The mechanism of dd fusion in crystals

E. Tsyganov

The University of Texas Southwestern Medical Center at Dallas

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CHARGED AND NEUTRAL PARTICLES CHANNELING PHENOMENA

Channeling 2008

Editors

Sultan B Dabagov & Luigi Palumbo

Channeling 2008

THERMAL EQUILIBRIUM OF LIGHT ATOMS AND IONS IN HEAVY CRYSTALS

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DD FUSION IN CRYSTALS

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(communicated by S.B. Dabagov)

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ЯДРА

DD-СИНТЕЗ В КРИСТАЛЛАХ

© 2010 г. Э. Н. Цыганов*

Юго-западный медицинский центр Техасского университета, Даллас, США

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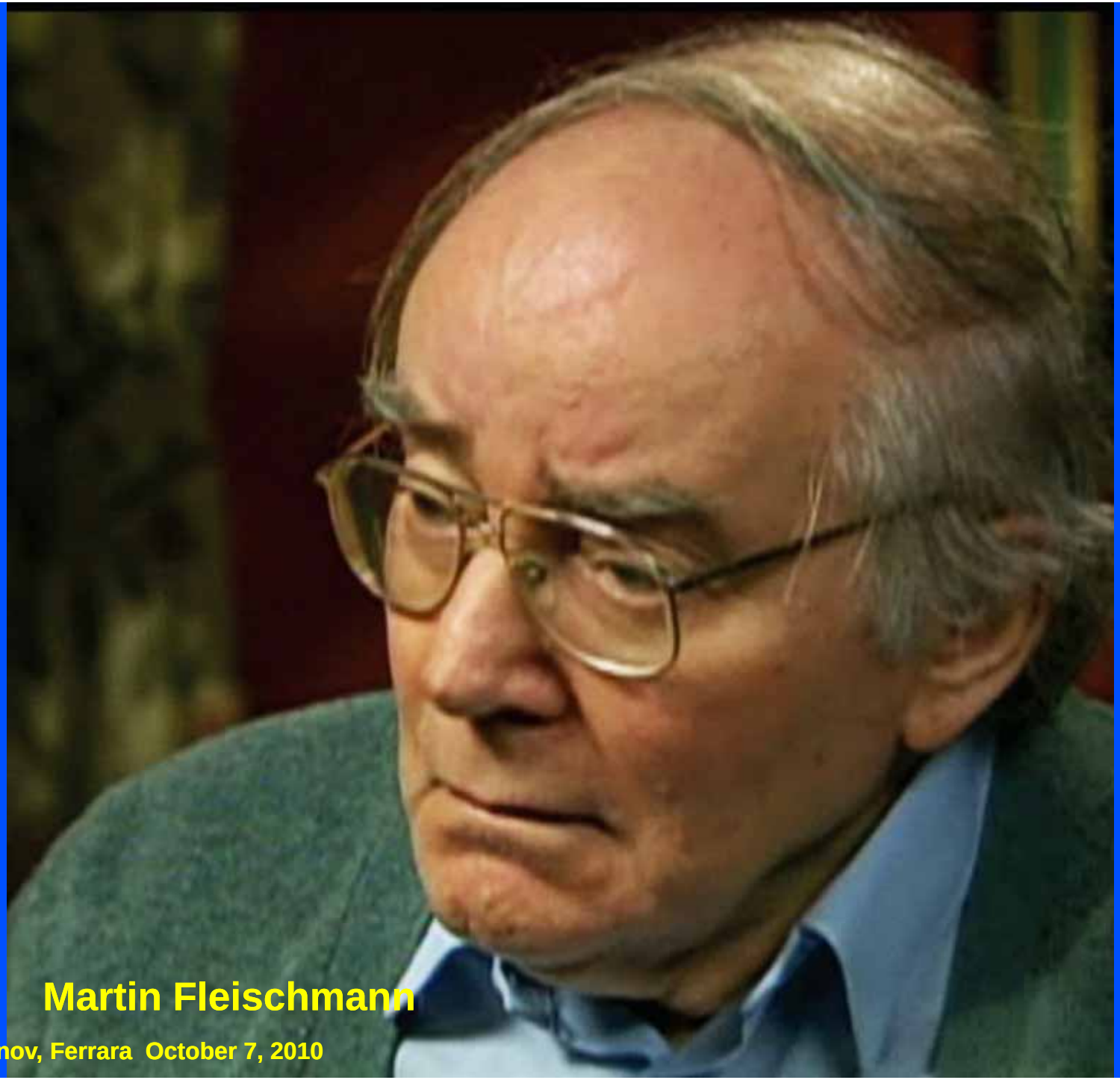
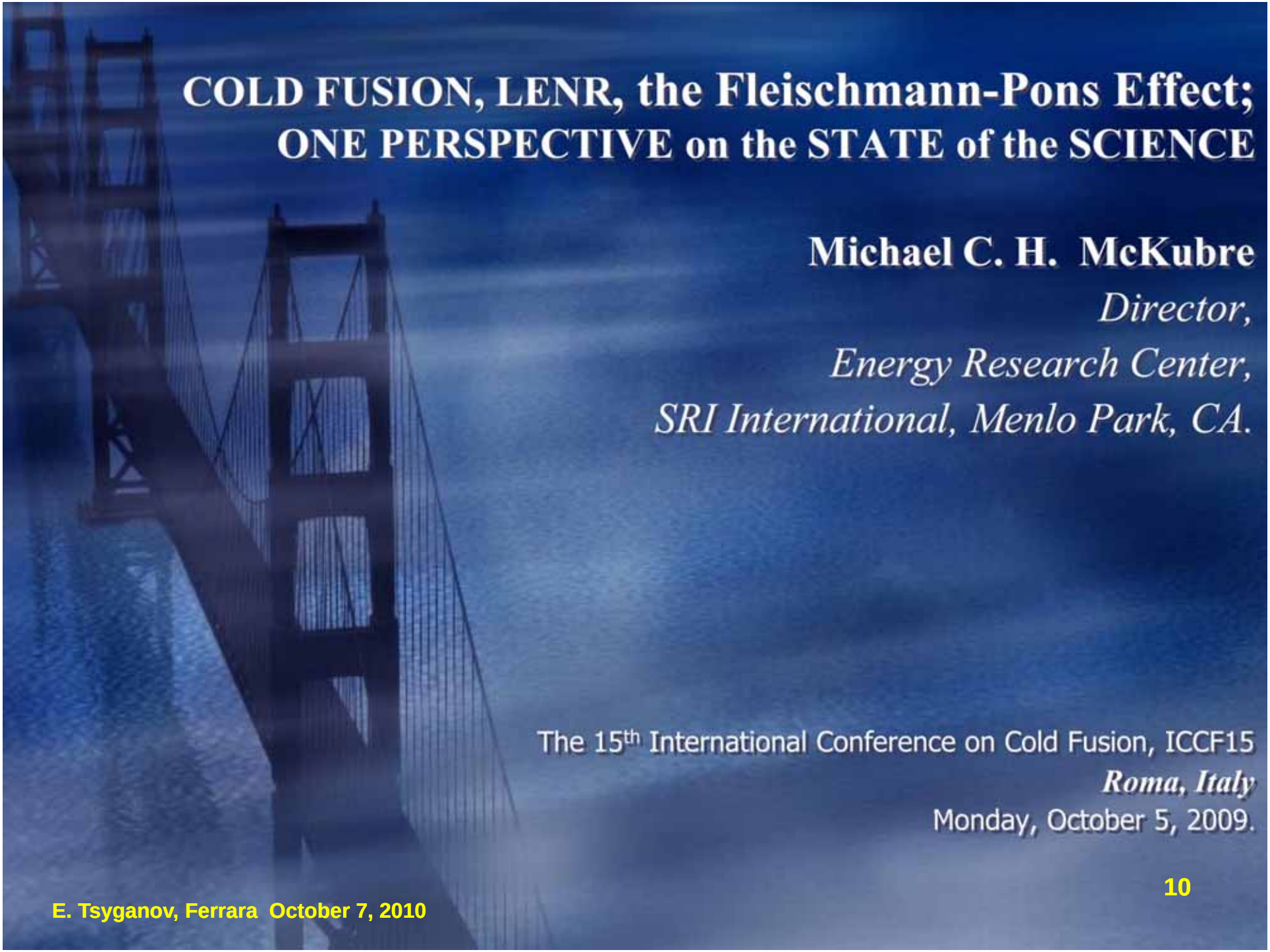
Обсуждается механизм DD → ^{4}He-синтеза и так называемая нерадиационная термализация этой реакции в кристаллах. Рассматривается динамика этого процесса. Предположение о том, что время распада составного ядра зависит от энергии его возбуждения, позволяет согласовать ускорительные данные с экспериментами в кристаллах. Рассматриваются процессы, повышающие интенсивность DD-синтеза в кристаллах по сравнению с аморфной средой, и приводятся оценки выхода этой реакции.

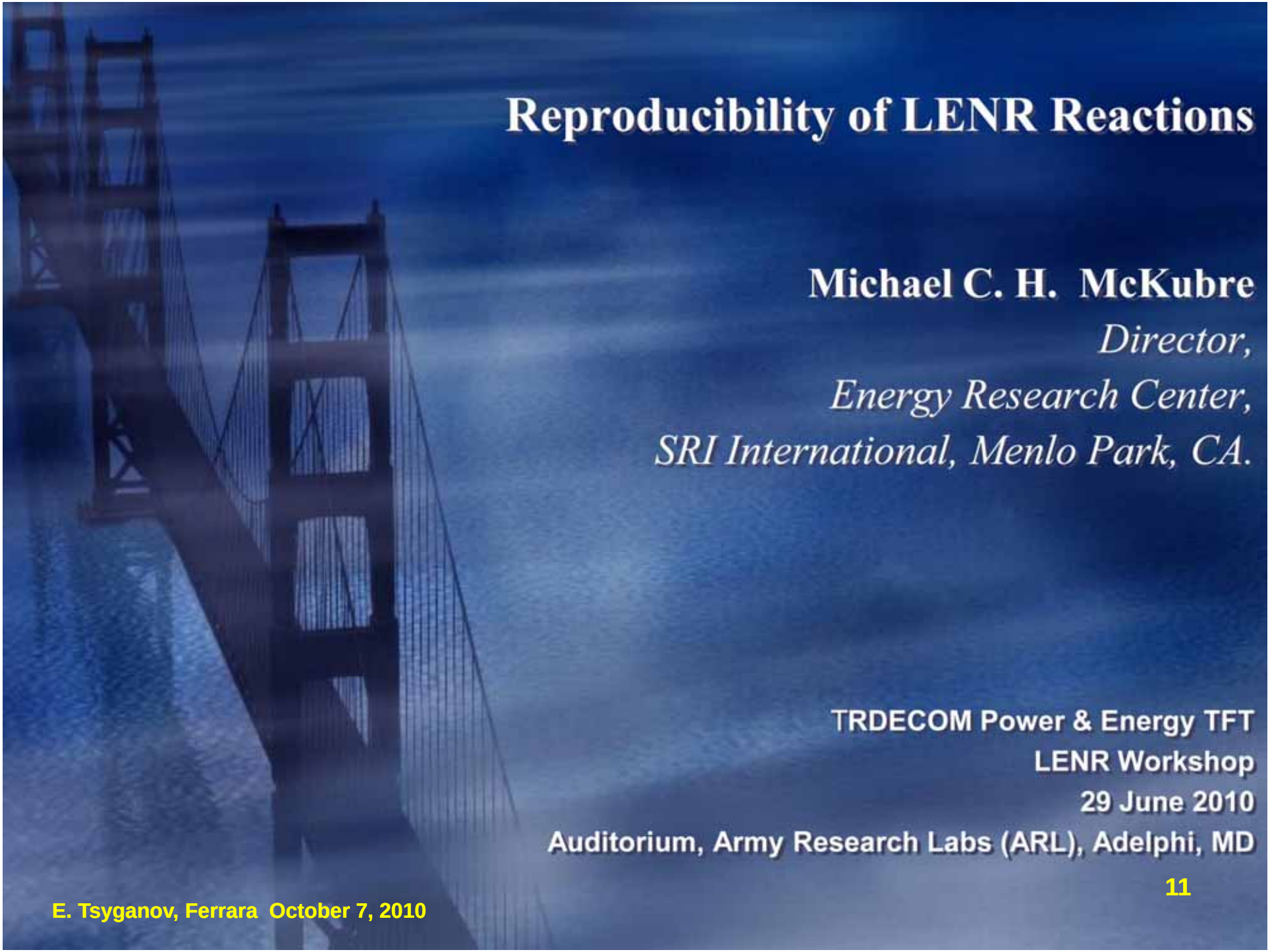
The mechanism of $DD \rightarrow {}^4He$ fusion and so-called nonradiative thermalization of the reaction in crystals was discussed and dynamics of this process was considered. The assumption that the decay time of the compound nucleus depends on its excitation energy makes experiments in crystals compatible with the acceleration data. The processes in the crystals that increase the intensity of *DD* fusion in comparison to the amorphous media were considered, and the yield of the reaction was estimated.



Martin Fleischmann

Michael McKubre


COLD FUSION, LENR, the Fleischmann-Pons Effect;
ONE PERSPECTIVE on the STATE of the SCIENCE
Michael C. H. McKubre
Director,
Energy Research Center,
SRI International, Menlo Park, CA.
The 15th International Conference on Cold Fusion, ICCF15
Roma, Italy
Monday, October 5, 2009.


Reproducibility of LENR Reactions
Michael C. H. McKubre
Director,
Energy Research Center,
SRI International, Menlo Park, CA.
TRDECOM Power & Energy TFT
LENR Workshop
29 June 2010
Auditorium, Army Research Labs (ARL), Adelphi, MD

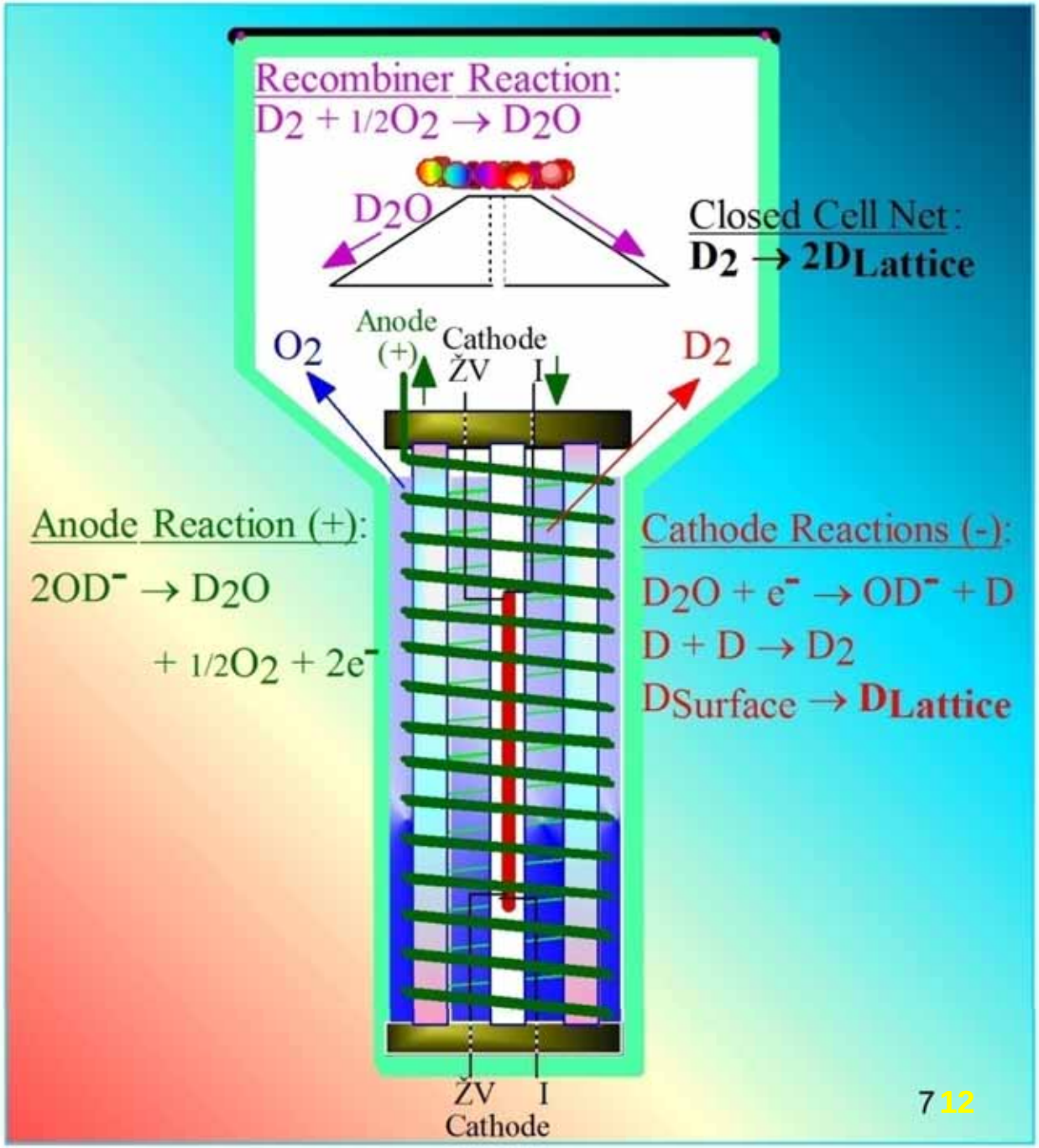
Loading Cell and Reactions.

