MW_{th} with 15-layer stack of such hotplates. Since radiation shielding and containment subsystems are unnecessary, physical dimensions and mass of LENR reactor vessel + fuel vastly smaller

Conclusions

Why build huge D-T fusion reactors if LENRs can be commercialized?

Greenness of LENRs could enable revolutionary portable nuclear power sources

- ✓ While LENRs do use safe ultralow energy neutrons to trigger release of nuclear binding energy (heat) from an enormous array of stable element target fuels, they are radically different from U and Th fission reactors that require criticality to operate properly. Unlike fission, LENRs don't involve multiplicative chain reactions with fuels that in turn release multiple neutrons which then explosively accelerate neutron production --- nuclear runaways are not a risk with LENRs
- ✓ D-T fusion reactors like ITER and other similar Tokamaks mainly create heat by harvesting the kinetic energy of deadly 14.1 MeV neutrons. Consequently, they require massive shielding and containment systems for safe operation and unsurprisingly have enormous costs and unavoidably huge physical size. Given that the Lithium LENR fuel cycle releases nearly 27 MeV versus a total Q-value of 17.6 MeV for the D-T fusion reaction, it is hard to imagine a sound economic argument for spending 100s of billions on commercial fusion reactors if LENR technology is successfully developed and scaled-up as we have outlined herein
- ✓ Lack of hard radiation and radioactive wastes permit *downward* scalability that could enable future development of revolutionary, compact battery-like portable LENR power sources that can compete directly on $ price/kwh with chemical batteries in many applications including power tools, tablets, and smartphones

Further reading

Index provides comprehensive guide to available online information

"Ultra low momentum neutron catalyzed nuclear reactions on metallic hydride surfaces"
A. Widom and L. Larsen
European Physical Journal C - Particles and Fields 46 pp. 107 - 112 (2006)
http://www.slideshare.net/lewisglarsen/widom-and-larsen-ulm-neutron-catalyzed-lenrs-on-metallic-hydride-surfacesepjc-march-2006

"A primer for electro-weak induced low energy nuclear reactions"
Y. Srivastava, A. Widom, and L. Larsen
Pramana - Journal of Physics 75 pp. 617 - 637 (2010) - author's copy below
http://www.slideshare.net/lewisglarsen/srivastava-widom-and-larsenprimer-for-electroweak-induced-low-energy-nuclear-reactionspramana-oct-2010

"Theoretical Standard Model rates of proton to neutron conversions near metallic hydride surfaces"
A. Widom and L. Larsen
Cornell physics preprint arXiv:nucl-th/0608059v2 12 pages (2007)
http://arxiv.org/pdf/nucl-th/0608059v2.pdf

"Index to key concepts and documents"
v. #21 updated and revised through Sept. 7, 2015
L. Larsen, Lattice Energy LLC, May 28, 2013 [133 slides]
http://www.slideshare.net/lewisglarsen/lattice-energy-llc-hyperlinked-index-to-documents-re-widomlarsen-theory-and-lenrs-september-7-2015

Strategic partnering and consulting

Deep expertise in LENRs and future ramifications of this technology

1-312-861-0115 lewisglarsen@gmail.com

L. Larsen c.v.: http://www.slideshare.net/lewisglarsen/lewis-g-larsen-cv-june-2013

- ✓ Lattice welcomes inquiries from large, established organizations that have an interest in seriously discussing the possibility of becoming a strategic capital and/or technology development partner in the near- or long-term time frames
- ✓ Lewis Larsen also selectively engages in fee-based third-party consulting. This work covers topics in the context of micron-scale, many-body collective quantum effects in condensed matter systems (including photosynthesis), safety issues arising from field failures causing Li-ion battery thermal runaways, nuclear waste remediation, chemical catalysis, and ultra-high-temperature superconductors, among others. Additional areas of expertise include long-term strategic implications of LENRs on high cap-ex long term investments in power generation and petroleum-related assets, as well as long-term price outlooks for and investments in precious metals and real price of energy. Will consult on such subjects as long as it does not involve my disclosing sensitive proprietary engineering details applicable to LENR power generation systems