Commercializing a Next-Generation Source of Safe Nuclear Energy

### Low Energy Nuclear Reactions (LENRs)

Weak interaction LENR transmutation reactions on Earth versus nucleosynthesis in stars

### Brief Semi-Technical Overview



"Energy, broadly defined, has become the most important geostrategic and geoeconomic challenge of our time."

Thomas Friedman
New York Times, April 28, 2006



#### Fusion and fission are not predominant in LENR systems

# Fundamental concepts of condensed matter weak interactions in Widom-Larsen theory of LENRs are illustrated below:

- E-M radiation on metallic hydride surface increases mass of surface plasmon electrons.
- 2. Heavy-mass surface plasmon polariton electrons ( $\stackrel{\sim}{e}$ ) react directly with surface protons ( $p^+$ ) or deuterons ( $d^+$ ) to produce ultra low momentum (ULM) neutrons ( $n_{ulm}$  or  $2n_{ulm}$ , respectively) and an electron neutrino ( $v_e$ )
- 3. Ultra low momentum neutrons  $(n_{ulm})$  are captured by nearby atomic nuclei (Z, A) representing some element with charge (Z) and atomic mass (A). ULM neutron absorption produces a heavier-mass isotope (Z, A+1) via transmutation. This new isotope (Z, A+1) may itself be stable or unstable
- 4. Unstable isotopes beta decay, producing:  $\sim$  transmuted new element with increased charge (Z+1),  $\sim$  same mass (A+1) as "parent" nucleus;  $\beta$  particle ( $e^-$ ); and antineutrino ( $\overline{V}_e$ )

No strong interaction fusion or heavy element fission taking place below

1. 
$$(\text{radiation}) + e^- \rightarrow \widetilde{e}^-$$

$$\widetilde{e}^- + p^+ \rightarrow n_{ulm} + \nu_e$$

$$\widetilde{e}^- + d^+ \rightarrow 2n_{ulm} + \nu_e$$

$$n_{ulm} + (Z,A) \rightarrow (Z,A+1)$$

Unstable or Stable

$$(Z,A+1) \rightarrow (Z+1,A+1) + e^- + \overline{\nu}_e$$
Unstable Isotope New element – stable or unstable

'Green' weak interaction β decays (above), alpha decays (not shown), and gamma-shielded neutron captures produce most of the energy

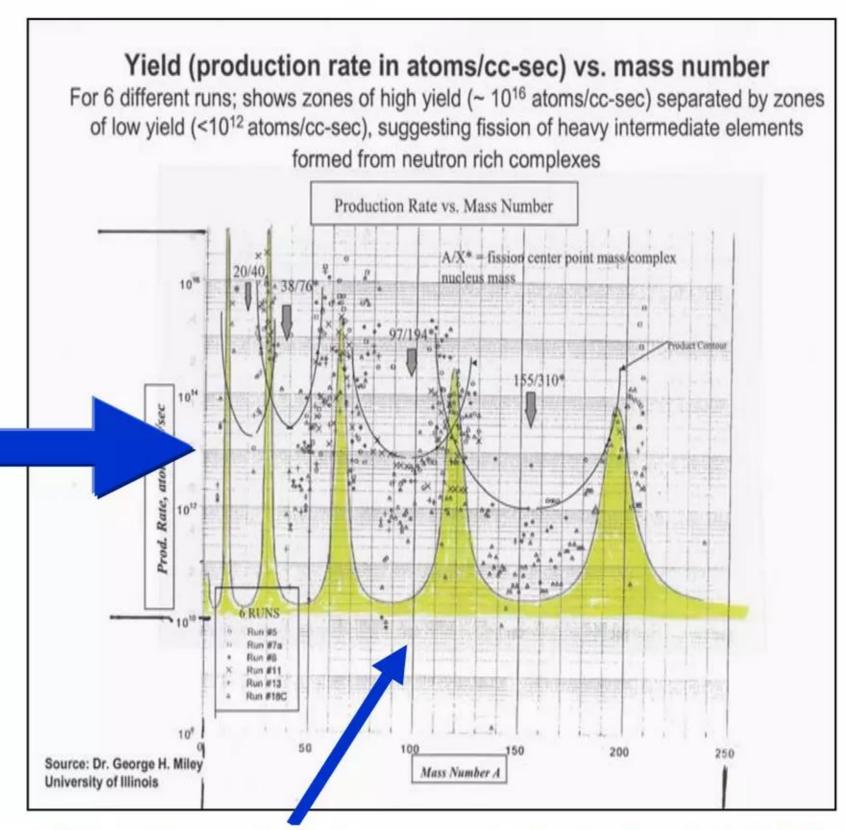
#### Neutron-capture transmutations on earth via LENRs