Wires:

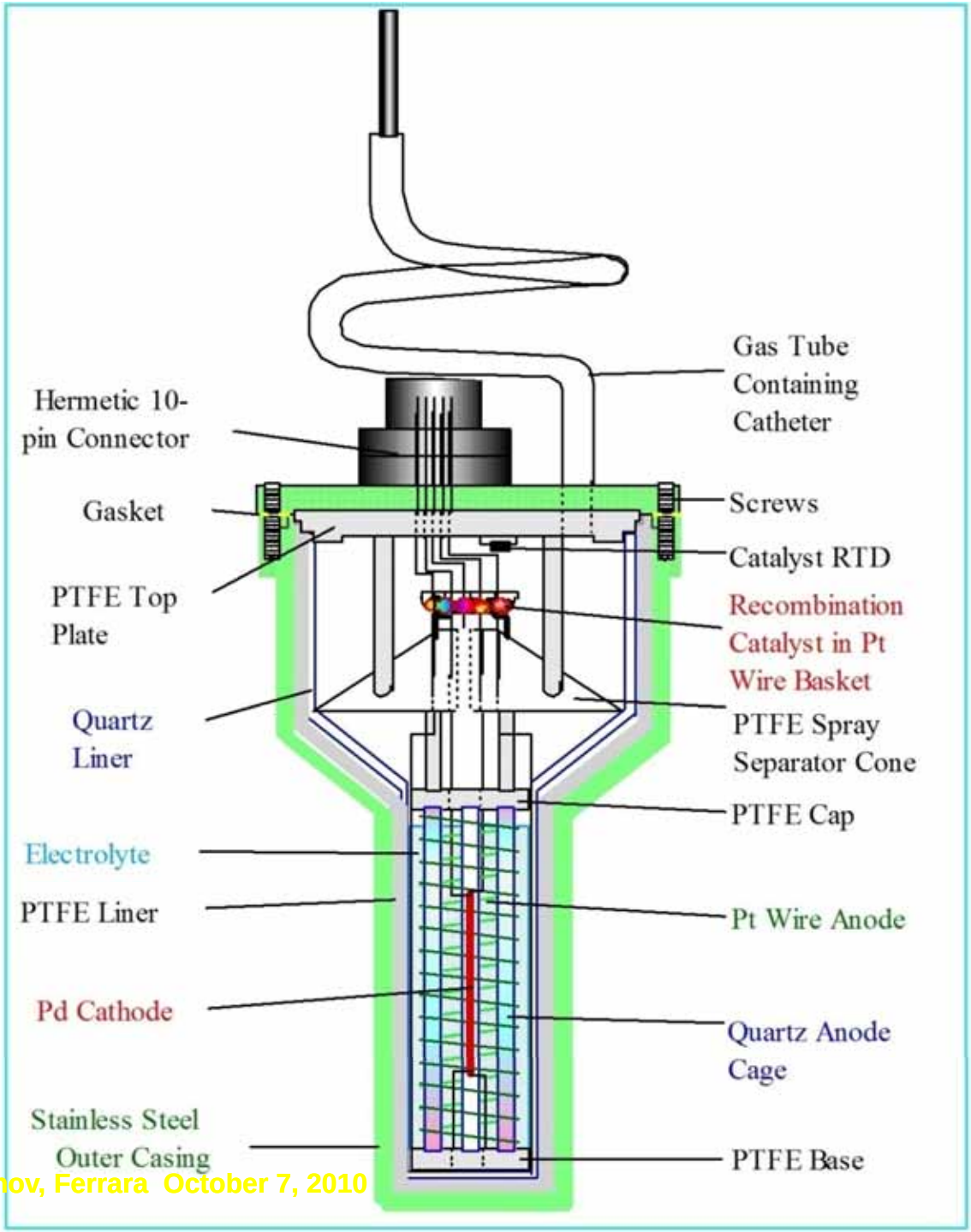
1 – 3 mm in dia.

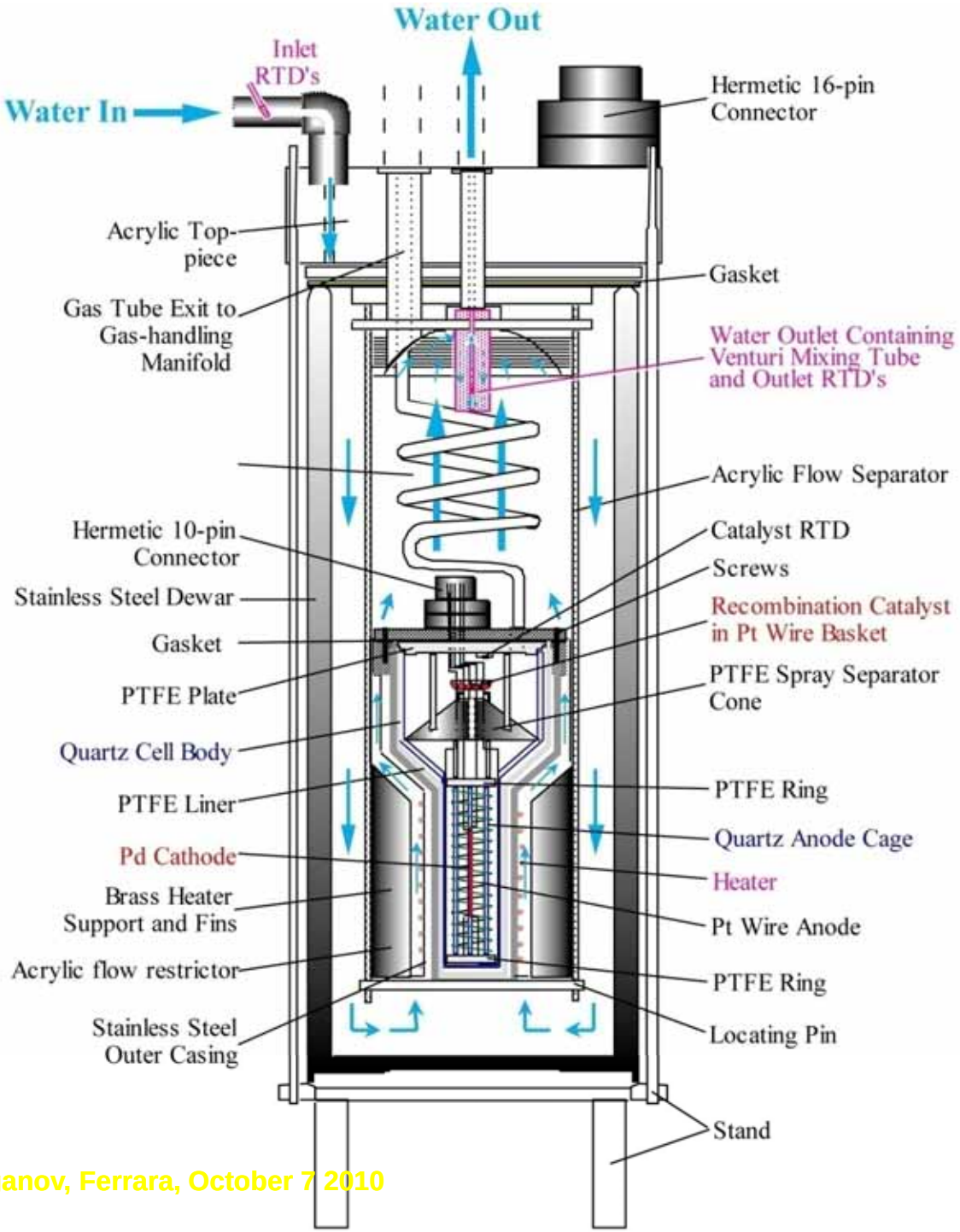
3 – 5 cm in length.

