APPENDIX B

Can we discover and control new energy efficient ways to enhance nuclear reaction rates ?

Ideas for a TINA pilot in ARPA-E on new ways to control and enhance nuclear reaction rates at low reaction energies

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Can we discover and control new energy efficient ways to enhance nuclear reactions ?

Fusion

- Rates of fusion reactions are set by the kinetic energy of the reaction partners (a kinetic energy of 1 keV equals a temperature of about 10 million degrees)
- Achieving energy gain from fusion requires very hot plasmas that are difficult and expensive
- We have observed that fusion reactions at a few keV can be enhanced 100-fold when the reactions take place in metals compared to the gas phase [1, 2]
- Preliminary results show large changes of the branching ratio in D-D fusion in experiments that combine electrochemistry and low energy ion beams indicating new nuclear processes (if confirmed)
- If we can understand the underlying mechanisms of these enhancements then this could lead to fusion energy without the need for very hot plasmas (without fulfilling the Lawson criteria), and a path to low cost, carbon free electricity

- The risk is that the observed effects can not be controlled well enough to be energy efficient

[1] T. Schenkel, et al., arXiv:1905.03400 (J. Appl. Phys., in press)
[2] C. P. Berlinguette, et al., Nature 570, 45 (2019)

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Nuclear decay

- Nuclear reactions like alpha decay are determined by the internal structure of nuclei (as well as by the energy of reacting nuclei)
- Some reports show enhanced alpha decay of heavy elements in the presence of high electric fields from plasmons [3]
- If we can understand the underlying mechanisms then this could lead to much shorter half lives for the decay of radioactive nuclei with a path to nuclear energy harvesting and a much reduced burden due to radioactive waste

- The risk is that these early reports are faulty and that the electrical fields needed require big lasers that make the process too expensive

[3] A. V. Simakin, G. A. Shafeev, Quantum Electronics 41, 614 (2011), and several other by these authors

Can we discover and control new energy efficient ways to enhance nuclear reactions ?

- **Ideas for experiments:**

    - Drive the loading of deuterium into metals by electrochemistry, and use low energy deuterium ions to trigger fusion reactions in the highly loaded metals (e. g. palladium)
    - Detect neutrons, tritium, protons, helium and quantify fusion yields and branching ratios, $B = Y(p+T)/Y(n+^3He)$
    - A handful of data points to date indicate enhanced tritium production, and a strong change in the branching ratio of the D-D fusion reaction in the combined electro-chemistry and low energy ion experiments (preliminary, in progress, ...)

    - Can we correlate the metal hydride lattice structure with D-D fusion yield enhancements ? E. g. using in situ electron diffraction while fusion reactions are induced by electro-chemistry and low energy ions in a series of materials

    - Can we act on nuclear reaction rates and tunnel barriers with electrical fields from plasmons?
    - Can we drive plasmon resonances with lasers and nanoparticles, then look for changes of fusion [4] and nuclear decay rates (alpha decay, electron capture type decay, analog to Be-7 decay changes at~1% levels in oxides vs. metals, but then enhanced) [3]

    - Ion beams (at low kinetic energy) are very energy inefficient in driving fusion reactions (because of collisional losses) but they can be used to enter a regime where some fusion can be observed. This can help open a learning path in materials design to enhance fusion reaction rates at lower and lower energies, towards a fraction of 1 eV and with efficient drivers (laser-plasmons, very low energy ions or plasmas) [1, 2]

[4] D. K. Fork, et al., US-10264661-B2 (2019)

Can we discover and control new energy efficient ways to enhance nuclear reactions ?

- Both fusion and nuclear decay enhancement studies require advances in theory, simulations/modeling and experiments

- The common factoring of nuclear reaction cross sections as the product of a geometric factor, the so called S-factor (which is supposed to contain all the nuclear physics) and the electron screening factor works very well for high reaction energies (and temperatures >100 million degrees) but might break down at energies below a few keV (and temperatures below a few million degrees), opening an opportunity to consider the full atomic-nuclear wave-function in the analysis of nuclear reactions in solid state environments.

$$\sigma_f(E, U_e) = \frac{1}{\sqrt{E(E+U_e)}} e^{-\sqrt{E_g/(E+U_e)}} S(E)$$

Cross section = geometric factor

* electron screening (atomic physics)

* astrophysical S-factor (nuclear physics)

(The cross section is a measure of the likelihood for of a nuclear reaction to take place, e. g. the likelihood for a fusion process in the collision for two hydrogen atoms).

Can we discover and control new energy efficient ways to enhance nuclear reactions ?

- In a TINA program a series of well defined hypothesis could be tested over the course of ~2 years to determine the scientific validity and depth as well as the technology promise of these directions
- Rough cost estimate: 4 to 5 projects at $ 0.5 to 1 M/y for ~2 years, ~ $ 4 to 10 M total
- Chances are that a TINA program in this area will lead to basic science discoveries and high impact publications, and it is quite possible that the observed effects then simply don't scale to anywhere near energy efficiency during follow up projects.
- It is also possible that a TINA program will open the door for a new learning path to control nuclear reactions and fusion processes much more efficiently then is possible today with disruptive impact on energy technology.