Miley et al. began with an ordinary Nickel cathode - two weeks later, ended-up with experimentally observed LENR transmutation product spectrum that looked like it had been created in a star

Start – Nickel (Ni) cathode placed in current-driven electrolytic chemical cell Stable Starting Isotopes of Nicke Portion of Hypothetical ULMN Catalyzed Nuclear Reaction Network with Nickel Starting Material "Seed" Material are Darker Blue Stable Reaction Products are Darker Blue 59-Ni (hl = 76,000 -Co (na = 100.0% years; 92.4 b; 3/2-) 47.2 b; 7/2-) Quasi-Stable Reaction Products are Light Blue +n\* ↓ 60-Co (hl = 5.2 Unstable Reaction Products are Red years; 2.0 b; 5+) +n\* **Beta Decay** 0-Ni (na = 26.2% +n\* indicates capture of an ultra low momentum 2.9 b; 0+) neutron (ULMN) **Beta Decay** +n\* ¥ Source of Data: Nuclides 2000 program and Handbook of Chemistry and Physics - 81st Edition (2000-2001) 63-Ni (hl = 100 15.0 b; 0+) The nickel light-water nuclear 0.74 b; 0+) reaction network is being lectron Capture; Beta+ arbitrarily cut-off right here. This is less than 1% of the 65-Zn (hl = 244 days; 66.0 b; 5/2-) Iltimate size and complexity of nuclear reaction network that +n' +n\* can occur in a cell with high ULM neutron fluxes that is run for weeks. For example, see Miley Ni/H transmutation Black arrows indicate product mass spectrum. absorption of ULMN neutrons +n\* +n\* Dark blue arrow indicates orbital electron capture 67-Zn (na = 4.10%; 0-Zn (na = 0.62 6.9 b; 5/2-) Red arrows indicate beta decay Pink arrows indicate electron Beta Decay Electron Capture capture, beta+ decay 68-Zn (na =18.75% 0.872 b; 0+) NOTE: 64-Co, 65-Co, and 66-Co are omitted: upon absorbing neutrons, they all Beta decay and end-up in 64-Ni, 65 Cu, and 66-Zn, respectively.

See: "Nuclear Abundances in Metallic Hydride Electrodes of Electrolytic Chemical Cells" arXiv:cond-mat/0602472 (Feb 2006) Widom and Larsen

Finish - Mass spectrum of LENR transmutation products in cathode



With no fitting, simple two-parameter 'optical' model of ULM neutron absorption based on W-L theory of LENRs predicts product isotopic abundance peaks shown in yellow above

#### Transmutations in nature: element nucleosynthesis in stars

- Except for Big Bang hydrogen/deuterium and helium, astrophysicists believe that most elements in the Universe lighter than Iron (Fe) were created by charged-particle fusion reactions inside stars
- Elements heavier than Fe thought to be created via neutron capture (absorption) nucleosynthesis reactions in stars. Two types of such neutron capture processes thought to occur in hot stellar plasmas:
  - s-process (slow) occurs in stars, e.g., red giants; neutron flux 10<sup>5</sup> 10<sup>11</sup> cm<sup>2</sup>/sec
  - r-process (rapid) occurs in supernova explosions; neutron flux > 10<sup>22</sup> cm<sup>2</sup>/sec
- Heavier elements (A > Fe) are formed in successive cycles of neutron creation, neutron absorption, neutrino production, beta decays of unstable neutron-rich isotopes, and stable element production