1M LiOD Electrolyte



SRI Quartz Calorimeter *and* Degree of Loading (DoL) Cell



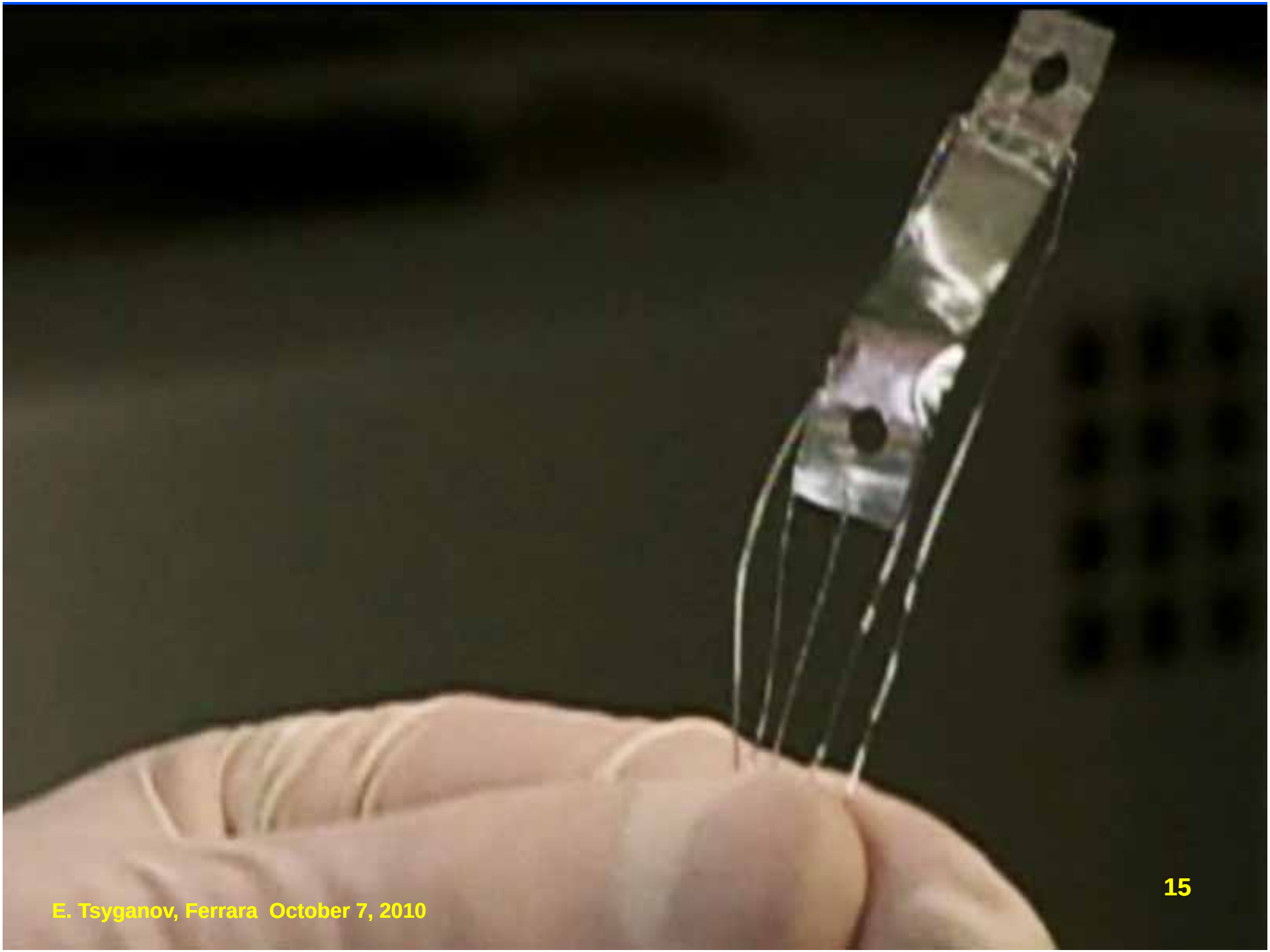


SRI Labyrinth (L and M) Calorimeter and Cell

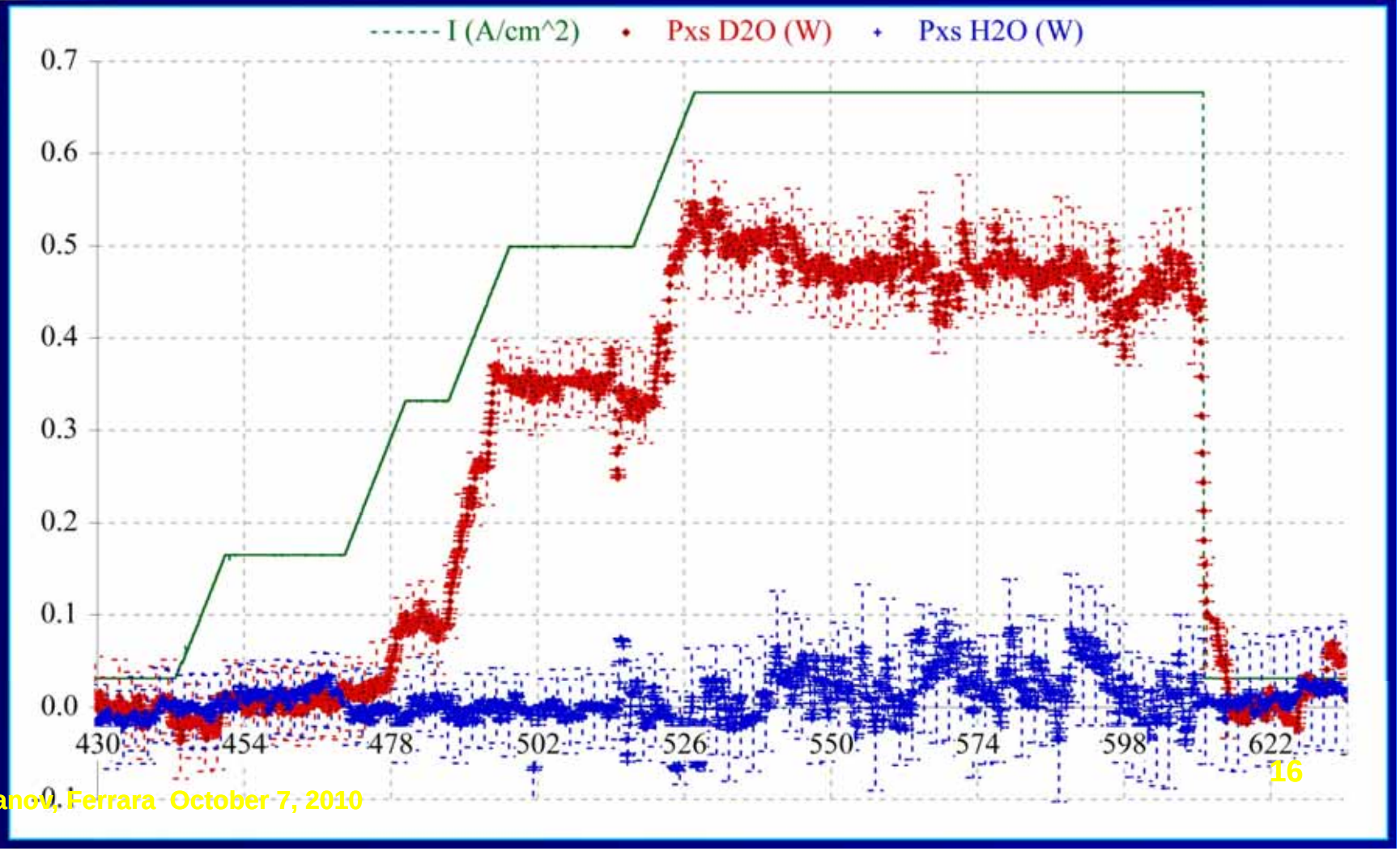
Accuracy: ±0.35%

Operation:
100 mW – 30W

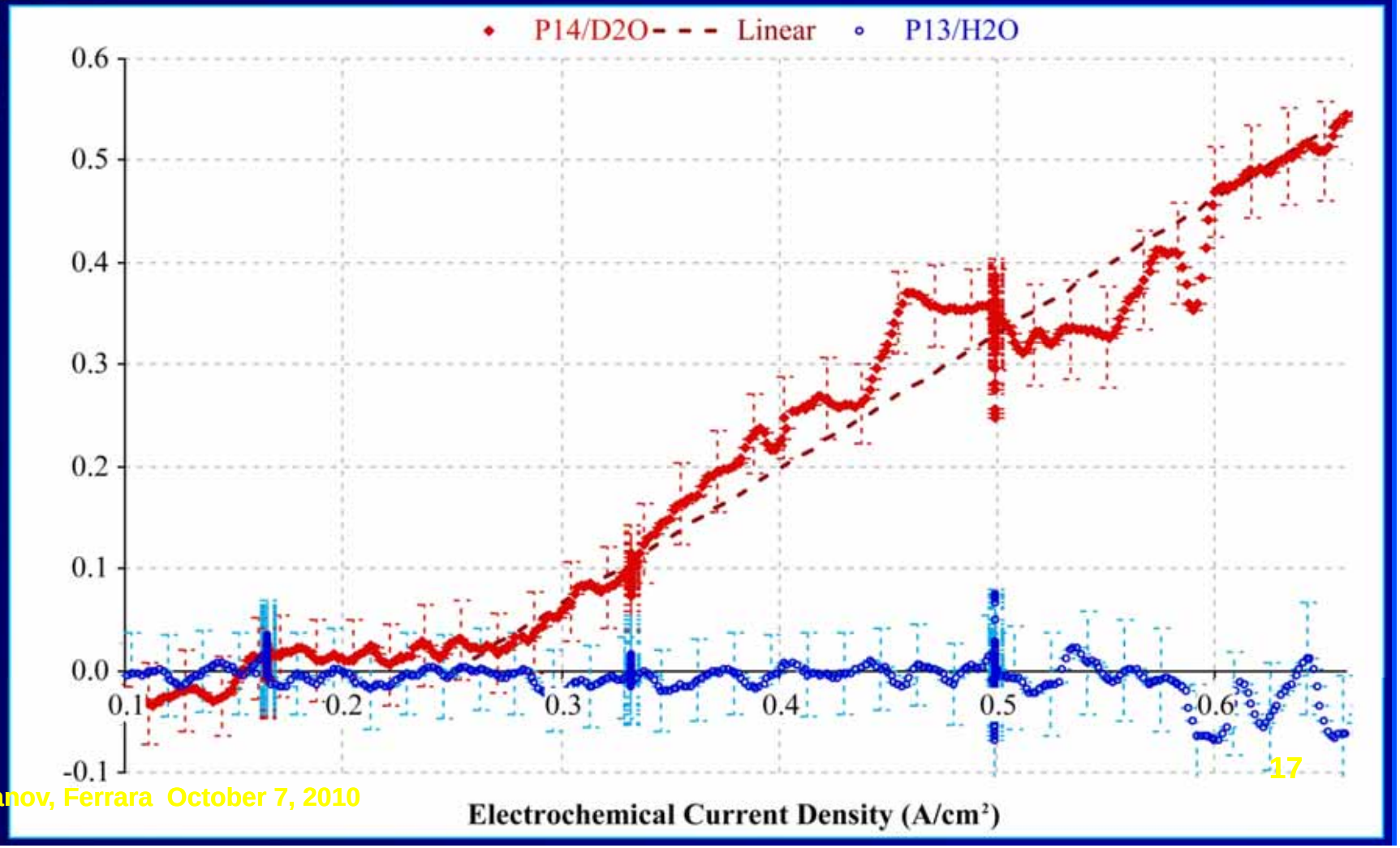
Stability:
> 1000 hours



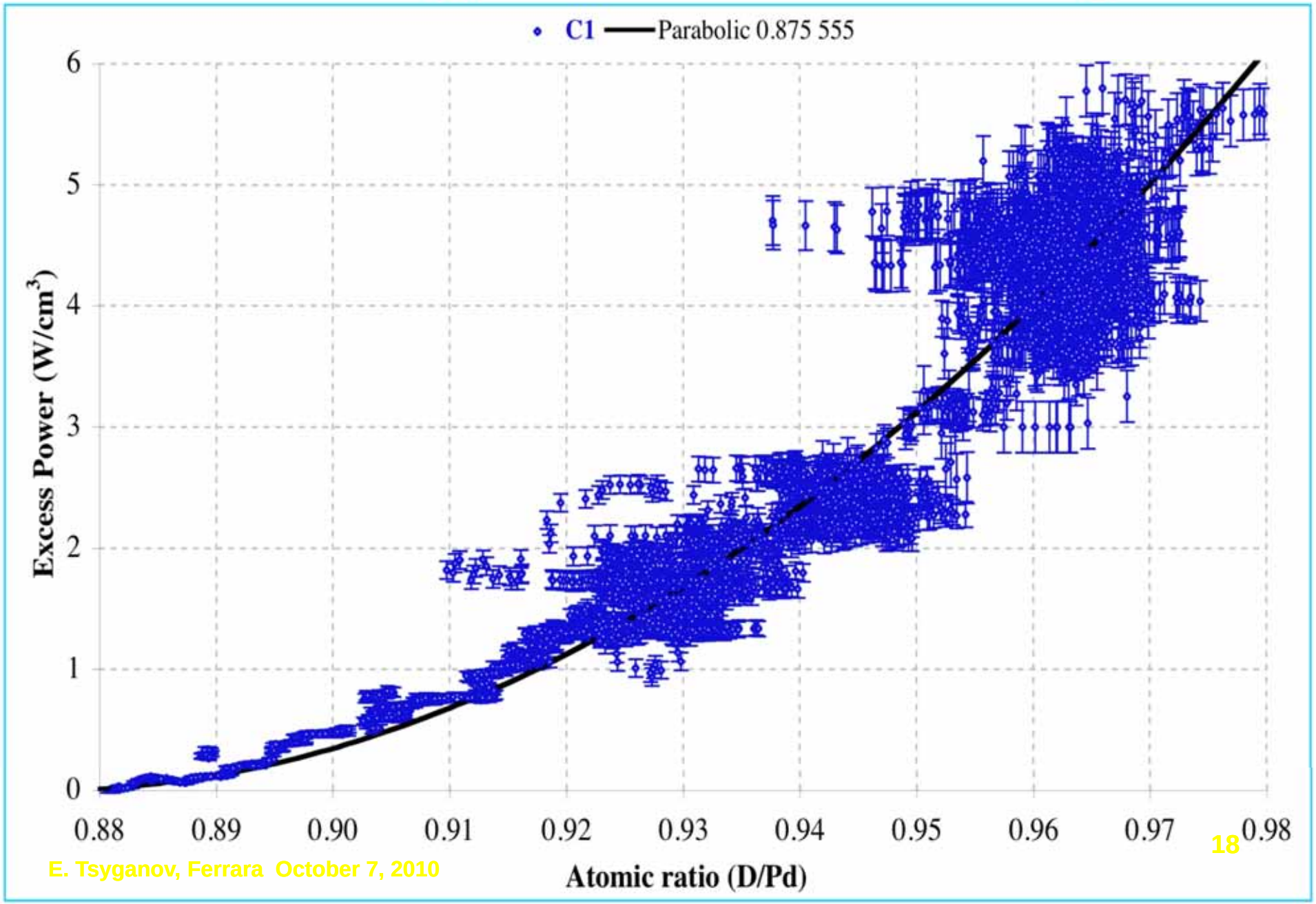
P13/14 Simultaneous Series Operation of Light & Heavy Water Cells; *Excess Power & Current Density vs. Time*



P13/14 Simultaneous Series Operation of Light & Heavy Water Cells; *Excess Power vs. Current Density*



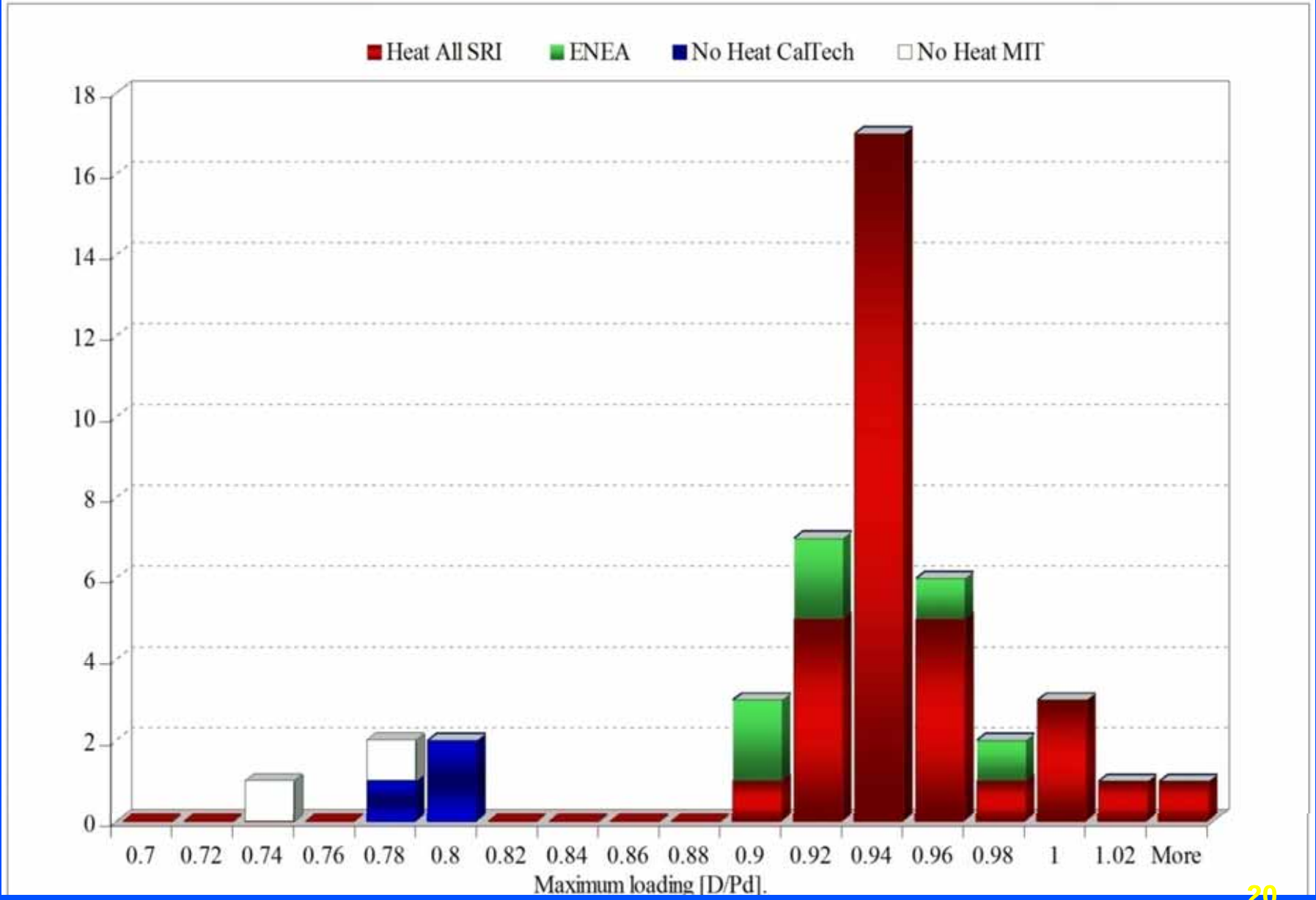
"Variation of P_{XS} with D/Pd Ratio (*Loading*)"



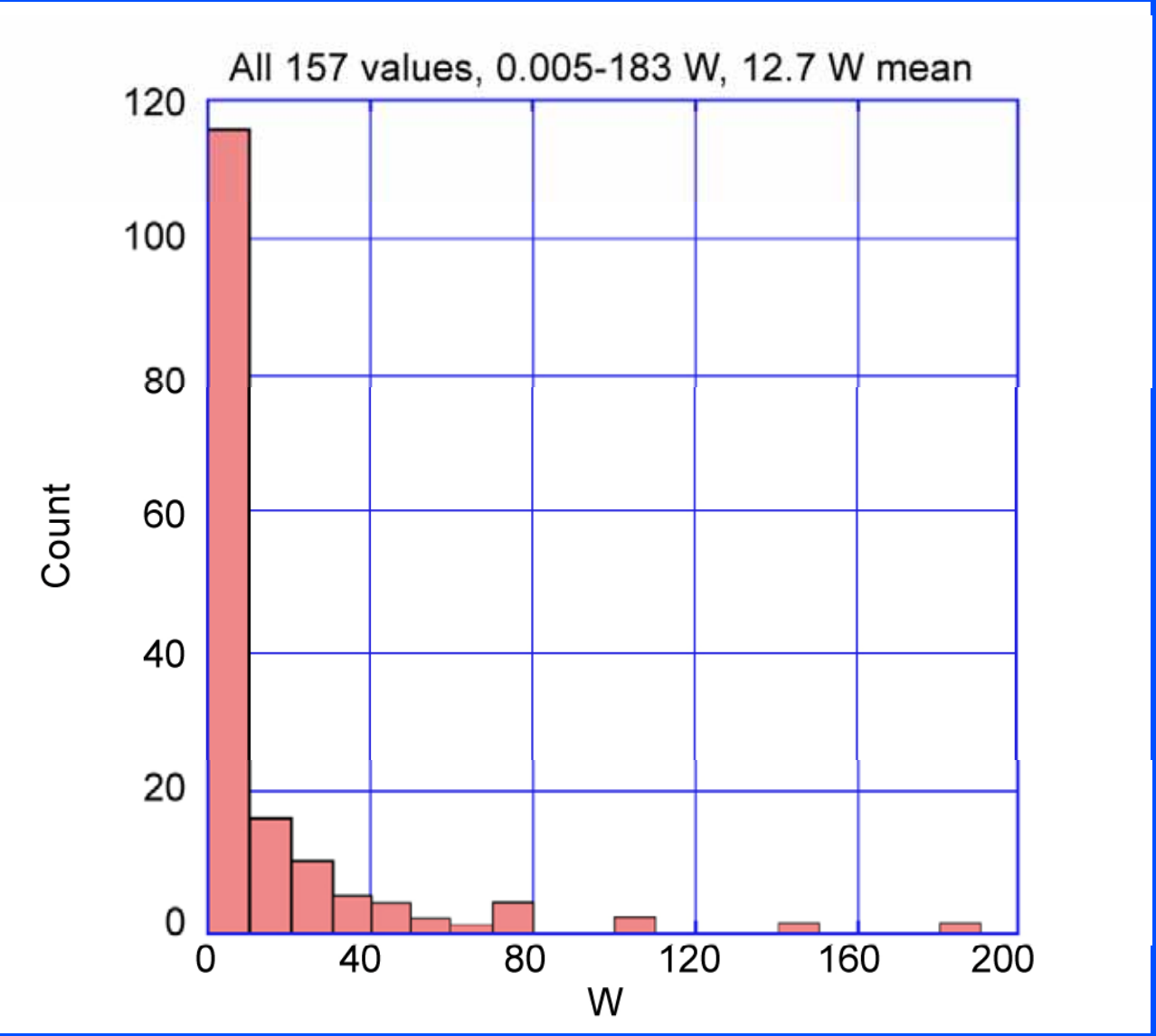
Overview

- March 23rd 1989 Fleischmann and Pons reported results of: an anomalous heat effect resulting from the extensive, electrochemical insertion of deuterium into palladium cathodes occurring over an extended period of time by means of electrolysis of heavy water in alkaline electrolytes.
- This heat effect was at a level consistent with Nuclear but not Chemical energy or known lattice Storage effects, but occurred (*mostly*) without penetrating radiation (α, β, γ, n°) or activation (^3H).
- Nuclear level heat effects have been observed in the D/Pd system with energies 100's or 1,000's times known chemical effects.
- We are concerned with answers to the following questions:
  - What do we think we know?
  - Why do we think we know it?
  - Why do doubts still exist in the broader scientific community?
  - How do we propose to make progress?

"Achieve High Maximum D/Pd Ratio (*Loading*)"



all experiments



Preliminary answers

❖ Is the effect real?

- The FPE is new effect in physics
- Requires a new mechanistic description and explanation
- Very likely associated with a significant number of CMN Effects
- Once explained the underlying effect will not seem "so strange"

❖ What is the effect?

- Heat production consistent with nuclear but not chemical energy or known lattice storage effects
- Temporally and quantitatively accompanied by ^4He
- A number of other nuclear products and processes (some of which may be of "more than scientific" interest)

❖ How do we make progress?

- Theory: quantitative, predictive fundamental physics description
- Science: we must engage the broader scientific community
- Commerce: create, market and sell product(s) based on the effect
- Public/Politic: growing public concern/interest in "Alternative Energy" options

Acknowledgements (from M. McKubre)

Funding Support:
EPRI, MITI, DARPA, DTRA

The author is also very much indebted to a group of scientists and engineers which had as it's core: *Yoshiaki Arata, Les Case, Jason Chao, Bindi Chexal, Brian Clarke, Steve Crouch-Baker, Jon McCarty, Irving Dardik, Arik El Boher, Ehud Greenspan, Peter Hagelstein, Alan Hauser, Graham Hubler, Nada Jevtic, David Knies, Shaul Lesin, Robert Nowak, Tom Passell, Andrew Riley, Romeu Rocha-Filho Joe Santucci, Maria Schreiber, Stuart Smedley, Fran Tanzella, Paolo Tripodi, Robert Weaver, Vittorio Violante, Kevin Wolf, Sharon Wing and Tanya Zilov.*

Some empirical rules in experiments with electrochemical insertions

No. 1. The D/Pd ratio in the bulk palladium cathode should be in excess of a critical value.

No. 2. The palladium must be free of cracks.

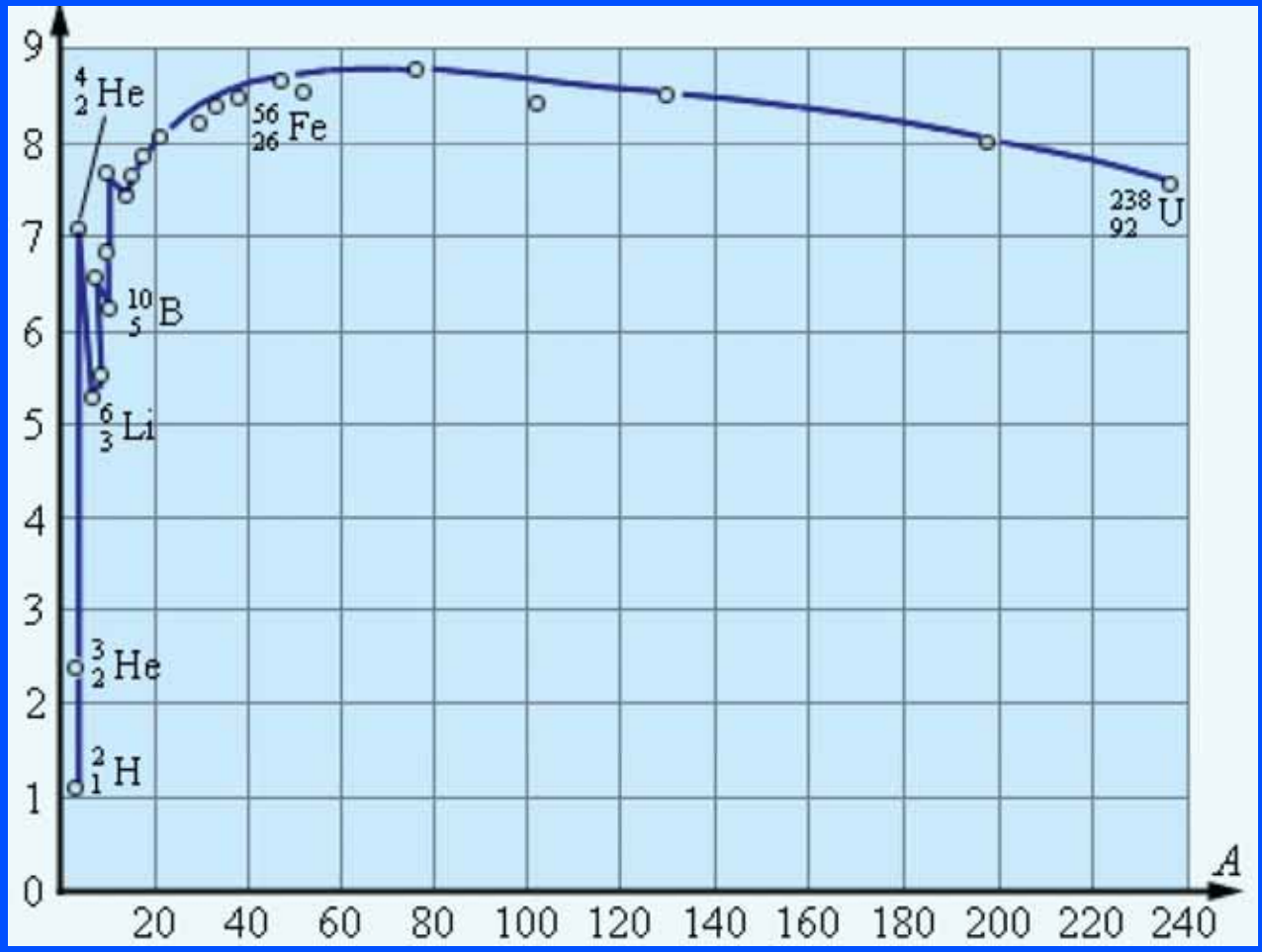
No. 3. The applied current density has to be above a critical value near 100 mA/cm^2 before detectable heat will be produced.

No. 4. The D_2O used in the electrolyte must be as free of H_2O as possible.

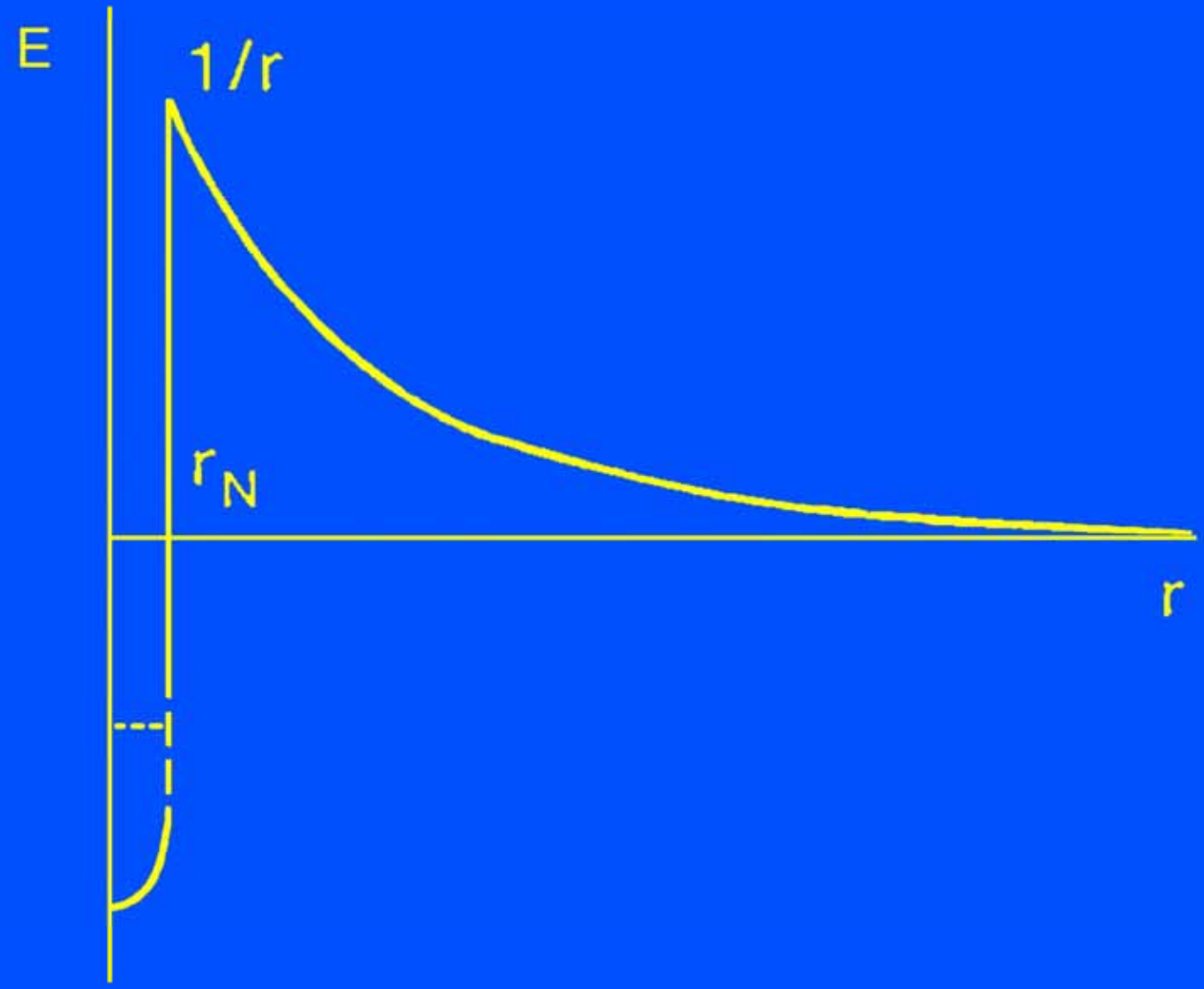
No. 5. Application of additional energy may help initiate the effect .

DD fusion

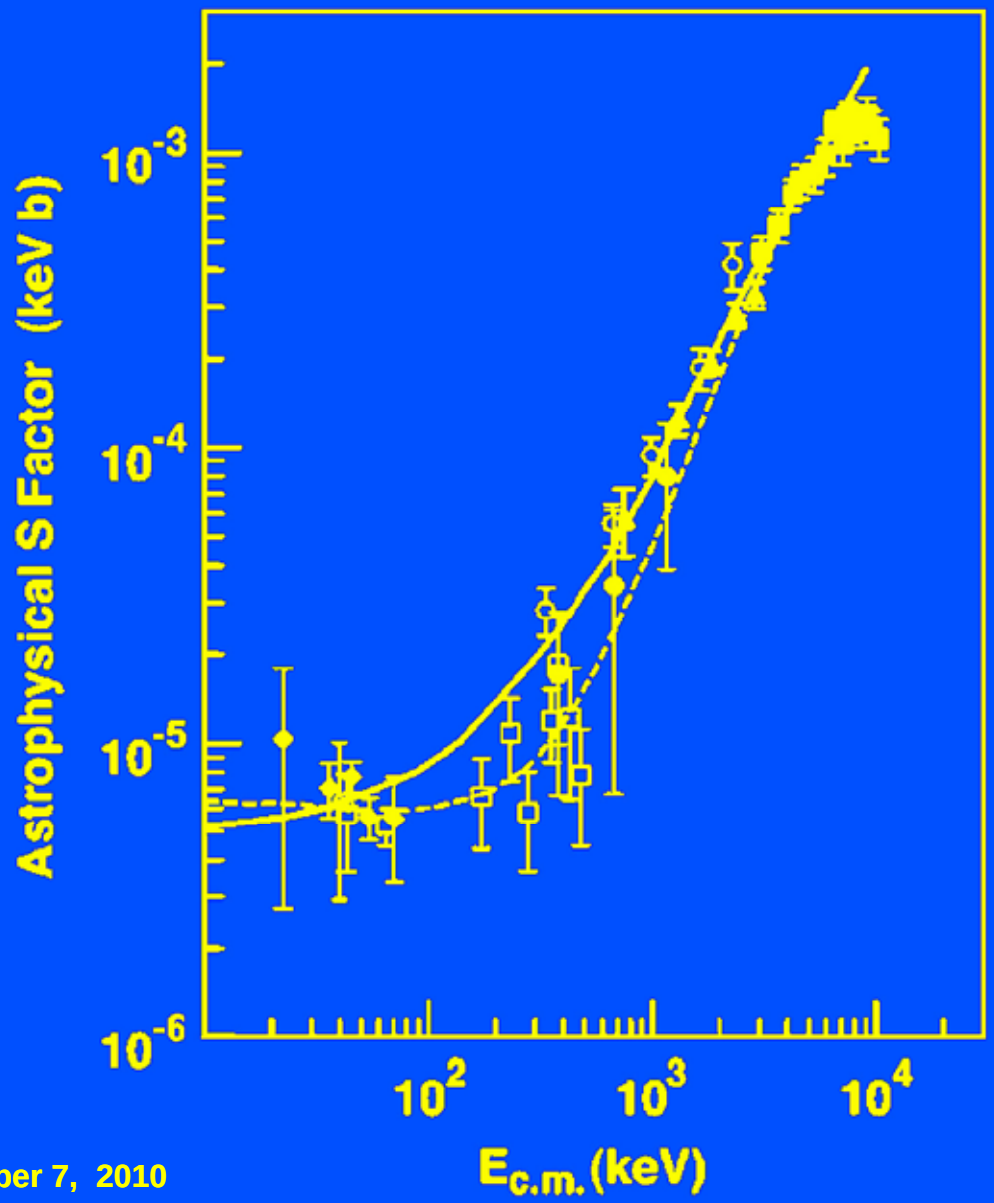
Binding energy per nucleon for different elements:



Potential barrier



D + D → ^{4}He


Astrophysical S Factor (keV b)
10^-3
10^-4
10^-5
10^-6
10^2
10^3
10^4
E_c.m. (keV)

Astrophysical S-factor for DD fusion

E in keV and σ in barn:

$$S(E) = E\sigma \cdot exp\left(\pi \frac{e^2}{\hbar c} \sqrt{\frac{M_d c^2}{E}} \right) = E\sigma \cdot exp(31.41/\sqrt{E})$$