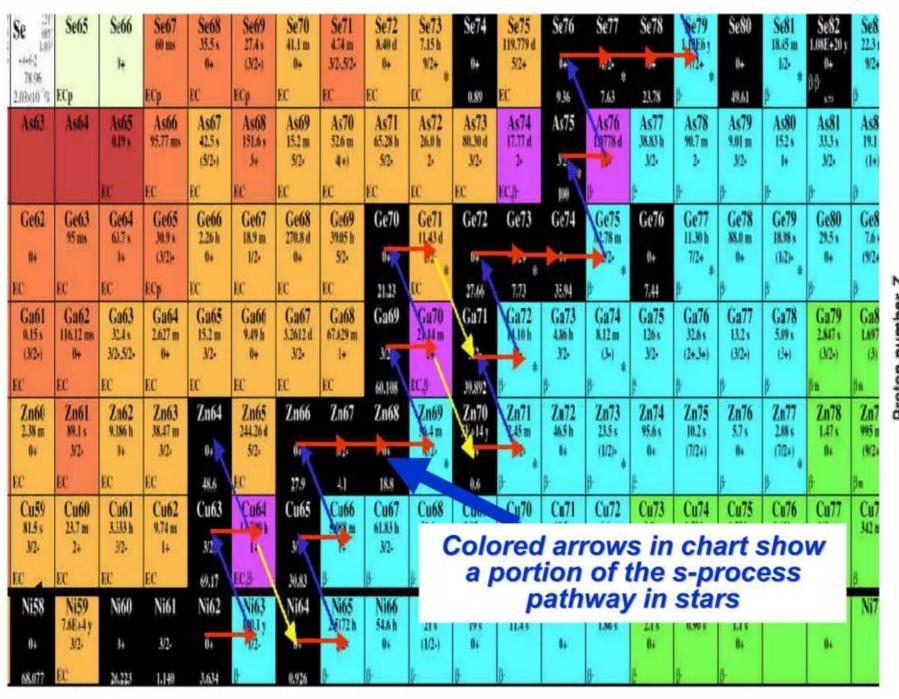
- According to Widom-Larsen, similar to condensed matter LENR systems where neutron flux can be 10° 10¹6 cm²/sec
- Difference is that neutrons in LENR systems can be ultra low momentum; vastly larger absorption cross-sections
- Also unlike stars, little gamma photodissociation; sometimes net rate of nucleosynthesis can be higher in LENR systems than in some stellar environments