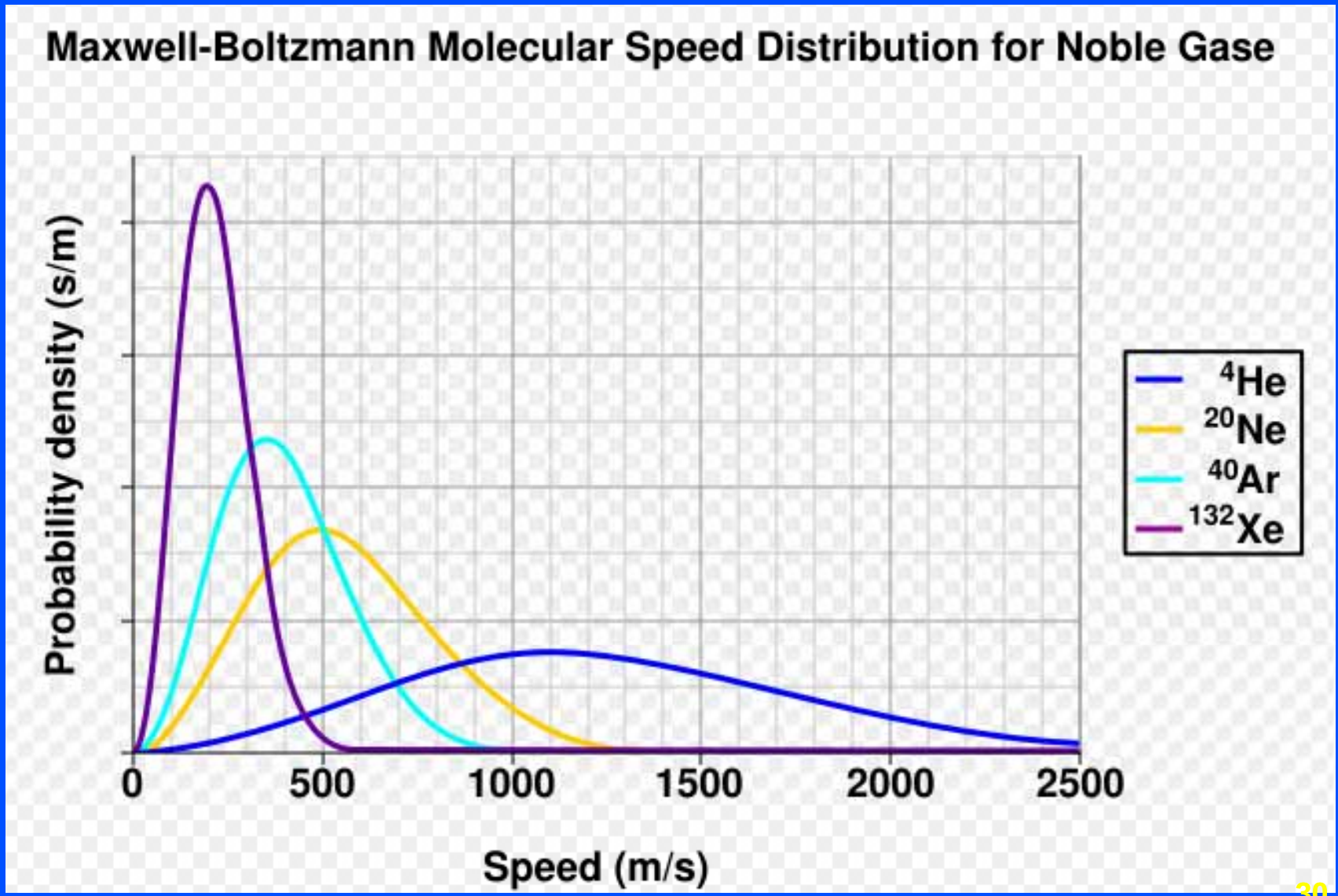
For 2 keV

$$\sigma = \frac{S(E)}{E} e^{-2\pi\eta}$$

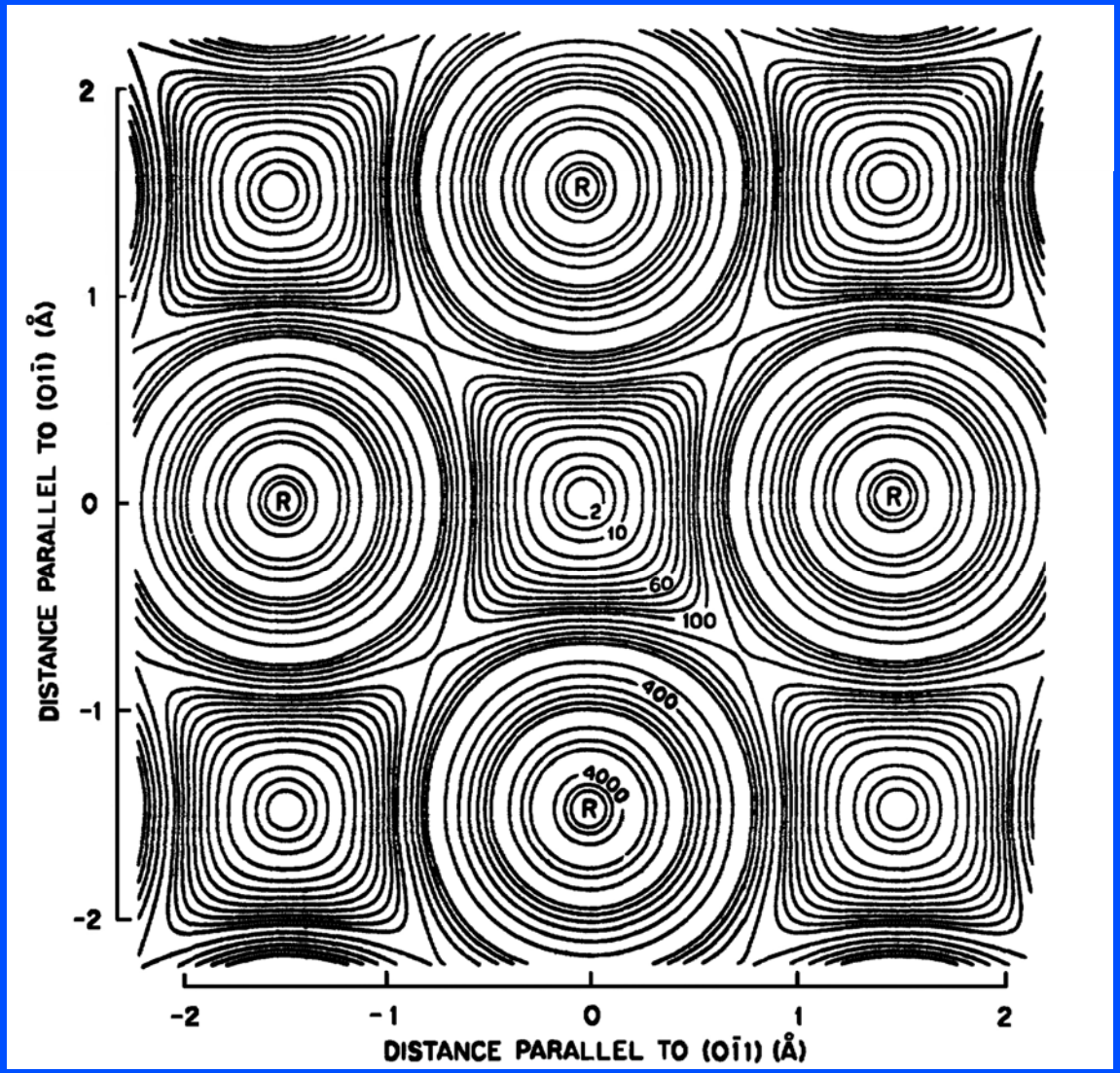
$$e^{-2\pi\eta} = e^{-31.4(E)^{-1/2}} = 1.86\times10^{-10}$$

$$\sigma(E = 2\ \text{кэВ}) = (1.86\times10^{-10}\times4.8\times10^{-6}\times10^{-24})/2 = 0.45\times10^{-39}\ \text{см}^2$$

Thermal energy distribution

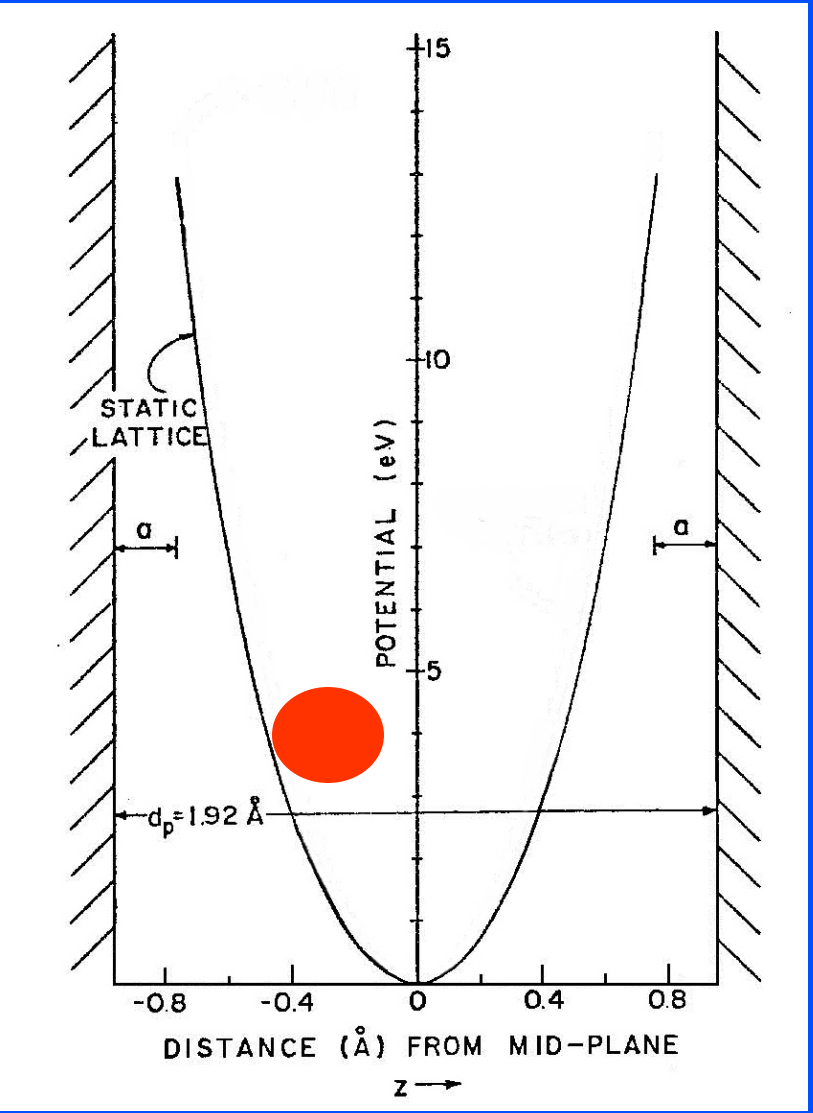


Silver crystal potentials

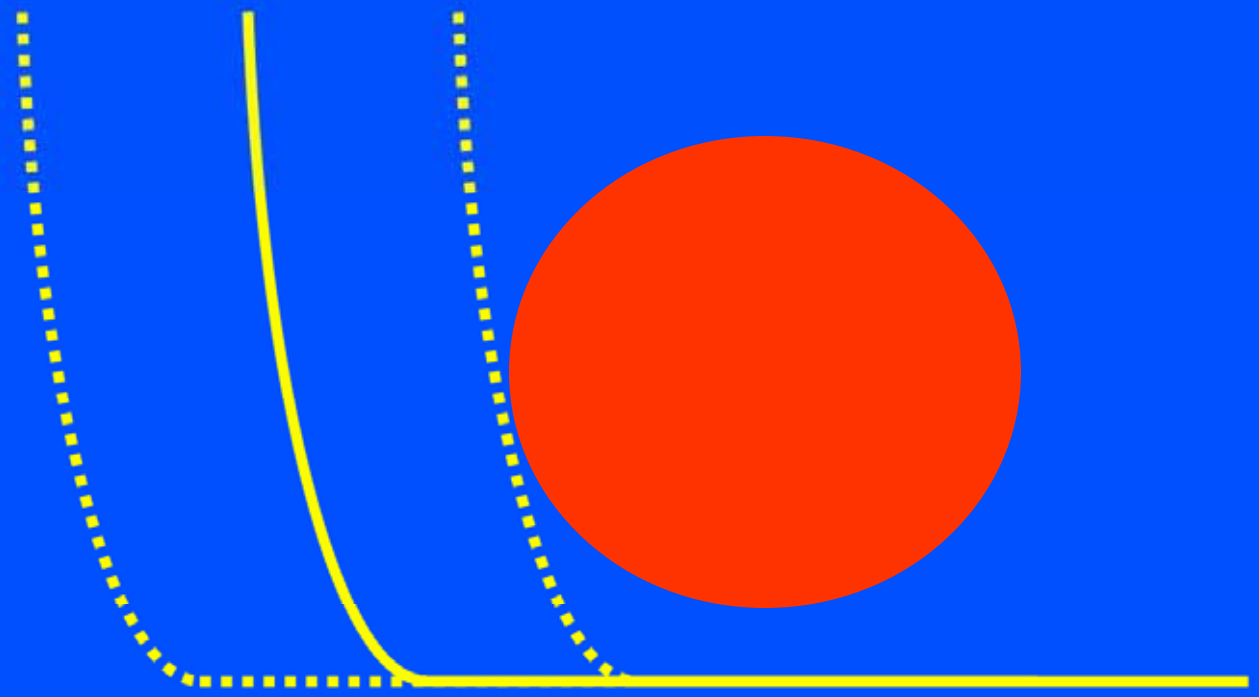


If a particle moves in a curved (distorted) channel with a static potential, its kinetic energy is conserved, and the particle moves along a certain equilibrium orbit. However, when a crystal lattice experiences collective long wave thermal vibrations, the particle in the curved channel experiences successive transverse kicks from a group of atoms of the lattice, and therefore absorbs the energy from the lattice. This small "thermal acceleration" of the deuterium atoms, in our view, is the origin of deuterium fusion in crystals.

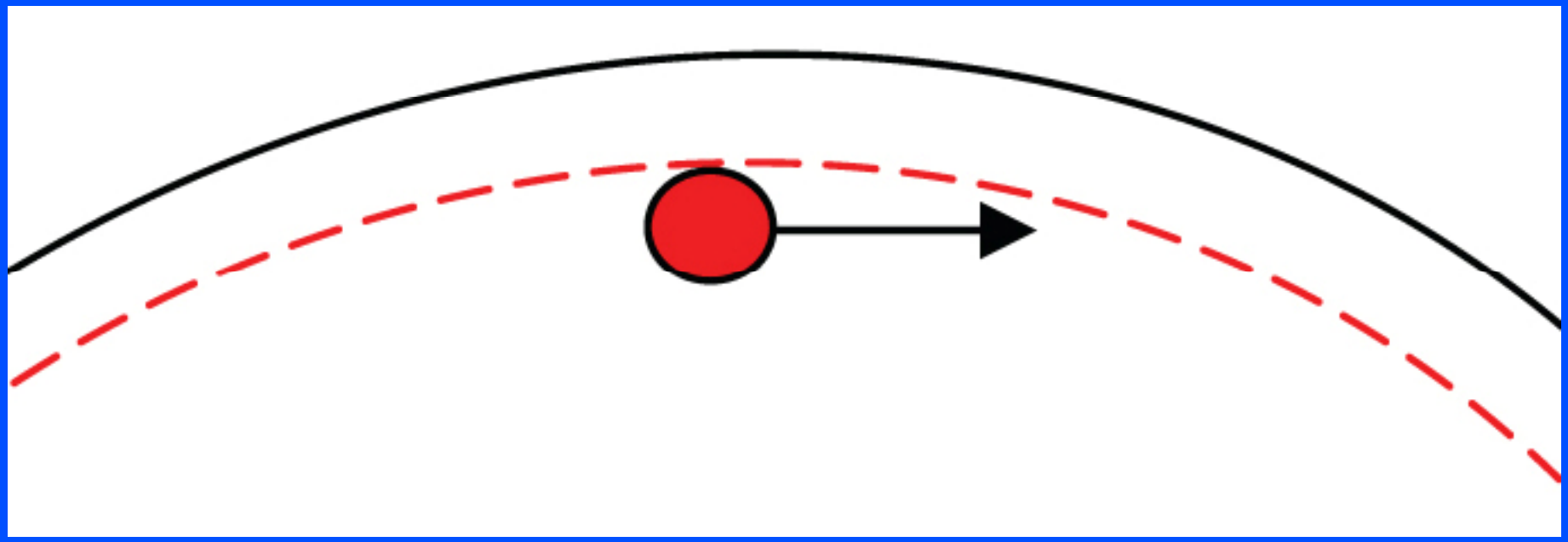
Channeling in crystal



Atomic potential (guess)



Swing effect



$$w = f \times s$$

At the moment, thermal equilibrium of light atom contaminations in palladium crystal lattice is still a puzzle. Obviously, it is not the Maxwell distribution, and definitively non- isotropic. In distorted crystals there are probable mechanisms that transfer the energy of lattice thermal vibration to the contaminants moving along the crystal hyperchannels.

In our considerations we neglected the shielding of deuterium electrical charge by his electron when calculating the barrier penetration. In accelerator experiment this effect is known as increasing the probability of barrier penetration by about 10%.

Peculiarities of DD fusion in crystals

1. Thermal equilibrium of D atoms along bent channel is not Maxwell

2. No ionization (process begins only after 50 keV)

3. Domino catalysis (thermodynamics). Very week chemical bound. As a result, all interactions are “hot” with an average room temperature

   up to ~ 10^{9}

4. Precision alignment between a projectile and a target

   ~ 10^{4}

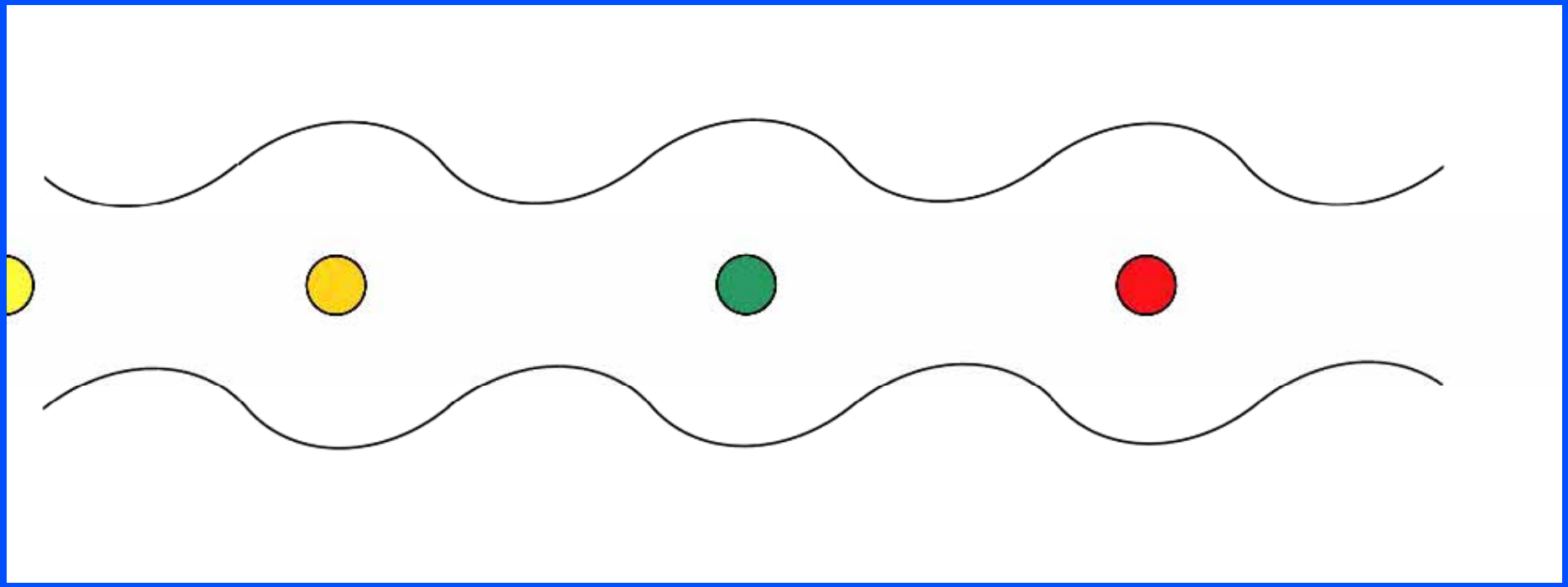
5. Deuterium has a condensed matter density

   > 10^{3}

6. Nuclear decay rate of compound nuclei at low excitation is much reduced

Pd-D chemical bound energy is low, ~120 *meV*

E_{therm} ~ 40 *meV* at 300 K

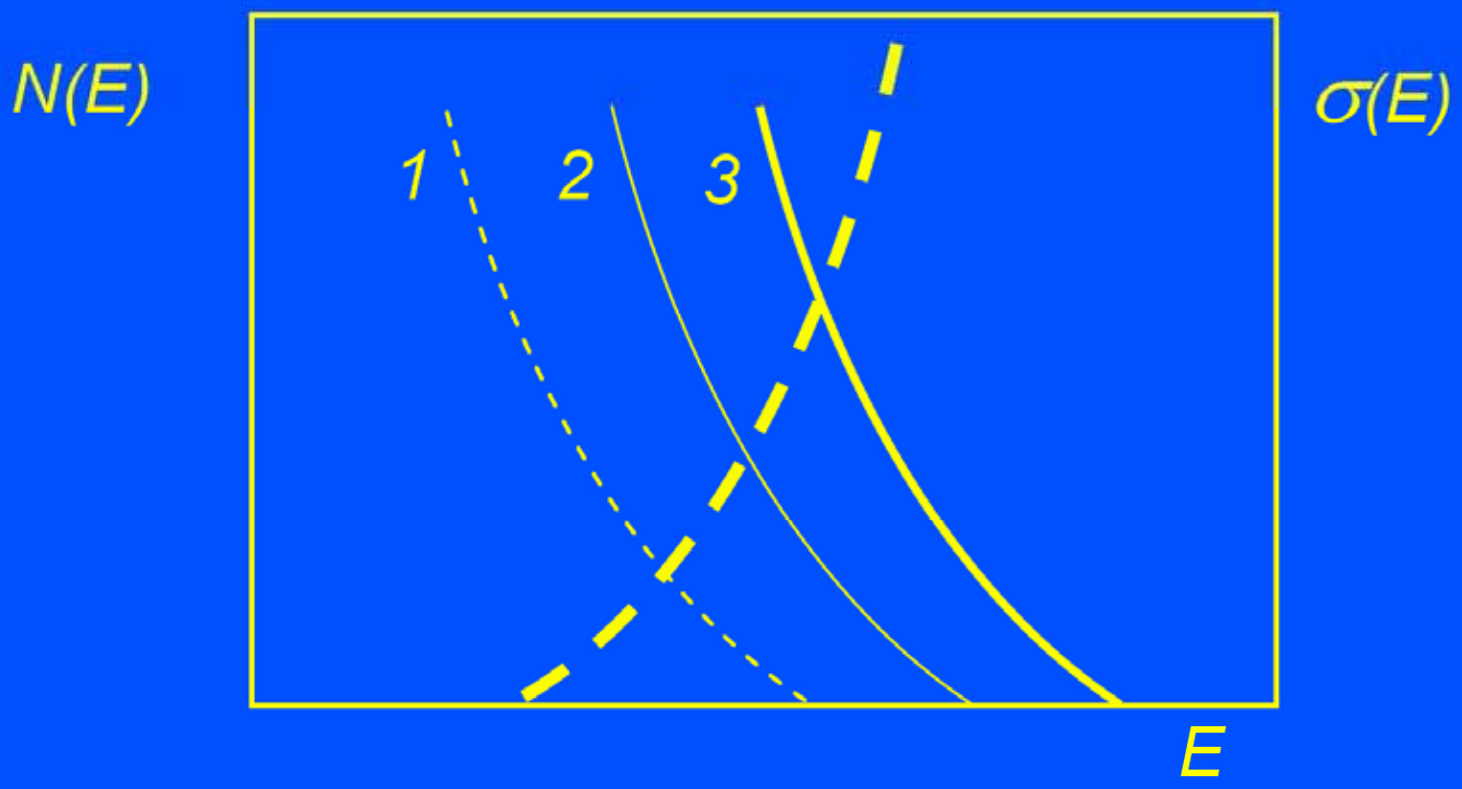


This is why contamination of H breaks up the process

Numerical results

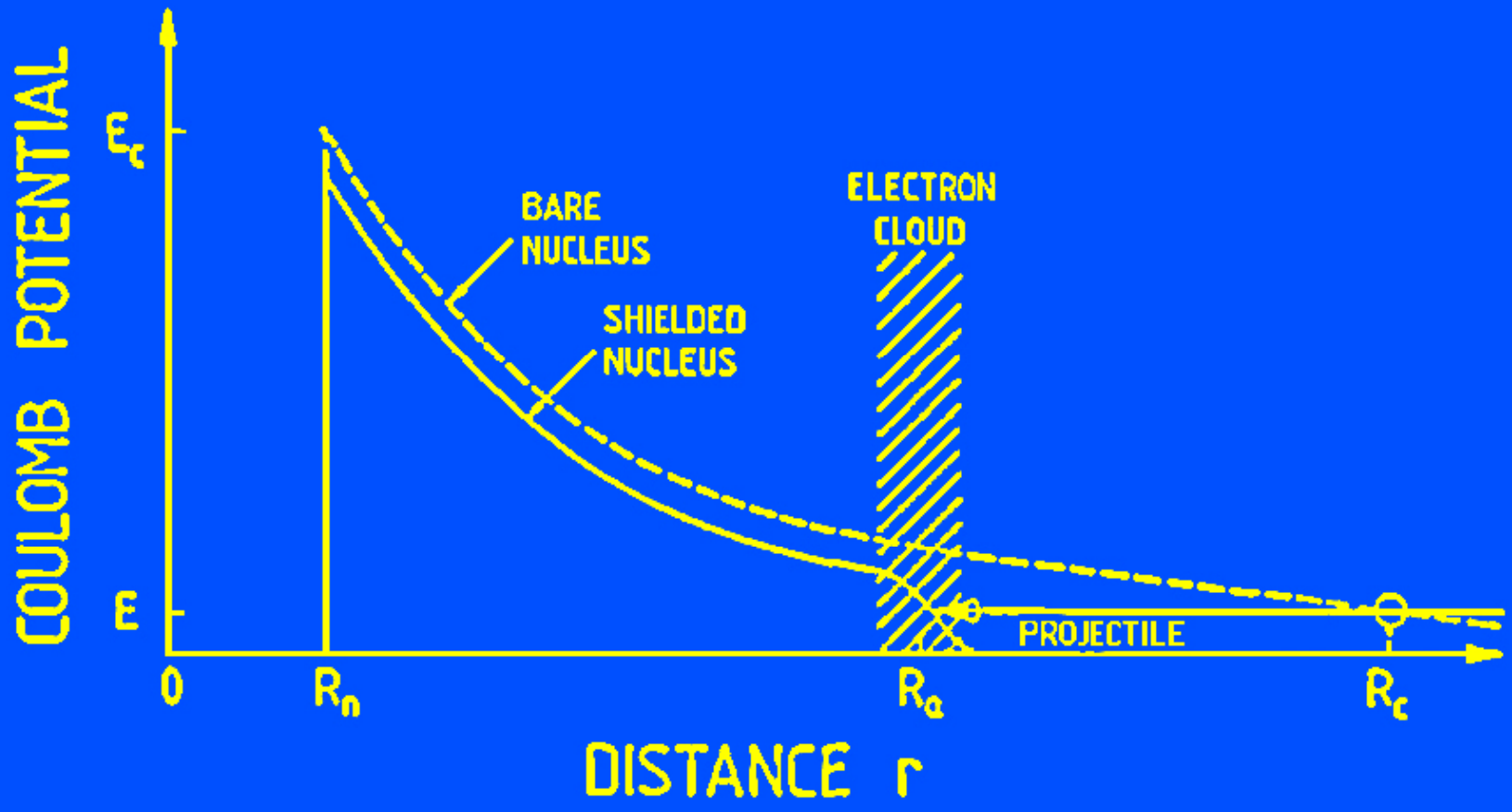
According to calculations, in 1 cm^3 of palladium deuterons having an energy of 1 keV in the center of mass yield 0.43×10^{10} ^4He fusion events per second, or 16.5 *mW*, at 2 keV the yield of the reaction is 2.5×10^{13} events per second, or 96 *W*, and at an energy of 3 keV the yield is 1.45×10^{15} events per second, or 5.6*kW*.

Thermal D-spectra and cross section



Effects of Electron Screening on Low-Energy Fusion Cross Sections

H.J. Assenbaum, K. Langanke and C. Rolfs
Z. Phys. A - Atomic Nuclei 327, p. 461-468 (1987)



Electron shielding
By H.J. Assenbaum and others:

$$\sigma(E) = S(E)E^{-1}\exp(-2\pi\eta(E))$$

$$E_{eff} = E + U_e$$

$$U_e = e^2 / R_a$$

$$\sigma(E_{eff}) / \sigma(E) = (E / E_{eff})\exp(-2\pi\eta(E_{eff})) / \exp(-2\pi\eta(E))$$

Electron shielding in in the static Born-Oppenheimer approximation

Table 1. Atomic screening effects on charged-particle-induced fusion reactions

System	U_e[a]	Enhancement ratio f[b]				Experiment	
	(keV)	$E/U_e = 1$	10	100	1000	E/U_e	Ref.
$d+d$	0.027	1.7×10^{24}	16.5	1.10	1.003	107	3
$d+{}^3He$	0.11	2.0×10^{26}	20.9	1.11	1.003	64	3
${}^3He+{}^3He$	0.22	7.4×10^{41}	131	1.18	1.006	73	3
$p+{}^7Li$	0.24	6.4×10^{22}	14.0	1.09	1.003	125	4
$p+{}^{11}B$	0.68	1.3×10^{23}	14.4	1.09	1.003	32	5, 6
$\alpha+{}^{12}C$	2.0	3.2×10^{58}	868	1.25	1.007	450	7
${}^{12}C+{}^{12}C$	5.9	3.2×10^{144}	1.9×10^{7}	1.76	1.016	338	8

[a] Equation (2); [b] Equation (3)

Cross sections with shielding corrections:

$$\sigma = \frac{S(E)}{E} e^{-2\pi\eta}$$

$$e^{-2\pi\eta} = e^{-31.4(E)^{-1/2}}$$

$$\sigma(E = 0.027\ keV) = 6.3 \times 10^{-111}\ cm^2$$

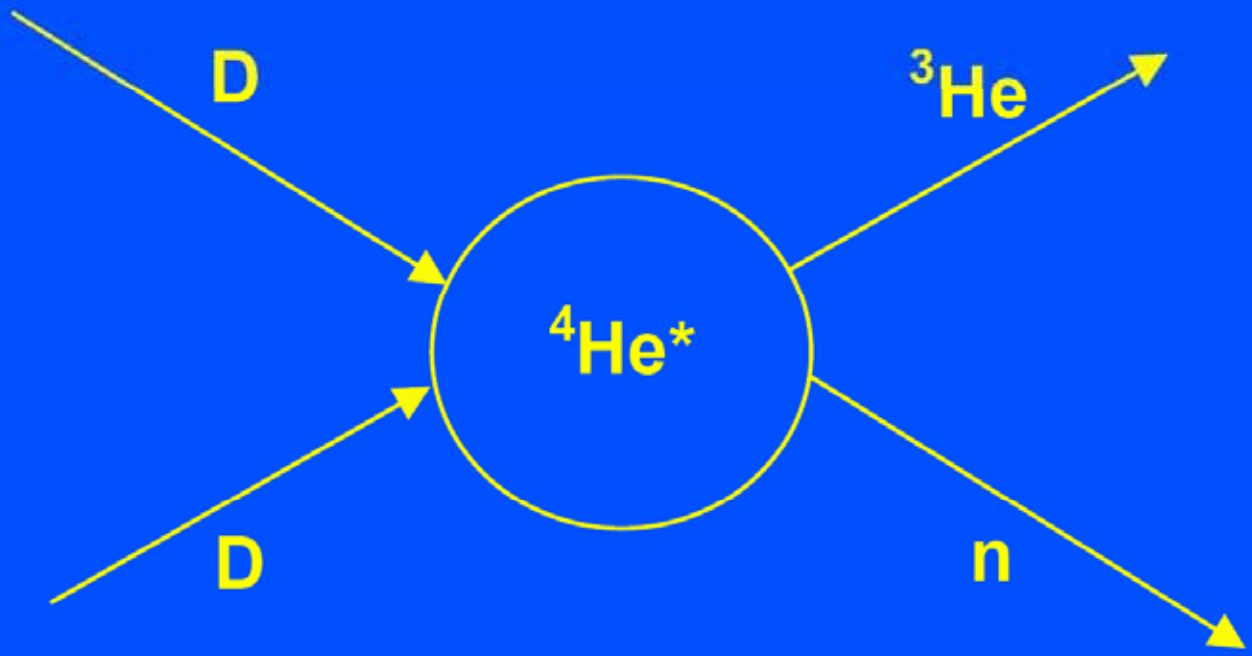
$$\sigma(E = 0.054\ keV) = 4.6 \times 10^{-87}\ cm^2$$

Correct solving the Schrödinger equation for *atomic* d-d collisions at very low energies is of the supreme importance now.