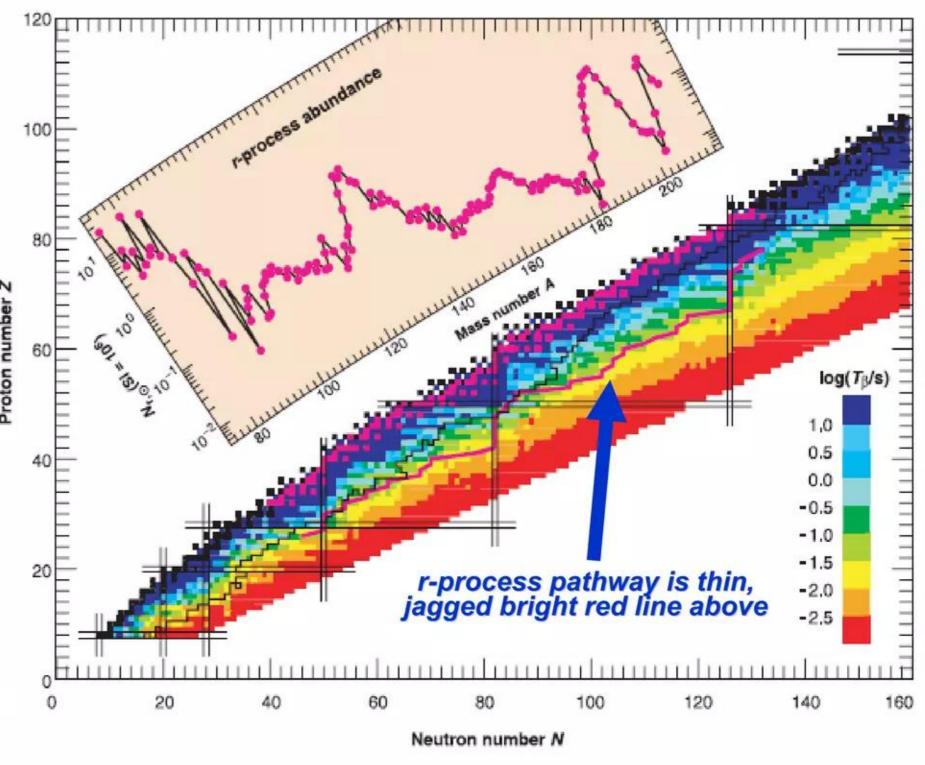


#### Astrophysics: neutron-capture nucleosynthesis in stars

#### Partial details of s-process in stars

#### Overall r-process in stars



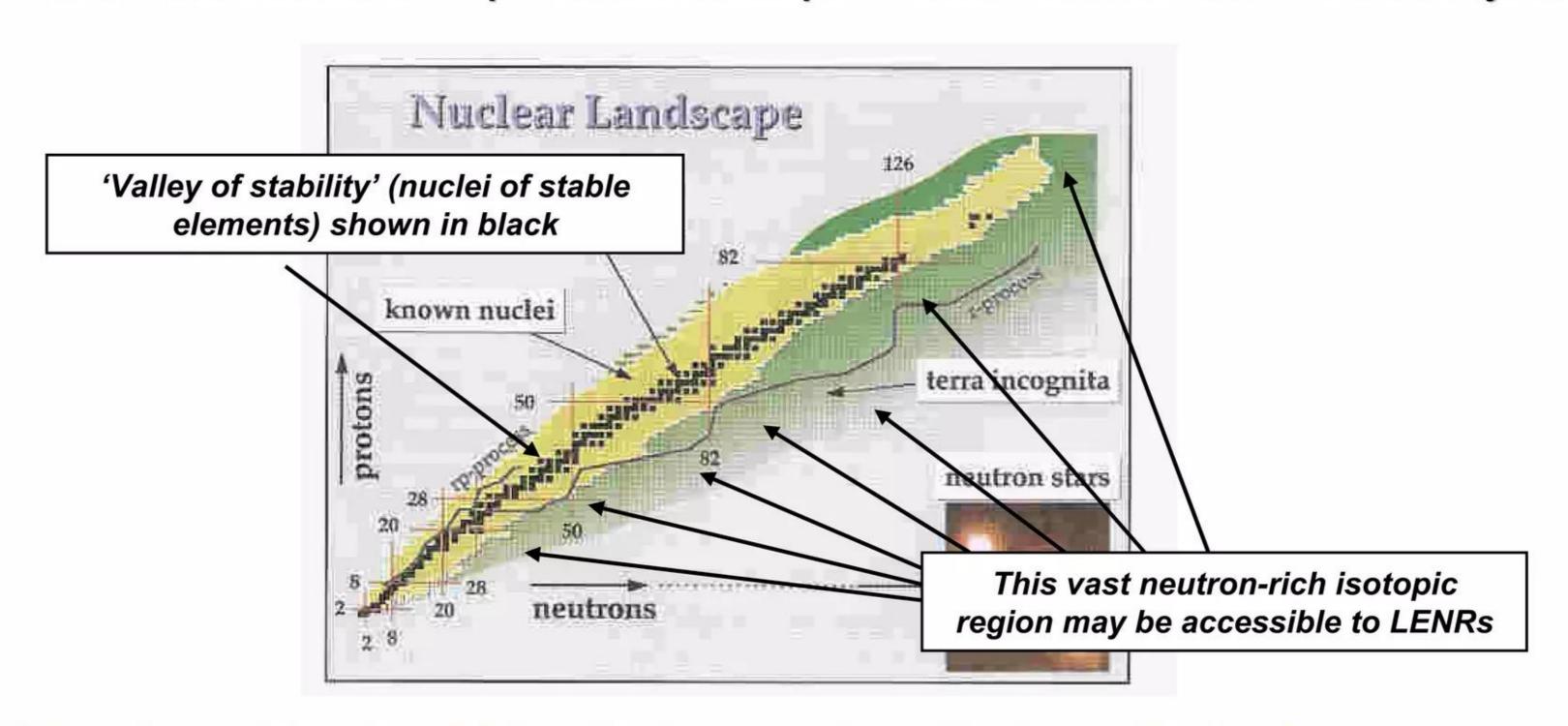


Note: stellar s- and r-process element abundance peaks generally differ somewhat from those produced in LENR experimental systems on earth

Above r-process figure is from Sneddon and Cowen, "Genesis of the Heaviest Elements in the Milky Way Galaxy" Science 299, 70 (2003)

#### Vast isotopic parameter space may be accessible to LENRs

'Map' of stable and unstable isotopes that could be produced in LENR condensed matter systems



LENR neutron-catalyzed weak interaction transmutations – involve combination of neutron production, neutron capture, and energetic beta decays of neutron-rich isotopes. LENRs can move back and forth between producing stable products in the (black) valley of stability to unstable β-decay isotopes located in neutron-rich (greenish) regions to the right of it. This is very similar to s- and r-process neutron-capture nucleosynthesis in stars, only at vastly lower temperatures/pressures