The most unexplainable:

Why are (almost) no nuclear products?
Where are neutrons?
Common statement: no neutrons – no fusion.

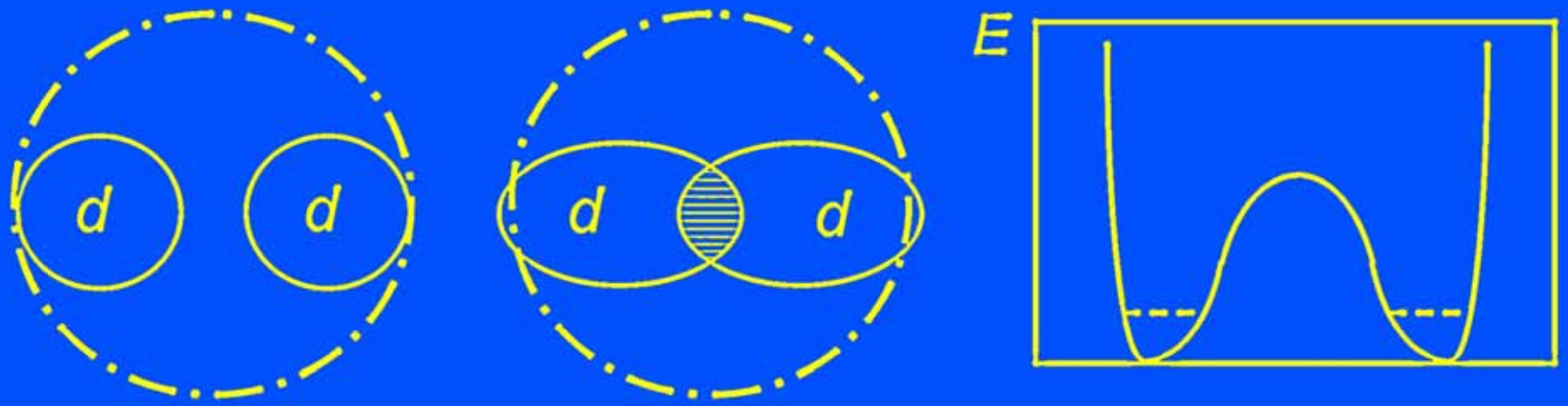
Compound nucleus decay with Heisenberg matrix elements calculations



This matrix approach is very fruitful in the description of many quantum-mechanical phenomena, but involuntarily served as the basis for the widely accepted opinion that all strong processes by the definition are fast.

Compound nucleus decay process diagram inspired by Schrödinger equation containing space-time coordinates in an explicit form.

Compound nucleus decay time



In this model nucleus decay time must depend on the excitation energy

If nucleus decay time depends on excitation energy:

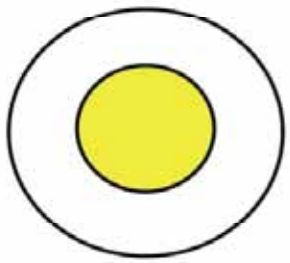
$$N(t)/N_0 = e^{-t\nu}$$

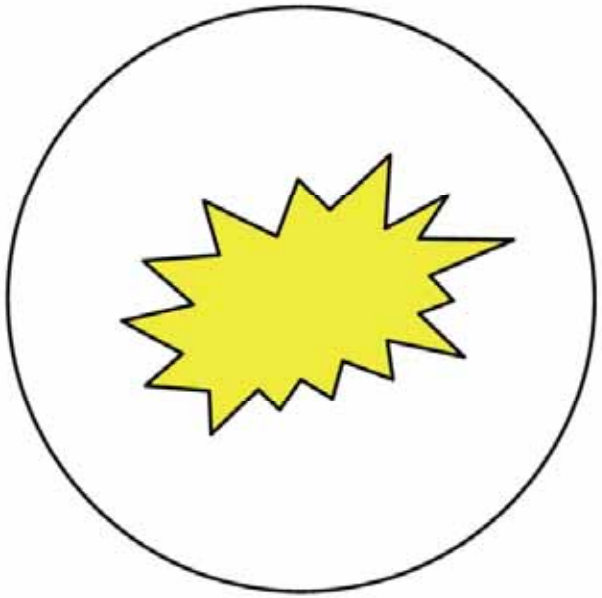
$$\nu = \nu_0 + aE + \ldots$$

If nucleus decay time depends on excitation energy:

Nuclear rates are usually about 10^{22}/s. The fusion reactions D+D → ^{4}He has a broad resonance at energy of about 8 MeV. Using the width of the resonance and the uncertainty relation gives the lifetime of the compound nucleus at this energy ~ 0.8×10^{-22} s. Then it increases approximately linearly with decreasing energy. It seems to us, McKubre group works in a range of about 2 keV. In these experiments the excitation energy is about 4×10^3 times less than in the resonance, and the decay time is ~ 0.3×10^{-18} s. This decrease in the nuclear reaction rate has no effect on the ratio of output decay channels, but only to a certain limit. This limit is ~ 6 keV. Then the compound nucleus is no longer an isolated system, since virtual photons from ^{4}He* can reach to the nearest electrons and carry out the excitation energy. For the distance to the nearest electron we have chosen the radius of electrons of a helium atom (3.1×10^{-11} m). From the uncertainty relation, the time of these processes is about 10^{-19} s.

If excitation energy is high:

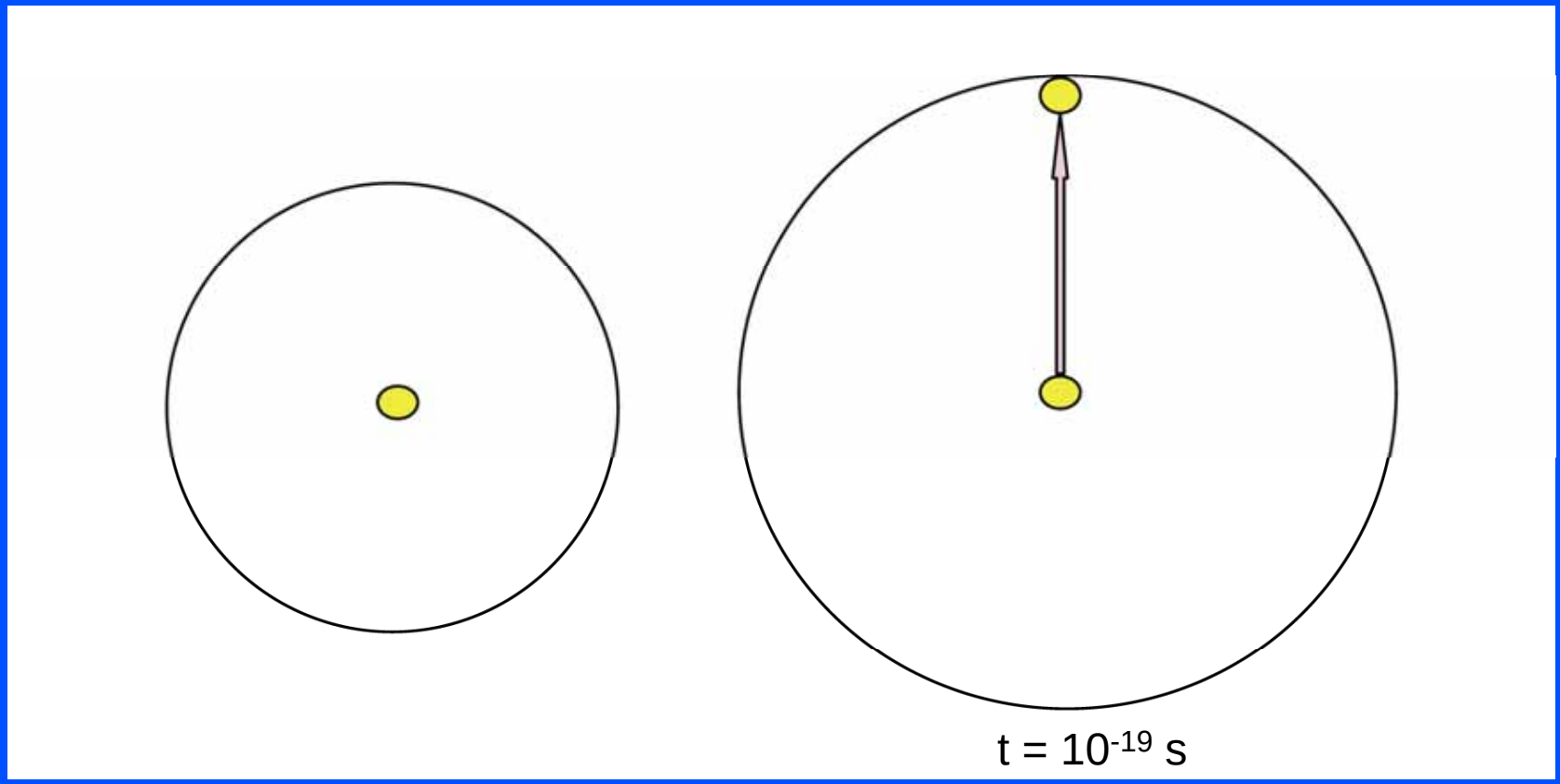




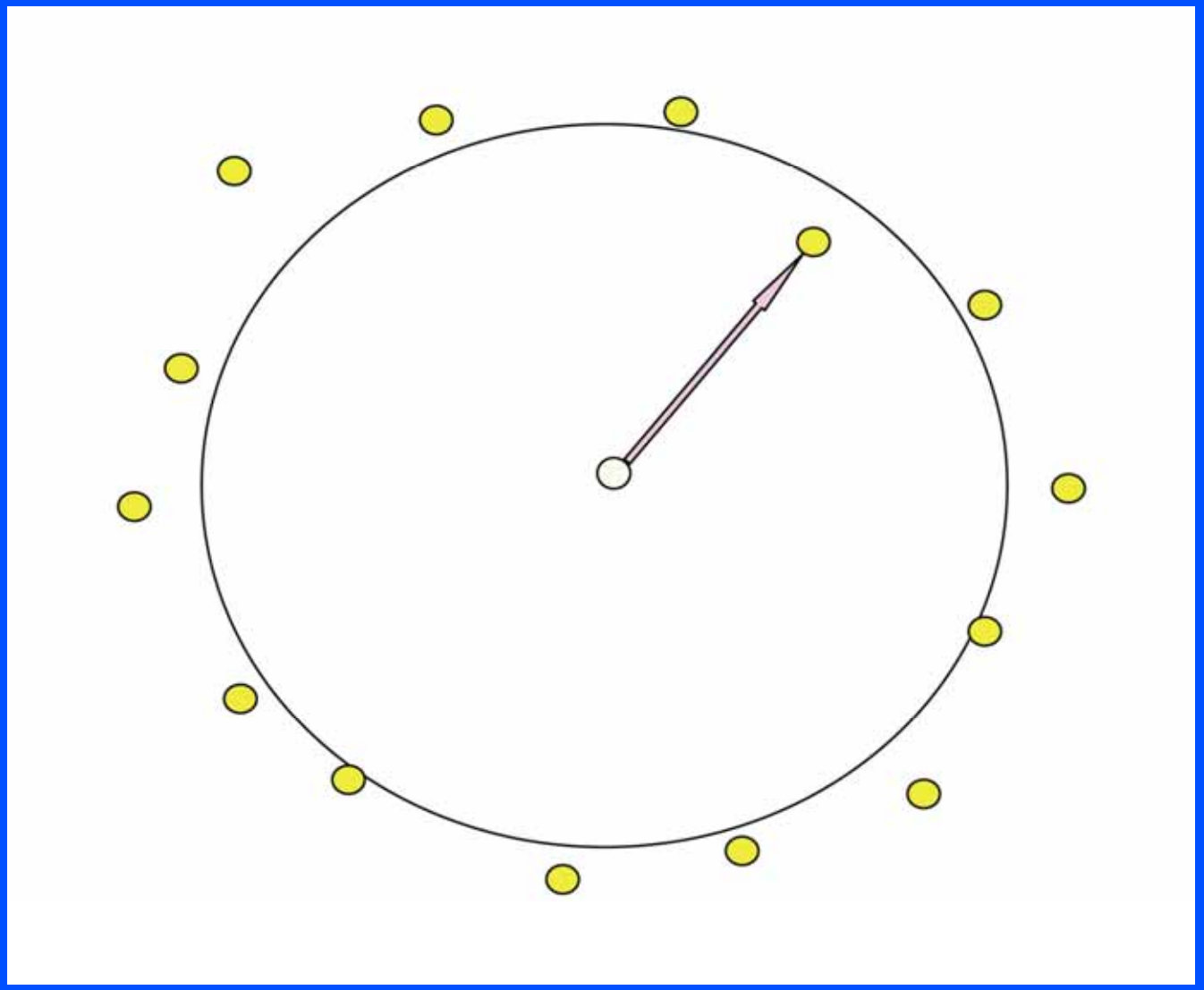
the beginning

the end

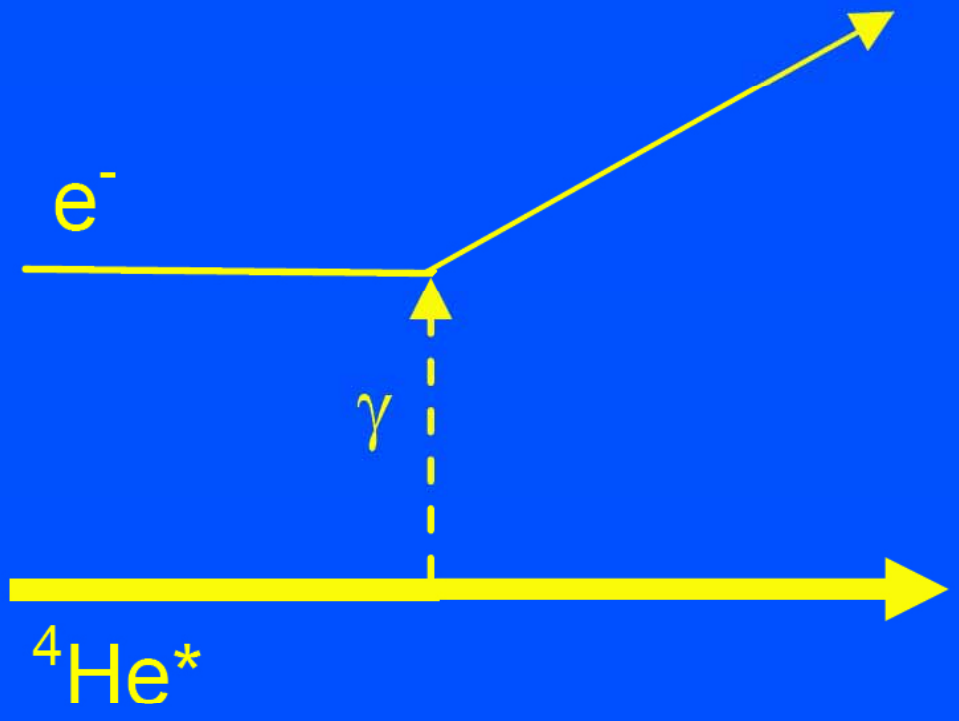
If excitation energy is very low:



excitation energy ~ zero

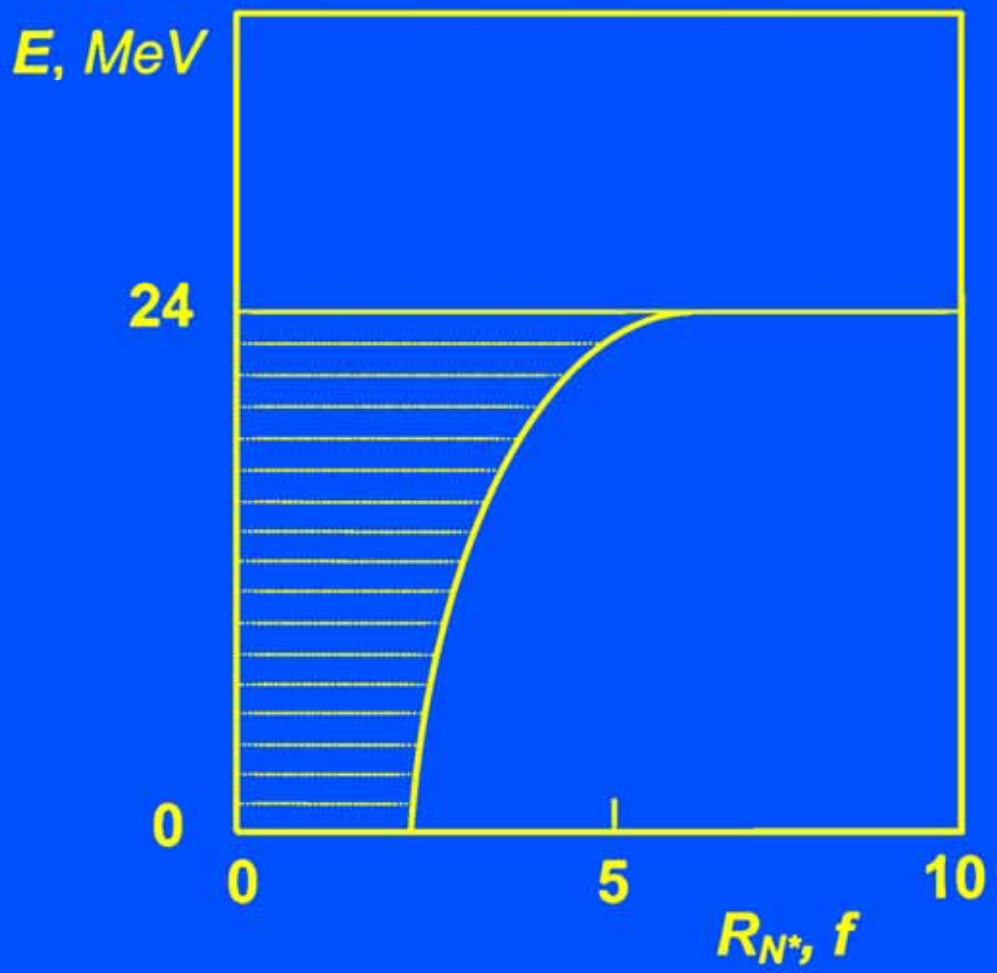


thermalization (glow discharge) diagram by virtual photons



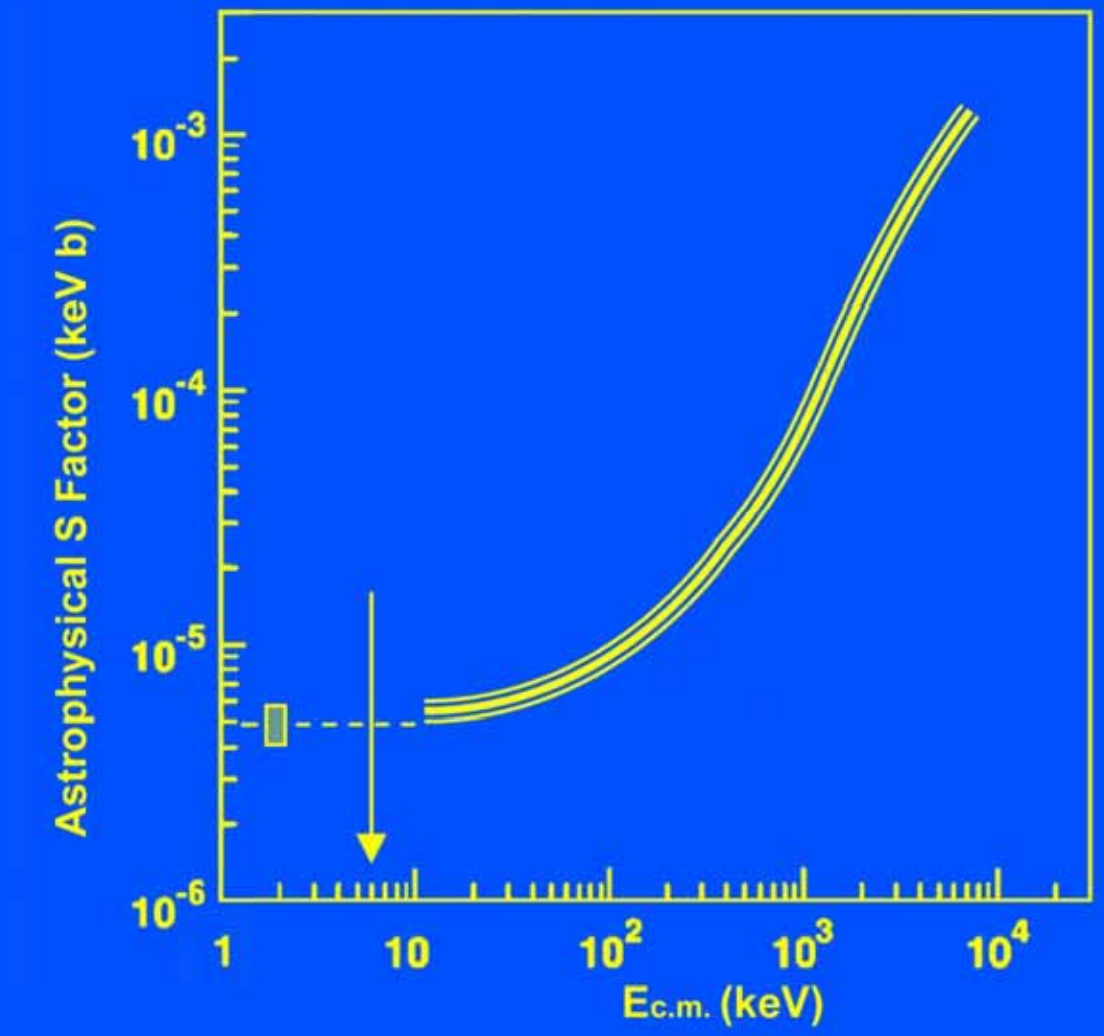
The process of exchange by virtual photons without changing the total angular momentum, called E0, is known in nuclear spectroscopy and sometimes called photonless exchange.

Presumable energy diagram of $^4He^*$



D + D → ^{4}He

new nuclear physics



We believe that the physics of the decay of the compound nucleus $^4He^*$ resulting from collisions of deuterons completely changes near 6 keV. In our view, the presented considerations restore the compatibility of all the experiments related to the reaction $D+D \rightarrow {}^4He$, and elevate cold fusion DD experiments in palladium to the rank of legitimate science.

The results of McKubre's experiments indicate that at low excitation energies of the compound nucleus $^4He^*$ the frequency of decays with emission of nucleons does not exceed ~10^{16} per second and cannot compete with the processes of energy exchange with the nearby electrons by virtual photons.

Conclusion

Peculiarities of behavior of deuterium atoms in a crystalline environment provide a gross increase in the probability of deuteron fusion and open up the possibility of practical application of this process. The assumption that decay time of the compound nucleus depends on its excitation energy makes experiments in crystals compatible with acceleration data.

It should be noted that an increase in the efficiency of the thermal acceleration of contaminant atoms of deuterium (for example, with the use of crystalline undulators), along with the sharp increase in the yield of fusion may open unwanted nuclear channels.

The new nuclear physics at low energies could have unexpected implications for the customary practice with nuclear reactions. For example, the rate of certain nuclear reactions excited by thermal neutrons may happen to be environmentally dependent.

Alternative approach: Takahashi model

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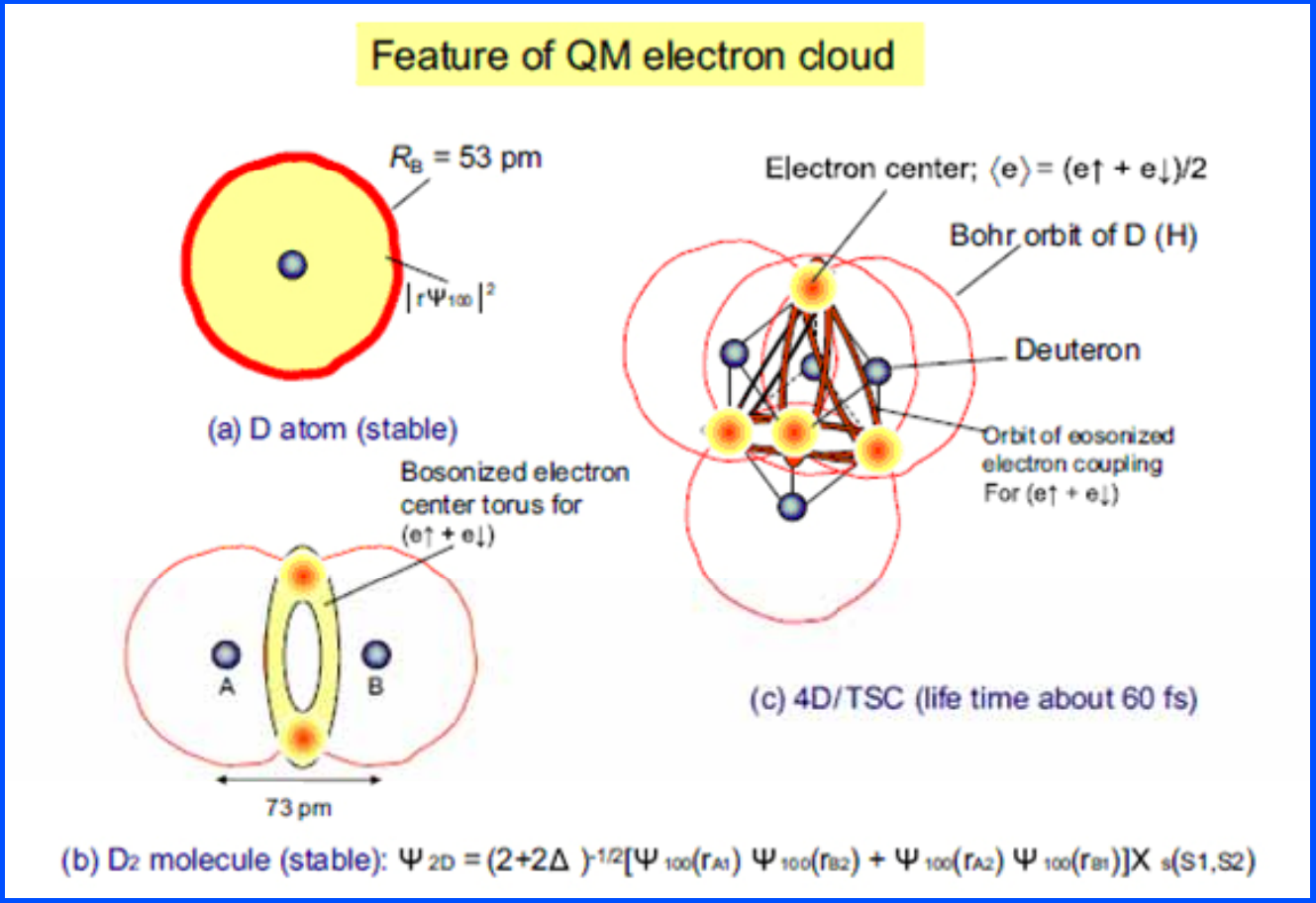
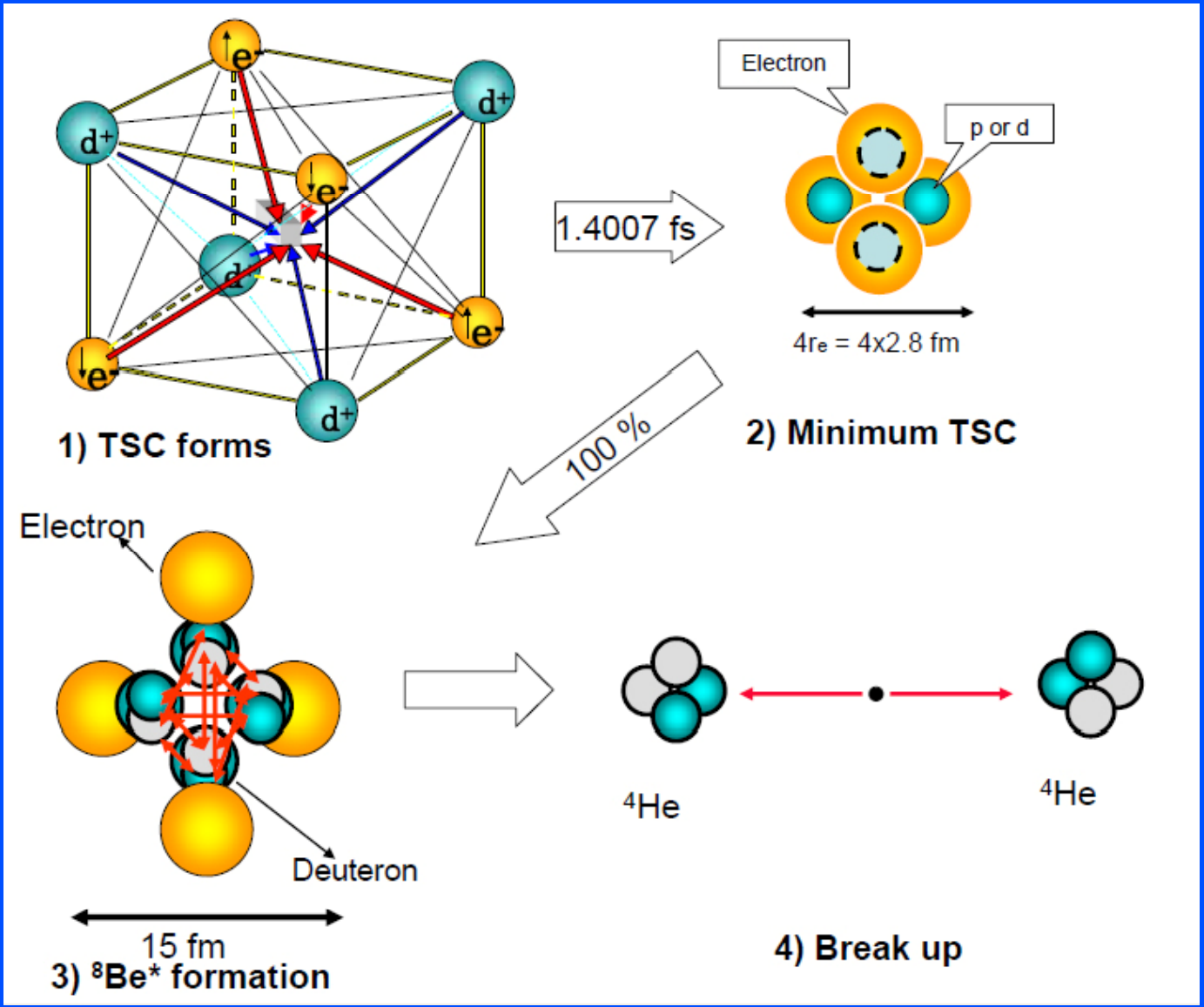
Dynamic Mechanism of TSC (tetrahedral symmetric condensate) Condensation Motion by the Langevin Equation



Takahashi model



Takahashi model

Fantastic!
However…

Seems to be contradictive internally. *The process is not reversible.* The process is exactly the same for H and D, *but ^{4}Be does not exist*…

Grazie per la vostra attenzione

Thanks for attention

Спасибо за внимание